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Assessment Of Water Quality And Distribution Of Vibrio Species From Water Samples From Ogbia And Yenagoa Areas Of Bayelsa State.

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Abstract
This study entails the assessment of physicochemical, bacteriological properties of underground and surface water from different localities in Ogbia and Yenagoa areas of Bayelsa State, Nigeria. The study further investigated the distribution of Vibrio species from these waterbodies and the statistical correlation between physicochemical and bacteriological metrics. A total of 126 underground and 126 surface water samples were collected from different localities in Ogbia and Yenagoa. Physicochemical and bacteriological assessments were determined. All samples were subjected to Vibrio species count, followed by species characterisation using an array of biochemical tests. Isolated Vibrio species were subjected to antibiotic sensitivity tests. The physicochemical parameters recorded for these water quality assessment metrics exceeded the World Health Organisation (WHO) acceptable limit. Out of the 63 samples, 36 (57.14%) were contaminated with Vibrio spp from underground water in Ogbia and 44 (69.44%) from Yenagoa. The distribution of strains of Vibrio spp from different localities in Ogbia and Yenagoa showed V. cholerae having the prevalence of 40.6%. All isolated Vibrio species were susceptible to ciprofloxacin, ofloxacin, and pefloxacin. The correlation between some physicochemical parameters, total heterotrophic, total coliform, and total Vibrio counts was high, especially in surface water. This could justify the proliferation and persistence of these bacteria in the environment. It is recommended that enlightenment on the potential public health risks of open defecation and provision of water treatment facilities in these communities will limit incidence of cholera-like infections and gastroenteritis within these localities.

Keywords: *Water quality, Vibrio species, Vibrio cholerae, Bayelsa State*

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I. Introduction

The quality of ground and surface waters is dependent on several factors, which could be seasonal variations and composition of the soils (Thivya *et al*., 2014; Vaishali & Punita, 2013). Human activities could be said to be the most prominent influencing factor on overall quality. Human activities could be attributed to industrial and domestic discharge of waste into the water bodies. These discharges affect the physical, chemical, and microbial qualities of the aquatic environment (Aladese & Ariyo, 2017).

The resultant effects of these discharges on the quality of waterbodies could give rise to an increase in the number of potentially pathogenic microorganisms, which could lead to an upsurge of possible pockets of epidemics within settlements exposed to these waters, especially areas with an abundance of surface waters like those found in creek communities in Bayelsa State in the Niger-Delta region.

One of these potentially pathogenic bacterial species with public health relevance are the *Vibrio* species. The genus *Vibrio* is predominantly associated with waterbodies and seafood. They have been implicated in outbreaks of waterborne diarrhoea diseases (Hutin *et al*., 2003; Idika *et al*., 2000). The most prominent *Vibrio* water transmissible disease is known as cholera (Idika *et al*., 2000; Aladese & Pondei, 2021). Cholera is caused by a bacterium known as a *V.cholerae*, which is a free-living bacterium with potential lysogenic conversion by filamentous bacteriophage designated as CTX plage (Faruque *et al*., 2003; Waldor & Mekalanos, 1996). Other *Vibrios* of public health concerns include *V.parahaemolyticus*, *V.vulnificus*, *V.fluvialis*, *V.mimicus*, *V.alginolyticus,* among others (Oramadike & Ogunbanwo, 2015; Makino *et al*., 2003; Elliott *et al*., 1998). Seafoods have been implicated as major reservoirs of these non-cholera *Vibrio* spp (Aladese *et al*., 2014; Elhadi *et al*., 2004).

This is aimed at the assessment of physicochemical and bacteriological quality of fresh and brackish water samples from Ogbia and Yenagoa areas of Bayelsa State, Nigeria. In addition, the distribution of potentially

pathogenic *Vibrio* spp from these water samples. This will provide insights into the possibility of exposure to cholera and cholera-like *Vibrio* infections.

II. Materials And Methods

Overview of Bayelsa State

Bayelsa State is a coastal state in southern Nigeria, known for its rich oil reserves, riverine landscape, and cultural heritage. It was created in 1996 from part of Rivers State. it is situated South-South geopolitical zone of Nigeria, in the heart of the Niger Delta. Bayelsa is characterised by Riverine and estuarine landscapes, dotted with creeks, mangroves, and coastal settlements. The inhabitants are predominantly Ijaw people. English remains the spoken language, but some dialects such Izon, Nembe, Ogbia, Epie-Atissa are spoken among the various communities. Bayelsa has eight local government administration areas with Yenagoa as its administrative capital. Fishing is the dominant occupation among the inhabitants of the rural areas; this is a result of its extensive riverine and coastal environment. Locals also engage in fish processing, trading, subsistence farming, and palm oil production.

Study areas

This study was conducted in Ogbia ($4^0$39N; $6^0$16E) and Yenagoa ($4^0$55; $6^0$15E) Local Government Areas (L.G.As). The study areas lie in the high rainfall belt of South-south Nigeria (Figure 1a). These areas exhibit a short dry season from November-March and an extensive rainy season from April-October. The short season of harmattan which is characterised by high haze and dusty winds occurs during December-January. The following settlements were selected in Ogbia LGA; Agbura, Elebele, Emeyal, Ogbia town, Onuegbum, Otuaba, Otuogori, Otuokpoti and Otuoke. In the same vein, the following localities namely, Agudama, Agudama, Biogbolo, Edepie, Okutukutu, Onopa, Ovom, and Swali were selected for samplings across Yenagoa.

Sample collection

A total of 126 freshwater samples were collected from different localities in Ogbia (63 samples) and Yenagoa (63 samples). Similarly, 126 brackish water samples were collected from these different localities in Ogbia (63 samples) and Yenagoa (63 samples). Samples were collected into sterile plastic containers and transferred to the laboratory for immediate analysis. In addition, 300ml specialized opaque bottles were used to collect samples for dissolved oxygen analysis.

