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Comparison of Total Viable Bacteria Counts and *in situ* Characteristics in Drinking Water Sources in Sagbama Town, Bayelsa State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Before the 21st century, most of Nigeria's rural and coastal communities obtained their drinking water from surface water sources. However, due to development, many coastal towns now get their drinking water from underground sources. Nevertheless, surface water remains a crucial source of drinking water in communities where groundwater is inaccessible. This study evaluated the density of total heterotrophic bacteria and *in situ* characteristics of drinking water sources in Sagbama town in the Sagbama Local Government Area of Bayelsa State, Nigeria. Triplicate water samples were obtained from five stations for each of the water types (ground and surface water). The water

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samples were analyzed following standard procedures. The results of ground and surface water ranged from 2.33 to 2.86 (overall mean of 2.52) Log CFU/mL and 2.70 to 3.87 (overall mean of 3.24) Log CFU/mL for total heterotrophic bacteria counts, 7.05 to 7.68 (overall mean 7.40) and 7.06 to 7.31 (overall mean 7.22) for pH, 146.67 to 232.00 (overall mean 169.13) mg/L and 40.23 to 45.60 (overall mean 41.50) mg/L for total dissolved solids, 207.57 to 327.67 (overall mean 239.31)µS/cm and 56.73 to 64.47 (overall mean 58.55) µS/cm for conductivity, and 0.11 ppt and 0.03 ppt (in all the stations) for salinity. The temperatures of both kinds of water were in the range of 26°C. Except for the pH, salinity, and conductivity of groundwater, an analysis of variance reveals no significant differences (p>0.05) across sites for any water type. The overall t-test revealed that all parameters, except pH and temperature, were statistically distinct (p<0.05) between the various water types. According to Pearson's correlation, conductivity correlates positively with total dissolved solids for both kinds of water. In contrast, salinity correlates positively with conductivity and total dissolved solids for surface water at p< 0.01. Except for total heterotrophic bacteria counts on surfaces, which exceeded World Health Organization standards, other parameters fell within the Standard Organization of Nigeria and World Health Organization guidelines. Therefore, drinking surface water from the research location without first purifying it increases the chance of avoidable ill health consequences.

Keywords: Contamination; drinking water; heterotrophic bacteria counts; human activities; water quality.

1. INTRODUCTION

Water is a vital resource essential to the existence of all living things [1-3]. Solid water (ice), gaseous water (vapor), and liquid water are the three distinct forms used to categorize various water resources. Water is found underground, on the surface (rivers), or as precipitation from the sky, i.e., rainfall. According to their origins, the three types of surface water resources are fresh water, salt water (also known as estuarine water), and brackish water (salt and freshwater interphase).

Additionally, water offers a home for several plant and animal species [4]. As a consequence, the life cycles of species responsible for transmitting illnesses to humans, such as mosquitoes are carried out in water [5-10]. So many human diseases are transmitted by different species of mosquitoes including *Aedes aegypti* (yellow and dengue fever), *Culex quinquefasciatus* (lymphatic filariasis), and *Anopheles gambiae, A. funestus, A. arabiensis,* and *A. melas* (malaria) [11-13].

Surface water is the most commonly used resource for transportation-related activities, although it has the lowest overall availability. The most prominent surface water uses are in recreational activities such as swimming, bathing, washing, cooking, and drinking. Additionally, groundwater is an essential resource for home use. Izah et al. [14] and Izah and Srivastav [4] stated that rain, ground, and surface waters are sources of potable water in Nigeria. In the coastal areas of the Niger Delta, drinking water sources are often contaminated [15, 16]. Human actions and, to a lesser degree, natural occurrences are often responsible for the pollution of water supplies. Inappropriate residential and industrial waste disposal (municipal, solid, and effluents) contributes to surface water contamination. These include dredging, oil and gas operations, agricultural operations, and food production [15-22]. Additionally, improper management and conservation techniques contribute to groundwater pollution.

