Original

Evaluation of the physicochemical and bacteriological quality of drinking water sources in rural communities of Cross River State, Nigeria

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ABSTRACT

Background: Rural communities in Nigeria and many Sub-Saharan African countries often depend on untreated water sources which are frequently contaminated by industrial effluents and various organic and inorganic pollutants, rendering the water unsafe for consumption. This study assessed the physicochemical and bacteriological quality of drinking water sources in rural communities of southern Nigeria.

Methods: A cross-sectional analytical design with 240 respondents selected via multi-stage sampling. Data were collected electronically using an interviewer-administered semi-structured questionnaire, along with an observational checklist and sample bottles. These were analysed using SPSS Version 23.

Results: Physicochemical analyses showed mean conductivity (118.45 µS/cm), total dissolved solids (TDS) (41.24 mg/L), dissolved oxygen (DO) (25.66 mg/L), and total suspended solids (TSS) (3.69 mg/L) were within WHO and NSDWQ permissible limits; several parameters exceeded standard thresholds. These include turbidity (13.83 FTU), salinity (39.43 PPT), colour (23.12 TCU), iron concentration (4.94 mg/L), and pH (23.22)- indicating potential health hazards and possible measurement error in pH values. Mean temperature was 5.61°C while bacteriological assessment revealed contamination with total coliform and faecal coliform counts exceeding the WHO and NSDWQ standard of 0 CFU/100ml in all tested sources. Among respondents, 117(48.8%) used sachet or bottled water, while 191(79.6%) had access to multiple water sources. Of these, 172(90.1%) cited rainwater as an alternative source.

Conclusion: There are significant quality and safety issues due to bacterial contamination, posing major public health concerns. This study recommends urgent interventions, including water treatment, monitoring and robust source protection to ensure safe drinking water access in these rural communities.

Keywords: Physicochemical, bacteriological quality, drinking water sources, rural communities.

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INTRODUCTION

Water is the Earth's most abundant resource, occurring naturally in three forms: groundwater, rainwater, and surface water. Among these, surface water is the most readily available.[1] Natural water is a vital resource that is essential for the survival of both animals and plants on Earth.[2,3] Water is consumed directly as drinking water or indirectly through its presence in food. It also plays a critical role in various daily activities.[4] As a result, access to potable drinking water is vital for health and is recognised as a fundamental human right.[1] Safe drinking water is defined as water that poses no significant health risk when consumed over a lifetime, taking into account varying sensitivities that may arise at different stages of life.[2,5] However, the rapid pace of industrialisation, urbanisation, and the growing global population has significantly increased the demand for high-quality water. This surge in demand for domestic, recreational, industrial, and other purposes has placed considerable pressure on the availability and quality of this essential resource.[4]

Ensuring access to potable drinking water in rural communities has consistently been a significant challenge.[1,4] According to reports from the World Health Organization (WHO) and United Nations Children's Fund (UNICEF), Nigeria and several other sub-Saharan African nations are notably behind many developing countries in terms of overall access to potable water and basic sanitation services.[6] This is primarily due to the widespread deterioration of public water infrastructures and frequent system failures. These issues often result in a shortage of potable water supply in the region.[6] In Nigeria, common sources of drinking water include tube wells, boreholes, and dug wells.[5] However, the source of drinking water often varies with the seasons; during the dry season, people are more likely to rely on water supplied by tanker trucks, water vendors, bottled water, or surface water.[6] In contrast, during the rainy season, rainwater harvesting becomes a more widely used option for obtaining drinking water.[5]

The physicochemical properties of water, such as turbidity, colour, taste, and odour, whether naturally occurring or by human activity that can affect how consumers perceive and accept water quality.[5]

Surface water serves as a natural habitat for various living organisms, some of which play a role in the transmission of infectious diseases like cholera, typhoid, dysentery, guinea worm, hepatitis, giardiasis, and schistosomiasis, among others, when polluted by a range of pathogenic microorganisms, including bacteria, fungi, viruses, protozoa, and other biological agents.[3,4] Sources of surface water include lakes, rivers, streams, canals, and ponds.[1] These water bodies are highly susceptible to contamination from both human and animal activities, as well as environmental factors such as storms or rainfall.[1,7] Many people in rural communities depend solely on untreated water sources like streams and rivers for their daily needs. Due to the lack of access to safe water, they had no alternative but to depend on surface water to accomplish their water requirements, which increases the risk of waterborne disease outbreaks.[4,6]

Despite significant financial investments by successive Nigerian governments at both the federal and state levels in the provision of access to potable water, rural communities still experience either limited access or a complete lack of coverage.[3] The lack of access to potable water, particularly in rural communities, significantly diminishes the quality of life for residents. Over time, this shortage has played a major role in the high prevalence of communicable diseases, contributing to a substantial proportion of both morbidity and mortality rates in these communities.[3] On a global scale, waterborne diseases, particularly diarrhoea, account for over two million deaths annually, with children under the age of five being the most vulnerable.[1] This issue is particularly profound in impoverished communities, primarily due to limited awareness of proper hygiene practices across various levels.[3,7] Enhancing water supply leads to significant improvements in public health generally.[3] The United Nations has established 2030 as the target year for achieving universal access to safe drinking water for all nations and populations, which is a key objective of the Sustainable Development Goal (SDG) 6, one of the 17 SDGs.[1]

METHODOLOGY

Study design: In order to evaluate the variables of interest and their relationships, this study employed a cross-sectional study design and quantitative methods for data collection, gathering information from the target population at a specific point in time.

Study population: The study population was made up of adults (males and females), 18 years and above, who reside in rural communities of Nigeria, and their drinking water sources.

