KAMPALA INTERNATIONAL UNIVERSITY
KIU
Journal of Science, Engineering and Technology

KJSET Research Article

Geostatistical-based spatial distribution of in-situ groundwater quality parameters in the crystalline basement aquifer in urban and peri-urban city: A case study of Akure, Nigeria

Fadugba Olaolu George[1,2*]

[1]*Department of Civil and Environmental Engineering, Federal University of Technology, Akure Nigeria*
[2]*Department of Civil Engineering, Kabale University, Kabale Municipality, P.O Box 317, Kabale, Uganda.*
ogfadugba@futa.edu.ng , ogfadugba@kab.ac.ug

Corresponding Author: ogfadugba@kab.ac.ug

Paper history:
Received 20 April 2025
Accepted in revised form 29 May 2025

Keywords
Groundwater; Geospatial; Crystalline basement; pH distribution; Electrical Conductivity; Total Dissolved Solid.

Abstract

This study examines the spatial distribution of in-situ groundwater quality parameters in the crystalline basement aquifer in Akure City, Nigeria using geostatistical methods. The area was divided into urban and peri-urban areas. Water samples were taken to the laboratory for characterization of the water quality parameters in the water samples obtained in the study area. The oil/water interphase meter was used to determine the depth to the surface of the selected wells in the study area. The depth of the well is between 3.07 and 7.03 meters. The well depth was divided into four categories: Low (3.07 to 7.03 m), Moderate (4.88 to 5.05 m), High (5.06 to 5.22 m), and Very High (5.23 to 7.03 m). Four categories were used to classify the well depth: Low (2.27 to 4.18 m), Moderate (4.19 to 4.29 m), High (4.30 to 4.41 m), and Very High (4.42 to 6.32 m). The pH scale is 5.48 to 6.71. Four pH ranges were identified: Low (5.48 to 5.91), Moderate (5.92 to 6.20), High (6.21 to 6.41), and Very High (6.42 to 6.71). Four categories were assigned to the ORP: Low (29.71% to 45.63%), Moderate (45.64 percent to 57.42%), High (57.43 percent to 66.16%), and Very High (66.17 percent to 77.95%). There were four categories for the Electrical Conductivity distribution (EC): Low (100.64 µS/cm to 242.50 µS/cm), Moderate (242.51 µS/cm to 347.61 µS/cm), High (347.52 µS/cm to 425.49 µS/cm), and Very High (425.50 µS/cm to 483.20 µS/cm). There were four categories for the Total Dissolved Solid (TDS): Low (50.87 ppm to 120.75 ppm), Moderate (120.76 ppm to 172.53 ppm), High (172.54 ppm to 210.89 ppm), and Very High (210.90 ppm to 239.32 ppm).

1.0 Introduction

Generally, groundwater is regarded as one of the most significant natural resource that people worldwide can access. Since it is an extremely important resource for human survival, it has a big impact on how a country's economy is shaped, especially in areas that are prone to drought, which includes a large portion of Sub-Saharan Africa and other places where there is less rain throughout the year (Lapworth, *et.al*., 2017).

Groundwater has been extensively used for residential, agricultural, and industrial purposes over the years, primarily through boreholes (Adabanija, *et.al*., 2020). Over 60% of the world's population relies on groundwater as their primary supply of drinking water, while it is estimated that 70% of groundwater extracted globally is utilized for agriculture (Nas 2009). These numbers keep rising as a result of rising water demands, global population growth, and fast industrialization that gradually depletes surface water supplies. Notably, the global groundwater usage has changed over time between 1950 at 124 m^3 per capita, rising to 152 m^3 in 2021 (Loaiciga & Doh, 2023).

Due to growing demand and excessive exploitation from groundwater resources, the quality of groundwater resources has deteriorated over time (Maroufpoor, *et.al*., 2017). The interplay of geology, hydrogeology, topography, hydrometeorology, and human activity can be used to characterize or drive the decline in groundwater quality. The composition of recharge water, mineral dissolution, water-soil interactions, chemicals, and groundwater residence duration are only a few examples of natural (geogenic) factors that can affect the quality of groundwater resources. Groundwater quality is also greatly influenced by other external variables, such as point and nonpoint pollution sources brought on by human activity (Saha, & Paul, 2019; Falowo *et. al.,*2019; Anku *et. al.,* 2008). Depending on hydrogeological interactions, groundwater contamination may persist for years or decades and might be challenging to detect. Therefore, to implement the best possible organization and management of groundwater resources, it is essential that constant monitoring of the quality of the groundwater is carried out (Karami, *et al*., 2018)

Groundwater resource management has found significant success recently with the use of Geographic Information Systems (GIS) in geostatistical analysis of groundwater facies and quality metrics. Other scientific fields, such as soil sciences, environmental sciences, and structural engineering, have also found success with the use of GIS and geostatistical analysis. Site suitability analysis, site inventory data management, groundwater vulnerability estimation, groundwater flow modeling, solute and leaching transport, groundwater pollution source location, and spatial variation/distribution prediction using groundwater quality assessment models to develop spatial decision support systems are all common uses of GIS in hydrogeological studies (Engel & Navavulur, 1999).

