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(Research Article)

Physicochemical, bacteriological, and correlational evaluation of water obtained from boreholes and springs in a sub-urban community

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Abstract

Inadequate safe and portable water supply particularly in underdeveloped and developing countries has been associated with posing serious public health implications, especially as water related diseases continue to be a major health challenge in resource limited settings worldwide. Physicochemical and bacteriological parameters of borehole and spring water sources in a sub-urban community were assessed to determine their potability and correlation index. Twenty (20) water samples, 10 from boreholes and 10 from springs were randomly collected from different locations and analysed using standard microbiological and physicochemical methods. The results were compared with NIS and WHO standards for drinking water. Physicochemical parameters including; temperature, pH, turbidity, electrical conductivity, total hardness, total dissolved solid, Iron, Manganese, Zinc, Chloride, Sodium, Nitrate, Ammonium and Potassium were determined following the procedures prescribed by American Public Health Association Standard Method. Results obtained revealed that 99.3% of the analysed physicochemical parameters were within the maximum acceptable limits of NIS and WHO guidelines for drinking water except borehole iron concentration (0.52mg/L) and Manganese concentration (0.14mg/L). The total heterotrophic bacterial count (THB), total coliform count and faecal coliform count ranged from 1.6x10^{3}cfu/100ml to 4.7x10^{3}cfu/100 ml, 8.0cfu/100ml to 25cfu/ml, 0cfu/100ml to 14cfu/100ml respectively for boreholes, and 1.7x10^{3}cfu/100ml to 4.6x10^{3}cfu/100ml, 10cfu/100ml to 21cfu/100ml, 9cfu/100ml to 17cfu/100ml respectively for samples from spring water supply. Phenotypic characterization of the samples revealed the presence of certain organisms with pathogenic potentials such as *Staphylococcus aureus* 27.5%, followed by *E. coli 19.6%*, *P. aeruginosa 11.8%*, *Klebsiella spp.* 9.8%, *Enterobacter spp*. 7.8%, *Enterococcus spp*. 7.8%, *Lactobacillus spp.* 5.9%, *Proteus spp*. 3.9%, *Shigella spp*. 3.9% and *Vibrio cholerae 2.0%*. Pearson's correlation analysis showed significantly strong positive correlation between total heterotrophic bacteria count and total coliforms (r = 0.643) and strong negative correlation between pH and total dissolved solids (r = -0.640). Other parameters such as faecal coliform, temperature, pH, turbidity, Zinc, Ammonium and Sodium shows significant correlation among variables.

Keywords: Water samples; Physicochemical parameters; Bacteria; Faecal coliform; Public health

1. Introduction

Water is vital for survival and absolutely necessary for most life driven processes [1]. Satisfactory supply of clean, safe, and hygienic drinking water is therefore imperative for good health amongst other benefits. Globally, 844 million people live without adequate access to improved water sources [2]. Inadequate safe water supply has serious public health implications as water related diseases continue to be one of the major health problems particularly in developing countries. Among such health challenges is diarrhea. The burden of diarrheal diseases is predominantly high in developing and low-income countries. Infact, the highest rates of under-five mortality due to diarrhea has been recorded in sub-Saharan Africa and South Asia, with India and Nigeria accounting for 42% of the total deaths [3]. Resource report

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suggests that about 90% of diarrheal cases were due to contaminated water [2], as one in five children globally have poor access to water sufficient enough to meet their daily needs [4]. Available data also suggests that about 1.42 billion People including 450 million children live in areas of high or extremely high-water vulnerability. Access to safe water is not only paramount to children's survival, it is also an essential component for other areas of their development including health, nutrition, education, safety and eventually employment [4].

Water quality is determined by several factors including the concentration of physical, chemical and biological contaminants. In the face of life-threatening water-related hazards, the United Nations included access for all to drinking water and sanitation at the heart of the Sustainable Development Goals (SDGs). Water supply and accessibility which is Goal 6 of the SDGs aimed at ensuring environmental sustainability [5, 6]. Historically, efforts to ensure access to safe drinking and food processing water have been focused on the community-based water sources [7, 8]. Water shortage and pollution of readily accessible water sources are evident in many regions of developing nations [5, 8]. This is largely attributed to low level of personal hygiene and inadequate treatment facilities for water and wastes that are consequent pollutants [9].

