USOD PUBLISHERS
United Scientific Open Discovery

Research Article

Journal of Earth Science Biointerfaces
Volume 2 | Issue 1

Groundwater Geochemical Facie Analysis, Vulnerability, and Control Factor in the Mangrove Swamp Formation, Southern Niger Delta, Nigeria

Pamela Nwabuzor[1], **Moses Uyota Ohwo**[2]*, **Ayamezimi Oziofu Ehinlaiye**[3] **and Victory Ehigie**[4]

[1]UBA, Yenagoa, Nigeria

[2]Department of Geology, Federal University of Petroleum Resources, Effurun, Nigeria

[3]Department of Geology, Nigeria Maritime University, Okerenkoko, Nigeria

[4]Department of Geology, University of Benin, Benin, Nigeria

***Corresponding author:** Moses Uyota Ohwo, Department of Geology, Federal University of Petroleum Resources, Effurun, Nigeria.

Citation: Pamela Nwabuzor, Moses Uyota Ohwo, Ayamezimi Oziofu Ehinlaiye and Victory Ehigie (2026) Groundwater Geochemical Facie Analysis, Vulnerability, and Control Factor in the Mangrove Swamp Formation, Southern Niger Delta, Nigeria. J. Ear Sci Bio Int 2(1): 1-7.

Received Date: June 15, 2026
Accepted Date: June 25, 2026
Published Date: June 30, 2026

Abstract

This study investigates the hydrogeochemical facies, groundwater vulnerability, and flow dynamics of the Mangrove Swamp Formation, southern Niger Delta, using borehole lithology and hydrochemical analyses. Hydrogeochemical facies were determined using Piper, Durov, and Schoeller, and the Gibbs diagrams were used to characterize the groundwater chemistry and identify the dominant geochemical processes controlling the groundwater chemistry. The groundwater flow direction was interpreted from static water level contours. Also, the aquifer vulnerability was assessed through detailed lithostratigraphic logs of three drilled boreholes, focusing on the nature and thickness of protective overburden layers. Results show that the groundwater is dominated by Ca–Na–K–SO_4 and Na–Ca–SO_4 facies, indicating that water–rock interaction and silicate weathering are the primary controls on groundwater evolution in the area. Gibbs plots confirm that all samples fall within the rock-dominance field. Total dissolved solids (1600–2340 mg/L) classify the groundwater as brackish, while hardness values (392.08–544.78 mg/L as $CaCO_3$) indicate very hard water conditions. A clay-rich overburden provides moderate aquifer protection; however, shallow static water levels (0.98–1.98 m) increase the susceptibility of the aquifer to contamination. Groundwater flow is predominantly from the northeast to the southwest, following the regional hydraulic gradient. The findings provide important baseline information for groundwater protection, sustainable water-resource management, and environmental planning in the vulnerable aquifers of the Niger Delta.

Keywords: Groundwater Composition, Static Water Level, Borehole Log, Salinity, Schoeller Diagram, Hardness

Introduction

In Nigeria, immense tracts of mangrove forests have been destroyed as a result of hydrocarbon exploitation in the mangroves, and these have not only caused degradation to the environment and destroyed the traditional livelihood of the region, but have also caused environmental pollution that has affected groundwater. In Nigeria, more than 60% of the population relies solely on groundwater for domestic consumption. This is due to the fact that most homes depend on self-supply of water rather than municipal water supply. The Mangrove Swamp Formation (MSF) in the Niger Delta Basin, Nigeria, is the aquifer system providing water for domestic usage for the populace in the study area. However, the hydrogeochemical processes, geomorphology and proximity to the Atlantic Ocean pose significant threats to the groundwater quality in the Formation's aquifer. The discharge of untreated wastewater, as well as saline water intrusion, agricultural water runoff from farms, can lead to the deterioration and contamination of groundwater in coastal aquifers through infiltration of the overlying formation. The geology of an area, the degree of chemical weathering of various rock types, and anthropogenic factors control the chemistry of groundwater. Hydrogeochemical studies have, over the years, played an essential role in interpreting mineralogical composition of the subsurface and inherent conditions in most geological settings. The resource plays an important role in the social and economic life of the people regarding domestic, industrial, and agricultural use. Groundwater chemistry is dependent on several factors, which include the nature of recharge, the residence time of the groundwater in the aquifer, rock-water interactions beneath the surface, and anthropogenic activities. The tendency for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer is known as groundwater vulnerability. The static water level within the Mangrove Swamp Formation is close to the surface, and this could affect the aquifer, which is regionally shallow. This shallow depth of occurrence commonly allows for easy pollution of groundwater. For this reason, a study on the hydrogeochemical and vulnerability assessment of groundwater within MSF was carried out. This will also significantly assist in deciphering the lithological processes affecting the groundwater in the study area. The objectives of this study are to determine the water chemistry and primary processes that are responsible for groundwater chemistry and vulnerability in the study area [1-10].

