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Hydrogeochemical process of ions in groundwater of communities along Southern-axis Atlantic Ocean in Bayelsa, Nigeria

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ABSTRACT

The hydrogeochemical process of groundwater from hand-dug well within communities located along the Southern axis of the Atlantic Ocean was examined based on its major ions concentration. Fifteen (15) water samples were collected across the study area and analyzed using the American Public Health Association (APHA) laboratory standard. With the aid of ArcGIS 10.7, the spatial distribution of physiochemical parameters and major ions (Ca^{2+} , Mg^{2+} , K^+ , Na^+ , HCO_3^- , SO_4^{2-} , Cl^- and PO_4^{3-}) were determined. The cations and anions of the groundwater trended as $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$ and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{PO}_4^{3-}$, respectively, while all values are within World Health Organization (WHO) allowable limit except Ca^{2+} . The positive correlation among major ions illustrated similarities in the sources and distributions based on principal component analysis, while the cluster analysis established the complexity of the hydrogeochemical processes. Piper and Durov plot aided the geochemical process identification where the groundwater of the area showed the dominance of $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^-$, $\text{Na}^+\text{-HCO}_3^-$ and $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-SO}_4^{2-}/\text{Cl}^-$; hence, the hydrogeochemical process was influenced by water–rock interaction of possible carbonate weathering characterized by the earth's alkaline water and weak acids.

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Hydrogeochemical process; groundwater; principal component analysis; water chemistry

Introduction

Groundwater remains a vital renewable natural resource that supports organisms, including humans, for their industrial, agricultural and domestic activities (Abdelshafy, Saber, Abdelhaleem, Abdelrazek, & Seleem, 2019). The suitability of groundwater for a series of activities is influenced by natural (Jalali, 2007; Subramani, Rajmohan, & Elango, 2010) and human activities (Afolabi et al., 2022). The activities include geological structure, geochemical process, and leachate of domestic and industrial waste, contributing to the obtainable groundwater quality in an environment. Groundwater chemistry is based on various hydrogeochemical processes that the groundwater undergoes over space and time (Narany et al., 2014).

Groundwater interacts with the aquifer minerals of their immediate environment, which determines the groundwater chemistry, commonly termed the hydrogeochemical process (Jeevanandam, Kannan, Srinivasalu, & Rammohan, 2007). Several interaction processes are accountable for groundwater chemistry, such as soil-rock water interaction during groundwater flow and recharge, extended aquifer storage, and mineral species dissolution (Jeevanandam, Kannan, Srinivasalu, & Rammohan, 2007). The processes occur

between groundwater and the mineralogical structure in the aquifer basement dissolution, percolation, precipitation, and cation exchange (Vespasiano, Muto, & Apollaro, 2021).

Bayelsa state is found within the Niger Delta region of Nigeria. According to (Abam, 1999), the region is enriched with surface and sub-surface water, criss-crossing many communities and maintaining their environmental stability. The study area consists of alluvial deposits and an extensive, low-lying, typical deltaic plain with essentially flat topography, which, in conjunction with the high annual rainfall, is responsible for the deplorable drainage conditions and the overall development of marshes and back swamps. There are several perennial streams, oxbow lakes and rivers in the area, e.g. Kolo Creek, Epie Creek, Yenagoa and Nun River. They all form a network which empties to the Atlantic Ocean through Nun River Estuary. The research area has exhibited sub-standard groundwater quality due to elevated levels of specific groundwater parameters and the intrusion of saltwater or brackish water into the freshwater aquifers (Nwankwoala & Peterside, 2019). According to (Nwankwoala & Daniel, 2016), the static water level in the area exhibits a range of 0–2 m during the rainy season and 1–3 m during the dry season. The water

permeates the porous sands of the Benin Formation, effectively replenishing the aquifers (Nwankwoala & Udom, 2011). Groundwater in the region primarily occurs under water table circumstances, as documented by (Short & Stauble, 1967) and (Udom & Amah, 2006).

Several studies have adopted the use of major ion chemistry of groundwater to study the hydrogeochemical processes. Previous studies made use of physiochemical properties and rock interaction (Abdelshafy, Saber, Abdelhaleem, Abdelrazek, & Seleem, 2019); graphical representation in the form of a Piper diagram (Hussien & Faiyad, 2016; Nwankwoala & Udom, 2011; Peterside, Hart, & Nwankwoala, 2022); geostatistical and geochemical approach (Islam, Mostafa, & Cinti, 2022; Kumar & James, 2016; Narany et al., 2014), hydrogeochemical characteristics and health risk assessment (Davraz & Batur, 2021). Recently, studies have combined three or more techniques in their study of hydrogeochemical processes (Xu, Gong, Tao, & Liu, 2022; Zhi, Cao, Zhang, Li, & Ren, 2021). However, some of the related studies carried out in Nigeria focused on the influence of human activities and its interaction with subsurface water, and there is a limited study that focuses on the possible influence of natural phenomena such as

seawater infiltration on shallow (hand-dug well) groundwater of a particular environment such as communities nearby the Atlantic Ocean. Therefore, the study aims to: (1) examine the spatial distribution of major ions in the shallow groundwater across the study area; (2) investigate the sources of the major ions in the shallow groundwater; and (3) identify the hydrogeochemical process.

