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COMPARATIVE ANALYSIS OF SURFACE AND GROUND WATER SYSTEM ALONG THE COURSE OF RIVER NUN, BAYELSA STATE, NIGERIA

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ABSTRACT

Despite the abundance of surface and groundwater resources in the Niger Delta region of Nigeria, access to safe and potable water remains inadequate, leading to public health and environmental concerns. This study analyses Physicochemical properties of surface and groundwater systems and determines the water quality index (WQI) for each water resource in Ekpetiama clan in the region. Standard procedures were employed and the results were subjected to statistical evaluation. Results showed that most water quality parameters were within the permissible levels in both water systems, however, mean turbidity concentration recorded 47.7±4.6 NTU in river water exceeded the permissible limit (5 NTU), while mean phenol concentration in both river and groundwater recorded 2.9 ± 0.35µg/L and 2.79 ± 0.24 µg/L respectively. exceeding the National (NSDWQ) permissible level (1.0 mg/L) for drinking water. The water quality indices for both systems using the weighted arithmetic index method was 54.3 for surface and 48.7 for ground water and classified as 'fair' and 'Good' qualities respectively. Groundwater demonstrated better quality than surface water in the study area. However, exceedances of phenol in both sources indicate contamination risks requiring treatment before consumption; also surface water vulnerability to pollution from

anthropogenic activities was evident through elevated turbidity. These findings underscore the need for remediation of contaminated sources, improved water governance, pollution control, and sustainable water management strategies to enhance equitable use and resilience of riparian communities in Bayelsa State.

KEYWORDS: *Groundwater, riparian communities, surface water, water quality index, water quality parameters.*

1.0 INTRODUCTION

Water quality assessment remains a critical component of sustainable water-resource management, particularly in regions where both groundwater and surface water serve domestic, agricultural, and industrial needs. Groundwater quality is influenced mainly by aquifer geology, residence time, and geochemical interactions, while surface water responds quickly to rainfall patterns, runoff, urban activities, and direct waste discharge. Recent studies in Africa and Asia have shown increasing deterioration of both water types due to population growth, land-use intensification, and inadequate wastewater management [1, 2].

Composite indicators such as the Water Quality Index (WQI) have gained prominence as they simplify complex data into a single numerical value that indicates overall suitability for use. Application of WQI for example has expanded significantly in recent years due to its usefulness in environmental monitoring and communication [3]. Comparative assessment of groundwater and surface water using WQI has become increasingly important as they provide insights into contamination drivers and help guide management interventions, such as source protection, treatment priorities, and monitoring schedules. They also help in understanding spatial variations in pollution and identifying high-risk water sources. Studies across Nigeria, India, Turkey, and South Africa show that surface water often exhibits higher WQI values due to its vulnerability to runoff, open defecation, agricultural chemicals, and industrial effluents, whereas groundwater—though generally better protected—may accumulate metals, nitrates, and salinity from natural and anthropogenic sources [4].

Given increasing pressures on water resources such as urban development and agricultural expansion to climate-related hydrological changes, there is a growing need for reliable, comparative assessments of groundwater and surface water. This study evaluates the physicochemical characteristics of groundwater and surface-water sources and applies a weighted arithmetic WQI approach to compare their quality. The aim is to provide evidencebased insights that support water-resource planning, public-health protection, and sustainable water-supply management.

2.0 MATERIALS AND METHODS

2.1 Study Area: The study area lies in the lower section of the Niger Delta and is characterised by extensive river networks and reliance of the inhabitants on its water resources for livelihoods. lies approximately within the square of latitude 4° 57’ 54’’ N and 5°00’ 54’’ N and longitudes 6°14’42’’ E and 6°18’ 34’’E, along the River Nun in Bayelsa State, Nigeria. The River Nun is a principal distributary of the River Niger that traverses the Niger Delta floodplain before discharging into the Atlantic Ocean. The area lies within a tropical humid climatic zone characterized by mean annual rainfall of approximately 2,800 ± 500 mm [5]. Mean annual temperature ranges between 26 °C and 32 °C. The predominant geology consists of Quaternary alluvium and coastal plain sands, with groundwater typically occurring within shallow unconfined aquifers.