Location and Geology of the Study Area

The study area is located in the Niger Delta region of Nigeria. It is about 10km away from the coast and lies on 5o48’45” E, 5o 50’15” E and 5o33’40” N, 5o34’20” N (Fig. 1). Accessibility is through the Warri main river, Southern Nigeria. The vegetation cover falls within the sensitive tropical wetland vegetation ecosystem. The terrain lies between 8±50m above sea level. The landscape is usually waterlogged during the rainy season, and tidal ranges on the rivers vary from 0.3 m to 1.3 m. The land surface of the study area is characterized by low-lying plains, which is typical of the Niger Delta. These plains have swamps that are commonly flooded during the peak of the rainy season. Regionally, the study area is part of the geologic sequence of the Quaternary and Tertiary formations of the Niger Delta, consisting of three main geological formations – the Benin formation, the Agbada formation, the Akata formation, and the Quaternary units overlying the Benin Formation. Lithologically, the study area is composed of medium-fine sands, silts and clays (Table 1.), which forms part of the geologic sequence of the Quaternary Formations of the Abandon Beach ridges and Mangrove swamp formations (Fig. 2). The main aquifer system in the Niger Delta region comprises two stratigraphic units: The Alluvium; the aquifer system within the alluvial deposits, especially the near surface beds close to the shore area, are often saline bearing. However, the lateral extent of these shallow aquifers is highly variable, occurring as sand lenses within the less permeable beds of silt and clay. While the second aquifer, the Benin Formation, forms the main aquifer system, with a thickness of over 2000 m [11].

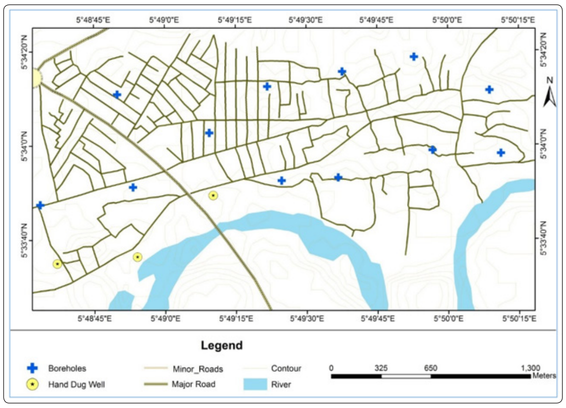

Figure 1: Topographical map of the study area

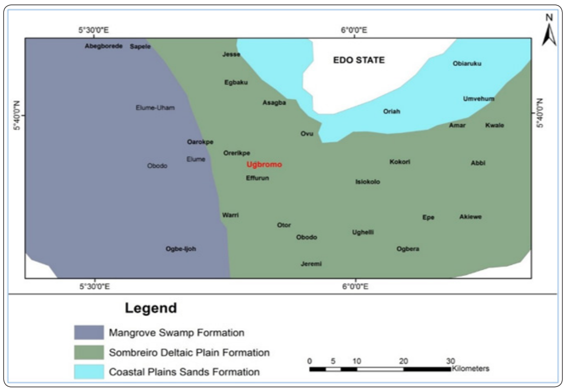

Figure 2: Geological map of the study area

Table 1: Stratigraphic sequence of the Niger Delta Basin with aquifer prospectivity [11-12].

