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PHYSICOCHEMICAL CHARACTERISTICS, HEAVY METAL CONCENTRATION, AND MICROBIAL CONTAMINATION IN KEY WATER SOURCES WITHIN BENUE SOUTH SENATORIAL DISTRICT, NIGERIA

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Abstract

Access to clean and safe water is crucial for human health and well-being. This study aimed to assess the physicochemical characteristics, heavy metal concentration, and microbial contamination in key water sources within the Benue South Senatorial District, Nigeria. A total of nine water samples were collected from three river sources, including Ohimini, Okpokwu, and Ofumenyi rivers, across different locations within the senatorial district. The physicochemical parameters analyzed included pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, temperature, and dissolved oxygen (DO). In addition, heavy metal concentrations, including lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), were determined using atomic absorption spectrometry. Microbial contamination was assessed by culture and antibiotic susceptibility. The results revealed considerable variations in the physicochemical characteristics of the water sources. The pH values ranged from acidic to slightly alkaline, whereas EC, TDS, and turbidity levels varied widely, indicating differences in water quality across the studied sites. The dissolved oxygen levels were

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generally within acceptable limits, indicating adequate aeration in the water sources. However, some samples exhibited elevated levels of heavy metal contamination, particularly lead, which exceeded the recommended guidelines for drinking water. This poses a significant health risk to communities relying on these water sources. Microbial analysis revealed widespread contamination of water sources with coliforms and E. coli, posing a risk of waterborne diseases, highlighting the need for improved treatment and sanitation practices in Benue South Senatorial District.

Running Title: Analyzing water quality in Benue South Senatorial District, Nigeria.

1. Introduction

Nigeria's abundant water bodies pose challenges for rural communities due to technological and economic constraints, leading to unsuitable water sources and environmental degradation.(Lin et al., 2022). In Nigeria, water bodies are rapidly separated due to anthropogenic factors, leading to contamination and water-borne diseases like cholera. Water quality assessment and sanitary risk identification are crucial for protecting the population and developing preventive measures. (*Nigeria*, 2020). Water availability is limited in many developing countries, with women and children spending over half their working day searching for water. Polluted sources, such as rivers, streams, wells, and springs, lead to high levels of water-borne and water-related diseases, causing death in young and adult populations.(Ortiz-Prado et al., 2022).

The World Health Organization has estimated that 80% of all sickness and diseases in the world are attributable to unhygienic water (*Drinking-Water*, n. d.). Water-borne diseases are among the leading causes of death in many developing countries today. In addition to the alarming mortality rates, it is estimated that people in developing countries lose 10% of their productive time because of diseases related to poor and contaminated water (*Sanitation*, n. d.). Otukpo is the traditional headquarters of the Benue Southern parts. The LGA came into existence in 1923, with its headquarters at Otukpo(*Nigeria*, 2020)

Akwete-Akpa The Idoma community is a community in Idoma land of Benue South Senatorial district, Benue State, North-central Nigeria. The community currently harbors the permanent site of the Federal University of Health Sciences, one of the newly approved specialized Universities in Nigeria on a six hundred (600) hectares of land(*Nigeria*, 2020). The Akwete community, primarily engaged in farming, faces challenges in accessing portable pipe-borne water due to a lack of supply from the state water board or non-functioning pipes. The primary water source is the River Ofumenyi, which is used for drinking, irrigation, and domestic purposes. The main source is the River Ohiminil, located in the Ohimini LGA of Benue State, while the River Okpokwu flows into the community and neighboring Otobi and Allan communities. A community survey revealed contamination of the Ohimini River two years ago due to industrial activities, preventing residents from using the water layer. In addition, a cholera outbreak was reported in the Akwete-Akpa community before the contamination. (Dan-Nwafor et al., 2019). The River Ofumenyi, a major water source for residents in the Benue South Senatorial District, Nigeria, is contaminated by mining activity and herbicide use. A field survey revealed that contaminants and toxic chemicals, particularly during the rainy season, eroded on farmlands and the water body. This poses a serious health threat to community residents. This research aims to evaluate the safety of major water sources used by residents, as they depend on these sources for drinking water.