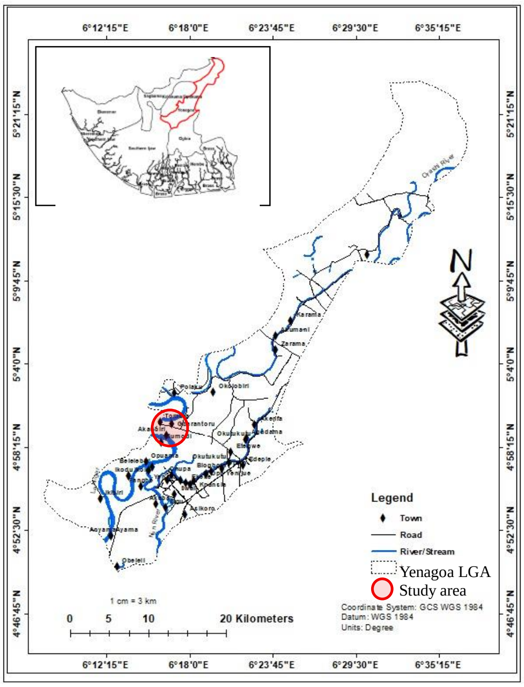

Fig.1 Map of Yenagoa L.G.A highlighting the Ekpetiama kingdom; *Inset* Bayelsa State.

2.1 Sampling Design: A purposive sampling strategy was employed to ensure adequate representation. Groundwater samples were obtained from five functional boreholes that serve domestic needs within the communities across the study area. Each river water sampling was carried out from about 20 cm below the surface, and was also done sequentially from downstream to upstream sites. Boreholes were purged for 5 minutes before sample collection.

Sampling was conducted monthly over a three-month period adhering strictly to standard protocols. Table 1a and 1b approximate geographic coordinates of surface and groundwater sampling sites respectively.

Table1a: Approximate geographic coordinates of river water sampling sites.

River water sites	Latitude	Longitude
1 (Downstream)	4°58'31"	6°16'17"
2 (Downstream)	4°59'6"	6°16'28"
3 (Mid-stream)	5°0’29”	6°15'30"
4 (Mid-stream)	5° 0'5"	6°16'2"
5 (Up-stream)	4°59'39"	6°16'23"

Table 1b: Table 1aapproximate geographic coordinates of groundwater sampling sites.

Groundwater sites	Latitude	Longitude
1	4°58'31"	6°16'17"
2	4°59'6"	6°16'28"
3	5°0’29”	6°15'30"
4	5° 0'5"	6°16'2"
5	4°59'39"	6°16'23"

2.2Physicochemical Analysis: Thirteen parameters were analyzed following the standard methods [6, 7]. Determination of Temperature, pH, Salinity, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) were made on site, assessed directly at the location using a calibrated Multifunction water quality tester model no. EZ 9910, in line with APHA 4500-H B guidelines. Turbidity, total hardness, dissolved Oxygen (DO). arsenic, aluminium. iron, zinc, and boron were determined in the Laboratory.

Turbidity was by nephelometric measurement with infrared LED (~860 nm). The instrument was standardized and turbidity read directly from instrument display. Intensity of light scattering is measured in Nephelometric Turbidity Units (NTU). Total Hardness was measured by titrating with EDTA using Eriochrome Black T. Results were expressed as mg/L $CaCO_3$.

DO was determined using a membrane electrode probe. The confirmatory analysis was by Winkler Azide Modification method (APHA 4500-O C). Titration with sodium thiosulfate gave the DO concentration in mg/L.

Phenol was determined by Chloroform Extract Method- 2.5ml NH_4OH solution was added to 100 ml of distillate in a 250 m1 beaker and the pH adjusted to 7.9 with a phosphate buffer.

