

Comparative Assessment of Drinking Water Quality: An Investigation of Physicochemical and Microbial Characteristics

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Abstract

Water pollution has been the major challenges in Nigeria. The consumption of contaminated water threatens the health and livelihoods of citizens. The study assesses the suitability of drinking water sources in Ikot Ekpene metropolis using physicochemical and microbial characteristics. Water samples were collected monthly between April 2023 and November 2023 in six drinking water sources; the samples were analyzed using standard laboratory techniques. The results revealed that the mean value of NO₂ in sachet and surface water and the pH value in surface water were deviated from Nigerian drinking water quality standard. The THBC values in sachet water ranged between 1.0 and 3.0 cfu/100mL, while surface water ranged between 24.0 and 167.0 cfu/100mL; the TCC ranged from 0.0 to 2.0 cfu/100mL in sachet water and 12.0 to 66.0 cfu/100mL in surface water; the TSBC ranged from 5.0 to 17.0 cfu/100mL in sachet water and 5.0 to 59.0 cfu/100mL in surface water, while TFCC values in sachet water ranged from 0.0 to 3.0 cfu/100mL and 6.0 to 50.0 cfu/100mL in surface water. The mean values of TSBC and TFCC (sachet water) and THBC, TCC, TSBC, TFCC (surface water) exceeded the limits for Nigerian drinking water quality. The *Clostridium* spp was the most abundant in surface water, while *Staphylococcus* spp was in sachet water samples. The WQI value was higher (67.0) in surface water compared with the 5.58 recorded in sachet water. The study revealed that the surface water is polluted compared with the sachet water, and not suitable for human consumption, owing to the prevalence of microbial parameters attributed to anthropogenic activities.

1. Introduction

Water is an extremely important natural resource for humans and economic development. It determined the wellness; well-being of an individual as well as essential part of human nutrition [1-5]. The action of monitoring, protecting, conserve, restore, and utilizing drinking water requires adequate understanding and knowledge of physicochemical and microbial characteristics, as it gives an insight on the suitability of drinking water for human consumptions [6]. Lack of accessible, reliable and good water quality, together with poor sanitation and hygiene, could threaten the health, and livelihoods of citizens [7]. The United Nations General Assembly declared access to safe water, and sanitation as human right [8]. In the year 2015, over 31.5% of Nigeria's residents were reported

not having access to a good drinking water, most especially the rural communities [9], which could be due to the prevalence of pollutants from point and non-point sources [10]. The condition could remain if note is properly managed by the relevant authorities. The microbial contamination of drinking water is associated with outbreaks of waterborne diseases emanated from agricultural and industrial activities [11]. Other sources of microbial pathogens in drinking water include open defecation, domestic effluents discharge, leeching from latrine and runoff from contaminated soil [12].

However, most of the drinking water produced and sold to public which is approved by National Agency for Food and Drug Administration and Control (NAFDAC) may not be well treated to a reasonable standard of national drinking water quality. The water sold to the public should be free from contamination that could impose adverse health effects in humans when consumed [13]. The variability of microbial pollutants and physicochemical characteristics in drinking water are governed by method of treatment, equipment used for collection, location of the water sources, geologic condition and human activities of the area [14 - 16]. Study [17] affirmed that bacterial pollution in water is one of the major issues concerning the quality for drinking purposes, and humans are exposed to these pathogens by ingestion of contaminated water [18].

The understanding of quality of water use for drinking is imperative for successful water and health risks management [19]. In the study area, limited research has been conducted on the suitability of drinking water sources regarding physicochemical and microbial quality. The Ikot Ekpene metropolis is known as a regional centre of commerce, with enormous industrial activities; the vulnerable people are dependent on sachet water, bottled water, streams, and rivers sources for drinking purposes and other domestic activities. Therefore, the study aims to assess the suitability of drinking water sources in Ikot Ekpene metropolis, Akwa Ibom State, Nigeria using physicochemical and microbial characteristics.

