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# Groundwater Physicochemical Characteristics and Water Quality Index Determination from Selected Water Wells in Akure, Ondo State, Nigeria

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**Abstract** The natural quality of groundwater is controlled by aquifer hydrology, geochemistry, and the geology. The principal objective of the study was to estimate and characterize the water quality parameters of groundwater using World Health Organisation (WHO) for drinking purpose. In view of objectives of the study, groundwater quality assessment was carried out in selected 67 water wells in Akure, Ondo State, Nigeria. The analyzed parameters are electrical conductivity, pH, oxidation potential (Eh), acidity, total alkalinity, total hardness, temperature, total dissolved solids (TDS), turbidity, calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), Sodium ($Na^{+}$), potassium ($K^{+}$), chloride ($Cl^{-}$), bi-carbonate ($HCO_3^{-}$), sulphate ($SO_4^{2-}$), and nitrate ($NO_3^{-}$). The temperature of the groundwater varies from 25.9 – 30.8 ℃ with a mean of 27.9 ℃. All the water samples are colourless, odourless, and tasteless, with clear appearance. The recorded pH varies from 5.2 – 7.0 and characterized by an acidic condition. The EC of water samples is in the range of 53 - 874 $\mu S/cm$ (avg. of 189.8 $\mu S/cm$). The water type is a recharged water, with value of TDS ranging from 40mg/l to 424 mg/l, and an average of 96.7 mg/l, indicative of fresh water. The cations and anions satisfy the WHO standard for drinking purpose with about 95% compliance. The sequence of the abundance of the major ions is in the following order: $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$ for anions, and $Ca^{2+} > K^{+} > Na^{+} > Mg^{2+}$ for cations .The calculated values of WQI vary from 22% to 60%. The study area is widely (90% areal coverage) characterized by “Good water” in the range of 26 – 50%, with hardness varying from soft to very hard water. The “Excellent water” is only associated with Sample S-34 in the northwestern part of the study area, while “Bad water” fall (S-21, S-28, S-57, and S-65) within a small portion of biotite granite and migmatite geologic units.

***Keywords:*** *Akure metropolis, water quality indices, groundwater, ionic balance error, total hardness, electrical conductivity*

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## 1. Introduction

Human survival and industrial development of any nation require availability of water and this consequently forms one of the major objectives of Nigeria governments in making water available for its citizenry. Generally, industries require approximately one quarter to one third of the public water supply under normal condition, the easiest and most convenient way to meet the public demand for water is to utilize surface water resources, but unfortunately, water such as river, lake, stream etc. are less plentiful than can be imagined. It can be recorded that surface water resources account for less than 2 percent of the world’s fresh water [1]. The fresh water available however is unevenly distributed while the sources that are available have been either contaminated or polluted [2].

However variation in quality of water can give hazardous effect to human health and society as well [3] and this would determines the quality of human lives [4]. The Akure Metropolis has witnessed rapid development in infrastructures (housing and estate development, surface or groundwater development etc.), establishment of new industries and expansion of older ones. Population explosion, aggravated by rural-urban migration and infrastructural growth, are accompanied by increase in industrial and domestic wastes. In the metropolis, municipal wastes are dumped in drainage channels, streams, indiscriminately located dump sites and market places [5]. Groundwater quality monitoring is intended to provide information on chemical status of groundwater, tracking its changes and signaling environmental threats. Monitoring activities allow proper management of groundwater resources and adequate assessment of preventive measure effectiveness.

For groundwater monitoring studies, assessing the water quality status for special use is the main objective of any water quality monitoring studies. Although the groundwater is less susceptible to pollution than surface water, the prolonged and systematic release of pollutants into the soil or the process of washing out pollutants, for example from the area of leaking landfill sites, caused by rain waters, can lead to permanent contamination of groundwater. In particular, aquifers located within the urban and industrial areas, as well as areas of intensive agricultural production, are the ones that are mostly exposed to pollution [6]. For most water uses, the chemical properties are as important as the physical properties and available quantity. Water Quality Index (WQI) indicates the quality of water in terms of index number which represents overall quality of water for any intended use. It is a mathematical instrument used to transform large quantities of water quality data into a single number which represents the water quality level. In fact, developing WQI in an area is a fundamental process in the planning of land use and water resources management. Mostly the WQI is usually calculated from the point of view of its suitability for human consumption.

The general WQI was developed by [7], however [8] suggested that the various water quality data could be aggregated into an overall index. Even though so many indices have been used by so many researchers for special purposes [9-17]. [6] present an index for evaluating and mapping the degree of groundwater contamination and test its applicability in Southwestern Finland and Central Slovakia. A simple WQI involving nine parameters was created by [18] to indicate the quality of groundwater from ten artesian wells located near the Dakhla Oasis in the Egyptian Western. The work of [19] reports the creation of a WQI both for surface waters and groundwater and the results of its application for water evaluation in Dalmatia, Croatia. For this study the water quality index using principal component of drinking water was conducted in Akure Metropolis, as a monitoring tool for groundwater quality in the area. This helps in characterizing the area into different groundwater quality zones by showing areas, most and least suitable drinking water using their physicochemical parameters.

## 2. Description of the Study Area

The study area (Akure, Ondo State) lies within Northings 790796 – 809322 mN and Eastings 733683 – 752092 mE, UTM Minna Zone 31 (Figure 1). It covers an aerial extent of about 320 km$^2$. The metropolis is located on a gently undulating terrain surrounded by isolated hills [5]. Topographic elevations vary between 260 and 470 m above sea level (Figure 2). The metropolis is drained by several streams and rivers exhibiting in most places the dendritic drainage pattern. The study area is underline by crystalline rock of the Precambrian basement complex of the southern Nigeria.

There are seven major different rock units in the area as shown in Figure 3, comprising of Migmatite-Gneiss, Quartzite, Charnokite, Biotite granite, Pelitic Schist, Granite Gneiss, and Granite. The Migmatite Gneiss occupies about 60% of the area with an intrusion of Quartzite and Biotite Granite in some places like along Alagbaka-Oda road, Akure-Idanre road. The study area exhibits varieties of structures such as foliation, schistosity, folds, faults, joints and fractures, with the structural trends of NNW-SSE and NNE-SSW. The groundwater in a typical basement complex area like the Akure Metropolis, is contained in two major aquifer units, namely weathered and fractured basement aquifers [20]. The weathered layer aquifer is derived from chemical alteration processes while the fractured basement aquifer system is as a result of tectonic activities [5]. The weathered layer aquifer may occur singly or in combination with the fractured aquifer [21]. The direct exposure of the uppermost part of the vadose zone or weathered layer aquifer system through mining and agricultural activities, makes it vulnerable to surface/near surface pollutants such as leachate from waste dump sites and flooding [5].