Samples were acidified with phosphoric acid and extracted into chloroform and was quantified by gas chromatography (GC). Polycyclic aromatic hydrocarbons (PAHs) were analyzed using Gas Chromatography-Mass Spectrometry (Agilent 6890N with 5975 mass selective detector).

Determination of metals flame AAS. Samples were digested with aqua Regia at controlled temperatures until a clear solution was obtained for instrumental analysis. Arsenic, Aluminum, Boron, Iron, Copper and Zinc,

2.3 Water Quality Index Computation: The weighted arithmetic method (WAM) [8, 9] was employed to determine the WQI of surface and ground water in the study area. This method is widely adopted in recent water quality studies [10]. In deriving an overall water quality index for the study area, the mean values of seven water quality parameters (pH, Electrical conductivity, Turbidity, Total hardness, Iron and fluoride) derived from the empirical data from five sites each, were used for the analysis of surface and groundwater respectively, the method of analysis is presented in three steps.

1. Parameter Weighting

Unit weight factor for each parameter is given by the equation 1.

$$W_n = \frac{K}{S_n} \qquad 1$$

where: W_n = Unit weight factor; summation of all unit weight factor is equal to 1

S_n = standard permissible value of nth parameter as given by NSDWQ

$$K = \text{coefficient} = \frac{1}{\frac{1}{S_1}+\frac{1}{S_2}+\frac{1}{S_3}+\dots\frac{1}{S_n}} \qquad 2$$

2. Sub-index Specification

$$\text{Sub index } Q_n = \frac{V_n - V_i}{S_n - V_i} \times 100 \qquad 3$$

where; Q_n = Quality rating for the nth water quality parameter

V_n = conc. /value of the nth parameter,

V_i = Ideal value of the nth parameter in portable water

S_n = Standard permissible value of nth parameter

$$\text{when } V_n = 0\ ; \quad Q_n = \frac{V_n}{S_n} \qquad 4$$

3. Aggregation Function

The Water Quality Index (WQI) was calculated using a weighted additive aggregation method. The formular for WQI is given in equation 5

$$WQI = \sum_{n=1}^{p} W_n \times Q_n \qquad 5$$

where: W_n is the unit weight factor of the nth parameter

Q_n is quality rating for the nth water quality parameter

P is the total no of parameters

Each of the unit weight index was multiplied by a corresponding quality rating. The resulting products were then summed to obtain the water quality index. The WQI was interpreted using the standard classification scheme by Brown et al. [11]

3.0 RESULTS AND DISCUSSION

3.1 Physicochemical parameters: Determination of temperature, pH, Total Dissolved Solids (TDS), Turbidity, Salinity, Electrical Conductivity (EC) and Dissolved Oxygen (DO).

Hydrogen Ion Concentration **(**pH**)** in river water had a range of 7.61– 7.98 with a mean concentration of 7.78, and a standard deviation of 0.14. In the groundwater samples pH had a range of 6.38 - 7.19 with a mean of 6.69, and a standard deviation of 0.19. The river water temperature readings ranged from 29.7 to 30.7 °C, with a mean of 30.34°C and standard deviation 0.4, while readings for ground water were 26.9 – 29. °C, with a mean value of 27.7 °C and standard deviation 0.9. Total dissolved solids **(**TDS): TDS recorded values between 33.00 and 33.18 mg/L The average was 33.30 mg/L with a standard deviation 0.16. The groundwater TDS concentrations ranged from 67.30 to 122 mg/L, with a mean of 91.7 mg/L and standard deviation 23. Turbidity range in surface water samples was 43 – 53 NTU, the average 47.7 NTU and standard deviation 4.6. Groundwater turbidity value ranged from 1.5 to 4.00 NTU with an average of 2.5 NTU and standard deviation 1.06. Values of DO in surface water ranged between 5.7 mg/L and 6.17mg/L, average was 5.91mg/L and standard deviation 0.2. The groundwater DO concentrations ranged from 3.87 to 4.6 mg/L, with a mean of 4.36 mg/L and standard deviation 0.3. The average value of EC in surface water was 66.26 µS/cm^3 with a standard deviation of 0.42. The range was 66.00 - 66.66 µS/cm^3. Electrical Conductivity in groundwater range was 137.7- 237.3 µS/cm^3 with a standard deviation of 43.7. The average concentration was 182 µS/cm^3. The values for Salinity in surface water were between 0.0031 - 0.0034 mg/L, giving an average of 0.00328 and a standard deviation of 0.00011. In groundwater the range for salinity was 0.007 to 0.16 mg/L, mean value was 0.011 and standard deviation 0.004.