A substantial amount of high-quality geographical and non-spatial data must be available to conduct a reliable analysis of groundwater quality characteristics. Spatial and spatiotemporal phenomena can be analyzed and represented using geostatistics. It takes advantage of statistical techniques to provide accurate predictions and depiction of the continuity of the high-quality groundwater quality parameters data over a given spatial or spatiotemporal boundary (Paramasivam 2019)

Groundwater availability in the crystalline aquifer rock region under study is mostly dependent on the presence of faulted, worn, or fractured rocks. By drilling boreholes through basement aquifers, groundwater resources in this area have been accessed. Groundwater is also reached by both protected and unprotected dug water wells in various rural or peri-urban areas of the state. This type of aquifer can provide high-quality groundwater, but it is also susceptible to contamination from domestic, industrial, and agricultural sources, particularly the shallow aquifers in this area.

In the Southwestern part of Nigeria, groundwater sources have been used as remedial alternatives to the largely unusable functional and developed surface water systems; however, geotechnical and water engineers continue to face difficulties in developing groundwater resources and managing contaminants in these areas (Obiadi, *et al*., 2012) The majority of Akure people now primarily rely on groundwater for their water needs because surface water has remained exposed to significant pollutants from careless waste management due to population growth and rapid industrialization in the majority of the peri-urban area. It is also impossible to ignore human activity in the state's many regions. Numerous studies have thoroughly examined the potential environmental impact of leachate formation resulting from practices like the careless disposal of municipal waste and the frequent release of industrial effluents. Roughly 90% of the state's urbanized population is thought to be dependent on groundwater in one way or another. (Ali, 2018; Retna *et al*., 2021; Rena *et al*., 2019; Ojuri *et al*., 2018)

According to a study by Adewumi & Babatola (2010), more than half of the population was estimated to be dependent on water from hand-dug wells. Over 12% of the population only used borehole water, while another 28% used both tap and well water. The acquired water is mostly used for irrigation in agriculture and home settings. The state's socioeconomic growth is at risk, in addition to crop production and human health, due to the further degradation of this water source brought on by the presence of hazardous chemicals (Falowo *et. al.,*2019; Anku *et. al.,* 2008). Infections linked to water, sanitation, and hygiene cause over 335,200 fatalities in Nigeria each year, accounting for 16.7% of all deaths. This is demonstrated by the World Health Organization's country-by-country data on the worldwide burden of fatalities associated with water, sanitation, and hygiene. Many daily activities contribute to groundwater pollution, and people in society don't care about the environment. Following the developing discipline of Geo-environmental engineering, it is necessary to comprehend and be knowledgeable about the physicochemical properties of our groundwater throughout the year to achieve Goal 6 (Ensure availability and sustainable management of water and sanitation for all) of the United Nations' 2030 Agenda for Sustainable Development Goals (SDGs).

2.0 Materials and Methods

2.1. Study Area

The study area is situated in the southwest region of Nigeria, in Akure, the capital of Ondo State. According to UTM Minna Zone 31, it is located between latitudes 7 16' and 7 32'N and longitudes 5 11' and 5 26'E (Northings 791976 – 809751 mN and Eastings 734127 – 749508 mE) (Figure 1). Crystalline basement outcrops are thought to underlie half of Nigeria's entire land area. Highlands and lowlands make up Akure as well. Its entire land area, which is around 991 km^2, is drained dendritically by some water bodies, including rivers and streams. One of the three main litho-petrological elements that make up Nigeria's geology is the crystalline basement complex, which is present in the research area. The study area's precambrian basement complex, which was distorted during the Pan African orogeny, a period of earth movement that occurred about 550 million years ago, is primarily made up of metamorphic lithological units with clearly defined geologic boundaries, such as banded gneiss, granite-gneiss, and migmatite-gneiss quartzite complex. These kinds of rocks are distinguished by their minimal permeabilities and low porosity.