Age	Stratigraphic Units	Lithologic Description	Aquifer Prospect
Quaternary	Alluvium	Gravel, sands, silt, and clays	Good
	Freshwater back swamp, Meander belt	Sands, clays, some silt, and gravel	Good
	Mangrove swamp, and backswamp	Medium-fine sands, clays, and some silt	Poor
	Active abandoned beach ridges	Fine sands to silt and silty clays and clays with organic matter	Poor (Saline water)
	Sombreiro-Warri deltaic plain	Sands, some silts, and clays	Medium
Miocene-Recent	Benin Formation	Sands, some silts, and clays	Prolific aquifer

Materials and Methods

Field Sampling and Borehole Drilling

Three monitoring boreholes (BH-1, BH-2, and BH-3) were drilled in the study area using the rotary drilling method. During drilling, representative cuttings were collected at regular intervals for lithological logging. Static water levels (SWL) were measured in the completed boreholes using a calibrated steel tape with chalk applied to the lower end. The depth to water was recorded immediately after drilling to minimize disturbance effects. Samples were collected after pumping for 10-15 minutes to ensure representation of aquifer water. In situ parameters, including pH, were measured on site using a calibrated multi-parameter pH meter. Samples for laboratory analysis were filtered through a 0.45 µm membrane filter, stored in pre-cleaned polyethylene bottles, and preserved at 4°C before analysis following APHA guidelines [13].

Laboratory Analysis

Major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^{-}, Cl^{-}, SO_4^{2-}) were analyzed using standard titrimetric and spectrophotometric methods. Total Dissolved Solids (TDS) were determined by the gravimetric method. Total hardness was calculated using the equation presented by (equation 2) [14].

Thus, the mathematical expression for Hardness HT is given as:

$$HT = Ca \times CaCO_3 / Ca + Mg \times CaCO_3 / Mg \quad \ldots\ldots\ldots\ldots (1)$$

Where HT, Ca, and Mg are measured in milligrams per litre, and the ratios are in equivalent weights. Eq. 1 reduces to

$$HT = 2.5\,Ca + 4.1\,Mg \quad \ldots\ldots\ldots\ldots (2)$$

Where concentrations are in mg/L as $CaCO_3$. All analyses were conducted in accordance with standard procedures [13].

Results and Discussion

Hydrogeochemical Facies

The geochemical origin of groundwater can be unraveled by plotting the concentration of major cations and anions using Piper, Durov, and Scholler diagrams. The diagram was constructed using Aquachem software version 2014.2. To understand the geochemical history/hydrochemistry of groundwater in the area, the concentrations of cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and anions (HCO_3-, $SO_4$2$^-$, and Cl^-) in mg/l. This diagram shows the similarities and differences among groundwater samples because those with similar qualities will tend to plot together as groups [14, 15]. The plot shows that 31 % of the groundwater samples plot in the field of Ca-Na-K-SO_4 and Na-Ca-SO_4 water type respectively, 9% falls within Ca-SO_4 facies, 6% falls into the Na-Ca-SO_4, K-SO_4, Na-Ca-Mg-SO_4 respectively and 3% of the samples fall into the Ca-Na-Mg-SO_4, Ca-Mg-SO_4, KCa-SO_4, and Na-Ca water type respectively (Fig. 5). The dominance of SO_4 ion in almost all the groupings show that silicate weathering of the bedrock is the most dominant process affecting groundwater in the area.

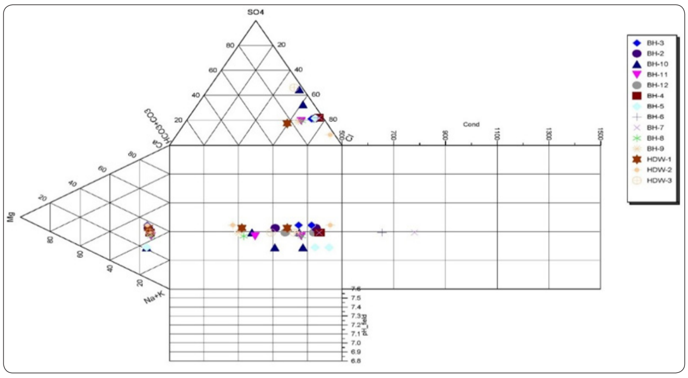

Figure 3: Durov, Piper, and Schoeller plots of groundwater composition in the study area.