Physico chemical analysis

The physico-chemical parameters of water samples investigated in this study were pH, temperature, salinity, conductivity, total dissolved solids, turbidity, total alkalinity and dissolved oxygen. Parameters of water samples in this study were determined according to methods described by American Public Health Association (APHA) (2023) and Ademoroti (1997). The parameters were all measured in mg/L except otherwise stated. The physico-chemical results obtained were compared with World Health Organisation (W.H.O) standards for acceptable limits.

Enumeration of total heterotrophic and total coliform counts of samples

Each water sample was inoculated in triplicates of 0.1% peptone water. Serial dilution was carried out up to a dilution factor of 10^{-6}. The pour plates method was carried out using 10^{-2}, 10^{-3} and 10^{-4} on nutrient and MacConkey agars (Oxoid, England) for total heterotrophic count and coliform counts, respectively. After incubation at 37 ^{0}C for 24 hrs, the colonies were counted and documented.

Enrichment and Enumeration of total *Vibrio* spp counts

Each water sample was inoculated in triplicate of 1% alkaline peptone water fortified with 3% sodium chloride (NaCl). After incubation for 18 hrs at 37^0 C, serial dilution was carried out up to dilution factor of 10^{-6}. This was followed by pour plate using 10^{-2}, 10^{-3} and 10^{-4} on Thiosulphate Citrate Bile salts Sucrose (TCBS) agar (Oxoid, England) and incubated at 37^0 C for 24 hrs, the colonies were counted and documented.

Isolation and identification *Vibrio* spp

After enrichment procedure, the enriched samples from 1% alkaline peptone water fortified with 3% sodium chloride were inoculated on Thiosulphate Citrate Bile salts Sucrose (TCBS) agar (Oxoid, England) and incubated at 37^0 C for 24 hrs. Suspected greenish and yellowish colonies were re-plated on freshly prepared Mueller-Hinton agar and cultures were subjected to Gram's reactions, oxidase test, motility test, lactose fermentation, string test, triple sugar iron agar, salt tolerance test and reactions to lysine decarboxylase, arginine dihydrolase, ornithine decarboxylase.

Antibiotics sensitivity tests

Isolated strains of *Vibrio* spp were inoculated into Luria-Bertani broth for 16-24 hrs. The inoculum was standardised by measuring the turbidity of growth, which was allowed to correspond with the values obtained from 0.5 McFarland turbidity standards. McFarland turbidity standards were prepared from the addition of 1 % sulphuric acid and 1.175 % barium chloride to obtain solutions with specific optical densities. The 0.5 McFarland turbidity standards provide an optical density comparable to the density of a bacterial suspension of 1.5 x 10^5 colony-forming units (cfu)/ml. Fresh Mueller-Hinton agar plates were inoculated through the spread-plate method with inoculum from the 1.5 x 10^5 colony-forming units (cfu)/ml. This was followed by antimicrobial susceptibility testing of the isolates using multi- disks diffusion method. The following antibiotics were tested for its efficacy against the isolated strains; augmentin (25 µg), amoxillin (25 µg), tetracycline (50 µg), ofloxacin (5 µg), cotrimozazole (25 µg), ciprofloxacin (10µg) and pefloxacin (5 µg). After the insertion of the disks, incubation followed at 35 ^{0}C for 18-24 hrs. The zones of inhibition were measured in millimetres, and susceptibility and resistance of isolates were determined through comparisons with the standards instituted by the Clinical Laboratory Standard Institute (2011).

Statistical evaluation

All statistical calculations, tabular and pictorial representations of data, were done using the Microsoft Excel version 2016. Analysis of variance (ANOVA) and post-hoc analysis using Duncan's Multiple Range test were determined using SPSS version 23.0. Statistical comparison of the values of strains with physico-chemical parameters using Pearson's correlation was determined using SPSS version 23.0.

III. Result

The examination of the water quality of freshwater samples showed all the physicochemical parameters, with the exception of turbidity (NTU), falling within the World Health Organisation (WHO) acceptable limit for freshwater samples from localities in Ogbia (Table 1) and Yenagoa (Table 2). The assessment of water quality of brackish waters in the different settlements in Ogbia using physicochemical indicators showed salinity, conductivity, dissolved solids, turbidity, and total alkalinity exceeding the WHO environmental limit of tolerance (Table 3). A similar trend was observed among the physicochemical indicators of water quality assessment of brackish water from different localities in Yenagoa (Table 4).

All the examined underground water samples of both localities were contaminated with bacterial loads beyond the acceptable limit of the WHO. Out of the 63 samples, 36 (57.14%) were contaminated with *Vibrio* spp from underground water in Ogbia and 44 (69.44%) from Yenagoa (Table 5). In Table 6, *Vibrio* spp recovered from 55 (87.30%) surface waters in Ogbia, while all (100%) examined surface waters from Yenagoa were contaminated with *Vibrio* species (Table 6)

The assessment of water quality through total heterotrophic count in fresh and brackish water showed high mean values of bacteria load in brackish water (Figure 1). Statistical comparison of the mean values of fresh and brackish water samples using Student's t-test showed a significant difference ($P<0.05$). Figure 2 shows the average values of the total coliform count of fresh and brackish water samples. The mean values of brackish water samples were higher with statistical significance ($P<0.05$). The sanitary examination of water quality using total *Vibrio* spp count showed higher average values in brackish waters with statistically significant difference ($P<0.05$) when compared to the values observed in freshwater samples (Figure 3).

The distribution of strains of *Vibrio* spp from different localities in Ogbia and Yenagoa showed *V.cholerae* having the prevalence of 40.6%. This was followed by *V.parahaemolyticus* and *V.vulnificus* with 27.8% and 22.8% respectively (Table 7). The antibiotic susceptibility of strains showed ciprofloxacin, ofloxacin, and pefloxacin as the most effective antibiotics, with total (100%) susceptibility of strains (Table 8).