Water is susceptible to contamination with microorganisms and organic matter among other pollutants regardless of the source [5, 10]. Significantly, microbial contaminants such as coliform bacteria*, Cryptosporidium parvum*, and *Giardia lamblia* compromise the safety of water [11]. The presence of *E. coli, Klebsiella spp.*, and *Enterobacter spp.* in water is a likely indicator of the presence of pathogenic organisms such as *Salmonella*, Protozoa amongst others. Drinking water can be contaminated at source, in the distribution system, during collection, transportation, and storage with disease vectors, pathogens or unacceptable level of toxins or suspended solid. Analysis of the physicochemical and bacteriological quality of drinking water is important in determining the sanitary quality. Therefore, the ability to monitor water sources for the presence of pathogenic microorganisms and chemicals substances that are dangerous to health is significant in order to ensure public health [12]. Many studies have focused on water supply and public health in sub-Saharan Africa, but comparatively few data are available regarding water quality consumed by people living in rural areas of Cross River State.

In Ugep, most of the communities depends on the available springs, and boreholes. Studies carried out by Oka *et al*. [13], reported that about 46% of respondents in Yakurr LGA, in Nigeria used borehole as their main source of water, while 23.2% depend on spring water sources. This study therefore will evaluate the physicochemical and bacteriological quality of borehole and spring water sources of selected communities in Ugep, Yakurr Local Government Area, Cross River State, Nigeria and determine the correlation among bacteriological and physicochemical parameters in the selected water sources.

2. Material and methods

2.1. Study area

Ugep geographically lies approximately between latitude 5^o 45' and 5^o 55' North of the equator and longitude 8°11' and 8°20' East of the Greenwich meridian and 120km2 (75 miles) North West of Calabar. The major language spoken by the people is Lokạạ with the population of approximately 144, 421 persons as at 2006 National Population Census. The area has both urban features as well as rural settings and is characterized by high temperature, rainfall and humidity. Ugep has four political wards namely; Ijom, Ijiman, Ikpakapit and Biko-Biko. Each ward has villages/settlements and the people are largely famers and exhibit high degree of social homogeneity with strong political, cultural and religious affinity.

2.2. Sample collection

Water sources (boreholes and spring) were randomly selected. Twenty (20) samples were obtained at different locations namely; Ekpowen, Old market road, Magistrate Road, Ndayi playground, Yenon, Unebu, Nkamkpo Health centre, Ikpakipit town hall, Lewankom, Akugom, Okamawen, Ubi Johnson spring, Lesekpowetu, Owetetewen, Kiwel, Onambelipol, Nma Oden, Lewewitu, Lonowei, and Isukpa. The water samples were aseptically collected in duplicates in two batches into well-labelled 500ml sterilized bottles, placed in sealed bags and transported at 4 °C (in a cool box with ice) to a standard laboratory for further estimation of the bacteriological and physicochemical parameters.

2.3. Analysis of physicochemical parameters

Parameters such as temperature, and pH, were measured using a thermometer, and portable digital pH meter respectively. The turbidity and electrical conductivity for each of the water samples collected was measured using a turbidity meter and Conductivity Meter (Hanna Instrument H18733). Other water-quality parameters including nitrate, iron, manganese, Zinc, calcium, potassium, podium, ammonium, free residual chlorine, and Total Dissolved Solids (TDS) were determined following standard methods, using a DR 2400 spectrophotometer (Loveland, USA).

2.4. Analysis of Bacteriological parameters

The media used for bacteriological analysis were prepared based on their manufacturer's instructions. The media preparation included autoclave sterilization at 121°C for 15 mins. 20ml of each media was poured into sterile petri dishes and allowed to cool before inoculation.

Total heterotrophic bacteria in the water samples were obtained using the pour plate method. The enumeration and isolation of coliform bacteria was by the use of the membrane filtration technique. For enumeration of coliform, the water samples were thoroughly shaken to mix and 100ml was measured from each sample and passed through a membrane filter (0.45 µm pore size), which allows water particles to pass through while bacteria cells are trapped. The membrane filter was carefully removed using sterile forceps and plated aseptically onto MacConkey agar for total coliforms and faecal coliforms following the standard protocols as described by Cheesbrough [14]. Incubation was carried out at 37 °C for 24h for total coliforms and 44.5 °C for 24h for faecal coliforms while bacterial count was carried out following the standard microbiological procedures by APHA [15]. All analyses were carryout in duplicate.