2. Materials and Methodology

2.1 Materials

2.1.1 Study Area and Sampling Points

The Ikot Ekpene is one of the major cities in Akwa Ibom state, Niger delta; having a land mass of 116 km² Nigeria. It lies within the Longitude 5°11'17N and Longitude 7°43'45E; comprising of 56 villages and a total of 145,077 human populations [20]. The drinking water sources (four certified NAFDAC sachet water and two surface waters) were collected within the city. The locations are given in Figure 1. The sachet water brands used in this study were tagged as stations 1, 2, 3, and 4, while the surface water used were tagged as stations 5 and 6. The factory of station 1 is located at 32 Ibong Road (Latitude 5°11'17.29N; Longitude 7°42'19.33E); station 2 is located at Uyo Road (Utu Ikot Ekpenyong) (Latitude 5°9'22.56N; Longitude 7°44'58.43E); station 3 is at Aba Road (Latitude 5°10'50.95N; Longitude 7°41'33.36E), while station 4 is located at Sani Ogun (Latitude 5°10'54.57N; Longitude 7°42'54.3E). For the surface water (stations 5 and 6); station 5 is located at Mbiaso community (Latitude 5°12'43.81N; Longitude 7°39'25.12E).

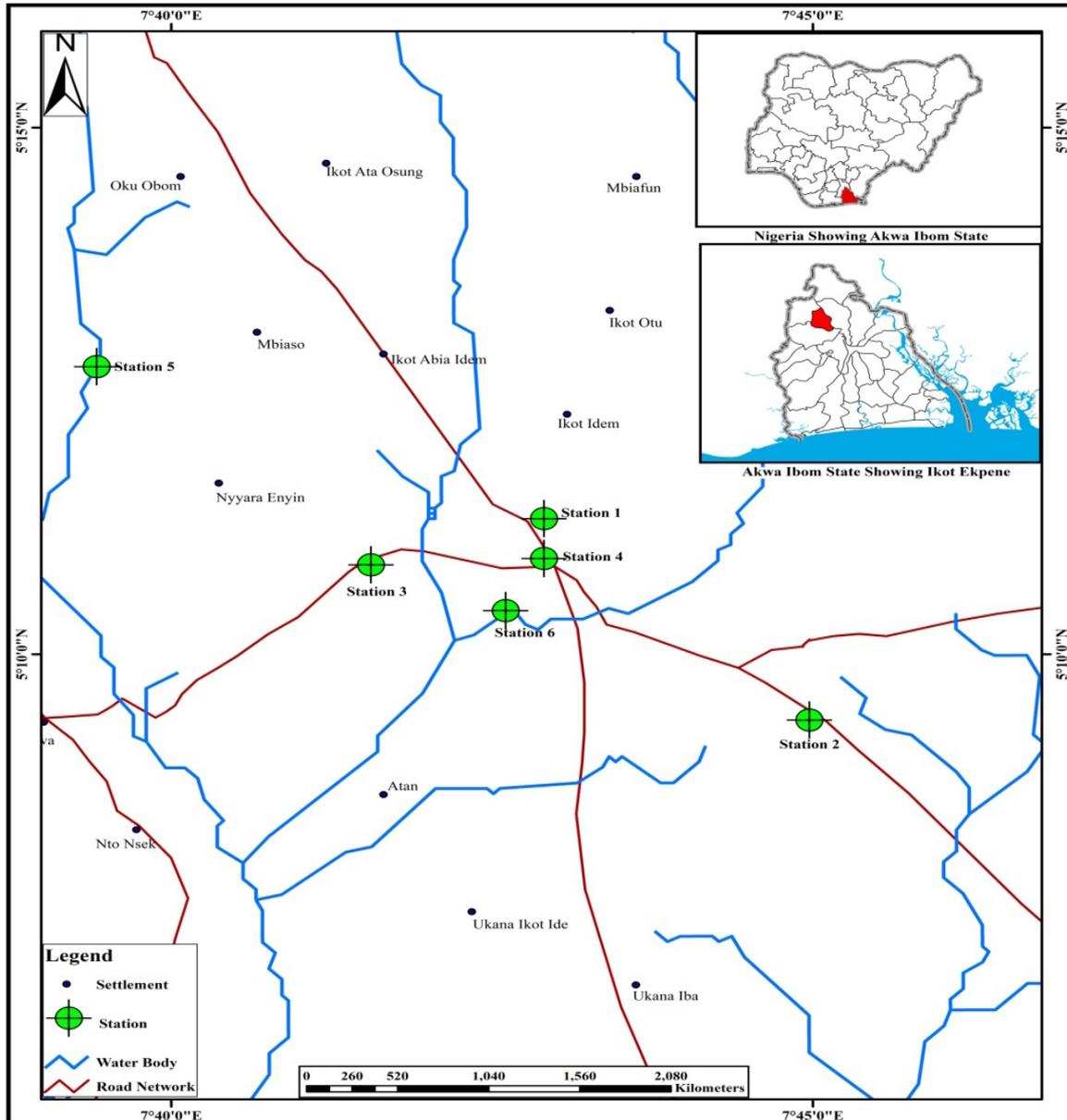


Fig. 1 Map showing the samples locations in Ikot Ekpene L. G. area

The human activities observed were bathing, laundry, sand mining and agricultural activities. The water is used for irrigation, drinking and recreational purposes. Wastes from the nearby communities are discharged directly into the water body and through surface runoff. Station 6 is situated at Spring Road, commonly known as Idim Enang (Latitude 5°10' 24.85N; Longitude 7°42'36.39E). The water is extracted for drinking and irrigation purposes. The water body is frequently exposed to pollutants from the community and nearby hospitals via runoff. Intense farming, laundering and bathing were recorded during the study period.

2.2 Methods

2.2.1 Water Samples Collection and Analysis

Forty-eight drinking water samples from six locations were collected between April 2023 and November 2023 within the city of Ikot Ekpene Local Government Area, to access the physicochemical and microbial characteristics. A 500 mL of sachet water samples (1 to 4) were directly bought from the factory, while sterile plastic bottles (1 Litre) were used for collection of water samples from stations 5 and 6 (streams), and then transferred to laboratory in small ice pack containers for the analysis of physicochemical parameters and microbial parameters. The physicochemical parameters analyzed were hydrogen-ion (pH), chloride (Cl⁻), electrical conductivity (EC),

