**Assessment of Physicochemical and Bacteriological Quality of Water in three Riverine Communities in Port Harcourt, Nigeria**

**Abstract**

**Introduction**: Boreholes and wells are the main sources of drinking water for communities and cities in Nigeria. However, inadequate protection of these sources can be dangerous as contaminants such as chemicals and pathogens from surface water can seep into the groundwater posing significant health risks to these communities.

**Aim**: This study evaluated the physicochemical and bacteriological quality of drinking water in three riverine communities in Port Harcourt, Nigeria. **Method**: Using standard techniques, water samples were collected three times within a month from four storage tanks (sources) and their distributions (11 taps). There were two sources in Ukukala-Ama, one in Somiari-Ama and another in Fimie-Ama. The samples were then evaluated for their physicochemical and bacteriological quality through standard procedures and assessed against the acceptable limits for drinking water set by the World Health Organization**.**

**Result**: The physicochemical parameters of water sources showed pH range of 5.12±0.02-5.87±0.063, temperature range of 24.63±0.03-25.85±0.08, sulphate 56.84±0.03-68.64±0.75, Chloride ranged from 8.43±0.63-16.22±0.05 Also, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) ranged from ranged from 42.94±10.58 -78.08±0.08 mg/l and respectively. Mercury (Hg), and Lead (Pb) Iron (Fe), ranged from 0.07±0.00-0.09±0.00, 0.12±0.00-0.39±0.00 and 3.42±0.00-5.04±0.01, respectively. The mean of Total Heterotrophic bacteria counts (THBC) ranged from 0.77±0.01 to 9.0±0.00 x 102 CFU/ml and was highest in water samples from one of Somiari-Ama distribution(tap 3) , the total faecal coliform counts ranged from 1.05 ±0.03 x 102 CFU/ml to 8.97 ± 1.07 x 102 CFU/ml, total Coliform Counts ranged from 1.0±0.00 x 102 CFU/ml to 8.33±0.33 x 102 CFU/ml while total *Salmonella Shigella* counts ranged from 0.57±0.03 x 102 CFU/ml to 8.33±0.33 x 102 CFU/ml. There was mean difference in water samples at *p=*.05 and was significant at 0.005, 0.009, <0.001 and <0.001 for THBC, TCC, TFCC and TSSC, respectively for the four sources. Bacteria genera isolated were *Escherichia coli*, *Citrobacter freundi*, *Proteus mirabilis*, *Serratia marcescens*, *Enterobacter aerogenes*, *Bacillus cereus* amongst others**. Conclusion**: The presence of faecal pollution indicators in all samples suggests significant contamination of groundwater by surrounding surface water and pit latrines located close to some of the water sources.

**Recommendation**: Groundwater in these communities requires treatment before consumption.

**Keywords**: Water sources, bacteriological quality, Physicochemical quality, bacteria isolates, boreholes.

**INTRODUCTION**

Globally most people rely on groundwater as their primary supply of water for daily needs (Egbueri et al., 2023). Groundwater is essential for man's well-being and survival and is imperative for promoting public health (Abanyie et al., 2023). It is estimated that 27% of the world’s population still lacks access to safe drinking water and 2.3 billion people lack access to adequate sanitation (WHO, 2020). Recent statistics indicate that water-related diseases account for 4 billion estimated cases of global disease burden and cause 3.4 million deaths annually, with 88% attributed to unsafe water drinking water supply and sanitation making it a global public health concern (Kahuho et al., 2019;(WHO, 2020) ;(Adesakin et al., 2020; Sahoo & Goswami, 2024). These challenges are influenced by natural processes and anthropogenic activities that continuously threaten this natural resource by introducing constituents that dissolve or suspend in water (Adamou et al., 2020; Akani et al., 2021; Egbueri et al., 2023). The global increase in industrialization, urbanization and the human population has led to a high demand for good quality water for domestic, recreational, industrial activities and other purposes and has continuously threatened the value of this resource (Adamou et al., 2020; Adesakin et al., 2020; Atiku et al., 2018a). In rural West Africa and Nigeria, groundwater is very often the main source of drinking water and is mostly through wells, manual hand pumps and increasingly from boreholes (Garoma et al., 2018; Odu et al., 2020; Sahoo & Goswami, 2024). Natural groundwater is usually of good quality, but this can deteriorate due to inadequate water source protection and poor resource management. Majority of the human population in semi-urban and urban areas in Nigeria are heavily reliant on ground water from boreholes as their main source of water supply for drinking and domestic use due to inadequate provision of potable pipe borne water from the government. These ground water sources can easily be contaminated by faecal matter and thus increase the incidence and outbreaks of preventable water-borne diseases (Atiku et al., 2018). Distortion of physicochemical properties and faecal contamination of drinking water are a major challenge in oil-bearing and riverine communities in the Niger Delta region of Nigeria like Rivers State (Maduka & Emmanuel-Ephraim, 2019). Assessing water quality is very important to reduce water-borne diseases, thereby improving the health status of society and the overall quality of life of the human population. Various water sources such as rivers, well, and pipe-borne water stored in tanks can become contaminated with pathogenic microorganisms, some of which are enteric bacteria, especially when the water is not treated periodically (Akani et al., 2021).

The sustainable management of water resources, along with access to safe water and sanitation, is essential for promoting economic growth and productivity. This also significantly enhances existing investments in health and education. However, many communities in Nigeria, including Rivers State, face substantial challenges in maintaining water quality. Therefore, it is crucial to monitor and improve water supplies, promote the sustainable use of water resources, and implement conservation measures to enhance public health and strengthen national economies.