The most common and oldest rock type in the research area is the migmatite-gneiss quartzite complex, which has undergone both mechanical and chemical weathering. The primary minerals that make up its makeup are hornblende, mica, quartz, and plagioclase. The chemical composition of granite-gneiss rocks that have experienced physical weathering-induced exfoliation on their surface is mostly composed of mica, feldspar, and quartz. In the research area, banded gneiss rocks are primarily found as hills. They are distinguished by bandings where minerals are aligned. Their current facies is the product of agricultural weathering, just like the other lithological units in this area. A region's groundwater availability is also significantly impacted by these weathering impacts. The two main aquifer units—weathered and fractured basement aquifers—contain the majority of the groundwater investigated in the rock types of this area. The latter is the result of tectonic activity, whereas the weathered aquifers are ascribed to chemical alteration processes (Acworth 1987).

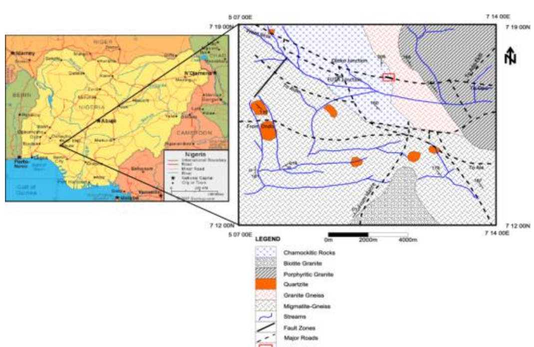

Figure 1. Geological map of Akure showing the study region (Adeyemo *et al*., 2012)

2.2. Methods

The *insitu* physicochemical quality characteristics of groundwater is the main focus of this investigation. Water's in situ physicochemical characteristics are commonly referred to as "quality-indicator" characteristics. They give a general sense of the integrity of the groundwater quality and may reveal which research areas need more investigation or data gathering. Researchers are also alerted by the measured parameter findings to potential health risks associated with water usage because of water pollutants (Aboagye and Zume 2018). A preliminary reconnaissance of possible groundwater locations or wells from which groundwater samples would be taken is the first step in the selection of data sources and data collection. Using conventional techniques, in situ groundwater quality measurements were randomly sampled throughout the study area. For additional examination, parameters including pH, temperature, electrical conductivity (EC), turbidity, dissolved oxygen, oxidation-reduction potential (ORP or Eh), total dissolved solids (TDS), and turbidity were assessed.

Following the gathering of data on groundwater quality, geostatistical analysis was performed on the data to identify semivariogram models, conduct exploratory data analysis, test the model by cross-validation, and establish a distribution pattern of in situ groundwater quality parameters. The quality metrics were spatially mapped using the spatial interpolation techniques offered by the ArcGIS geostatistical analyst extension. As a useful tool for showing spatial trends in data, spatial interpolation—which estimates parameter values at sites where data has not been measured—was employed in this study (Gupta et al., 2016; Chang 2008).

3.0 Results and Discussions

3.1 Well Characterization

3.1.1 Well Depth Distribution

The distribution map of well depth over Akure is displayed in Figure 2. The depth of the well is between 3.07 and 7.03 meters. The well depth was divided into four categories: Low (3.07 to 7.03 m), Moderate (4.88 to 5.05 m), High (5.06 to 5.22 m), and Very High (5.23 to 7.03 m). According to the distribution, locations in the low water depth region include FUTA, Igoba, Eleyeowo, Ogbese, Oja Oba, Airport, and Alagbaka. Areas with moderate water depth include Iju, Aladura, Alagbado, Imafo Ilado, and Oda. Locations in the high water depth area include Shasha and Ijoka Olope. Adofure, Seebi, Aule, and Olokuta are located in the area of Very High water depth.

