LAUTECH Journal of Engineering and Technology 19 (1) 2025: 39-53
10.36108/laujet/5202.91.0140

Assessment of Groundwater Quality for Drinking and Construction Usage in Odo-Oba Town, Southwestern Nigeria.

[1*]Oladeji T. and [2]Adewoye A. O.

[1,2]Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Oyo State
[1]helenetemi@gmail.com, [2]aoadewoye55@lautech.edu.ng

Article Info

Article history:

Received: Dec. 20, 2024
Revised: Jan. 23, 2025
Accepted: Jan. 27, 2025

Keywords:

Assessment,
Groundwater,
Quality,
Construction,
Drinking,
Suitability.

Corresponding Author:
helenetemi@gmail.com,
aoadewoye55@lautech.edu.ng

ABSTRACT

Groundwater is a crucial natural resource for human survival, serving as the primary source of freshwater worldwide. However, a lack of data on water quality can have detrimental effects on human health and resource management. This study aims to assess the chemical composition of groundwater in the Odo-Oba area of Oyo State, Nigeria, to determine the water facies type and assess its suitability for sustainable development, particularly for potable water supply and construction purposes. Twenty groundwater samples were collected within the study area and analyzed for physical and chemical parameters. The results were compared to international standards such as (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) to evaluate water quality and identify potential contaminants. Water quality indices were calculated to assess the overall quality and suitability. It exhibited a slightly acidic pH ranging from 5.52 to 6.7 and moderate temperatures (27.8 to 38.9ºC). Elevated levels of dissolved minerals suggest hard water. Potassium was the most abundant cation, followed by sodium, calcium, and magnesium. Chloride was the dominant anion, followed by bicarbonate, sulfate, and nitrate. Most chemical parameters were within acceptable limits, but the water quality varied, with some samples unsuitable for drinking. Hydrogeochemical analysis indicated that rock-water interactions influence the water chemistry. It is not suitable for drinking without treatment, but it is suitable for construction purposes, microbiological analysis is needed to assess its overall quality. Proper waste management is crucial to protect groundwater resources. pH testing of samples is recommended to evaluate potential impacts on structural integrity

INTRODUCTION

Water is an indispensable natural resource essential for all life on Earth. (Du Plessis, 2017). It plays a crucial role in human health, agriculture, and industry. According to the United Nations (2023), 71% of the planet is covered by water, only a small fraction is freshwater, primarily locked in glaciers and ice caps. Groundwater, a significant component of freshwater, is a vital resource for many communities, particularly in regions with limited surface water availability. (Jong 2017). Groundwater quality is influenced by various factors, including geological, hydrological, and meteorological conditions. Human activities and natural processes can significantly impact groundwater quality by introducing contaminants and altering its chemical composition. (Adewoye *et al*. 2017). Hydrochemical analysis is a valuable tool for assessing water suitability for different purposes, such as drinking and construction (Aghazadeh and Mogaddam 2010). In many developing countries, including Nigeria, groundwater is a primary source of drinking water. However, concerns about groundwater quality are growing due to pollution and over-exploitation. (Adewoye *et al*. 2017). The World Health Organization emphasizes the link between water quality and human health, highlighting the importance of safe drinking water in preventing waterborne diseases. This study assessed the quality of groundwater in the Odo-Oba area of Oyo State, Nigeria. The evaluation involved analyzing the chemical composition of groundwater samples and identifying the hydrogeochemical processes influencing their characteristics. Additionally, the study aimed to determine the suitability of the groundwater for drinking and construction purposes using various water quality indices and statistical analysis. The findings from this research are expected to support sustainable water management practices, enhance public health strategies, and promote the overall socio-economic development of the region.

STUDY AREA

The study area lies between the latitude 80 0′0´´ to 80 4′28″ N and longitude 40 5′ 45″ to 40 10′ 28″ E. It is a settlement that is situated in the southwest of Ogbomoso, Oyo State. The entire town is well accessible through major and minor road networks, connecting locations separated by rivers, while some areas are only accessible by minor roads (mostly untarred) and footpaths. The average elevation of the study area is about 267 m. Materials being carried from several tributaries over the years are deposited around Oba River, a major river for irrigation in the study area. The climate is tropical climate of averagely high relative humidity. (Eruola *et al*. 2021). According to Adewoye *et al.* (2019), the vegetation in the study area can be classified as rainforest vegetation. The land surface areas are cultivated leaving only the seasonal permanent plants. Out of the four Hydrogeological provinces in Nigeria, Odo Oba lies perfectly on the Precambrian basement domain of SW Nigeria which is composed of metamorphic and crystalline rocks of > 550 (Sunmonu *et al*. 2012). This geological domain is constituted by gneiss, meta-sedimentary, and older granites (Adagunodo and Sunmonu 2012). The study area is characterized by a dendritic drainage pattern with high relief towards the eastern part with altitudes that range from 300m to 345m and western relief that range from 285m to 315m with the lowest relief of 270m found in the southern part of the area. The relief of the Odo-Oba area is generally low-lying with an N-S gradient defined by outcropping rocks. season (Adagunodo *et al*. 2017). Exposures of rock in Odo Oba are generally limited, but where visible, they predominantly consist of banded gneiss, with granite appearing as a secondary rock. Banded gneiss is a metamorphic rock with alternating dark and light bands, ranging from millimetres to meters in thickness, giving it a distinct striped appearance (Adewoye *et al*. 2019). Granite, located mostly in the western part of the area, has a pinkish hue due to alkali feldspar. There is also an unmappable quartzite intrusion that trends northeast to southwest, dipping westward. Quartzite is found mainly in the southern part of the area as a minor rock type (Adewoye *et al*. 2017). Two other significant rock types in the region are quartzite and quartz-schist.