2. Materials and procedures

2.1. Study location

Benue South Senatorial District is a senatorial district in Benue State, Nigeria, located in the North-Central geopolitical zone("Benue South Senatorial District," 2023). Benue South Senatorial District, part of the Benue Trough geological feature, is known for its fertile land and agriculture. It shares boundaries with other senatorial districts and neighboring states (Fig. 1). The district has a tropical climate with distinct wet and dry seasons, a diverse population, and a mix of rural and urban settlements, with major towns like Otukpo serving as economic and administrative centers.

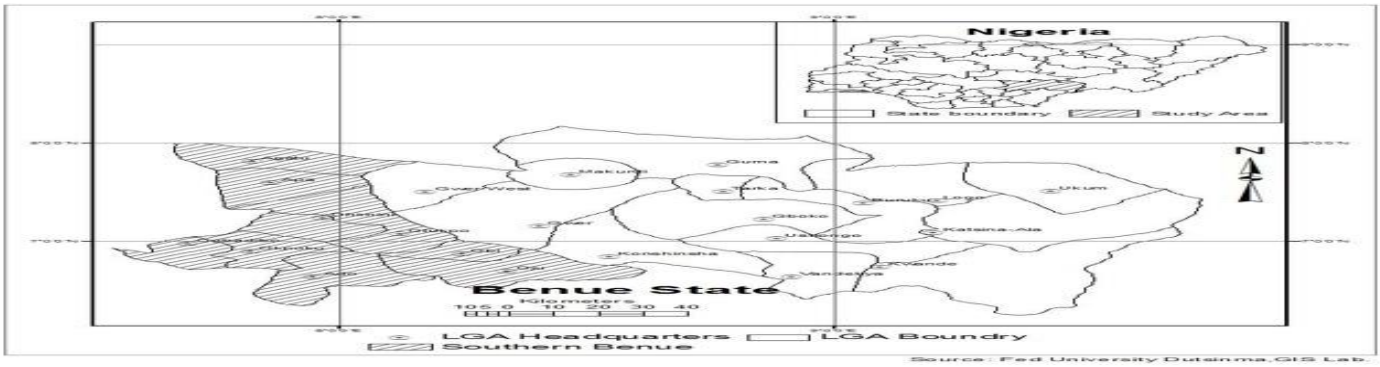

Figure 1. Map of Benue State Nigeria indicating shaded region of Benue South Senatorial District

2.2. Sample collection:

Exactly 2 L of water was collected aseptically from each of the three principal sources of drinking water in Benue South Senatorial District (Ohimini, Okpokwu, and Ofumenyi) and delivered to the laboratory for examination within 24 h. Standard procedures were used for on-site measurements.

2.3. Sample analysis

2.3.1. Physicochemical and heavy metal analyses

A variety of measures were used to assess water quality and pollution levels, including Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO), electrical conductivity (EC), Total Dissolved Solids (TDS), dissolved oxygen (DO), and pH of the river water samples were determined through the use of a thermo-probe, a DO meter, a pre-calibrated microprocessor, and a pH meter. Water turbidity was analyzed with a turbidity meter, while temperature with conductivity, temperature, and conductivity were measured on site. Spectrophophotometric and titrimetric techniques were used to determine the inorganic salts (nitrate, phosphate, sulfate, and carbonate). An Atomic Absorption Spectrophotometer was used to analyze metals(Priyanshi et al., 2023). Culture mediums were used for microbial evaluation, and antibiotic susceptibility tests were performed on selected isolates. The water quality and pollution status were assessed using the WHO and NSDWQ and the American Public Health Association-APHA. criteria to identify samples that did not meet the guideline values (Hryniszyn et al., 2013; Olusola et al., 2017; Rahman et al., 2021; World Health Organization, 2011)

3.3.2. Microbial load analysis

The water was cultured to test its microbiological content using culture medium. Cheesbrough biochemistry procedures were used to identify the bacteria. (Alum et al., 2023; Bayot & Bragg, 2023) (Figure 2 and 3). Briefly, the analysis was performed following standard microbiological techniques by diluting the water samples with sterilized distilled water. One milliliter of the diluted fraction (10^{-3}) was inoculated into sterilized plate count agar by the pour plate method. The plates were incubated at room temperature (25°C) for 24 h (bacteria), and 72 h (Fungi). Bacterial count was performed using conventional colony counting, which was expressed as colony

forming units (CFU/mL). The bacterial colonies were sub cultured on MacConkey agar, SSA, PDA, TCBS agar, and aeromorison agar. The plates were incubated for 24 hours; this is for proper isolation and identification of the possible organisms.

