# Hydrochemical Properties And Groundwater Quality Assessment In Kurudu Area, Abuja, North Central Nigeria

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**Abstract:** The hydrochemical properties and groundwater quality assessment of groundwater samples from Kurudu area of Abuja, north central Nigeria, was investigated with the aim to evaluating their suitability for drinking and irrigation purposes. Physicochemical parameters such as temperature, pH, total dissolved solids, total hardness, and electrical conductivity were analysed. The major cations and anions were also analysed. Hydrochemical facies of the water samples were analysed employing Piper diagram and Gibbs diagram while the suitability of the water for irrigation purposes was assessed using indices such as Kelly's ratio, Sodium percentage ratio, Magnesium hazard, Permeability Index and Sodium Absorption Ratio (SAR). The physicochemical parameters of the water samples are within the acceptable limit recommended by WHO (2011). Physiochemical results showed that the dominant cation occur in the order of $Ca^{2+}$> $Na^{+}$> $K^{+}$> $Mg^{2+}$ with average values of 19.9mg/l, 16.15mg/l, 7.01mg/l and 4.38mg/l respectively, while the dominant anion ranged in the order of $HCO_3^-$> $Cl^-$> $SO_4^{2-}$> $NO_3^-$with average values of 56.93mg/l, 35.5 mg/l, 8.38mg/l and 3.85mg/l respectively. The dominant hydrochemical facies identified in the samples is the mixed Ca-Mg-Cl which is a result of linear mixing processes of water in the study area. Gibbs plot indicated that ions concentration in the water is primarily contributed by chemical weathering of the rock-forming minerals. Irrigation indices all suggested that the water samples are good for irrigation purposes. Results from the study indicate that, with a few exceptions, water in the study area is suitable for human consumption and irrigation purposes.

**Keywords**: Groundwater quality, hydrochemical facies, irrigation, Kurudu, physiochemical.

## I. INTRODUCTION

Groundwater is a vital and essential water source for domestic, agricultural, and industrial use. It is most reliable water source for human consumption. However, this water resource faces many challenges including contamination, pollution, degradation and over abstraction. Groundwater resource is largely affected by industrial development, urbanization, agricultural and mining activities. The quality of groundwater is an important factor to determine its suitability for domestic and agricultural purposes. The usefulness of water also depends on its physical and chemical properties. Recently, a study conducted by the World Health Organization revealed that the contamination of ground water is responsible for the mortality of about 1.5 million kids annually (WHO 2017;WHO & UNICEF 2014). The reality of WHO statistics gives an insight into the health and the socio-economic status of affected countries linking the possible solutions to the high death rate to the ability to provide drinkable water (Chandrasekar et al., 2014; Chuah et al., 2016; Das & Nag 2017; Edjah et al., 2017).

The hydrochemical studies of some subsurface water extensively depend on the rate of precipitation of minerals present in the host rock, the interaction between underground aquifers and the soil, rate of water recharge and other anthropogenic sources (Alfy et al., 2018; Emenike et al., 2016; Emenike et al., 2017). The statistical analysis of the total dissolved solids (TDS), hydrogen ion concentration (pH), electrical conductivity (EC) amongst others have proved useful in clarifying the evaluation of groundwater contamination (Alfy et al., 2018; Gbadebo 2012, Giridharan et al., 2008; Giridharan et al., 2009; Golchin & Moghaddam 2016).

In Kurudu, Abuja, groundwater is useful for daily domestic, agricultural and industrial activities (Barzegar et al., 2017; Igibah & Tanko 2019). The usage of groundwater in Kurudu, the study area, is grossly affected by contamination caused by anthropogenic activities. Generally, most groundwater contamination in Abuja is mostly from abattoirs, wood processing mills, and mechanical workplaces, mainly through improper waste disposal. The well-being of residents in this area has been compromised.

Thus, there is a need to investigate the level of groundwater contamination in the study area in order to ascertain the suitability of the water for human consumption. The recent study aims to assess the groundwater quality in Kurudu Area, Abuja, by evaluating the physicochemical parameters and irrigation indices of the water samples to determine their suitability for domestic and agricultural purposes.