total dissolved solids (TDS), calcium (Ca²⁺), sodium (Na⁺), magnesium (Mg²⁺), nitrite (NO₂⁻), nitrate (NO₃⁻) and sulphate (SO₄²⁻). The pH was determined using JENWAY 550 portable pH meter, Cl⁻ was determined by Argentometric method, EC and TDS was by using potable TDS/EC meter (HACH CO. 150), while Ca²⁺, Na⁺ and Mg²⁺ were measured by atomic emission spectrophotometry method. The concentration of NO₂⁻ and NO₃⁻ was by cadmium reduction method, while SO₄²⁻ was by turbidimetric method [21]. The Weighted Arithmetic Water Quality Index (WAWQI) was further used to assess the suitability of the drinking water sources. The index has been used by researchers to assess the suitability of water for the specified purpose [22 - 24], and it is based on the level of purity, using water quality parameters such as hydrogen-ion, chloride, electrical conductivity, total dissolved solids, sodium, magnesium, nitrate and sulphate for the calculation. The results were compared with the recommended data of water quality standard for drinking purposes based on the index as presented in Table 1. The equation for the calculation of WQI was made by Brown et al. [25] showing in equation 1, while the quality rating scale (Qi) for each parameter was calculated by using equation 2.

$$WQI = \sum QiWi / \sum Wi \tag{1}$$

$$Qi = 100[(Vi - Vo/Si - Vo)] \tag{2}$$

Where, Vi = estimated concentration of ith parameter in the analyzed water; Vo = the ideal value of this parameter in pure water. Vo = 0 (except pH =7.0), Si = recommended standard value of ith parameter based on the Nigerian Drinking Water Quality Standard (SON, 2015) [26]. The unit weight (Wi) for each water quality parameter was calculated by using the following equation:

$$Wi = K/Si \tag{Eq. 3}$$

Where, K = proportionality constant.

Table 1 Water quality rating as per weight arithmetic water quality index

Water quality index value	Rating of water quality	Grading
0 - 25	Excellent water quality	A
26 - 50	Good water quality	B
51 - 75	Poor water quality	C
76 - 100	Very poor water quality	D
>100	Unsuitable for drinking purpose	E

Brown et al. [25]

2.2.2 Microbial Analysis and Identification

Membrane filtration technique was employed for the analysis of microbial parameters in the water samples using Nutrient Agar as a medium for the isolation of Total Heterotrophic Bacteria Counts (THBC), MacConkey Agar for the Total Coliform Counts (TCC), Mannitol Salt Agar for Total Staphylococcus Bacteria Counts (TSBC), and Eosin Methylene Blue Agar for the isolation of Faecal Coliform Count (FCC) [27]. Aliquots of water sample (100 mL) were drawn through a membrane filter (0.45µ pore size) with the aid of a vacuum pump. The filtered water samples were transferred onto a petri dish, each containing medium such as Nutrient Agar, MacConkey Agar, Mannitol Salt Agar, and Eosin Methylene Blue Agar, then incubated at room temperature (37°C) for 2 days for easy enumeration of microbial colonies. The numbers of microbial colonies forming units (cfu/mL) were counted with the help of colony counting machines and express as the number of colonies per 100 milliliters of the water sample. The samples were analyzed in duplicates to determine the reliability and validity of the laboratory method, and counting was with the aid of electronic microscope. The characterization and identification of the isolated microbes was based on the morphological features, and pigmentation as described in relevant keys [28 - 30].