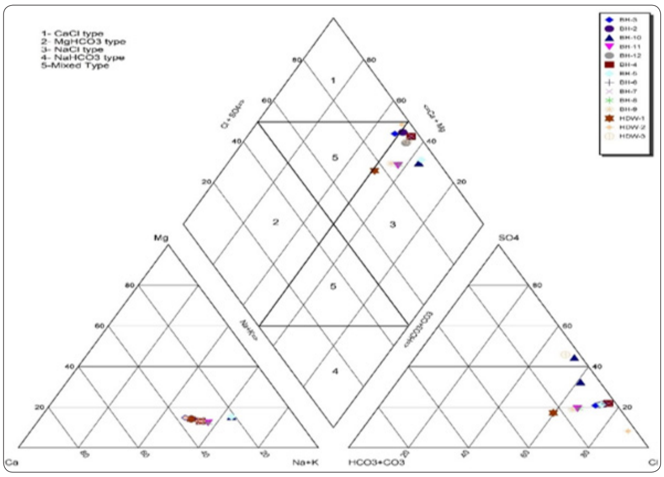

Figure 4: Piper plots of groundwater composition in the study area

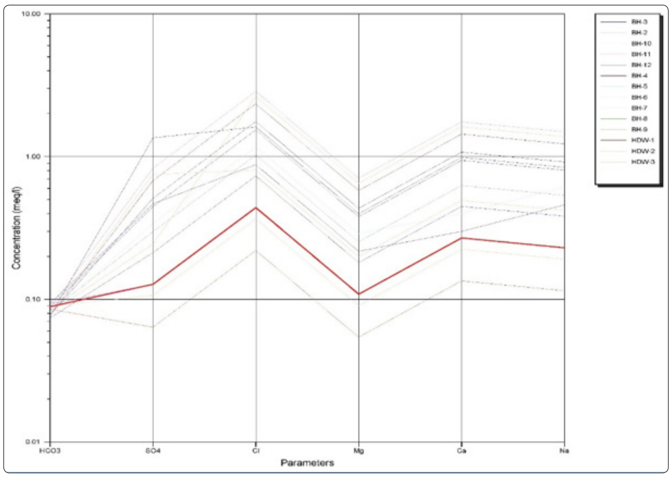

Figure 5: Schoeller plots of groundwater composition in the study area.

Groundwater Chemistry Control Factor

The mechanism that controls groundwater chemical composition establishes a close relationship between water chemistry and aquifer lithological characteristics [15]. This mechanism, established by recognizes three distinct mechanisms that control groundwater chemistry. These are evaporation dominance (rate of evaporation), rainfall dominance (chemistry of precipitated water), and rock water interaction on water chemistry. Two plots are used to decipher these mechanisms. In the first plot, Cl/ (Cl+HCO_3) (for anions) values are plotted against TDS, and in the second plot, the values of Na/ (Na+Ca) (for cations) of the groundwater samples are plotted against the values of TDS. Fig. 6 indicates that all the groundwater samples fall within the rock-dominance zone. This implies that the chemistry of groundwater in the area is as a result of the dissolution of the rock that makes up the aquifer in which the groundwater is stored. Dissolution of rocks is a dominant process in areas within the tropical zone. In Nigeria, groundwater occurs within the weathered zones in Basement Complex terrain, where intense weathering has occurred. Therefore, there is a high tendency for ionic dissolution from these rocks in the groundwater of the area [16, 17].

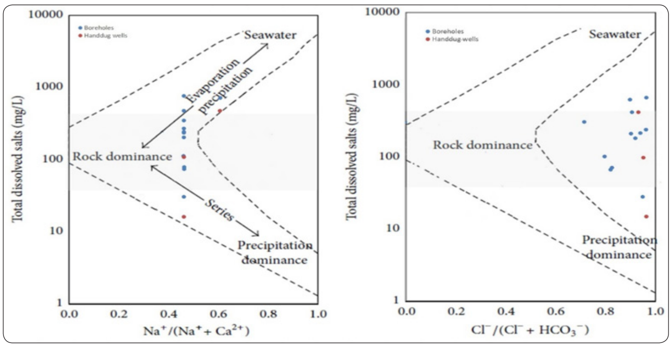

Figure 6: A Gibbs plot showing the processes that release ions into the groundwater of the study area.

Groundwater Salinity

The result of the groundwater from the three boreholes indicates brackish water (Table 3). Many groundwaters contain dissolved salts in such concentrations as to make them unusable for ordinary water supply purposes [18]. Saline groundwater is a general term referring to any groundwater containing more than 1000 mg/l total dissolved solids [14]. Various classification schemes based on dissolved solids have been proposed; the simplicity of the one shown in Table 2 makes it particularly convenient.

Table 2: Classification of saline groundwater [19].

Water Type	Total Dissolved Solids, mg/l
Fresh water	0-1,000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine	>100,000

Table 3: Result of TDS concentration compared with Carroll, (1962) classification of saline groundwater hardness in the three boreholes.