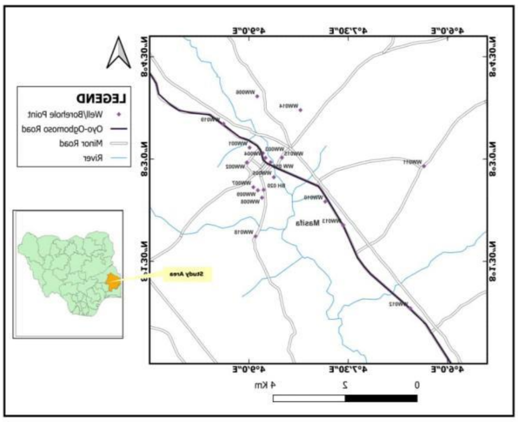


Figure 1 Drainage Map Showing Location and Sampling Points in the study area.

MATERIALS AND METHODS

Twenty groundwater samples were randomly collected: 18 from hand-dug wells (with depth ranging from 8 to13m) and 2 from boreholes. Detailed inventories of the hand-dug wells were recorded, including their coordinates (longitude and latitude), determined using a Garmin eTrex®10 GPS.

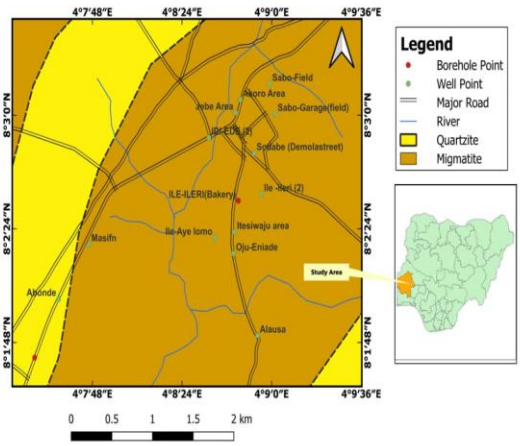


Figure 2 Geologic Map of study area showing sampling points

The water samples were collected in 500ml plastic sterile bottles, which were first rinsed, sealed well with a plastic cork after sampling and well labeled.

Physical parameters such as pH, electrical conductivity (EC) and Total Dissolved Solids (TDS) of the water were measured in situ using a pH/EC digital meter and were taken to the laboratory for major ions analysis. A digital meter was utilized to measure the pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature of the water samples. A total of twenty (20) samples were analyzed at the Central Laboratory of the University of Ibadan using spectrophotometric and flame photometric methods to determine the concentrations of major anions and cations. The results of the chemical constituents are presented in Table 4. These concentrations were further analyzed and plotted on a Piper trilinear diagram and Gibbs plot, which are instrumental in understanding the geochemical evolution and processes affecting the groundwater in the study.

ASSESSMENT OF WATER FOR DRINKING PURPOSE

The Water Quality Index (WQI) Estimation.

WQI is a rating that reflects the combined influence of various water quality parameters. It's calculated by assigning weights to water quality parameters based on their perceived threat to water quality.

The WQI is calculated in four steps:

(a) Relative Weight (Wi)

The relative weight of each parameter is calculated based on its importance.

$$\text{Wi}= W_i \frac{wi}{\sum_{i=1}^{n} wi} \tag{1}$$

where Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

(b) Quality Rating (qi):

The quality rating for each parameter is determined by comparing its concentration to the World Health Organization (WHO) standard. In this second step, the quality rating scale for each parameter is calculated by dividing its concentration in each water sample by its respective standards (WHO 2017) and multiplying the results by 100:

$$q_i = \left[\frac{C_i}{S_i}\right] * 100 \tag{2}$$

where qi is the quality rating, Ci is the concentration of each parameter in each groundwater sample in (mg/L) and Si is the (WHO 2017) standard for each parameter in mg/L.

(c) Subindex (SIi)

The subindex for each parameter is calculated by multiplying the relative weight and quality rating. In the third step, the subindex (SIi) is determined for each parameter

$$SI_i = W_i * q_i \tag{3}$$

(d) Water Quality Index (WQI)

The WQI is calculated by summing the subindices of all parameters. In this final step, the sum of SI values gives the water quality index for each groundwater sample.

$$WQI = \sum SI_i \tag{4}$$

where SIi is the subindex of ith parameter, Wi is the relative weight, Qi is the rating based on the concentration of ith parameter and WQI is the water quality index of each sample.

Pollution Index of Groundwater (PIG) Estimation

The PIG, introduced by Subba Rao (2012), assesses the relative impact of water quality parameters. It is calculated using variables such as pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, etc.

PIG Calculation involves the following steps:

(a) Weight Assignment (Rw): Weights are assigned to chemical parameters based on their significance.

(b) Weight Parameter (Wp): Wp is calculated from the assigned weights using the equation below, where Wp represents the weight parameter, and Rw is the weight of each constituent.

$$Wp=\frac{Rw}{\sum Rw} \quad (5)$$

The concentration status is determined by comparing its value to the WHO standard. It is calculated by dividing the chemical concentration of each water sample by its corresponding WHO drinking water quality standard (2017). Here, Sc is the concentration status, C is the chemical concentration of the water sample, and Ds is the WHO standard for that chemical.

$$Sc = C/Ds \quad (6)$$

(d) Overall Chemical Quality (Ow): The overall chemical quality is calculated by multiplying the weight parameter (Wp) with the concentration status (Sc). Here, Ow represents the overall chemical quality, Wp is the weight parameter, and Sc is the concentration status.

$$Ow = Wp * Sc \quad (7)$$

The PIG is obtained by summing the overall chemical quality values for all parameters. If Ow exceeds 0.1, it contributes 10% of the PIG value (1.0), highlighting the significance of groundwater pollution (Rao 2012).

Correlation Analysis.

Correlation analysis using SPSS 23 software was used to categorize the sampled groundwater; identify the geochemical processes governing their chemistry and calculate basic statistics like mean, standard deviation, minimum and maximum for the water quality parameters. It was also used to determine the strength and direction of relationships between different water quality parameters which helps in understanding the factors influencing water quality.