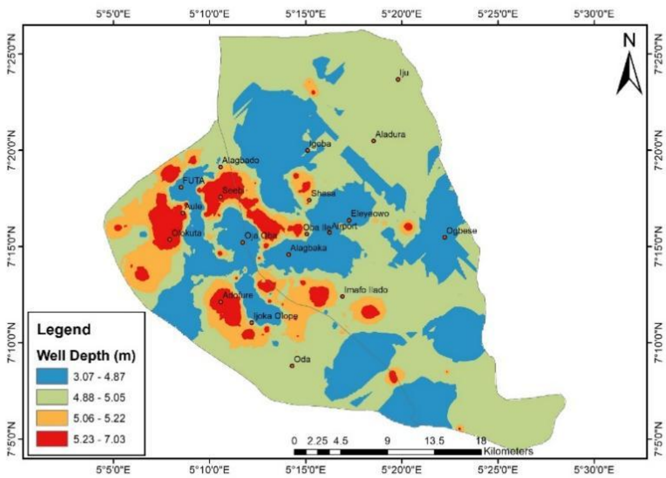

Figure 2. Wells Depth Distributions in Sampled Area

3.1.2 Well Wall Height Distributions

The distribution of well wall heights across Akure is depicted in Figure 3. The height of the well wall varies between 0.62 and 0.81 metres. There were four categories for the well depth distributions: Low (0.62 to 0.66 m), Moderate (0.67 to 0.69 m), High (0.70 to 0.74 m), and Very High (0.75 to 0.81 m). Locations like FUTA, Ogbese, and Alagbaka are located in the Low of Well wall height zone, according to the distribution. Locations in the Moderate of Well wall height region includes Eleyeowo, Oba Ile, Imafo Ilado, Oda, Adofure, and Ijoka Olope. The highest groundwater depth area includes locations like Iju, Aladura, Igoba, Alagabdo, Shasha, Airport, Aule, Olokuta, and Oja Oba. The region with moderately high groundwater depth is where Seebi is located.

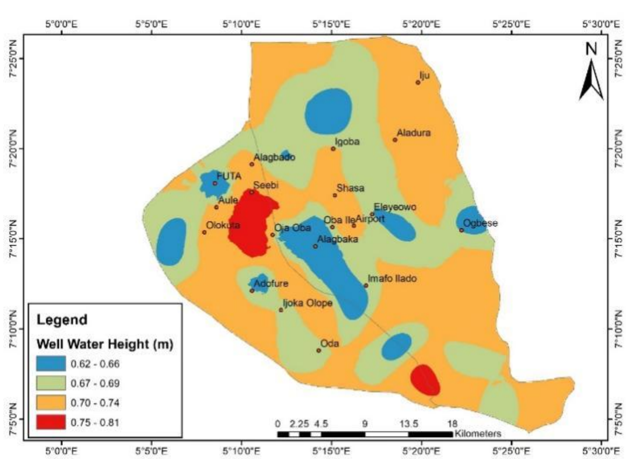

Figure 3. Well Wall Height Distributions

3.1.3 Real Water Depth Distribution

Figure 4 displays a map showing the distribution of real water depth over Akure at the time of sampling; the real water depth spans from 2.27 to 6.32 meters. Four categories were used to classify the well depth: Low (2.27 to 4.18 m), Moderate (4.19 to 4.29 m), High (4.30 to 4.41 m), and Very High (4.42 to 6.32 m). Locations like FUTA, Igoba, Eleyeowo, Airport, Ogbese, Alagbaka, and Oja Oba are located in the Low Real water depth zone, according to the distribution. The Moderate Real water depth region includes locations like Iju, Aladura, Alagabado, and Oda. Locations in the High Real water depth region include Shasha, Oba Ile, Ijoka Olope, and Imafo Ilado. The region with the Very High Real water depth includes Olokuta, Aule, Seebi, and Adofure.

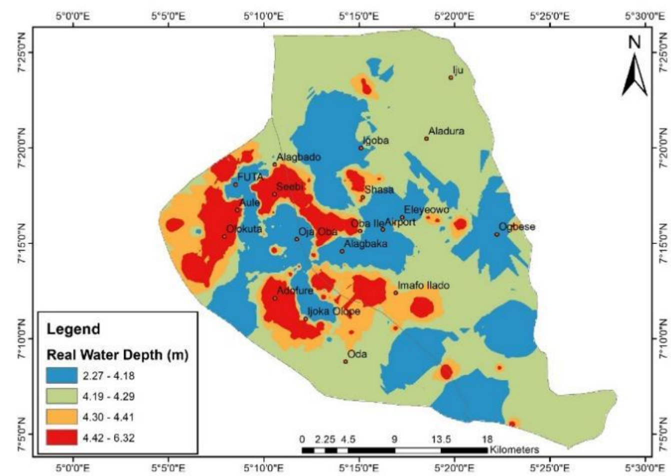

Figure 4. Real Water Depth

3.2 Physico-Chemical Characterisation.

3.2.1 pH Distribution

The existence and activity of microbial communities in groundwater are influenced by its pH. This particularly applies to methanogens. The pH range of 6 to 8 standard units is typically preferred by microbes that can break down petroleum hydrocarbon compounds and chlorinated aliphatic hydrocarbons. The pH distribution map across the study area is displayed in Figure 5. The pH is between 5.48 and 6.71. Four pH ranges were identified: Low (5.48 to 5.91), Moderate (5.92 to 6.20), High (6.21 to 6.41), and Very High (6.42 to 6.71) according to Gupta & Sarma (2016). The distribution indicates that the low pH zone contains a portion of the FUTA area. The Moderate PH zone includes Alejolowo, West Gate, and another area of FUTA. The pH range of Apatapiti, Road Block, Aba Layout, and Awule is Very High. To avoid corrosion, the World Health Organization [17] advises that drinking water have a pH of 6.5 or above. However, when using chlorine to purify and disinfect drinking water, a pH higher than 8.0 would be detrimental (UNICEF 2008)

