

World News of Natural Sciences

An International Scientific Journal

WNOFNS 65 (2026) 276-298

EISSN 2543-5426

Surface Water Quality Assessment of Offshore Field Y Using Geo-Spatial Interpolation and Mapping

Shaibu Abdurlrasheed¹, Izeze Ovie^{1,*}, Felix Oluranti Okeowo²

¹ Department of Geology, Federal University of Petroleum Resources, Effurun, Nigeria

² Department of Mining Engineering, Federal Univeristy of Technology, Akure, Nigeria

*E-mail address: izeze.ovie@fupre.edu.ng

ABSTRACT

Surface water quality assessment is essential for effective environmental management, particularly in oil-producing regions such as the Niger Delta, Nigeria. This study evaluates the physicochemical and trace metal characteristics of surface water in Offshore Field Y using geospatial interpolation and mapping techniques. Water and sediment samples were collected monthly from ten sampling locations within the study area and analyzed for key water quality parameters, including pH, temperature, electrical conductivity, total dissolved solids (TDS), biochemical oxygen demand (BOD), nutrients (nitrate, phosphate, sulphate, ammonium), major ions (calcium and magnesium), and trace metals (chromium, lead, and arsenic). Standard analytical procedures in accordance with ASTM and APHA guidelines were employed. Geographic coordinates of sampling points were acquired using GPS, and spatial distribution maps of selected parameters were generated using Geographic Information System (GIS) techniques to identify pollution trends and hotspots. The results reveal spatial variations in surface water chemistry influenced by natural geological controls, hydrological processes, and anthropogenic activities such as oil exploration, urbanization, and agricultural practices. Some parameters showed localized elevations relative to World Health Organization (WHO) guidelines, indicating potential environmental and public health concerns. The integration of geochemical analysis with geospatial mapping proved effective in visualizing water quality patterns and identifying areas of high pollution risk. This study provides baseline data for Offshore Field Y and underscores the importance of continuous monitoring and sustainable management of surface water resources in the Niger Delta.

Keywords: Niger Delta, Geographic Information System, World Health Organization, Standard analytical procedures, Surface water quality assessment

1. INTRODUCTION

The Niger Delta Province contains a single recognized petroleum system, known as the Tertiary Niger Delta (Akata–Agbada) petroleum system. The development of the delta is linked to a rift triple junction associated with the opening of the South Atlantic Ocean, which commenced in the Late Jurassic and continued through the Cretaceous period. Significant deltaic sedimentation began during the Eocene, resulting in the accumulation of sedimentary sequences exceeding 10 km in thickness. The lithostratigraphy of the Niger Delta Basin is comprised of three formations which are the basal Akata formation, the middle Agbada formation and topmost Benin formation. Hydrocarbon generation within the basin is primarily attributed to the upper Akata Formation, which comprises marine shale facies that serve as the principal source rock. Additional hydrocarbon input may originate from interbedded marine shales within the lowermost Agbada Formation.

Petroleum production is largely derived from sandstone reservoirs within the Agbada Formation. However, turbidite sand bodies within the upper Akata Formation represent prospective exploration targets, particularly in deep offshore settings and potentially beneath existing onshore producing intervals (Michele et al., 1999). Climatically, the study area is situated within a humid equatorial tropical zone influenced by its proximity to the Gulf of Guinea. The region experiences a pronounced wet season between April and October, followed by a dry season extending from November to March. From a geological perspective, the study area and its surrounding environment fall within the freshwater zone of the Niger Delta and are predominantly of Miocene age. The aim of this research was to ascertain the concentration of Pollutant of surface water in offshore, Niger-Delta, Nigeria. The objectives of this research were to understand the natural factors that control surface water chemistry, decipher how spatial and temporal patterns in surface water chemistry occur, explain how water use by humans leads to a deterioration in water quality, define the different sources of pollution to surface waters and discern how changes in agricultural practices and urbanization affect water quality. The research answered the question of how does the application of geo-spatial interpolation techniques (e.g., IDW, Kriging) impact the accuracy of surface water quality mapping in offshore Field Y, and what are the implications for environmental monitoring and management.

Hydrogeological water quality analysis is commonly based on four major methodological approaches. These include direct inspection of chemical data combined with simple mathematical and statistical treatments to identify similarities among water samples, spatial and temporal interpolation or extrapolation using geostatistical techniques, and the use of graphical and cartographic tools such as plots, maps, and diagrams to illustrate hydrochemical relationships. Among these approaches, multivariate statistical methods are particularly important in hydrogeochemical studies. These techniques enable large datasets to be summarized in a compact and interpretable form, serving as an initial step in comprehensive data analysis and facilitating the formulation of hypotheses related to hydrogeochemical processes (Güler & Thyne, 2002). Cluster analysis is one of the most effective multivariate tools for interpreting water chemistry data, as it allows water samples to be classified into

distinct hydrogeochemical groups that may reflect geological controls, groundwater flow paths, or sources of contamination. The method assumes that the variables exhibit homoscedasticity and follow a normal distribution (Krantzberg et al., 2010). Another widely applied multivariate technique is Principal Component Analysis (PCA), which reduces the dimensionality of complex datasets by transforming correlated variables into a smaller number of independent components. These components can be displayed in low-dimensional space, typically two dimensions, providing insights into the structure and controlling factors of the hydrochemical data matrix (Güler & Thyne, 2002).

Extensive research has been conducted on heavy metal contamination in urban and industrial environments, both globally and within Nigeria. Much of the understanding of the geology, economic significance, and environmental challenges of the Niger Delta Basin is derived from the works of researchers such as Reymont (1965), Short and Stauble (1967), Kogbe (1976), Onyeagocha (1980), and more recent studies by Akujieze and Irabor (2014). Studies in Benin City by Erah et al. (2002) revealed elevated concentrations of heavy metals and faecal coliforms in groundwater sources, indicating significant public health risks. Similarly, Ighere et al. (2014) assessed the physicochemical properties of River Jamieson and found that most parameters complied with WHO standards, although continued monitoring was recommended to prevent future degradation. Investigations in Yenagoa by Nwankwoala et al. (2014) identified elevated concentrations of several heavy metals above permissible limits, which were attributed to industrial effluents and oil-related activities. Akujieze and Irabor (2014) also documented contamination of soils and groundwater around the Benin West Moat, highlighting the environmental risks associated with improper waste disposal. Amadi (2011) demonstrated that leachates from the Aladimma dumpsite adversely affected nearby soils and shallow groundwater, with multivariate factor analysis identifying multiple pollution sources and confirming poor groundwater quality.

Several studies outside Nigeria further illustrate the applicability of hydrogeochemical methods. Oki and Akana (2016) reported that groundwater in Yenagoa is predominantly of the calcium–chloride type and generally suitable for domestic use with minor treatment. Olobaniyi and Owoyemi (2016) applied factor analysis to characterize groundwater facies in the Warri area, linking chemical variations to geological and geochemical processes. Other international studies from India, Vietnam, and Kashmir Valley demonstrated that groundwater chemistry is largely controlled by rock–water interactions, weathering processes, and hydrological flow patterns (Jeelani et al., 2014; Thuy et al., 2014; Ramkumar et al., 2009). Under natural conditions, surface water chemistry is primarily influenced by atmospheric inputs, rock weathering, and climatic factors such as evaporation and precipitation (Gibbs, 1970; Meybeck et al., 1996). Calcium and bicarbonate dominate the dissolved load of most global rivers, reflecting the widespread influence of bedrock weathering (Meybeck, 1981; Walling & Webb, 1986).