RESULTS AND DISCUSSION

The Piper diagram classifies the water samples into three distinct water facies, as illustrated in Figure 3. The dominant water type is Na-Cl, with 11 out of 20 samples falling into this category, followed by mixed Ca-Mg-Cl and Ca-Cl water types. These water types reflect the prevalence of alkalis over alkaline earth elements and the dominance of strong acids over weak acids. In terms of ionic composition, the cationic contents are predominantly alkali-rich (Na-K), accounting for 55% of the samples, while the remaining 45% fall into the no-dominant-cation category. The anionic analysis indicates a chloride-dominated water type.

From the Piper plot again, it is evident that the Na-Cl water type is the most prevalent, characterized by high sodium (Na^{+}) and chloride (Cl^{-}) ions, with relatively low levels of calcium (Ca^{2+}) and magnesium (Mg^{2+}). This water type often points to groundwater influenced by evaporitic deposits or water-rock interactions. As explained by Todd and Mays (2011), the dissolution of evaporite minerals, such as halite (NaCl), can significantly elevate sodium and chloride concentrations. Additionally, anthropogenic activities such as wastewater discharge and agricultural practices may contribute substantial sodium and chloride ions to groundwater, further amplifying their dominance.

The mixed Ca-Mg-Cl water type demonstrates significant proportions of calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^{-}) ions without any one ion being overwhelmingly dominant. This composition suggests that the groundwater is influenced by the weathering of calcium-bearing minerals and may reflect mixing between different water sources, such as freshwater and saline water.

Table 1: Summary of Concentrations of Parameters of Groundwater Samples

Parameters / units	Min.	Max.	Mean	Standard deviation
pH	5.52	6.7	6.049	0.321
TEMP (°C)	27.8	38.9	30.275	2.271
EC (μs/cm)	83	3570	709.35	773.367
TDS (PPM	42	1730	359.4	374.813
DO (mv)	60	288	201.85	66.346
Ca (mg/L)	1.473	65.78	19.772	17.796
Mg (mg/L	1.403	50.45	17.687	17.746
K (mg/L)	1.8	879	59.636	196.028
Na (mg/l)	5.03	230.5	44.531	52.360
Cl- (mg/l)	13.256	344.7	79.870	82.126
HCO_3 (mg/L)	14.4	194.4	32.94	38.743
NO_3 (mg/L)	0.115	9.126	3.572	2.756
SO_4 (mg/L)	5.038	28.56	9.123	6.779
Alkalinity	0	52.78	12.586	14.378
Hardness	9.5	418.9	122.377	114.360

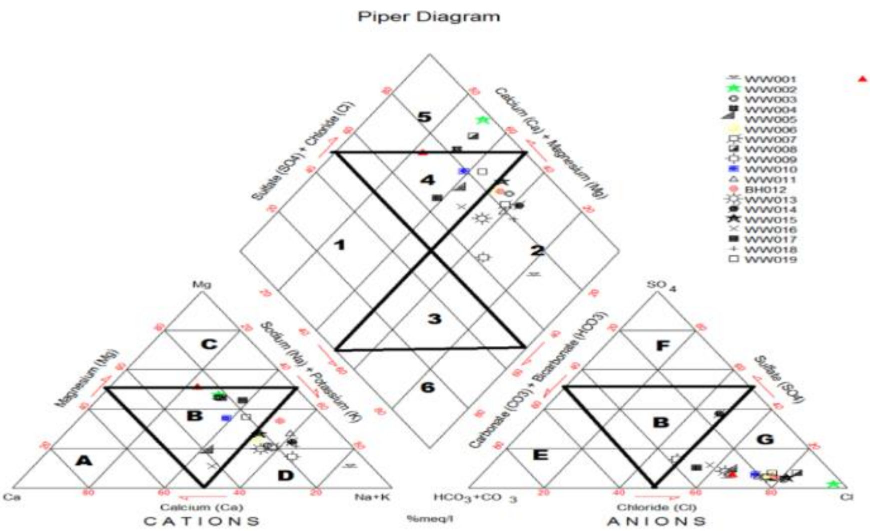
It also indicates water-rock interactions involving both carbonates and silicate minerals, particularly in areas where groundwater from various aquifer layers or recharge zones converges.

Todd (2004) notes that such mixing often highlights dynamic interactions between geological formations and groundwater flow systems.

The Ca-Cl water type is characterized by high levels of calcium and chloride ions. This indicates groundwater is influenced by rocks rich in calcium-bearing minerals, likely from the dissolution of calcium salts or carbonates. The presence of this water type could also suggest contributions from agricultural or industrial activities where calcium chloride salts are present. According to Prasanna *et al*. (2011), the dominance of Ca-Cl water types often signifies significant rock-water interactions or freshwater recharge in specific hydrogeological settings.

These water types reflect the mineralogy of the aquifer materials and the extent of ion exchange, dissolution, and mixing processes impacting groundwater chemistry. The results suggest that the hydrochemical dynamic of groundwater from the study area is a combination of influence from rocks-water interaction and anthropogenic inputs. Gibbs plots were used to know the controlling mechanism of groundwater chemistry of the study area. To further understand the dominant hydrochemical process controlling the groundwater chemistry, the data were plotted on Gibbs as shown in Figure 4. The plot demonstrated that many water samples fall in the rock-dominance zone indicating that groundwater chemistry is influenced by the interplay of groundwater and aquifer rock chemistry (Kom *et al*.2021).

This could also imply that the process of rock and mineral weathering is a factor influencing groundwater quality in the study area. This work agrees with the work done by Adewoye *et al*. (2017) in the Ogbomoso environs.



1). $CaHCO_3$ (2) .NaCl (3).Mixed $CaNaHCO_3$ (4).Mixed CaMgCl (5).Ca Cl (6.)$NaHCO_3$
A. Calcium type B. No dominant C. Magnesium type D. Sodium type
E. Bicarbonate type F. Sulphate type G. Chloride type.