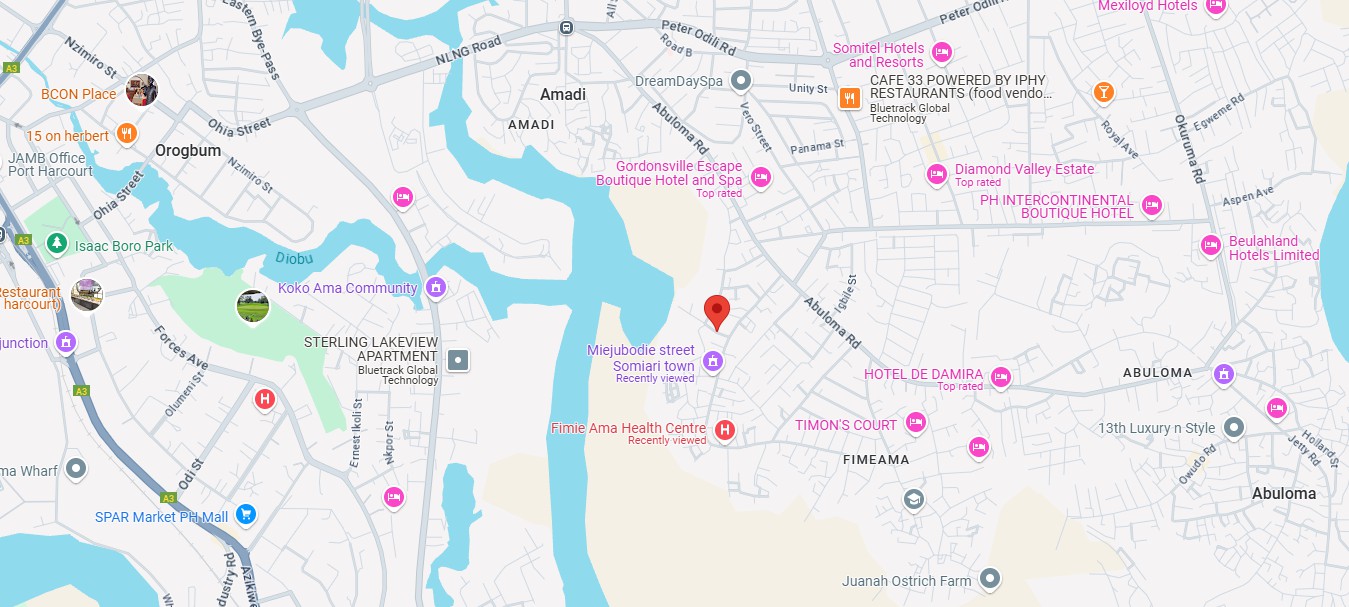
The current study focused on three riverine communities in Port Harcourt City Local Government Area, which like a few communities in the region, have established their own community water supply systems in a bid to provide drinking water from an improved source, where collection time is not more than thirty minutes for a roundtrip, including queuing. However, despite these efforts to provide basic water service, these communities are not without their environmental challenges. The proximity of pit latrines, refuse dumps, and polluted surface water contaminated by illegal crude oil refining poses a considerable risk to the quality of their water supply and rendering the basic water service vulnerable as pit latrines and refuse dumps can leach harmful pathogens and chemicals into nearby water bodies, while pollution from illegal refining activities may introduce hazardous substances such as heavy metals and hydrocarbons. These factors collectively exacerbate the risks associated with water consumption and use from this basic water supply and are the basis for the current study.

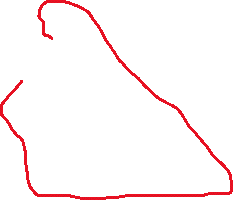
The study aimed to assess the physicochemical and bacteriological quality of the drinking water in these riverine communities and evaluate the associated human health risks. By this, the research sought to understand the extent of contamination and its impact on the health of residents. The findings will provide valuable insights into the effectiveness of current water supply systems and highlight the urgent need for improved water management practices to mitigate health risks and enhance community well-being.

**MATERIALS AND METHODS**

**THE STUDY AREA:** The study was conducted between November 2023- January 2024 in Ukukala-Ama, Somiari-Ama and Fimie-Ama communities with coordinates 4.784154, 7.033126, 4.78085, 7.02982 and 4.77979,7.03890, respectively in Port Harcourt City Local Government Area in Rivers State. These three communities are collectively called Tera-Ama which is a dynamic area partly surrounded by water bodies. Tera-Ama is bounded by Amadi creek to the north, a notable water body in Port Harcourt and to the Southeast by Marine base which is a waterfront in Port Harcourt City Local Government Area in Rivers State. Purposive sampling was used to select these three communities for the study based on certain characteristics like the availability of community water supply which serves most community members, anthropogenic activities related to spills and leaks, and proximity to potential contamination sources like soak pits**.**

A map of nigeria with black text

AI-generated content may be incorrect.****



**Figure 1: Map of Nigeria showing Rivers State and Map of Rivers State showing study areas**

**Study Areas: Ukukala-Ama , Somiari-Ama , Fimie-Ama**

**SAMPLE COLLECTION**



Permission to collect water samples from storage reservoirs (tanks) and distribution taps for water quality assessment was obtained from the leadership of the three communities during the entry activities. A total of 15 water samples were collected at three different intervals, including four from storage tanks (two in Ukukala-Ama, one in Somiari-Ama, and one in Fimie-Ama) and eleven from distribution taps across the communities. Water samples were collected using 1.5-liter polystyrene bottles. Prior to sampling, each bottle was thoroughly washed and rinsed three times with water from the respective source to minimize contamination. The bottles were then filled with water, leaving approximately two inches of headspace to facilitate proper mixing and analysis. All collected samples were appropriately labeled, stored in an ice cooler, and transported immediately to the laboratory for microbiological, physicochemical, and heavy metal analysis.

**PHYSICOCHEMICAL ANALYSIS**

Water temperature and pH were measured in-situ using standard methods (APHA, 2001) with a mercury-in-glass bulb thermometer that was used to measure water temperature (0C). Also, 2mls of concentrated nitrate (HN03) was added to each sample to preserve the metals and to avoid contamination. Physicochemical parameters such as Temperatures, pH, turbidity, salinity, and Dissolved Oxygen (DO) were analyzed using the Hanna multi-parameter (HI9829). Biological Oxygen Demand (BOD) total suspended solids (TSS) and total dissolved solids (TDS) were also analyzed. Chloride and Sulphates were analyzed using the Argentometric and Turbidimetric methods respectively as prescribed by APHA, (1999). Heavy metals (Mercury, Lead and Iron) were analyzed using a flame atomic absorption spectrophotometer (Wright & Stuczynski, 2018). The calibration curves were prepared separately for all the metals by running different concentration of standard solutions. The instrument was to zero by running the respective reagent blanks. Average values of three replicates were taken for each determination**.**  Parameters obtained were compared with the limits set up by the WHO, (2011).

**MICROBIOLOGICAL ANALYSIS**

Serial tenfold dilution was carried out by pipetting 1ml of each water sample into 9 ml of already prepared sterile normal saline to obtain dilutions up to 10-4. Aliquots of the diluted samples were cultured, using the spread plate techniques, on Petri dishes containing appropriate bacteriological media such as Nutrient Agar for Total Heterotrophic Bacterial (THB) count; Eosin Methylene blue agar for *Escherichia coli*; *Salmonella/Shigella/Shigella* counts, Thiosulphate-citrate-bile-salts-sucrose agar for Vibrio Counts and MacConkey Agar for enteric bacteria. The inoculated plates were incubated at 37oC for 18 to 24 hours after which growths were counted and analyzed. Pure cultures of bacteria were obtained as described by (Hakam & Obire, 2015) by aseptically streaking representative colonies of different morphological types which appeared on the cultured plates onto freshly prepared agar plates and incubated at 37 oC for 18 to 24 hours.