Climate change plays a crucial role by regulating weathering rates and solute concentration through dilution or evaporation, while seasonal and storm-related hydrological changes can cause short-term fluctuations in solute concentrations. Biological processes also strongly influence surface water quality. Photosynthesis and respiration control variations in dissolved oxygen and pH, while agricultural practices introduce nutrients, pesticides, and organic matter into water bodies. Nitrate and phosphate from fertilizers and livestock waste contribute to eutrophication and water quality deterioration (Jarvie et al., 2007; Hatch et al., 2002). In addition, acidification resulting from atmospheric pollution can mobilize toxic metals

such as aluminum, posing severe risks to aquatic ecosystems (Schindler, 1988; Jackson & Jackson, 2000). Hence, water quality assessment relies on both chemical and biological indicators. While chemical analyses identify pollutant concentrations, biological monitoring methods such as the Biological Monitoring Working Party (BMWP) system assess ecological impacts (Armitage et al., 1983). The combined use of these approaches provides a comprehensive framework for evaluating surface and groundwater quality, understanding pollution sources, and supporting sustainable water resource management.

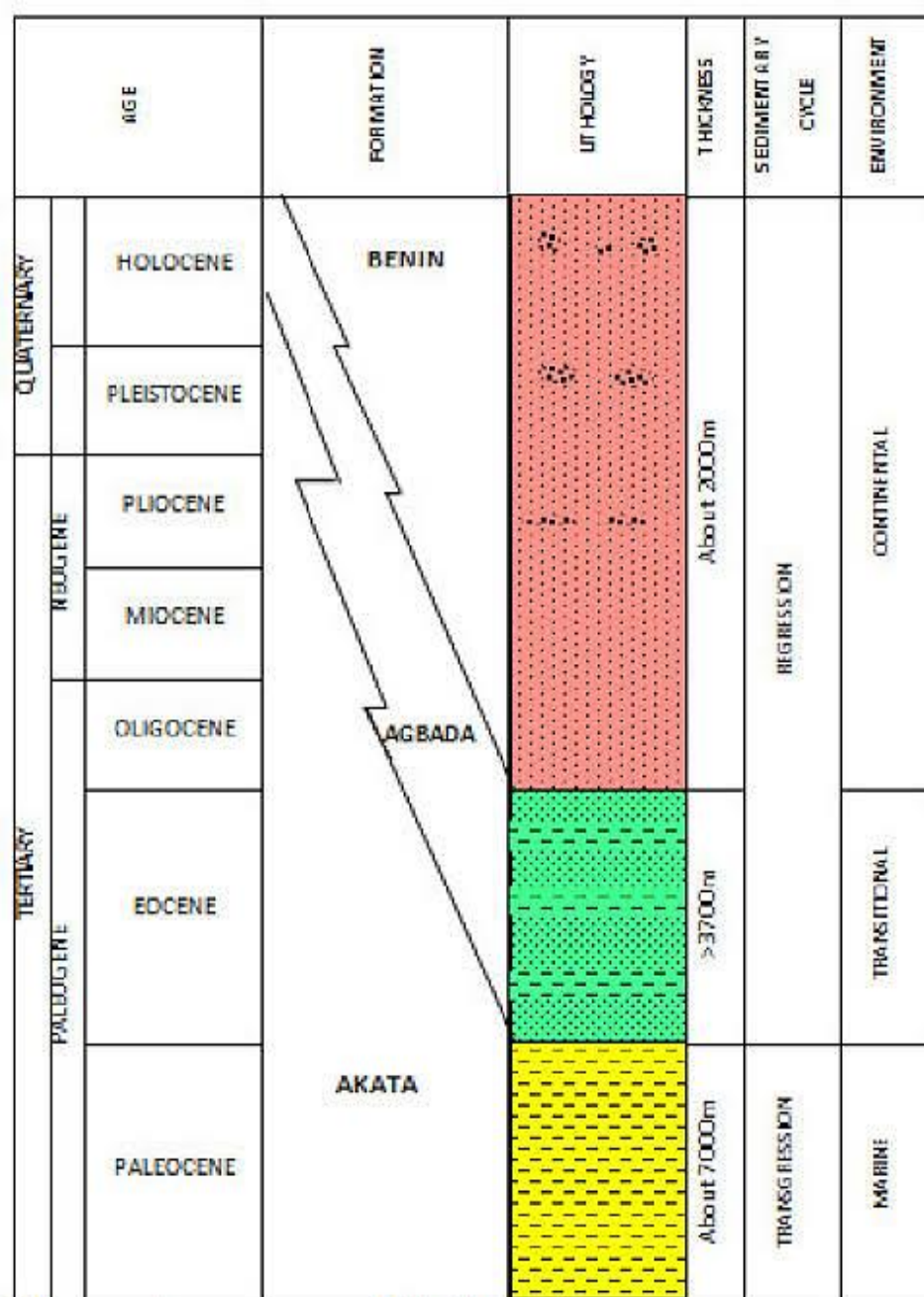


Figure 1. Lithostratigraphy of the Niger Delta.

Here, this research focuses on identifying areas of high pollution risk and recommending strategies for mitigation and management, while demonstrating the application of geo-spatial analysis and mapping in environmental monitoring and management of offshore fields.

Specifically, the study (1) assesses surface water quality in offshore field Y using geo-spatial interpolation techniques, and (2) evaluates the effectiveness of different interpolation methods (e.g., Inverse distance weighting (IDW), and Kriging) in capturing spatial variability of water quality parameters. The remainder of this paper is organized as follows. Section 2 describes the materials and methods; Section 3 presents the results; Section 4 discusses the findings; and the conclusion of the study is provided in section 5.