On completion of the culture, bacteriological species were identified using standard biochemical tests as described in APHA [15]. Stock cultures of the identified organisms also prepared and preserved.

2.5. Statistical analysis

Statistical analyses were conducted using SPSS v22 and Microsoft Excel v2013. Pearson product moment correlation coefficient was utilised to analyse the association between various water parameters, and detect significant variations among selected water quality parameters of the water samples.

3. Results and discussion

Contaminated water sources containing different physicochemical and bacteriological contaminants can be associated with numerous health related consequences. In this study, the local inhabitants mostly belong to low-income class and are unable to afford improved or portable water supply.

3.1. Physicochemical analysis

The results of the physicochemical parameters of boreholes and spring water samples were presented in Table 1 and Table 2 respectively. In this study, all the sampled water sources were clear in appearance, with temperature range from 23.5°C-26.2°C and in line with NIS and WHO standard [16]. Temperature is one of the most essential parameters in water and has significant impact on growth and acidity of ecological life. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria in water bodies. The values of pH ranged from 6.72 to 8.10 for borehole and 6.83 to 7.89 for spring water sources. The highest pH 8.10 was recorded in BO_3, while the lowest pH 6.83 was recorded in BO_4. It is vital to note that water pH usually has no direct impact. However, it is one of the most important operational water quality parameters. Low pH water is likely to be corrosive [17].

The observed Turbidity values from this study ranged from 0.21 NTU to 0.98 NTU for borehole water and 0.34 NTU to 1.97 NTU spring water respectively. All the values analysed were within the national and international acceptable level (>5NTU) for drinking water. The result of this finding was also in agreement with the report of Agbo *et al.* [18], which reported that turbidity of boreholes in Calabar Municipality ranged from 0.42 NTU - 0.17 NTU. However, high turbidity may indicate the presence of disease-causing organisms and suspended insoluble materials. Additionally, turbidity can interfere with the efficiency of disinfection thereby providing protection for microorganisms.

In this study, the values of electrical conductivity ranged from 43.2µs/cm to 89.3µs/cm for borehole water samples evaluated, and 42.6µs/cm to 98.1µs/cm for spring water samples. SP_3 recorded the highest concentration 98.1µs/cm. The ability of water to conduct electricity has no health consequences on humans. In this study, total hardness values ranged from 18.0mg/L to 36.2mg/l for boreholes and 17.1mg/l to 21.4mg/l for spring water samples. The values of water samples analysed were within maximum permissible limits and conforms to acceptable standards [16]. Total hardness values ranged from 18.0mg/l to 36.2mg/l for boreholes and 17.1mg/l to 21.4mg/l for spring water samples. All the water samples have their values within the permissible limits. Total Hardness is caused by the presence of calcium and magnesium salt. However, public acceptability of the degree of hardness of water may vary considerably from one community to another [16].

In this study, the TDS values ranged from 21.8mg/L to 36.3mg/L for borehole water and 27.3mg/L to 58.9mg/L in spring water samples. The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l. The higher the TDS in water the higher the chemical and biological oxygen demand that will lead to decreasing level of dissolved oxygen in water. TDS of the water samples compared to the standard were within the acceptable limit. The presence of high levels of TDS may also be objectionable to consumers, owing to unnecessary scaling in water pipes, heaters, boilers and household appliances [16].

The results of chemical parameters analysed showed that the concentration of iron recorded for all the water samples ranged from 0.14mg/L to 0.52mg/L for boreholes and 0.18mg/L to 0.34mg/L for spring water samples and were within the acceptable limit except BO_6 (0.52mg/L). This finding is of serious medical importance, as it has been established that excess amount of iron, (more than 10.00 mg/kg) causes speedy increase in respiration, coagulation of blood vessels and hypertension [19].