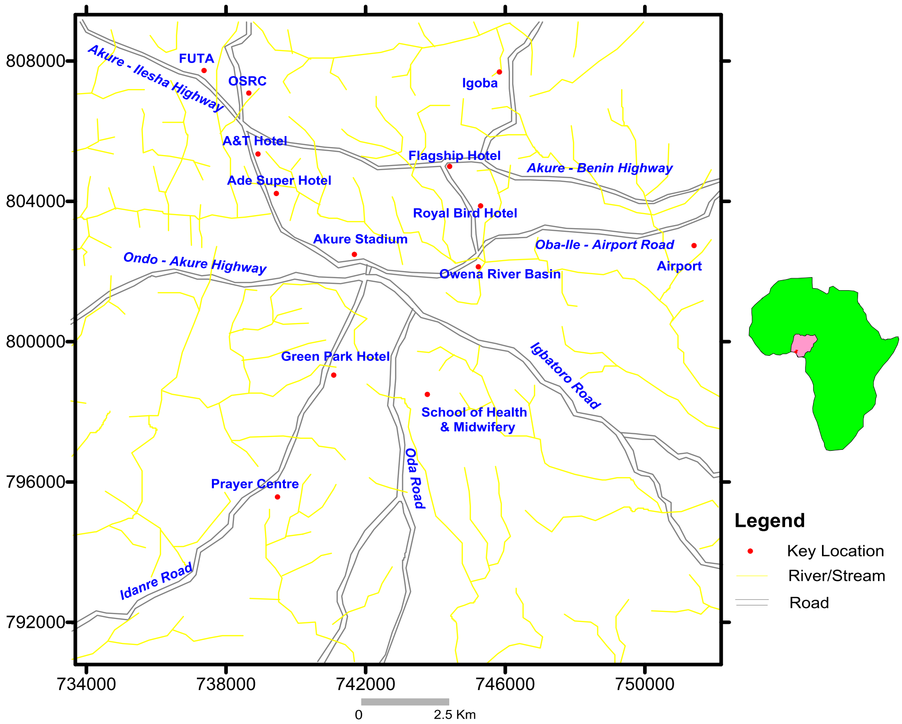


**Figure 1.** Map of Akure Metropolis

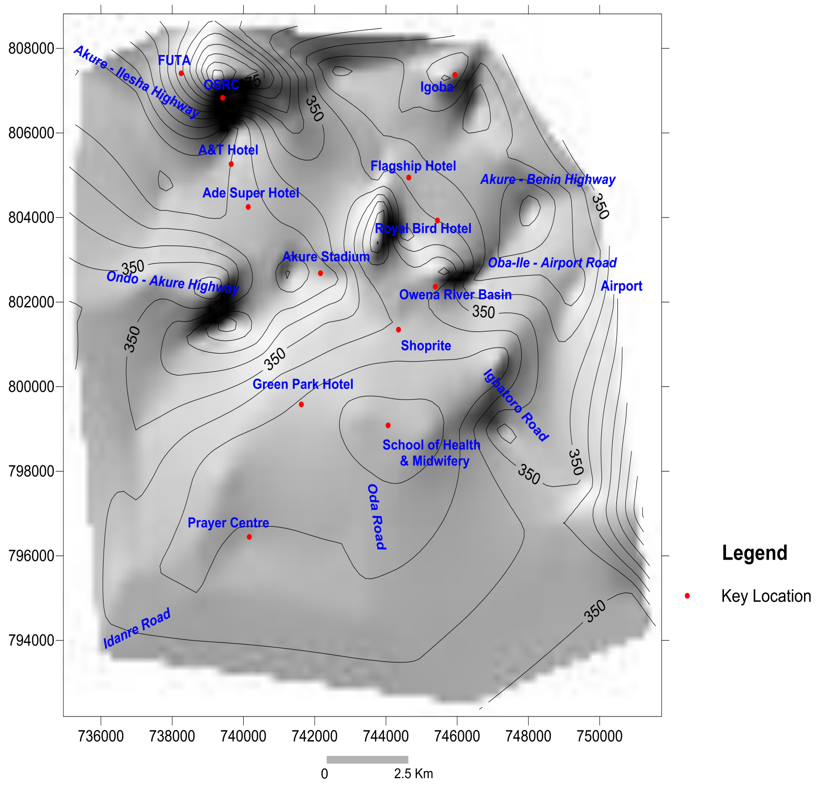


**Figure 2.** Topographical Variation across the Study Area

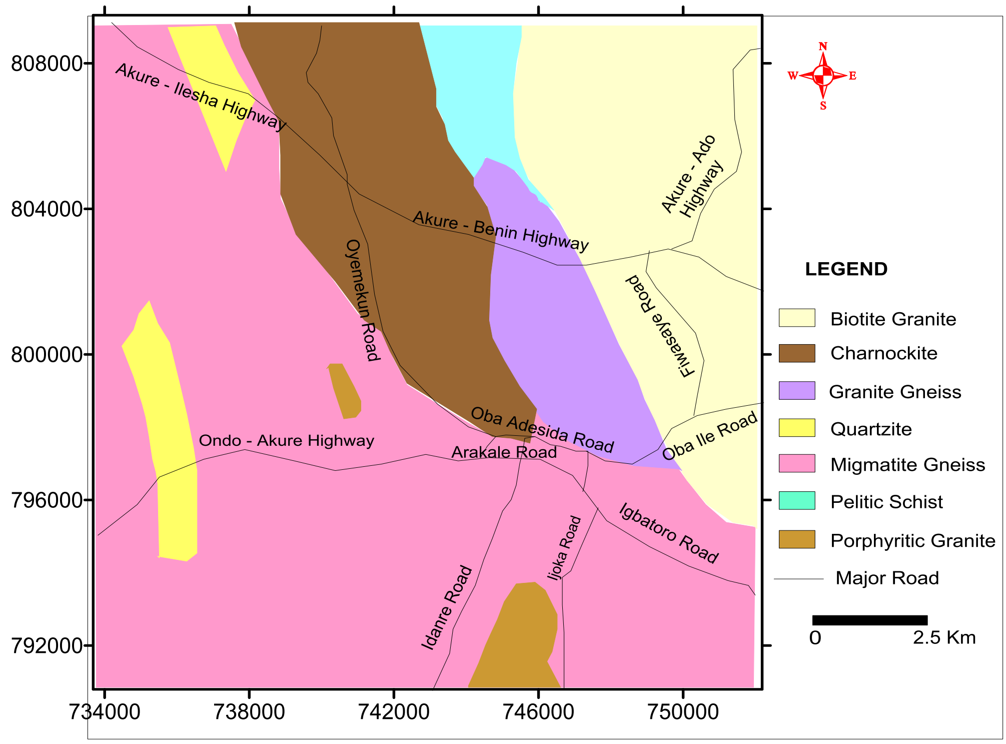


**Figure 3.** Geological Map of Akure (modified after [5])

## 3. Methodology

The map of the study area was first gridded into different zones from which representative samples was collected and geo-referenced with the use of Global Positioning System (GARMIN 78 12-Channels). Sixty Seven (67) water samples were taken for a period of three (3) months as shown in Table 1 and Figure 4. The samples were collected at depth levels (static water level) varying between 1.1 – 8.0 m and average of 3.7 m. The hydraulic head of the sampled wells range between 320.2 and 392.1 m and an average of 345.6 m. The aquifer units in the area are weathered layer aquifer and confined/unconfined fractured basement. The major source of groundwater recharge is atmospheric precipitation.

**Table 1. Summary of Well Information in the Sampled Locations**

| Well No. | Easting (mE) | Northing (mN) | Elevation (m) | Static Water Level (m) | Hydraulic Head (m) |
|---|---|---|---|---|---|
| 1 | 749311 | 802346 | 336 | 1.4 | 334.6 |
| 2 | 748381 | 802542 | 341 | 1.8 | 339.2 |
| 3 | 747089 | 803032 | 335 | 3.6 | 331.4 |
| 4 | 748071 | 804258 | 326 | 5.8 | 320.2 |
| 5 | 749414 | 804699 | 343 | 4.2 | 338.8 |
| 6 | 747502 | 805483 | 341 | 6.8 | 334.2 |
| 7 | 745901 | 805777 | 336 | 5.9 | 330.1 |
| 8 | 747192 | 800533 | 365 | 4.9 | 360.1 |
| 9 | 747296 | 798964 | 342 | 5.3 | 336.7 |
| 10 | 748846 | 796759 | 355 | 4.7 | 350.3 |
| 11 | 745694 | 802738 | 363 | 6.4 | 356.6 |
| 12 | 746314 | 802444 | 340 | 3.1 | 336.9 |
| 13 | 744196 | 801464 | 355 | 3.3 | 351.8 |
| 14 | 742594 | 802591 | 338 | 1.1 | 336.9 |
| 15 | 744506 | 803572 | 341 | 1.6 | 339.4 |
| 16 | 743730 | 804846 | 344 | 4.1 | 339.9 |
| 17 | 745694 | 807296 | 352 | 4.4 | 347.6 |
| 18 | 744506 | 807738 | 340 | 5.2 | 334.8 |
| 19 | 745074 | 807100 | 341 | 2.1 | 338.9 |
| 20 | 746624 | 807541 | 339 | 5.5 | 333.5 |
| 21 | 743885 | 805924 | 340 | 1.2 | 338.8 |
| 22 | 743885 | 804258 | 368 | 2.0 | 366.0 |
| 23 | 743782 | 803375 | 371 | 3.8 | 367.2 |
| 24 | 745229 | 798817 | 369 | 4.5 | 364.5 |
| 25 | 743265 | 799357 | 368 | 3.6 | 364.4 |
| 26 | 742749 | 796318 | 360 | 4.1 | 355.9 |
| 27 | 740062 | 796269 | 358 | 3.0 | 355.0 |
| 28 | 738667 | 796269 | 362 | 3.4 | 358.6 |
| 29 | 739493 | 797886 | 365 | 3.2 | 361.8 |
| 30 | 738357 | 801121 | 340 | 5.2 | 334.8 |
| 31 | 741095 | 801464 | 344 | 4.8 | 339.2 |
| 32 | 739235 | 802248 | 361 | 2.2 | 358.8 |
| 33 | 737427 | 802591 | 354 | 3.5 | 350.5 |
| 34 | 734946 | 801856 | 356 | 2.7 | 353.3 |
| 35 | 736962 | 798964 | 350 | 4.7 | 345.3 |
| 36 | 735670 | 793377 | 351 | 3.7 | 347.3 |
| 37 | 736599 | 795485 | 359 | 3.4 | 355.6 |
| 38 | 743472 | 794406 | 359 | 1.8 | 357.2 |
| 39 | 738718 | 795093 | 360 | 4.6 | 355.4 |
| 40 | 737582 | 808718 | 355 | 3.7 | 351.3 |
| 41 | 738563 | 808375 | 361 | 5.7 | 355.3 |
| 42 | 739079 | 808816 | 363 | 1.8 | 361.3 |
| 43 | 739235 | 807296 | 396 | 3.9 | 392.1 |
| 44 | 740372 | 807443 | 381 | 3.3 | 377.8 |
| 45 | 741354 | 806316 | 359 | 6.1 | 353.0 |
| 46 | 739752 | 806169 | 333 | 1.1 | 331.9 |
| 47 | 742542 | 807541 | 333 | 3.1 | 329.9 |
| 48 | 737737 | 804699 | 329 | 3.8 | 325.2 |
| 49 | 737013 | 806757 | 333 | 3.2 | 329.8 |
| 50 | 735101 | 807590 | 329 | 2.5 | 326.5 |
| 51 | 741199 | 802640 | 328 | 1.7 | 326.3 |
| 52 | 746366 | 792201 | 350 | 4.4 | 345.6 |
| 53 | 749569 | 797690 | 350 | 3.9 | 346.1 |
| 54 | 751326 | 796955 | 388 | 5.2 | 382.8 |
| 55 | 750913 | 795044 | 349 | 4.0 | 345.0 |
| 56 | 751740 | 793965 | 347 | 2.3 | 344.7 |
| 57 | 750293 | 803425 | 348 | 2.0 | 346.0 |
| 58 | 740940 | 802738 | 335 | 6.6 | 328.4 |
| 59 | 740010 | 803326 | 337 | 2.4 | 334.6 |
| 60 | 741457 | 803424 | 338 | 3.1 | 334.9 |
| 61 | 739493 | 801513 | 324 | 3.2 | 320.8 |
| 62 | 738770 | 804209 | 333 | 3.5 | 329.5 |
| 63 | 746624 | 806757 | 329 | 2.4 | 326.6 |
| 64 | 746934 | 808473 | 345 | 5.1 | 339.9 |
| 65 | 750297 | 804503 | 356 | 1.1 | 354.9 |
| 66 | 740940 | 800141 | 356 | 8.0 | 348.0 |
| 67 | 742284 | 801513 | 350 | 6.3 | 343.8 |