## II. DESCRIPTION OF THE STUDY AREA

The area studied is Kurudu, a peri-urban fragment of the Abuja Municipal Area Council (AMAC). Abuja is an area of geological interest evident in the presence of the Aso rock, which has about 400 meter megalith and the Zuma rock which has about 800-meter megalith. Kurudu is located within latitude $8^0$ 55' 53" N as well as Longitude $7^0$ 33' 00" E. Kurudu is a relatively major town that falls under Asokoro, bounded by communities such as Guzape, Aya, Nyanyu, and the new Karu. The area is a good fit for this research work because the expansion and growth of Abuja have directed people to such areas. Figure 1 shows the location map of the study area.

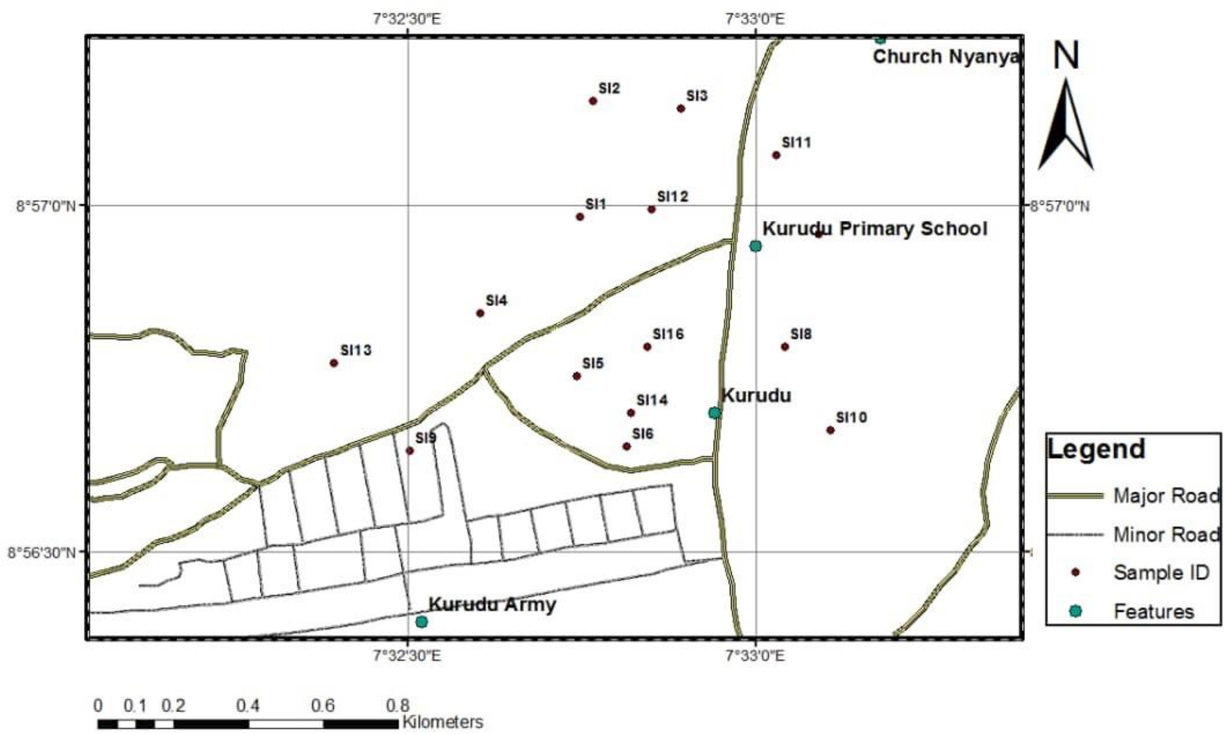


**Figure 1: Location map of the study area showing the water samples**.

## III. METHODOLOGY

Sixteen (16) water samples were collected from the boreholes within the study area. Before the samples used in this study were collected, polyethene (plastic) bottles with lids were washed properly with sanitized $H_2O$ adding a little tri-oxo nitrate V acid after which the bottles were air dried. The bottles were washed thrice with the identified water sample at the sample site before filling and labelling. The well-labeled water samples were then taken to the laboratory and kept under a temperature of $4^oC$, the standard method of preservation was followed (APHA 2005). The taps of the identified boreholes were left to run for an average of 5-15 minutes before five samples were randomly selected to calculate the average physico-chemical parameters. Measurement of pH (H+ concentration), electrical conductivity (EC), total dissolved solids (TDS), and the measure of alkalinity were conducted on the site through the use of Hanna 198194 pH, EC, and TDS meter. Other water properties such as the cation, silica ($SiO_2$), sodium ($Na^+$), Magnesium $Mg^+$, Potassium $K^+$ and Calcium $Ca^{2+}$ and major anions such as chloride Cl**-**, carbonate $CO_3^{2-}$, Sulphate $SO_4^{2-}$ , Nitrates $NO^{3-}$ were identified using the APHA standard (APHA, 2005). The water samples were analysed using **software** and the statistical test was carried using SPSS software.

## IV. RESULTS AND DISCUSSION

### A. Physicochemical Characteristics

Physicochemical parameters such as temperature, pH, total hardness (TH), electrical conductivity (EC), total dissolved solids (TDS) along with dominant anions and cations were analyzed for all water samples and their results are presented in Table 1. The temperature of the water samples ranged from $22.2^0C$ to $27.9^0C$ with average of $25.76^0C$. The temperature values are within the WHO (2011) permissible limit of $30^0C$.