Sample size determination: The Fisher's formula was used to determine the sample size:

$$n= \frac{z^2pq}{d^2}$$

Where;

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n = Desired sample size
Z = Confidence level
p = Prevalence rate
q = Proportion of non-occurrence (1-p)
d = margin of error
Therefore:
Z = 95% (1.96)
p = 83.4% = 0.834 (Proportion of 83.4% of those depending on surface water for drinking from a study by [8].
q = 1 – 0.834 = 0.166
d^2 = 5% = $(0.05)^2$ = 0.0025

$$n = \frac{1.96^2 x\ 0.834\ x\ 0.166}{0.0025}$$

$$n = \frac{3.841\ x\ 0.834 x\ 0.166}{0.0025}$$

n = 212.7
n~ 213

$$\frac{n}{1\ - NRR}$$

Assuming a nonresponsive rate of 10% (0.1)

$$n = \frac{213}{1 - 0.10}$$

$$n = \frac{213}{0.90}$$

= 236.7
The total sample is 237.
For the purpose of this study, 240 respondents were used.

Sampling procedure

Stage 1: Selection of wards: Odukpani has 13 wards, and six were selected through a simple random sampling method. To do this, the names of all 13 wards were written on separate pieces of paper, folded, and placed in a container. The papers were then thoroughly mixed, and six were picked one by one without replacement. This approach ensured that every ward had an equal chance of being selected.
Stage 2: Selection of clusters: From each of the six selected wards, cluster sampling was used to select 30 clusters for the study. By first dividing the entire population into groups.
Stage 3: Selecting the respondents: From each of the selected clusters in each ward, eight respondents (240/30 = 8) were chosen using a simple random sampling technique.
Water sample collection: Water samples from different drinking water sources in chosen communities were gathered using sterile sample bottles, labelled, kept in cooler bags, and delivered within six hours to the Cross River State Water Board Limited, Calabar quality control laboratory for laboratory analysis. Two samples of water were taken from each source.
Samples from surface sources: Water samples from surface sources were taken from the point where the community members fetch their drinking water. At each water source, sample bottles were rinsed twice with the water to be collected. The sample bottles were held at the lower part and submerged to a depth of about 20cm with the mouth facing upward in the direction of the current. The bottle was then capped before being removed from the water and labelled properly with the sources and time of collection stated.
Sampling from a borehole: The tap of the borehole outlet was sterilised with methylated spirit-soaked cotton wool. The tap was flamed with a lighter to ensure complete sterilisation. The tap was opened and allowed to run for 1-2 minutes. The cap of the sterilised sample bottle was carefully unscrewed, and the water was collected 2cm below the mouth. The bottle was then capped, labelled, and placed in a cooler bag.
Sampling from dug-wells: Step 1: Sterilised sample bottles were prepared, and a weight was attached to them with a 20-metre string.
Step 2: A 20m string was rolled around a stick and tied to the bottle strongly.
Step 3: The bottle with a weight was lowered into the well by unwinding the string slowly without touching the sides of the well.
Step 4: The bottle was completely immersed below the surface but was not allowed to touch the bottom of the well or disturb any sediments until it was filled.
Step 5: The bottle was brought up by rewinding the string around the stick. A little water was discarded from the bottle to provide air space.
Step 6: The bottle was recapped, labelled, and placed in a storage container.
Samples were placed in containers containing ice packs to maintain the required temperature of about 40 °C and ensure protection from sunlight. Samples were transferred immediately to the refrigerator on arrival from the field and analysed within 2 hours.
Bacteriological and physicochemical analyses: For this investigation, the following water quality characteristics were analysed: conductivity, turbidity, pH, faecal coliform, total coliform, iron, zinc, manganese, and aluminium. The parameters were chosen in accordance with the minimal requirements for routine monitoring specified by the Nigerian Standard

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for Drinking Water Quality (NSDWQ). Standard techniques and the indicator organism, Escherichia coli, were used to determine the bacteriological analysis (faecal coliform and total coliform count), and standard methods were also used to analyse the physicochemical features of the water samples. With the use of the Atomic Absorption Spectrometer (AAS), chemical characteristics like iron, zinc, aluminium, and manganese were examined.

Determination of the bacteriological quality of water: The media used are nutritional agar for the heterotrophic count, MF-C agar base for the faecal coliform count, and Endo agar for the total coliform count. These were made in accordance with the manufacturer's instructions and autoclave sterilised for 15 minutes at 121°C. Before being inoculated, they were put into 120 mL sterile petri plates and left to chill. Additionally, the stainless-steel filtering units and glassware were sterilised for one hour at 150°C in a hot air oven.

After shaking the samples to combine them, 100 millilitres were taken and filtered through a membrane filter with a pore size of 0.45 µm. These plates were incubated at 37°C for a whole day. Following the incubation phase, emerging colonies were counted using a colony count method. Counts were noted appropriately.

Determination of the physicochemical properties of water: Physicochemical characteristics of the water samples were analysed using standard methods. The pH, temperature, and turbidity were measured using a pH meter.

Chemical parameters: Iron, zinc, and manganese were analysed using methods described by the American Public Health Association (APHA) (1998) using the atomic absorption spectrophotometer (AAS). Digestion was done for all the water samples meant for metal analyses. Here, fifteen millilitres (15ml) of concentrated HNO_3 will be added to the 50ml of each sample; the mixture was heated slowly to evaporate to a lower volume of 5ml, after which 5ml concentrated HNO_3 was again added to the 15ml of the mixture obtained. The mixture was then diluted to 50ml with distilled water. This was heated slowly to obtain a gentle refluxing action.

Further heating continued until digestion is complete (a light-coloured solution). The sample was transferred to 50ml volumetric flask and diluted to the mark, then allowed to cool for about 30 minutes. The level of the individual metals was then determined using an Atomic Absorption Spectrometer.

Instruments for data collection: The instruments for data collection were a semi-structured interviewer-administered questionnaire and an observational checklist prepared based on the research objectives. Sterilised sample bottles were also used for the collection of water samples.

Methods of data collection: Three well-trained research assistants assisted the researchers in gathering data using an interviewer-administered questionnaire and an observational checklist. The observational checklist and questionnaire, designed in English, featured a mix of structured and open-ended questions. Water samples were collected with sterilized sample bottles from various drinking water sources of selected communities, as stated in 3.4.1.

Methods of data analysis: Once finished, the questionnaire was manually reviewed to verify its completeness. All relevant data were meticulously recorded, cleaned, and analysed using Microsoft Excel. Following this, the data were transferred into the Statistical Product and Service Solutions (SPSS) Version 27 for further analysis. Water samples were analysed at Cross River State Water Board Limited.