Figures 2 – 5 compares the values of river and groundwater samples across sampling sites.

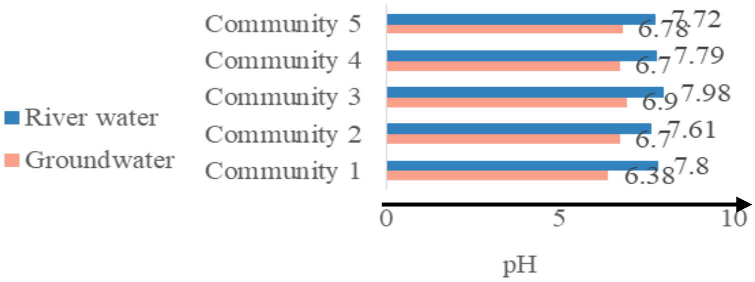

Fig. 2 pH values in surface and groundwater in each site.

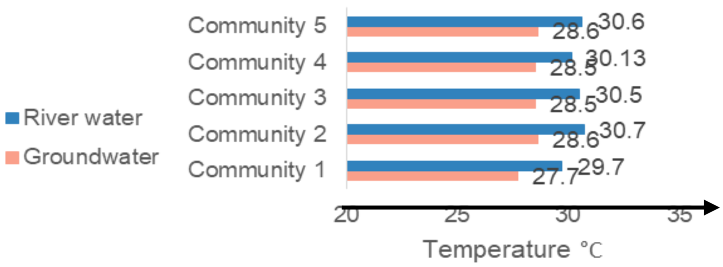

Fig. 3 Temperature values in surface and groundwater samples

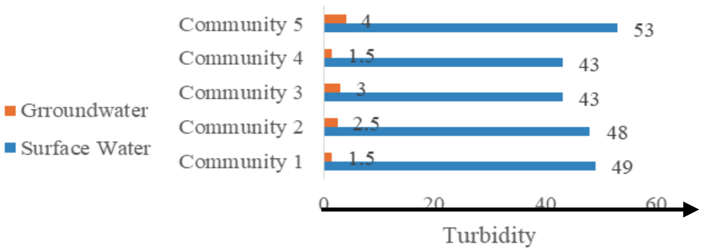

Fig. 4 Turbidity in surface and groundwater across communities

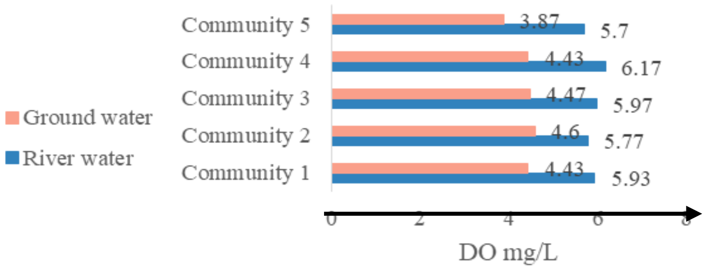

Fig. 5. DO in surface and groundwater across communities.