Materials and methods

Study area

The study was carried out at the communities within the Southern Ijaw Local Government Area of Bayelsa State, Nigeria, within the Longitude of $6^{\circ}00'10''\text{N}$ and $6^{\circ}25'15''\text{N}$ and Latitude of $4^{\circ}40'07''\text{E}$ and $5^{\circ}5'20''\text{E}$ (Figure 1). The geological formation of the region was described by (Short & Stauble, 1967) and (Kogbe, 1976) while (Abam & Nwankwoala, 2020) referred to the sedimentary formation to be a “complex regressive off-lap sequence of clastic sediments ranging in thickness from 9000 m – 12000 m. The region is arranged into the three-layered lithologic formation of Benin, Agbada and Akata formation, while the aquifers are fortified by permeable soil formation, which ensures

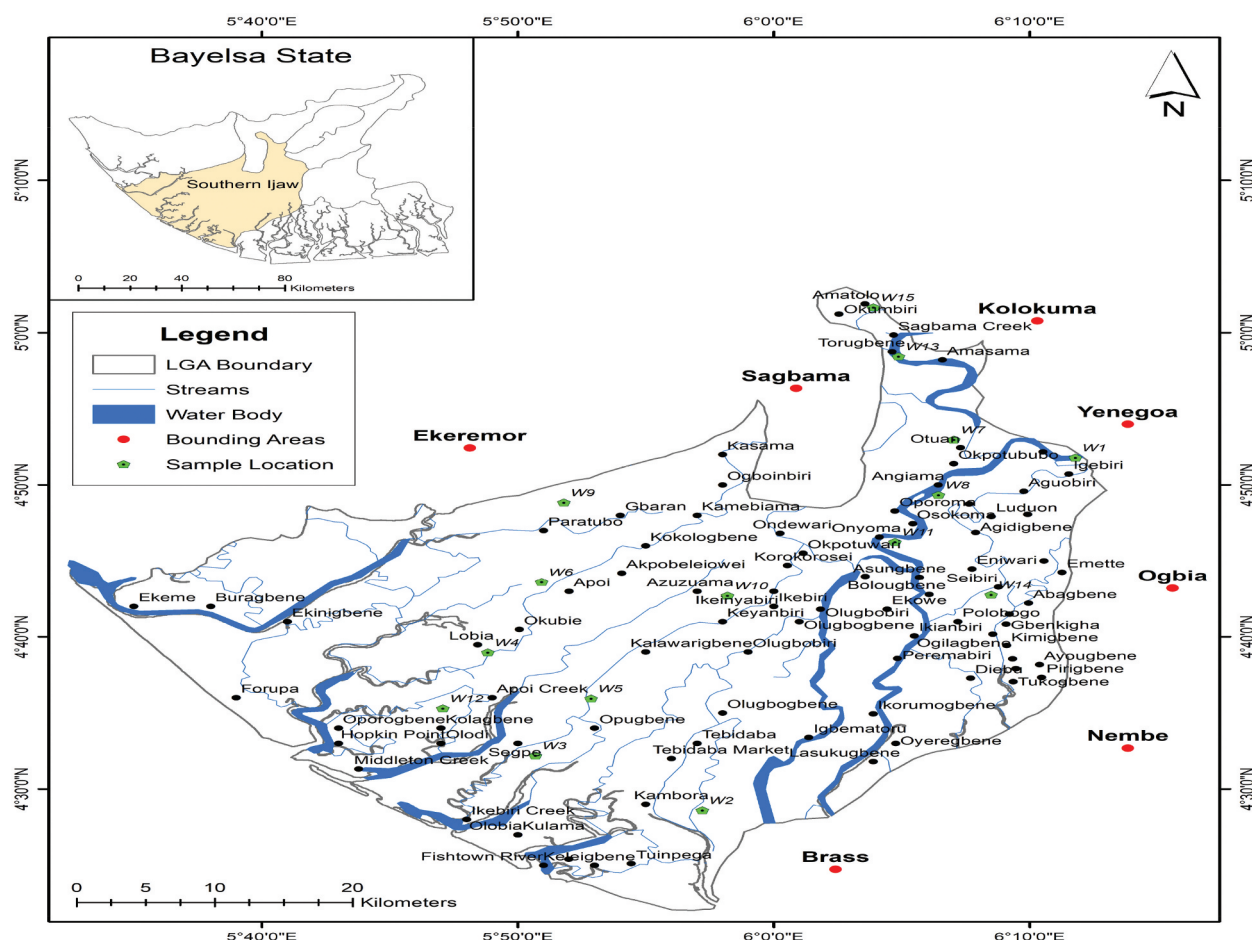


Figure 1. Overview of the Southern Ijaw local government area in Bayelsa state.

accessibility to water at shallow aquifers due to the abundance of Benin Formation (Ngah & Nwankwoala, 2013; Nwankwoala & Omemu, 2019). The aquifers are arranged in stacks and easily recharged by precipitation accumulated in the region between 2540 and 5000 mm (Nwankwoala & Mzaga, 2017). The well in the region has a refilling rate of 20,000 l/hour and is typically higher with a borehole system (Amadi et al., 2012).

The anthropogenic activities of the study area are classified as either landward or seaward due to the region's unique geographical pattern that includes both terrestrial and aquatic ecosystems. The primary economic activity in the inland area is crop cultivation, while in the coastal region, fishing and aquaculture dominate (Ifeanyieze, Alkali, Okoye, & Ikehi, 2016). Economic activities can be categorized as either land-based or water-based and area has great potential for productive and economically beneficial land-based operations, especially for cultivating a wide range of crops (Ikehi, Ifeanyieze, Onu, Ejoifor, & Nwankwo, 2022). Additionally, many aquatic ecosystems in the area support economic activities that rely on water (Ifeanyieze, Alkali, Okoye, & Ikehi, 2016; Ikehi, Ifeanyieze, Onu, Ejoifor, & Nwankwo, 2022).

Sample collection

Groundwater from wells (hand-dug) was sourced from fifteen (15) positions across the study area. All the samples were collected during the rainy season (July 2020) using suitable techniques described by (Afolabi et al., 2022). The collected samples were taken to the laboratory, and the parameters were analyzed by Geospectra Engineering Services Limited, Port Harcourt using standard protocol for laboratory analysis.