**METHOD OF IDENTIFICATION OF THE BACTERIAL ISOLATES**

Pure isolates of bacteria were identified by the method described by Cheesbrough (2002) and (Sampson et al., 2021). Various indices employed to characterize and identify bacteria isolates were colonial appearances in solid media, changes in the surrounding medium, pigment production, gram reaction, and microscopic appearance. The pure bacterial isolates were subjected to Biochemical tests which include motility, catalase test, indole test, methyl red test, Voges Proskauer test, starch hydrolysis test, citrate test and sugar fermentation test. Based on the results of the morphology and biochemical characteristics obtained, the bacterial isolates were identified with reference to being matched with those in Bergey’s Manual of Determinative Bacteriology (Holt, et al., 1994).

**STATISTICAL ANALYSIS**

Data obtained from all experiments carried out were subjected to statistical analysis using Statistical Package for Social Sciences (SPSS) version 20. Descriptive statistics (mean, standard deviation, etc.) were applied to summarize data for tabulation and graphical representation. Analysis of variance (ANOVA) was used to test for significant difference between counts from various sources at *P*=.05.

**RESULTS**

The statistical analysis of the physicochemical characteristics of water samples from Ukukala-Ama, Somiari-Ama, and Fimie-Ama revealed significant differences among several parameters (Table 1). The pH levels varied significantly (P < 0.001), ranging from 5.12 ± 0.02 (Ukukala-Ama Source 2) to 5.87 ± 0.063 (Somiari-Ama), with all sources recording values below the WHO recommended range of 6.5–8.5, indicating acidic water. Salinity also showed significant variation (P < 0.001), with the lowest concentration in Ukukala-Ama Source 1 (0.02 ± 0.00 mg/L) and the highest in Ukukala-Ama Source 2 (0.06 ± 0.00 mg/L), though all values remained well below the WHO limit of 200 mg/L.

Sulphate levels differed significantly (*P* < 0.001), ranging from 56.84 ± 0.03 mg/L (Fimie-Ama) to 68.64 ± 0.75 mg/L (Somiari-Ama), with Somiari-Ama exceeding the WHO permissible limit of 50 mg/L. Chloride concentrations also varied significantly (*P* < 0.001), with the lowest value recorded in Ukukala-Ama Source 1 (8.43 ± 0.63 mg/L) and the highest in Fimie-Ama (16.22 ± 0.05 mg/L), though all values remained within the WHO guideline of 200–300 mg/L.

Dissolved oxygen (DO) levels showed significant differences (*P* < 0.001), ranging from 1.86 ± 0.16 mg/L (Ukukala-Ama Source 2) to 3.29 ± 0.01 mg/L (Fimie-Ama), with all values below the WHO recommended range of 4–7.5 mg/L, indicating potential oxygen depletion. Chemical oxygen demand (COD) (*P* = 0.005) varied significantly, with the lowest value recorded in Ukukala-Ama Source 2 (42.94 ± 10.58 mg/L) and the highest in Fimie-Ama (78.08 ± 0.06 mg/L), far exceeding the WHO permissible limit of 10 mg/L. Similarly, biochemical oxygen demand (BOD) (P < 0.001) ranged from 4.64 ± 0.08 mg/L (Somiari-Ama) to 6.62 ± 0.02 mg/L (Fimie-Ama), with Fimie-Ama exceeding the WHO limit of 6 mg/L, indicating organic pollution.

Heavy metal concentrations varied significantly, with mercury (P < 0.001) ranging from 0.07 ± 0.00 mg/L (Ukukala-Ama Source 2) to 0.09 ± 0.00 mg/L (Somiari-Ama and Fimie-Ama), all exceeding the WHO limit of 0.01 mg/L. Lead (P = 0.05) ranged from 0.12 ± 0.00 mg/L (Ukukala-Ama Source 2) to 0.39 ± 0.00 mg/L (Fimie-Ama), with all sources surpassing the WHO limit of 0.01 mg/L. Iron (P < 0.001) showed significant variation, with the lowest value in Ukukala-Ama Source 1 (3.42 ± 0.00 mg/L) and the highest in Somiari-Ama (5.04 ± 0.01 mg/L), exceeding the WHO permissible limit of 0.003 mg/L.

Conversely, temperature (P = 0.27), turbidity (P = 0.10), total dissolved solids (TDS) (P = 0.09), total suspended solids (TSS) (P = 0.36), and fluoride (P = 0.08) did not show statistically significant differences among the water sources. Temperature ranged from 24.63 ± 0.03°C (Ukukala-Ama Source 1) to 25.85 ± 0.08°C (Ukukala-Ama Source 2), remaining within the WHO recommended range of 22–29°C. Turbidity values ranged from 0.69 ± 0.07 NTU (Ukukala-Ama Source 2) to 0.84 ± 0.00 NTU (Fimie-Ama), all well below the WHO limit of 5.0 NTU. TDS ranged from 0.06 ± 0.01 mg/L (Ukukala-Ama) to 0.08 ± 0.00 mg/L (Fimie-Ama), staying within the WHO acceptable range of 500–1000 mg/L. TSS ranged from 0.04 ± 0.00 mg/L (Somiari-Ama) to 0.06 ± 0.00 mg/L (Fimie-Ama), all below the WHO limit of 75 mg/L. Fluoride levels varied from 0.26 ± 0.08 mg/L (Ukukala-Ama Source 2) to 0.57 ± 0.09 mg/L (Somiari-Ama), remaining within the WHO range of 1.0–1.5 mg/L.