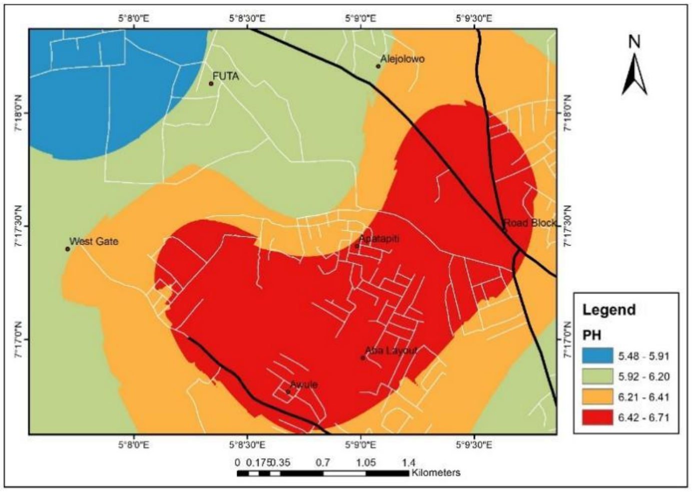

Figure 5. pH distribution of Study Area at the sampling Period

3.2.2 Oxidation-Reduction Potential Distributions

Figure 6 shows the distribution map of Oxidation-Reduction Potential (ORP) across the study area. The range of the ORP is 29.71% to 77.95%. Four categories were assigned to the ORP: Low (29.71% to 45.63%), Moderate (45.64 percent to 57.42%), High (57.43 percent to 66.16%), and Very High (66.17 percent to 77.95%). According to the distribution, the FUTA area is located in the Low ORP zone. West Gate, Alejolowo, and Road Block are all in the Moderate ORP area. Awule, Aba Layout, and Apatapiti are located in the Very High ORP zone.

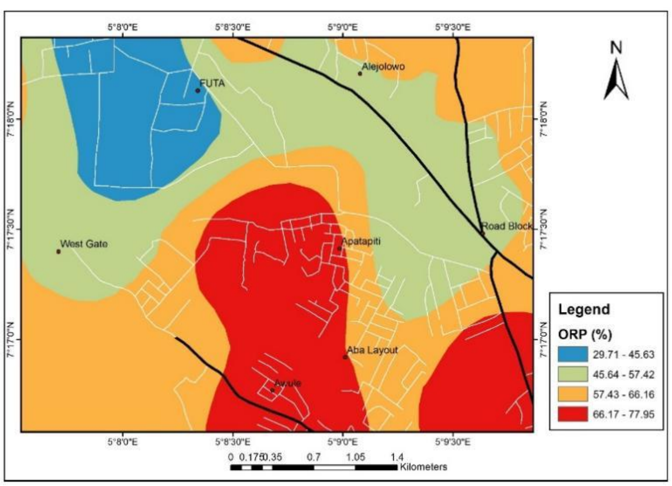

Figure 6. Oxidation-Reduction Potential Distributions

3.2.3 Electrical Conductivity Distributions

The EC distribution map over the research area is displayed in Figure 7. Between 100.64 µS/cm and 483.20 µS/cm is the range of the EC. The EC was divided into four categories: Low (100.64 µS/cm to 242.50 µS/cm), Moderate (242.51 µS/cm to 347.61 µS/cm), High (347.52 µS/cm to 425.49 µS/cm), and Very High (425.50 µS/cm to 483.20 µS/cm). According to the distribution, the FUTA area is located in the Low EC region. West Gate and Alejolowo are located in the High EC area. The High EC area includes Apatapiti and Road Block. The Very High EC region is where the Awule and Aba Layout is located.