Data analysis

Laboratory analysis

The collected samples were analyzed for relevant physicochemical and major ions parameters according to internationally accepted procedures and standard methods (American Public Health Association standard- APHA, 2012). The parameters analyzed in the groundwater include pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chloride (Cl^-), Sodium (Na^+), Phosphate (PO_4), Sulphate (SO_4), Magnesium (Mg^{2+}), Potassium (K^+), Calcium (Ca^{2+}) and Bicarbonate (HCO_3^-). The laboratory analysis procedure and quality control were similar to those described by (Afolabi et al., 2022).

To ascertain the quality of the outcome from various analyses, standard procedures and laboratory quality assurance were strictly followed while samples were analyzed in triplicates, and the mean was

estimated for accuracy and precision. All analyses were subjected to a high-quality reagent from Geospectra Engineering Services Limited, and all instruments such as Pyrex glassware and containers for the analysis were washed adequately in deionized water, then soaked overnight with a 10% HNO_3 in 1% HCl solution and later washed with deionized water and desiccated.

Statistical analysis

The source and distribution of major ions of the groundwater were analyzed through statistical tools such as Pearson's Correlation Coefficient (PCC) analysis, Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) using the Statistical Package for the Social Sciences (SPSS) version 21 platform. The use of HCA has been previously adopted as clustering tools of various water quality parameters (Chegbele, Akurugu, & Yidana, 2020) and (Egbueri, 2020) while dendrograms show the quality of the clusters of the water sample parameters (Egbueri, 2020). PCC and PCA have been combined by previous studies as a tool for establishing possible relationship, extent of the relationship and sources identification among parameters (Afolabi et al., 2022; Afolabi et al., 2023).

Results and discussion

Concentration and spatial variation

The outcome of the studied area's physiochemical and major ions parameters (points) is presented in Table 1. The pH ranged from 5.27 at L1W to 7.45 at L6W, with an average of 6.62. This indicates a slightly acidic nature of the groundwater similar to those reported by (Nwankwoala & Udom, 2011) and (Afolabi, Ogundana, & Ogundipe, 2022) for the same region but lower to those reported by (Yusuf, Abiye, Ibrahim, & Abubakar, 2021) for Lagos coastal belt which was alkaline in nature. The acidity could be linked to the anthropogenic impact of gas flaring across the state and soil organic matter (Nwankwoala & Udom, 2011). The EC reports ranged from 294 $\mu\text{S cm}^{-1}$ at L14W to 1143 $\mu\text{S cm}^{-1}$ at L8W with an average of 698.7 $\mu\text{S cm}^{-1}$, which exceeded those reported by (Davraz & Batur, 2021). The EC of L8W (1143 $\mu\text{S cm}^{-1}$) and L11W (1124 $\mu\text{S cm}^{-1}$) exceeded the Nigerian Industrial Standard (NIS) limit of 1000 $\mu\text{S cm}^{-1}$ NIS, 2007 but within the WHO limit of 1200 $\mu\text{S cm}^{-1}$ (World Health Organization (WHO), 2017). The TDS of the study area indicated an average value of 316.53 mgL^{-1} , while the TDS values for L3W (546 mgL^{-1}), L4W (624 mgL^{-1}), L8W (543 mgL^{-1}), and L11W (546 mgL^{-1}) exceeded the WHO and NIS allowable limit of 500 mgL^{-1} , respectively (NIS, 2007) (World Health Organization WHO, 2017); TDS

Table 1. Physiochemical and major ion parameters.

	pH	EC	TDS	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	PO ₄ ³⁻	HCO ₃ ⁻	Cl ⁻
L1W	5.27	647	204	1.23	6.41	34.5	7.54	7.9	0.084	39.4	15
L2W	5.74	864	117	0.43	5.30	19.5	9.54	4.33	0.066	102.4	16.9
L3W	6.70	985	546	3.22	12.4	34.5	8.56	20.6	0.066	86.7	12.0
L4W	6.45	856	624	3.10	10.2	55.4	10.23	33.4	0.052	78.1	30.0
L5W	7.27	345	274	0.56	0.53	20.4	8.13	12.4	0.023	100	7.00
L6W	7.45	323	208	0.56	4.32	13.2	6.22	12.4	0.044	100	7.00
L7W	6.85	298	171	1.45	2.43	54.8	7.22	6.52	0.054	122	12.00
L8W	5.44	1143	543	2.03	3.42	17.9	14.2	55.6	0.065	100	29.0
L9W	7.01	714	322	1.00	4.52	29.8	4.22	12.4	0.012	143	0.022
L10W	7.40	777	389	7.54	5.45	49.0	6.62	29.5	0.019	156	0.015
L11W	7.04	1124	546	1.00	4.32	36.20	4.22	4.28	0.03	102.5	30
L12W	6.34	738	184	1.01	3.47	22.6	3.25	30.30	0.03	10.2	24
L13W	6.34	738	184	0.10	3.33	19.50	14.20	10.80	0.02	70.5	24
L14W	6.92	294	284	0.21	0.42	18.00	10.18	55.60	0.07	148	15
L15W	7.02	634	152	0.014	2.46	13.60	7.34	12.40	0.08	102.4	6.0
Min.	5.27	294.	117	.014	.420	13.20	3.25	4.28	.012	10.2	.015
Max.	7.45	1143	624	7.54	12.4	55.4	14.2	55.6	.084	156.0	30.0
SD.	.68	282.7	170.4	1.92	3.21	14.39	3.23	16.99	0.02	38.69	10.31
Avg.	6.62	698.7	316.53	1.56	4.59	29.26	8.11	20.56	0.05	97.41	15.2
R1	7.85	227.14	144.28	3.83	0.42	45.87	13.15	10.0	-	187.10	2.94
R2	4.7	293.1	210.5	14.5	4.1	21.8	19.5	129.2	-	5.6	5.4
R3	5.10	50.0	25.0	0.01	0.004	3.94	0.445	18.0	0.01	7.47	13.0
R4	7.02	669.6	413.2	4.14	1.27	95.64	32.62	16.46	0.99	418.6	31.2
WHO	6.5–9.5	1200	500	50	10	75	50	250	10	100	250
NIS	6.5–8.5	1000	500	200	-	-	0.2	100	-	-	250

*Minimum (Min), Maximum (Max), Standard deviation (SD), Average (Avg), World Health Organisation (WHO, 2017), NIS-Nigerian Industrial Standard (2007).