The statistical relationship of bacteria load and physicochemical indices of water quality assessment using Pearson's correlation in fresh waters showed high correlation coefficients among total heterotrophic counts, total coliform counts, and total *Vibrio* counts (Table 9). In addition, a high coefficient of correlation is also observed in values of conductivity and salinity (0.997), and conductivity and dissolved solids (0.938).

In Table 10, the coefficients of Pearson's correlation revealed a high relationship in the values of total heterotrophic counts, total coliform counts and total *Vibrio* counts. It was observed that the pH showed high correlation with mean values of total heterotrophic counts (0.787), total coliform counts (0.846), and total *Vibrio* counts (0.763) with statistical significance ($P<0.01$). Salinity of brackish waters also exhibited statistical significance ($P<0.01$) in correlation with values of total heterotrophic counts (0.521), total coliform counts (0.656), total *Vibrio* counts (0.604), pH (0.896), conductivity (0.774), Dissolved solids (0.783) and Turbidity (0.732).

Table 1. Physicochemical parameters of underground samples from localities in Ogbia region

	Agbura	Otuokpoti	Otuogori	WHO limits
pH	6.87±0.02	6.86±0.02	6.90±0.02	6.5-8.5
Temp	30.70±0.20	30.90±0.10	30.80±0.10	Unspecified
Salinity	33.96±0.20	34.32±0.41	33.84±0.41	100mg/L
Conductivity	10.42±0.61	10.61±0.62	11.32±0.61	1000 µS/cm
TDS	7.34±0.53	7.44±0.59	7.78±0.81	500mg/L
Turbidity	6.87±0.56	7.37±0.57	7.28±0.57	5.0 NTU
Total Alkalinity	65.07±3.52	67.10±6.10	68.53±6.55	100mg/L
Dissolved oxygen	5.23±0.15	5.48±0.20	5.95±0.15	Unspecified
	Ogbia	Emeyal	Elebele	
pH	6.87±0.02	6.77±0.13	6.83±0.02	6.5-8.5
Temp	30.10±0.10	30.13±0.12	30.10±0.10	Unspecified
Salinity	34.20±0.54	34.20±0.54	23.19±0.54	100mg/L
Conductivity	9.34±0.60	9.20±0.75	8.95±0.61	1000 µS/cm
TDS	6.83±0.46	6.71±0.59	6.77±0.57	500mg/L
Turbidity	7.08±0.58	7.92±0.61	8.99±0.66	5.0 NTU
Total Alkalinity	68.83±3.00	58.97±3.52	54.90±6.10	100mg/L
Dissolved oxygen	6.75±0.15	7.53±0.23	7.78±0.20	Unspecified
	Otuoke	Otuaba	Onuegbum	
pH	6.83±0.02	6.87±0.01	6.84±0.02	6.5-8.5
Temp	30.03±0.15	30.20±0.10	30.20±0.10	Unspecified
Salinity	33.73±0.71	34.08±0.71`	34.08±0.71	100mg/L
Conductivity	10.36±0.63	10.63±0.62	10.38±0.64	1000 µS/cm
TDS	7.36±0.46	6.80±1.46	6.81±1.43	500mg/L
Turbidity	9.38±0.56	9.09±0.57	9.58±0.56	5.0 NTU
Total Alkalinity	44.73±3.52	38.63±3.52	40.67±3.52	100mg/L
Dissolved oxygen	7.60±0.28	7.42±0.30	6.87±0.20	Unspecified

Table 2. Physicochemical parameters of underground samples from localities in Yenagoa region

	Amarata	Opolo	Biogbolo	WHO limits
pH	6.94±0.02	6.90±0.03	6.90±0.02	6.5-8.5
Temp	30.23±0.12	30.40±0.10	30.20±0.10	Unspecified
Salinity	34.08±0.71	34.32±0.41	34.08±0.71	100mg/L
Conductivity	8.26±0.04	8.33±0.03	8.35±0.05	1000 µS/cm
TDS	6.00±0.02	6.06±0.02	6.09±0.03	500mg/L
Turbidity	6.77±0.43	6.67±0.54	6.49±0.44	5.0 NTU
Total Alkalinity	69.81±3.54	77.94±2.35	80.66±4.23	100mg/L
Dissolved oxygen	4.30±0.09	4.24±0.09	4.40±0.09	Unspecified
	Okutukutu	Agudama	Edepie	
pH	6.87±0.02	6.89±0.01	6.87±0.02	6.5-8.5
Temp	30.20±0.10	30.27±0.15	30.20±0.10	Unspecified
Salinity	34.08±0.71	34.79±0.71	34.67±0.74	100mg/L
Conductivity	8.64±0.05	8.46±0.06	8.39±0.06	1000 µS/cm
TDS	6.29±0.03	6.21±0.09	6.14±0.06	500mg/L
Turbidity	8.51±0.41	8.96±0.50	6.89±0.58	5.0 NTU
Total Alkalinity	75.51±3.54	63.71±3.11	57.61±3.11	100mg/L
Dissolved oxygen	4.61±0.09	5.32±0.11	6.67±0.11	Unspecified
	Swali	Onopa	Ovom	
pH	6.88±0.02	6.92±0.02	6.92±0.02	6.5-8.5
Temp	30.00±0.10	30.17±0.06	30.23±0.06	Unspecified
Salinity	34.55±0.20	34.32±0.41	34.79±0.71	100mg/L
Conductivity	8.39±0.05	8.32±0.10	8.29±0.05	1000 µS/cm
TDS	6.14±0.08	6.06±0.03	6.01±0.04	500mg/L
Turbidity	6.90±0.50	6.72±0.43	8.33±0.11	5.0 NTU
Total Alkalinity	52.19±3.11	49.48±1.17	52.19±3.11	100mg/L
Dissolved oxygen	7.42±0.11	6.86±0.09	7.31±0.09	Unspecified

Table 3. Physicochemical parameters of surface water samples from localities in Ogbia region