**Table 1:** Mean and Comparison of mean values of Physicochemical characteristics of water samples from Ukukala-Ama, Somiari-Ama and Fimie-Ama community water sources using One way ANOVA at P≤ 0.05

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | Ukukala-Ama  Source 1  Mean±SE | Ukukala-Ama  Source2 Mean±SE | Somiari-Ama Source Mean±SE | Fimie-Ama Source  Mean±SE | *P*-value | WHO |  |
| pH | 5.22±0.05 | 5.12±0.02 | 5.87±0.063 | 5.52±0.06 | \*<0.001 | 6.5-8.5 |  |
| Temperature(oC) | 24.63±0.03 | 25.85±0.08 | 25.42±0.23 | 24.93±0.79 | 0.27 | 22-29 |  |
| Turbidity (NTU) | 0.71±0.04 | 0.69±0.07 | 0.75±0.00 | 0.84±0.00 | 0.10 | 5.0 |  |
| Salinity(mg/l) | 0.02±0.00 | 0.06±0.00 | 0.05±0.00 | 0.05±0.00 | \*<0.001 | 200 |  |
| TDS (mg/l) | 0.06±0.01 | 0.06±0.01 | 0.08±0.00 | 0.08±0.00 | 0.09 | 500-1000 |  |
| TSS (mg/l) | 0.05±0.00 | 0.05±0.01 | 0.04±0.00 | 0.06±0.00 | 0.36 | 75 |  |
| Sulphate(mg/l) | 57.54±0.16 | 61.60±0.64 | 68.64±0.75 | 56.84±0.03 | \*<0.001 | 50 |  |
| Chloride(mg/l) | 8.43±0.63 | 9.03±0.02 | 13.36±0.04 | 16.22±0.05 | \*<0.001 | 200-300 |  |
| Flouride (mg/l) | 0.29±0.01 | 0.26±0.08 | 0.57±0.09 | 0.37±0.10 | 0.08 | 1.0-1.5 |  |
| DO (mg/l) | 2.02±0.13 | 1.86±0.16 | 2.88±0.04 | 3.29±0.01 | \*<0.001 | 4-7.5 |  |
| COD (mg/l) | 63.10±0.62 | 42.94±10.58 | 44.15±1.66 | 78.08±0.06 | \*0.005 | 10 |  |
| BOD (mg/l) | 5.15±0.04 | 4.66±0.25 | 4.64±0.08 | 6.62±0.02 | \*<0.001 | 6 |  |
| Hg(mg/l) | 0.08±0.00 | 0.07±0.00 | 0.09±0.00 | 0.09±0.00 | \*<0.001 | 0.01 |  |
| PB (mg/l) | 0.29±0.13 | 0.12±0.00 | 0.15±0.01 | 0.39±0.00 | \*0.05 | 0.01 |  |
| Fe (mg/l) | 3.42±0.00 | 4.53±0.02 | 5.04±0.01 | 4.15±0.01 | \*< 0.001 | 0.003 |  |

\*Level of significance difference between means of various sources

The microbiological analysis of water samples from Ukukala-Ama, Somiari-Ama, and Fimie-Ama community water sources(tanks) and their distribution (taps) is as shown (Table 3). The mean differences between the various sources of water at *P=.05* are reported in table 4.

From Table 4,the Total Heterotrophic Bacteria Count (THBC) varied significantly (*P* = 0.005), ranging from 0.90 ± 0.02×102CFU/ml (Ukukala-Ama Source 1) to 3.72 ± 0.83 ×102CFU/ml (Fimie-Ama). The highest values were recorded in Somiari-Ama (3.58 ± 0.95 ×102CFU/ml) and Fimie-Ama, indicating potential bacterial contamination.

Total Coliform Count (TCC) also showed significant variation (P = 0.009), with values ranging from 1.20 ± 0.08 ×102CFU/ml Ukukala-Ama Source 2) to 3.33 ± 0.88 ×102CFU/ml (Fimie-Ama). The presence of coliform bacteria suggests possible fecal contamination and potential health risks.

Total Fecal Coliform Count (TFCC) exhibited highly significant differences (P < 0.001), ranging from 1.12 ± 0.03 ×102CFU/ml (Ukukala-Ama Source 2) to 5.48 ± 1.07 ×102CFU/ml (Somiari-Ama), indicating severe fecal contamination in Somiari-Ama and Fimie-Ama (3.97 ± 0.75 ×102CFU/ml).

Similarly, Total Salmonella Shigella Count (TSSC) showed significant differences (P < 0.001), with the lowest values in Ukukala-Ama Source 1 (0.96 ± 0.08 ×102CFU/ml) and the highest in Fimie-Ama (4.51 ± 0.78 ×102CFU/ml). The elevated levels in Somiari-Ama (3.21 ± 0.77 ×102CFU/ml) and Fimie-Ama indicate a high risk of waterborne diseases.

Table 2: Mean values of microbiological characteristics of water samples from Ukukala-Ama, Somiari-Ama and Fimie-Ama community water sources(tanks) and their distributions (taps).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location | Number of samples | THBC (×102CFU/ml) | TCC (×102CFU/ml) | TFCC (×102CFU/ml) | TSSC (×102CFU/ml) |
| Ukukala-Ama Source 1 | 3 | 0.77±0.01 | 1.01±0.01 | 1.05±0.03 | 0.57±0.03 |
| Ukukala-Ama Source 1 Tap 1 | 3 | 0.95±0.00 | 1.20±0.00 | 1.18±0.00 | 1.11±0.00 |
| Ukukala-Ama Source 1 Tap 2 | 3 | 0.98±0.00 | 1.34±0.00 | 1.16±0.01 | 1.27±0.01 |
| Ukukala-Ama Source 1 Tap 3 | 3 | 0.88±0.00 | 1.22±0.00 | 1.18±0.00 | 0.88±0.00 |
| Ukukala-Ama Source 2 | 3 | 1.23±0.01 | 1.52±0.01 | 1.21±0.01 | 1.29±0.01 |
| Ukukala-Ama Source 2 Tap 1 | 3 | 1.26±0.00 | 1.04±0.00 | 1.11±0.00 | 0.73±0.00 |
| Ukukala-Ama Source 2 Tap 2 | 3 | 1.16±0.00 | 1.02±0.00 | 1.32±0.00 | 1.0±0.00 |
| Somiari-Ama Source | 3 | 1.67±0.14 | 3.67±0.57 | 1.57±0.18 | 7.43±0.30 |
| Somiari-Ama Tap 1 | 3 | 2.07±0.03 | 1.47±0.07 | 8.97±0.03 | 1.33±0.33 |
| Somiari-Ama Tap 2 | 3 | 1.60±0.06 | 1.47±0.03 | 8.97±0.03 | 3.0±0.06 |
| Somiari-Ama Tap3 | 3 | 9.0±0.00 | 4.70±0.12 | 2.23±0.07 | 1.07±0.07 |
| Fimie-Ama Source | 3 | 8.33±0.33 | 8.33±0.33 | 1.43±0.07 | 8.33±0.33 |
| Fimie-Ama Tap 1 | 3 | 1.93±0.07 | 1.83±0.17 | 1.60±0.20 | 1.1±0.01 |
| Fimie-Ama Tap2 | 3 | 1.43±0.03 | 1.00±0.00 | 6.67±0.03 | 3.93±0.07 |
| Fimie-Ama Tap 3 | 3 | 3.17±0.17 | 2.17±0.17 | 6.17±0.17 | 4.67±0.33 |