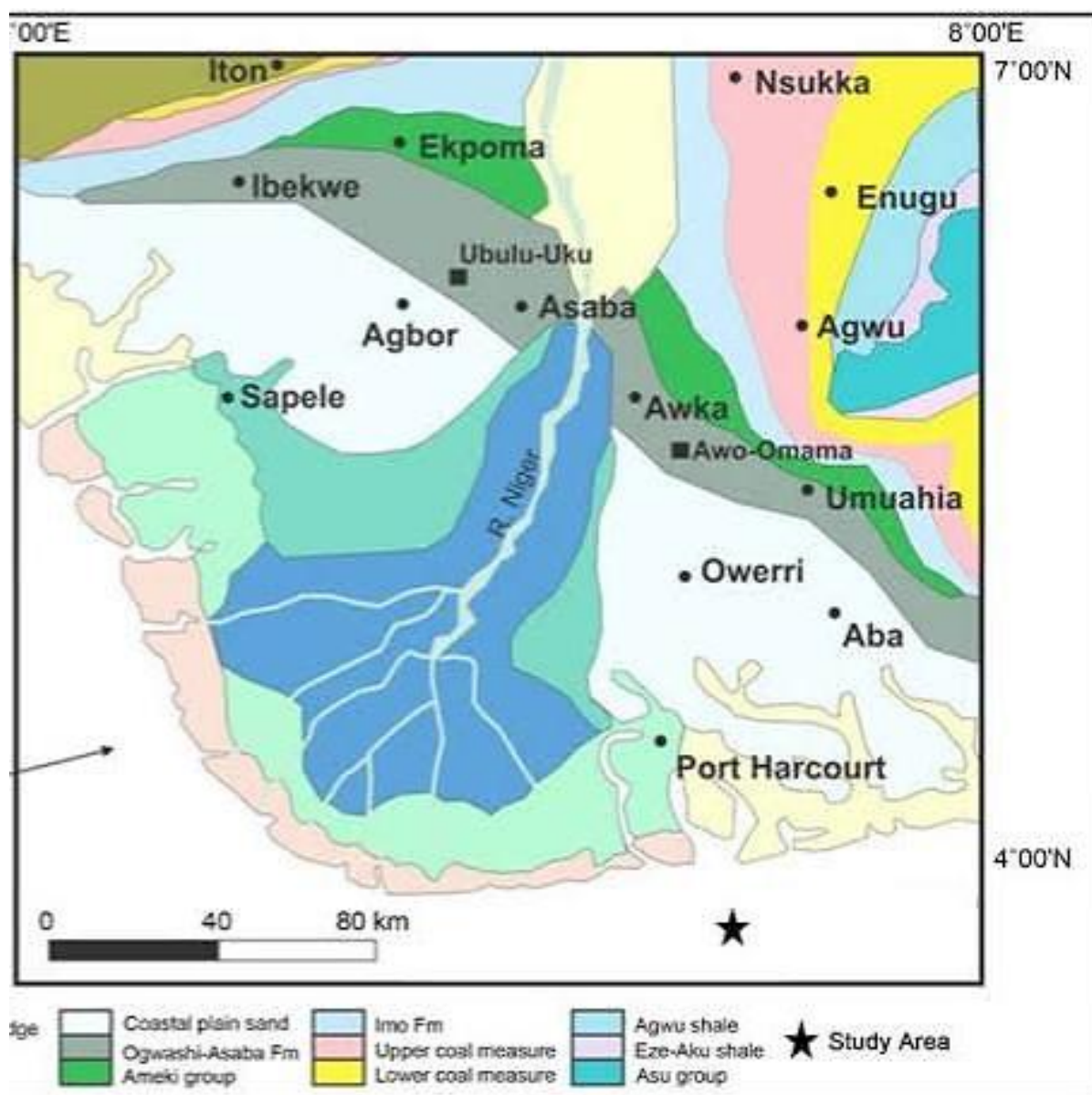


Figure 2. Map of the Study area indicating the location of the study area by a dark star.

2. MATERIALS AND METHODS

This study comprised field reconnaissance and geotechnical investigations involving the random collection of water samples from the southwestern region of Nigeria. The sampling strategy, spatial distribution of sampling locations, as well as the equipment, materials, and analytical techniques used for the determination of various geochemical parameters are described in detail.

2. 1. Sampling



Figure 3. Study area where the samples were collected

Table 1. Showing the coordinates of the Study area.

S/N	SAMPLING POINT	LATITUDE	LONGITUDE
1	Point 1	4.9716782	5.55356051
2	Point 2	4.9743353	5.55017587
3	Point 3	4.9832961	5.54850237

4	Point 4	4.9834673	5.54876534
5	Point 5	4.9746419	5.55060491
6	Point 6	4.9810768	5.54876543
7	Point 7	4.9809328	5.55278755
8	Point 8	4.9835674	5.55256743
9	Point 9	4.9824567	5.55238976
10	Point 10	4.9823457	5.54523489

Water and sediment samples were obtained on a monthly basis from each of the ten designated sampling locations within the study area. Surface water samples were collected using 350 mL high-density polyethylene (HDPE) bottles, which were pre-rinsed twice with site water prior to sample collection. Sediment samples were collected using a plastic pipe to scoop surface sediments and were stored in clean, sterile polyethylene bags. All samples were securely sealed and transported in an ice chest to the laboratory for subsequent analysis.

2. 2. Water Sampling Procedure

Water sampling was carried out using a random sampling approach within a major city in the study area. A total of ten (10) water samples were collected from selected locations. Samples were obtained using new 1-litre opaque polyethylene containers, which were thoroughly rinsed with the sampled water prior to collection. To preserve the samples and prevent the adsorption or precipitation of heavy metals onto the container walls, two drops of concentrated nitric acid were added to each sample. Key physicochemical parameters, including temperature, pH, and electrical conductivity, were measured on-site using calibrated thermometers, pH meters, and conductivity meters. The geographic coordinates and elevation of each sampling point were recorded using a Global Positioning System (GPS). All samples were transported to the laboratory and analyzed within the recommended holding time to ensure data reliability.

During sampling, strict quality control measures were observed, including proper labeling of all samples with location, date, and flushing time, and careful filling of containers to avoid overfilling and contamination.

2. 3. Cleaning Procedure for Sampling Bottles

Polyethylene sampling bottles and caps were cleaned following a standard protocol. Initially, the bottles and caps were rinsed with tap water and filled with a 5% Decon 90 solution, shaken gently, and left to stand for at least two hours. Afterward, they were emptied and rinsed thoroughly with running tap water until no foam remained, followed by rinsing with deionized water. The bottles were then filled with a 1:1 nitric acid solution and allowed to stand for another two hours before being emptied and rinsed three times with deionized water. Finally, the bottles and caps were dried in an oven at 50 °C prior to use.

2. 4. Laboratory Analysis

Laboratory analyses were conducted at Dukoria International Ltd., a certified environmental services company providing analytical, hydrogeological, GIS, and safety services to the oil and gas and manufacturing industries in Nigeria. All analyses were performed following standard procedures outlined by the American Society for Testing and Materials (ASTM, 1969) and the American Public Health Association (APHA, 1989). Analyses commenced immediately upon sample arrival to minimize chemical alterations.

2. 5. Determination of Trace Elements

Trace metals of interest, chromium (Cr), lead (Pb), and arsenic (As) were analyzed using a computerized Varian 220 Flame Atomic Absorption Spectrophotometer. Calibration standards were prepared by diluting 1000 mg/L stock solutions to concentrations ranging from 0.1 to 10.0 mg/L. External calibration was applied using deionized water blanks and standard solutions. Metal concentrations in the samples were calculated from calibration curves after correcting for blank values.

2. 6. Determination of Nutrients and Major Ions

Phosphate concentrations were determined using the APHA ascorbic acid method, with absorbance measured at 680 nm using a UV–visible spectrophotometer. Nitrate levels were analyzed following ASTM procedures involving acid digestion and spectrophotometric measurement at 410 nm. Sulphate determination followed the APHA turbidimetric method using barium chloride. Calcium and magnesium concentrations were determined through EDTA titration in accordance with APHA standards, using appropriate indicators to detect endpoint color changes. Ammonium ions were analyzed using the phenate method, with absorbance measured at 635 nm after color development and calibration against prepared standards.

2. 7. Statistical Analysis

The results obtained from laboratory analyses were subjected to descriptive statistical analysis, including the determination of minimum, maximum, and mean values. Prior to sampling, all bottles were rinsed with borehole water, filled completely, tightly sealed to retain dissolved gases, properly labeled, and transported in ice chests to prevent contamination and chemical changes.

Sampling was conducted only under favorable weather conditions to avoid dilution or contamination from rainfall. Borehole depths were recorded where available, and a maximum of ten samples were collected per visit to minimize sample deterioration. GPS measurements were used to document sampling coordinates and elevations.

Due to the sensitivity of groundwater chemistry to environmental factors, several parameters including colour, pH, electrical conductivity, temperature, turbidity, alkalinity, and total suspended solids were measured and recorded in situ.

3. RESULTS AND DISCUSSION

Table 2. Statistical parameters for surface water.

Parameters	SW1	SW2	SW3	SW4	SW5
pH	6.8	5.9	5.79	5.34	6.8
EC, $\mu\text{s}/\text{cm}$	1600	1365	2056	462	751
TDS, mg/L	1024	873.6	1375.84	295.68	480.64
TSS, mg/L	23.17	18.36	21.32	20.15	16.83
Turbidity, NTU	26.36	20.36	19.59	17.65	20.36
Temperature, $^{\circ}\text{C}$	28.7	29.32	28.6	28.3	30.26
Alkalinity, mg/L	38.26	27.96	32.36	43.02	30.95
Sulphate, mg/L	22.35	19.58	30.2	45.36	28.01
Hardness, mg/L	29.35	27.02	15.85	25.89	35.98
Nitrite, mg/L	4.58	3.26	3.5	4.14	2.58

Table 3. Statistical parameters for surface water (continue).