	Agbura	Otuokpoti	Otuogori	WHO limits
pH	7.08±0.03	7.12±0.03	7.13±0.03	6.5-8.5
Temp	30.97±0.06	31.07±0.12	31.13±0.15	Unspecified
Salinity	122.12±0.71	123.07±1.08	123.30±0.41	100mg/L
Conductivity	2078.33±51.76	2064.37±51.28	2040.64±50.79	1000 µS/cm
TDS	1508.18±35.42	1498.02±35.11	1480.12±35.81	500mg/L
Turbidity	11.21±0.15	11.19±0.20	11.73±0.55	5.0 NTU
Total Alkalinity	162.67±7.04	166.73±7.04	180.97±3.52	100mg/L
Dissolved oxygen	3.05±0.13	3.11±0.17	3.32±0.26	Unspecified
	Ogbia	Emeyal	Elebele	

pH	7.08±0.03	7.08±0.02	7.09±0.02	6.5-8.5
Temp	32.03±0.15	31.90±0.10	31.83±0.06	Unspecified
Salinity	123.54±0.71	124.25±0.71	125.20±0.82	100mg/L
Conductivity	2535.42±53.23	2918.47±54.72	3457.03±55.72	1000 µS/cm
TDS	1839.01±37.33	2115.45±40.35	2440.60±150.21	500mg/L
Turbidity	12.57±0.07	13.62±0.10	13.20±0.44	5.0 NTU
Total Alkalinity	174.87±3.52	187.07±3.52	168.77±3.52	100mg/L
Dissolved oxygen	4.30±0.10	4.44±0.16	3.47±0.15	Unspecified
	Otuoke	Otuaba	Onuegbum	
pH	7.31±0.04	7.30±0.02	7.28±0.03	6.5-8.5
Temp	31.70±0.10	31.77±0.15	31.67±0.15	Unspecified
Salinity	129.46±1.48	130.17±1.08	132.53±1.08	100mg/L
Conductivity	3743.13±57.73	3388.84±58.32	3622.52±56.80	1000 µS/cm
TDS	2713.75±41.89	2456.80±42.44	2624.16±44.45	500mg/L
Turbidity	12.98±0.55	12.74±0.47	12.40±0.42	5.0 NTU
Total Alkalinity	152.50±6.10	156.57±3.52	154.53±3.52	100mg/L
Dissolved oxygen	3.50±0.10	3.47±0.15	3.43±0.15	Unspecified

Table 4. Physicochemical parameters of surface water samples from localities in Yenagoa region

	Amarata	Opolo	Biogbolo	WHO limits
pH	7.19±0.02	7.20±0.02	7.16±0.01	6.5-8.5
Temp	31.07±0.21	30.90±0.10	30.83±0.25	Unspecified
Salinity	124.01±0.82	124.96±0.71	125.20±0.41	100mg/L
Conductivity	2125.41±120.11	2137.55±64.24	2157.22±96.40	1000 µS/cm
TDS	1540.92±87.08	1549.72±46.57	1563.95±	500mg/L
Turbidity	12.18±0.16	12.13±0.16	13.18±0.30	5.0 NTU
Total Alkalinity	211.47±7.04	215.53±3.52	211.47±3.52	100mg/L
Dissolved oxygen	3.13±0.12	3.17±0.15	3.33±0.25	Unspecified
	Okutukutu	Agudama	Edepie	
pH	7.35±0.02	7.35±0.02	7.36±0.01	6.5-8.5
Temp	31.40±0.50	30.27±0.25	30.40±0.10	Unspecified
Salinity	129.69±1.08	131.35±0.71	132.06±0.71	100mg/L
Conductivity	2479.80±100.10	3377.81±146.29	3842.56±164.00	1000 µS/cm
TDS	1797.76±72.42	2442.14±97.05	2785.86±118.90	500mg/L
Turbidity	14.34±0.50	14.88±0.64	16.11±0.87	5.0 NTU
Total Alkalinity	225.70±0.01	219.60±0.01	205.37±3.52	100mg/L
Dissolved oxygen	4.07±0.15	4.27±0.12	4.47±0.15	Unspecified
	Swali	Onopa	Ovom	
pH	7.33±0.03	7.36±0.02	7.36±0.01	6.5-8.5
Temp	30.80±0.10	30.70±0.10	30.77±0.06	Unspecified
Salinity	135.14±1.08	136.08±1.08	137.50±0.82	100mg/L
Conductivity	3600.44±220.96	3429.42±169.56	3444.76±119.60	1000 µS/cm
TDS	2610.21±160.25	2486.22±122.78	2497.45±86.71	500mg/L
Turbidity	15.38±	14.78±0.98	14.06±0.20	5.0 NTU
Total Alkalinity	205.37±	203.33±3.52	223.67±3.52	100mg/L
Dissolved oxygen	4.60±0.20	4.40±0.20	4.30±0.36	Unspecified

Table 5. Prevalence of heterotrophic bacteria, coliform, and *Vibrio* spp from Underground waters in Ogbia and Yenagoa areas of Bayelsa

Ogbia		
	Number positive for contamination	Total number examined
Total heterotrophic count (THC)	63 (100.00)	63
Total Coliform Count (TCC)	46 (73.02)	63
Total *Vibrio* spp Count (TVC)	36 (57.14)	63
Yenagoa		
	Number positive for contamination	Total number examined
Total heterotrophic count (THC)	63 (100.00)	63
Total Coliform Count (TCC)	61 (96.83)	63
Total *Vibrio* spp Count (TVC)	44 (69.84)	63

** Figures in parentheses are the percentages of the number of contaminations to the corresponding total number examined*

**Colony counts of 100 and above of CFU/100ml are considered positive contamination for THC; *Colony counts of 10 and above of CFU/100ml are considered positive contamination for TCC;*
**Colony counts of 01 and above of CFU/100ml are considered positive contamination for TVC*

Table 6. Prevalence of heterotrophic bacteria, coliform, and *Vibrio* spp from Surface waters in Ogbia and Yenagoa areas of Bayelsa