Figure 3: Piper plot showing the chemical composition

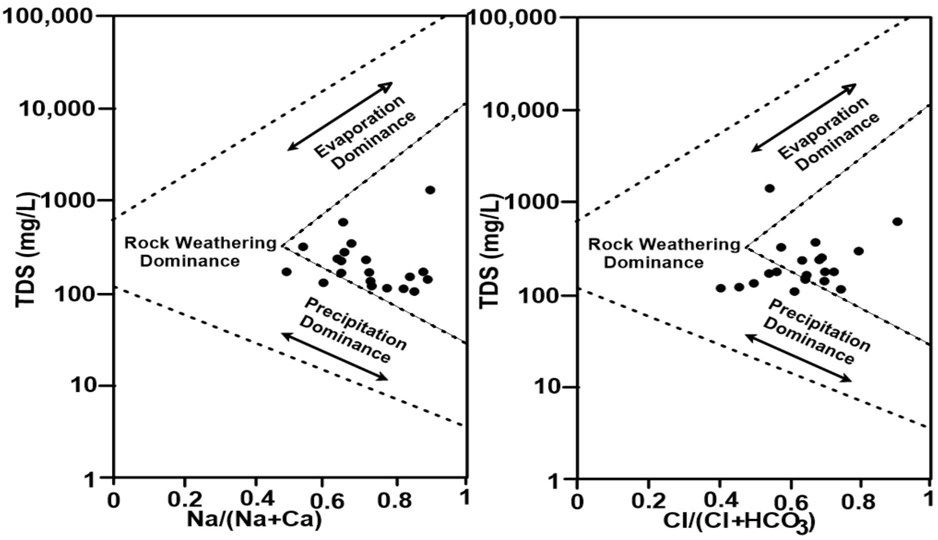


Figure 4. Gibbs Diagram shows the Mechanism Controlling Groundwater Chemistry.

Groundwater Quality Assessment for Drinking and Construction use

The summary of concentrations and ranges of values of the physicochemical parameters are presented and compared against the standard limits provided in Table4a set by the World Health Organization (WHO 2017) for drinking water quality and the Nigerian Standards for Drinking Water Quality (NSDWQ 2015).

pH: The study revealed that pH values in the research area ranged from 5.52 to 6.7, with an average of 6.05, indicating slightly acidic conditions. Most groundwater samples were not within the WHO (2017) and NSDWQ (2015) recommended range of 6.5–8.5 for drinking water. However, exceptions were noted in samples from wells at Sabo (field), Orisun-Iye, and Ile-Ileri (1), which met the standard limits and were deemed suitable for drinking purposes. These findings align with studies by Adewoye (2012, 2019), which observed that groundwater samples in Odo-Oba varied between slightly acidic and slightly alkaline. The acidic conditions could result from weathering of underlying rocks that release acidic ions, high organic matter such as humic acids, or contamination of water sources (Salami and Akperi, 2023). Acidic water poses risks to human health and ecosystems (Akharame and Obianke, 2024). Additionally, the pH of water significantly impacts concrete mixing, as a balanced pH (6.0–8.5) is essential for cement hydration, strength, and durability. Eleven samples with pH below the acceptable range indicate slightly acidic conditions that may hinder cement hydration and weaken concrete by forming less robust microstructures (BOQU, 2024). Studies by Saravanakumar and Dhinakaran (2010) corroborate these findings, emphasizing the adverse effects of acidic water on concrete strength, durability, and corrosion resistance.

Water temperatures ranged from 27.8°C to 38.9°C, with an average of 30.3°C. Most samples exceeded the WHO maximum allowable temperature for drinking water (28°C), except for one sample (27.8°C). However, all samples except four (Sabo [garage], Idi-Ede [2], Sodabe, and Alausa met the NSDWQ range of 25–30°C. High temperatures enhance microbial growth, increasing taste, odor, and color (Ilori *et al*., 2019).

The electrical conductivity (EC) of water, indicative of dissolved substances, chemicals, and minerals, ranged from 83 to 3570 µS/cm, with a mean of 709.35 µS/cm. Nine samples (45%) exceeded the WHO limit of 500 µS/cm for drinking water, although 80% fell within the NSDWQ permissible limit of 1000 µS/cm. Four samples (Sabo [field and garage], Idi-Ede [2], and Ile-Ileri [2]) exceeded the NSDWQ limit, possibly due to proximity to dumpsites. This aligns with Adewoye *et al*. (2019), who observed high EC values near dumpsites in Odo-Oba. Elevated EC suggests a high concentration of dissolved solids, potentially resulting from anthropogenic activities and intensive rock-water interactions (Saraswat *et al*., 2019). High EC values may affect water taste, and testing for construction suitability is essential to avoid quality compromises.

Total Dissolved Solids (TDS) values ranged from 42 to 1730 mg/L, with a mean of 359.4 mg/L. While most samples were within the WHO and NSDWQ limits of 500 mg/L for drinking water, 20% exceeded this threshold, particularly in wells near dumpsites (Sabo [field and garage], Idi-Ede, and Ile-Ileri). Elevated TDS contributes to water salinity, potentially causing health issues such as gastrointestinal irritation. Waste disposal and uncovered wells are significant contributors to high TDS in the region (Adewoye *et al*., 2017). For construction purposes, all samples fell below the NIS 2:2017 limit of 3000 mg/L, ensuring suitability for concrete use, as high TDS levels can impact concrete quality and strength (Mane, 2023).

Total hardness (TH) ranged from 9.5 to 418.88 mg/L, with an average of 122.38 mg/L. While all samples were within the WHO maximum limit of 500 mg/L, 20% exceeded the NSDWQ permissible limit of 150 mg/L. Using Sawyer and McCarty (1967) classifications, 45% of samples were soft, 30% moderately hard, 10% hard, and 15% very hard. Hard and very hard water was noted in wells at Ita-Maya, Idi-Ede, and Sabo. Hardness primarily results from geogenic sources, such as dissolved calcium and magnesium from rock weathering, as supported by Kom *et al*. (2021). Though hard water provides essential nutrients, excessive hardness can cause aesthetic and physiological issues. Mitigation methods include boiling and precipitation.