The pH of the samples ranged from 2.51 to 7.25 with average of 6.14 which indicates that the water samples are dominantly acidic to slightly alkaline. The relatively acidic values of the water could be attributed to dissolve $CO_2$ in the water. Only six (6) of the water samples fall within the WHO permissible limit of 6.5 **-** 9.2 pH values for drinkable water.

The Electrical conductivity (EC) of water generally depends on mobility and concentration of ions in the water. The EC of the water samples ranged from 30 **-** 650 with an average of 316. All water samples fall within the WHO (2011) limit of 1500 (Table 2). According to Sarath Prasanth *et al*., (2012), the electrical conductivity can be divided into three types depending on the salt enrichment levels: type I if the salt enrichments are modest (EC: 1500 µs/cm), type II between 1500 and 3000 µs/cm, and type III over 3000 µs/cm. Hence, the water samples falls within type I accordingly to their salt enrichment.

Total dissolved solid (TDS) is a measure of how many different kinds of dissolved minerals are in a given volume of water. Minerals such as bicarbonates, phosphates, potassium, calcium, carbonates, chlorides, sulfates, magnesium, sodium, and potassium make up the bulk of the dissolved solids found in natural waters. The TDS values for the samples ranged from 20mg/l to 360mg/l with average of 173mg/l. The WHO (2011) permissible limits for TDS is 500mg/l indicating all samples falls within the permissible limit of drinking water specified by WHO. According to Todd (1980), water can be classed fresh if the TDS is less than 1000 mg/l; brackish if the TDS is between 1000 and 10,000 mg/l; salty if the TDS is between 10,000 and 1,000,000 mg/l; and brine if the TDS is greater than 1,000,000 mg/l; indicating all samples from the study area are fresh having TDS values less than 1000mg/l.

The total hardness of the water samples ranged from 13mg/l to 165mg/l with average of 71mg/l. All water samples falls within the WHO (2011) acceptable limits of 150mg/l except samples SI5 and SI15 with total hardness values of 165mg/l and 160mg/l respectively. According to Sawyer and McCarty (1967), soft water has calcium carbonate less than 75mg/l, moderate hard (75mg/l **-** 150mg/l), hard water sample (150mg/l to 300mg/l) while very hard water contains calcium carbonate greater than 300mg/l. Hence, the water samples can be classified as soft to moderate hardness except sample SI5 and SI15 which fall under hard.