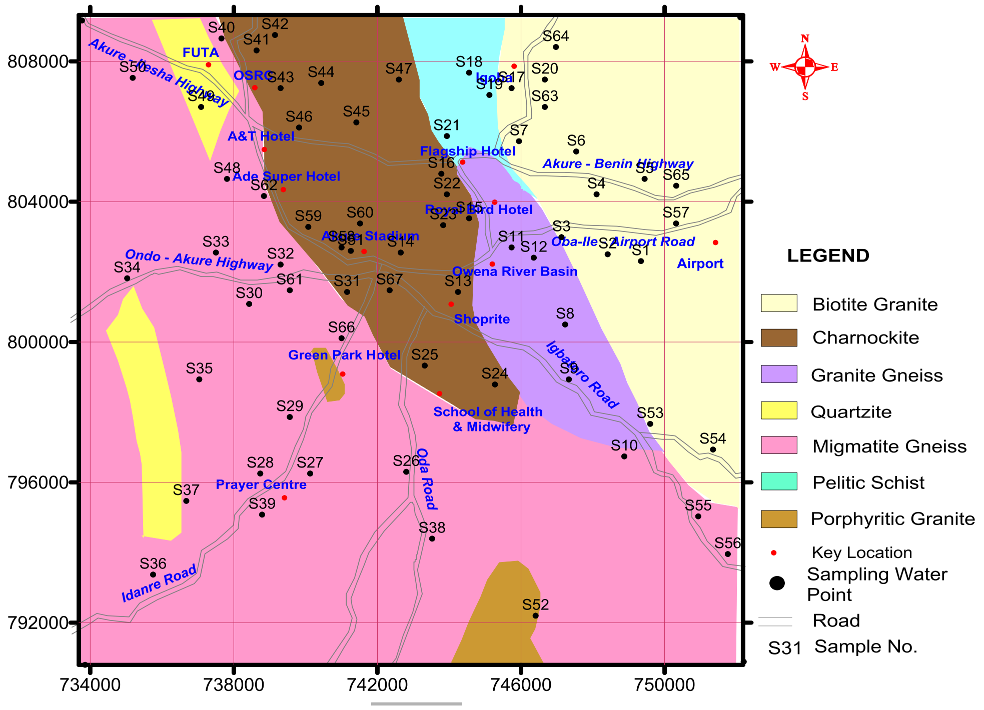


**Figure 4.** Data acquisition Map for the Study showing the Sampling points/Numbers

Selected physicochemical parameters were determined in the samples. The samples were collected in polythene bottles, pre-cleaned by washing with non-ionic detergents, rinsed with water, and finally with de-ionized water. However before sampling, the bottles were rinsed three times with sample water. The water quality parameter determination was done using standard methods and techniques. Samples were brought to the laboratory for analysis of physical and chemical parameters. The colour, odour, turbidity (using digital turbidity meter), taste, appearance, temperature measured using mercury in glass thermometer, pH, electrical conductivity (EC), oxidation potential (Eh), and Total Dissolved Solids (TDS) of the samples were measured at the point of collection. Digital pH meter model-361 was used to determine the pH values. Electrical conductivity of the samples was determined using digital conductivity meter. Total Alkalinity was determined by titrimetric method. Total Hardness was measured using EDTA (Ethylene Diamine Tetra Acetic Acid) as titrant with ammonium chloride and ammonium hydroxide buffer solution (PH-10) and Erichrome Black T as indicator. Chloride content was determined by Mohr's method using silver nitrate as titrant and potassium chromate solution as indicator. Total Dissolved Solid was determined by evaporation method (Gravimetric method) in an oven at 200 ℃ for 2hours.

The analytical precision for the measurements of ions was determined by calculating the ionic balance error (IBE) using equation 1 is +9%. The value is generally within acceptable limit of ± 10 %. Thus the data can be used for the interpretation of quality of groundwater for any purpose (drinking purpose)

$$IBE = \frac{(TCC + TCA)}{TCC - TCA} \times 100 \qquad (1)$$

where, TCC = total concentration of cations
TCA = total concentration of anions.

Water quality index is one of the most effective tools that helps in communicating information on the quality of water to the concerned citizens and policy makers (especially governments at all levels). It thus becomes an important parameter for the assessment and management of groundwater [22]. The Water Quality Index (WQI) was calculated through three steps. The first step was the assignment of weight ($w_w$) to each parameter measured in the water samples according to their relative importance in the overall quality of water for drinking purpose as proposed by [23,24]. In this study, a maximum weight of five (5) was assigned to $K^+$, TDS, $NO_3^-$, $Cl^-$; four (4) to pH and EC; three (3) was assigned to $Ca^{2+}$, $Mg^{2+}$, $HCO_3^-$, $SO_4^{2-}$ while $Na^+$ and Total Hardness (TH) assigned a weight of two (2). Alkalinity and oxidation potential (Eh) assigned a weight of one (1).

The second step involved the determination of the relative weight ($W_i$) using equation 2;

$$W_i = \frac{w_w}{\sum_{i=1}^{n} w_w} \qquad (2)$$

where, $w_w$ is the weight of each parameter
$W_i$ is relative weight
n is the number of parameters.

The third step was the calculation of the quality rating scale ($q_i$) for each parameter by applying equation 3:

$$q_i = \frac{C_i}{S_i} \times 100 \qquad (3)$$

where, $q_i$ is the quality rating
$C_i$ is the concentration of each water sample
$S_i$ is World Health Organisation [25] water standard for each parameter in mg/l

The final stage is the calculation of WQI by applying equation 4:

$$WQI = \sum_{i=1}^{n} SL_i \quad (4)$$

where $SL_i$ is the product of $w_i$ and $q_i$.

The suitability of WQI values for human consumption according to [26] was used in this study as shown in Table 2.

**Table 2. Water Quality Indices Rating**

| WQI values | Rating |
|---|---|
| 0-25 | Excellent |
| 26-50 | Good |
| 51-75 | Bad |
| 76-100 | Very Bad |
| 100 & above | Unfit |

## 4. Results and Discussion

The results of the analyses of the water sampled are presented in Table 3 and Table 4. The range/mean concentrations of the analyzed parameters are compared with World Health Organisation (WHO) standard.

The temperature of the earth affects the usefulness of water for many purposes. The temperature of the groundwater varies from 25.9 – 30.8℃ with a mean of 27.9℃. The range of values show a uniformly moderate temperature. All the water samples are colourless, odourless, and tasteless, with clear appearance. The turbidity of water ranges from 0.6 to 9.5NTU and an average of 3.16 NTU which is within the recommended 5NTU by WHO. This indicates that are characterized with less suspended matter such as clay, silt, fine fragments of organic matter, and similar material. The pH plays a vital role to react with acidic or alkaline. It is controlled by $CO_2$ – $CO_3^{2-}$ - $HCO_3^-$ equilibrium. The combination of $CO_2$ with $H_2O$ (water) forms $H_2CO_3$ (carbonic acid), which affects the pH of water. Water can be classified as acidic and alkaline on the basis of pH, which varies from 1 to 14 (Table 5). The recorded pH varies from 5.2 – 7.0 in the groundwater. As per the classification of pH, the water is characterized by an acidic condition, as $H^+$ is more than $OH^-$ in the water [27]. The oxidation potential (Eh) shows a positive value (0.4190 – 0.5610 volts) which indicates that the water is an oxidizing type [4]. From Figure 5, it shows a near oxidizing acidic water.