2.2.3 Data Analysis

The data from the physicochemical variables and microbial parameters from the six drinking water sources were summarized in a Microsoft Excel sheet and then exported to the appropriate statistical software using one-way analysis of variance (ANOVA) for descriptive analyses. To confirm the mean level of significance of physicochemical variables and microbial parameters between the sachet and the surface water, a post hoc test (Tukey Pairwise significant difference) was conducted and set at 0.05 (95%) significant level.

3. Results

3.1 Physicochemical Parameters

The summary of physicochemical concentrations is presented in Table 2. The Hydrogen-ion (pH) values for sachet water samples ranged between 6.6 (station 3) in June 2023 and 7.6 (station 2) in October 2023. All the values were within the acceptable limits (6.5 – 8.5) set by SON [26]. In surface water, the value ranged between 5.3 (station 6) in August 2023 and 5.5 (station 5) in June 2023. The values were below the acceptable limits (6.5 - 8.5) for drinking water set by SON [26]. The mean value in sachet and surface water were significantly different ($p < 0.05$, $p = 0.013$).

Table 2 The summary of physicochemical properties between sachet and surface drinking water sources

Parameters	Sachet Water			Surface Water			P-value	*SON
	Min.	Max.	Mean±SE	Min.	Max.	Mean±SE		
pH	6.5	8.5	7.1±0.22a	5.5	6.5	5.4±0.10b	$P < 0.05$	6.5 – 8.5
Cl ⁻ (mg/L)	16.3	65.3	33.1±3.18 ^a	55.8	76.5	66.2±2.82 ^b	$P < 0.05$	250
EC (uS/cm)	112.7	138.2	124.7±3.28 ^a	163.5	186.6	170.1±2.98 ^b	$P < 0.05$	1000
TDS (mg/L)	29.6	54.3	40.9±1.53 ^a	86.5	113.8	90.2±0.84 ^b	$P < 0.05$	500
Ca ²⁺ (mg/L)	0.37	1.62	0.81±0.28 ^a	0.57	0.96	0.60±0.42 ^a	$P > 0.05$	NI
Na ⁺ (mg/L)	0.32	1.13	0.68±0.17 ^a	0.41	0.45	0.43±1.24 ^a	$P > 0.05$	200
Mg ²⁺ (mg/L)	0.26	0.82	0.49±0.41 ^a	0.49	0.63	0.56±0.33 ^a	$P > 0.05$	20
NO ₂ (mg/L)	0.18	0.63	0.32±0.22 ^a	1.39	2.92	2.15±0.22 ^b	$P < 0.05$	0.2
NO ₃ (mg/L)	0.68	0.95	0.83±0.89 ^a	3.54	6.87	5.21±0.98 ^b	$P < 0.05$	50
SO ₄ (mg/L)	0.46	56.2	14.5±0.33 ^a	56.7	76.3	66.5±0.17 ^b	$P < 0.05$	100
WQI	5.58 ^a			67.0 ^b				
Status	Excellent water quality			Poor water quality				

Means value with different superscripts (a, b) along the same row are significantly different ($P < 0.05$); *SON = Nigerian Standard for Drinking Water Quality [26]; NI = Not indicated