The concentration of manganese recorded in all the water samples analysed ranged from 0.024mg/l to 0.14mg/l for boreholes and 0.024mg/l to 0.07mg/l for spring water. High concentration of Manganese causes neurological disorder and the study reveals that they are all within the acceptable limit except BO_2 (0.14mg/l) above the acceptable limit. Manganese in water supplies that exceed 0.1mg/l may cause undesirable taste in beverages and stains sanitary ware and laundry. Water containing zinc at concentrations in excess of 3–5 mg/l may appear opalescent and develop a greasy film on boiling [16]. In this study, Zinc values ranged from 0.66mg/l to 1.09mg/l for boreholes and 0.64mg/l to 0.81mg/l for spring water samples and were within the acceptable limit.

Nitrate concentration obtained from the present study ranged from 2.08mg/l to 5.60mg/l for boreholes and 2.16mg/l to 6.30mg/l for spring water. Nitrate concentration for all sampled water samples were in line with both national and international standard [16, 20]. Nitrate usually occurs naturally in ground water, but high concentration might be associated with animal and human waste, poor sewage systems, fertilization of farms and poor sanitation practices. Ammonium as the derivatives of Nitrogen enters the water body through the organisms that survives or by sewage effluent and runoff from land were manure has been applied or stored. In this study, Ammonium values ranged from 0.08mg/l to 0.17mg/l and 0.13mg/l to 0.35mg/l for boreholes and spring water samples respectively. The various concentration of nitrate and ammonium gives a useful indication of the level of micro-nutrients in the water and hence the ability to support plant growths.

In this study, chloride value ranged from 2.11mg/l to 4.71mg/l for boreholes and 2.33mg/L to 5.43mg/l for spring water samples. The values obtained were within the acceptable limit. High concentration of chloride indicates sewage pollution and has laxative effect. Chloride are common constituents of all natural waters, higher value of it impacts a salty taste to the water, making it unacceptable for human consumption. The concentrations of sodium recorded in the water quality investigated ranged from 0.91mg/l to 3.76mg/l for boreholes and 1.09mg/l to 4.76mg/l for spring water samples. Potassium values ranged from 2.11mg/l to 3.81mg/l and 1.67mg/l to 3.28mg/l for boreholes and spring water samples. Sodium and Potassium were all within the acceptable range given by national and international standard.

3.2. Bacteriological analysis

Based on bacteriological water quality standards, the degree of water contamination is determined by the density of coliform group of bacteria. Result obtained from the bacteriological analysis of borehole water sampled from eight different boreholes revealed that total heterotrophic count ranged between $1.6x10^3$cfu/100 ml to $4.7x10^3$ cfu/100 ml, and total coliform ranged from 8.0cfu/100ml to 25cfu/100ml, while faecal coliform count ranged between 0 cfu/100 ml to 14cfu/100 ml (Table. 3). BO_5 recorded the highest value of total heterotrophic bacteria count and total coliform count while BO_7 with the least for same parameters. Also, the highest value of faecal coliform was obtained in BO_3 while BO_2, BO_4 and BO_7 had no isolated faecal coliform bacteria.

Table 1 Summary of the result of physicochemical analysis of borehole water in Ugep