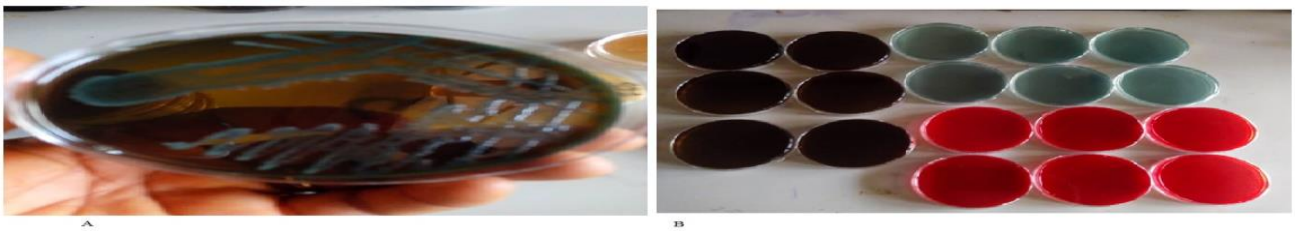

Figure 2: A- plate count agar inoculation showing bacteria growth B- Sub-cultured onto plats for MacConkey Agar, SSA, PDA, TCBS agar, and aeromorison agar

Figure 3: Sub-cultured onto plats for MacConkey Agar, SSA, PDA, TCBS agar, and aeromorison agar

2.4. Statistical Examinations

The mean and standard deviation of the three duplicate values were calculated to examine the data. ANOVA was used to test for differences between samples, and significant differences were estimated at $P<0.05$.

3. Results

3.1. Physicochemical properties of assessed water bodies in the Benue South Senatorial District, Nigeria

Table 1: **Physico-chemical properties of assessed water bodies in Benue South Senatorial District, Nigeria**

Water parameter	Ofumenyi	Ohimini,	Okpokwu,	WHO (2012)	NSDWQ (2007)
Colour	Cloudy	Cloudy	Muddy	Colourless	Colourless
Taste	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
Odour	Odourless	Odourless	Odourless	Odourless	Odourless
Temperature (ºC)	29	29	30	27-28	-
Conductivity (µs/cm)	0.9±0.01	0.77±	0.84±	250	100
TDS (mg/L)	193±4.26*,a	22±1.01a	0.22±	500	500
pH	6.10	6.80	7.89	6.20-8.50	6.50-8.50
DO (mg/L)	0.93±0.06	0.81±0.01	0.15± 0.02	Not specified	Not specified
Turbidity (FAU)	4.41± 0.10	3.14±0.51	0.24± 0.2	5	Not specified
COD (mg/L)	8±0.09*	7.08±0.10*	7.04±0.21	10*	Not specified
(BOD)Mg/L	3.83±0.15*	4.1±0.82*	3.53±0.15a	3	3

BOD- Biological oxygen demand, COD-Chemical oxygen demand, DO=Dissolved oxygen, TDS-Total Dissolved solids. Data is presented as Mean ±SD (n= replica of 3). Rows with different superscripts are significantly different at $p<0.05$

Table 1 presents the physicochemical properties of drinking water in the assessed water bodies in Benue South Senatorial District, Nigeria. The water meets WHO and NSDWQ standards for taste and odor; however, the water bodies showed varying colors ranging from cloudy to muddy, which were below the WHO and NSDWQ standards. River Ofumenyi and Ohimini had higher temperatures than WHO standards, and Okpokwu was within the WHO standard. More so, conductivity and pH are below WHO standards and Okpokwu pH is below WHO and NSDWQ standards, while Ofumenyi and Ohimini have higher values. The total dissolved solids were less than both the WHO and NSDWQ standards in the three studied water bodies, namely, the rivers Ofumenyi, Ohimini, and Okpokwu. Biological oxygen demand (BOD) was significantly higher than the WHO and NSDWQ standards and higher in Ohimini than in Ofumenyi and Okpokwu. Chemical oxygen demand (COD) was lower than the WHO and NSDWQ standards. Across the three water bodies, and these were significant

3.2. Distribution of various chemical characteristics in Benue South Senatorial District, Nigeria's primary drinking water source

Table 2: Other chemical properties of assessed water bodies in Benue South Senatorial District, Nigeria