S/N	Total dissolved solids, mg/l	Remark
BH-1	1600	Brackish water
BH-2	2310	Brackish water
BH-3	2340	Brackish water

Groundwater Hardness

The result of the groundwater in the three boreholes drilled indicates that they are very hard (Table 5). Hardness results from the presence of divalent metallic cations, of which calcium and magnesium are the most abundant in groundwater. These ions react with soap to form precipitates and with certain anions present in the water to form scale. The hardness in water is derived from the solution of carbon dioxide, released by bacterial action in the soil, in percolating rainwater [20].

Table 4: Hardness classification of water [20].

Hardness, mg/l as $CaCO_3$	Water Class
0-75	Soft
75-150	Moderately hard
150-300	Hard
Over 300	Very hard

Table 5: Results of water hardness in the three drilled boreholes.

S/N	Hardness, mg/l as $CaCO_3$	Remark
BH-1	392.08 mg/l	Very hard
BH-2	544.78 mg/l	Very hard
BH-3	453.52 mg/l	Very hard

Aquifer Vulnerability

Three (3) boreholes were drilled within the study area using the rotary drilling method. The lithostratigraphy in the study area, where the three monitoring boreholes were drilled, comprises dark humic loamy sediment/topsoil (Fig. 7), with a clayey lithology ranging from 1.2 m from the surface to a depth of 4.3 m. This clay material overlies a fine silty-sand layer that is approximately 0.9 m thick. Underlying this fine silty-sand layer is a sandy-silty layer that stretches down 5.2 m to a depth of 7.3 m with an average thickness of 2.1m (Fig. 7). This sandy-silty layer is underlain by fine-medium sand sediments that become coarser with increasing depth, and join the aquifer to a depth greater than 17 m (Fig. 7). Analysis of the vulnerability of the aquifer to contamination from the three borehole logs indicates that the aquifer system in which groundwater occurs is protected to some degree from surface contaminants leaching by an impermeable overburden of clay layer that is 3.1 m thick. The fine-grained silty-sand and fine-grained sandy-silt suggest a transition/phreatic zone with low permeability transitioning the aquiferous zone, which is characterized by high porosity and permeability ranging from 7.3m>17 m downwards (Fig. 7).

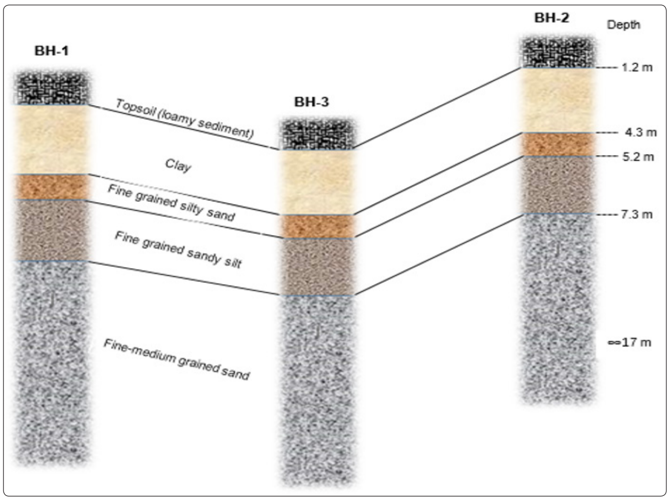

Figure 7: Lithology log of three boreholes prepared from well cuttings in the study area.

Groundwater Flow Direction

Groundwater flow direction in the area was determined using the static water level measured in the three boreholes. The static water level measured in the three boreholes ranges from 0.98 m in borehole-1, to 1.62 m in borehole-2, and 1.98m in borehole-3. The data shows that the groundwater flow direction in the area is from Northeast to Southwest (Fig. 8). This conforms with the regional groundwater flow direction in the Niger Delta, which is from the northeast towards the coast in the South. Thus, if there is any pollution of groundwater in the area, those South of the point of pollution are most likely to be affected. The groundwater recharge is via percolation from precipitation and surface water bodies (Escravos River and its tributaries). Consequently, the base flow of the surface water bodies influences the groundwater recharge rate, especially during the dry season when the water table level drops. The water level data determined in boreholes in different geomorphologic units in the area are given in Table 6 below:

Table 6: Static water levels (SWL) of boreholes in the study area

S/No.	Depth (m)
Borehole-1	0.98
Borehole-2	1.62
Borehole-2	1.98

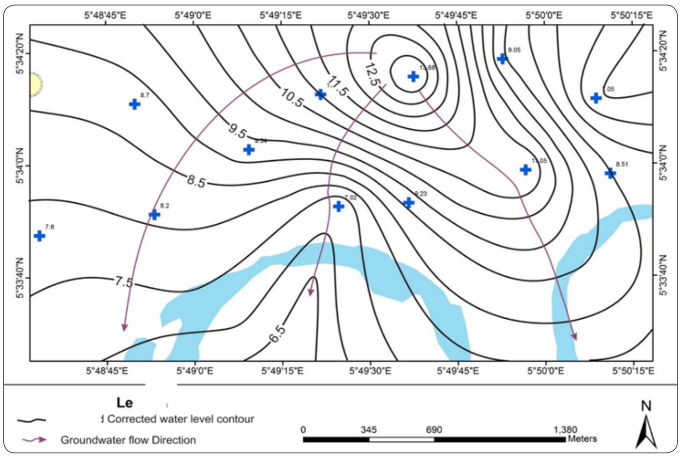

Figure 8: Map of the study area showing water table head distribution, sampling points, and groundwater flow direction.

Major Ion Chemistry of Groundwater

The concentrations of the major ions (K^+, Na^+, SO_4^{2-}, Mg^{2+}, Cl^-, and Ca^{2+}) in groundwater samples from boreholes (BH) and hand-dug wells (HDW) are presented in Figure 9. The results reveal considerable spatial variations in ionic composition, reflecting differences in lithological control, water–rock interaction, and possible anthropogenic influences within the aquifer system. A comparison of groundwater sources reveals distinct hydrochemical characteristics: Boreholes (BH1–BH11) generally exhibit lower ionic concentrations, indicating better protection from surface contamination and greater hydrochemical stability. Hand-dug wells (HDW1–HDW3) consistently record higher concentrations of most major ions, particularly chloride, calcium, sodium, potassium, and sulphate. HDW3 shows the highest concentrations for nearly all measured ions, suggesting intensified water-rock interaction, evaporation effects or localized anthropogenic influence. These observations indicate that groundwater quality deteriorates slightly in shallow groundwater systems relative to deeper borehole sources, although all measured parameters remain within acceptable drinking-water limits (WHO, 2011, and NSDWQ, 2007).