THBC- Total heterotrophic bacteria count, T CC- Total coliform count, TFCC- Total Faecal coliform count, TSSC- Total shigella salmonella count

Table 3: Comparison of mean values of microbiological characteristics of water samples from Ukukala-Ama, Somiari-Ama and Fimie-Ama community water sources using One way ANOVA at P≤ 0.05

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Parameters | No. of Samples | Ukukala-Ama Source 1  (×102CFU/ml) | Ukukala-Ama Source 2  (×102CFU/ml) | Somiari-Ama  (×102CFU/ml) | Fimie-Ama  ×102CFU/ml | P-Value |
| Total Heterotrophic Bacteria Count (THBC) | 45 | 0.90±0.02 | 1.22±0.01 | 3.58±0.95 | 3.72±0.83 | \*0.005 |
| Total Coliform Count (TCC) | 45 | 1.91±0.04 | 1.20±0.08 | 2.83±0.44 | 3.33±0.88 | \*0.009 |
| Total Fecal Coliform Count (TFCC) | 45 | 1.14±0.02 | 1.12±0.03 | 5.48±1.07 | 3.97±0.75 | \*< 0.001 |
| Total Salmonella Shigella Count (TSSC) | 45 | 0.96±0.08 | 1.01±0.08 | 3.21±0.77 | 4.51±0.78 | \*< 0.001 |
| P- Value | 45 | \*< 0.001 | \*< 0.001 | \*< 0.001 | \*< 0.001 |  |

\*Level of significance difference between means of various sources

The bacterial isolates from the community water sources in Ukukala-Ama, Somiari-Ama, and Fimie-Ama exhibited diverse morphological, biochemical, and sugar fermentation characteristics (Table 4).

In Ukukala-Ama Source, the isolates included *Serratia marcescens*, *Citrobacter freundii*, *Micrococcus tetteus*, *Escherichia coli*, *Serratia odorifera*, *Proteus mirabilis*, *Enterobacter aerogenes*, *Citrobacter freundii*, *Klebsiella pneumoniae*, and *Enterobacter cloacae*. Most isolates were Gram-negative, apart from *Micrococcus tetteus*, which was Gram-positive. The isolates displayed varied colors ranging from red and pink to cream and blue. The catalase test was positive for all isolates, while the motility test showed that some species, such as *E. coli*, *S. marcescens*, and *Proteus mirabilis*, were motile. Sugar fermentation patterns varied, with *E. coli*, *Enterobacter aerogenes*, and *Citrobacter freundii* fermenting multiple sugars, including glucose, sucrose, and lactose.

In Somiari-Ama, bacterial isolates included *Bacillus cereus*, *Pseudomonas aeruginosa*, *Citrobacter freundii*, *Serratia marcescens*, and *Citrobacter diversus*. Unlike Ukukala-Ama, Bacillus cereus was the only Gram-positive isolate, while the others were Gram-negative. Colony textures ranged from moist to dry, with most having a raised elevation. Notably, *Pseudomonas aeruginosa* tested negative for Voges-Proskauer (VP) but positive for citrate and catalase. Sugar fermentation varied, with *Citrobacter freundii* and *Citrobacter diversus* fermenting multiple sugars, while *Serratia marcescens* exhibited limited fermentation.

In Fimie-Ama, isolates included *Proteus mirabilis*, *Staphylococcus intermedius*, and *Enterobacter aerogenes*. The Gram-positive isolate was *Staphylococcus intermedius*, while the others were Gram-negative. Colonies were round and moist with a raised elevation. The catalase test was positive for all isolates, while *Proteus mirabilis* tested negative for Voges-Proskauer (VP). Sugar fermentation showed that *Enterobacter aerogenes* were capable of fermenting multiple sugars, whereas *Proteus mirabilis* had limited sugar fermentation abilities.

Table 4: Morphology, Biochemical Characteristics, and Sugar Fermentation of Bacteria Isolates from community water samples



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Morphological Characteristics | | | | | | | Biochemical Test | | | | | | | | Sugar Fermentation | | | | |
| S/No | Gram Rxn | Colour | Shape | Texture | Elevation | Catalase | | Citrate | Motility | MR | VP | Indole | Starch hydrolysis | Glu | | Suc | MAN | LAC | Probable Organism |
| Bacteria Isolates from Ukukala-Ama Community Water Supply | | | | | | | | | | | | | | | | | | | |
| 1 | - | Red | Circular | Moist | Flat | + | | + | + | - | - | - | - | + | | + | + | - | *Serrafia marcescens* |
| 2 | - | Cream | Circular | Moist | Flat | + | | + | + | + | - | - | + | + | | + | + | + | *Citrobacter freundi* |
| 3 | + | Yellow | Circular | Moist | Raised | + | | - | - | + | + | - | - | + | | + | + | + | *Micrococcous tetteus* |
| 4 | - | Pale pink | Circular | Moist | Raised | + | | - | + | + | - | + | - | + | | - | + | + | *Escherichia coli* |
| 5 | - | Red | Circular | Moist | Raised | + | | + | + | - | - | - | - | + | | + | + | - | *Serratia odonfera* |
| 6 | - | Colorless | Circular | Dry | Convex | + | | - | + | + | - | - | + | + | | + | - | - | *Proteus mirabilis* |
| 7 | - | Light pink | Circular | Mucoid | Raised | + | | + | + | - | + | - | + | + | | + | + | + | *Enterobacter aerogenes* |
| 8 | - | Dark pink | Circular | Dry | Convex | - | | + | - | + | - | - | - | + | | + | + | + | *Citrobacter fruendii* |
| 9 | - | Blue | Circular | Moist | Raised | + | | + | - | - | + | - | - | + | | + | + | + | *Kebsiella pnemoniae* |
| 10 | - | Pale Pink with purple | Circular | Moist | Raised | + | | + | + | + | + | - | - | + | | + | + | + | *Enterobacter clocae* |
| Bacteria Isolates from Somiari-Ama Community Water Supply | | | | | | | | | | | | | | | | | | | |
| 1 | + | Cream | Circular | Dry | Flat | + | | + | + | - | + | - | - | + | | + | - | - | *Bacillus cereus* |
| 2 | + | Cream | Round | Moist | Flat | + | | + | + | - | - | + | + | - | | - | + | - | *Pseudomonas aeroginosa* |
| 3 | - | Pink | Round | Moist | Raised | + | | + | + | + | - | - | + | + | | + | + | - | *Citrobacter freundi* |
| 4 | - | Red | Filamentous | Dry | Raised | + | | - | + | - | + | + | + | - | | - | + | - | *Serratia maraescena* |
| 5 | - | Pink | Round | Moist | Raised | + | | + | + | + | - | + | - | + | | + | + | \_ | *Citrobacter diversus* |
| Bacteria Isolates from Fimie-Ama Community Water Supply | | | | | | | | | | | | | | | | | | | |
| 1 | - | Pink | Round | Moist | Raised | + | | + | + | - | - | - | - | + | | + | - | - | *Proteus mirabilis* |
| 2 | + | Milk | Round | Moist | Raised | + | | + | + | - | + | - | - | + | | + | + | + | *Staphylococcus Intermedius* |
| 3 | - | Pink | Round | Moist | Raised | + | | + | + | - | - | - | + | + | | + | + | + | *Enterobacter aerogenes* |