The leaching of over-filled soakaways resulting from poor home development in many coastal locations and insufficient sanitation services causes groundwater pollution. Due to the high-water tables in certain coastal regions, notably in Bayelsa State [2], it is easy for effluents and runoff to penetrate the coastal aquifer. In addition, water pollutants also increase nutrient levels, resulting in eutrophication, acidification, and hydrological changes in surface water resources. Consequently, it might harm the productive capacity of such waterways in terms of fish population composition and dispersion [23-25].

The presence of microorganisms, heavy metals, and the water's basic physicochemical features are the three most essential factors for determining the overall quality of water [24–34]. Microorganisms are widespread and water contaminated by microorganisms, such as harmful bacteria, parasites, and viruses, increase the chances of human illness. As a result, poor-quality water can potentially serve as a transmission medium for harmful microorganisms such as bacteria and viruses. Several species of microorganisms have been reported in different drinking water sources (surface and groundwater) in Bayelsa State, Nigeria. Among these microorganisms are *Pseudomonas, Enterobacter, Bacillus, Citrobacter, Erminia, Klebsiella, Shigella, Salmonella, Proteus, Serratia, Streptococcus, Micrococcus, Yersia, Corynebacterium* species, *Aspergillus flavus, Aspergillus fumigatus, Aspergillus niger* [24, 29]. In addition, some of these microorganisms are found in soil and air [25], as well as in ready-to-eat meals and beverages in different regions of Bayelsa State [36-38].

In many coastal regions of Bayelsa State, Nigeria, many residents of the area depend on the available water resources for drinking and other domestic purposes. However, due to urbanization, many indigenous people are now depending more on groundwater than the surface water that used to be their main source of drinking water in the 1990s. Furthermore, with increased human activities, the rate of environmental pollution has increased. The surface water indirectly receives most of the environmental pollutants. Based on these, several studies have reported on water quality, however, literature on the total viable counts and basic in situ characteristics of the drinking water quality in Sagbama town, Sagbama Local Government Area of Bayelsa State, is scanty. Therefore, the focus of this study is to assess the microbial quality and in-situ characteristics of potable water in Sagbama town. The findings of this work will be of benefit to the users of the various types of water under study and the general public.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Sagbama town, which stands as the headquarters of the Sagbama local government area in Bayelsa State. The primary occupation of the indigenous people of the area is farming, including fishing. Few other people are civil servants. Like other major communities in the area, surface water passes through the town. The surface water is a major receiver of municipal solid waste. The water is also used for domestic purposes, although now, due to industrialization, many people in the area now use groundwater as their drinking water source.

2.2 Sample Collection

A total of thirty water samples were randomly collected from the study area. The sample collection was done covering the major miles in the town, which were labeled A, B, C, D, and E. Therefore, fifteen samples were collected for a particular water type (ground and surface water). For each type of water, triplicate samples were collected from each of the sampling stations. The water samples were collected in sterile containers. For the surface water, the sample bottle was submerged in the water and opened. The bottles were filled to near brim and capped before exposing the bottle. For the groundwater, the water was allowed to rush from the tap for approximately 5 minutes, after which the samples were collected under the tap.

2.3 Enumeration of Total Heterotrophic Bacteria Counts

Nutrient Agar was used as a medium to enumerate total heterotrophic bacteria. Previously reported by Pepper and Gerba [39] and Benson [40], the pour plate method was adopted. The nutrient agar used was prepared following the manufacturer's directions. A 1.0 ml water sample was aseptically plated and incubated inverted at 37℃for 24 to 48 hours. For each water sample, the outcome was a colony count expressed as colony-forming units.

2.4 Determination of the In-situ Characteristics of the Water

The manufacturers' guide determined all the in-situ parameters using a multipurpose meter that analyses pH, total dissolution, conductivity, salinity, and temperature.

2.5 Statistical Analysis

The statistical analysis was done by SPSS software version 20, which expressed the data as mean and standard deviation. One-way analysis of variance at P = 0.05 and Waller-Duncan's statistics discern the source of the observed differences for each water type across the various locations. A t-test compares the overall water quality for each parameter. Finally, the Spearman rho correlation matrix identifies the relationship between the in-situ parameters and total heterotrophic bacteria counts.