Parameters	Unit	BO_1	BO_2	BO_3	BO_4	BO_5	BO_6	BO_7	BO_8	BO_9	BO_{10}	NIS	WHO
Appearance		Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear		Clear
Temperature	^{o}C	25.3	25.4	24.2	24.5	25.5	24.6	23.5	25.5	23.8	24.2	Ambient	20 – 30
Ph		7.19	7.91	8.10	6.72	7.21	7.11	7.36	7.96	7.82	8.03	6.5 – 8.5	6.5 - 8.5
Turbidity	NTU	0.34	0.22	0.97	0.24	0.23	0.22	0.21	0.98	0.43	0.68	>5.0	>5.0
Conductivity	µS/cm	64.6	43.2	58.9	79.5	67.8	62.1	89.3	39.7	45.4	56.3	1000	500
Total hardness ($CaCO_3$)	mg/L	19.2	18.0	18.0	36.2	32.4	21.3	34.2	34.2	24.2	28.1	150	500
Total dissolved solids	mg/L	38.76	25.92	35.34	47.70	40.68	37.26	53.58	23.82	27.24	33.78	500	1000
Iron	mg/L	0.24	0.17	0.28	0.21	0.14	0.52	0.30	0.26	0.24	0.19	0.3	0.3
Manganese	mg/L	0.05	0.14	0.071	0.044	0.052	0.024	0.031	0.028	0.041	0.035	0.20	0.10
Zinc	mg/L	0.78	0.81	0.66	0.91	0.77	0.83	1.09	0.92	0.98	0.72	3.0	3.0
Nitrate	mg/L	2.08	3.12	2.40	3.30	5.60	2.16	3.66	2.81	3.45	4.11	50	50
Ammonium (NH_4)	mg/L	0.13	0.15	0.17	0.11	0.20	0.25	0.14	0.08	0.22	0.19	-	0.50
Chloride	mg/L	3.56	2.45	2.11	4.70	3.81	4.71	3.22	4.11	3.88	4.12	250	250
Sodium	mg/L	1.09	2.01	1.17	0.91	1.31	3.76	2.78	2.99	2.13	1.98	200	200
Potassium	mg/L	3.81	2.22	2.17	3.09	2.78	2.54	2.11	3.85	3.24	2.86	-	200

Note: NIS-Nigerian Industrial Standard, **BO_1**- Ekpowen, **BO_2**-Old market road, **BO_3** - Magistrate Road, **BO_4** – Ndayi playground, **BO_5**-Yenon, **BO_6** – Unebu Borehole, **BO_7** – Nkamkpo Health centre, BO_8 – Ikpakipit town hall $B0_9$ –Lewankom borehole, BO_{10} – Akugom borehole

Table 2 Summary of the result of physicochemical analysis of spring water sources in Ugep

Parameters	**Unit**	**SP_1**	**SP_2**	**SP_3**	**SP_4**	**SP_5**	**SP_6**	**SP_7**	**SP_8**	**SP_9**	**SP_{10}**	**NIS**	**WHO**
Appearance		Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear		clear
Temperature	° C	24.6	25.3	25.4	25.5	26.2	25.6	25.8	26.1	25.9	25.5	Ambient	20-30
Ph		7.11	7.29	7.26	6.83	7.50	7.10	7.89	7.45	7.31	7.52	6.5 – 8.5	6.5 – 8.5
Turbidity	NTU	0.34	0.62	0.48	0.49	0.68	0.41	1.97	0.56	0.69	0.71	>5.0	>5.0
Electrical Conductivity	µS/cm	62.1	67.3	98.1	78.8	55.9	60.3	42.6	65.3	57.4	69.2	1000	500
Total hardness ($CaCO_3$)	mg/L	17.4	17.1	17.6	18.2	17.1	17.2	21.4	18.4	18.6	17.9	150	500
Total dissolved solids	mg/L	37.26	40.38	58.86	47.28	33.54	36.18	25.56	39.18	34.44	41.52	500	1000
Iron	mg/L	0.22	0.15	0.19	0.25	0.29	0.34	0.18	0.23	0.17	0.22	0.3	0.30
Manganese	mg/L	0.024	0.07	0.025	0.031	0.052	0.043	0.026	0.041	0.065	0.082	0.20	0.10
Zinc	mg/L	0.69	0.72	0.81	0.77	0.71	0.63	0.66	0.78	0.69	0.74	3.0	3.0
Nitrate	mg/L	2.16	2.17	4.30	2.20	2.16	6.30	3.50	3.90	4.20	4.80	50	50
Ammonium (NH_4)	mg/L	0.35	0.13	0.15	0.14	0.15	0.17	0.19	0.24	0.18	0.26	-	0.50
Chloride	mg/L	4.71	3.17	3.22	6.51	2.33	4.31	5.43	4.41	5.22	4.86	250	250
Sodium	mg/L	4.76	2.65	1.09	2.76	3.65	2.90	2.21	3.42	4.21	3.91	200	200
Potassium	mg/L	2.54	3.28	1.67	2.90	2.21	2.98	2.92	2.11	2.67	2.82	-	200