The Chloride (Cl⁻) content in sachet water ranged between 16.3 mg/L (station 2) in May 2023 and 65.3 mg/L (station 3) in October 2023, while in surface water ranged between 55.8 mg/L (station 5) in September 2023 and 76.5 mg/L (station 6) in April 2023. The values in sachet and surface water were within the acceptable limit (250 mg/L) set by SON [26] for drinking water quality. The mean value recorded in surface water was significantly higher ($p < 0.05$, $p = 0.000$) than the sachet water. The Electrical Conductivity (EC) values for the sachet water ranged between 112.7 uS/cm (station 2) in October 2023 and 138.2 uS/cm (station 1) in April 2023. The values were within the acceptable limit (1000 uS/cm) set by SON [26] for drinking water. In surface water, the values recorded ranged between 163.5 uS/cm (station 5) in September 2023 and 186.6 uS/cm (station 6) in April 2023. All the values were within the acceptable limit (1000 uS/cm) set by SON [26] for drinking water. Significant difference ($p < 0.05$, $p = 0.017$) between the mean value of sachet and surface water was recorded. The Total Dissolved Solids (STDs) recorded in sachet water ranged from 29.6 mg/L (station 2) in October 2023 and 54.3 mg/L (station 1) in April 2023. The values were within the acceptable limit (500 mg/L) set by SON [26] for drinking water. In surface water, the value ranged between 86.5 mg/L (station 5) in September 2023 and 113.8 mg/L (station 6) in April 2023. All the values were within the acceptable limit (500 mg/L) set by SON [26]. The mean values recorded for surface water were significantly higher ($p < 0.05$, $p = 0.009$) when compared with the sachet water samples. The Calcium (Ca²⁺) content in sachet water ranged from 0.37 mg/L (station 3) in November 2023 and 1.62 mg/L (station 4) in June 2023. In surface water, the values ranged between 0.57 mg/L (station 5) in August 2023 and 0.96 mg/L (station 6) in October 2023. There is no limit set by SON [26] for Ca²⁺ in drinking

water quality. No significant difference ($p > 0.05$, $p = 0.082$) between the mean value of sachet and surface water was recorded.

The Sodium (Na^+) content in sachet water ranged from 0.32 mg/L (station 3) in November 2023 and 1.13 mg/L (station 4) in June 2023. For the surface water, the values ranged between 0.41 mg/L (station 5) in August 2023 and 0.45 mg/L (station 6) in October 2023. The values recorded were within the limit (200 mg/L) set by SON [26] for drinking water quality. No significant difference ($p > 0.05$, $p = 2.129$) between the mean value of sachet and surface water was recorded. The Magnesium (Mg^{2+}) recorded in sachet water ranged from 0.26 mg/L (station 3) in November 2023 and 0.82 mg/L (station 4) in June 2023. In surface water, the value ranged between 0.49 mg/L (station 5) in August 2023 and 0.63 mg/L (station 6) in October 2023. All values recorded were within the limit (20 mg/L) set by SON [26] for drinking water quality. ANOVA indicates no significant difference ($p > 0.05$, $p = 0.310$) between the mean value of sachet and surface water. The Nitrite (NO_2^-) recorded for sachet water ranged from 0.18 mg/L (station 1) in April 2023 and 0.63 mg/L (station 2) in May 2023. In surface water, the values ranged between 1.39 mg/L (station 6) in September 2023 and 2.92 mg/L (station 5) in April 2023. The values recorded across the stations exceeded the limit (0.2 mg/L) for drinking water quality. ANOVA indicates a significant difference ($p < 0.05$, $p = 0.001$) between the mean value of sachet and surface water.

The Nitrate (NO_3^-) for the sachet water recorded ranged between 0.68 mg/L (station 4) in May 2023 and 0.95 mg/L (station 3) in May 2023. For the surface water, the values ranged between 3.54 mg/L (station 6) in September 2023 and 6.87 mg/L (station 5) in April 2023. The values recorded were within the limit (50 mg/L) set by SON [26] for drinking water quality. ANOVA indicates a significant difference ($p < 0.05$, $p = 0.000$) between the mean value of sachet and surface water. The Sulphate (SO_4^{2-}) for the sachet water ranged between 0.46 mg/L (station 2) in November 2023 and 56.2 mg/L (station 4) in September 2023, while surface water ranged between 56.7 mg/L (station 5) in August 2023 and 76.3 mg/L (station 6) in May 2023. The values were within the limit (100 mg/L) set by SON [26] for drinking water quality. ANOVA revealed significant difference ($p < 0.05$, $p = 0.021$) between the mean value of sachet and the surface water.

The WQI values for sachet and surface water are shown in Table 2. The values were higher in surface water when compared with the sachet water samples. The WQI value for sachet water ranged from 0.19 to 8.12 with the mean value of 5.58; the highest value was recorded in July 2023 while the lowest was in October 2023. In the surface water, the values ranged between 34.5 and 86.8 with the mean value of 67.0. The highest value was recorded in August 2023 while the lowest was in April 2023. The values obtained between the sachet and the surface water were significantly ($p < 0.05$, $p = 0.015$) difference.