The major anions and cations concentration of water samples were analysed to evaluate the dominant anions and cations. Results showed the dominant cation ranged in the order of $Ca^{2+} > Na^+ > K^+ > Mg^{2+}$ with average values of 19.9mg/l, 16.15mg/l, 7.01mg/l and 4.38mg/l respectively while the dominant anion ranged in the order of $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$ with average values of 56.93mg/l, 35.5 mg/l, 8.38mg/l and 3.85mg/l respectively.

**Table 1: Physiochemical parameters of water samples in the study area.**

| Sample ID | Temp $^0C$ | pH | EC | TDS | TH | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $Cl^-$ | $HCO_3^-$ | $SO4^{2-}$ | $NO_3^-$ | $F^{-1}$ | $PO4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SI1 | 22.3 | 6.47 | 120 | 70 | 54 | 2.34 | 0.82 | 17.02 | 2.27 | 24 | 36 | 6.75 | 0.7 | 0.03 | 0.24 |
| SI2 | 24.1 | 4.69 | 320 | 170 | 41 | 17.94 | 11.48 | 12.81 | 1.41 | 27.06 | 26 | 5.11 | 1.9 | 0.08 | 0.33 |
| SI3 | 22.7 | 6.43 | 220 | 120 | 44 | 14.04 | 2.87 | 13.08 | 3.11 | 23.11 | 28 | 4.92 | 0.03 | 0.05 | 0.24 |
| SI4 | 25.3 | 6.46 | 280 | 150 | 48 | 17.96 | 4.1 | 15.23 | 1.69 | 42.13 | 14 | 10.22 | 2.05 | 0.2 | 0.42 |
| SI5 | 26.8 | 6.91 | 490 | 280 | 165 | 24.94 | 16.81 | 39.24 | 10.81 | 46.25 | 180 | 17.85 | 2.04 | 0.43 | 11.27 |
| SI6 | 26.5 | 6.68 | 330 | 170 | 68 | 18.72 | 5.74 | 19.62 | 5.6 | 34.63 | 36 | 7.65 | 0.96 | 0.14 | 0.69 |
| SI7 | 22.2 | 5.86 | 270 | 150 | 41 | 17.16 | 3.28 | 16.35 | 2.58 | 43.75 | 28 | 0.85 | 3.08 | 0.13 | 0.54 |
| SI8 | 27.4 | 6.48 | 410 | 220 | 106 | 16.92 | 4.08 | 31.61 | 5.12 | 49.16 | 60 | 10.2 | 0.07 | 0.23 | 0.78 |
| SI9 | 25.9 | 6.47 | 120 | 70 | 54 | 2.34 | 0.82 | 17.02 | 2.27 | 24 | 36 | 6.75 | 0.7 | 0.03 | 0.24 |
| SI10 | 25.5 | 6.53 | 380 | 200 | 81 | 22.62 | 11.89 | 21.78 | 5.63 | 18.05 | 36 | 11.9 | 21 | 0.05 | 0.31 |
| SI11 | 26.7 | 6.91 | 490 | 280 | 165 | 24.94 | 16.81 | 39.24 | 10.81 | 46.25 | 180 | 17.85 | 2.04 | 0.43 | 11.27 |
| SI12 | 26.9 | 6.7 | 280 | 150 | 64 | 22.62 | 13.53 | 14.72 | 6.53 | 22.06 | 62 | 11.05 | 11 | 0.15 | 0.67 |
| SI13 | 26.5 | 6.48 | 410 | 220 | 106 | 16.92 | 4.08 | 31.61 | 5.12 | 49.16 | 60 | 10.2 | 0.07 | 0.23 | 0.78 |
| SI14 | 27.8 | 7.25 | 260 | 140 | 46 | 19.5 | 11.8 | 14.68 | 2.14 | 17.83 | 44 | 10.2 | 10 | 0.26 | 1.39 |
| SI15 | 27.6 | 5.38 | 30 | 20 | 13 | 0.78 | 0.41 | 2.18 | 1.05 | 12.1 | 18 | 1.7 | 0.001 | 0.01 | 0.14 |
| SI16 | 27.9 | 2.51 | 650 | 360 | 41 | 18.72 | 3.69 | 12.56 | 4.01 | 88.67 | 67 | 0.9 | 6 | 0.09 | 0.41 |
| Average | 25.8 | 6.14 | 316 | 173 | 71 | 16.15 | 7.01 | 19.92 | 4.38 | 35.51 | 56.94 | 8.38 | 3.85 | 0.16 | 1.86 |
| Min | 22.2 | 2.51 | 30 | 20 | 13 | 0.78 | 0.41 | 2.18 | 1.05 | 12.10 | 14.00 | 0.85 | 0.00 | 0.01 | 0.14 |
| Max | 27.9 | 7.25 | 650 | 360 | 165 | 24.94 | 16.81 | 39.24 | 10.81 | 88.67 | 180 | 17.85 | 21 | 0.43 | 11.27 |