The electrical conductivity (EC) is a measure of a material's ability to conduct electric current. The weak acids ($HCO_3^-$ and $CO_3^{2-}$) have low conductivity, while strong acids ($Cl^-$, $SO_4^{2-}$ and $NO_3^-$) show high conductivity. The higher the EC, the greater is the enrichment of salts in water. The EC of water samples is in the range of 53 - 874 $\mu S/cm$ (avg. of 189.8 $\mu S/cm$). Using Table 6, the water can be classified as Type I (EC less than 1500 $\mu S/cm$) characterized by low salt enrichment, low infiltration, high run off, and high topography. The water type is presume to be a recharge water. The spatial distribution of EC (Figure 6) shows predominant values in the range of 0 – 200 $\mu S/cm$. The total dissolved solids (TDS) indicate the total salt concentration of dissolved ions from soils and rocks (including any organic matter and some water of crystallization) in water. The amount and character of dissolved solids depend on the solubility and type of rocks with which the water has been in contact. Generally, low TDS is caused by the influence of rock-water interaction in relation to recharge water at topographic highs, and high TDS is due to impact of anthropogenic origin with respect to discharge water at topographic lows [27]. The value of TDS ranges from 40mg/l to 424 mg/l, and an average of 96.7 mg/l. Therefore using Table 7, the water is fresh with TDS less than 1000 mg/l. The spatial distribution of TDS shows a predominant range of 40 – 140 mg/l (Figure 7) while small closures of high TDS are found in Igoba area, FUTA north gate, and along Akure-Owo road.

The chemical nature of water continually evolves as it moves through the hydrologic cycle. The kind of chemical constituents found in groundwater depends in part on the chemistry of the precipitation and recharge water as well as the geologic environment [28,29]. Total alkalinity (TA) is a measure of the capacity of water to neutralize acid in terms of calcium carbonate ($CaCO_3$). The TA is in between 40 – 340 mg/l (av. 123.9 mg/l). This range of values is within the recommended WHO permissible standard of 200mg/l. The total hardness (TA) of the samples widely varies from 10 to 392 mg/l (av. 100.9mg/l).

Hard water forms scale in boilers, water heater, and pipes. The higher the TH, the greater is the soap lather. The classification of TH is shown in Table 8, therefore the water from the study area varies from soft – very hard water. Spatial distribution of TH is shown in Figure 8 and shows relatively high TH values. High TH are observed in biotite granite and migmatite geologic units, prominent in the northeast.

Based on TA and TH, the water can be classified as excess alkalinity (EA) type of hardness characterized by $Na^+$ of $HCO_3^-$ ions [27]. However both TH and TA of the water samples satisfy the WHO recommended permissible limits of 400 mg/l and 200 mg/l respectively.

Calcium ($Ca^{2+}$) is usually derived from minerals like plagioclase, pyroxene and amphiboles. The presence of carbon dioxide in the soil zone is another source of calcium in groundwater. $Ca^{2+}$ varies from 8.8 – 60.9mg/l with average of 21.3mg/l (Figure 9a) and still within the recommended 75mg/l specified by WHO. Calcium feldspars present in the rocks in the study area are the source of calcium in the groundwater.

Magnesium ($Mg^{2+}$) is an important component of basic igneous rocks, volcanic rocks, metamorphic rocks, derived from minerals such as olivine, hornblende, serpentine, biotite, augite etc. Seawater, mining activities and industrial effluents are also source of magnesium in groundwater. The $Mg^{2+}$ ranges from 0.8 – 19.5 (av. 4.0). This range of value is still within the minimum acceptable limit of 50 mg/l. Sodium ($Na^+$) ranges from 1.4 – 19.5mg/l with an average value of 5.1mg/l, hence is within the WHO standard (50 mg/l) for drinking water. The concentration of $Na^+$ in the samples is generally low and could be attributed to less influence of anthropogenic activities on the groundwater. Spatial distribution of $Na^+$ shows relatively high values in in migmatite and quartzite environments (Figure 9b). The potassium ($K^+$) is in between 2.2 mg/l and 23.6 mg/l (av. 7.7mg/l), important sources include orthoclase feldspar, nepheline, leucite and biotite. Chemical fertilizers are other sources of potassium especially in sample no. 65. Generally lower content of $K^+$ could be due to its absorption on clay minerals.

**Table 3. Result obtained from the Physical Parameters measured/examined**

| Well No. | Temp (℃) | pH | TDS (mg/l) | EC (μS/cm) | Eh (volts) | Turb. NTU |
|---|---|---|---|---|---|---|
| 1 | 30.8 | 6.4 | 100 | 204 | 0.483 | 1.8 |
| 2 | 28.4 | 5.6 | 73 | 145 | 0.432 | 1.5 |
| 3 | 30.4 | 5.5 | 75 | 151 | 0.420 | 2.5 |
| 4 | 27.6 | 5.6 | 65 | 131 | 0.477 | 2.9 |
| 5 | 28.1 | 6.4 | 376 | 754 | 0.464 | 8.6 |
| 6 | 29.3 | 5.8 | 56 | 115 | 0.512 | 1.2 |
| 7 | 29.4 | 5.7 | 50 | 101 | 0.511 | 1.5 |
| 8 | 28.5 | 5.7 | 42 | 83 | 0.543 | 2.2 |
| 9 | 29.6 | 5.6 | 50 | 101 | 0.561 | 3.4 |
| 10 | 29.2 | 6.2 | 91 | 181 | 0.485 | 1.1 |
| 11 | 29.2 | 5.7 | 150 | 303 | 0.481 | 1.2 |
| 12 | 30.5 | 5.6 | 74 | 152 | 0.515 | 4.6 |
| 13 | 29.6 | 5.7 | 66 | 132 | 0.505 | 6.2 |
| 14 | 30.1 | 6.4 | 130 | 61 | 0.457 | 5.1 |
| 15 | 29.6 | 5.7 | 64 | 127 | 0.450 | 6.5 |
| 16 | 29.8 | 6.4 | 50 | 101 | 0.475 | 8.2 |
| 17 | 27.4 | 6.3 | 78 | 156 | 0.460 | 4.2 |
| 18 | 28.2 | 7.0 | 424 | 874 | 0.421 | 1.2 |
| 19 | 27.0 | 6.6 | 281 | 563 | 0.419 | 1.5 |
| 20 | 28.2 | 6.3 | 143 | 286 | 0.432 | 2.3 |
| 21 | 27.4 | 6.6 | 165 | 331 | 0.474 | 1.8 |
| 22 | 29.5 | 5.3 | 40 | 79 | 0.492 | 1.5 |
| 23 | 27.5 | 5.8 | 161 | 323 | 0.435 | 1.1 |
| 24 | 28.2 | 5.2 | 66 | 141 | 0.480 | 0.8 |
| 25 | 26.8 | 5.5 | 62 | 124 | 0.477 | 4.7 |
| 26 | 27.5 | 5.6 | 42 | 84 | 0.481 | 1.2 |
| 27 | 26.4 | 5.2 | 101 | 203 | 0.535 | 3.5 |
| 28 | 28.5 | 5.5 | 83 | 167 | 0.502 | 2.5 |
| 29 | 27.8 | 5.6 | 73 | 146 | 0.490 | 1.2 |
| 30 | 28.4 | 6.3 | 112 | 224 | 0.555 | 4.4 |
| 31 | 25.7 | 5.9 | 57 | 114 | 0.493 | 3.2 |
| 32 | 27.5 | 5.6 | 105 | 210 | 0.526 | 5.8 |
| 33 | 27.6 | 6.8 | 119 | 238 | 0.495 | 6.9 |
| 34 | 28.1 | 6.3 | 123 | 246 | 0.490 | 7.8 |
| 35 | 26.8 | 6.4 | 84 | 169 | 0.501 | 0.6 |
| 36 | 26.5 | 6.5 | 89 | 179 | 0.498 | 1.2 |
| 37 | 27.7 | 6.9 | 101 | 202 | 0.521 | 1.5 |
| 38 | 28.3 | 5.9 | 63 | 127 | 0.430 | 1.8 |
| 39 | 27.9 | 5.8 | 48 | 96 | 0.540 | 1.2 |
| 40 | 29.8 | 6.4 | 44 | 89 | 0.455 | 1.2 |
| 41 | 27.2 | 6.2 | 57 | 114 | 0.504 | 1.3 |
| 42 | 27.6 | 6.4 | 103 | 206 | 0.490 | 1.2 |
| 43 | 27.5 | 6.9 | 50 | 101 | 0.464 | 1.4 |
| 44 | 27.3 | 6.4 | 72 | 144 | 0.510 | 1.6 |
| 45 | 27.1 | 6.1 | 78 | 157 | 0.519 | 1.4 |
| 46 | 26.5 | 6.1 | 57 | 115 | 0.497 | 2.2 |
| 47 | 27.8 | 6.9 | 49 | 98 | 0.465 | 3.2 |
| 48 | 27.5 | 6.3 | 46 | 91 | 0.420 | 4.5 |
| 49 | 27.4 | 6.2 | 83 | 166 | 0.429 | 6.8 |
| 50 | 27.2 | 6.8 | 331 | 662 | 0.465 | 4.8 |
| 51 | 27.8 | 6.7 | 125 | 250 | 0.452 | 1.5 |
| 52 | 27.5 | 5.8 | 142 | 285 | 0.432 | 1.1 |
| 53 | 27.6 | 6.1 | 53 | 108 | 0.463 | 1.4 |
| 54 | 27.7 | 5.7 | 62 | 125 | 0.421 | 4.4 |
| 55 | 28.3 | 5.9 | 41 | 83 | 0.472 | 5.8 |
| 56 | 27.4 | 6.3 | 54 | 108 | 0.422 | 7.9 |
| 57 | 27.9 | 6.6 | 115 | 231 | 0.523 | 4.5 |
| 58 | 27.3 | 6.9 | 174 | 348 | 0.522 | 2.6 |
| 59 | 26.1 | 6.2 | 52 | 228 | 0.490 | 1.2 |
| 60 | 26.5 | 5.9 | 89 | 178 | 0.515 | 1.2 |
| 61 | 26.9 | 6.5 | 46 | 53 | 0.498 | 1.2 |
| 62 | 27.8 | 5.8 | 62 | 122 | 0.520 | 5.5 |
| 63 | 28.4 | 5.4 | 78 | 156 | 0.531 | 9.5 |
| 64 | 26.3 | 5.7 | 42 | 98 | 0.437 | 6.5 |
| 65 | 26.9 | 5.3 | 47 | 101 | 0.433 | 4.2 |
| 66 | 26.1 | 5.2 | 150 | 122 | 0.452 | 2.2 |
| 67 | 26.4 | 5.7 | 48 | 65 | 0.497 | 1.2 |
| Min. | 25.9 | 5.2 | 40 | 53 | 0.419 | 0.6 |
| Max. | 30.8 | 7.0 | 424 | 874 | 0.561 | 9.5 |
| Average | 27.9 | 6.0 | 96.7 | 189.8 | 0.481 | 3.16 |
| WHO Standard/Limit (2008) | 27 | 6.5 – 8.5 | 1000 | 1200 | - | 5 |