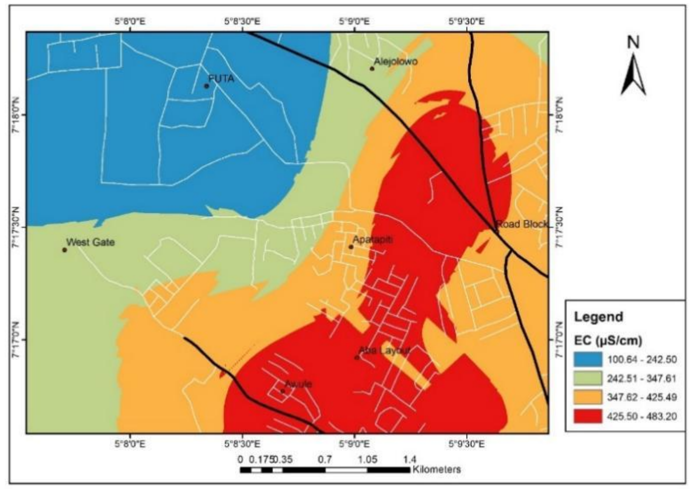

Figure 7. Electrical Conductivity (EC) Distribution

3.2.4 Total Dissolved Solid (TDS) distributions

The TDS distribution map for the research region is displayed in Figure 8. The range of the TDS is 50.87 ppm to 239.32 ppm. There were four TDS classifications: Low (50.87 ppm to 120.75 ppm), Moderate (120.76 ppm to 172.53 ppm), High (172.54 ppm to 210.89 ppm), and Very High (210.90 ppm to 239.32 ppm). According to the distribution, the FUTA area is in the Low TDS region. Alejolowo and West Gate are located in the Moderate TDS area. Road Block and Apatapiti are located in the High TDS area. The Very High TDS area includes the Awule and Aba Layout. All test locations for total dissolved solids (TDS) fall below the maximum contamination level of 500 mg/l (EPA 2009). Water with a value higher than this could taste bad, discolor vessels, or cause scale to form in the conveying pipes

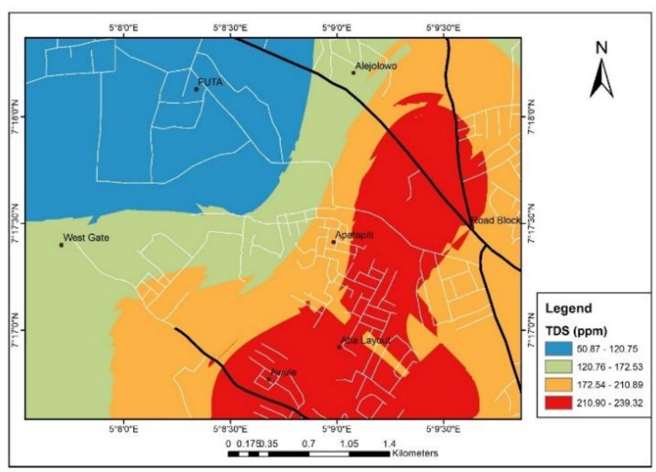

Figure 8. Total Dissolved Solid Distribution

3.2.5 Salinity Distribution

The distribution of Salinity PSU over the study area is depicted on the map in Figure 9. The range of the Salinity PSU is 0.142 ppm to 0.189 ppm. Four categories were assigned to the Salinity PSU: Low (0.1142 ppm to 0.160 ppm), Moderate (0.161 ppm to 0.165 ppm), High (0.166 ppm to 0.170 ppm), and Very High (0.171 ppm to 0.189 ppm). According to the distribution, the FUTA area is located in the PSU zone with low salinity. Alejolowo and West Gate are located in the PSU region with a moderate salinity. Road Block, Apatapiti, Aba Layout, and Awule are located in the Very High Salinity PSU area.