**Table 2: Summary of the physiochemical parameters of the study area compared with WHO (2011).**

| Physiochemical Parameters | Average | Min | Max | WHO standard (2011) |
|---|---|---|---|---|
| Temp $^0C$ | 25.76 | 22.2 | 27.9 | 30 |
| pH | 6.14 | 2.51 | 7.25 | 6.5-9.2 |
| EC | 316 | 30 | 650 | 1500 |
| TDS | 173 | 20 | 360 | 100 |
| TH | 71 | 13 | 165 | 150 |
| $Na^+$ | 16.15 | 0.78 | 24.94 | 200 |
| $K^+$ | 7.01 | 0.41 | 16.81 | 12 |
| $Ca^{2+}$ | 19.92 | 2.18 | 39.24 | 75 |
| $Mg^{2+}$ | 4.38 | 1.05 | 10.81 | 50 |
| $Cl^-$ | 35.51 | 12.1 | 88.67 | 250 |
| $HCO_3^-$ | 56.94 | 14 | 180 | 500 |
| $SO4^{2-}$ | 8.38 | 0.85 | 17.85 | 250 |
| $NO_3^-$ | 3.85 | 0.001 | 21 | 45 |

### B. Statistical Analysis

Statistical analysis was carried out using Pearson correlation matrix, the degree of linear association between two numerical variables is quantified using Pearson's correlation analysis. It gives shorthand for the relative size of linearly related sets of data. There is a range of possible values for relationship, from minus one to plus one, with plus one indicating a perfectly positive linear relationship, zero indicating no linear relationship, and negative one indicating a perfectly inverse linear relationship (Singh and Chandra, 2015). Table 3 shows the Pearson correlation matrix between physiochemical parameters of the water samples collected from the study area. The bold values show areas of positive correlations between parameters. Total hardness (TH) correlates positively with cations and increases with increasing cation concentration with $Ca^{2+}$, exhibiting the highest correlation value of 0.97. While concentrations of anions such as $HCO_3^-$ and $SO_4^{2-}$ shows positive correlation with dominant cation of $Na^+$, $Mg^{2+}$, $K^+$ and $Ca^{2+}$. Except for a small number of outliers, the concentrations of the key ions tested tend to rise as TDS increases, showing positive correlation.