NB: All parameters are in mgL⁻¹ except EC (μS cm⁻¹) and pH (no unit) in all reported Tables and Figures.

R1 (Davraz & Batur, 2021), R2 (Utom, Odoh, & Egboka, 2013), R3 (Nwankwoala & Udom, 2011) and R4 (Islam, Mostafa, & Cinti, 2022).

influences the nature of groundwater quality and level of contamination (Abdelshafy, Saber, Abdelhaleem, Abdelrazek, & Seleem, 2019), and has a strong link with EC (Fan, Shu, Yang, & Chen, 2006).

The cations (Na⁺, K⁺, Mg²⁺ and Ca²⁺) reported for this study trended as Ca²⁺ > Mg²⁺ > K⁺ > Na⁺ at an average value of 29.26 mgL⁻¹, 8.11 mgL⁻¹, 4.59 mgL⁻¹ and 1.56 mgL⁻¹ respectively and are within WHO limit of 75 mgL⁻¹, 50 mgL⁻¹, 10 mgL⁻¹ and 50 mgL⁻¹ WHO, (2017). The trend was similar to those reported by (Kumar & James, 2016). The anions of the groundwater trended as HCO₃⁻ > SO₄²⁻ > Cl⁻ > PO₄³⁻ at an average value of 97.41 mgL⁻¹, 20.56 mgL⁻¹, 15.2 mgL⁻¹, and 0.5 mgL⁻¹ respectively. All the major ions values exceeded those reported within the Niger Delta region (Nwankwoala & Udom, 2011) and other parts of Nigeria (Utom, Odoh, & Egboka, 2013) except for Mg²⁺ and SO₄²⁻. The Na⁺ in the study area range from 0.014 mgL⁻¹ at L15W to 7.54 at L10W while Na⁺ average value of 1.56 mgL⁻¹ is within the WHO and NIS limits of 50 mgL⁻¹ WHO (2017); NIS (2007). The PO₄³⁻ in the study area range from 0.012 mgL⁻¹ at L9W to 0.084 mgL⁻¹ at L1W while PO₄³⁻ average value of 0.05 mgL⁻¹ is within the WHO limits of 10 mgL⁻¹ WHO (2017). The hydro-geochemical parameters show wide spatial variation, indicating the complex hydrogeochemical processes in the study area (Figure 2).

Sources and distributions

The PCA coupled with the PCC, rotation component matrix for groundwater major ions and screen plot (Figure 3) were analyzed and presented accordingly.

Among all the physicochemical and major ions parameters, the PCC analysis (Table 2) indicated that parameters such as EC, TDS, K⁺, and Cl⁻ have a significant relationship and are positively correlated (where $r \geq 0.5$, $p \leq 0.05$). Showing a similar trend was the relationship between Ca-Na⁺ and pH-HCO₃⁻ while pH-Cl⁻ and Cl-HCO₃⁻ have a significant relationship and are negatively correlated (where $r \geq -0.5$, $p \leq 0.05$). Among the carbonate components, pH indicated a weak positive correlation with Ca²⁺ ($r = 0.081$) and negative correlation with Mg²⁺ ($r = -0.456$). It has a significant role of low pH on the calco-carbonic equilibrium and potentiality of carbonate mineral/rock weathering (Islam, Mostafa, & Cinti, 2022). The weak negative correlation between Ca²⁺ and Mg²⁺ suggested that the ions may not necessarily be involved in several physicochemical reactions of the groundwater aquifer. All the major ions showed a weak and negative correlation among themselves, indicating a complex hydrogeochemical process, different hydrogeochemical composition and sources.

The PCA was carried out under varimax rotation, and four (4) principal components (PC-4) were noticed (Table 3). The analysis indicated a total variance of 77.35% with eigenvalue > 1 extracted by R-mode. From PC1, the variation among the parameters can only be explained by the 24.532% variance, while parameters such as Na⁺, Ca²⁺ and K⁺ are strongly correlated (0.835, 0.798 and 0.797 respectively) with eigenvalues > 1. The PC2 showed 22.078% of the variance, while a strong correlation of Cl⁻ (0.858) and a strong negative correlation of HCO₃³⁻ (-0.740). PC3 revealed a strong correlation for SO₄²⁻