Ogbia		
	Number positive for contamination	Total number examined
Total heterotrophic count (THC)	63 (100.00)	63
Total Coliform Count (TCC)	60 (95.24)	63
Total *Vibrio* spp Count (TVC)	55 (87.30)	63
Yenagoa		
	Number positive for contamination	Total number examined
Total heterotrophic count (THC)	63 (100.00)	63
Total Coliform Count (TCC)	63 (100.00)	63
Total *Vibrio* spp Count (TVC)	63 (100.00)	63

** Figures in parentheses are the percentages of the number of contaminations to the corresponding total number examined*

**Colony counts of 100 and above of CFU/100ml are considered positive contamination for THC; *Colony counts of 10 and above of CFU/100ml are considered positive contamination for TCC;*
**Colony counts of 01 and above of CFU/100ml are considered positive contamination for TV*

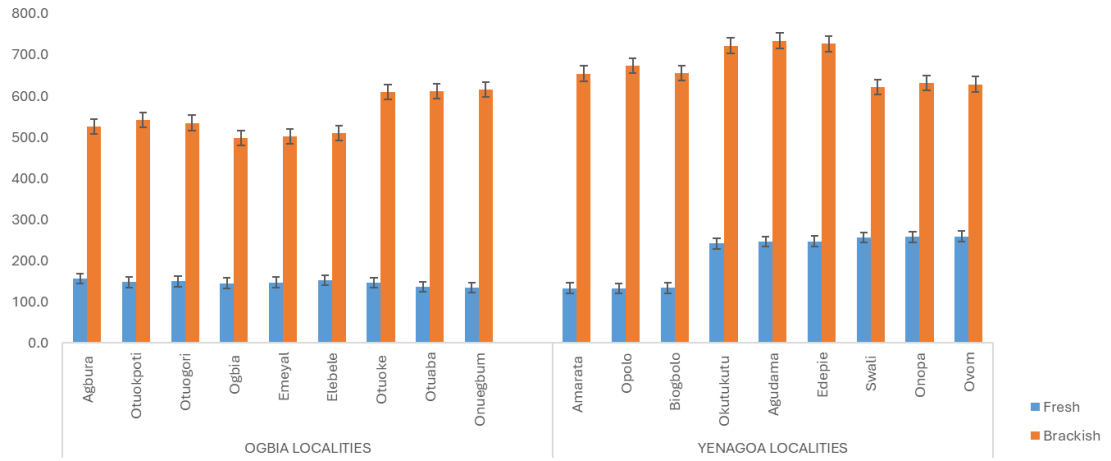

Figure 1. Total heterotrophic count of Fresh and brackish water samples from selected localities in Ogbia and Yenagoa.

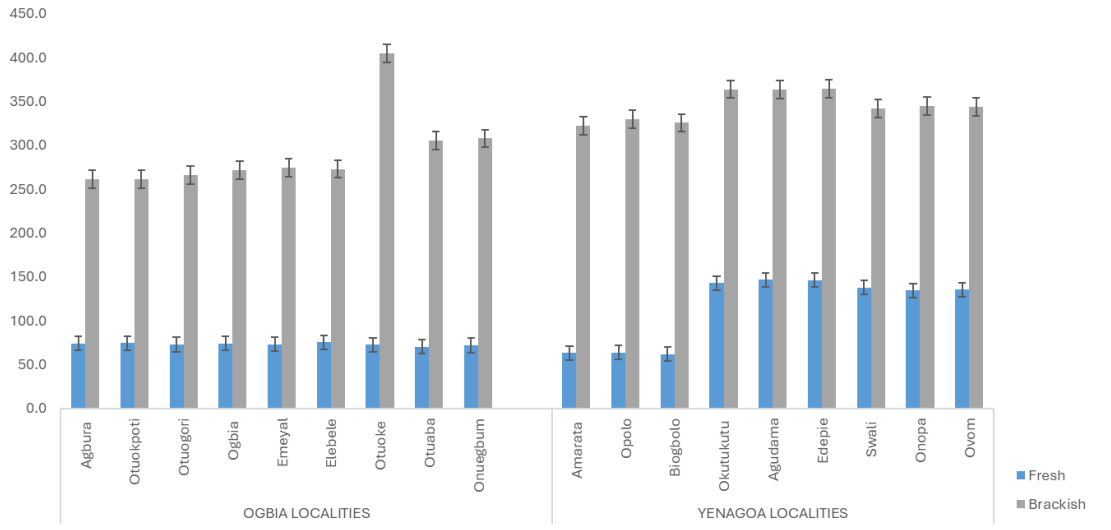

Figure 2. Total coliform count of Fresh and brackish water samples from selected localities from Ogbia and Yenagoa

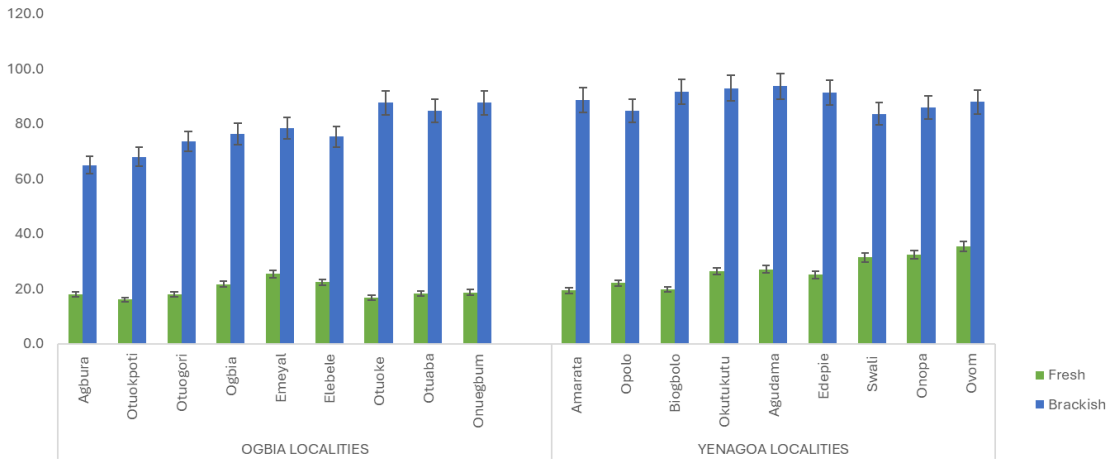

Figure 3. Total *Vibrio* spp count of Fresh and brackish water samples from selected localities from Ogbia and Yenagoa

Table 7. Distribution of potentially pathogenic *Vibrio* spp from selected localities in Ogbia and Yenagoa.