Calcium ion concentrations ranged from 1.5 to 65.78 mg/L, with a mean of 19.78 mg/L, all within

WHO (2017) and NSDWQ (2015) limits for consumption. Calcium primarily originates from the dissolution of carbonate rocks (e.g., limestone, dolomite) and the weathering of calcic-plagioclase feldspars and pyroxenes (Nawale *et al*., 2021; Saha *et al*., 2019). Calcium's presence underscores the geological influences on groundwater composition (Ganyaglo *et al*., 2010). Although calcium is essential for health rickets, hypertension, and stroke (Ansari and Umar, 2019).

Table 2: Classification based on NIS 2:2017, standards for key parameters for water quality for construction purposes.

Parameters	Acceptable/ Permissible Limits (NIS 2:2017)	No of samples within limits	Samples not within the permissible Limits	Location of sample (not within limits)
pH value	6.0 -8.5	Nine (9) WW001,005,006,007 ,010,013,016,018,020	Eleven (11) WW002,003,004,008,009, 011,012,014,0015,017,019	Sabo (Garage), Jebe, Akoro, Ile Ayelomo, Oju- Eniade, Masifa, Adeogun, Sedu, Id-iEde, Itesiwaju, Ile-Abu
Chloride	500mg/L-reinforced concrete 2000mg/L- plain concrete	20	100%	All 20 locations
Sulphate	100mg/L	20	100%	All 20 locations
TDS	2000mg/L	20	100%	All 20 locations
Alkalinity	Not specific but still with pH value above			

The magnesium (Mg^{2+}) varies from 1.40 to 50.45 mg/L, and 17.69 mg/L as the mean value. Most of the groundwater samples have Mg2+ ion present in all samples is below the WHO recommended limit of (50mg/L) for drinking except for two of the samples (WW001, WW002) in the Sabo area that exceed the limit. For NSDWQ standards with a limit of 30mg/L, most of the samples also fall within except three of the samples from the well in Sabo and Ile-ileri area that exceed the permissible limit. The most common sources of magnesium (Mg) in groundwater are dolomites and mafic minerals in the bedrock. (Saraswat *et al*. 2019).

Sodium (Na^{+}) ranged between 5.03 and 230.5 mg/L, and the mean of 44.53 mg/L. Under the WHO drinking water standard (WHO 2011) and NSDWQ 2007), the highest restriction value for Na+ is 200 mg/L. The result found that all the groundwater samples have values below the maximum permissible limit except the well from the Sabo area(230.4mg/L) which surpassed the guideline value. The contributing factors for increasing Na+ ion in groundwater could be from the degradation of deposits and decomposing of diverse minerals, for example, sodium dissolved when interacting water with igneous rocks (Sharmin *et al*. 2020), Also, sodium can enter natural waters through industrial, municipal waste discharges and diffuse source runoff (Reddy *et al*. 2019).

The results of potassium(K^+) concentrations in studied groundwater ranged from 1.8–879.02 mg/L, with the mean value of 59.64 mg/L. The sample values indicates that 5% (one)of the sample from the well (WW002) with concentration of 879.02mg/L exceeds the WHO (2017) permissible limit of 200mg/L for drinking water while other samples of

95% were found below the permissible limit which makes it suitable for drinking purposes.

Table 3: Comparison of the parameters of the study area's groundwater samples with WHO (2017) and NSDWQ (2015) standards for drinking purposes and their effects

Parameters	MIN. Value	MAX. Value	WHO (2017)	Water sampled WHO	NSDWQ (2015)	Water sampled NSDWQ	Undesirable effects beyond permissible Limits
pH	5.52	6.7	6.5-8.5	17	6.5-8.5	17	Cause skin, eye and mucous membrane irritation and water supply system
TEMP (°C)	27.8	38.9	28	19	25-30	4	
EC (μs/cm)	83	3570	500	9	1000	4	Gastro-intestinal irritation
TDS (PPM)	42	1730	500	4	500	4	Gastro-intestinal irritation, bad taste, Odour and Colour
DO (Mg/L)	6	28.8	5		5- 8		
Ca (mg/l)	1.47	65.78	75	0	50	0	Scale formation
Mg (mg/L)	1.40	50.45	50	2	30	3	Diarrhea, abdominal cramping
K (mg/L)	1.8	879.02	200	1	12	6	Acute ingestion, bitter taste
Na (mg/L)	5.03	230.54	200	1	200	1	Delectable taste, high blood pressure, heart attack, and stroke
Cl (mg/L)	13.26	344.67	250	2	250	2	Salty taste, deterioration of organoleptic properties
HCO_3(mg/L)	14.4	194.4	200	0	100-200	0	An aesthetic problem, Kidney failure
NO_3 (mg/L)	0.12	9.126	50	0	50	0	Diseases of a cardiovascular, blue baby syndrome, headache and fatigue
SO_4 (mg/L)	5.04	28.56	250	0	200	0	
Alkalinity	0	52.78	200	0	20-200		
Hardness	9.5	418.88	500	0	150		

However, for NSDWQ standards that have a permissible limit of 12mg/L, Six of the groundwater samples at Sabo(field), Jebe, Sodabe, Ile-ileri (2), Abonde, Alausa area exceed the limit. The high values of potassium ion in that area might be because of sewage wastes or leaching of potassium fertilizer through the soil which are the primary sources of potassium in groundwater. (Kom *et al.* 2012). The order of abundance or the sequence of distribution of the cations is $K^+ > Na^+ > Ca^{2+} > Mg^{2+}$