3. RESULTS AND DISCUSSION

The levels of total heterotrophic bacteria count and *in situ* characteristics of ground and surface waters from Sagbama town, Bayelsa State, Nigeria, are shown in Tables 1 and 2, respectively. The total heterotrophic bacteria count ranged from 2.33 to 2.86 Log CFU/mL and 2.70 to 3.87 Log CFU/mL for ground and surface water, respectively. There was no statistical deviation (p>0.05) in the different locations for each water type. On average, the mean values of total heterotrophic bacteria counts were 2.52 Log CFU/mL and 3.24 87 Log CFU/mL for ground and surface water, respectively, being statistically different (p = 0.001) (Table 3). The values showed that the total heterotrophic bacteria counts were higher in the surface water than in the groundwater since several human activities occur in the surface water. The lack of significant variation in the overall heterotrophic bacteria counts across the various water types and locations implies that similar activities contaminate each water type in the region [24].

This study contradicts prior research on drinking water quality in Bayelsa State. 1.78 to 9.30 x 10^6 CFU/ml from river nun at Amassoma axis [23]; 5.38 to 6.74 Log CFU/ml from Epie stream [24]; 4.53 to 5.82 logs CFU/ml in Taylor Creek [41]; 0.74 to 8.43 x 10^6 CFU/ml from Ikoli creek [17] and 2.97 to 6.03 x 10^4 CFU/ml from Imiringi [34]. Variations in these values reflect human activities that influence the density of total heterotrophic bacteria counts in drinking water sources. The levels above the World Health Organization/Food and Agriculture Organization permissible limit of 1.0 x 10^2 CFU/ml for surface water [29] were within the range for surface water. Consequently, the overall density of heterotrophic bacteria in surface water exceeded the permissible level and potential health risks exist.

The pH range for ground and surface water was 7.05 to 7.68 and 7.06 to 7.31, respectively. For surface water, there was no statistical variance across sites; however, there was a statistical deviation for groundwater. The post hoc test revealed no divergence between stations A - C and C- E. Nonetheless, there was a difference between A and D. The average pH values for groundwater and surface water were 7.40 and 7.22, respectively, with no statistically significant difference (p = 0.057). (Table 3). The modest variation in pH levels for groundwater may be attributable to variances in compounding variables, such as the depth of the aquifer, direction of flow of the water, materials, and water treatment procedures. Essentially, the values are comparable to those obtained in some regions of Bayelsa State.

Some of the studies include Nun River at the Gbarantoru and Tombia towns (6.27 to 6.45) [42]; 5.80 to 7.01 from Epie Creek [25]; Nun River at Amassoma axis (6.53 to 7.35) [2,33]. The discrepancy is attributable to the quantity of acidic materials leached into the water due to several human activities [25,42]. Nevertheless, based on the water quality standard established by the Standard Organization of Nigeria (SON) and the World Health Organization (WHO), which is between 6.5 and 8.5, the results discovered in this research indicate that the water is safe to consume.

Table 1. Level of Total heterotrophic bacteria counts and in-situ characteristics of groundwater from Sagbama town, Bayelsa State, Nigeria

Locations	THB, Log CFU/mL	pH	Salinity, ppt	Conductivity, µS/cm	TDS, mg/L	Temperature, ℃
A	2.33±0.11a	7.68±0.23c	0.11±0.01a	207.57±11.66a	146.67±7.51a	26.60±0.10a
B	2.86±0.06a	7.54±0.13bc	0.11±0.01a	229.00±20.66a	162.00±15.10a	26.47±0.06a
C	2.40±0.11a	7.50±0.39abc	0.11±0.08a	327.67±65.58a	232.00±46.81a	26.47±0.23a
D	2.64±0.60a	7.05±0.08a	0.11±0.01b	220.33±12.90b	154.33±12.66a	26.50±0.20a
E	2.35±0.04a	7.20±0.13ab	0.11±0.01a	212.00±17.69a	150.67±12.58a	26.43±0.06a
SON Limit	-	6.5-8.5	-	1000	500	Ambient
WHO Limit	2.0	6.5-8.5	100-200	1000	500	40

Data is expressed as mean ± Standard deviation; Different alphabets along the column (from locations A –E) indicate significance difference (P<0.05) according to Waller Duncan statistics