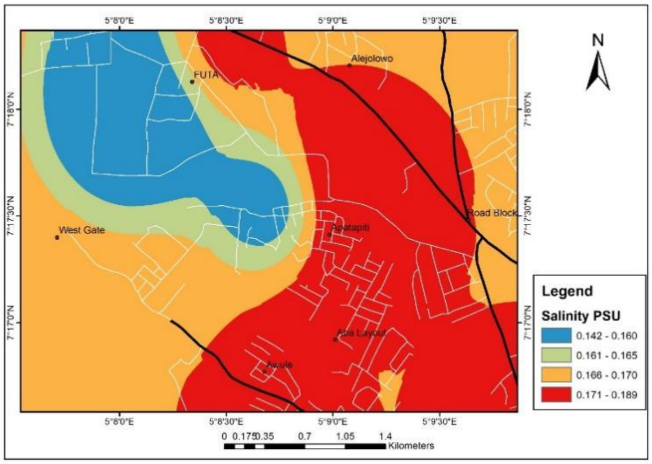

Figure 9. Salinity Distribution

3.2.6 Dissolved Oxygen Distribution

The most thermodynamically preferred electron acceptor that bacteria use for the biodegradation of organic carbon, whether it be man-made or natural, is dissolved oxygen. One measure of the availability of electron acceptors is the amount of dissolved oxygen present (ITRC 2005). The aerobic biodegradation of petroleum pollutants, including gasoline, has been reported to be facilitated by the addition of oxygen to contaminating plumes. contaminated transport, degradation, or plume stability can be inferred from the dissolved oxygen (DO) content in groundwater and its distribution over the contaminated plume. Organic pollutant load is often reflected in the DO concentration (the lower the DO, the greater the contaminant concentrations). The DO distribution map over the research area is displayed in Figure 10 The DO is between 0.50 and 1.33 parts per million. Four DO classifications were made: Low (0.50 ppm to 0.83 ppm), Moderate (0.84 ppm to 0.91 ppm), High (0.92 ppm to 1.00 ppm), and Very High (1.01 ppm to 1.33 ppm). According to the distribution, the West Gate and FUTA areas are located in the Low DO region. The Moderate DO region includes Alejolowo. Awule, Road Block, and Apatapiti are located in the High DO area. Aba Layout is located in the region of Very High DO.

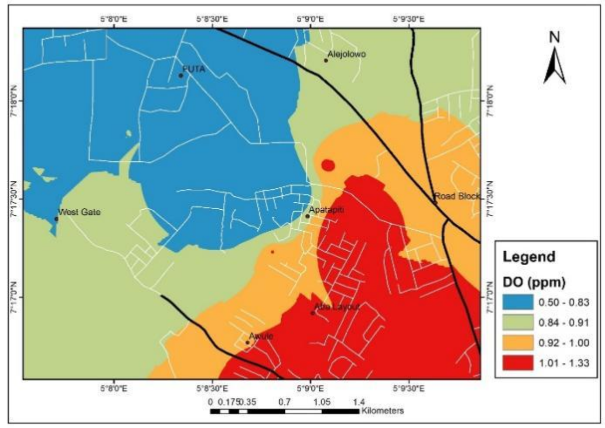

Figure 10. Dissolved Oxygen Distributions

4.0 Conclusions

The investigation yielded the following conclusions:

- Based on field samplings in all research regions, the well depth was divided into four categories: 3.07 to 7.03 m (Low), 4.88 to 5.05 m (Moderate), 5.06 to 5.22 m (High), and 5.23 to 7.03 m (Very High).
- There were four classifications for the well depth: Low (2.27 to 4.18 m), Moderate (4.19 to 4.29 m), High (4.30 to 4.41 m), and Very High (4.42 to 6.32 m).
- The pH falls between 5.48 and 6.71. Four pH ranges were identified: Low (5.48 to 5.91), Moderate (5.92 to 6.20), High (6.21 to 6.41), and Very High (6.42 to 6.71).
- The range of the ORP is 29.71% to 77.95%.
- The TDS falls between 50.87 to 239.32 parts per million. There were four TDS classifications: Low (50.87 ppm to 120.75 ppm), Moderate (120.76 ppm to 172.53 ppm), High (172.54 ppm to 210.89 ppm), and Very High (210.90 ppm to 239.32 ppm).
- The DO falls between 0.50 and 1.33 parts per million. Four DO classifications were made: Low (0.50 ppm to 0.83 ppm), Moderate (0.84 ppm to 0.91 ppm), High (0.92 ppm to 1.00 ppm), and Very High (1.01 ppm to 1.33 ppm).

Acknowledgments: The author acknowledged the following students for data gathering from the field

Author contributions OGF: Conceptualization, Design of the study; Data curation, Methodology, Project supervision, Writing—review & editing

Funding: This research received no funding

Data availability: The study data will be made available upon request.

Declarations
Competing interests: The author declares no competing interests.

References

Acworth, R. (1987). The development of crystalline basement aquifers in a tropical environment. Quarterly Journal of Engineering Geology and Hydrogeology - Q J ENG GEOL HYDROGEOL. 20. 265- 272. 10.1144/GSL.QJEG.1987.020.04.02.

Adabanija, M., Adegoke, A., & Lawal, L.. (2020). The influence of bedrocks on groundwater chemistry in a crystalline basement complex of southwestern Nigeria. Environmental Earth Sciences. 79. 10.1007/s12665-020-8822-y.

Adewumi, J. & Babatola, J. O., (2010). A case study on the status of water supply for domestic purposes in Akure, Ondo State, Nigeria. Botswana Journal of Technology. 18. 10.4314/bjt.v18i1.52250.

Adeyemo, I. G. & Omosuyi, G. (2012). Geophysical Investigation of road pavement instability along part of Akure-Owo expressway, Southwestern Nigeria. American Journal of Scientific and Industrial Research 3.191- 197 3. 191-197. 10.5251/ajsir.. 2012.3.4.191.197.

Ali. S. (2018): Leachate Characterization and its impact on Groundwater Quality near Municipal Solid Waste Landfill Site of Dubagga Lucknow. International Journal of Management Technology Engineering 8,9, 1766-1773.