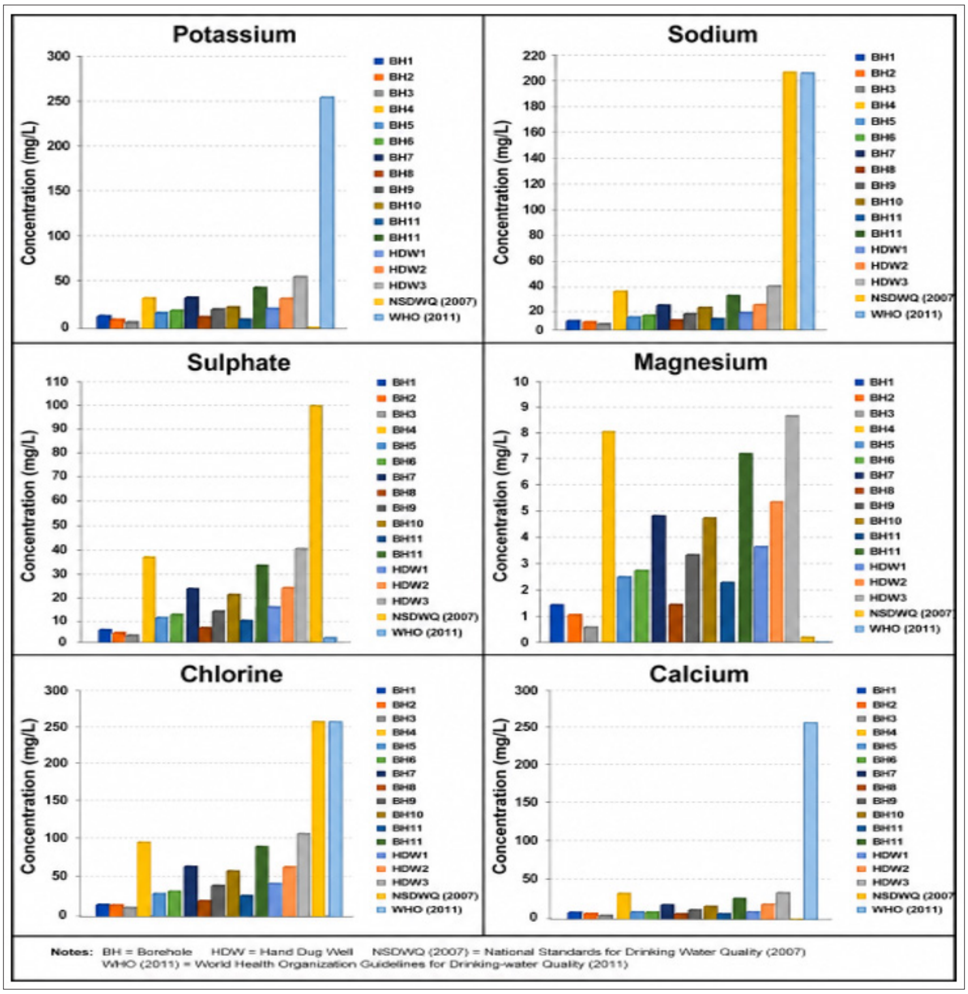

Figure 9: Spatial distribution of potassium, sodium, sulphate, magnesium, chlorine, and calcium ions concentration in boreholes and hand-dug wells in the studied location.

Conclusion and Recommendations

The integrated hydrogeochemical, lithological, and hydraulic analyses reveal that groundwater quality in the Mangrove Swamp Formation is primarily controlled by water–rock interaction and silicate weathering, as evidenced by the dominance of sulphate-rich hydrochemical facies and Gibbs plot interpretations. Groundwater in the area is generally brackish and very hard, reflecting the influence of aquifer lithology and natural geochemical processes.

Although the aquifer benefits from a protective clay overburden, the shallow water table makes it vulnerable to contamination from hydrocarbon activities, saline intrusion, and other anthropogenic activities. Groundwater flow is directed from the northeast toward the southwest, implying that pollutants introduced upgradient could migrate toward downstream communities and wetlands. Overall, the study highlights the need for continuous groundwater monitoring, improved environmental management, and sustainable groundwater protection strategies to safeguard the aquifers of the Niger Delta. Future studies integrating isotopic, geospatial, and advanced hydrogeochemical modelling techniques are recommended to improve the understanding of groundwater recharge and contaminant transport pathways [21-29].

Acknowledgment

The views expressed in this paper reflect the collective experiences of the authors gained through the research. The authors may have undoubtedly failed to cite some vital concepts. We take sole responsibility for any omission or bias.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