Patient involvement statement: Patients were not involved in this study.

RESULTS

Sociodemographic characteristics of respondents: A total of 240 questionnaires were distributed, and all were successfully retrieved, resulting in a 100% response rate. Table 1 presents the sociodemographic characteristics of the study participants. The mean age of the respondents was 35.19 ± 11.635 years. The majority, 82(34.2%), were aged between 18 and 28 years. Most respondents, 145(60.4%), were married or cohabiting. A significant proportion, 229(95.4%), identified as Christians. The highest level of educational attainment for 117(48.8%) respondents was secondary school education. Additionally, 120(50%) respondents reported a household size ranging from 6 to 10 members.

Types of drinking water sources available in the rural communities: **Table 2** presents the distribution of drinking water sources available to respondents in rural communities. A significant proportion of respondents, 117(48.8%), reported sachet or bottled water as their primary source of drinking water.

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Furthermore, the majority, 191(79.6%), indicated access to multiple water sources, with 172(90.1%) of them identifying rainwater as an alternative source.

Table 1 Sociodemographic characteristics of respondents

Variable	Frequency (n=240)	Percent
Age (years)	**Mean = 35.19, SD = 11.635**	
18-28	82	34.2
29-38	79	32.9
39-48	39	16.3
49-58	31	12.9
59 and above	9	3.8
Marital status		
Single	71	29.6
Married/Co-habiting	145	60.4
Divorced/ Separated	8	3.3
Widowed	16	6.7
Religion		
Christianity	229	95.4
Islam	2	0.8
Traditional religion	2	0.8
None	7	2.9
Highest level of education completed		
No formal education	24	10.0
Primary school	45	18.8
Secondary school	117	48.8
Tertiary (e.g., College of Health, Nursing)	54	22.5
Number of persons in a house		
1-5	120	50.0
6-10	116	48.3
11 and above	4	1.7

Table 2: Types of drinking water sources available in the communities **(n=240)**

Variable	Freq	Percent (%)
Primary source of drinking water		
Borehole	49	20.4
Hand-dug well	29	12.1
River/stream	16	6.7
Sachet/bottled water	117	48.8
Public tap/standpipe	18	7.5
Other (please specify)	11	4.6
Access to multiple sources of drinking water		
Access	191	79.6
No access	49	20.4
****Alternative source of water**		
Borehole	6	3.1
Hand-dug well	26	13.6
Rainwater collection	172	90.1
River/stream	66	34.6
Sachet/bottled water	26	13.6
Public tap/standpipe	13	6.8

Primary source of drinking water (others) = Spring ** Multiple response allowed, hence percentage not equal to 100%

Physicochemical quality of drinking water sources

Physicochemical quality of drinking water sources is presented in Table 3 and detailed as follows:

Conductivity (µS/cm): The average conductivity was 118.45 µS/cm, which is well within the WHO acceptable range of 400–800 µS/cm and the NSDWQ maximum of 1000 µS/cm. This indicates a low concentration of dissolved ions and minerals, reflecting good water quality in terms of ionic content.

Turbidity (FTU): The mean turbidity level was 13.83 FTU, significantly exceeding both the WHO limit of <5 FTU and the NSDWQ permissible limit of ≤5 FTU. Elevated turbidity suggests the presence of suspended solids, which may harbour pathogenic microorganisms, making the water potentially unsafe for direct consumption without treatment.

Salinity (PPT): With a mean salinity value of 39.43 PPT, the water far exceeds the WHO and NSDWQ safe limit of 0.5 PPT. This high salinity level is unsuitable for drinking purposes and may pose health risks, especially to individuals with hypertension or kidney-related issues.

pH: The reported mean pH value was 23.22, which is far outside the standard acceptable range of 6.5–8.5 specified by both WHO and NSDWQ. This value is unrealistic for natural water systems and likely indicates a measurement or recording error that should be re-evaluated.

Dissolved Oxygen (DO, mg/L): The average DO concentration was 25.66 mg/L, which surpasses the minimum requirement of 5 mg/L set by both WHO and NSDWQ. Although this is favourable for aquatic ecosystems, such high DO levels are uncommon in natural water sources and may warrant further validation.

Temperature (°C): The mean temperature of the water samples was 5.61°C, which is below the recommended maximum of 25°C. This value is within safe limits, suggesting favourable conditions for water storage and microbial control. However, such low temperatures could also point to samples being taken from colder or shaded sources.

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Total Dissolved Solids (TDS): The average TDS was 41.24 mg/L, which is well below the WHO recommended limit of 1000 mg/L and the NSDWQ limit of 500 mg/L. This indicates that the water has low levels of dissolved inorganic salts, making it safe for drinking from a TDS perspective.

Colour (True Colour Units): The mean colour intensity was 23.12 TCU, which exceeds the WHO and NSDWQ limits of 15 TCU. This suggests the water may contain dissolved organic matter or metals like iron and manganese, which can affect both the aesthetic and chemical quality of the water.

Iron (mg/L): Iron concentration averaged 4.94 mg/L, significantly higher than the maximum permissible limit of 0.3 mg/L set by both WHO and NSDWQ. Excess iron can lead to staining, unpleasant taste, and potential health effects if consumed over a long period.

Total Suspended Solids (TSS, mg/L): The mean TSS was 3.69 mg/L, which is within the safe limit of <10 mg/L. This indicates relatively low levels of particulate matter in suspension, contributing to acceptable physical clarity when turbidity is not considered.

Bacteriological quality of drinking water: Based on the analysis of the water samples, the Total Coliform Count (TCC) and Faecal Coliform (FEC) levels were found to significantly exceed the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines, which stipulate that both TCC and FEC should be 0 CFU/100ml for water to be considered microbiologically safe for consumption. The majority of the samples analysed showed high bacterial contamination, with several entries marked as "Too Numerous to Count" (TNTC), indicating gross microbial pollution likely due to faecal contamination or inadequate sanitation practices. These findings clearly indicate that most of the water sources assessed are unsafe for drinking and pose a serious public health risk, necessitating urgent intervention through proper treatment, improved hygiene practices, and regular monitoring (Table 4).