Water parameter	Ofumenyi	Ohimini,	Okpokwu,	WHO (2021)	NSDWQ (2007)
Hardness ($CaCO_3$)	152±3.16*	145.77±3.16*,[a]	136±1.22*	500	150
PO_4 (mg/L)	1.033±0.14*	0.87±0.04[a*]	0.69±1.58[a]	0.10	-
SO_4 (mg/L)	0.933±0.12*	0.92±0.021/	0.92±0.07*	200	100
NO_3 (mg/L)	1.73±0.1	1.40±0.21	0.87±0.11	50	50
NH_4 (mg/L)	2.00±2.08	1.33±0.40	1.13±0.15	0.10	-
Cl^- (mg/L)	61.67±2.56*,[a]	51.63±2.57*,[a]	42.9±1.37*,[c]	200	-
Ca (mg/L)	46.50±0.07*,[a]	38.48±0.55*,[a]	33.5±1.59*,[c]	75.0	-
Mg (mg/L)	9.33±.90*,[a]	7.35±0.05*,[a]	5.87±0.31*,[c]	6.5	0.2
K (mg/L)	0.63±0.06	0.56±0.01	0.51±0.02	-	-

. Data is presented as Mean ±SD (n= replica of 3). Rows with different superscripts are significantly different at $p<0.05$

Table 2 depicts the distribution of various chemical features in the primary drinking water sources in Benue South Senatorial District, Nigeria. The chemical compounds CaCO3, PO4 (mg/L), SO4 (mg/L), NO3 (mg/L), NH4 (mg/L), Cl (mg/L), Ca (mg/L), Mg (mg/L), and K (mg/L) were assessed in the three water bodies, and all chemical compounds were below WHO and NSDWQ standards, with the exception of PO_4 (mg/L), NH_4 (mg/L), and Mg (mg/L), which were higher than WHO and NSDW standards. Moreover, the values of these three PO_4 (mg/L), NH_4 (mg/L), and Mg (mg/L) were significantly higher ($p<0.05$) in Ofumenyi than in Ohimini and Okpokwu.

3.3. Metal content of three major drinking water sources in the Benue South Senatorial District, Nigeria

Table 3; Heavy metal composition **of assessed water bodies in Benue South Senatorial District, Nigeria**

Water parameter	Ofumenyi	Ohimini,	Okpokwu,	WHO (2021)	NSDWQ (2007)
Zn (mg/L)	0.03±0.01*,[a]	**0.03**±0.01*,[a]	0.02±0.01*,[a]	3.0	3.0
Pb (mg/L)	0.04±0.01*,[a]	0.04±0.01*,[a]	0.0013±0.00	0.01	0.01
Fe (mg/L)	0.023±0.01	0.02±0.01	0.02±0.01	0.30	0.30
Cu (Mg/L	0.36±0.05	0.36±0.05	0.35±0.06		
Cr (mg/L)	0.001±0.00	**0.0013**±0.00	0.0013±0.00	0.05	-
Cd (mg/L)	0.001±0.00	**0.0013**±0.00	0.0017±0.00S	0.003	0.003

Data is presented as Mean ±SD (n= replica of 3). Rows with different superscripts are significantly different at $p<0.05$

Table 3 shows the metal content of the three major drinking water sources in Benue South Senatorial District, Nigeria. All of the macromineral elements exhibited levels lower than the WHO and NSDWQ criteria. The levels of lead Pb (0.04±0.01 and 0.04±0.01) (mg/L) in Ofumenyi and Ohimini were, however, found to be beyond the WHO and NSDWQ guidelines.

3.4. Microbial study of water samples collected from the investigated sources of water in Benue South Senatorial District, Nigeria

Table 4: Total microbial counts (bacterial)

SN	Sample	Number of colonies	CFU/mL
1	Ofumenyi	28	$2.8x10^2$
2	Ohimini,	**16**	$\mathbf{1.6x}10^2$
3	Okpokwu,	**46**	$\mathbf{4.8x}10^2$

Table 4: Distribution of the organisms based on the different water samples

SN	Sample	Location	Organism isolated
1	1	Ofumenyi	*Staphyllococcuss spps*
2	**2**	Ohimini,	*Staphyllococcuss spps*
3	**3**	Okpokwu,	*Staphyllococcuss spps, E. coli, and aeromonas spps*

Bacterial colonies and identified organisms obtained from water samples from Ofumenyi, Ohimini, and Okpokwu are shown in Tables 4 and 5. There were over 28, 16, and 48 ($x10^2$) colonies of bacterial counts in Ofumenyi, Ohimini, and Okpokwu, respectively. This trend was further justified by the higher isolates of Staphylococcus spp., *E. coli, and aeromonas spp. in* Okpokwu compared with Ofumenyi, Ohimini, which had only *Staphylococcus spp.* Notably, no fungi were identified or isolated from any of the studied samples.