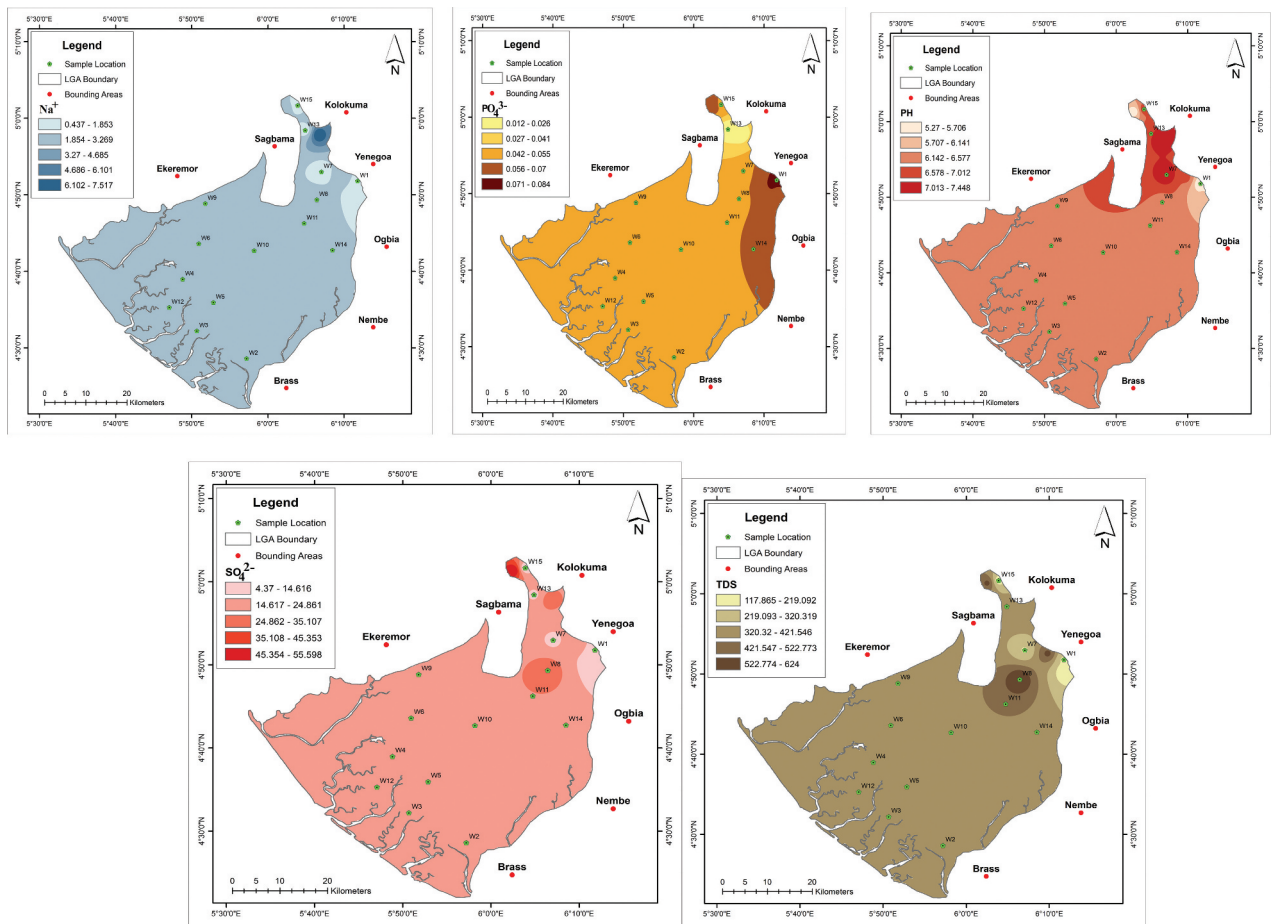


Figure 2a.

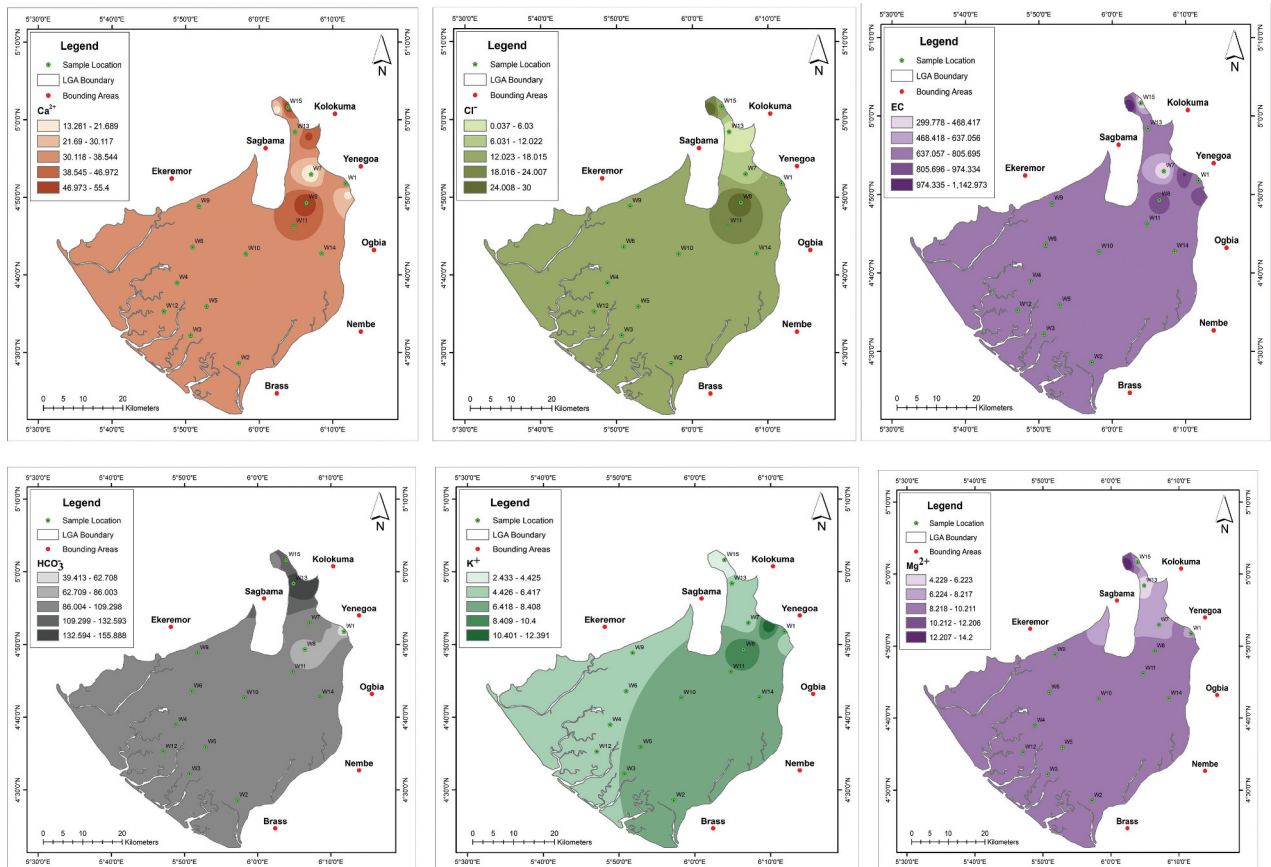


Figure 2b. Spatial variation of the physicochemical and major ions Concentrations.