Note: **SP_1**–Okamawen, **SP_2**–Ubi Johnson spring, **SP_3** – Lesekpowetu, **SP_4** – Owetetewen, **SP_5** – Kiwel, **SP_6** –Onambelipol, SP_7 –Nma Oden, SP_8 – Lewewitu, SP_9 -Lonowei SP_{10} -Isukpa

Table 3 Result of bacteriological analysis of sampled borehole water (CFU/100ml) (Mean bacteria count) n = 10

Samples	**Total Heterotrophic Bacteria counts (x10^3)**	**Total Coliform counts**	**Faecal coliform counts**
BO_1	22	15	9
BO_2	39	14	0
BO_3	28	19	14
BO_4	16	10	0
BO_5	47	27	7
BO_6	35	21	6
BO_7	20	11	0
BO_8	33	12	13
BO_9	32	16	11
BO_{10}	27	14	12
Mean	29.900	15.900	7.200
SD	9.315	5.174	5.554
S_{EM}	2.946	1.636	1.756

Note; SD – Standard Deviation S_{EM} – Standard Error of mean

Table 4 Result of bacteriological analysis of sampled spring water (CFU/100ml) (Mean bacteria count) n = 10

Samples	**Total Heterotrophic Bacteria counts (x10^3)**	**Total Coliform counts**	**Faecal coliform counts**
Sp_1	38	11	9
Sp_2	46	17	10
Sp_3	17	10	14
Sp_4	34	16	11
Sp_5	23	14	10
Sp_6	31	12	9

Sp_7	32	21	17
SP_8	41	19	15
SP_9	39	20	13
SP_{10}	40	18	12
Mean	34.100	15.800	12.000
SD	8.774	3.882	2.708
S_{EM}	2.775	1.227	0.856

Note; SD – Standard Deviation S_{EM} – Standard Error of mean

Table 5 Summary of morphological and biochemical characteristics of bacteria isolated from drinking water sources

Morphological characteristics	**Gram Reaction/ shape**	**Catalase**	**Coagulase**	**Motility**	**Indole**	**Methyl Red**	**Voges Proskauer**	**Citrate**	**Oxidase**	**Lactose**	**Glucose**	**Sucrose**	**Probable Organism**
Small pink, creamy	+Cocci	+	+	-	-	+	+	+	-	+	+	+	*Staphylococcus aureus*
Pink, round, entire, convex	-Rod	+	NA	-	-	+	-	+	-	+	+	+	*Klebsiella spp.*
Purple, irregular, and flat	-Rod	+	NA	+	-	-	+	-	-	+	+	-	*Enterobacter spp.*
Creamy, Translucent and moist	-Rod	+	NA	+	-	+	-	+	+	-	+	-	*Pseudomonas aeruginosa*
Smooth round and convex	-Rod	+	NT	+	+	+	+	+	+		+	+	*Vibrio cholerae*
Wrinkled, tiny and magenta	+Cocci	-	-	-	-	-	+	+	-	+	+	+	*Enterococcus spp.*
Creamy, Pink, irregular, raised	-Rod	+	NA	+	-	+	-	+	-	+	+	+	*Escherichia coli*

Convex, entire, opaque	+Rod	-	NA	-	-	-	-	+	-	+	+	+	*Lactobacillus spp.*
Moist, mucoid and shiny light pink	-Rod	+	NA	-	-	+	-	-	-	-	+	-	*Shigella spp.*
Irregular and colourless	-Rod	+	NA	+	+	+	-	+	-	-	+	+	*Proteus spp.*

Note; + Positive, -Negative, NT – Not Applicable,

Table 6 Pearson's product moment correlation coefficient (r) matrixes of bacteriological and physicochemical parameters in sampled drinking water sources