Table 2: ***Physicochemical values in river water and groundwater samples.***

S/no	Parameter	Unit	Surface Water Mean ± SD	Groundwater Mean ± SD	WHO/NSDWQ Limit
1	pH	-	7.8 ± 0.1	6.7 ± 0.2	6.5-8.5
2	Temp	°C	30.3 ± 0.4	28.4 ± 0.4	Ambient
3	Turbidity	NTU	47.7 ± 4.6	2.5 ± 1.1	5
4	EC	µS/cm	66.3 ± 0.4	182 ± 43	1500
5	Dissolved oxygen	mg/L	5.9 ± 0.2	4.4 ± 0.3	
6	Total Dissolved Solid	mg/L	33.2 ± 0.2	92 ± 23	500
7	Salinity	mg/L	0.003 ± 0.001	0.110 ± 0.011	
8	Fluoride	mg/L	0.05 ± 0.00	0.18 ± 0.12	1.5

3.1.2 Heavy Metals: Arsenic, aluminium, and boron, all registered below detection limit (BDL) in both surface and groundwater. Copper, Iron, and Zinc recorded appreciable levels. Copper (Cu) ranged from 0.0283 to 0.0323mg/L in the river water, the mean 0.031 mg/L and a standard deviation of 0.02. Copper values in groundwater ranged from 0.024 to 0.028 mg/L, mean was 0. 0.027 mg/L and standard deviation of 0.003. Iron (Fe) in river water had a range of 0.027 - 0.039 mg/L, mean 0.0318 mg/L and a standard deviation of 0.005. Iron in groundwater had a range of 0.090 - 0.172 mg/L, with a mean 0.122 mg/L and a standard deviation of 0.03. Zinc (Zn) had a range of 0.015 - 0.019 mg/L, with a mean 0.017 mg/L and a standard deviation of 0.0015. The range for groundwater zinc was 0.016 - 0.046 mg/L, with a mean of 0.031 and a standard deviation of 0.011.

Table 3: Mean Heavy Metals Concentrations in River and Groundwater.

S/no	Parameter	Unit	Surface Water Mean ± SD	Groundwater Mean±SD	WHO/NSDWQ Limit
1	Arsenic*	mg/L	0.0005 ± 0	0.0005 ± 0	0.01
2	Aluminium*	mg/L	0.0005± 0	0.0005 ± 0	0.2
3	Boron*	mg/L	0.0005 ± 0	0.0005 ± 0	
4	Copper	mg/L	0.019 ± 0.005	0.268 ± 0.002	1.0
5	Iron	mg/L	0.032 ± 0.005	0.122 ± 0.030	0.3
6	Zinc	mg/L	0.017 ± 0.002	0.032 ± 0.011	3.0

** BDL Below detection limit*

3.1.3 Organics: The 16 compounds in polycyclic aromatic hydrocarbons (PAH) all recorded below detection limit of < 0.01 mg/L. The value of Phenol in river water ranged from 2.593 to 3.510 µg/L. Mean value was of 2.916 µg/L and standard deviation 0.35. In groundwater range was 0.257 and 3.180 µg/L average 2.79 µg/L and standard deviation 0.2.

Table 7: Mean Organics concentrations in River and Groundwater

S/no	Parameter	Unit	Surface Water Mean ± SD	Groundwater Mean ± SD	WHO/NSDWQ Limit
1	Phenol	μg/L	2.9 ± 0.35	2.79 ± 0.24	1
2	PAH	mg/L	0.005 ± 0	0.005 ± 0	0.007

3.2 Water Quality Index

3.2.1. Computation of WQI*:* The computed water quality index in the study area for surface water was 54.3, while groundwater WQI was 48.7. This classifies the water systems as 'fair' and 'Good' for surface and ground water respectively, on an established five threshold classification scheme (Very poor, Poor, Fair, Good and Excellent) [11].