Anku, Y., Banoeng-Yakubo, B., Asiedu, D., & Yidana, S., (2008). Water Quality Analysis of Groundwater in Crystalline Basement Rocks, Northern Ghana. Environmental Geology. 58. 989-997. 10.1007/s00254-008-1578-4.

Chang, Kang-tsung. (2008). Introduction to Geographic Information Systems. Library of the National Institute of Transportation SCEE. Fourth Edition.

Engel, B.A., & Navavulur, K.S., 1999. The role of geographical information systems in groundwater engineering. In: Delleur, J.W. (Ed.), The Handbook of Groundwater Engineering. CRC Press, pp. 703e718.

EPA (2009). National secondary drinking water regulation. U.S. Environmental Protection Agency.

Falowo O.,Oluwasegunfunmi, V., Akindureni, Y., Olabisi, W. & Adekunle, A. (2019). Groundwater Physicochemical Characteristics and Water Quality Index Determination from Selected Water Wells in Akure, Ondo State, Nigeria. 10.12691/ajwr-7-2-5.

Gupta, P., Sarma, K., & Dubey, S. (2016). Spatial distribution of various parameters in groundwater of Delhi, India. Cogent Engineering. 3. 1138596. 10.1080/23311916.2016.1138596.

ITRC (Interstate Technology & Regulatory Council) (2005) Technical and Regulatory guidance for in situ chemical oxidation of contaminated soil and groundwater, 2nd edn. ISCO-2. Interstate Technology & Regulatory Council, In Situ Chemical Oxidation Team, Washington, D.C. http://www.itrcweb.org

Karami, S., Madani, H., Katibeh, H. & Marj, A. (2018). Assessment and modeling of the groundwater hydrogeochemical quality parameters via geostatistical approaches. Applied Water Science. 8. 10.1007/s13201- 018-0641-x.

Lapworth, D.J., Nkhuwa, D.C.W., Okotto-Okotto, J. (2017). Urban groundwater quality in sub-Saharan Africa: current status and implications for water security and public health. Hydrogeol J 25, 1093–1116 https://doi.org/10.1007/s10040-016-1516-6e

Loaiciga, H.A. & Doh, R. (2023). Groundwater for People and the Environment: A Globally Threatened Resource. Groundwater 62, no. 3: 332–340

Maroufpoor, S. & fakheri F.A., & Shiri, J. (2017). Study of the spatial distribution of groundwater quality using soft computing and geostatistical models. ISH Journal of Hydraulic Engineering. 25. 1-7. 10.1080/09715010.2017.1408036.

Nas, B.. (2009). Geostatistical approach to the assessment of spatial distribution of groundwater quality. Polish Journal of Environmental Studies. 18. 1073-1082.

Obiadi, I., Onwuemesi, A., Anike, O., Obiadi, C., Anakwuba, E., Akpunonu, O. (2012). Modelling Crystalline Rock Porosity and Permeability from Geological and Geophysical Field Studies: The Igarra Example. International Journal of Environmental Engineering Research. 1. 5-15.

Ojuri, O.O., Ayodele, , F.O. and Oluwatuyi, O.E.(2018): Risk assessment and rehabilitation potential of a millennium city dumpsite in Sub-Saharan Africa, Waste Manag. 76 (2018) 621–662, https://doi.org/10.1016/j.wasman.2018.03.002.

Paramasivam, C.R. (2019). GIS and Geostatistical Techniques for Groundwater Science. An Introduction to Various Spatial Analysis Techniques. (), 23–30. doi:10.1016/B978-0-12-815413-7.00003-1

Rana, R., Ganguly, R. and Gupta, A. K.(2018): Indexing method for assessment of pollution potential of leachate from non-engineered landfill sites and its effect on groundwater quality, Environ. Monit. Assess. 190 46, https://doi.org/10.1007/s10661-017-6417-1.

Ratna, M. V., Kumar G. V., Dileep, G. (2021): The Effects of leachate from Municipal Solid Waste Landfill Dump Sites on Ground Water Contamination. Levant Journal, Volume 20, Issue 7, pp 194-207

Saha, P. & Paul, B. (2019). Groundwater quality assessment in an industrial hotspot through interdisciplinary techniques. Environmental Monitoring and Assessment. 191. 10.1007/s10661-019-7418-z.

UNICEF (2008). UNICEF Handbook on Water Quality. United Nations Children's Fund (UNICEF), New York, USA., Pp: 179.

WHO, 2010. Guideline for Drinking Water Quality. 3rd Edn., World Health Organization, Geneva, Switzerland.