Table 2. Level of Total heterotrophic bacteria counts and in-situ characteristics of surface water from Sagbama town, Bayelsa State, Nigeria

Locations	THB, Log CFU/mL	pH	Salinity, ppt	Conductivity, µS/cm	TDS, mg/L	Temperature, ℃
A	3.87±0.49a	7.30±0.17a	0.03±0.01a	57.63±3.28a	40.75±2.22a	26.53±0.12a
B	3.04±0.52a	7.28±0.12a	0.03±0.00a	56.73±2.94a	40.23±2.12a	26.50±0.10a
C	2.70±0.16a	7.06±0.06a	0.03±0.00a	56.80±1.31a	40.40±0.98a	26.50±0.10a
D	3.05±0.63a	7.14±0.06a	0.03±0.00a	57.13±2.58a	40.50±1.64a	26.57±0.06a
E	3.53±1.18a	7.31±0.23a	0.03±0.01a	64.47±13.28a	45.60±9.70a	26.57±0.15a
SON Limit	-	6.5-8.5	-	1000	500	Ambient
WHO Limit	2.0	6.5-8.5	100-200	1000	500	40

Data is expressed as mean ± Standard deviation; Different alphabets along the column (from locations A –E) indicate significance difference (P<0.05) according to Waller Duncan statistics

Table 3. Comparative analysis of drinking water sources (surface and ground water) in Sagbama town, Bayelsa State, Nigeria

Parameters	N	Ground water	Surface water	t-value	P-value	Implications
		Mean± Std. Deviation	Mean± Std. Deviation			
THB, Log CFU/mL	15	2.52±0.32	3.24±0.72	-3.558	0.001	Significant deviation
pH	15	7.40±0.31	7.22±0.16	1.982	0.057	No significant deviation
Salinity, ppt	15	0.11±0.03	0.03±0.00	9.422	0.000	Significant deviation
Conductivity, µS/cm	15	239.31±53.96	58.55±6.22	12.889	0.000	Significant deviation
TDS, mg/L	15	169.13±38.54	41.50±4.46	12.742	0.000	Significant deviation
Temperature, ℃	15	26.49±0.14	26.53±0.10	-0.913	0.369	No significant deviation

The salinity of groundwater was 0.11 ppt, while that of surface water was 0.03 ppt. There was no statistical difference between the sites for both kinds of water. However, a significant difference (p <0.001) existed across the water types (Table 3). There was no noticeable variation in water quality across the various water types, indicating that their freshness levels are equivalent [25]. However, the statistical variance found for the various water types indicates that their properties vary. The results found in this study are comparable to those obtained in earlier research from the Nun River in Gbarantoru and Tombia (0.03 mg/L) [42] and Ikoli Creek (0.01-0.03 mg/l) [32]. Furthermore, the levels were within the WHO guidelines for drinking water (100 to 200ppt).

The range of total dissolved solids for groundwater was 146.67 to 232.00 mg/L, whereas the range for surface water was 40.23 to 45.60 mg/L. There was no statistical difference between the sites for both kinds of water. The mean values of total dissolved solids for groundwater and surface water were 169.13 mg/L and 41.50 mg/L, respectively, which were statistically distinct (p <0.001) (Table 3). The discrepancy between the two kinds of water revealed changes in salt content. Again, water has various chemical qualities and human activity fluctuations can alter its quality and geology. In general, the values reported are comparable to those previously documented in Epie Creek [25] and are greater than those in the Nun River [2,33] and Kolo Creek [31]. However, the total dissolved solids observed in this study are far below the SON and WHO limits of 500 mg/L.

The range of conductivity for ground and surface water was 212.00 to 327.67 µS/cm and 56.73 to 64.47 µS/cm, respectively. For surface water, there was no statistical variance across sites. However, there was a statistical deviation for groundwater. Station D is the cause of the observed statistical variation based on the post hoc test. Overall, the mean conductivity values for ground and surface water were 239.31S/cm and 58.55S/cm, respectively, which were statistically distinct (p <0.001) (Table 3). The statistical dissimilarity identified in the groundwater for location D is due to depth and treatment materials.