Parameter	**THB**	**TC**	**FC**	**Temp**	**pH**	**Tur.**	**TDS**	**Fe**	**Mn**	**Zn**	**NO_3**	**NH_4**	**Na**	**K**
THB	1.000													
TC	0.643^{**}	1.000												
FC	0.188	0.298	1.000											
Temp	0.343	0.269	0.404	1.000										
pH	0.084	0.127	0.363	-0.119	1.000									
Tur.	0.045	0.247	0.697^{**}	0.301	0.540^{*}	1.000								
TDS	-0.376	-0.259	-0.237	-0.168	-0.640^{**}	-0.446^{*}	1.000							
Fe	-0.219	-0.054	-0.164	-0.237	-0.165	-0.207	0.013	1.000						
Mn	0.338	0.138	-0.301	0.180	0.287	-0.143	-0.270	-0.331	1.000					
Zn	-0.333	-0.317	-0.520^{*}	-0.543^{*}	-0.049	-0.398	0.240	0.161	-0.163	1.000				
NO_3	0.133	0.152	0.052	0.156	-0.023	-0.051	0.129	-0.207	0.037	-0.106	1.000			
NH_4	0.419	0.273	0.181	-0.101	-0.040	-0.072	-0.082	0.136	-0.122	-0.280	0.091	1.000		
Na	0.434	0.036	0.149	0.239	-0.107	0.021	-0.194	0.289	-0.096	-0.180	-0.091	0.548^{*}	1.000	
K	0.125	0.021	0.062	0.016	-0.032	0.137	-0.401	-0.079	-0.117	0.060	-0.119	-0.281	-0.098	1.000

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed), THB – Total Heterotrophic Bacteria Count, TC – Total coliform, FC – Faecal Coliform, Temp-Temperature, Tur.- Turbidity

For spring water samples, results obtained revealed that total heterotrophic bacteria count ranged from 1.7x10^3 cfu/100 ml to 4.6x10^3 cfu/100 ml for total heterotrophic count, 10cfu/100ml to 21cfu/100ml for total coliform and 9cfu/100ml to 17cfu/100 ml for faecal coliform (Table. 4). SP$_2$ had the highest value of total heterotrophic bacteria count and total coliform count while SP$_3$ had the least. Additionally, SP$_7$ had the highest value for faecal coliform while SP$_5$ had the least faecal coliform count. Result obtained further revealed that spring water had the highest bacterial count, and the bacterial load exceeded the WHO recommended standard of 100 cfu/100ml for THB, and 0 for total coliform and faecal coliform in all the spring water samples analysed in this study. Previous studies have reported several factors that promotes contamination of spring water sources in most sub-urban and rural communities which includes open defecation. Majority of the rural dwellers practice open defecation and this could be a source of faecal coliform contamination of the spring water sources. The result of the bacteriological analysis revealed the unsanitary condition of most drinking water sources. This finding is similar to that reported by Agbo *et al*. [18], Itah and Akpan [21] and Adegoke *et al.* [22].

The analyses of spring water shows that none of the sampled water sources was portable for drinking with the level of faecal and total coliforms observed from the study. While three out of the ten boreholes showed 0cfu/ml faecal coliform. This is a source of concern considering that borehole and spring water supply appears to be the most accessible sources of drinking water in the study area. The presence of faecal coliform suggests faecal contamination and the possible presence of pathogenic organisms that compromises the safety of the water sources [21, 23]. The result also agrees with the reports by Agbo *et al*. [18] that untreated spring water samples have a high faecal coliform and high total coliform bacterial load usually above the recommended standard (10 cfu/100 ml). Other factors that promotes faecal contamination of water sources includes the proximity of boreholes to septic tanks. Taken together, the presence of coliform bacteria in the groundwater suggests the existence of pathogenic organisms which can lead to intestinal disorders, cholera, hepatitis A, etc. [24].