Parameters	SW6	SW7	SW8	SW9	SW10	NUPRC/WHO permissible
pH	6.49	7.46	6.61	7.31	6.83	6.5 – 9.2
EC, $\mu\text{s}/\text{cm}$	342	531	654	235	409	NS
TDS mg/l	218.88	339.84	418.56	150.4	261.76	1500
TSS mg/l	14.69	22.02	19.36	17.36	13.8	NS
Turbidity, NTU	25.64	31.06	28.12	15.36	25.3	NS
Temperature $^{\circ}\text{C}$	32.01	28.03	27.06	28.6	27.9	NS
Alkalinity mg/l	28.25	29.45	30.26	35.16	37.06	NS
Sulphate mg/l	18.25	32.05	63.02	26.09	45.65	400
Hardness mg/l	30.96	36.95	31.08	24.52	16.56	NS
Nitrate mg/l	3.26	4.25	3.8	4.36	2.08	NS

Table 4. Statistical parameters for surface water.

Parameters	Min	Max	Mean
pH	5.37	7.46	6.26
EC, $\mu\text{s}/\text{cm}$	235	2056	1105
TDS, mg/L	150.4	1475.84	805.26
TSS, mg/L	13.8	23.17	18.5
Turbidity, NTU	17.65	31.06	22.7
Temperature, $^{\circ}\text{C}$	27.06	32.01	28.9
Alkalinity, mg/L	27.16	43.02	36.65
Sulphate, mg/L	19.58	64.03	38.52
Hardness, mg/L	15.85	36.95	24.53
Nitrite, mg/L	2.08	4.58	3.68
Oil and grease, mg/L	1.78	5.16	3.45
Ammonia, mg/L	0.86	7.02	3.02
Phosphorous, mg/L	0.35	51	25.03
Nitrate, mg/L	0.125	4.268	2.65
DO mg/L	2.06	4.1	3.02
BOD mg/L	2.9	4 1	3.4
Magnesium, mg/L	21.26	38 26	30.67
Sodium, mg/L	14.52	40.32	25.43
Potassium, mg/L	19.26	32.36	25.70
Calcium, mg/L	15.25	24.03	19.52
Iron, mg/L	2 04	11.25	7.89
Cadmium, mg/L	<0.001	<0.001	<0.001
Zinc, mg/L	0.14	0.365	0.26
Copper, mg/L	<0.001	0.15	0.05
Chromium, mg/L	<0.001	0.031	0.015

3. 1. Water quality assessment using QGIS

Water quality evaluation was carried out using the Quantum Geographic Information System (QGIS) to produce spatial distribution maps of the measured parameters. The Inverse Distance Weighted (IDW) technique was employed to model spatial variability in water quality, as it is well suited for studies with a relatively small number of sampling locations. Hydrogeochemical characterization of surface water within the study area was performed to assess its suitability for drinking purposes and to examine the possible sources and controls of heavy metal contamination in groundwater. The resulting water quality data were then spatially interpolated and mapped to highlight their distribution patterns across the study area.

3. 2. pH

Results from the analysis of water samples (SW1- SW10) show a range of values which are compared to the WHO (World Health Organization) standard for portable drinking water. Samples (SW1- SW10) were found to be within the range of the permissible limit set by WHO (6.5 – 9.5). The Surface water pH obtained from SW1 - SW10 are slightly acidic and basic in nature ranging from pH (5.34 – 7.46).

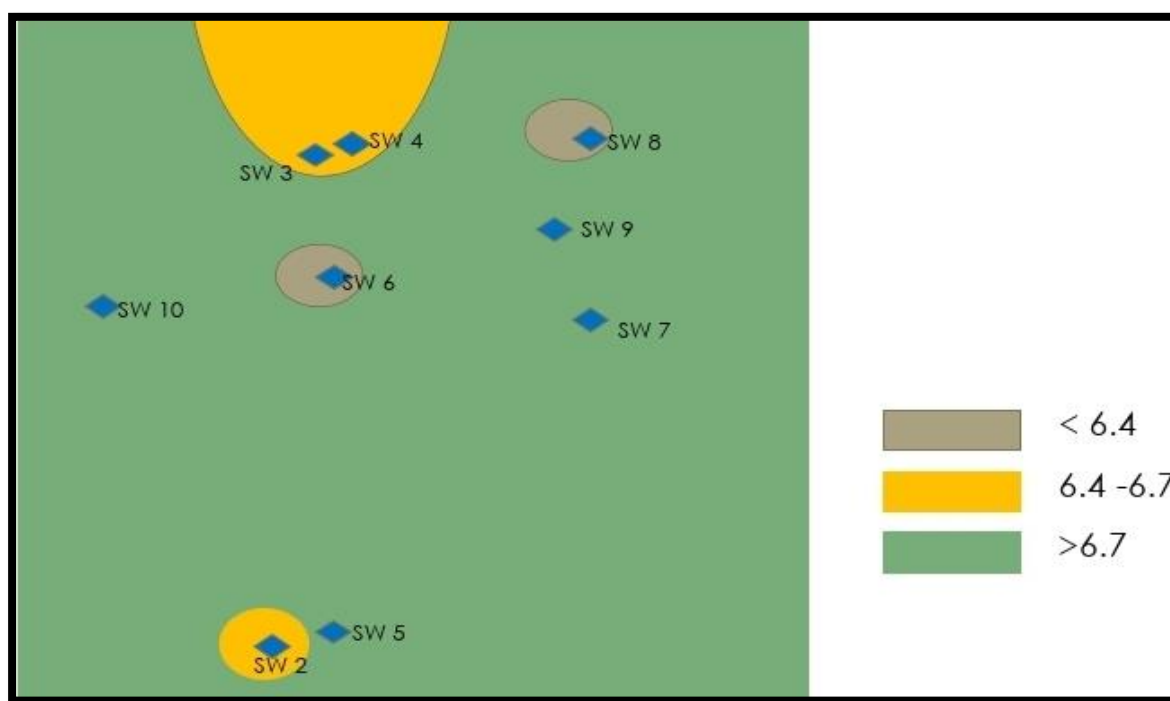


Figure 4. pH spatial distribution map of study area.

3. 3. Electrical Conductivity

The Electrical Conductivity observed on all water samples were found to be higher than the WHO standard for portable drinking. The value SW3 (2056 μ S/cm) was the highest observed in the study area, and the value of SW9 (235 μ S/cm) was the lowest. Both values are greater and lower than the WHO standard (500 μ S/cm) respectively hence, the water in study area is a cause for concern.

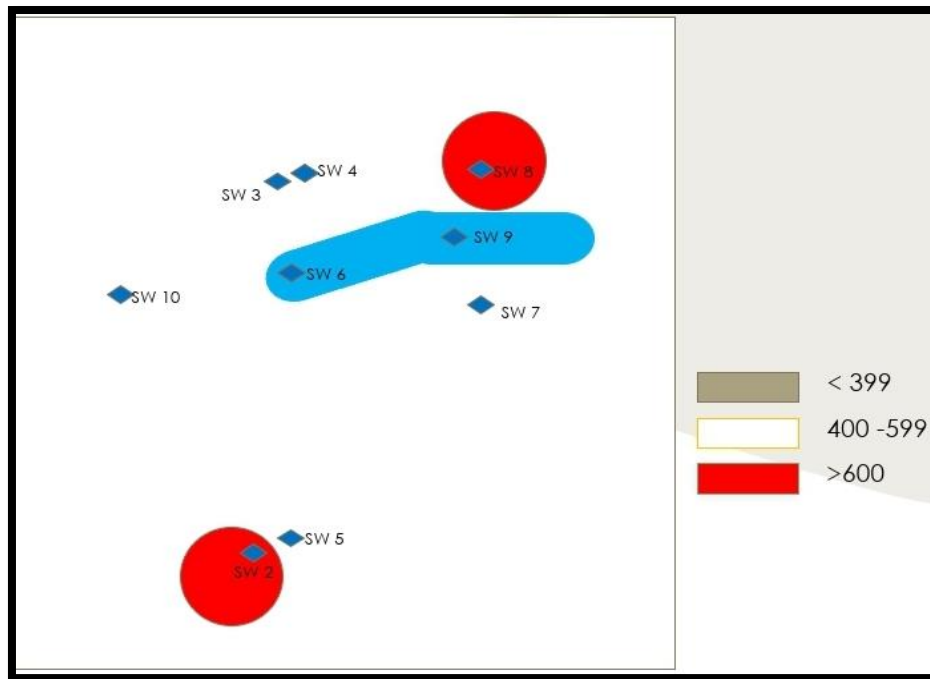


Figure 5. Spatial distribution map of electrical conductivity values in the study area.