**Keys: MR – Methylated Red; VP – Voges Proskaeur; + = positive; - = negative**

**DISCUSSION**

**PHYSICOCHEMICAL QUALITY OF WATER SOURCES**

The study revealed that temperature ranged from 24.63±0.03-25.85±0.08 oC which is within the WHO recommended for drinking water. This finding is to Reuben et al., (2018) who reported a temperature range of 23.5 to 25.0 oC and 24.8 to 27.0 oC, with mean temperatures of 24.48±0.354 oC and 25.56±0.497 oC for the North and South Rivers respectively. Similarly, Akani et al., (2018) reported a temperature range of 27-28 oC of all water samples from storage tanks in a tertiary institution in Rivers State. However, Duressa et al. (2019) reported lower temperatures, ranging from 16.8 oC to 22.1oC while Maduka and Ephraim, (2019) in their study in oil bearing communities in the Niger Delta reported significantly higher temperature ranges of 29.6-30.2 oC, 30.6-34.2 oC and 29.6-33.2 oC for Rivers, Bayelsa and Delta States respectively. Temperature is among the major physicochemical parameters which are important in evaluation of household drinking water quality. It affects biological properties of water and influences performance of coagulants and disinfection products(Ondieki et al., 2021; Reuben et al., 2018). The pH of water samples from this study revealed a range of 5.12±0.02-5.87±0.063 with a mean difference of < 0.001. The lowest mean pH value from the samples was recorded in Ukukala-Ama source 2 while the highest mean pH value was recorded in Somiari-Ama water source. A similar finding was recorded in borehole samples from different points in Mgboushimini, Port Harcourt where pH ranged from 4.31-4.73 (Ebong et al., 2018). This shows the water samples from both studies were too acidic and fell below the WHO recommended range of 6.5-8.5. According to Adesakin et al. (2020), such acidic water is unfit for human consumption as it can cause health concerns such as acidosis infections and lower pH has synergistic effects on heavy meals toxicity in water bodies. However, studies by Maduka and Ephraim, (2019) reported a mean pH of 6.4-7.0 in gas flaring communities and 5.8-7.0 in non-gas flaring communities all in the Niger Delta region of Nigeria, Reuben et al. (2018) reported a pH range of 6.0-6.6, and Adesakin et al. (2020) reported a pH range of 6.2-6.7(6.40±0.11) in borehole samples. These reports have the lower limits of their mean pH to be slightly acidic and fall little below the WHO limits which is 6.5-8. Odu et al. (2020) reported that the pH of all water samples from wells and boreholes in two communities in Rivers State range from 9.79-11.13 and were above the recommended limit of the WHO. This report is not in agreement with the findings from this study. pH is an important drinking water quality parameter as changes in pH may affect the toxicity of microbial poisons and effectiveness of disinfection in the water, as well as impacts corrosion of pipes (Maduka & Ephraim-Emmanuel, 2019; Odu et al., 2020; Ondieki et al., 2021). Different factors are known to influence the pH of water, including man-made and natural conditions, and further implicated storage conditions as one of the factors that contributes to the difference in pH. However, the difference in the pH readings in this study could be attributed to differences in location as well as other chemical properties. The chemical oxygen demand (COD) in this study ranged from 42.94-78.08mg/l and is significantly higher than the WHO recommended level of 10mg/l. This finding indicate a high level of organic pollutants and potential contamination from sewage and industrial waste(Adamou et al., 2020; Reuben et al., 2018; Yeboah et al., 2022). This can be further reiterated by the dissolved oxygen (DO) range of 1.86-3.29 which was also below the WHO minimum recommended value of 5mg/l that suggest oxygen depletion due to potential pollution sources such as organic decomposition or industrial effluents. Contrary values of Dissolved Oxygen (DO) were reported by Reuben et al., (2018) were 8.33±0.830 mg/L and 9.08±1.535 mg/L for water samples from both rivers which were higher than the acceptable limit (7.5 mg/L) and Akani et al. (2018) reported a DO range of 3.18±0.01-7.36±0.01 with its minimum range lower than the minimum recommended value by WHO. DO is an essential measure of the extent of pollution, the lower its value, the higher the pollution concentration and vice versa(Lutterodt et al., 2018; Reuben et al., 2018; Sahoo & Goswami, 2024). Heavy metals were analyzed using a flame atomic absorption spectrophotometer for the presence of Lead, Mercury, and Iron. The obtained results showed that Iron ranged from 3.421-5.023, Lead (0.121-0.430), and Mercury (0.07-0.092) were at levels that surpassed their permissible limits as per World Health Organization (WHO) guidelines for safe drinking water. These results present potential health risks to the communities that drink from these sources. Consumption of water with Lead (Pb) concentration greater than 0.01mg/L (10µg/L) is highly toxic and at possible risk of causing problems such as fever, nerve damage, kidney damage, liver & brain damage, lung & stomach cancer, neurological impairment in fetuses as well as brain impairment in young children during development stages (Ismael et al., 2021). Furthermore, contamination of Mercury (Hg) in drinking water (consumption) over time can cause fever, fatigue, chills, high leukocyte count, muscle pain, increased tremors, skin rashes, reddening & peeling skin on the palm of the hand(Eid et al., 2024; Marufi et al., 2024)