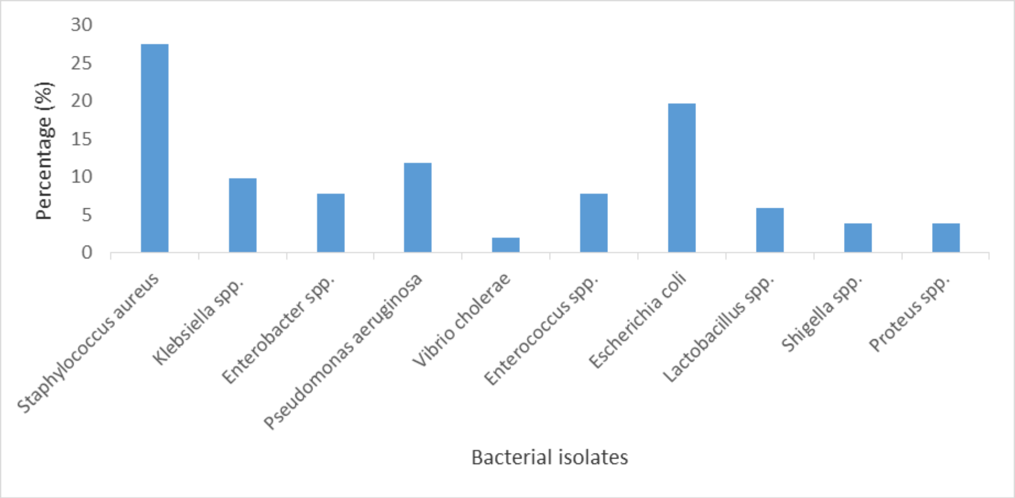

Figure 1 Percentage incidence of bacterial isolates from sampled water sources

Based on the morphological and biochemical characteristics of bacteria isolated from the water sources as presented in Table 5. The following bacteria were isolated; *Proteus spp, S. aureus, Pseudomonas spp., Escherichia coli, Vibrio cholerae, Corynebacterium diptheriae, Enterobacter spp., Lactobacillus spp., Enterococcus spp.* and *Shigella spp.* The percentage occurrence of isolated bacteria in the present study are: *Staphylococcus aureus* (27.5%), *E. coli (*19.6%), *P. aeruginosa* (11.8%), *Klebsiella spp.* (9.8%), *Enterobacter spp.* (7.8%), *Enterococcus spp*. (7.8%), *Lactobacillus spp*. (5.9%), *Proteus spp*. (3.9%), Shigella *spp.* (3.9%), and *Vibrio cholerae* (2.0%) as presented in Figure 1.

3.3. Correlation among bacteriological and physicochemical variables

Pearson's correlation statistics with 2-tailed significance was used to measure the strength and direction of the association between the detected faecal coliforms and selected physiochemical parameters in the sampled water sources. The results revealed that total contamination with faecal coliform in sampled water may have close relationship with the fraction of each corresponding parameter and among physicochemical parameters. The correlation analysis shows significantly strong positive correlation between THB and TC, FC and Tur, pH and Tur, and NH$_3$ and Na and significantly strong negative correlation between pH and TDS, Temp and Zn, and Fe and Zn, while Turbidity and TDS shows moderate negative correlation (Table 6).

This correlation between total heterotrophic bacteria counts and total coliforms suggests the likelihood of observed contamination from common environmental pollution sources. The physiochemical properties of water may stimulate the density of bacteria and other disease-causing organisms, which are usually influenced by multiple factors. There was strong positive correlation between THB and faecal coliforms (r = 0.643**), FC and Turbidity (r = 0.697**), pH and turbidity (r = 0.540*), and NH_3 and Zn (r = 0.548*) and strong negative correlation between pH and TDS (r = -0.640**), Turbidity and TDS (r = -0.446*), Temperature and Zn (r = -0.520*) and moderate negative correlation between Turbidity and TDS (r = -0.446*) strongly implicating a likely common source of organic contamination.

Therefore, this result supports that turbidity may play an important role in determining the environmental expressions of faecal coliforms and other disease-causing organisms in an aquatic environment. Other physicochemical parameters may also have influence on the bacteriological contamination of ground water sources.

4. Conclusion

The concentrations of physiochemical parameters including pH, temperature, turbidity, colour, TDS, Electrical conductivity, and total hardness were within the acceptable and safe limits except in few locations, whereas faecal contamination in selected drinking water sources exceeded the standard desirable limits for drinking water quality recommended by WHO and NIS, except in few sampled boreholes. Correlation analysis revealed a significantly strong positive correlation between faecal coliform and selected physiochemical variables. There is a need to enlighten the general public on the importance of maintaining hygienic standards especially around water sources routinely consumed. Additionally, relevant government institutions should frequently monitor public water source to ascertain its quality. Environmental Protection Authority and other relevant institutions should routinely monitor drinking water quality, and increase awareness among residents regarding potential health risks for various exposures to faecal and other contamination. Furthermore, the study also suggests provision of adequate and suitable sanitation facilities and continuous health and hygiene education to rural and urban communities.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there was no conflict of interest regarding the publication of this manuscript.

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