**Table 3: Pearson correlation matrix between physiochemical parameters of the samples.**

| Variables | pH | EC | TDS | TH | Na | K | Ca | Mg | Cl | HCO3 | SO4 | NO3 | F | PO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | **1** | | | | | | | | | | | | | |
| EC | -0.3237 | **1** | | | | | | | | | | | | |
| TDS | -0.3254 | **0.9973** | **1** | | | | | | | | | | | |
| TH | 0.4212 | **0.5761** | **0.5987** | **1** | | | | | | | | | | |
| Na | 0.1177 | **0.7702** | **0.7539** | **0.5617** | **1** | | | | | | | | | |
| K | 0.2915 | 0.4860 | 0.4928 | **0.6313** | **0.7941** | **1** | | | | | | | | |
| Ca | 0.4262 | **0.5858** | **0.6018** | **0.9733** | **0.5370** | **0.5215** | **1** | | | | | | | |
| Mg | 0.3134 | **0.6265** | **0.6476** | **0.9173** | **0.6590** | **0.7135** | **0.8350** | **1** | | | | | | |
| Cl | **-0.5613** | **0.8106** | **0.8205** | 0.2958 | 0.3622 | -0.0258 | 0.3549 | 0.3037 | **1** | | | | | |
| HCO3 | 0.1961 | **0.5924** | **0.6356** | **0.8944** | **0.5244** | **0.6884** | **0.8049** | **0.9083** | 0.3689 | **1** | | | | |
| SO4 | **0.6532** | 0.3549 | 0.3661 | **0.8634** | **0.5688** | **0.7483** | **0.8031** | **0.7876** | -0.0402 | **0.7338** | **1** | | | |
| NO3 | 0.0509 | 0.1956 | 0.1708 | -0.0364 | 0.4315 | 0.4548 | -0.0828 | 0.1267 | -0.1984 | -0.0547 | 0.1967 | **1** | | |
| F | 0.3981 | **0.5647** | **0.5876** | **0.8402** | **0.6693** | **0.6819** | **0.8129** | **0.7631** | 0.3435 | **0.8371** | **0.7900** | -0.0904 | **1** | |
| PO4 | 0.2914 | 0.4526 | **0.4989** | **0.8509** | 0.4818 | **0.6950** | **0.7511** | **0.8390** | 0.2274 | **0.9587** | **0.7413** | -0.1078 | **0.8443** | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

### C. Hydrochemical Facies

It is possible to gain an understanding of the geochemical development of groundwater by plotting the concentrations of main cations and anions in the Piper trilinear diagram. It is a mixture of the anion triangle and the cation triangle, and it rests on the same base line (Singh and Kumar, 2015). Hydrochemical facies can be predicted with the help of the Piper Trilinear Diagram (1944).

Piper diagram was plotted showing the hydrochemical facies of the water samples in the study area. Four hydrochemical facies have been identified, they include Na-Cl type, Ca-$HCO_3$ type, Na-Ca-$HCO_3$ type and mixed CaMgCl water type which corresponds to type 1, 2, 3 and 4 respectively. The dominant water type is the mixed CaMgCl which is a result of linear mixing processes of water, while water facies type 1 and 2 results from ion exchange activities between Calcium and Sodium (Figure 2).

The majority of the samples plot along the simple dissolution or mixing line in the Durov diagram (Figure 3), further supporting the idea that mixed water type predominates in the study area. Using the categorization developed by Lloyd and Heathcoat (1985), we can explain this pattern as the result of simple dissolution or mixing in recharged fresh water, with neither an anion nor cation dominating the system. Dolomite association is indicated by the presence of $Ca^{2+}$ and $HCO_3^-$ as the dominant anion and cation in a small number of samples.

The chemical composition of the water samples can be shown and compared with greater precision using a Stiff diagram (Stiff, 1957), which displays the absolute value of major ions. Total ionic content can be roughly estimated from the pattern's width. Almost all samples share the same dominant cation ($Ca^{2+}$) and anion ($HCO_3^-$), as shown by the consistent pattern (Figure 4). In order to comprehend where the dissolved ions in groundwater come from, it is helpful to look at Gibb's diagram (Figure 5). The majority of water samples lie inside the zone where rock weathering is predominate. Except for samples SI1 and SI15, which show precipitation dominance, Gibb's diagrams indicate that ions concentration in the water is primarily contributed by chemical weathering of the rock-forming minerals.