Table 4a: ***Computation of the WQI for Surface water.***

Parameters	**Standard limits**	$\frac{1}{S_n}$	$\sum\frac{1}{S_n}$	$K=\frac{1}{\sum\frac{1}{S_n}}$	$W_n=\frac{K}{S_n}$	**Ideal value**	V_n	$\frac{V_n}{S_n}$	$Q_n=\frac{V_n}{S_n}\times 100$	$W_n \times Q_n$
pH	8.5	0.1176	4.3273	0.23109	0.027187	7	7.78	0.52	52	1.413728
EC	1000	0.001	4.3273	0.23109	0.000231	0	66.3	0.0663	6.63	0.001532
TDS	500	0.002	4.3273	0.23109	0.000462	0	33.8	0.0676	6.76	0.003124
TH	150	0.0067	4.3273	0.23109	0.001541	0	28.47	0.1898	18.98	0.029241
Turbidity	5	0.2	4.3273	0.23109	0.046218	0	47.7	9.54	954	44.09202
Fe	0.3	3.3333	4.3273	0.23109	0.770301	0	0.032	0.1067	10.667	8.216542
Fluoride	1.5	0.6667	4.3273	0.23109	0.15406	0	0.05	0.03333	3.333	0.513534
		4.3273			1					**54.26972**

Concentrations are expressed in mg/L except EC in μS/cm. pH is unitless

Table 4b: ***Computation of the WQI for Groundwater***

Parameters	Standard's limits	$\frac{1}{S_n}$	$\sum\frac{1}{S_n}$	$K=\frac{1}{\sum\frac{1}{S_n}}$	$W_n=\frac{K}{S_n}$	Ideal value	V_n	$\frac{V_n}{S_n}$	$Q_n=\frac{V_n}{S_n}\times 100$	$W_n \times Q_n$
pH	8.5	0.117647	4.3273	0.23109	0.027187	7	6.85	0.100	10.	0.2718
EC	1000	0.001	4.3273	0.23109	0.000231	0	181.5	0.182	18.15	0.0043
TDS	500	0.0020	4.3273	0.23109	0.000462	0	91.9	0.184	18.38	0.0085
TH	150	0.0067	4.3273	0.23109	0.001541	0	38.84	0.259	25.89	0.0399
Turbidity	5	0.200	4.3273	0.23109	0.046218	0	11.6	2.320	232.00	10.7226
Fe	0.3	3.3333	4.3273	0.23109	0.770301	0	0.14	0.467	46.67	35.9474
Fluoride	1.5	0.6667	4.3273	0.23109	0.15406	0	0.17	0.113	11.33	1.7460
		4.3273			1					**48.7404**

Concentrations are expressed in mg/L except EC in μS/cm. pH is unitless

3.2.2. Classification of Water Quality Index: WQI values were 54.27 and 48.74 for surface and ground water respectively. Figure 5 is the chart for WQI showing both water sources compared against the thresholds in the standard classification scheme by Brown et al. [11]