	Ogbia region			Yenagoa region			
	Agbura	Ogbia	Otuoke	Amarata	Okutukutu	Swali	Total
V. parahaemolyticus	7	8	8	8	9	10	50 (27.8)
V. vulnificus	5	6	8	6	9	7	41 (22.8)
V. mimicus	1	2	3	1	3	2	12 (6.7)
V. cholerae	8	10	13	12	18	12	73 (40.6)
V. alginolyticus	1	0	0	0	0	1	2 (1.1)
V. metschnikovii	1	0	0	0	0	1	2 (1.1)
Total	23 (12.8)	26 (14.4)	32 (17.8)	27 (15.0)	39 (21.7)	33 (18.3)	180 (100)

Table 8. The antibiotic susceptibility pattern of *Vibrio* spp

	V. parahaemolyticus	*V. vulnificus*	*V. mimicus*	*V. cholerae*	*V. alginolyticus*	*V. metschnikovii*	Total number of susceptible strains
Amoxicillin	12	11	3	18	1	2	47 (26.1%)
Augmentin	26	20	5	35	1	2	89 (49.4%)
Cotrimoxazole	36	28	7	52	1	2	126 (70.0%)
Tetracycline	46	37	10	68	2	2	165 (91.7%)
Pefloxacin	50	41	12	73	2	2	180 (100%)
Ofloxacin	50	41	12	73	2	2	180 (100%)
Ciprofloxacin	50	41	12	73	2	2	180 (100%)

Table 9. Correlation of microbial and physicochemical indices of water quality in underground water (Freshwater)

		THC	TCC	TVC	pH	Temp	Salinity	Cond	DS	Turbidity	Alkalinity	DO
THC	Pearson Correlation	1	.985**	.857**	.289	.095	.203	-.532*	-.506*	-.041	-.147	.165
	Sig. (2-tailed)		.000	.000	.244	.708	.418	.023	.032	.873	.561	.512
	N	18	18	18	18	18	18	18	18	18	18	18
TCC	Pearson Correlation	.985**	1	.800**	.235	.133	.216	-.512*	-.498*	.030	-.136	.134
	Sig. (2-tailed)	.000		.000	.347	.600	.390	.030	.035	.906	.590	.595
	N	18	18	18	18	18	18	18	18	18	18	18
TVC	Pearson Correlation	.857**	.800**	1	.248	.196	.112	-.696**	-.673**	-.093	-.139	.261

	Sig. (2-tailed)	.000	.000		.321	.437	.659	.001	.002	.714	.582	.296
	N	18	18	18	18	18	18	18	18	18	18	18
pH	Pearson Correlation	.289	.235	.248	1	.036	.300	-.358	-.436	-.473*	.305	-.507*
	Sig. (2-tailed)	.244	.347	.321		.888	.226	.144	.070	.048	.219	.032
	N	18	18	18	18	18	18	18	18	18	18	18
Temp	Pearson Correlation	.095	.133	.196	.036	1	-.023	-.248	-.293	.196	-.073	.170
	Sig. (2-tailed)	.708	.600	.437	.888		.928	.322	.239	.435	.772	.501
	N	18	18	18	18	18	18	18	18	18	18	18
Salinity	Pearson Correlation	.203	.216	.112	.300	-.023	1	.001	-.143	-.293	.103	-.295
	Sig. (2-tailed)	.418	.390	.659	.226	.928		.997	.571	.238	.683	.234
	N	18	18	18	18	18	18	18	18	18	18	18
Cond	Pearson Correlation	-.532*	-.512*	-.696**	-.358	-.248	.001	1	.938**	.328	-.285	.207
	Sig. (2-tailed)	.023	.030	.001	.144	.322	.997		.000	.184	.251	.410
	N	18	18	18	18	18	18	18	18	18	18	18
TDS	Pearson Correlation	-.506*	-.498*	-.673**	-.436	-.293	-.143	.938**	1	.243	-.135	.204
	Sig. (2-tailed)	.032	.035	.002	.070	.239	.571	.000		.332	.593	.416
	N	18	18	18	18	18	18	18	18	18	18	18
Turbidity	Pearson Correlation	-.041	.030	-.093	-.473*	.196	-.293	.328	.243	1	-.598**	.462
	Sig. (2-tailed)	.873	.906	.714	.048	.435	.238	.184	.332		.009	.053
	N	18	18	18	18	18	18	18	18	18	18	18
Alkalinity	Pearson Correlation	-.147	-.136	-.139	.305	-.073	.103	-.285	-.135	-.598**	1	-.825**
	Sig. (2-tailed)	.561	.590	.582	.219	.772	.683	.251	.593	.009		.000
	N	18	18	18	18	18	18	18	18	18	18	18
DO	Pearson Correlation	.165	.134	.261	-.507*	.170	-.295	.207	.204	.462	-.825**	1
	Sig. (2-tailed)	.512	.595	.296	.032	.501	.234	.410	.416	.053	.000	
	N	18	18	18	18	18	18	18	18	18	18	18
**. Correlation is significant at the 0.01 level (2-tailed).												
*. Correlation is significant at the 0.05 level (2-tailed).												