3.2 Characterization of Microbial Parameters

The summary of microbial load in drinking water sources is presented in Table 3, while spatial composition of microbial species isolated from the six drinking water sources is given in Table 4. The microbes recorded showed significant variations between the drinking water sources. The total heterotrophic bacteria count (THBC) recorded in sachet water ranged from 1.0 to 3.0 cfu/100mL; the highest count was recorded in station 4 (November 2023), while the lowest was in stations 1, 2 and 3 (May 2023). For the surface water, the THBC recorded ranged between 24.0 cfu/100mL in October 2023 (station 6) and 167.0 cfu/mL in May 2023 (station 5). The THBC value recorded in station 5 (May 2023) for the surface water exceeded the limit (100cfu/mL) for drinking water quality [26]. ANOVA indicates significant difference ($p < 0.05$, $p = 0.033$) between the mean values of the drinking water sources. The total coliform counts (TCC) recorded in sachet water ranged from 0.0 cfu/100mL (stations 1 and 2) in October 2023 to 2.0 cfu/100mL (station 3) in April 2023. The values were within the acceptable limit (10 cfu/100mL) for drinking water quality [26]. In surface water, the value ranged between 12.0 cfu/100mL (station 5) in May 2023 and 66.0 cfu/100mL (station 5) in October 2023. The values exceeded the acceptable limit (10 cfu/100mL) for drinking water quality [26]. The mean value of surface water was significantly higher ($p < 0.05$, $p = 0.014$) when compared with the sachet water. The total staphylococcus bacteria count (TSBC) recorded between the sachet water ranged from 5.0 cfu/100mL (station 1) in June 2023 to 17.0 cfu/100mL (station 2) in April 2023. In surface water, the values for TSBC ranged between 5.0 cfu/100mL (station 5) in April 2023 and 59.0 cfu/100mL (station 6) in October 2023. The values in sachet and surface water exceeded the acceptable limit (0 cfu/100mL) set by SON [26] for drinking water quality. The mean value recorded in surface water was significantly higher ($p < 0.05$, $p = 0.000$) when compared with the sachet water. The total faecal coliform counts (TFCC) recorded in sachet water ranged from 0.0 cfu/100mL (stations 1, 2 and 4) in October 2023 to 3.0 cfu/100mL (station 3) in July 2023, while the surface water ranged between 6.0 cfu/100mL (station 5) in November 2023 and 50.0 cfu/100mL (station 6) in April 2023. The value in July 2023 (sachet water) and all the values in surface water exceeded the acceptable limit (0 cfu/100mL) for drinking water [26]. ANOVA indicates significant variation between the mean values ($p < 0.05$, $p = 0.01$).

Table 3 Characterization of microbial parameters between the sachet and surface drinking water sources

Microbial (cfu/100mL)	Sachet Water			Surface Water			P-value	*SON
	Min.	Max.	Mean±SE	Min.	Max.	Mean±SE		
THBC	1.0	3.0	0.75±0.36 ^a	24.0	167.0	82.2±3.39 ^b	$P < 0.05$	100
TCC	0.0	2.0	0.37±0.23 ^a	12.0	66.0	54.5±0.04 ^b	$P < 0.05$	10
TSBC	5.0	17.0	6.37±2.97 ^a	5.0	59.0	30.2±2.73 ^b	$P < 0.05$	0
TFCC	0.0	3.0	0.37±0.03 ^a	6.0	50.0	24.5±0.14 ^b	$P < 0.05$	0

Means value with different superscripts (a, b) along the same row are significantly different ($P < 0.05$); *SON = Nigerian Standard for Drinking Water Quality [26]; THBC = Total Heterotrophic Bacteria Counts; TCC = Total Coliforms Counts; TSBC = Total Staphylococcus Bacteria counts; TFCC = Total Faecal Coliform Counts.