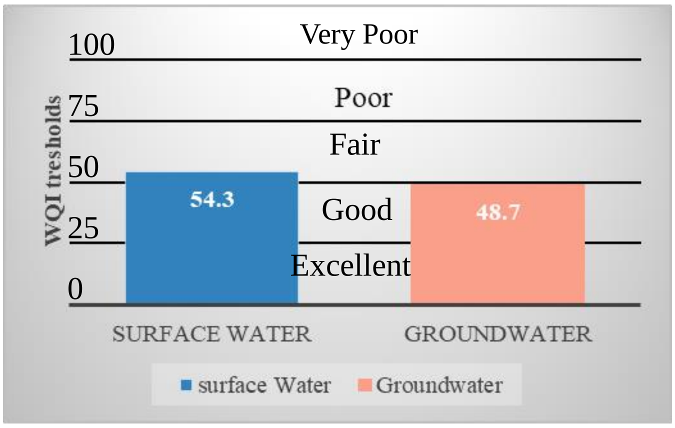

Fig. 6. Classification of WQI for river and groundwater

4.0 DISCUSSION

4.1 Water Quality Parameters: The pH of water is an important water parameter as it affects the solubility and availability of nutrients and their utilization by aquatic organisms [12]. The mean pH concentration of 7.8±0.1 and 6.7±0.2 for surface and groundwater respectively fall within the acceptable range for drinking water (6.5–8.5) recommended by NSDWQ. The result of this study is similar to a study 66\[13] which recorded groundwater pH values as 6.9 to 8.1. Slightly acidic to neutral pH for groundwater and slightly alkaline river water resource is typical in tropical regions and supports its suitability for most domestic and agricultural uses. pH influences the solubility and mobility of metals in groundwater, thus pH < 6.5 mg/L may enhance the leaching of toxic metals into the water column, compounding any contamination risk.

Temperature is an important parameter in water quality assessment. It influences dissolved oxygen concentrations, microbial activity, and the solubility of chemical constituents, thereby indirectly affecting compliance with established physicochemical and microbiological standards [14]. The average groundwater temperature of 28±0,4 °C in this study is consistent with the temperature range reported in a study [15] of boreholes in Okobo, Akwa Ibom State, Nigeria, where groundwater mean temperature was 28°C. Similarly, another study [16] in the Port Harcourt University reported temperature ranges from 26.4°C to 30.3°C. Temperature is largely influenced by local climatic conditions and the 28 °C and 30.34 °C values found in this study aligns well with typical tropical and subtropical ground and surface water temperatures. The Salinity results show that both river water and groundwater fall well within the freshwater classification of 0.5 ppt or 500 mg/L permissible limits of [14] [17].

Mean TDS concentrations in this study 91.7 mg/L for groundwater, lie well below the WHO and Nigerian standard threshold of 500 mg/L. Similar to this research, a study [18] in Agbonchia recorded groundwater TDS levels between 89.8–91.2 mg/L, while another study in Minna [19] recorded between 38-258 mg/L for regional studies. the groundwater's moderate TDS suggests modest interactions with subsurface geologic matrices consistent with typical fresh aquifer recharge zone characteristics in sedimentary terrains. The World Health Organisation opines that in the hydrogeological setting of Bayelsa/Niger Delta, such spatial contrasts are plausible given site-specific lithology/ localized anthropogenic inputs.

In this study, the turbidity values in groundwater samples had mean value of 2.5 NTU and within the permissible threshold of 5 NTU [14] [17] for drinking water. Similar to our study groundwater turbidity values reported byin Omoku, ranged between 0.4 - 2.6 NTU [20]. Another study [21] reported much higher turbidity levels ranging between 7.6 - 15.4 NTU in the Ethiope River in Delta State.

For the Heavy metals, the mean copper concentration was within the recommended threshold of WHO for drinking water (1 mg/L). A Similar study [22] in Bayelsa recorded values of 0.02 – 0.05 mg/L in Aghoro community. While surface water in Elechi creek recorded slightly higher values (1.21 -1.42 mg/L) [23]. Copper is less mobile in groundwater because it adsorbs strongly to aquifer materials and carbonate surfaces. Although copper (Cu) is a vital micronutrient for humans, consuming it in excess can lead to gastrointestinal issues and liver toxicity [14] The findings from the current study indicate that there is minimal human-induced Cu enrichment in the area under investigation. However, due to the nearby oil facilities and the potential for pipeline corrosion, ongoing monitoring is advised to detect any increase in concentrations early. Groundwater measurements of Iron were within the acceptable specified limits of 0.3 mg/L for iron [17]. There is no health-based guideline by WHO for iron, issues with taste, color, and staining, generally occur around 0.3 mg/L Similar values for Iron were obtained in Elechi creek recording 0.14 – 0.20 mg/L [23], while Elebele recorded higher values 0.3 – 12.4 mg/L [24]. The slightly higher iron levels in groundwater compared to river water aligns with hydrogeochemical conditions typical of subsurface environments, such as the microbially driven reduction of Fe (III) oxyhydroxides to soluble Fe (II) and prolonged water-rock interaction [25]. Since the study area values are both below

0.3 mg/L, the aesthetic risk is minimal, however, regular monitoring is recommended because changes in redox conditions and flow paths can occasionally raise iron levels in wells, even if surface water remains stable.