Observational checklist: Findings from the observational checklist revealed several critical concerns regarding the safety and condition of drinking water sources. A total of 77(77.0%) of the drinking water sources were observed to be used for other domestic purposes, such as bathing and washing materials, potentially increasing the risk of contamination. Evidence of human activities like farming or residential presence was seen around 89(89.0%) of the water sources, indicating possible exposure to pollutants. Additionally, 56(56.0%) of the sources had an objectionable odour, while 62(62.0%) were reported to have an unpleasant taste. Physical impurities were also notable, with 52(52.0%) of the sources containing debris or suspended particulate matter. Moreover, 56(56.0%) of the observed waste disposal patterns were considered unsatisfactory, and 42(42.0%) of the excreta disposal patterns failed to meet acceptable standards. Lastly, 51(51.0%) of the water sources were located at distances greater than 1km, posing challenges to water accessibility for nearby residents (Table 5).

Table 3: Physicochemical quality of drinking water sources

DISCUSSION

Types of drinking water sources

The findings from this study revealed that nearly half of the respondents, 117(48.8%), rely on sachet or bottled water as their primary drinking water source. Additionally, a considerable majority, 191(79.6%) reported access to multiple sources of water, with rainwater being a common alternative, 172(90.1%), among those with multiple sources. Reliance on multiple water sources is common in rural and peri-urban areas due to limited access to safe, reliable drinking water. The dependence on rainwater as a supplementary source is likely driven by seasonal availability, cost considerations, and inadequate public water infrastructures. The results of this study align with the results of a study along the Uganda-Kenya border, by [9], that reported that residents used a mix of springs (94.0%), groundwater (57.3%), tap water (53.0%), and streams (28.1%) for drinking. Further supporting this observation was the assessment of water quality in the lower Yellow River basin, which found residents utilised different types of water sources, particularly surface water (rivers and reservoirs) and groundwater (springs and wells). The dependence on rainwater and commercial water (sachet/bottled) underscores the urgency for interventions that address both quality and reliability.

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PARAMETER /UNIT	Drinking water sources	Conductivity (Us/cm)	Turbidity (FTU)	Salinity (PPT)	PH	DO (mg/c)	Temperature (0C)	TDS	Colour	Iron (mgl)	TSS
S1	Creek Town stream	110.5	1.8	54.91	6.2	11.8	22.4	66.3	L5	0.33	0.016
S2	Creek Town borehole	275.8	1.6	141.5	6.3	12	22.5	165.48	L5	0.46	0.013
S3	Creek Town stream	166.5	4.6	57.84	6.1	19.6	22.2	99.9	10	0.43	0.023
S4	Creek Town dug well	39.19	46.5	19.79	6.3	18.4	22.6	23.514	10	0.32	0.022
S5	Creek Town borehole	39.44	45.9	19.21	6.5	17.5	22.4	23.664	10	0.29	0.028
S6	Creek Town dug well	37.79	3.4	18.29	5.4	191.5	22.3	22.674	5	0.31	0.02
S7	Creek Town stream	81.3	2.6	39.13	4.9	18.8	24.1	48.78	L5	0.37	0,012
S8	Creek Town stream	46.1	3.8	17.52	5.1	17.6	23	27.66	L5	0.51	0
S9	Creek Town stream	66.3	1.9	21.3	6.3	17.6	23.3	39.78	L5	0.39	0.01
S10	Creek Town borehole	53.2	1.4	13.83	6.2	18	24.5	31.92	L5	0.44	0.008
S11	Creek Town borehole	66.5	2.3	15.01	5.8	16.5	26.3	39.9	L5	0.56	0.006
S12	Creek Town stream	101.1	3.8	13.6	5.6	17.3	22.6	60.66	5	0.19	0.021
S13	Creek Town stream	72.3	2.6	19.4	7.01	16.6	25.1	43.38	L5	0.25	0.001
S14	Creek Town dug well	80.2	3.8	12.51	6.5	19.3	25.3	48.12	L5	0.47	0.008
S15	Creek Town stream	65.3	4.1	17.81	6.2	12.9	24.4	39.18	L5	0.36	0.009
S16	Creek Town stream	49.3	3.9	19.51	7.2	15	23.8	29.58	L5	0.42	0.031
S17	Ekori/Anaku stream	55.6	3.8	16.22	6.8	13.8	25.3	33.36	5	0.35	0.001
S18	Ekori/Anaku borehole	72.1	4.1	18.52	5.6	16.8	24.3	43.26	10	0.48	0.028
S19	Ekori/Anaku dug well	33.3	2.8	16.01	5.9	12.6	22.8	19.98	L5	0.46	0.013
S20	Ekori/Anaku borehole	40.1	3.1	18.11	4.3	17.8	26.3	24.06	L5	0.51	0.01
S21	Ekori/Anaku stream	58.6	3.5	17.5	4.8	17.6	26.1	35.16	L5	0.53	0.014
S22	Ekori/Anaku dug well	181	4.44	L5	41.39	108.9	0.014	18.5	23. 6	0.39	0.33
S23	Ekori/Anaku stream	67.3	4.13	L5	62.4	40.38	0.017	17.6	24.5	0.54	0.31