The range of chloride (Cl^-) concentration throughout the research region ranges significantly from 13.26 to 344.67 mg/L, with 79.8 mg/L of the mean value. The analysis found that the two wells in the Sabo area surpassed the WHO (2017) and NSDWQ (2015) recommended chloride level of 250 mg/L, while others (90%) of the samples were found to be below the permissible limit. The primary source of chloride in groundwater could come through geogenic processes like rock weathering, and leaching and anthropogenic processes like household and municipal effluents (Kumar and Kuriachan 2020). It was compared with the study of Adewoye *et al.* (2019) in Odo-Oba area which showed higher chloride content was obtained very close to the dumpsite and high concentrations cause salty taste, in drinking water and organoleptic deterioration, etc. Chlorides in water can significantly harm concrete durability. NIS 2:2017 sets permissible limits of 500 mg/L for reinforced concrete and 2000 mg/L for plain concrete. All groundwater samples analyzed were below these limits, making them suitable for construction. The presence of chlorides in water used for concrete construction can have significant detrimental effects on the durability and performance of concrete structures. High chloride levels can lead to steel reinforcement corrosion and efflorescence). It can lead to the formation of white, powdery deposits on the concrete surface known as efflorescence (Joshi and Deshmukh 2019). Bicarbonate (HCO_3^-) values range from 14.4 –194.4 mg/L with a mean of 32.94 mg/L. The values of all the groundwater samples are within the maximum allowable limits of 200mg/L for WHO (2017) and 100-200mg/L for NSDWQ (2015).

Sulphate concentrations ranged from 5.04 to 28.56 mg/L, the normal sulphate concentration limit for drinking water is 250 mg/L (WHO,2017) and 200 mg/L for NSDWQ (2015). The result shows that sulphate (SO_2^{-} ^{4}) values of all the groundwater samples are within the maximum allowable limits of WHO (2017) and NSDWQ (2015) standards for drinking water. Sulfates can also negatively impact concrete durability. The acceptable limit is 400 mg/L according to NIS 2:2017. All groundwater samples were below this limit. Exceeding the limit can cause a sulphate attack, leading to expansion and cracking due to reactions with cement hydration products. (Bansal,2016). Regular testing of water quality, particularly for sulphate content, is crucial to maintain the durability and performance of concrete structures. The Nitrate NO_3^- value is between 0.12 and 9.13mg/L, and 3.57mg/L is the mean value. The results of the analysis revealed that all groundwater samples contained nitrate levels lower than the WHO (2017) and NSDWQ standards' desirable limit of 50mg/L. This agrees with the work of Kom *et al.* 2021 when compared. Hence, the order of abundance or the sequence of distribution of the anions is Cl- > HCO^{3-}> SO_4^{2-}>NO_3

Water Quality Index (WQI):

The overall assessment of WQI values of the study area ranged from 36.0 to 160.9. Based on this classification of drinking water quality, the findings indicate that in the study area, three(3)samples from wells located at Masifa , Abonde and Ile-Abu in the study area are in a good category (Good water quality), seven(7) samples located in the North-east(NE) and southeast(SE) part of the study area comes under the poor water category (Poor water quality) seven (7) samples located in the Northeast(NE)part of the map of the study area belongs to the "very poor water type", three(3)samples from well located in Sabo(field and garage)area and Ile-ayelomo area comes under "unsuitable for drinking" water category. The evaluation indicates that no water sample falls under the excellent category, and it was observed that water samples that are unsuitable for drinking might be due to anthropogenic sources of pollution, (those very close to the dumpsites in the study area) or geogenic sources for Ile-ayelomo.

Pollution Index of Groundwater (PIG)

In the assessment of PIG, the relative contribution of the concentration of water quality variables of each water sample was considered. If the overall quality of water (Ow) is > 0.1, it contributes 10% of the value of 1.0 of the PIG denoting the significance of pollution on the groundwater quality (Rao 2012). Based on the classification of PIG, most of the groundwater samples fall under an insignificant pollution zone, five of the groundwater samples fall under a low pollution zone, and One sample falls under a moderate pollution zone. Most of the samples in the study region are occupied by insignificant to low pollution zones which are shown in green and yellow colors in the distribution map of PIG as shown in Figure 5.

However, a very high pollution zone is not evident, but a moderate pollution zone is found in the Northeastern part (Sabo area) of the study region. It helps in showing how the water quality index values vary it was discovered that the areas of low values for the water quality index which depicts good water quality according to WHO classification appear pollution index values are of low or insignificant pollution while areas with high values of WQI which increases to the left for areas of poor water quality shows high pollution index values which depict low pollution area to moderate pollution zones in the study area.

Statistical Analysis

Pearson's correlation analysis revealed significant relationships between groundwater variables. Temperature and dissolved oxygen showed a positive correlation, while pH had weak correlations with most variables. EC and TDS were highly correlated, suggesting a strong influence of mineral dissolution. Major ions like Ca, Mg, Na, and Cl were strongly correlated with EC and TDS, indicating water-rock interactions. Carbonate weathering was a significant factor in controlling water chemistry, as evidenced by the relationship between bicarbonate and other major ions. Nitrate and sulfate correlations suggested both natural and anthropogenic influences. Overall, the geochemical composition of the groundwater was primarily controlled by water-rock interactions, with some contributions from human activities.