The values reported in this research are comparable to those obtained previously from Epie Creek [25] and Kolo Creek [31]. The conductivity of water may provide information about the overall concentration of ionic solutes in water [25,33]. According to WHO and SON's recommendations for safe drinking water, the water's conductivity falls within the acceptable range of 1000 S/cm.

Table 4. Pearson's correlation of the ground water characteristics in Sagbama town, Bayelsa State, Nigeria

Parameters	THB	pH	Salinity	Conductivity	TDS	Temperature
THB	1.000					
pH	-0.063	1.000				
Salinity	-0.018	0.441	1.000			
Conductivity	0.000	0.178	-0.055	1.000		
TDS	0.012	0.184	-0.058	0.999**	1.000	
Temperature	0.233	0.272	-0.051	0.205	0.202	1.000

***. Strong significant correlation at the 0.01 level. N=15*

Table 5. Pearson's correlation of the surface water characteristics in Sagbama town, Bayelsa State, Nigeria

Parameters	THB	pH	Salinity	Conductivity	TDS	Temperature
THB	1.000					
pH	0.300	1.000				
Salinity	0.061	0.284	1.000			
Conductivity	-0.073	0.415	0.787**	1.000		
TDS	-0.072	0.418	0.779**	0.999**	1.000	
Temperature	-0.041	-0.211	-0.139	-0.435	-0.452	1.000

***. Strong significant correlation at the 0.01 level. N=15*

Ground and surface water temperatures were within the range of 26 degrees Celsius. There was no statistical difference between the sites for both kinds of water. In addition, there was no significant difference ($p = 0.369$) in the mean values of the two water types (Table 3). The absence of statistical variance indicates that the ambient air environment during the water sample was comparable. Also, it indicates that human activities did not statically modify the water over the research period. The average values reported are within the range of values that promote the survival of many mesophilic species within the temperature range for potable water. These values are marginally lower than those found in the Nun River [2], Kolo Creek [31], and Ikoli Creek [32] but slightly higher than those found in the Nun River by Ogamba et al. [33]. This discrepancy depends on the sample period's meteorological circumstances, such as the season and time of day.

Tables 4 and 5 illustrate the Pearson correlation between ground and surface water characteristics in Sagbama, Bayelsa State, Nigeria. At $p = 0.01$, there was a statistically significant positive correlation between conductivity, total dissolved groundwater (Table 4), and surface water (Table 5). Moreover, surface water salinity correlates with conductivity and total dissolved solids at a significance level of $p = 0.01$. Similar factors may have a positive effect on parameters that are positively correlated. The ions in the water may have affected the connections between conductivity and total dissolved solids and between conductivity, total dissolved solids, and salinity observed in the study. According to Rusydi [43], conductivity and total dissolved solids are utilized to determine salt levels as water quality indicators. In addition, the author reported that total dissolved solids are crucial because they help explain groundwater quality, namely inorganic salts, organic detritus, and saltwater intrusion. Conductivity and total dissolved solids are essential for determining the water's salinity. Therefore, there is no need for a link between salinity, conductivity, and total dissolved solids. Natural and artificial or manufactured variables, such as the salinity of the water, may be the primary determinants of the relationships.

4. CONCLUSION

This study evaluated the total viable bacterial density and in situ characteristics of drinking water sources (surface and groundwater) in Sagbama town, in the Sagbama Local Government area of Bayelsa State, Nigeria. The results of the evaluation revealed that the density of bacteria was in the order of 10^2–10^3 CFU/ml, with a higher density found in the surface water. The physico-chemical parameters showed an allowable level for drinking water. The characteristics of the water under study showed that they are within the Standard Organization of Nigeria and World Health Organization guidelines, except for the total heterotrophic bacteria in the surface water. The consumption of the surface water without treatment could expose users to health hazards. Therefore, there is a need to purify the water using appropriate techniques before use to prevent any potential health risks. Research on the identification of the microbial community as well as trace element composition in the various types of drinking water in the area needs to be carried out. Also, there is a need to sensitize the users of the water in the area about the quality of their potable water sources and provide advice on how to minimize microbial contamination.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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