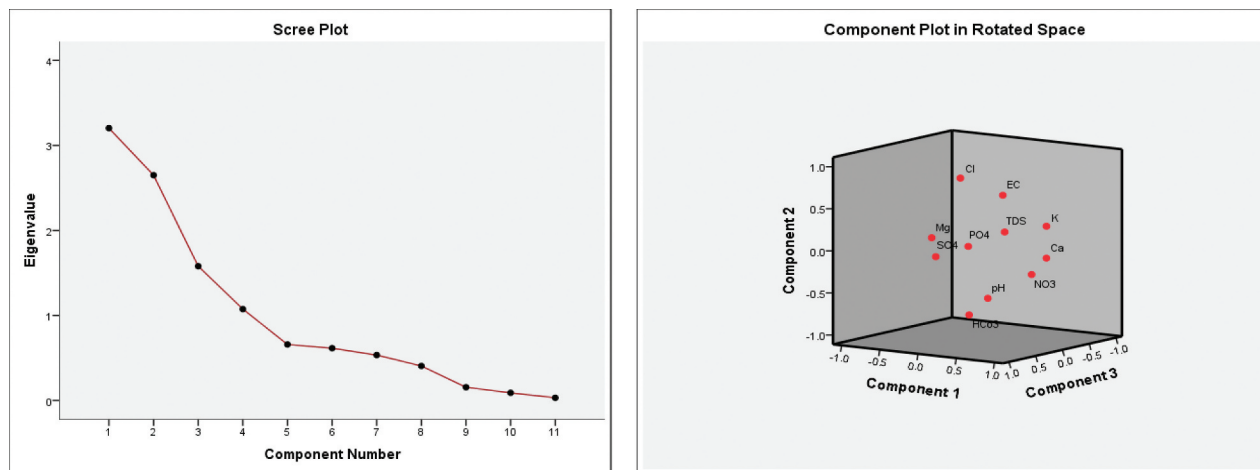


Figure 3. Scree plot of eigenvalues after PCA and rotated component matrix of groundwater ion.

Table 2. Pearson's correlation coefficient (PCC) analysis.

	Ph	EC	TDS	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	PO ₄ ³⁻	HCO ₃	Cl
pH		-.429	.018	.163	-.205	.081	-.456	-.143	-.498	0.534*	-.542*
EC	-.429		0.620*	.305	0.528*	.124	.150	.106	-.009	-.200	0.523*
TDS	.018	0.620*		.492	0.551*	.424	.145	.417	-.072	.131	.396
Na ⁺	.163	.305	.492		.473	0.635*	-.057	.258	-.204	.281	-.198
K ⁺	-.205	0.528*	0.551*	.473		.469	.010	-.068	.176	-.233	.148
Ca ²⁺	.081	.124	.424	0.635*	.469		-.181	-.088	-.128	.132	.055
Mg ²⁺	-.456	.150	.145	-.057	.010	-.181		.398	.294	.034	.378
SO ₄ ²⁻	-.143	.106	.417	.258	-.068	-.088	.398		.174	.144	.262
PO ₄ ³⁻	-.498	-.009	-.072	-.204	.176	-.128	.294	.174		-.154	.143
HCO ₃ ⁻	0.534*	-.200	.131	.281	-.233	.132	.034	.144	-.154		-.517*
Cl	-.542*	0.523	.396	-.198	.148	.055	.378	.262	.143	-.517*	

*Correlation is significant at the $p = 0.05$ (2-tailed).

Table 3. Rotation component matrix for major ions.

	PC1	PC2	PC3	PC4
Na ⁺	0.835			
Ca ²⁺	0.798			
K ⁺	0.797			
Cl ⁻		0.303		
HCO ₃ ⁻		0.858		
SO ₄ ²⁻		-0.740	0.374	
Mg ²⁺			0.863	
PO ₄ ³⁻			0.681	0.385
Eigenvalues	2.699	2.429	1.806	0.904
% of Variance	24.532	22.078	16.422	14.321
Cumulative %	24.532	46.610	63.033	77.354

Mg²⁺ at 16.422% variance; however, the first three (3) PC loading showed 63.033% of the total variance. According to (Islam, Mostafa, & Cinti, 2022), the values of PCA (with + or - signs) imply the possible impact and non-impact by the presence of extracted loads on an exact constituent. PCA revealed that a significant positive correlation among major ions illustrated similarities in the sources and distributions (Afolabi & Adesope, 2022) while the absence of such correlation between and among parameters implies a lack of mutual forms of source and distribution pattern (Ustaoğlu, Tepe, & Tas, 2020).

HCA was carried out for 15 samples using 11 parameters to discover the clusters of samples that showed similarities in their water chemistry (Figure 4). From

the analysis, the major likes-variables maintained a specific cluster area and were closely connected with associated cluster(s), while clusters with fewer similarities were relatively connected to form a more extensive cluster (Chegbele, Akurugu, & Yidana, 2020). The hydrogeochemical parameters of samples showed five (5) and two (2) main cluster groups (cluster I and cluster II) based on a dendrogram. Cluster II showed a closed cluster distance between L8W and L11W with similar chemistries with L3W and L4W. This is reflected in all four (4) wells having TDS above allowable limits. The cluster arrangement of the wells further indicated the complexity of the hydrogeochemical processes within the groundwater, and each well showed similarities in their water chemistries.