4. Discussion

The assessment focuses on various parameters that determine the quality of drinking water in the Benue South Senatorial District, Nigeria. The water from the assessed water bodies meets the standards set by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) in terms of taste and odor. This is a positive indication that the water is acceptable for consumption in terms of sensory qualities. The water bodies, however, exhibit varying colors ranging from cloudy to muddy. These colors fall below the WHO and

NSDWQ standards. Water color can be an important esthetic factor, but it might not necessarily affect the safety or health of the water(O'Donnell, 2021; Omer, 2019).

The temperatures of the assessed water bodies are mentioned. The rivers Ofumenyi and Ohimini have higher temperatures compared to the WHO standards, while Okpokwu's temperature is within the WHO standard. Elevated water temperatures can influence the aquatic ecosystem and potentially affect the suitability of the water for various purposes(Bonacina et al., 2023). Both conductivity and pH values are below WHO standards. In addition, Okpokwu's pH is below both the WHO and NSDWQ standards, whereas Ofumenyi and Ohimini have higher pH values. These parameters are essential for assessing the water's ability to conduct electricity, and its acidity/basicity can impact its suitability for different uses (Tula et al., 2022). The TDS values are reported to be below both the WHO and NSDWQ standards in all three studied water bodies. TDS is an important indicator of water quality because it reflects the concentration of dissolved substances in the water.(Omer, 2019)

The BOD values are significantly higher than those of both the WHO and NSDWQ standards. In addition, Ohimini's BOD is higher than that of Ofumenyi and Okpokwu. BOD is a measure of the amount of oxygen consumed by microorganisms while decomposing organic matter in water. Elevated BOD levels indicate pollution and can lead to oxygen depletion in aquatic systems(Bendicho & Lavilla, 2019; O'Donnell, 2021). The COD values are lower than those of the WHO and NSDWQ standards. COD is a measure of the amount of oxygen required to chemically oxidize pollutants in water. Lower COD values suggest lower levels of organic pollutants. While the assessed water bodies generally meet the standards for taste and odor, there are several areas where they deviate from the WHO and NSDWQ standards. These deviations include color, temperature, pH, BOD, and COD values. The presence of elevated BOD values and deviations in pH can raise concerns about pollution and the overall health of water bodies. It is important to address these issues to ensure water safety for various uses.

Table 2 presents the distribution of various chemical features found in primary drinking water sources within the Benue South Senatorial District of Nigeria. The table displays the concentrations of different chemical compounds, including CaCO3, PO4 (mg/L), SO4 (mg/L), NO3 (mg/L), NH4 (mg/L), Cl (mg/L), Ca (mg/L), Mg (mg/L), and K (mg/L), across three different water bodies. The focus of the analysis was to evaluate whether these chemical concentrations adhere to the standards set by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ).

The key findings of this analysis were as follows. The concentrations of most of the chemical compounds examined were within the limits established by both the WHO and NSDWQ standards. This implies that for most chemical features, the water quality meets the recommended levels for safe drinking. However, three chemical compounds, namely PO4 (phosphate), NH4 (ammonium), and Mg (magnesium), were identified to have concentrations exceeding the established standards by both the WHO and NSDWQ. This suggests potential concerns about the quality of water in terms of these particular chemical components(Castro et al., 2023; Weissman & Tully, 2020). One notable observation was that the concentrations of the three chemicals that exceeded the standards (PO4, NH4, and Mg) were significantly higher in the water body labeled "Ofumenyi" when compared to the other two bodies ("Ohimini" and "Okpokwu"). This difference was deemed statistically significant with a p-value of 0.05. The results suggest that while most chemical features in the primary drinking water sources of Benue South Senatorial District meet the WHO and NSDWQ standards, there are concerns related to elevated concentrations of phosphate (PO4), ammonium (NH4), and magnesium (Mg). Moreover, the water source labeled "Ofumenyi" showed significantly higher levels of these three compounds than the other two sources ("Ohimini" and "Okpokwu"). Further investigation and potential remediation measures may be necessary to ensure the safety and quality of the drinking water supply, particularly in the Ofumenyi area.