**BACTERIOLOGICAL QUALITY OF WATER SOURCES**

The mean total heterotrophic bacteria count, total coliform count, total faecal coliform count and total *Shigella Salmonella* count recorded in both reservoir (sources) and their distributions from the three communities were above the WHO stipulated recommendation for drinking water. The findings from this study is corroborated by other research findings in different localities such as Shambu town by (Garoma et al., 2018), that reported the total coliform in the water sample from all sampling sites in their study area was higher than the lower limit of the WHO, (2014) in which the number of total coliform in the sample sites range from 4 CFU/100 ml to 151 CFU/100 ml which are significantly different from each other. The presence of coliforms and faecal coliforms was also reported by studies conducted globally and in Nigeria (Adamou et al., 2020; Adesakin et al., 2020; Akani et al., 2021; Atiku et al., 2018; Duressa et al., 2019; ). Studies by Maduka & Emmanuel-Ephraim (2019) in the Niger Delta region of Nigeria, Obioma et al. (2020) and Odu et al. (2020) in Port Harcourt, Rivers State who reported High levels of coliform counts and bacteriological pathogen. This implies that these localities have some environmental stressors in common. This study agrees with the report of that extremely high total heterotrophic bacterial load in water suggest the water has been contaminated by potentially dangerous microorganism and unfit for human consumption (Adamou et al., 2020; Bamigboye & Amina, 2018; Onyegeme-Okerenta et al., 2016; Yeboah et al., 2022). As opined by (Egbueri et al., 2023) bacteria occasionally, find their way into ground water sometimes in dangerously high concentrations through runoffs or seepage. From this present study, it shows that boreholes could be contaminated through floodwater forming after rainfall because of the topographical terrain of the Niger Delta region as well as the depth of the groundwater or through broken underground pipes under this condition, the surrounding floodwater seeps into the pipe through the cracks as deeper ground water contains little or no presence of bacteria could have been removed by extensive filtration as water percolates through the soil (Uzoigwe & Agwa, 2012; Adesakin et al., 2020; Egbueri et al., 2023; Garoma et al., 2018). The proximity of these boreholes to pit latrines and soak pits and the poor environmental sanitation around the borehole are human factors that cannot be overlooked as have been reported to jeopardize groundwater quality (Garoma et al., 2018; Lutterodt et al., 2018; Obioma et al., 2020). The major diseases that could arise from bacteriological contamination of groundwater include typhoid, diarrhea and cholera(Adesakin et al., 2020; Akani et al., 2021). The presence of these coliform spp. was confirmed by the characterization of the isolates from the ground water samples from the sampling locations under study that were highly contaminated with one or more bacterial pathogens. The high bacterial loads of genera like *Escherichia coli*, *Citrobacter freundi*, *Proteus mirabilis*, *Serratia marcescens*, *Enterobacter aerogenes*, *Bacillus cereus* amongst others indicate the presence of high faecal contamination and health risk for human consumption. Hence it is recommended that water from these community supplies needs to be treated before use. There is a need to increase the awareness of the public health importance of borehole construction away from pit latrines, septic tanks and waste dumps.

**CONCLUSION AND RECOMMENDATION**

The results obtained from the analysis of the water samples from these communities showed that the boreholes were contaminated by pollutants from natural and anthropogenic sources. It shows the high levels of bacteria counts in the water supplies of these communities which is against the WHO recommendation of zero bacteria/coliform in 100ml of water sample for drinking purposes. Also, the presence of heavy metals and high COD levels indicates the need for pollution control measures and health education to mitigate health risks in these communities. This may be due to the anthropogenic activities related to spills and leaks, and proximity to potential contamination sources like soak pits, hence the need for intensified enlightenment campaigns in these communities on the dangers and possible sources of pollution and the need for individuals to help maintain a pollution free environment and water. Treatment of drinking water using sedimentation, filtration and boiling methods should be encouraged at household level. Further research should be conducted to assess seasonal variations in these communities.

**REFERENCES**

Abanyie, S. K., Apea, O. B., Abagale, S. A., Amuah, E. E. Y., & Sunkari, E. D. (2023). Sources and factors influencing groundwater quality and associated health implications: A review. *Emerging Contaminants*, *9*(2), 100207. https://doi.org/10.1016/j.emcon.2023.100207

Adamou, H., Ibrahim, B., Salack, S., Adamou, R., Sanfo, S., & Liersch, S. (2020). Physico-chemical and bacteriological quality of groundwater in a rural area of Western Niger: A case study of Bonkoukou. *Journal of Water and Health*, *18*(1), 77–90. https://doi.org/10.2166/wh.2020.082

Adesakin, T. A., Oyewale, A. T., Bayero, U., Mohammed, A. N., Aduwo, I. A., Ahmed, P. Z., Abubakar, N. D., & Barje, I. B. (2020). Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. *Heliyon*, *6*(8), e04773. https://doi.org/10.1016/j.heliyon.2020.e04773

Akani, N. P., Sampson, T., Disegha, G. C., & Vincent-Okwuosa, V. (2021). Physicochemical and Bacteriological Quality of Water from Storage Tanks in a Tertiary Institution in Rivers State, Nigeria. *Journal of Advances in Microbiology*, 6–17. https://doi.org/10.9734/jamb/2021/v21i630355

APHA. (1999). *Standard Methods for the Examination of Water and Wastewater* (20th Ed). APHA.

APHA. (2001). *Standard Methods for the Examination of Water and Wastewater* ((21st Ed.). APHA.

Atiku, S., Ogbaga, C. C., Alonge, O. O., & Nwagbara, O. F. (2018a). Comparative study of the physicochemical and bacteriological qualities of some drinking water sources in Abuja, Nigeria. *Global Journal of Pure and Applied Sciences*, *24*(1), 91. https://doi.org/10.4314/gjpas.v24i1.11

Atiku, S., Ogbaga, C. C., Alonge, O. O., & Nwagbara, O. F. (2018b). Comparative study of the physicochemical and bacteriological qualities of some drinking water sources in Abuja, Nigeria. *Global Journal of Pure and Applied Sciences*, *24*(1), 91. https://doi.org/10.4314/gjpas.v24i1.11

Bamigboye, C. O., & Amina, T. M. (2018). Physicochemical and Microbiological Assessments of Newly Dug Borehole Water Sources in Rafi Local Government, Minna, Niger State. *Annual Research & Review in Biology*, *29*(4), 1–9. https://doi.org/10.9734/ARRB/2018/44646

Cheesbrough. (2002). *District Laboratory Practice in Tropical Countries.* (2nd ed.). University Press, University of Cambridge, Edinburgh, Cambridge, United Kingdom.