Table 4 Numerical composition of microbial species isolated from the six drinking water sources

Microbes	Sachet Water (cfu/100mL)					Surface Water (cfu/100mL)		
	S. 1	S. 2	S. 3	S. 4	Total / %	S. 5	S. 6	Total / %
<i>Citrobacter</i> spp	0	0	2	0	2 (3.2)	54	79	133 (8.7)
<i>Clostridium</i> spp	1	1	0	1	3 (4.7)	249	146	395(25.9)
<i>Enterobacter</i> spp	0	0	3	0	3 (4.7)	119	63	182(11.9)
<i>Escherichia coli</i>	0	0	0	0	0 (0)	155	111	266(17.4)
<i>Micrococcus</i> spp	0	0	0	0	0(0)	48	48	96(6.3)
<i>Pseudomonas</i> sp	0	0	1	3	4(6.3)	86	46	132(8.6)
<i>Serratia</i> sp	1	0	0	0	1(1.5)	63	18	81(5.3)
<i>Staphylococcus</i> spp	18	9	9	15	51(79.6)	88	153	241(15.9)
Ground Total					64			1526

The bacterial species were higher in surface water compared to the sachet water. The *Citrobacter* spp recorded was higher in stations 5 (54 cfu/100mL) and 6 (79 cfu/100mL), and 2 cfu/100mL was recorded in station 3, while 0 cfu/100mL was recorded in stations 1, 2 and 4 (sachet water). The higher number of *Clostridium* spp (249 cfu/100mL) was recorded in station 5, while 146 cfu/100mL was in station 6. Abundant *Enterobacter* spp was recorded in station 5 (119 cfu/100mL), and 63 cfu/100mL in station 6, while 0 cfu/100mL was recorded in stations 1, 2 and 4 (sachet water). The *Escherichia coli* was not recorded in sachet water samples, while 155 cfu/100mL and 111 cfu/100mL were recorded in stations 5 and 6 respectively. A total number of 48 cfu/100mL of *Micrococcus* spp was recorded in stations 5 and 6, and absent in stations 1 to 4. The *Pseudomonas* sp and *Serratia* sp were high in station 5 (surface water). For the *Staphylococcus* spp, 18 cfu/100mL was recorded in station 1; 9 cfu/100mL in stations 2 and 3, while 15 cfu/100mL was in station 4 (sachet water). The highest number of *Staphylococcus* spp was recorded in station 6 (153 cfu/100mL), while 88 cfu/100mL was in station 5 (Table 4).

4. Discussion

In this study, we assessed the water quality of some drinking water sources in Ikot Ekpene metropolis, South-South Nigeria using physicochemical and microbial characteristics. The physicochemical and microbial properties are significant tools to access in drinking water before consumption. The study revealed that the concentrations of water parameters were low in sachet water compared to the values obtained in surface water. The values obtained were within the acceptable limits for drinking purpose recommended by Nigerian Drinking Water Quality Standard [26] except pH levels across the surface water. The pH level deviated from 6.5 - 8.5 is undesirable in drinking water SON [26]. The pH levels recorded is similar with the findings reported by Jonah et al. [31] and Ekpo et al. [32] in the region. The low pH recorded in August 2023 (station 6) and June 2024 (station 5) could be

due to geogenic nature of the environment [33]. The acidic contents of pH recorded across the surface water could be attributed to impact of sand mining and agricultural activities [34]. The highest values of Cl⁻ recorded in stations 5 and 6 when compared with sachet water (stations 1 - 4) could be associated with the domestic activities such as laundering, bathing and washing of motorcycle [35]. Wastes containing detergent could be responsible for the elevated concentration of Chloride in water. The concentrations of EC and TD followed the same trend with the highest values in station 6 (April 2023). However, the highest mean values of these parameters were recorded in surface water. According to SON [26], the EC and TDS contents have no significant effects on human health. The elevated values in surface water when compared with sachet water samples suggest pollutants from the widespread agricultural activities in the study areas and coupled with urban runoff [36 - 38]. The cations (Ca²⁺, Na⁺ and Mg²⁺) followed the same trends in both sachet and surface water samples. Knowledge about the concentrations of Ca²⁺, Na⁺ and Mg²⁺ in drinking water is crucial for human safety as excessive concentration could be detrimental to human health. The elevated value of Na⁺ in drinking water should be a concern to for individuals with hypertension and the values recorded in this study are within the acceptable limit (200 mg/L) recommended by SON [26]. In the other hand, Ca²⁺ and Mg²⁺ are important for human health, playing roles in bone development, muscle function and nerve transmission, while Na⁺ is essential for electrolytes, involving in maintaining fluid balance and nerve function in humans. The values recorded for surface water are similar with the values reported elsewhere by Adetunji et al. [39] in rural stream southeast Nigeria and lower than the values reported by Jonah and Akpan [40] in Northern Akwa Ibom state, Nigeria. In addition, Ca²⁺ is one of the major inorganic substances present in nearly all water systems attributable to its easy solubility from all rocks, including limestone, chalk, dolomite and gypsum [40]. The trends in the cations could be attributed to seasonal influential factors as in the case of other parameters [41]. However, low values of Ca²⁺ and Na⁺ in surface water could be ascribed to impact of rainfall, resulting in dilution of its contents.