3. 4. Total Dissolved solids

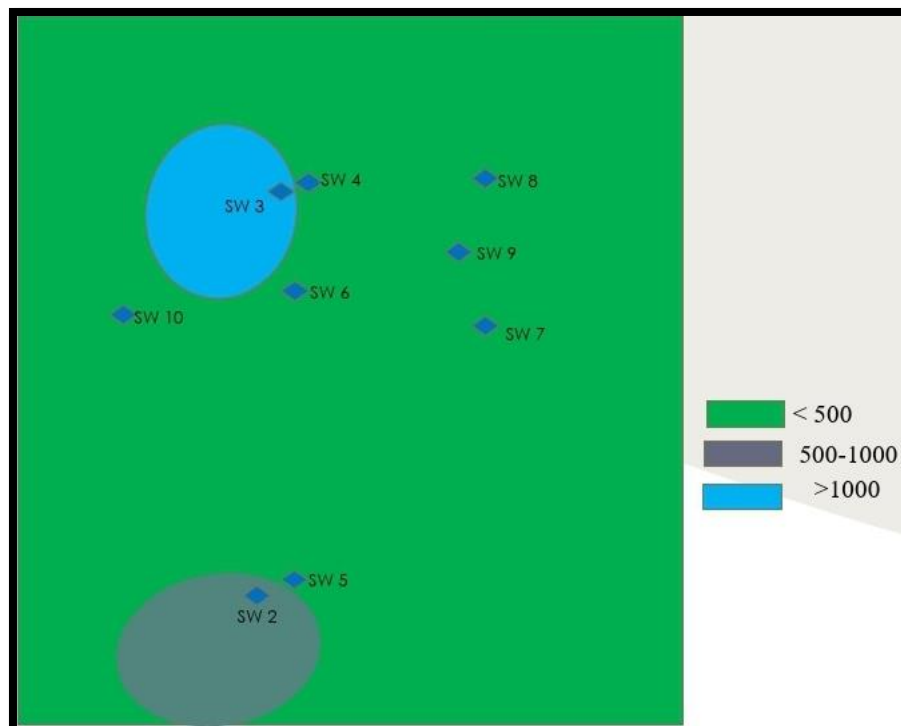


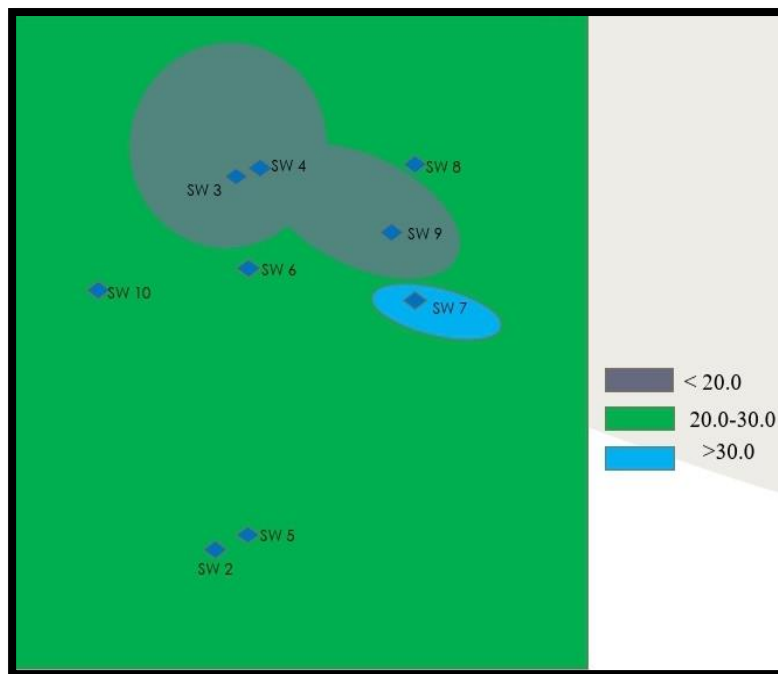
Figure 6. Spatial distribution map of Total Dissolved solids values in the study area.

Total Dissolved solids of each surface water sample were found to be major below WHO standard for portable drinking water and slightly about at SW 3 (1375.84 ppm).

3. 5. Turbidity

The Turbidity of each surface water sample was were found to be above WHO standard for portable drinking water.

Figure 7. Spatial distribution map of Turbidity values in the study area



3. 6. Temperature



Figure 8. Spatial distribution map of Temperature in study area.

The Temperature of each surface water sample was were found to be above WHO standard for portable drinking water (12 °C – 25 °C).

3. 7. Total Suspended Solids

Suspended Solids (TSS) observed on all samples were found to be above the WHO standard for portable drinking water hence the water is considered a concern for human intake.

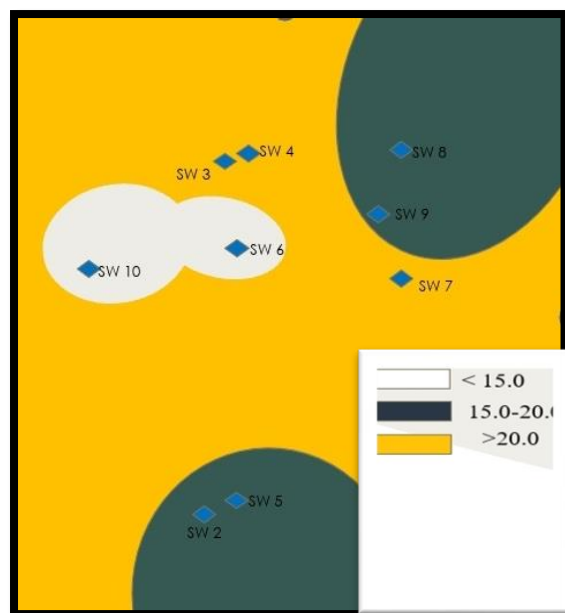


Figure 9. Spatial distribution map of total suspended solids in study area.

3. 8. Alkalinity

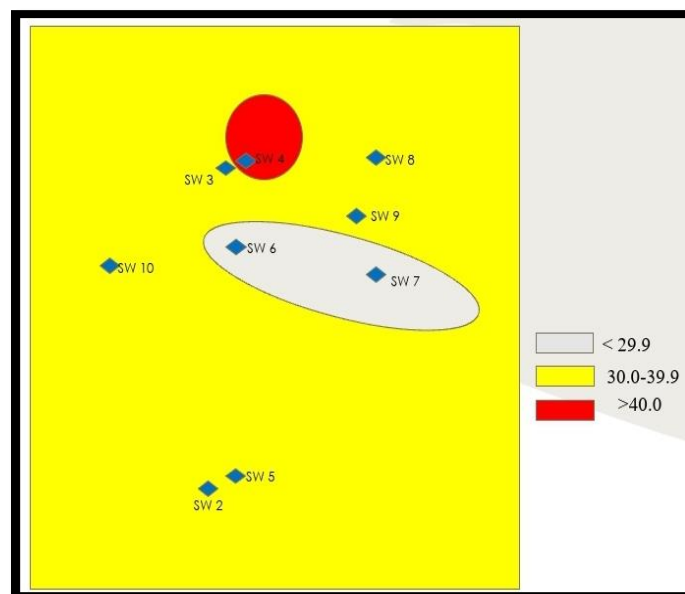


Figure 10. Spatial distributions of alkalinity within the study area.

Alkalinity in the study area range from 27.5 – 43.3 mg/l and according to WHO Standard, it should not exceed 250 mg/l. In terms of chlorine concentration, the groundwater is good for consumption.