Table 4: Water Quality Classification based on Water Quality Index (WQI) Value for WHO Standards (2017)

			WHO Standards			
S/NO	WQI Value	Rating of Water Quality	No of samples	Well(ww)/ BH No.	Location in the study area	Percentage of water samples
1	0-25	Excellent water quality	0	None		0
2	26-50	Good water Quality	3	WW (11. 13, 19)	Masifa, Abonde, Ile-Abu	15%
3	51-75	Poor water Quality	7	WW (10,12,14,16,17,18)	Ojueniade, Itamaya, Adeogun, Sedu, Orisuniye, :Itesiwaju, Alausa	35%
4	76-100	Very poor water quality	7	WW (3,4,5,6,7,15), BH	Jebe, Akoro, Idi-Ede(2), So daabe, Ile-ede(2)	35%
5	Above	Unsuitable for drinking	3	WW (1,2,8)	Sabo(field), Sabo(garage), Ile- ayelomo	15%

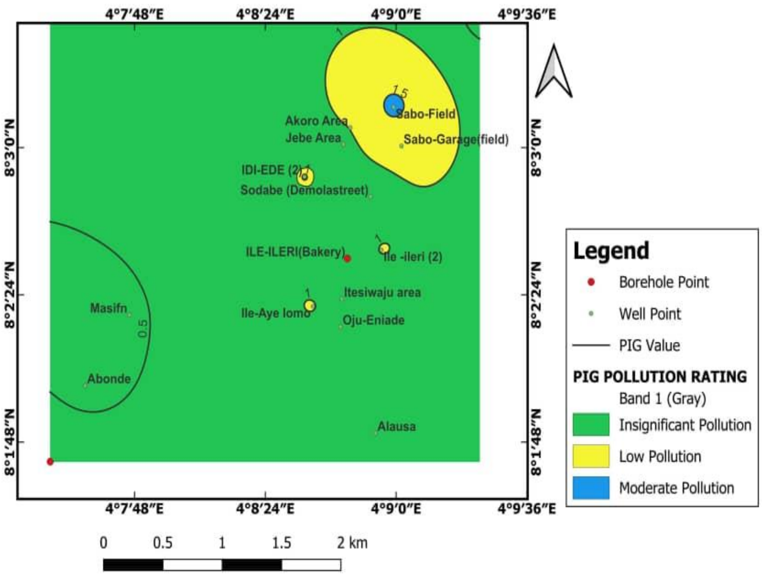


Figure 5: Spatial distribution map of pollution index of groundwater (PIG) in the study area

Parameters	pH	Temperature	EC	TDS	DO	Ca	Mg	K	Na	Cl	HCO_3	NO_3	SO_4	Alkalinity	Hardness
pH	1														
Temperature	.043	1													
EC	.276	.119	1												
TDS	.248	.144	**.995****	1											
DO	-.146	.473*	.041	.078	1										
Ca	.124	-.137	**.598****	**.600****	-.089	1									
Mg	-.036	-.115	**.715****	**.715****	-.039	**.879****	1								
K	.331	-.117	**.885****	**.877****	.008	.439	.480*	1							
Na	.180	-.177	**.864****	**.856****	-.046	**.754****	**.744****	**.887****	1						
Cl	-.086	-.033	**.747****	**.732****	-.003	**.719****	**.922****	**.512***	**.734****	1					
HCO_3	.349	-.129	.868**	.855**	-.016	.411	.471*	.980**	.877**	.515*	1				
NO_3	-.052	-.154	**.641****	**.660****	.064	**.884****	**.883****	.488*	**.760****	**.779****	.434	1			
SO_4	.092	-.181	**.505***	.499*	.036	.216	.288	**.645****	**.554***	.350	**.628****	.214	1		
Alkalinity	.051	.173	-.053	-.062	.231	.126	.069	-.197	-.036	.061	-.121	.152	-.230	1	
Hardness	.026	-.127	**.692****	**.693****	-.060	**.952****	**.983****	.480*	**.772****	**.871****	.464*	**.910****	.271	**.093**	1

Figure 6: Chemical composition of groundwater in the research area as determined using Pearson's correlation matrix.

CONCLUSION AND RECOMMENDATION

Groundwater quality assessment in the study area reveals varying levels of contamination, primarily due to natural and anthropogenic factors. Major ions in groundwater are predominantly chloride, bicarbonate, sulfate, and nitrate, while potassium, sodium, calcium, and magnesium are the dominant cations. Most groundwater samples are within acceptable limits for most parameters, except for elevated magnesium and potassium levels in a few cases. Water-rock interactions and anthropogenic influences shape groundwater chemistry, leading to diverse water types, including sodium chloride, calcium-magnesium chloride, and calcium chloride.

Groundwater is generally slightly acidic, with varying hardness levels. Water quality ranges from excellent to unsuitable for drinking, with most samples being minimally polluted. A significant portion of groundwater is unfit for drinking due to poor quality, necessitating proper treatment and casing of hand-dug wells Effective waste management, microbiological assessments, and regular pH monitoring of concrete are crucial to mitigate pollution and ensure structural integrity. Public awareness programs are essential to address declining groundwater quality and its health implications

REFERENCES

Adagunodo, T.A. and Sunmonu, L.A. (2012). Ground magnetic Survey to Investigate on the Fault Pattern of Industrial Estate Ogbomoso, Southwestern Nigeria. Advances in Applied Science Research, 3142-3149.

Adagunodo, T.A.; Sunmonu, L.A.; Adabanija, M.A.; Suleiman, E.A. and Odetunmibi, O.A. (2017). Geophysical Investigation into the Integrity of a Reclaimed Open Dumpsite for Civil Engineering Purpose. Interciencia Journal, 42(11), 324-

Adewoye, A. O., Ayantoye O. I., Bello O. S. (2 (2017): Water Quality Index and Processes in Basement Complex Terr3-1060 aim of Southwestern, Nigeria. International Journal of Multidisciplinary and Current Research. 5:105.

Adewoye A.O; Olayinka, A.I; and Abimbola, A.F. (2019). Hydrogeochemical geometry of subsurface layers in Odo-Oba Town, Southwestern Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences, 10 (2). Retrieved from https://hdl.hand-le.net/10520/EJC178ff857

Aghazadeh, N.; Asghari, A. and Moghaddam, A (2010). Assessment of Groundwater Quality and its suitability for Drinking and Agricultural Uses in the Oshnavieh Area, Northwest of Iran. Journal of EnvironmentalProtection,30-40.

Choudhary, S., Prajapat, O., Suthar, B. Kumar, and Kumar, M. (2020). Requirements and Planning of Badliya Village for converting it into Smart Village Category in Banswara, Rajasthan. International Journal of Engineering and Advanced Technology (IJEAT), 9(3S), 40-44.