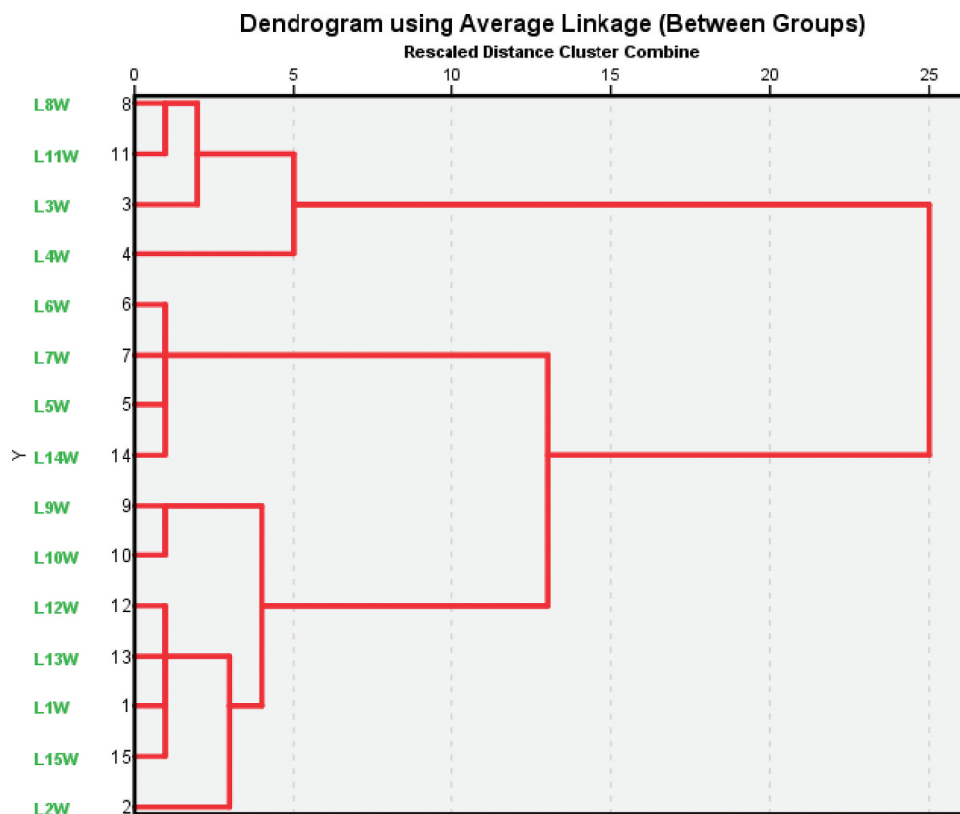


Figure 4. Dendrogram of hierarchical cluster analysis for sampled groundwater.

Hydrogeochemical process

The hydrogeochemical process of a place/region is based on the precipitation, evaporation and rock-water interaction process, which eventually influences the groundwater chemistry (Kumar & James,

2016). A combined graphical representation plotting of the Piper diagram (Figure 5) and Durov diagram (Figure 6) was adopted in describing the relative enrichment of cations and anions and the geochemical process of the groundwater (Piper, 1944). The

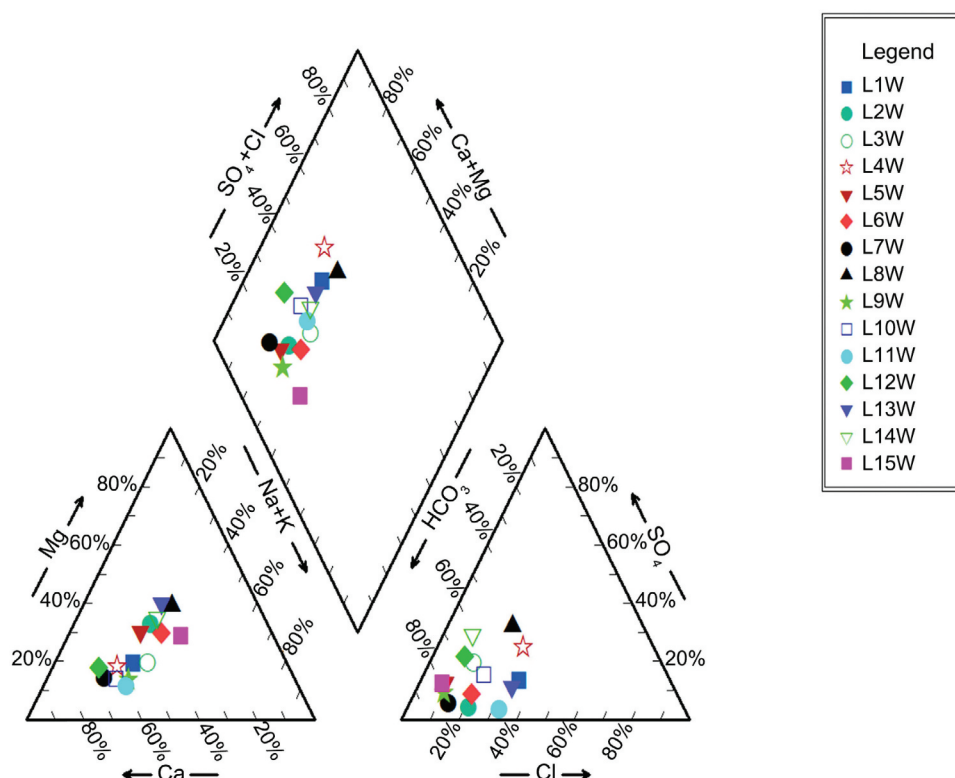


Figure 5. Piper Trilinear diagram for Hydrochemical facies.