3. 9. Sulphate

The WHO standard for sulphate in drinking water is 200 mg/l, in the study area, the sulphate concentrations in groundwater are within the standards and can be used as portable water.

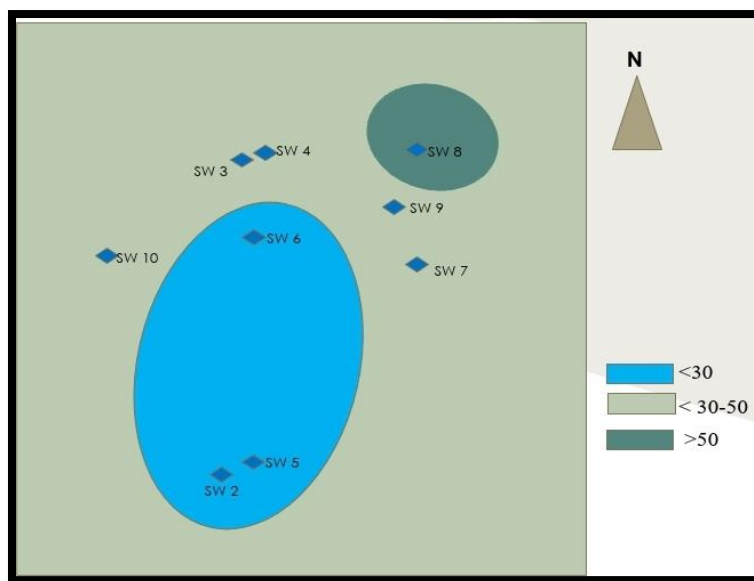


Figure 11. Spatial distribution map of sulphate concentrations within the study area.

3. 10. Sodium

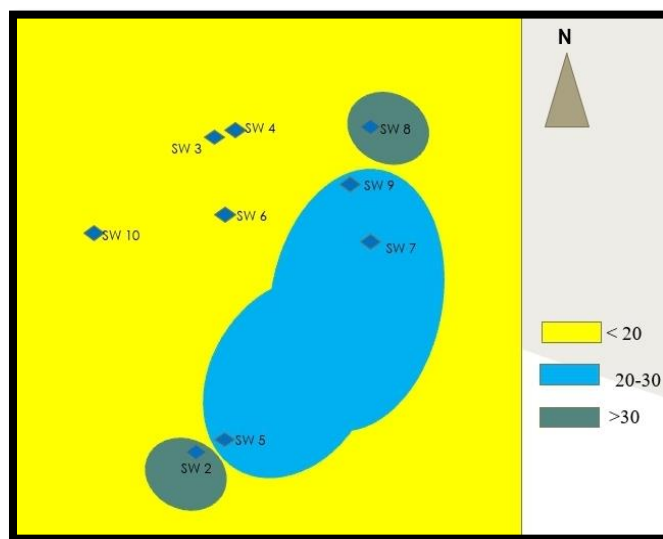


Figure 12. Spatial distribution map of sodium concentration within the study area.

Sodium concentration analyzed from the water samples gave values which did not exceed the limit set by the WHO standard. The values recorded range from 14.5 mg/l to 40.3 mg/l. The WHO standard for sodium in drinking water should not exceed 250 mg/l.

3. 11. Nitrate

In the study area, nitrate concentrations range between 0.15 – 4.2, naturally occurring levels do not exceed 4–9 mg/l for nitrate, thus within the acceptable limits of nitrate by WHO.

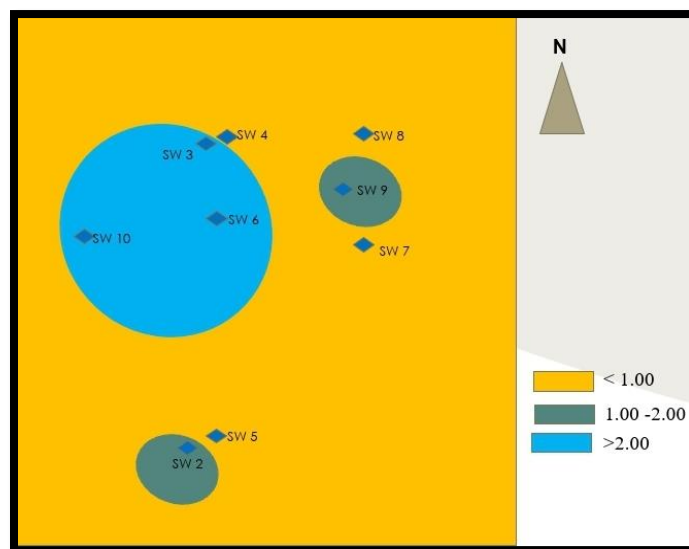


Figure 13. Nitrate spatial map of study area.

3. 12. Magnesium

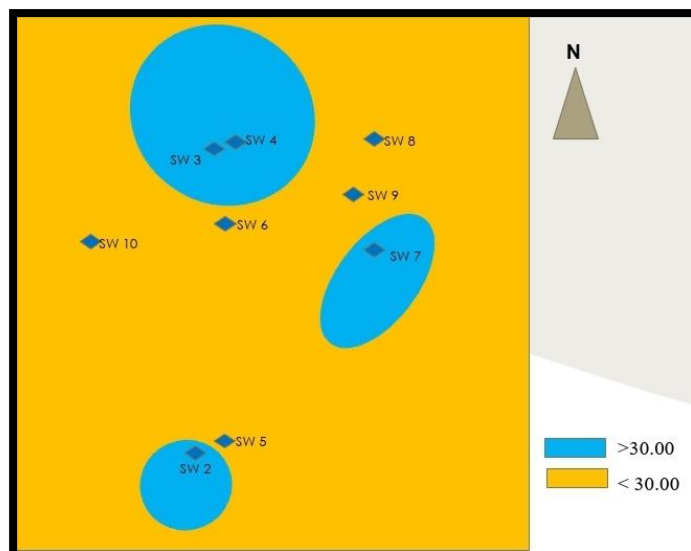


Figure 14. Spatial distribution map of magnesium in study area.

Magnesium concentrations observed in the study area did not exceed 38.2, this shows that magnesium concentration is relatively low in study area. According to W.H.O (World Health Organization), the limit for magnesium in drinking water is 100 mg/l.

3. 13. Iron

Iron was found to be in the analyzed water samples ranging from 5.8 – 11.25 The recorded permissible limit by WHO for iron is 0.3 mg/l and all the analyzed samples are above this value. Iron is mostly an aesthetic contaminant. The high value of iron in the surface water samples is probably responsible for a brownish tint in the colour of the water samples.

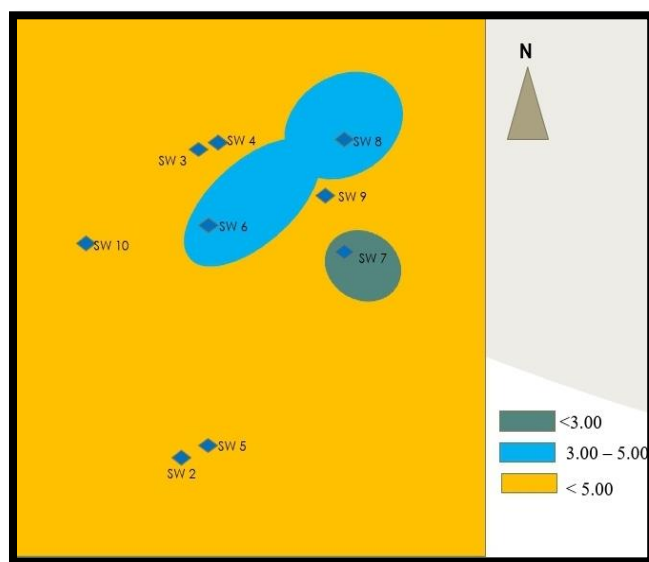


Figure 15. Spatial distribution map of iron concentration in study area.