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PARAMETER /UNIT	Drinking water sources	Conductivity (Us/cm)	Turbidity (FTU)	Salinity (PPT)	PH	DO (mg/c)	Temperature (0C)	TDS	Colour	Iron (mgl)	TSS
S24	Ekori/Anaku dug well	67.8	3.66	5	46.8	40.68	0.01	18.8	25.1	1.06	0.43
S25	Ekori/Anaku borehole	42.6	3.83	L5	42.34	25.56	0.064	17.4	26.7	0.41	0.29
S26	Ekori/Anaku stream	138.3	3.99	L5	21.37	82.98	0.019	19.3	25.6	0.48	0.56
S27	Ekori/Anaku stream	102.2	4.08	L5	33.29	61.32	0.01	18.8	25. 3	0.27	0.41
S28	Ekori/Anaku stream	41.4	3.79	5	10.96	24.84	0.058	19.4	25.6	1.23	0.48
S29	Ekori/Anaku dug well	107.5	4.01	L5	34.16	64.5	0.013	7.1	23.9	0.61	0.51
S30	Ekori/Anaku stream	136.6	5.21	L5	36.1	81.96	0.018	12.8	24	0.8	0.62
S31	Ekori/Anaku borehole	63.7	4.98	L5	41.18	38.22	0.018	12.6	24.1	1.26	0.48
S32	Ekori/Anaku stream	98.1	5.66	5	28.26	88.86	0.043	11.9	26.1	0.73	0.59
S33	Akamkpa ward borehole	49.4	4.22	L5	31.62	29.64	0.06	16.8	26.3	1.22	0.61
S34	Akamkpa ward dug well	71.2	5.92	5	52.14	42.72	0.055	10.9	25.4	0.7	0.55
S35	Akamkpa ward borehole	66.4	6.11	L5	41.21	39.84	0.061	12.6	23.6	0.69	0.45
S36	Akamkpa ward dug well	81.2	6.02	L5	56.6	48.72	0.048	13.7	23.3	0.58	0.71
S37	Akamkpa ward borehole	76.7	6.31	L5	48.12	46.02	0.044	19.1	24.4	0.73	0.59
S38	Akamkpa ward stream	78.2	5.99	L5	51.31	46.92	0.063	14.3	25.6	0.55	0.38
S39	Akamkpa ward borehole	69.3	4.31	L5	48.61	41.58	0.039	16.7	26. 7	0.49	0.48
S40	Akamkpa ward stream	101.1	4.44	L5	71.31	60.66	0.042	18.3	25.2	0.61	0.46
S41	Akamkpa ward borehole	84.6	4.63	L5	60.11	50.76	0.057	18.5	24.8	0.71	0.47
S42	Akamkpa ward dug well	81.1	5.57	L5	70.16	48.66	0.079	18.8	26.1	1.1	0.55
S43	Akamkpa ward stream	74.5	6.1	5	58.91	44.7	0.069	17.6	25	1.33	0.61
S44	Akamkpa ward stream	82.6	5.71	5	56.31	49.56	0.056	14.9	24.8	0.96	0.53
S45	Akamkpa ward dug well	80	6.1	5	66.11	48	0.071	19.6	25.3	1.21	0.68
S46	Akamkpa ward borehole	96.3	23.4	39.13	5.4	16.5	0.45	3.6	57.78	10	0.033

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PARAMETER /UNIT	Drinking water sources	Conductivity (Us/cm)	Turbidity (FTU)	Salinity (PPT)	PH	DO (mg/c)	Temperature (0C)	TDS	Colour	Iron (mgl)	TSS
S47	Akamkpa ward borehole	127.8	24.1	23.8	6.2	18.3	0.55	2.3	76.68	5	0.039
S48	Akamkpa ward dug well	76.55	23.9	29.63	5.9	21.5	0.51	1.9	45.9	5	0.018
S49	Eki borehole	116.3	24.6	20.77	4.8	13.6	0.63	0.8	69.78	L5	0.01
S50	Eki borehole	65.4	25	24.63	5.5	10. 8	0.54	0.1	39.24	L5	0.003
S51	Eki dug well	82.5	23.3	29.22	5.1	12.6	0.5	0.1	49.5	L5	0.005
S52	Eki borehole	60.1	22.9	31.66	6.2	11.3	0.62	0.2	36.06	L5	0.008
S53	Eki borehole	87.9	23	37.16	5.9	10.2	0.51	0.9	52.74	L5	0.014
S54	Eki dug well	134.6	24.1	28.2	4.3	14.7	0.48	1.1	80.76	L5	0.033
S55	Eki stream	142.1	25.6	40.12	4.8	16.1	0.49	2.9	85.26	10	0.083
S56	Eki dug well	106.5	23.6	38.12	4.9	16.5	0.52	1.6	63.9	5	0.028
S57	Eki stream	76.5	23.4	28.42	5.6	15.8	0.36	0.7	45.9	L5	0.009
S58	Eki stream	101.9	24	24.9	6.6	15.7	0.41	0.6	61.14	L5	0.007
S59	Eki dug well	124.4	25.1	33.21	6.3	10.6	0.38	1.5	74.64	5	0.012
S60	Eki stream	118	24.3	38.75	5.9	13.3	0.5	1.9	70.8	5	0.016
S61	Eki stream	79.9	23.6	20.41	5.6	12.8	0.33	0.6	47.94	L5	0.008
S62	Eki dug well	69.5	23.5	21.31	4.9	14.9	0.41	0.8	41.7	L5	0.008
S63	Eki stream	136.6	24.1	40.14	5.3	15	0.46	1.7	81.96	5	0.052
S64	Eki stream	126.8	23.4	37.19	5.8	16.5	0.48	1.3	76.08	L5	0.019
S65	Odukpani central stream	131.3	24.4	40.33	5.6	13.7	0.31	1.6	78.78	5	0.025
S66	Odukpani central dug well	126.5	26.1	36.22	6.7	15.5	0.42	1.1	75.9	L5	0.039
S67	Odukpani central dug well	103.3	26.3	31.68	4.9	13.8	0.38	0.9	61.98	L5	0.02
S68	Odukpani central stream	118.4	25.2	36.5	5	16.2	0.39	1	71.04	L5	0.018
S69	Odukpani central stream	148.78	23.5	39.13	6.12	20.8	1.8	89.27	5	0.011	0.67
S70	Odukpani central stream	164.9	23.8	234.8	5.14	19.6	5.1	98.94	15	0.108	0.58
S71	Odukpani central stream	419.8	23.6	298.6	5.16	24.6	3.2	251.88	15	0.094	1.32
S72	Odukpani central dug well	298.9	24.1	206.7	6.43	21.5	2.7	179.34	10	0.067	0.48
S73	Odukpani central borehole	281.6	23.6	203.4	5.71	19.6	2.2	168.96	5	0.049	0.35
S74	Odukpani central borehole	403.5	23.7	291.2	4.69	25.3	3.1	242.1	15	0.088	1.51