Ansari, J. A., and Umar, R. (2019). Evaluation of hydrogeochemical characteristics and groundwater quality in the quaternary aquifers of Unnao District, Uttar Pradesh, India. Hydro Research, 1,36–47.

BOQU. (2024). Understanding the Impact of pH on Concrete Curing and Strength. Expert in Water Quality Measurement and Water Treatment project Shanghai BOQU Instrument Co Ltd . pg1.

Du Plessis, A. (2017). Current and future water scarcity and stress. In A. Du Plessis Ed. Freshwater challenges of South Africa and its upper Vaal River (pp. 13–25) Springer International Publishing.https://doi.or-g/10.1007/978-3-319-49502-6_2.

Eruola, A.O.; Makinde, A.A.; Eruola, G.A. and Ayoola, K.O. (2021). Assessment of the rainfall exceedance in Nigeria. Nigerian Journal of Technology. doi:10.4314/njt.v40i4.22.

Ganyaglo, S. Y., Banoeng-Yakubo, B., Osae, S., Dampare, S. B., and Fianko, R. (2010). Water quality assessment of groundwater in some rock types in parts of the eastern region of Ghana. Environmental Earth Sciences, 62(5), 1055–1069. https://doi.or-g/10.1007/s12665-010-0594-3

Joshi DM, Kumar A, Agrawal N (2009). Assessment of the irrigation water quality of river Ganga in Haridwar district India. J Chem 2(2):285–92.

Kom, K. P., Gurugnanam, B., Sunitha, V., Reddy, Y. S., and Kadam, A. K. (2022). Hydrogeochemical assessment of groundwater quality for drinking and irrigation purposes in western Coimbatore, South India. International Journal of Energy and Water Resources, 6(4), 475-494.

Kumar, P. J. S., and Kuriachan, L. (2020). Chemometric appraisal of groundwater quality for domestic, irrigation and industrial purposes in Lower Bhavani River basin, Tamil Nadu, India. International Journal of Environmental Analytical Chemistry. https://doi.o-rg/10.1080/03067319.2-020.1770241.

Nawale, V. P., Malpe, D. B., Marghade, D., and Yenkie, R. (2021). Non-carcinogenic health risk assessment with source identification of nitrate and fluoride polluted groundwater of Wardha sub-basin, central India. Ecotoxicology and Environmental Safety, 208, 111548. pg 1.

Nigerian Industrial Standard (2015). Nigerian Standard for Drinking Water Quality (NSDWQ) – ICS 13.060.20. Standard Organization of Nigeria. 1-28.

Okoroh, D. O. and Ibuot, J. C. (2022). Hydrogeochemical Assessment of Ground water Quality: A case study of Federal College of Education (Technical), Omoku, Rivers State. Water Practice & Technology, 17(7), 1458-1469.

Panneerselvam, B.; Paramasivam, S.K.; Karuppannan, S.; Ravichandran, N. and Selvaraj, P. (2020). A GIS-based evaluation o f hydrochemical characterization of groundwater in hard rock region, South Tamil Nadu. India. Arabian Journal of Geoscience, 13(17), 1-

Reddy, B. M., Sunitha, V., Prasad, M., Reddy, Y. S., and Reddy, M. R. (2019). Evaluation of groundwater suitability for domestic and agricultural utility in semi-arid region Anantapur, Andhra Pradesh State, South India. Groundwater for Sustainable Development, 9, 100262. https://doi.org/10.1016/j.gsd.2019.100262.

Saraswat, C., Kumar, P., Dasgupta, R., Avtar, R., and Bhalani, P. (2019). Sustainability assessment of the groundwater quality in the Western India to achieve urban water security. Applied Water Science, 9, 1-17.

Saha, S., Reza, A. H.., and Roy, M. K. (2019). Hydro chemical evaluation of groundwater quality of the Tista floodplain, Rangpur, Bangladesh. Applied Water Science. https://doi.org/10.1007/s13201-019-1085-7.

Sharmin, S., Mia, J., Miah, M. S., and Zakir, H. M. (2020). Hydro geochemistry and heavy metal contamination in groundwaters of Dhaka metropolitan city, Bangladesh: Assessment of human health impact. Hydro Research, 3, 106-117 https://doi.org/10.1016/j.hydr-es.2020.10.003.

Standards organization of Nigeria. (2017). Nigerian Industrial Standard (NIS) 2:201Standards for Drinking Water Quality. Abuja, Nigeria: Standards organization of Nigeria, N1554, Abuja, 1-14.

Subba Rao, N. (2012). PIG: A Numerical Index for Dissemination of Groundwater Contamination Zones. Hydrological processes, 26(22), 3344-3350.

Sunmonu, L.A.; Adagunodo, T.A.; Olafisoye, E.R. and Oladejo, O.P. (2012). The Potential Evaluation at Industrial Estate Ogbomoso Southwestern Nigeria. Materials and Geoenvironmental, 59(4), 363–390.

Todd, D. K., and Mays, L. W. (2011). Groundwater Hydrology (p. 123). John Wiley and Sons.

Van Breemen, O.; Pidgeon, R. and Bowden, P. (1997). Age and isotopic studies of Pan-African Granites from North-Central Nigeria. Precambrian Research, 4, 307-319.

Venkatramanan, S.; Chung, S. Y.; Park, N.; Ramkumar, T. and Gnanachandrasamy, G. (2014) A Preliminary Investigation of Hydro geochemistry, Metals and Saturation Indices of Minerals in Nakdong Surface Water and Adjacent Deltaic Ground water using WATEQ4F Geochemical Model. International Journal of Earth Science and Engineering, 456-466.

World Health Organization. (2017). WHO model list of essential medicines, 20th list (March 2017, amended August 2017) www.dbpedia.org

Zhou, Z. (2015). A Global Assessment of Nitrate Contamination in Groundwater. Wageningen UR.