3. 14. Copper

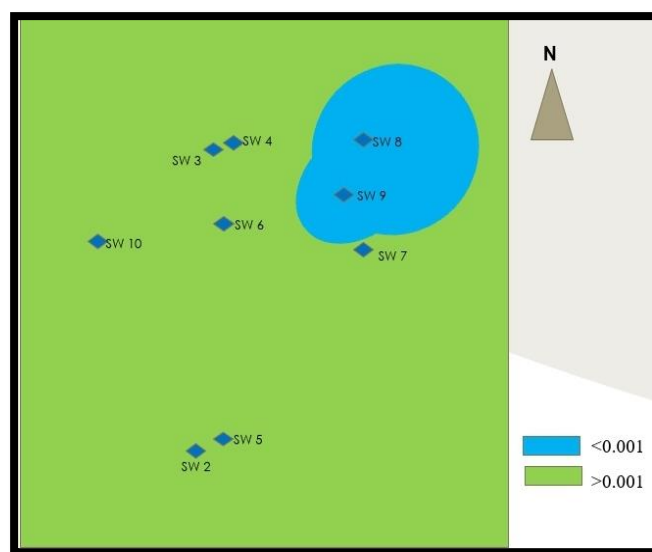


Figure 16. Spatial distribution map of copper in the study area.

Copper was found in the study area but did not exceed 0.009 mg/l. The recorded permissible limit by WHO for Copper is 0.50 mg/l and all the analyzed samples fall within this value.

3. 15. Cadmium

Cadmium was found in the study area but did not exceed 0.001 mg/l. The recorded permissible limit by WHO for chromium is 0.1mg/l and all analyzed samples fall within this value.



Figure 17. Spatial distribution map of Cadmium in the study area.

3. 16. Chromium

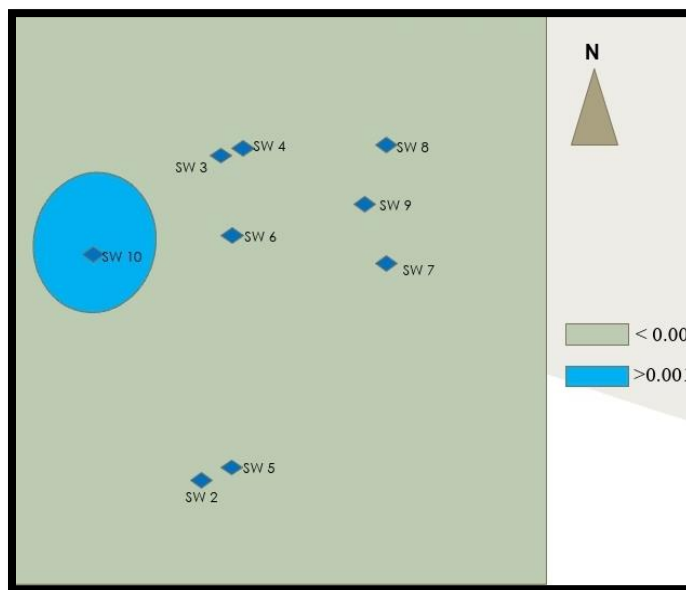


Figure 18. Spatial distribution map of Chromium in the study area.

Chromium as found in the study area but did not exceed 0.002mg/l. The recorded permissible limit by WHO for chromium is 0.1mg/l and all analyzed samples fall within this value.

3. 17. Hardness

The Hardness is usually measured in relation to the amount of calcium present in water. The total hardness of water samples measured in the study area had a maximum value of 36.95, which falls within the permissible limit of 500 given by WHO.

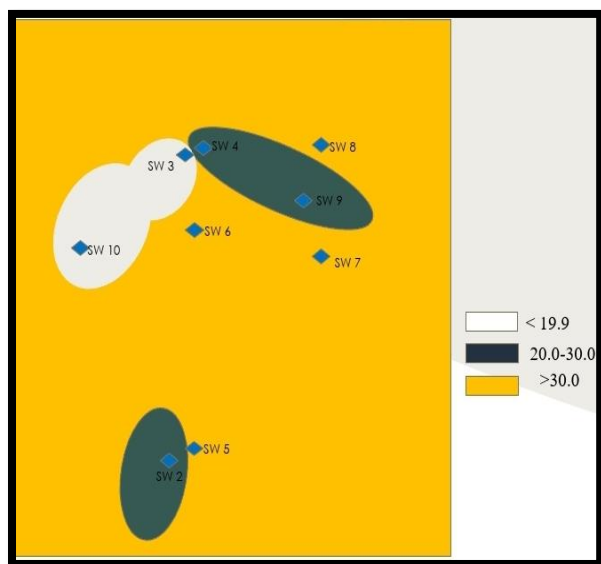


Figure 19. Spatial distribution map of hardness in study area.

3. 18. Spatial Analysis and Interpretation of Water Quality Parameters

The pH of the studied surface water samples ranges from 5.37 to 7.46 with a mean value of 6.70. This is within the acceptable limit of 6.5-8.5 stipulated by W.H.O, 2007. It is favorable for human activities and aquatic life. Consequently, anthropogenic activities within the study area may not have affected the pH level of the water. Electrical conductivity (EC) of the studied samples ranged from 235 to 2056 $\mu\text{S}/\text{cm}$. This is higher than the 500 $\mu\text{S}/\text{cm}$ permissible limit given by W.H.O. The high values of EC could be attributed to the presence of ions in the water. There are positive correlations between EC and Cl^- (0.620); EC and Mg^{2+} (0.8747); EC and SO_4^{2-} (0.769). The value EC in the study area is a reason for concern as it makes water unfit for drinking. The presence of Cl^- ion as a dominant parameter is of no surprise as it correlates positively with three other parameters.

The values of the Total Suspended Solids (TSS) of the studied samples varied between 13.8 to 23.17 mg/l, values higher than 0.01 recommended by W.H.O (2006). TSS is a dominant physical parameter in the water samples from the study area. High concentrations of TSS are often caused by excessive concentrations of phytoplankton, zooplankton, particles in storm water run-off and sediments. High TSS caused by sediments may affect oxygen concentrations. The suspended particles may also be endothermic there by increasing the water temperature.

This is seen in the correlation matrix as TSS and T(°C) have a positive correlation of 0.776. TSS can also affect the aesthetic appeal of water. Hence water might not be safe for drinking or other anthropogenic uses. The Total Dissolved solids is also a dominant physical parameter in the studied samples, with values ranging from 150.4 to 1375.85 which is lower than 1500 permissible limit as stated by W.H.O, 2006. High TDS in water may be due to high discharge of organic waste effluents into the water. Calcium is also a dominant parameter in the water samples from study area. The values in the study area ranges from 15.25 to 24.63 mg/l, which is within the W.H.O permissible limit.

Calcium is naturally present in water. It may dissolve from rocks such as limestone, calcite, marble etc. Surface water reaches even higher concentrations from Ca^{2+} ions from rocks and soils. Calcium is also a determinant of water hardness because it can be found in water as Ca^{2+} ions. Magnesium is the other water hardness determinant. From Iron values in studied water samples ranges from 2.04 to 11.25 mg/l. This is a lot higher than the 0.3mg/l permissible limit stipulated by W.H.O. (2006). Iron in surface water is normally present as ferrous iron, where it is soluble. It is also easily oxidized when exposed to the atmosphere, giving the water a brownish to orange colour. Iron has little effect on health or aquatic life. It is mostly an aesthetic contaminant.