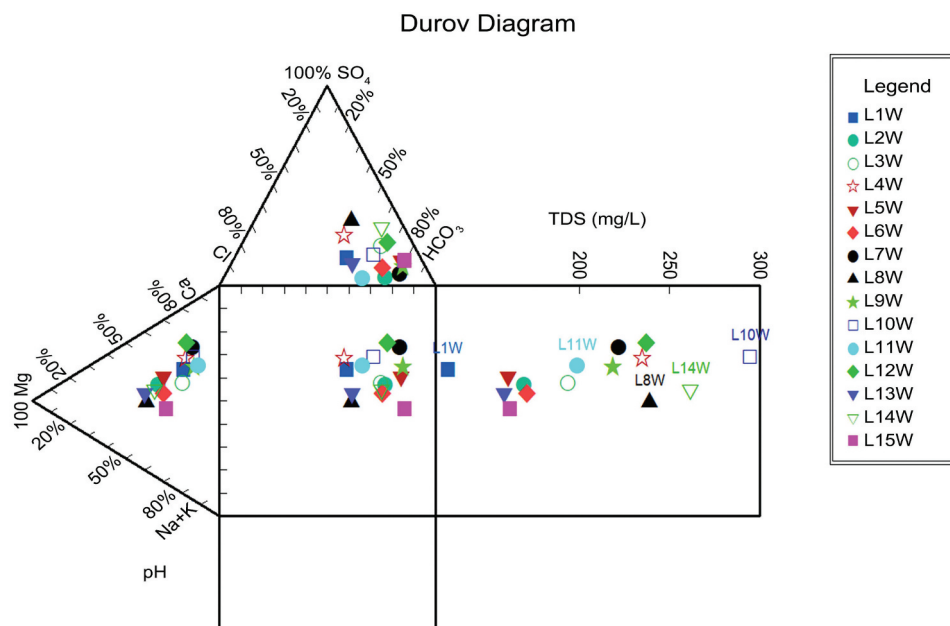


Figure 6. Durov plot depicting hydrogeochemical process.

Piper diagram is a very useful tool in bringing out the groundwater chemical relationship in more concise terms (Walton, 1970). From the analysis, three different hydrogeochemical facies were identified. The Ca^{2+} - Mg^{2+} - HCO_3^- type of water dominates among the facies, followed by Na^+ - HCO_3^- and lastly by Ca^{2+} - Mg^{2+} - $\text{SO}_4^{2-}/\text{Cl}^-$. The high concentration of HCO_3^- is an indication of chemical weathering (Yusuf, 2020). A similar outcome was reported for a freshwater aquifer along a coastal belt (Yusuf, Abiye, Ibrahim, & Abubakar, 2021). The Ca^{2+} - HCO_3^- water type, therefore, is thought to be generally derived from the carbonate dissolution such as calcite, which contributes Ca^{2+} and HCO_3^- to the groundwater (Afolabi, Ogundana, & Ogundipe, 2022; Yusuf, Abiye, Ibrahim, & Abubakar, 2021). Furthermore, the Na^+ - HCO_3^- and Ca^{2+} - Mg^{2+} - HCO_3^- types are typically dominated by the earth's alkaline water and weak acids, as observed in the present study (Karanth, 1987). The concentration of Ca^{2+} and Mg^{2+} relatively indicated the total cation dominance of about 75%, and therefore, the study proposed a possible carbonate weathering that influences the groundwater quality of the area. The outcome was validated by the R^2 value of both Ca^{2+} and Mg^{2+} at 0.798 and 0.681, respectively. For the Durov plot, which defines the hydrogeochemical processes, anions and cations are projected on a square shape subdivided into nine facies based on (Lloyd & Heathcote's, 1985) water classification scheme. The

water type showed a dominance of Ca^{2+} and HCO_3^- (in Fields 1 and 2), Na^+ and HCO_3^- (Field 3), Ca^{2+} and SO_4^{2-} (Field 4), Field 5 showed no dominance of either anion or cation, Na^+ and SO_4^{2-} (Field 6) while Na^+ and Cl^- were dominant in Field 7–9. This outcome further established the complexity of the hydrogeochemical processes from the cluster analysis, which also indicated that some wells indicated similarities in their water chemistry.

Conclusion

This study investigates the hydrogeochemical processes of major ions in groundwater aquifers close to the Atlantic Ocean's coastal belt, with the aim of comprehending the geochemical dynamics inside and around these aquifers. Based on the average values, the physiochemical parameters demonstrate conformity to the standards set by the WHO and NIS, indicating that all parameters fall within the acceptable range, with the exception of Ca^{2+} . However, it should be noted that EC and TDS levels exceed the prescribed limit in some wells. The cations and anions of the groundwater trended as $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$ and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{PO}_4^{3-}$, respectively. The Piper diagram revealed that the groundwater in the region had a prevalence of Ca^{2+} - Mg^{2+} - HCO_3^- , Na^+ - HCO_3^- , and Ca^{2+} - Mg^{2+} - $\text{SO}_4^{2-}/\text{Cl}^-$ as dominant ion compositions. Conversely, the Durov plot suggested that the cations Ca^{2+} and Na^+ were dominant, while the anions HCO_3^- and SO_4^{2-} exhibited dominance.

The primary finding of this study indicates that natural processes substantially impact groundwater chemistry, as evidenced by the observed water–rock interaction. Specifically, carbonate dissolution and ion exchange were identified as the prominent geochemical processes governing groundwater chemistry in the investigated area. However, it is important to note that this study did not observe any potential anthropogenic influences on groundwater chemistry.

In summary, primary determinants influencing the hydrogeochemical processes of groundwater in the communities located along the Southern-Axis Atlantic Ocean in Bayelsa, Nigeria, have been inferred. Hence, it is advisable to ensure that anthropogenic activities in the region are conducted ecologically friendly to mitigate pollution. Additionally, it is essential to continuously monitor the aquifer to assess pollution trends across the basin, both temporally and spatially.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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