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PARAMETER /UNIT	Drinking water sources	Conductivity (Us/cm)	Turbidity (FTU)	Salinity (PPT)	PH	DO (mg/c)	Temperature (0C)	TDS	Colour	Iron (mgl)	TSS
S75	Odukpani central dug well	349.8	23.5	247.4	6.11	21.3	2.6	209.88	10	0.06	0.98
S76	Odukpani central borehole	89.5	23.8	64.27	6.21	14.6	0.9	53.7	<5	0.012	0.32
S77	Odukpani central borehole	94.04	23.6	69.9	6.33	16.2	1	56.43	<5	0.005	0.48
S78	Odukpani central borehole	310.7	23.9	82.18	6.48	21.3	2.6	186.42	5	0.033	0.89
S79	Odukpani central borehole	270.4	24	29.81	6.31	17.9	3	162.24	10	0.078	0.78
S80	Odukpani central dug well	115.3	23.9	81.4	5.1	15.8	1.5	69.18	5	0.01	0.62
S81	Odukpani central stream	88.7	24.1	29.4	5.68	12.5	0.8	53.22	<5	0.024	0.27
S82	Odukpani central borehole	147.3	23.9	38.66	5.82	18.3	1.9	88.38	5	0.011	0.36
S83	Adiabor/Efut stream	187.2	24.2	32.5	6.11	27.4	1.9	112.32	5	0.013	0.53
S84	Adiabor/Efut stream	311.6	23.6	79.4	5.68	18.6	2.8	186.96	10	0.014	0.41
S85	Adiabor/Efut borehole	148	23.9	35.61	5.88	19.9	1.3	88.8	5	0.016	0.46
S86	Adiabor/Efut dug well	216.3	24	48.7	5.05	16.8	1.2	129.78	<5	0.012	0.51
S87	Adiabor/Efut stream	165.8	24	30.7	6.6	15.8	1.1	99.48	<5	0.012	0.39
S88	Adiabor/Efut dug well	201.3	23.8	56.81	6.81	19.8	1.4	120.78	<5	0.016	0.61
S89	Adiabor/Efut stream	143.2	23.6	39.44	6.35	14.8	1.6	88.92	<5	0.018	0.46
S90	Adiabor/Efut borehole	80.4	4.99	23.7	48.24	<5	0.39	0.61	0.017	39.13	171
S91	Adiabor/Efut borehole	93.1	5.01	23.5	55.86	<5	0.44	0.38	0.008	27.33	19.5
S92	Adiabor/Efut dug well	95.1	5.37	24.1	157.06	<5	0.28	0.66	0.01	31.21	18.9
S93	Adiabor/Efut stream	161.1	5.11	23.3	96.66	<5	0.31	1.31	0.036	36.1	18.4
S94	Adiabor/Efut stream	132.6	4.92	24.5	79.56	<5	0.5	0.72	0.041	32.16	13.38

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PARAMETER /UNIT	Drinking water sources	Conductivity (Us/cm)	Turbidity (FTU)	Salinity (PPT)	PH	DO (mg/c)	Temperature (0C)	TDS	Colour	Iron (mgl)	TSS
S95	Adiabor/Efut dug well	99.5	4.35	24.5	59.7	<5	0.38	0.41	0.012	22.71	14.11
S96	Adiabor/Efut stream	106.5	4.66	23.6	63.9	<5	0.47	0.66	0.015	36.1	14.91
S97	Adiabor/Efut borehole	89.7	5.1	25	53.82	<5	0.33	0.34	0.007	20.63	16.34
S98	Adiabor/Efut stream	116.1	5.23	24.8	69.66	<5	0.36	0.55	0.011	29.9	16.56
S99	Adiabor/Efut dug well	131	5.62	23.1	78.6	<5	0.49	0.38	0.016	34.26	18.63
S100	Adiabor/Efut borehole	121.6	5.14	23.8	72.96	<5	0.43	0.37	0.01	31.47	17.81
	Mean	118.45.	13.83	39.43	23.22	25.66	5.61	41.24	23.12	4.94	3.69
	SD	76.85	10.84	57.48	28.02	25.83	9.52	58.12	24.8	9.63	17.72
	Std Error	7.68	1.08	2.80	2.59	0.95	5.81	2.52	0.96	1.78	3.97
	WHO safe limits	≤ 400 - 800	<5	< 0.5	6.5 – 8.5	5	< 25°C	< 1000	< 15	≤ 0.3	< 10
	NSDW	1000	≤ 5	≤ 0.5	6.5 – 8.5	≥ 5	< 25	≤ 500	≤ 15	≤ 0.3	≤ 10

WHO: World Health Organisation
NSDWQ: Nigerian Standard for Drinking Water Quality

Table 4: Bacteriological quality of drinking water

PARAMETER/UNIT	Drinking water sources	TCC, 100ml/Cfu	FEC/100ml/Cfu
S1	Creek Town stream	61	29
S2	Creek Town borehole	39	20
S3	Creek Town stream	101	42
S4	Creek Town dug wel	98	51
S5	Creek Town borehole	106	70
S6	Creek Town dug well	77	38
S7	Creek Town stream	54	21
S8	Creek Town stream	80	29
S9	Creek Town stream	48	20
S10	Creek Town borehole	53	27
S11	Creek Town borehole	113	46
S12	Creek Town stream	104	50
S13	Creek Town stream	99	48
S14	Creek Town dug well	106	39
S15	Creek Town stream	121	58
S16	Creek Town stream	89	36
S17	Ekori/Anaku stream	91	42
S18	Ekori/Anaku borehole	116	53
S19	Ekori/Anaku dug well	89	28
S20	Ekori/Anaku borehole	78	30
S21	Ekori/Anaku stream	94	46
S22	Ekori/Anaku dug well	57	19
S23	Ekori/Anaku stream	46	22