**Table 4. Summary of the Analyzed Chemical Parameters**

| Well No. | T.A | Acidity | T.H | $HCO_3^-$ | $Ca^{2+}$ | $Mg^{2+}$ | $Cl^-$ | $Na^+$ | $K^+$ | $SO_4^{2-}$ | $NO_3^-$ | WQI (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 180 | 360 | 228 | 219.5 | 52.5 | 5.72 | 49.7 | 5.4 | 10.5 | 3.2 | 1.1 | 50 |
| 2 | 210 | 220 | 10 | 120.1 | 23.3 | 0.9 | 5.5 | 2.5 | 2.3 | 0.9 | 0.9 | 25 |
| 3 | 150 | 200 | 20 | 142.2 | 14.5 | 0.8 | 15.5 | 2.8 | 4.5 | 1.2 | 0.8 | 28 |
| 4 | 40 | 260 | 55 | 123.4 | 21.2 | 2.2 | 20.5 | 2.9 | 9.5 | 2.5 | 4.5 | 33 |
| 5 | 340 | 380 | 392 | 214.8 | 60.9 | 19.5 | 74.5 | 4.2 | 7.8 | 4.5 | 1.3 | 61 |
| 6 | 60 | 280 | 88 | 73.2 | 10.0 | 3.8 | 17.7 | 3.0 | 5.7 | 6.0 | 4.5 | 26 |
| 7 | 85 | 210 | 65 | 54.5 | 11.2 | 2.8 | 20.5 | 2.8 | 10.2 | 5.5 | 3.2 | 29 |
| 8 | 60 | 260 | 84 | 73.2 | 13.4 | 2.9 | 14.2 | 2.4 | 8.8 | 12.5 | 0.9 | 28 |
| 9 | 60 | 460 | 68 | 73.2 | 10.9 | 2.5 | 12.4 | 2.1 | 9.8 | 7.5 | 1.1 | 28 |
| 10 | 90 | 320 | 68 | 63.4 | 22.1 | 8.2 | 24.3 | 2.2 | 4.6 | 2.4 | 3.5 | 27 |
| 11 | 120 | 250 | 112 | 51.2 | 22.3 | 4.4 | 18.9 | 3.4 | 6.8 | 0.9 | 8.2 | 30 |
| 12 | 140 | 180 | 84 | 170.8 | 15.1 | 2.7 | 23.8 | 4.3 | 7.0 | 13.5 | 3.4 | 35 |
| 13 | 180 | 290 | 45 | 111.2 | 11.4 | 3.3 | 25.5 | 10.1 | 9.2 | 3.3 | 3.2 | 34 |
| 14 | 140 | 260 | 52 | 170.8 | 20.9 | 0.9 | 33.7 | 2.4 | 4.5 | 5.5 | 5.9 | 34 |
| 15 | 140 | 240 | 42 | 85.3 | 9.5 | 1.1 | 14.2 | 9.8 | 4.6 | 1.2 | 8.2 | 26 |
| 16 | 100 | 200 | 88 | 122.1 | 16.8 | 2.9 | 14.2 | 2.0 | 4.4 | 8.5 | 7.4 | 29 |
| 17 | 140 | 200 | 152 | 170.8 | 25.2 | 5.2 | 17.5 | 2.8 | 7.3 | 12.2 | 0.9 | 37 |
| 18 | 60 | 380 | 96 | 73.2 | 25.3 | 1.9 | 28.4 | 2.6 | 11.8 | 4.7 | 0.8 | 44 |
| 19 | 40 | 320 | 83 | 40.3 | 20.2 | 1.2 | 30.2 | 6.5 | 15.2 | 4.1 | 0.9 | 41 |
| 20 | 70 | 300 | 62 | 20.3 | 11.2 | 1.3 | 33.2 | 8.8 | 12.2 | 2.3 | 1.1 | 32 |
| 21 | 260 | 340 | 264 | 317.2 | 57.9 | 7.9 | 10.6 | 5.2 | 7.9 | 2.5 | 1.2 | 55 |
| 22 | 100 | 400 | 60 | 122.1 | 11.7 | 1.9 | 12.4 | 10.2 | 6.1 | 13.7 | 1.9 | 28 |
| 23 | 190 | 380 | 48 | 68.3 | 14.5 | 1.4 | 42.2 | 2.9 | 4.4 | 3.3 | 2.2 | 28 |
| 24 | 60 | 220 | 84 | 73.2 | 31.6 | 0.8 | 14.2 | 11.5 | 6.0 | 4.5 | 1.5 | 27 |
| 25 | 80 | 410 | 92 | 44.9 | 16.5 | 1.1 | 32.1 | 14.2 | 6.2 | 9.9 | 3.1 | 26 |
| 26 | 40 | 400 | 38 | 48.8 | 15.4 | 0.9 | 12.3 | 3.8 | 8.7 | 9.5 | 0.8 | 25 |
| 27 | 200 | 360 | 116 | 244.0 | 25.3 | 3.1 | 23.8 | 4.6 | 4.2 | 11.5 | 3.4 | 39 |
| 28 | 70 | 260 | 55 | 33.5 | 23.3 | 5.6 | 12.2 | 5.0 | 5.8 | 8.4 | 2.3 | 24 |
| 29 | 300 | 500 | 292 | 366 | 54.1 | 16.5 | 44.3 | 4.9 | 6.9 | 12.2 | 4.5 | 58 |
| 30 | 100 | 290 | 165 | 15.2 | 22.3 | 2.2 | 5.5 | 6.9 | 12.3 | 6.2 | 1.2 | 32 |
| 31 | 60 | 340 | 108 | 73.2 | 18.5 | 3.6 | 12.3 | 2.7 | 10.1 | 15.7 | 0.9 | 31 |
| 32 | 80 | 340 | 152 | 97.6 | 21.7 | 5.7 | 23.8 | 3.7 | 8.8 | 6.5 | 1.2 | 33 |
| 33 | 82 | 310 | 182 | 18.3 | 20.4 | 4.4 | 2.5 | 8.8 | 5.5 | 2.2 | 1.4 | 26 |
| 34 | 110 | 300 | 122 | 20.2 | 18.2 | 2.2 | 3.9 | 19.5 | 3.2 | 2.4 | 3.8 | 24 |
| 35 | 150 | 310 | 145 | 22.5 | 18.4 | 1.3 | 8.8 | 12.2 | 4.2 | 3.5 | 5.6 | 25 |
| 36 | 320 | 420 | 140 | 390.4 | 23.5 | 4.7 | 10.5 | 2.3 | 9.3 | 8.1 | 6.2 | 57 |
| 37 | 100 | 320 | 25 | 42.2 | 22.4 | 9.4 | 18.2 | 4.1 | 10.2 | 5.5 | 0.9 | 32 |
| 38 | 140 | 300 | 28 | 33.2 | 10.2 | 4.1 | 20.1 | 3.9 | 11.1 | 1.8 | 0.8 | 29 |
| 39 | 80 | 450 | 35 | 45.0 | 8.8 | 6.0 | 14.3 | 3.8 | 10.5 | 1.1 | 0.8 | 28 |
| 40 | 60 | 400 | 44 | 90.1 | 14.5 | 1.5 | 21.1 | 10.1 | 6.2 | 4.2 | 0.9 | 27 |
| 41 | 60 | 420 | 72 | 73.2 | 14.1 | 2.0 | 10.6 | 3.0 | 10.6 | 9.5 | 1.6 | 31 |
| 42 | 40 | 340 | 63 | 122.1 | 30.1 | 1.8 | 15.2 | 9.4 | 5.2 | 6.5 | 4.5 | 32 |
| 43 | 160 | 300 | 132 | $195.2^-$ | 25.3 | $4.4^{2+}$ | 12.3 | 10.7 | 10.2 | 3.7 | $4.4^-$ | 43 |
| 44 | 80 | 400 | 71 | 82.2 | 33.2 | 6.2 | 13.4 | 8.5 | 8.1 | 7.3 | 3.3 | 32 |
| 45 | 100 | 420 | 136 | 122.0 | 25.3 | 4.2 | 23.8 | 2.5 | 11.5 | 4.5 | 3.4 | 38 |
| 46 | 200 | 440 | 92 | 244.0 | 18.5 | 2.6 | 7.1 | 2.1 | 10.9 | 5.5 | 4.8 | 44 |
| 47 | 160 | 380 | 80 | 195.2 | 15.4 | 2.7 | 10.5 | 11.9 | 8.3 | 3.2 | 8.7 | 40 |
| 48 | 120 | 400 | 45 | 56.6 | 14.2 | 7.2 | 8.8 | 2.9 | 4.4 | 1.3 | 8.4 | 25 |
| 49 | 100 | 410 | 62 | 54.4 | 20.1 | 8.6 | 8.2 | 2.6 | 3.3 | 1.5 | 4.4 | 24 |
| 50 | 60 | 350 | 60 | 38.2 | 19.9 | 9.9 | 12.5 | 3.4 | 2.2 | 2.6 | 6.5 | 29 |
| 51 | 200 | 200 | 164 | 244.0 | 18.5 | 6.7 | 23.8 | 3.2 | 7.8 | 4.1 | 1.5 | 45 |
| 52 | 40 | 300 | 113 | 24.5 | 17.7 | 1.5 | 19.0 | 3.5 | 10.1 | 2.8 | 1.6 | 29 |
| 53 | 120 | 380 | 72 | 146.4 | 15..2 | 2.0 | 10.5 | 2.8 | 4.9 | 8.5 | 3.2 | 30 |
| 54 | 80 | 220 | 63 | 56.8 | 18.5 | 6.2 | 19.0 | 4.4 | 6.3 | 8.9 | 1.9 | 26 |
| 55 | 100 | 380 | 76 | 122.1 | 20.9 | 1.9 | 12.2 | 6.5 | 10.0 | 3.0 | 0.9 | 33 |
| 56 | 110 | 240 | 44 | 44.2 | 9.8 | 3.3 | 18.1 | 3.4 | 3.3 | 4.5 | 3.4 | 21 |
| 57 | 200 | 580 | 292 | 244.0 | 37.1 | 11.8 | 15.9 | 3.1 | 10.5 | 3.5 | 1.3 | 51 |
| 58 | 200 | 380 | 244 | 244.2 | 47.1 | 7.9 | 8.8 | 3.1 | 7.7 | 4.2 | 1.2 | 49 |
| 59 | 210 | 250 | 182 | 25.8 | 10.5 | 4.1 | 15.2 | 9.5 | 2.9 | 9.8 | 1.8 | 23 |
| 60 | 250 | 310 | 120 | 55.5 | 12.2 | 1.0 | 12.2 | 2.9 | 4.2 | 3.6 | 4.4 | 26 |
| 61 | 120 | 240 | 52 | 146.4 | 18.4 | 0.8 | 13.2 | 3.2 | 5.9 | 1.4 | 4.2 | 31 |
| 62 | 120 | 300 | 42 | 92.2 | 16.4 | 3.2 | 39.4 | 2.6 | 4.1 | 2.5 | 1.7 | 26 |
| 63 | 120 | 420 | 135 | 145.2 | 23.5 | 4.5 | 14.3 | 2.8 | 10.5 | 1.1 | 5.7 | 38 |
| 64 | 100 | 300 | 72 | 122.1 | 22.7 | 1.5 | 20.2 | 3.9 | 4.8 | 1.4 | 5.9 | 29 |
| 65 | 100 | 300 | 64 | 122.1 | 21.8 | 1.5 | 22.3 | 2.9 | 23.6 | 2.5 | 6.5 | 49 |
| 66 | 40 | 200 | 52 | 55.8 | 10.0 | 3.2 | 20.1 | 4.4 | 10.6 | 3.5 | 7.8 | 30 |
| 67 | 80 | 180 | 68 | 97.6 | 20.1 | 1.2 | 39.5 | 1.4 | 6.3 | 1.7 | 8.2 | 29 |
| Min | 40 | 180 | 10 | 15.2 | 8.8 | 0.8 | 2.5 | 1.4 | 2.2 | 0.9 | 0.8 | |
| Max | 340 | 580 | 392 | 390.4 | 60.9 | 19.5 | 74.5 | 19.5 | 23.6 | 15.7 | 8.7 | |
| Mean | 123 | 323 | 101 | 112.1 | 21.3 | 4.0 | 19.2 | 5.1 | 7.7 | 5.2 | 3.2 | |
| WHO Standard | 200 | - | 400 | 100 | 75 | 50 | 250 | 50 | 10 | 400 | 50 | |