Duressa, G., Assefa, F., & Jida, M. (2019). Assessment of Bacteriological and Physicochemical Quality of Drinking Water from Source to Household Tap Connection in Nekemte, Oromia, Ethiopia. *Journal of Environmental and Public Health*, *2019*, 1–7. https://doi.org/10.1155/2019/2129792

Ebong, S., Etim D. Uko, N. Otugo, V., & E. Uko, O. (2018). Evaluation of Physicochemical and Microbiological Characteristics of Borehole Water in Mgboushimini Community of Rivers State, Nigeria. *Journal of Advances in Medicine and Medical Research*, *27*(8), 1–9. https://doi.org/10.9734/JAMMR/2018/42959

Egbueri, J. C., Agbasi, J. C., Ayejoto, D. A., Khan, M. I., & Khan, M. Y. A. (2023). Extent of anthropogenic influence on groundwater quality and human health-related risks: An integrated assessment based on selected physicochemical characteristics. *Geocarto International*, *38*(1), 2210100. https://doi.org/10.1080/10106049.2023.2210100

Eid, M. H., Eissa, M., Mohamed, E. A., Ramadan, H. S., Tamás, M., Kovács, A., & Szűcs, P. (2024). New approach into human health risk assessment associated with heavy metals in surface water and groundwater using Monte Carlo Method. *Scientific Reports*, *14*(1), 1008. https://doi.org/10.1038/s41598-023-50000-y

Garoma, B., Kenasa, G., & Jida, M. (2018). *Drinking Water Quality Test of Shambu Town (Ethiopia) from Source to Household Taps Using Some Physico-chemical and Biological Parameters*. *6*(4).

Hakam, I., & Obire, O. (2015). *Evaluation of the Microbiological Quality of Palm Fruits in the Various Stages of Palm Oil Production*. Unpublished. https://doi.org/10.13140/RG.2.2.10801.33127

Holt, G., J., Kreig, N. R., Sneath, P. H., A., Stanley, J., & Willams, S. (1994). *Bergey’s manual of determinative bacteriology* (Ninth Edition). Lippincott, Williams & Wilkins, Baltimore.

Ismael, M., Mokhtar, A., Farooq, M., & Lü, X. (2021). Assessing drinking water quality based on physical, chemical and microbial parameters in the Red Sea State, Sudan using a combination of water quality index and artificial neural network model. *Groundwater for Sustainable Development*, *14*, 100612. https://doi.org/10.1016/j.gsd.2021.100612

Kahuho, P., Nassali, P., Maina, J., & Byatta, P. (2019). Optimizing access to safe water through chlorinated dispensers in Rural Kenya. *Uganda and Malawi*.

Lutterodt, G., Van De Vossenberg, J., Hoiting, Y., Kamara, A., Oduro-Kwarteng, S., & Foppen, J. (2018). Microbial Groundwater Quality Status of Hand-Dug Wells and Boreholes in the Dodowa Area of Ghana. *International Journal of Environmental Research and Public Health*, *15*(4), 730. https://doi.org/10.3390/ijerph15040730

Maduka, O., & Ephraim-Emmanuel, B. (2019). The quality of public sources of drinking water in oil-bearing communities in the Niger Delta region of Nigeria. *AAS Open Research*, *2*, 23. https://doi.org/10.12688/aasopenres.12964.1

Marufi, N., Oliveri Conti, G., Ahmadinejad, P., Ferrante, M., & Mohammadi, A. A. (2024). Carcinogenic and non-carcinogenic human health risk assessments of heavy metals contamination in drinking water supplies in Iran: A systematic review. *Reviews on Environmental Health*, *39*(1), 91–100. https://doi.org/10.1515/reveh-2022-0060

Obioma, A., Ihua Nnenna, & Ohwondah Golden. (2020). Bacteriological Risk Assessment of Borehole Sources of Drinking Water in Some Part of Port Harcourt Metropolis of Niger Delta, Nigeria. *Biomedical Journal of Scientific & Technical Research*, *24*(4). https://doi.org/10.26717/BJSTR.2020.24.004093

Odu, N. N., Omunakwe Amadi Lawrence, & Makililo Millicent. (2020). Comparative Assessment on the Physicochemical Water Quality of Wells and Boreholes in Two Rivers State Communities, Nigeria. *International Journal of Research Studies in Microbiology and Biotechnology*, *6*(3). https://doi.org/10.20431/2454-9428.0603002

Ondieki, J. K., Akunga, D. N., Warutere, P. N., & Kenyanya, O. (2021). Bacteriological and physico-chemical quality of household drinking water in Kisii Town, Kisii County, Kenya. *Heliyon*, *7*(5), e06937. https://doi.org/10.1016/j.heliyon.2021.e06937

Onyegeme-Okerenta, B., Obia, C., & Wegwu, M. (2016). Physicochemical properties of water quality of Imeh, Edegelem and Chokocho communities located along Otamiri-oche River in Etche Ethnic Nationality of Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *20*(1), 113. https://doi.org/10.4314/jasem.v20i1.14

Reuben, R., Gyar, S., & Aliyu, Y. (2018). Physicochemical and Microbiological Parameters of Water from Rivers in Keffi, Central Nigeria. *Microbiology Research Journal International*, *24*(3), 1–12. https://doi.org/10.9734/MRJI/2018/42547

Sahoo, S. K., & Goswami, S. S. (2024). Theoretical framework for assessing the economic and environmental impact of water pollution: A detailed study on sustainable development of India. *Journal of Future Sustainability*, *4*(1), 23–34. https://doi.org/10.5267/j.jfs.2024.1.003

Sampson, T., Giami, L. K., & Okedike, J. A. (2021). Phenotypic Characterization of Bacteria Isolated from the Recreational Sites of Two Rivers in Orashi Region, Rivers State, Nigeria. *South Asian Journal of Research in Microbiology*, 16–23. https://doi.org/10.9734/sajrm/2021/v9i330209

Uzoigwe, C. I., & Agwa, O., K. (2012). Microbiological quality of water collected from boreholes sited near refuse dumpsites in Port Harcourt, Nigeria. *AFRICAN JOURNAL OF BIOTECHNOLOGY*, *11*(13). https://doi.org/10.5897/AJB10.2664

WHO. (2011). *Guidelines for Drinking-Water Quality, Fourth 565 edition.* (p. 565).

WHO. (2014). *Drinking water parameters. Microbiological, chemical and indicator parameters. An overview of parameters and their importance..*

WHO. (2020). *Water Supply and Sanitation: Progress on Sanitation and Drinking Water .*

Wright, R. J., & Stuczynski, T. (2018). Atomic Absorption and Flame Emission Spectrometry. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston, & M. E. Sumner (Eds.), *SSSA Book Series* (pp. 65–90). Soil Science Society of America, American Society of Agronomy. https://doi.org/10.2136/sssabookser5.3.c4

Yeboah, S. I. I. K., Antwi-Agyei, P., & Domfeh, M. K. (2022). Drinking water quality and health risk assessment of intake and point-of-use water sources in Tano North Municipality, Ghana. *Journal of Water, Sanitation and Hygiene for Development*, *12*(2), 157–167. https://doi.org/10.2166/washdev.2022.152