PARAMETER/UNIT	Drinking water sources	TCC, 100ml/Cfu	FEC/100ml/Cfu
S24	Ekori/Anaku dug well	51	27
S25	Ekori/Anaku borehole	62	31
S26	Ekori/Anaku stream	77	30
S27	Ekori/Anaku stream	51	23
S28	Ekori/Anaku stream	102	40
S29	Ekori/Anaku dug well	56	27
S30	Ekori/Anaku stream	80	29
S31	Ekori/Anaku borehole	76	61
S32	Ekori/Anaku stream	51	33
S33	Akamkpa ward borehole	60	29
S34	Akamkpa ward dug well	71	37
S35	Akamkpa ward borehole	62	26
S36	Akamkpa ward dug well	49	19
S37	Akamkpa ward borehole	71	21
S38	Akamkpa ward stream	66	29
S39	Akamkpa ward borehole	91	30
S40	Akamkpa ward stream	112	57
S41	Akamkpa ward borehole	87	41
S42	Akamkpa ward dug well	131	86
S43	Akamkpa ward stream	93	40
S44	Akamkpa ward stream	73	29
S45	Akamkpa ward dug well	118	41
S46	Akamkpa ward borehole	TNTC	TNTC
S47	Akamkpa ward borehole	189	77
S48	Akamkpa ward dug well	125	60
S49	Eki borehole	54	20
S50	Eki borehole	39	18
S51	Eki dug well	48	21
S52	Eki borehole	37	19
S53	Eki borehole	60	25
S54	Eki dug well	85	32
S55	Eki stream	TNTC	TNTC
S56	Eki dug well	77	34
S57	Eki stream	53	21
S58	Eki stream	59	24
S59	Eki dug well	90	41
S60	Eki stream	89	48
S61	Eki stream	48	22
S62	Eki dug well	49	26
S63	Eki stream	107	36
S64	Eki stream	76	29
S65	Odukpani central stream	102	44
S66	Odukpani central dug well	73	30
S67	Odukpani central dug well	56	36
S68	Odukpani central stream	57	20
S69	Odukpani central stream	208	66
S70	Odukpani central stream	TNTC	TNTC
S71	Odukpani central stream	197	58

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PARAMETER/UNIT	Drinking water sources	TCC, 100ml/Cfu	FEC/100ml/Cfu
S72	Odukpani central dug well	103	30
S73	Odukpani central borehole	123	46
S74	Odukpani central borehole	TNTC	TNTC
S75	Odukpani central dug well	118	89
S76	Odukpani central borehole	44	19
S77	Odukpani central borehole	39	21
S78	Odukpani central borehole	100	41
S79	Odukpani central borehole	155	68
S80	Odukpani central dug well	187	63
S81	Odukpani central stream	46	22
S82	Odukpani central borehole	116	72
S83	Adiabor/Efut stream	102	66
S84	Adiabor/Efut stream	TNTC	TNTC
S85	Adiabor/Efut borehole	96	40
S86	Adiabor/Efut dug well	141	51
S87	Adiabor/Efut stream	93	43
S88	Adiabor/Efut dug well	90	58
S89	Adiabor/Efut stream	121	39
S90	Adiabor/Efut borehole	-	-
S91	Adiabor/Efut borehole	-	-
S92	Adiabor/Efut dug well	-	-
S93	Adiabor/Efut stream	-	-
S94	Adiabor/Efut stream	-	-
S95	Adiabor/Efut dug well	-	-
S96	Adiabor/Efut stream	-	-
S97	Adiabor/Efut borehole	-	-
S98	Adiabor/Efut stream	-	-
S99	Adiabor/Efut dug well	-	-
S100	Adiabor/Efut borehole	-	-
	WHO safe limits	0	0
	NSDWQ limits	0	0

Table 5: Observational checklist

Variables	Yes	No
Are water sources used for other purposes, like bathing and washing of materials?	77(77.0%)	23(23.0%)
Is there evidence of human activities like farming/residence around the drinking source?	89(89.0%)	11(11.0%)
Does the drinking water source have an objectionable odour?	56(56.0%)	44(44.0%)
Does the drinking water source have an objectionable taste?	62(62.0%)	38(38.0%)
Does the drinking water source have colour?	25(25.0%)	75(75%)
Do the drinking water sources contain debris and suspended particulate matter?	52(52%)	48(48%)
Is the waste disposal pattern observed satisfactory?	44(44.0%)	56(56%)
Is the excreta management pattern as observed satisfactory?	58(58.0%)	42(42.0%)
Observed that the longest distance to the water source is less than 1km	49(49.0%)	51(51.0%)

The physicochemical qualities of drinking water sources

The analysis of the physicochemical parameters of drinking water sources sampled in this study revealed a mixed profile of water quality, with some pointers falling within permissible limits while others exceeded recommended baselines, raising concerns about the safety of these water sources for human consumption. The average electrical conductivity (118.45 µS/cm) was well within both the World Health Organisation (WHO) recommended range (400–800 µS/cm) and the Nigerian Standards for Drinking Water Quality (NSDWQ) limits (1000 µS/cm), suggesting a low concentration of dissolved ions. Similarly, the mean Total Dissolved Solids (TDS) of 41.24 mg/L was far below the permissible baseline of 1000 mg/L (WHO) and 500 mg/L (NSDWQ), indicating minimal presence of inorganic salts. These results imply good ionic composition and salinity levels suitable for drinking. Conversely, several critical parameters exceeded permissible limits. Turbidity averaged 13.83 FTU, significantly higher than the WHO and NSDWQ limits of ≤5 FTU. Elevated turbidity suggests the presence of suspended particles that may shelter pathogenic microorganisms, thus undermining microbiological safety. Additionally, the mean colour intensity (23.12 TCU) surpassed the acceptable limit of 15 TCU, indicating the presence of dissolved organic matter or metals, which not only affect aesthetic quality but may also signal potential contamination. Salinity presented a major concern, with an average value of 39.43 PPT, drastically exceeding the recommended maximum of 0.5 PPT is drastically exceeding the recommended maximum of 0.5 PPT. Such high salinity renders the water unfit for consumption and poses significant health risks, most especially to individuals with pre-existing health conditions like hypertension or kidney disorders. Similarly, iron levels were excessively high (mean = 4.94 mg/L) compared to the permissible limit of 0.3 mg/L. Elevated iron content in water results in an unpleasant taste, staining, and long-term health implications. While the mean Total Suspended Solids (TSS) was within recommended safe limits (3.69 mg/L vs. <10 mg/L threshold), the high Dissolved Oxygen (DO) level of 25.66 mg/L and pH value of 23.22 exceed the range typically observed in natural water sources. Likewise, the mean temperature of 5.61°C, although within safe limits, may reflect sampling from shaded or underground sources rather than surface water. These findings are consistent with [10] in Ethiopia found that found only 38% of rural residents understood acceptable levels for parameters such as pH and turbidity, with education significantly influencing awareness. Similarly, [11] in Pakistan, reported that while 45% of households were familiar with safety limits for contaminants like nitrates and arsenic, only 25% understood their associated health risks. Education and access to information were significant predictors of knowledge. In Kenya, [12] revealed that only 29% of respondents recognized pH and turbidity as critical indicators of water quality. Their mixed-methods approach highlighted the importance of income and participation in educational campaigns as enablers of better understanding. Supporting this, [13] in rural Nigeria found that while 40% of respondents were aware of visible indicators like colour and odour, less than 20% could identify or interpret the acceptable levels for less perceptible contaminants like fluoride and nitrates. Occupation and education were again pivotal in shaping water quality awareness.