Note: All units are in mg/l.

**Table 5. Classification of pH according to [27]**

| pH Range | Type | Dominance of ions |
|---|---|---|
| 1 – 7 | Acid | $H^+$ is more than $OH^-$ |
| 7 | Neutral | Equal amounts of $H^+$ and $OH^-$ |
| 7 – 14 | Basic | $OH^-$ is more than $H^+$ |

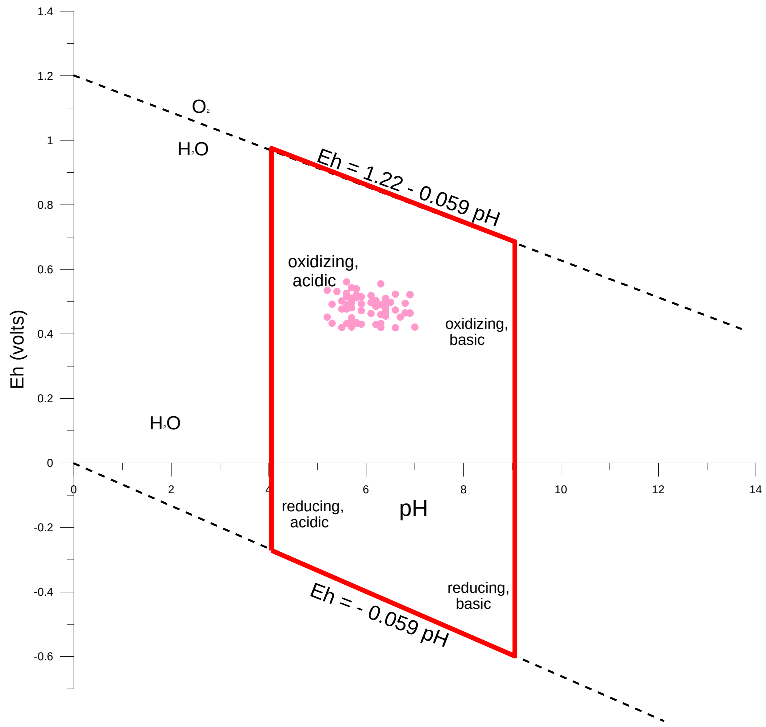


**Figure 5.** Framework of aqueous Eh – pH field showing a near oxidizing acidic condition for the sampled waters

**Table 6. Classification of EC [27]**

| EC Range ($\mu S/cm$) | Type | Enrichment of salts | Topography | Runoff | Infiltration | Water type |
|---|---|---|---|---|---|---|
| <1,500 | I | Low | High | High | Low | Recharge water |
| 1,500 – 3,000 | II | Medium | Moderate | Medium | Medium | - |
| >3000 | III | High | Low | Low | High | Discharge water |