THC: Total heterotrophic count; TCC: Total coliform count; TVC: Total *Vibrio* count; Temp: Temperature. Cond: Conductivity, DS: D.O: Dissolved solids; Dissolved oxygen

Table 10. Correlation of microbial and physicochemical indices of water quality in surface water (brackish water)

		THC	TCC	TVC	pH	Temp	Salinity	Cond	DS	Turbidity	Alkalinity	D.O
THC	Pearson Correlation	1	.806**	.857**	.787**	-.634**	.521*	.235	.245	.573*	.663**	.215
	Sig. (2-tailed)		.000	.000	.000	.005	.027	.348	.327	.013	.003	.391
	N	18	18	18	18	18	18	18	18	18	18	18
TCC	Pearson Correlation	.806**	1	.836**	.846**	-.394	.656**	.518*	.529*	.646**	.450	.366
	Sig. (2-tailed)	.000		.000	.000	.106	.003	.028	.024	.004	.061	.135
	N	18	18	18	18	18	18	18	18	18	18	18

TVC	Pearson Correlation	.857**	.836**	1	.763**	-.315	.604**	.428	.436	.642**	.581*	.367
	Sig. (2-tailed)	.000	.000		.000	.203	.008	.076	.070	.004	.012	.134
	N	18	18	18	18	18	18	18	18	18	18	18
pH	Pearson Correlation	.787**	.846**	.763**	1	-.458	.896**	.642**	.655**	.704**	.410	.479*
	Sig. (2-tailed)	.000	.000	.000		.056	.000	.004	.003	.001	.091	.044
	N	18	18	18	18	18	18	18	18	18	18	18
Temp	Pearson Correlation	-.634**	-.394	-.315	-.458	1	-.358	.001	-.007	-.417	-.645**	-.172
	Sig. (2-tailed)	.005	.106	.203	.056		.144	.997	.977	.085	.004	.496
	N	18	18	18	18	18	18	18	18	18	18	18
Salinity	Pearson Correlation	.521*	.656**	.604**	.896**	-.358	1	.774**	.783**	.732**	.322	.623**
	Sig. (2-tailed)	.027	.003	.008	.000	.144		.000	.000	.001	.192	.006
	N	18	18	18	18	18	18	18	18	18	18	18
Cond	Pearson Correlation	.235	.518*	.428	.642**	.001	.774**	1	1.000**	.679**	-.107	.576*
	Sig. (2-tailed)	.348	.028	.076	.004	.997	.000		.000	.002	.671	.012
	N	18	18	18	18	18	18	18	18	18	18	18
TDS	Pearson Correlation	.245	.529*	.436	.655**	-.007	.783**	1.000**	1	.682**	-.103	.583*
	Sig. (2-tailed)	.327	.024	.070	.003	.977	.000	.000		.002	.685	.011
	N	18	18	18	18	18	18	18	18	18	18	18
Turbidity	Pearson Correlation	.573*	.646**	.642**	.704**	-.417	.732**	.679**	.682**	1	.550*	.852**
	Sig. (2-tailed)	.013	.004	.004	.001	.085	.001	.002	.002		.018	.000
	N	18	18	18	18	18	18	18	18	18	18	18
Alkalinity	Pearson Correlation	.663**	.450	.581*	.410	-.645**	.322	-.107	-.103	.550*	1	.422
	Sig. (2-tailed)	.003	.061	.012	.091	.004	.192	.671	.685	.018		.081
	N	18	18	18	18	18	18	18	18	18	18	18
D.O	Pearson Correlation	.215	.366	.367	.479*	-.172	.623**	.576*	.583*	.852**	.422	1
	Sig. (2-tailed)	.391	.135	.134	.044	.496	.006	.012	.011	.000	.081	
	N	18	18	18	18	18	18	18	18	18	18	18
**. Correlation is significant at the 0.01 level (2-tailed).												
*. Correlation is significant at the 0.05 level (2-tailed).												

THC: Total heterotrophic count; TCC: Total coliform count; TVC: Total *Vibrio* count; Temp: Temperature. Cond: Conductivity, DS: D.O: Dissolved solids; Dissolved oxygen

IV. Discussion

The physicochemical indices of freshwater quality assessment showed that turbidity exceeded the World Health Organisation's acceptable limit in both localities (Table 1, Table 2). These high turbidity values are indicative of potential public health risks that could be associated with the consumption of these waters. The physicochemical metrics exceeded the environmental tolerance limits in brackish water samples from different localities in Ogbia (Table 3) and Yenagoa (Table 4).

The values of total heterotrophic count for bacteriological quality assessment of fresh and brackish water (Figure 1) showed mean values exceeding 100 CFU/100 mL, which is the recommended acceptable limit. A statistical comparison revealed a significant difference in the average values of underground water and surface water between the two regions. Observation from this study from data from tables 5 and 6 showed that there is higher contamination in water samples from Yenagoa. This could be attributed to two reasons, one is that Ogbia has higher than Yenagoa in geographical depth and could less likely be prone to flooding and run-off water and secondly, Yenagoa, being political capital has a higher population density with significant increase in human and agricultural activities. Expectedly, the values of bacterial load were much higher in brackish (surface) water from the same locality. Similar trends were observed in total coliform count (Figure 2) and total *Vibrio* species count (Figure 3).

Our findings on both physicochemical and bacteriological quality assessment, exhibiting high turbidity, electrical conductivity, total dissolved solids (TDS), and total heterotrophic count, indicating pollution, agree with the report of Ajuzie et al. (2025). The high value of the total coliform count is indicative of pollution from human activities due to faecal contamination. High coliform contamination has been documented in studies of sold packaged water (Gamawa & Okpanachi, 2023) and locally brewed alcoholic beverages (Aladese *et al.,* 2013).

Bayelsa State, situated in the Niger Delta region of Nigeria, is characterised by its abundance of water bodies, including rivers, creeks, and wetlands. Communities in Ogbia and Yenagoa rely heavily on these water sources for domestic, agricultural, and fishing activities. However, these water bodies are increasingly threatened by microbial contamination, particularly by *Vibrio* species, which pose significant public health risks.