Bacteriological quality of drinking water sources.

The results of this study revealed alarmingly high levels of bacteriological contamination in the drinking water sources analysed. Both Total Coliform Count (TCC) and Faecal Coliform (FEC) significantly exceeded the maximum permissible limits established by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ), which stipulate that water should contain 0 CFU/100 ml of both indicators to be considered bacteriologically safe. Many samples recorded coliform levels classified as "Too Numerous to Count" (TNTC), indicating gross microbial contamination. This suggests a high likelihood of faecal pollution, likely resulting from inadequate sanitation infrastructure, poor hygiene practices, and proximity of water sources to contaminating agents such as open defecation sites, livestock waste, and unprotected latrines. These findings are consistent with studies across sub-Saharan Africa, which highlight the persistent challenge of microbial contamination in rural water sources. [14] in their study of rural villages in the Mohale Basin of Lesotho, they found E. coli in all sampled water sources, with counts ranging from 30 CFU/100 ml in protected sources to an astonishing 43,500,000 CFU/100 ml in unprotected ones. The study found significant associations between high E. coli counts and factors such as the absence of water source protection, nearby open defecation practices, livestock presence, and latrine proximity. This parallels the findings from the present study, where unprotected sources and likely sources of faecal contamination

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contributed to high bacterial loads. [15] assessed both water sources and household storage containers in Delta State, Nigeria, and similarly reported total coliform counts exceeding WHO standards. E. coli levels ranged from 10.2 CFU/100 ml in boreholes to 44.6 CFU/100 ml in stream sources, with storage containers also showing high levels of contamination. Their grading system placed several water sources in the "unacceptable" and "grossly polluted" categories. Notably, they observed that water quality degraded during storage, and water handling practices played a key role. This highlights the dual threat posed by source contamination and poor post-collection hygiene, both of which are likely at play in the present study area. Further emphasizing the widespread nature of bacteriological contamination, [9] reported that 98.6% of water samples from the Uganda-Kenya border tested positive for TCC, while 72.2% were contaminated with E. coli. Pathogens such as Salmonella spp. and Helicobacter pylori were also frequently detected.

Although water treatment practices were more common in that region (with 74.6% of households reportedly treating their water), contamination levels remained high, suggesting that treatment practices were either inconsistent or ineffective, an issue likely mirrored in the current study context, where treatment practices were not routinely evaluated but may be similarly limited or poorly implemented. In Nigeria, [16] documented high microbial loads in multiple surface water sources in Abia State. Total heterotrophic bacterial counts (THBC) ranged from 1.0×10^5 to 2.0×10^5 CFU/ml, and TCC values reached up to 1100 MPN/100 ml. Isolated organisms included major waterborne pathogens such as Escherichia coli, Salmonella spp., Vibrio cholerae, and Shigella sp., posing serious health threats to consumers. The bacterial diversity observed in that study supports the likelihood that similar pathogenic organisms are present in the water sources assessed in the present research, particularly given the TNTC counts and poor sanitary conditions.

CONCLUSION

This study highlights critical concerns regarding the quality and safety of drinking water sources in rural communities of southern Nigeria. While some physicochemical parameters, such as conductivity, TDS, DO, and TSS were within acceptable limits, others, particularly turbidity, salinity, colour, iron content, and pH deviated significantly from established standards. More alarmingly, bacteriological analysis revealed widespread contamination with both total and faecal coliforms, underscoring a significant risk to public health. Reliance on multiple untreated water sources, such as rainwater and sachet water, exacerbates the risk. Findings call for urgent interventions: water treatment, source protection, improved sanitation, and routine quality monitoring.

Declarations

Author contributions: The study was conceived by authors ISA and JDB, who also participated in every step of data collection, analysis, and result interpretation. Data collection and analysis involved OEO, BBT, NNS, and EJE. The results were analyzed and evaluated by UMU and ISA. The manuscript was prepared by ISA, ABC, and EJE. The research contents were critically reviewed by ISA and NNS. The findings and the completed text were examined by each author.

Funding: No funding was received for this study.

Data availability: In order to assess the physicochemical and bacteriological quality of drinking water sources in rural communities of Cross River State, Nigeria, a questionnaire, an observational checklist, and sterile sample bottles were used to gather the dataset. SPSS Version 27 was then used to enter and analyze the data. Subject to institutional and ethical restrictions, the data can be obtained from the associated author upon reasonable request. This study did not use any secondary data.

Ethics approval: The Ethics and Research Committee of the University of Calabar's Department of Public Health granted ethical permission for the study (Reference: UC/CM/PUH/ETH/2244). Pre-survey visits were carried out in the chosen research locations before data collection. To avoid unwanted access, all information gathered via the observational checklist and questionnaire was handled with the utmost discretion. The study's methods complied with the Helsinki Declaration's ethical guidelines.

Consent to participate: Individual consents from individuals were obtained through informed consent. The study was completely voluntary, and participants could leave at any time without facing any repercussions.

Consent to publish: The publication of this work has been approved by all authors.

Clinical trial number: Not applicable.

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