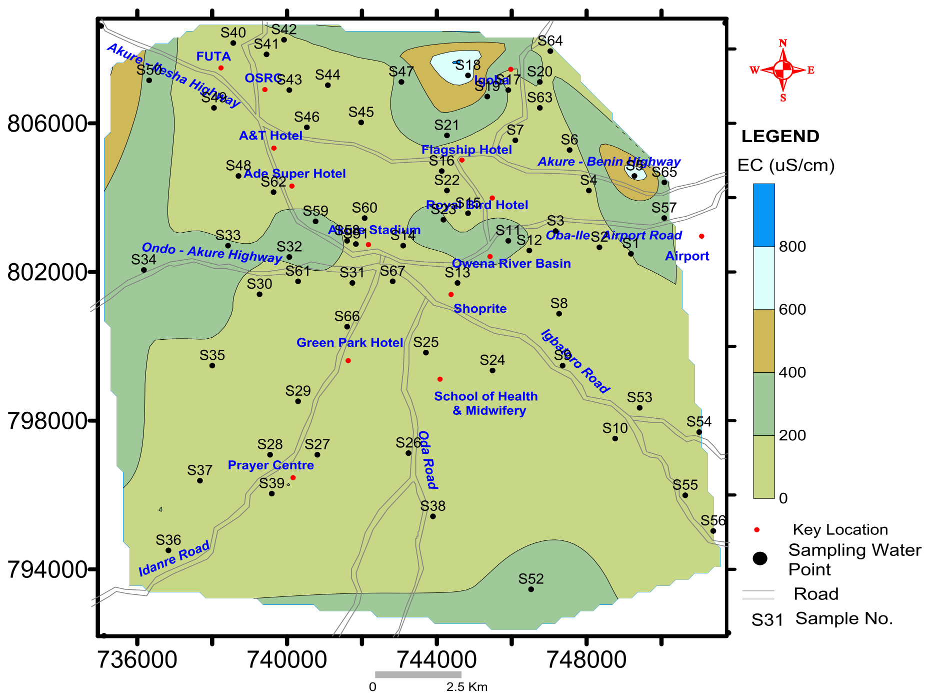


**Figure 6.** Spatial Distribution of Electrical Conductivity

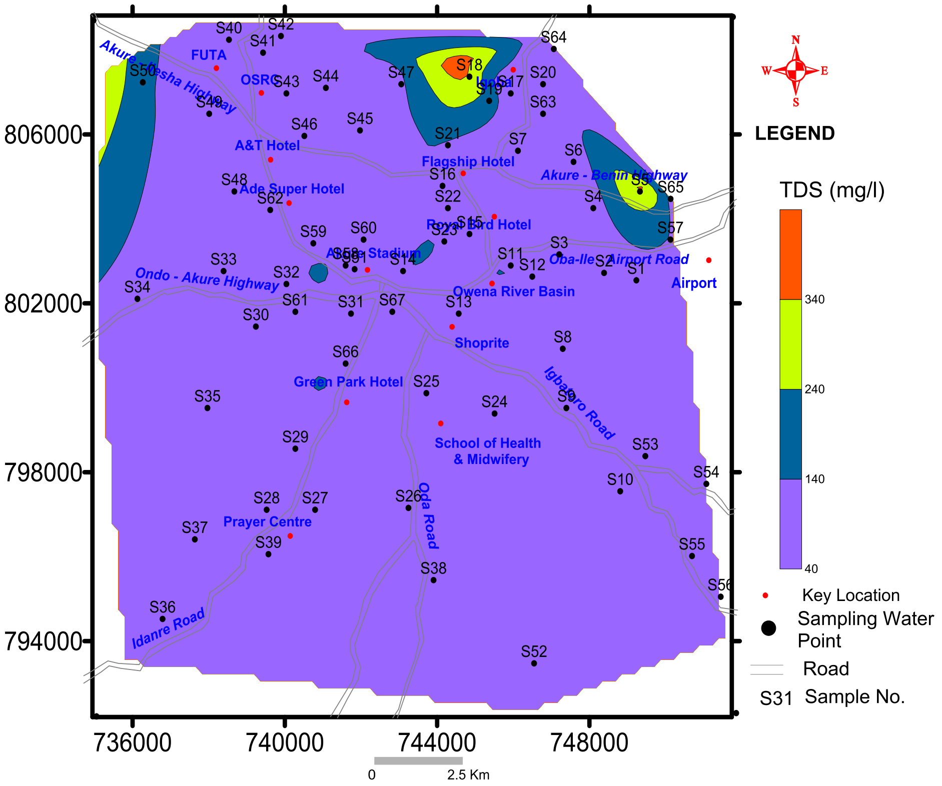


**Figure 7.** Spatial Distribution of Total Dissolved Solids

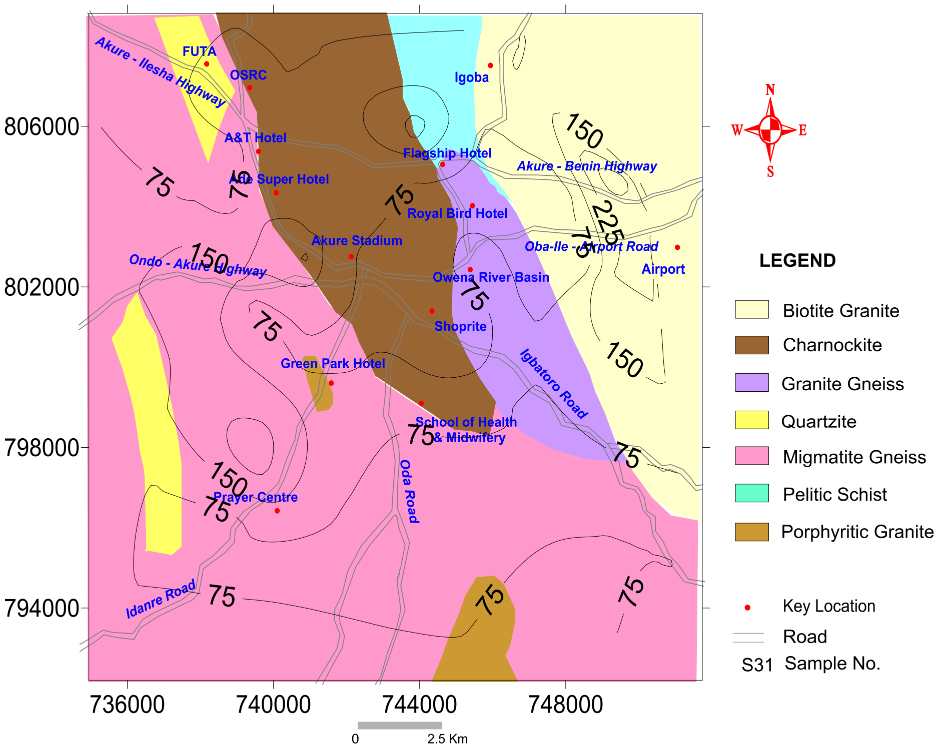


**Figure 8.** Spatial distribution of Total Hardness over the geological units in the study area

**Table 7.** Classification of TDS [4]

| TDS range (mg/l) | Classification |
|---|---|
| <1,000 | Fresh |
| 1,000 to 10,000 | Brackish |
| 10,000 to 100,000 | Saline |
| >100,000 | Brine |

**Table 8.** Classification of Total Hardness [30]

| TH range (mg/l) | Classification |
|---|---|
| <75 | Soft |
| 75 – 150 | Moderately hard |
| 150 - 300 | Hard |
| >300 | Very hard |