1. Amadi AN, Olasehinde PI, Dan-Hassan MA, Okoye NO and Ezeagu GG (2014) Hydrochemical Facies Classification and Groundwater Quality Studies in Eastern Niger Delta, Nigeria. International Journal of Engineering Research and Development 3: 1-09.
2. Omole DO (2013) Sustainable Groundwater Exploitation in Nigeria, Journal of Water Resources and Ocean Science 2: 9-14.
3. Omole DO, Ndambuki JM (2015) Nigeria's Legal Instruments for Land and Water Use: Implications for National Developmentin E. Osabuohien (ed.), InCountry Determinants and Implications of Foreign Land Acquisitions. 354- 373.
4. Abdel-Satar AM (2001) Environmental studies on the impact of the drains effluent upon the southern sector of Lake Manzalah. Egyptian Journal of Aquatic Biology 5: 17-30.
5. Adams RH, Guzmán-Osorio FJ, Zavala CJ (2008) Water repellency in oil contaminated sandy and clayey soils. International Journal of Environmental Science and Technology 5: 445-454.
6. Giridharan L, Venugopal T, Jayaprakash M, (2008) Evaluation of the seasonal variation on the geochemical parameters and quality assessment of the groundwater in the proximity of River Cooum, Chennai, India. Environmental monitoring and assessment, 143: 161-178.
7. Ekwere AS, Edet A, (2012) Hydrogeochemical Signatures of Different Aquifer Layers in the Crystalline Basement of Oban Area (SE Nigeria). Journal of Geography and Geology 4: 90-102,
8. Adewumi AJ, Anifowose AYB, Olabode FO, Laniyan TA (2018) Hydrogeochemical Characterization and Vulnerability Assessment of Shallow Groundwater in Basement Complex Area, Southwest Nigeria. Contemp.Trends.Geosci 7: 72-103.
9. Andre L, Franceschi P, Pouchan P, Atteia O (2005) Using geochemical data and modelling to enhance the understanding of groundwater flow in a regional deep aquifer, Aquitaine Basin, south-west of France. Journal of Hydrology 33: 50-62,
10. National Research Council (1993) Ground water vulnerability assessment: Predicting relative contamination potential under conditions of uncertainty. National Academies Press https://www.nationalacademies.org/publications/2050.
11. Etu-Efeotor JO, Akpokodje EG, (1990) Aquifer Systems of the Niger Delta. Journal of Mining and Geology 26: 279-285.
12. Olobaniyi SB, Owoyemi FB (2006) Characterization by Factor Analysis of the Chemical Facies of Ground Water in the Deltaic Plain Sands Aquifer of Warri Western Niger Delta. Nigeria African Journal of Science and Technology 7: 73-81.
13. American Public Health Association (APHA) (2012) Standard methods for the examination of water and wastewater (22nd Ed.). American Public Health Association
14. https://www.xm.com/landing/gold-low-spreads/en?utm_source=adsterra&utm_medium=ppc&utm_content=259206&utm_campaign=in_display_en_lowgold_desktop&adsterra_clid=6a4db52f004d337044d0907bf9f94ba5&adsterra_placement_id=26390356&gid=259206&countryConfiguration=default.
14. Todd DK, Mays LW (2005) Groundwater Hydrology, 3rd edition. John Wiley and Sons Inc 652.
15. Selvakumar S, Chandrasekar N, Srinivas Y, Simon-peter T and Magesh NS (2014) Evaluation of the groundwater quality along coastal stretch between Vembar and Taruvaikulam, Tamil Nadu, India: a statistical approach. Journal of Coastal Sciences 1: 22-26.
16. Gibbs RJ (1970) Mechanisms controlling world water chemistry. Science, 170: 1088-1090.
17. Akanmu TO, Adewumi AJ, (2016) Geophysical Characterization of Aquifer Parameters within Basement Complex Rocks Using Electrical Sounding Data from the Polytechnic, Ibadan, Southwestern Nigeria. International Journal of Scientific Research in Knowledge 4: 112-126.
18. Krieger RA, JL Hatchett, JL Poole (1957) Preliminary survey of the saline-water resources of the United States, U.S. Geological Survey Water-Supply Paper 1374: 172.
19. Carroll D (1962) Rainwater as a chemical agent of geological processes-A review, U.S. Geological Survey Water-Supply Paper 1535-G 18.
20. Sawyer CN, PL McCarty (1967) Chemistry for sanitary engineers, 2nd ed., McGraw-Hill, New York 518.
21. Amadi AN, Olasehinde PI, Yisa J, Okosun EA and Nwankwoala HO, et al. (2013) Geostatistical Assessment of Groundwater Quality from Coastal Aquifers of Eastern Niger Delta, Nigeria. Geosciences 2: 51-59.
22. American Public Health Association (APHA) (2005) Standard methods for examination of water and wastewater". American Public Health Association, 21th Edition, Washington DC 4-144.
23. Hem JD (1970) Study and interpretation of the chemical characteristics of natural water, 2nd ed., U.S. Geological Survey Water-Supply Paper 1473: 363.
24. Macklin MG, Brewer PA, Balteanu D, Coulthard TJ and Driga B, et al. (2003) The long-term fate and environmental significance of contaminant metals released by the January and March 2000 mining tailings dam failure in Maramures County, upper Tisa basin, Romania. Applied Geochemistry 18: 241-257.
25. Nwawuike N, Ishiga H (2018) Geochemical Evaluation of Surface Sediments in Niger Delta Mangrove, Nigeria. Journal of Environment and Earth Science 8.

26. Piper AM (1944) A graphic procedure in the geochemical interpretation of water-analyses, Trans. Amer. Geophysical Union 25: 914-928.
27. Schoeller H (1962) Les eaux souterraines, Masson & Cie, Paris 642.
28. Sefie A, Aris AZ, Shamsuddin MKN, Tawnie I and Suratman S, et al. (2015) Hydrogeochemistry of groundwater from different aquifer in Lower Kelantan Basin, Kelantan, Malaysia. Procedia Environmental Sciences 30: 151-156.
29. Stiff HA Jr (1951) The interpretation of chemical water analysis by means of patterns, Jour. Petr. Technology 3: 15-17.