The NO₂⁻ and NO₃⁻ in drinking water above the limit are detriment to human health. The cyanosis and asphyxia (blue-baby syndrome) in infants are less than 3 months associated with high intake of NO₂⁻ and NO₃⁻ [26]. The elevated mean value of NO₂⁻ in sachet and surface water exceeded the limit (0.2 mg/L); however, the NO₂⁻ value recorded in sachet water could be attributed to geogenic influence, contamination during treatment, and possible leaching from the plastic nylon to the water. However, the higher concentration NO₂⁻ in surface water (stations 5 and 6) could be ascribed to impact sand mining, bathing, laundry, intense agricultural activities and coupled storm water from the nearby communities during rainfall. Agrochemicals and animal waste from contaminated soil leached into water bodies could elevate the concentration of nitrite and NO₂⁻ [42 - 44]. The elevated mean value of SO₄²⁻ recorded in surface water compared with the sachet water suggest geogenic influence, coupled with human activities such as washing of motor cycles, laundering and bathing [45]; though, the values recorded were within the acceptable limit (< 100 mg/L). The mean value of WQI recorded in sachet water was lower compared to the value in surface water. The value in sachet water was below 50, which is classified as good drinking quality, while the surface water was > 50 and classified as poor quality, not suitable for drinking purposes. The higher value recorded in surface water suggests impact of combining effects of human activities such as bathing, laundry, sand mining and agricultural activities Jonah et al. [23]. In a normal circumstance, the suitability and overall health of drinking water is determined by its microbial characteristics. Studies [46 - 48] reported that the occurrence of pathogenic organism in water drinking is an indication of faecal contamination, leading to widespread diseases such as dysentery, typhoid, cholera and cancer in humans. In this study, the total heterotrophic bacteria, coliforms, staphylococcus bacteria and faecal coliform counts recorded in surface water samples were higher than the number obtained in sachet water samples.

The abundance of these pathogenic organisms in surface runoff suggests impact of surface runoff into the water bodies. Excessive stormwater or flooding from the communities and roadside during rainfall could also be responsible for the higher number of microbes in surface water. During bathing, water can be contaminated with pathogenic organisms [27]. The higher number of THBC, TCC, TSBC, and TFCC in surface water were recorded; the findings affirmed the previous report of Ekanem et al. [27] in this region, which recorded the presence of TCC and TFCC above the permissible level in surface water sources. The staphylococcus bacteria and faecal coliform recorded in sachet water suggest splashing from contaminated source during production and possible use of contaminated storage facility to store the water before production, indicating that the water samples were not properly treated during production [49]. Also, poor hygiene, and leakage from septic tank could be the reasons for the occurrence of microbial pathogens in sachet water samples. The abundance of *Clostridium* spp, *Escherichia* spp, *Pseudomonas* spp and *Staphylococcus* spp in stations 5 and 6 is an indication of serious microbial pollution, suggesting impact of indiscriminate disposal of used dippers containing faeces contamination into the water and waterways which possibly get into these water bodies. However, there were significant differences ($p < 0.05$) between the microbial parameters in sachet and the surface water samples.

5. Conclusion

The study revealed that the physicochemical and microbial characteristics are varied between drinking water sources. The surface water samples are more susceptible to the consumers than the sachet water. The mean concentration of nitrite in sachet and surface water, and pH in surface water exceeded the standard limits for drinking water quality. The value for WQI and microbial composition was high in the surface water, indicating that the water is not suitable for human consumption compared to the sachet water samples. The abundance of *Clostridium* spp, *Escherichia* spp, *Pseudomonas* spp and *Staphylococcus* spp in stations 5 and 6 indicates impact of human activities.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the article.

Author contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Cecilia F. Mendie, Udeme E. Jonah; **data collection:** Cecilia F. Mendie; **analysis and interpretation of results:** Cecilia F. Mendie, Udeme E. Jonah; **draft manuscript preparation:** Udeme E. Jonah. All authors reviewed the results and approved the final version of the manuscript.

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