The results presented in Table 3 provide information about the metal content of the three significant drinking water sources within the Benue South Senatorial District of Nigeria. This study focuses on both macromineral elements and heavy metals in these water sources. The findings indicated that while the levels of macromineral elements generally met the criteria set by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ), there were concerns regarding the concentration of lead in certain sources.
Macrominerals are essential minerals required by the human body in relatively large amounts(Ali, 2023). The results of this study suggest that the levels of these macromineral elements (such as calcium, magnesium, sodium, and potassium) in the drinking water sources were within acceptable limits according to both the WHO and NSDWQ guidelines. This implies that these sources provide water that is suitable for consumption in terms of macromineral elements. The concentration of lead in the Ofumenyi and Ohimini water sources exceeded the recommended guidelines established by both the WHO and NSDWQ. Lead is a toxic heavy metal that can have harmful effects on human health, especially when ingested over prolonged periods(Balali-Mood et al., 2021; Engwa et al., 2019; Mitra et al., 2022). The presence of lead in drinking water can result from various sources, including old plumbing systems or industrial pollution. Exceeding the recommended levels of lead in drinking water is a serious concern because it can lead to lead poisoning and various health issues, particularly in children and pregnant women. It is important to note that lead contamination in drinking water is a significant public health issue that requires immediate attention and intervention. The findings suggest that measures should be taken to reduce lead levels in the affected water sources to bring them in line with the recommended guidelines. This might involve improving water treatment processes, identifying and addressing potential sources of lead contamination, and ensuring regular monitoring to ensure the safety of the drinking water supply. While the macromineral content of the drinking water sources in the Benue South Senatorial District generally met regulatory criteria, the presence of elevated lead levels in some sources is a cause for concern and requires appropriate actions to ensure the safety and quality of the drinking water supply in those areas.
The Bacterial Colony Counts: for the different water bodies were - Ofumenyi: Over 28 x 10^2 bacterial colonies - Ohimini: Over 16 x 10^2 bacterial colonies, and Okpokwu: Over 48 x 10^2 bacterial colonies. Tables 4 and 5 These colony counts provide an indication of the bacterial load or density in the water samples. The counts for Okpokwu were notably higher than those for Ofumenyi and Ohimini, suggesting that the water in Okpokwu may have a higher concentration of bacteria than the other two locations. The study also identified specific bacterial species in the water samples. The key bacterial species identified are: *Staphylococcus spp, E. coli* (*Escherichia coli*), and *Aeromonas spp.* Interestingly, Okpokwu stands out with a broader range of identified bacterial species compared with Ofumenyi and Ohimini. This difference in bacterial diversity may be indicative of different environmental conditions or pollution levels between the three locations. The presence of E. coli and Aeromonas spp. in Okpokwu suggests that this location might have water quality issues, as these bacteria are often associated with fecal contamination and waterborne diseases(Bisi-Johnson et al., 2023; Burke et al., 1984).
No fungi were identified or isolated from any of the water samples. This absence of fungi could be due to various factors, including the specific sampling methods used, the environmental conditions of the study areas, or the inherent nature of the water sources themselves(Ren et al., 2023). Fungi are less common in water environments than bacteria, and their absence might not be surprising depending on the context of the study. In conclusion, the results indicate variations in bacterial colony counts and identified species among the water samples from the three locations. The higher bacterial colony counts and diversity of identified species in Okpokwu, along with the absence of fungi, suggest potential differences in water quality and environmental conditions between these areas.

5. Conclusion: While the majority of the assessed parameters meet water quality standards, deviations in color, temperature, pH, BOD, and COD values, as well as elevated concentrations of certain chemical compounds and lead, raise concerns about water safety and quality. Addressing these issues through proper management, treatment, and monitoring is crucial to ensure a safe and reliable drinking water supply in Benue South Senatorial District.

Consent to participate

Not Applicable

Consent to publish

Not Applicable

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Availability of data and materials

Available from the corresponding author upon request

Authors Contributions

IB, AOI, SA.A, and V O conceived and designed the study; MOI, AO.E, and AE.A conducted the literature search and practical procedures; and DEU wrote the original draft of the manuscript. IB has revised the manuscript for intellectual content. All authors approved the final draft of the manuscript for submission and publication.

Conflict of Interest

We have no conflicts of interest to declare.

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