The mean concentration of Zinc is below the NAFDAC's recommended threshold for drinking water which is 0.3 mg/L and the NSDWQ aesthetic recommended threshold of 3 mg/L, suggesting minimal contamination from industrial or urban activities. Comparable findings recorded low Zinc levels in boreholes in Aghoro southern Ijaw ranging from 0.012 – 0.016 mg/L [22]. The generally low Zn concentrations imply that zinc poses low health risk in the study area at present. Continued monitoring is, however, recommended to detect possible increases resulting from expanding artisanal, domestic, or industrial activities. Higher levels were observed in Yenagoa metropolis where surface water had a range of 1-1.42 mg/L [23].

4.2 Water Quality Index: The river water WQI score implies that while it is not recommended for drinking and domestic use without treatment, it can be used for agricultural and industrial purposes only in its current state. The groundwater WQI score implies that it is not recommended for drinking, but it can be used for other domestic activities, agricultural and Industrial purposes.

The river water WQI score is similar with to a study in Orashi river within the region that recorded WQI values of 56.49 [26]. Groundwater in the study area recorded better WQI score than surface water. This is consistent with a study in Emohua LGA, Rivers State, where WQI result for surface water was 2.832, being lower than that of ground water 1.778 [27]. These results show that surface water sources were more polluted than the ground water sources. This suggests that, overall, groundwater is less susceptible to direct contamination in the study area, likely due to natural filtration as water percolates through soil and subsurface layers. On the other hand, surface water appeared more vulnerable to pollution due to its open nature. Higher turbidity from the environment and contributions from surface runoff and domestic activities likely contributing to lower WQI values in the river. Some areas have recorded relatively poor WQI compared to our study; a study in perti-urban town in south eastern Nigeria reported WQI values for groundwater above 100 classified as poor water [28]. WQI values of 56.49 and 57.21 (poor drinking water quality) and 79.70 which categorised as very poor drinking water quality were recorded [29]. The present study suggests that groundwater in the study remains relatively less degraded.

5.0 CONCLUSION

This study examined the physicochemical characteristics of surface water and groundwater in the study area and evaluated their overall status using the Water Quality Index (WQI). The results indicate that groundwater generally presented more acceptable quality, consistent with its natural filtration and reduced exposure to direct contamination. However, boreholes and syrface water recorded elevated concentrations of phenol indicating health and ecological risks. Surface water also showed exceedances of turbidity above guideline values, reflecting its sensitivity to land-use practices, seasonal runoff, and other anthropogenic pressures. The WQI outcomes aligned with these observations, surface water classified as ‘fair’ making it unsuitable for direct domestic use without treatment while groundwater fell in the “good” category, suitable for some domestic uses, but not for drinking. The results generally indicate that although groundwater remains a comparatively safer source, neither source can be considered uniformly safe for drinking without treatment. Continuous surveillance and cite-specific management interventions remain essential for maintaining water quality and safeguarding public health.

RECOMMENDATIONS

- A structured monitoring programme should be established for both water sources to track emerging changes and support early detection of deterioration.
- Waste disposal near rivers or poorly constructed boreholes should be controlled through, enforcement, and community awareness.
- Water intended for domestic use should be subjected to basic filtration and disinfection at household or community level.
- Expanding piped water supply and rehabilitating existing facilities would reduce reliance on vulnerable water sources.

Statements and Declarations

Acknowledgements: The authors acknowledge the support received from the community resident’s who facilitated field access and sample collection, and also the laboratory staff for the technical support provided during this study.

External Funding: This research received no external funding

Ethical Approval: Not applicable, as the study involved environmental water sampling and laboratory analysis

Informed Consent: Verbal permission was obtained from borehole owners before sample collection.

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