4. CONCLUSIONS

The detailed assessment of surface water quality reveals a complex interaction between anthropogenic activities particularly, oil and gas exploration and the surrounding environment. Although pH values generally fall within internationally acceptable limits, further evaluation of electrical conductivity (EC), dominant ions such as chloride (Cl^-), and total suspended solids (TSS) indicates potential contamination sources associated with exploration activities. Elevated EC values and their positive correlations with specific ions suggest that oil and gas operations may significantly influence surface water chemistry, underscoring the need for focused investigations into the extent and nature of these impacts. The occurrence of TSS concentrations above recommended standards points to the direct effects of exploration-related activities, including sediment runoff and discharge from operational sites.

This highlights the necessity for improved sediment management strategies to reduce ecological disturbances and preserve water clarity. While total dissolved solids (TDS) values remain below permissible limits, their presence may reflect inputs from organic waste effluents linked to exploration processes, emphasizing the importance of effective waste handling and treatment practices within the industry. Variations in calcium, magnesium, and iron concentrations reflect both natural geological controls and possible alterations induced by exploration activities.

Elevated iron levels, although primarily an aesthetic concern, further stress the need for industry-led initiatives aimed at reducing environmental degradation.

The findings demonstrate that oil and gas exploration play a substantial role in shaping surface water quality. Addressing these challenges requires a coordinated and proactive approach involving continuous monitoring, targeted scientific research, strict adherence to environmental regulations, and the adoption of sustainable exploration practices. Achieving a balance between energy development and environmental protection is essential to safeguarding water resources for present and future generations.

Based on the findings of this study and with specific emphasis on oil and gas exploration activities, the following recommendations are proposed: Exploration-Specific impact assessment, Adoption of Advanced Waste Management Technologies, Implementation of Best Practices at Exploration Sites, Strengthened Monitoring Programs Regulatory Compliance and Collaboration, Stakeholder Engagement and Public Awareness, Research and Development for Sustainable Exploration and Industry-Wide Environmental Standards.

References

- [1] Akujieze, C. N., & Irabor, O. O. (2014). Impact of waste disposal on soil and groundwater quality in Benin West Moat, Nigeria. *Environmental Earth Sciences*, 72(1), 1–14
- [2] Amadi, A. N. (2011). Geochemical assessment of the impact of Aladimma dumpsite on soil and groundwater quality in Owerri, southeastern Nigeria. *Journal of Applied Sciences and Environmental Management*, 15(1), 105–113
- [3] American Public Health Association (APHA). (1989). Standard methods for the examination of water and wastewater (17th ed.). Washington, DC: APHA.
- [4] American Society for Testing and Materials (ASTM). (1969). Annual book of ASTM standards. Philadelphia: ASTM.
- [5] Armitage, P. D., Moss, D., Wright, J. F., & Furse, M. T. (1983). The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research*, 17(3), 333–347
- [6] Burns, D. A., Murdoch, P. S., Lawrence, G. B., & Michel, R. L. (2006). Effect of groundwater springs on NO_3^- concentrations during summer in Catskill Mountain streams. *Water Resources Research*, 42(9), W09401
- [7] Chapman, P. J., Edwards, A. C., & Cresser, M. S. (1993). The nitrogen composition of streams in upland Scotland: Some implications of changes in land use. *Hydrological Processes*, 7(2), 133–142
- [8] Doust, H., & Omatsola, E. (1989). Niger Delta. In J. D. Edwards & P. A. Santogrossi (Eds.), *Divergent/passive margin basins* (AAPG Memoir 48, pp. 201–238). Tulsa, OK: AAPG
- [9] Driscoll, C. T., Likens, G. E., & Church, M. R. (1989). Recovery of surface waters in the northeastern United States from decreases in atmospheric deposition of sulphur. *Water, Air, and Soil Pollution*, 45(3–4), 319–329
- [10] Erah, P. O., Akujieze, C. N., & Oteze, G. E. (2002). The quality of groundwater in Benin City: A baseline study on inorganic chemicals and microbial contaminants of health importance in boreholes and open wells. *Tropical Journal of Pharmaceutical Research*, 1(2), 75–82
- [11] Gibbs, R. J. (1970). Mechanisms controlling world water chemistry. *Science*, 170(3962), 1088–1090

- [12] Güler, C., & Thyne, G. D. (2002). Hydrologic and geologic factors controlling surface and groundwater chemistry in Indian Wells–Owens Valley area, southeastern California, USA. *Journal of Hydrology*, 285(1–4), 177–198
- [13] Hatch, D. J., Jarvis, S. C., Parkinson, R. J., & Johnson, A. E. (2002). Nitrogen dynamics in grazing systems. *Grass and Forage Science*, 57(2), 121–135
- [14] Hinton, M. J., Schiff, S. L., & English, M. C. (1992). Sources and flowpaths of dissolved organic carbon during storms in two forested watersheds of the Precambrian Shield. *Biogeochemistry*, 18(3), 175–197
- [15] Ighere, J. O., Odiwe, A. I., & Omorogieva, O. M. (2014). Assessment of physicochemical parameters of River Jamieson, Nigeria. *Journal of Applied Sciences and Environmental Management*, 18(4), 643–648
- [16] Issa, B. R., Arimoro, F. O., Ibrahim, A. A., Birma, G. J., & Fadairo, E. A. (2010). Assessment of sediment contamination by heavy metals in River Orogo, Delta State, Nigeria. *Current World Environment*, 5(1), 29–38
- [17] Jackson, T. A., & Jackson, A. L. (2000). Aluminum speciation and toxicity in aquatic systems. *Environmental Toxicology and Chemistry*, 19(1), 1–9
- [18] Jarvie, H. P., Neal, C., & Withers, P. J. A. (2007). Sewage-effluent phosphorus: A greater risk to river eutrophication than agricultural phosphorus? *Science of the Total Environment*, 360(1–3), 246–253
- [19] Jeelani, G., Shah, R. A., & Bhat, N. A. (2014). Hydrogeochemical assessment of groundwater quality in Kashmir Valley, India. *Environmental Earth Sciences*, 71(10), 4477–4494
- [20] Kogbe, C. A. (1989). *Geology of Nigeria* (2nd ed.). Lagos: Rock View (Nigeria) Ltd.
- [21] Likens, G. E., Bormann, F. H., Johnson, N. M., Fisher, D. W., & Pierce, R. S. (1977). Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecological Monographs*, 47(1), 23–47
- [22] Meybeck, M. (1981). River transport of dissolved solids to the oceans: Present-day controls and global balance. *American Journal of Science*, 281(4), 401–427
- [23] Meybeck, M., Chapman, D., & Helmer, R. (1996). *Global freshwater quality: A first assessment*. Oxford: Blackwell.
- [24] Monteith, D. T., Evans, C. D., & Reynolds, B. (2000). Are temporal variations in nitrate concentrations in UK upland streams linked to the North Atlantic Oscillation? *Hydrological Processes*, 14(10), 1745–1749
- [25] Nwankwoala, H. O., Amadi, A. N., Oborie, E., & Ushie, F. A. (2014). Hydrochemical factors and correlation analysis in groundwater quality in Yenagoa, Bayelsa State, Nigeria. *Applied Water Science*, 4(3), 217–233
- [26] Olobaniyi, S. B., & Owoyemi, F. B. (2006). Characterization by factor analysis of the chemical facies of groundwater in the deltaic plain sands' aquifer of Warri, Western Niger Delta, Nigeria. *African Journal of Science and Technology*, 7(1), 73–81
- [27] Pearson, S. (1970). *Vegetation of the Niger Delta*. Ibadan: University of Ibadan Press.

- [28] Schindler, D. W. (1988). Effects of acid rain on freshwater ecosystems. *Science*, 239(4836), 149–157
- [29] Short, K. C., & Stauble, A. J. (1967). Outline of geology of Niger Delta. *AAPG Bulletin*, 51(5), 761–779
- [30] Wetzel, R. G. (2001). *Limnology: Lake and river ecosystems* (3rd ed.). San Diego, CA: Academic Press.
- [31] World Health Organization (WHO). (2017). *Guidelines for drinking-water quality* (4th ed.). Geneva: WHO.