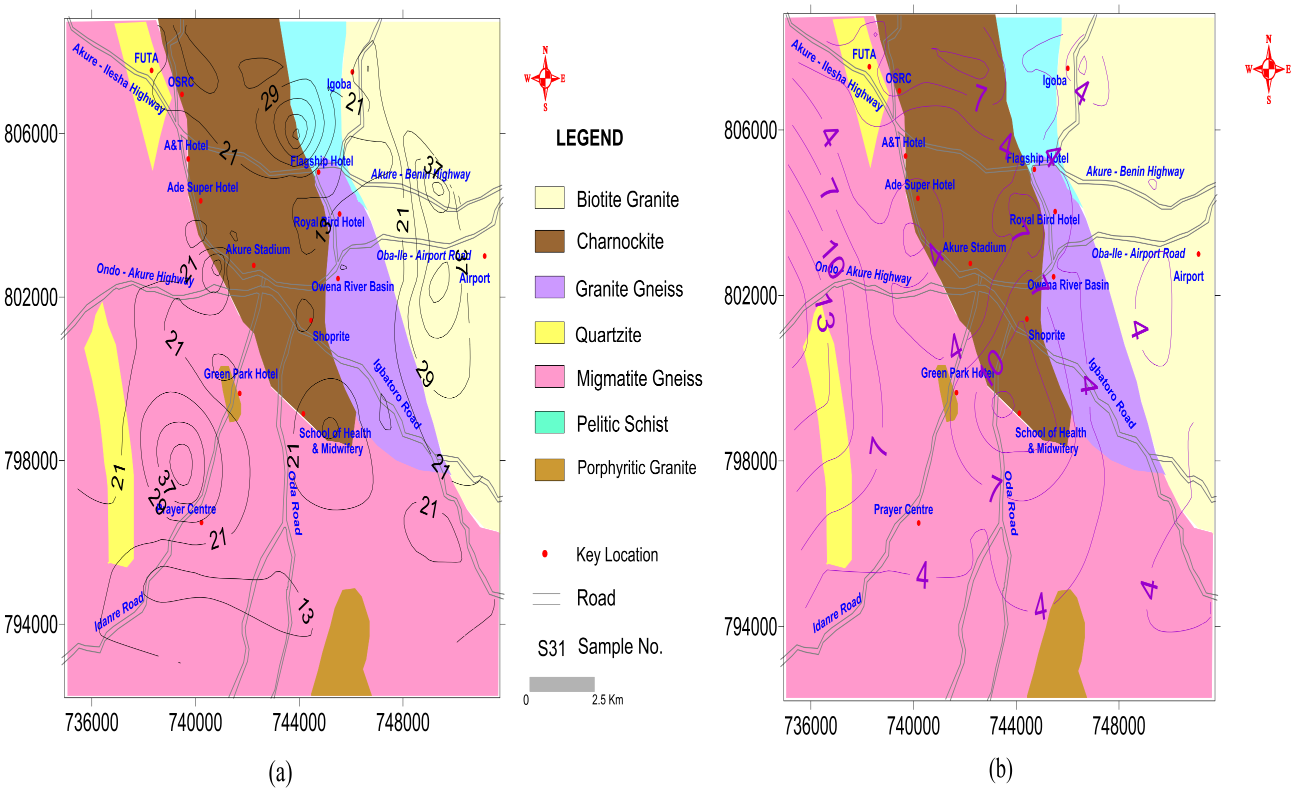


**Figure 9.** Spatial Distribution of (a) $Ca^{2+}$ and (b) $Na^{+}$ over the geological units

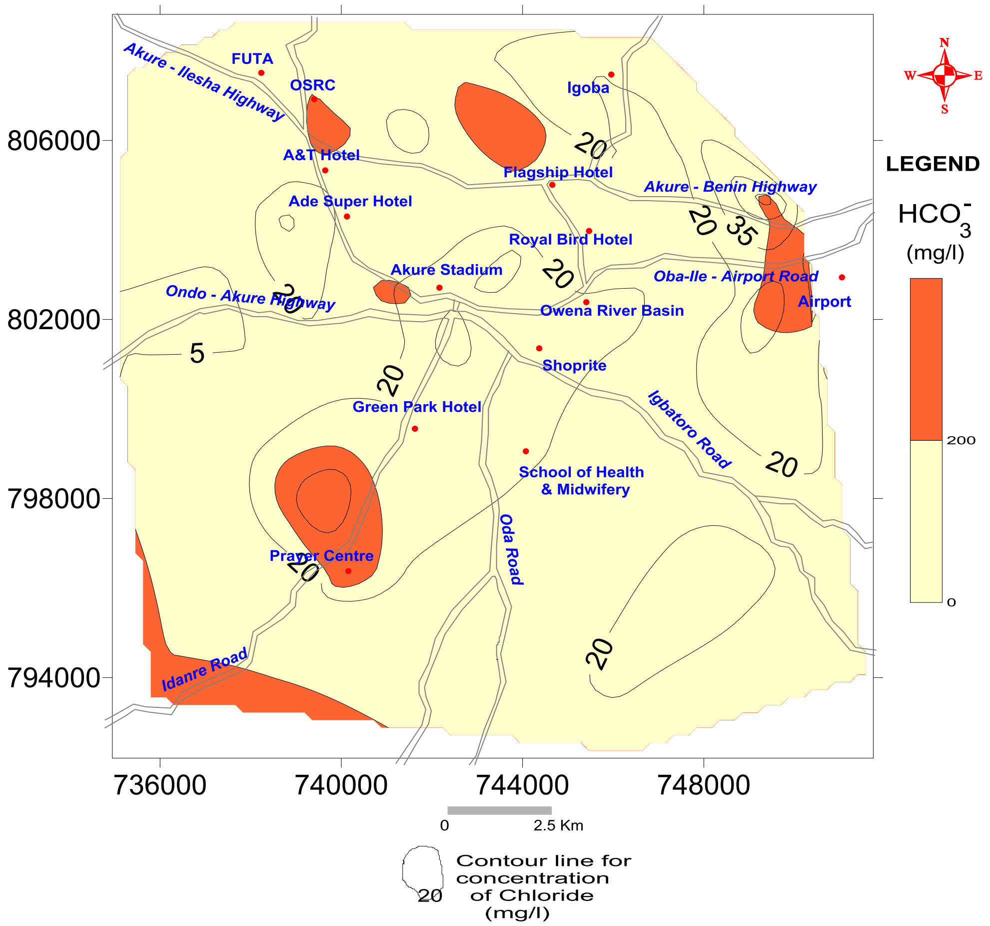


**Figure 10.** Spatial distribution of $HCO_3^-$ and $Cl^-$

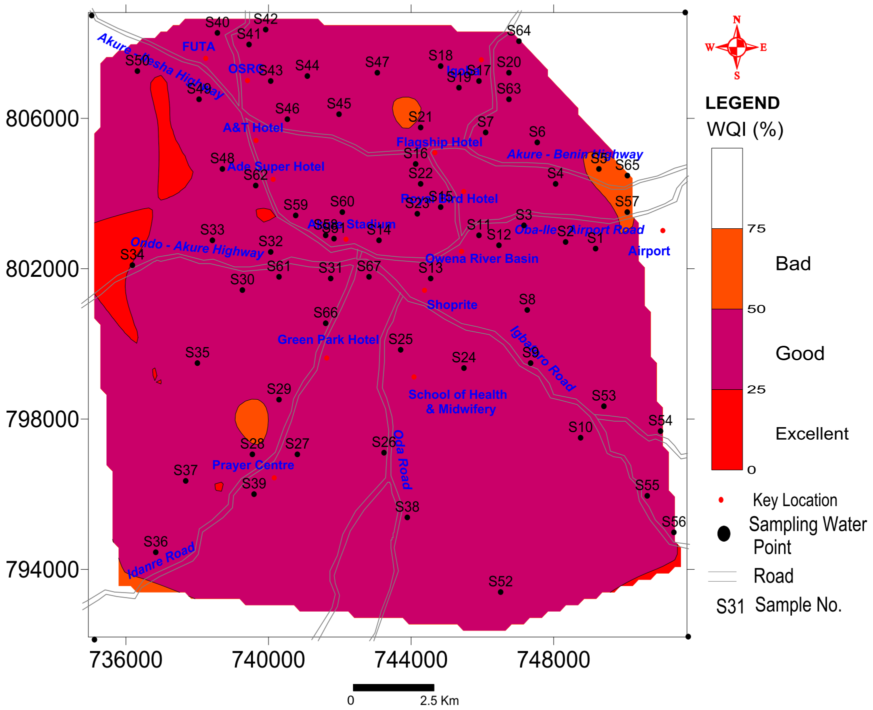


**Figure 11.** Spatial distribution of calculated WQI in the study area

The bicarbonate ($HCO_3^-$) varies from 15.2 – 390.4 mg/l (av. 112.1mg/l) as shown in Figure 10. This range of values is within the acceptable limit of WHO standard. Soil $CO_2$ is the main source of $HCO_3^-$ in the groundwater. In addition decay of organic matter also releases carbon dioxide for dissolution. The analyzed water samples contain sulphate ($SO_4^{2-}$) in the range of 0.91 – 15.7mg/l (av. 5.2mg/l). This mean value recorded satisfies the WHO requirement for drinking water. The Chloride ($Cl^-$) is dissolved from rocks and soils in the study area, and its values range from 2.5 – 74.5mg/l which within the acceptable limit of 250 mg/l [25]. Other sources of $Cl^-$ in the water could be attributed to domestic waste water. The spatial distribution of $HCO_3^-$ and $Cl^-$ is shown in Figure 10 and shows a predominant range of 0-200mg/l. The map also shows corresponding high $Cl^-$ and $HCO_3^-$ at the northeastern and southwestern parts. The nitrate ($NO_3^-$) in the water samples varies from 0.8 mg/l to 8.7 mg/l (av. 3.2mg/l). The source of nitrate decaying organic matter, sewage, nitrate fertilizers, and nitrate in soil [31]. Since the concentration of $NO_3^-$ is less than 10mg/l, its likely source is suspected nitrate fertilizers and nitrate in soil. However the values obtained satisfy the WHO recommendation. The calculated values of WQI vary from 22% to 60% (Table 4; Figure 11). The study area is widely (90% areal coverage) characterized by “Good water” only the range of 26 – 50%. The “Excellent water” is only associated with Sample S-34 in the northwestern part of the study area, while “Bad water” fall (S-21, S-28, S-57, and S-65) within a small portion of biotite granite and migmatite geologic unit.

# 5. Conclusion

The results from the study show that the groundwater in the area is physically and chemically suitable for drinking and domestic purposes, having satisfied the recommended standard of WHO. The WQI obtained show that the water is good for drinking with WQI values ranging between 22 and 60%. The “Good water” accounts for about 90 % of the water type in the area.

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