Recent assessments of water quality in Ogbia and Yenagoa have revealed concerning levels of microbial and physicochemical contamination. Groundwater in Ogbia showed poor to marginal quality, with elevated levels of electrical conductivity, chloride, and microbial load. Their findings are in concordance with the results obtained in this study. The high microbial loads in Ogbia and Yenagoa localities could be attributed to a number of factors, prominent is that these areas are geographically below the sea level. Hence, attempting to access potable water through underground means could be challenging.

The presence of potentially pathogenic *Vibrio* spp in the water samples from these localities is a public health concern, which could act as a justification for the incidence of cholera outbreaks from creek settlements in the Niger Delta region. Furthermore, the persistence of these species (table 5) is a public health "*red flag"* for possible cholera and *Vibrio* gastroenteritis in the future.

The study of Aladese and Ariyo (2021) investigated the prevalence of *Vibrio cholerae* and other *Vibrio* species in Bayelsa State. Their study reported that 54.55% of freshwater, 46.67% of brackish water, 34.38% of seafood, and 36.36% of seafood samples were contaminated. Their study was focused on the prevalence of V. cholerae and related species from different sources in selected localities in Bayelsa State. This is to ascertain possible associated risk of exposure to these sources and infection with cholera and cholera-like *Vibrios.* While their study generalised the distribution patterns of *Vibrio* spp from different sources. Our study centres on the distribution of these potentially virulent *Vibrios* in ground and surface waters, which not only shows the distribution patterns but also ascertains the probable relationship of physicochemical properties of these water sources with the survival, persistence, and proliferation of this group of bacteria.

The total heterotrophic count exceeded the WHO limit of 100 CFU/ml in all the sampled underground and surface waters from Ogbia and Yenagoa. This infers that the water sources from these localities are not suitable for consumption without some form of treatment. In the same vein, the mean values of the load of total coliform and total vibrio count further underline the associated risks that could be posed to public health. These findings suggest that both surface and groundwater sources in the region are not safe for direct human consumption without treatment. The incidence of coliforms and other indicator microorganisms in contaminated waterbodies has been documented (Olalemi & Ogundare, 2022)

The *Vibrio* spp distribution pattern (Table 5), which showed the highest prevalence of *Vibrio cholerae*, was unexpected. An earlier report of Aladese & Enabulele (2014) had reported that *V. parahaemolyticus* was the dominant species. The justification for this high distribution of *V. cholerae* and other potentially pathogenic *Vibrio* spp from water sources from these localities validates the occurrence of cholera and *Vibrio* gastroenteritis in recent times and the propensity for future outbreaks to recur.

The attributable factors influencing the environmental persistence of *Vibrio* spp are both natural occurrences and human activities. Several environmental factors contribute to the presence and spread of *Vibrio* species in Bayelsa. Seasonal variation has been implicated as one of the justifications for the survival and persistence of these bacteria. Dry months showed significantly higher *Vibrio* counts due to lower dilution and stagnant water conditions. Past literature has also shown a correlation between environmental indices such as temperature, salinity, and the persistence of potentially pathogenic *Vibrio* spp. Tropical temperatures and brackish conditions in coastal areas provide ideal environments for *Vibrio* growth (Angaye & Yougha, 2015). This study has been conducted to establish a correlation between physicochemical metrics of water quality and the persistence of these bacteria in aquatic environments. There is a high statistical correlation between pH and bacterial concentration, especially in surface waters (Table 10). This could be attributed to numerous geographical phenomena, such as flooding. Recurrent flooding due to the below-sea-level terrain of Yenagoa is another major factor contributing to the contamination of surface water by effluents, wastewater, and sewage. This has been opined as one of the risks of increasing gastrointestinal-related infections and cholera outbreaks in Bayelsa. Waste disposal, fishing, and market runoff contribute to nutrient loading and microbial contamination in water bodies.

Another justification for the high correlation of pH and physicochemical assessment indices could be incessant and indiscriminate dumping of human waste into surface water. This practice of open defecation is prominent in many coastal settlements along the South-South coasts of Nigeria. The unhealthy disposal of domestic waste has been fingered as a probable source of continuous contamination of bodies and their potential threats to public health (Idika *et* al., 2000; Ayeni *et al*., 2014; Aladese & Ariyo, 2021). The molecular

epidemiological surveillance has shown high genetic relatedness among strains of water samples and strains *V. cholerae* of epidemic potential (Aladese & Pondei, 2019)

Antibiotic susceptibility tests showed that *V. cholerae* strains were generally susceptible to ciprofloxacin, ofloxacin, and pefloxacin (Table 6), with variable resistance patterns observed in the efficacies of tetracycline, amoxicillin, and amoxicillin-clavulanate (Augmentin). The results of these antibiotic sensitivity profiles agree with previous studies (Ottaviani *et al.*, 2001; Oramadike, & Ogunbanwo, 2015). It is opined that the above fluoroquinolone class of antibiotics are the recommended as the best line of treatment for cholera-like infections and *Vibrio* species gastroenteritis.

V. Conclusion

The study has ascertained the potential public health-associated risks associated with drinking untreated underground and surface water from these areas of study in Bayelsa State. To avert future pockets of sporadic outbreaks among these vulnerable communities, it is recommended that water treatment infrastructure be provided in rural communities and that existing water treatment facilities in urban communities be improved. Secondly, an effective monitoring system to track microbial loads should be implemented and embedded in a robust flood management system. Finally, public enlightenment and legislation should be formulated to discourage the practice of open defecation and indiscriminate disposal of excreta and market run-off into water bodies. Expectedly, these recommendations will significantly reduce the incidence of these potentially pathogenic microorganisms, leading to a healthier community, which will have a multiplier effect on the economic growth arising from an improved productivity of a vibrant, healthy population.

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