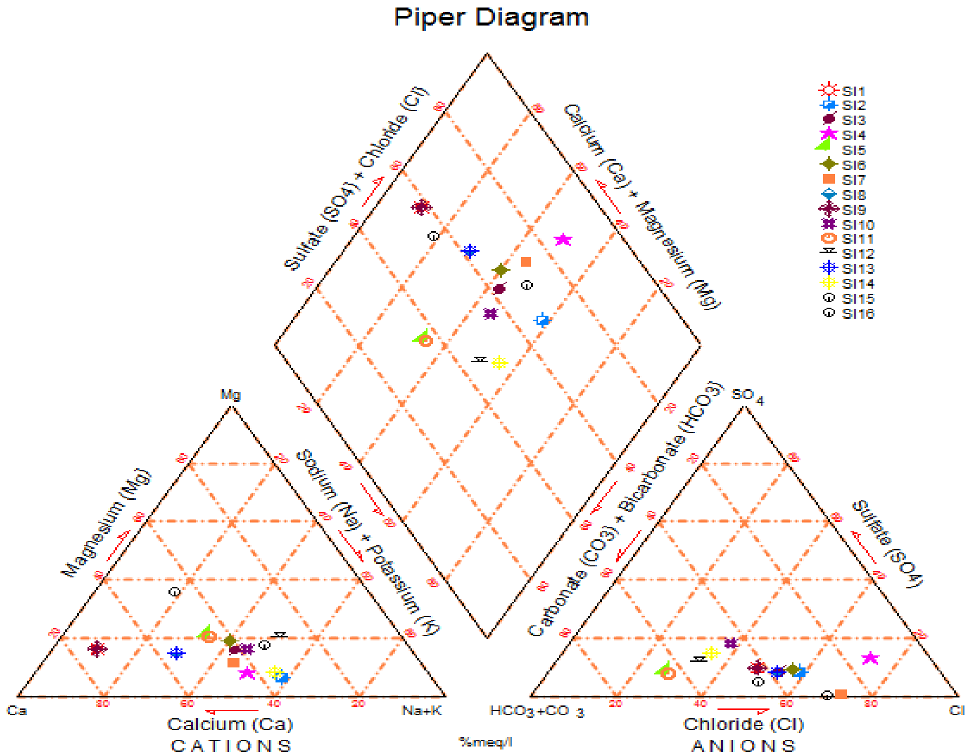


**Figure 2: Piper Diagram showing hydrochemical facies of the water samples in the study area.**

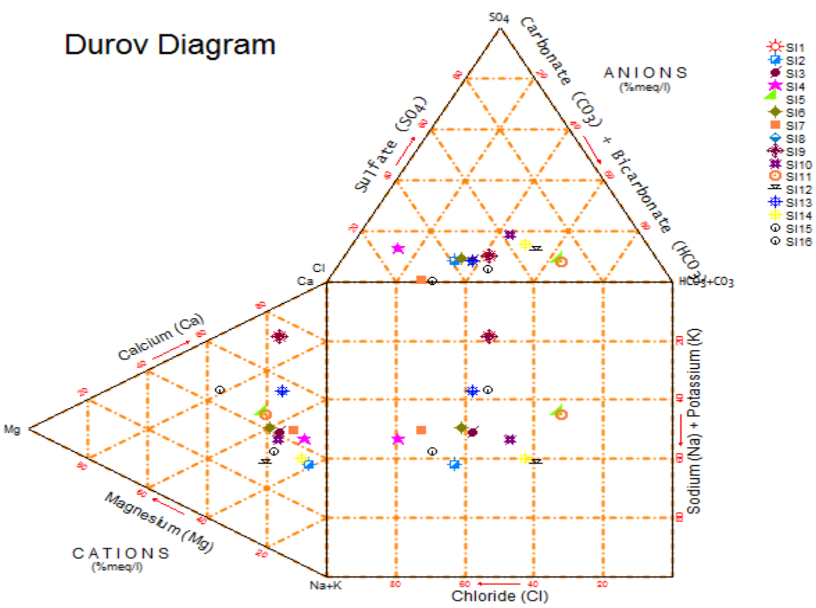


**Figure 3: Durov diagram showing position of water samples in the study area.**

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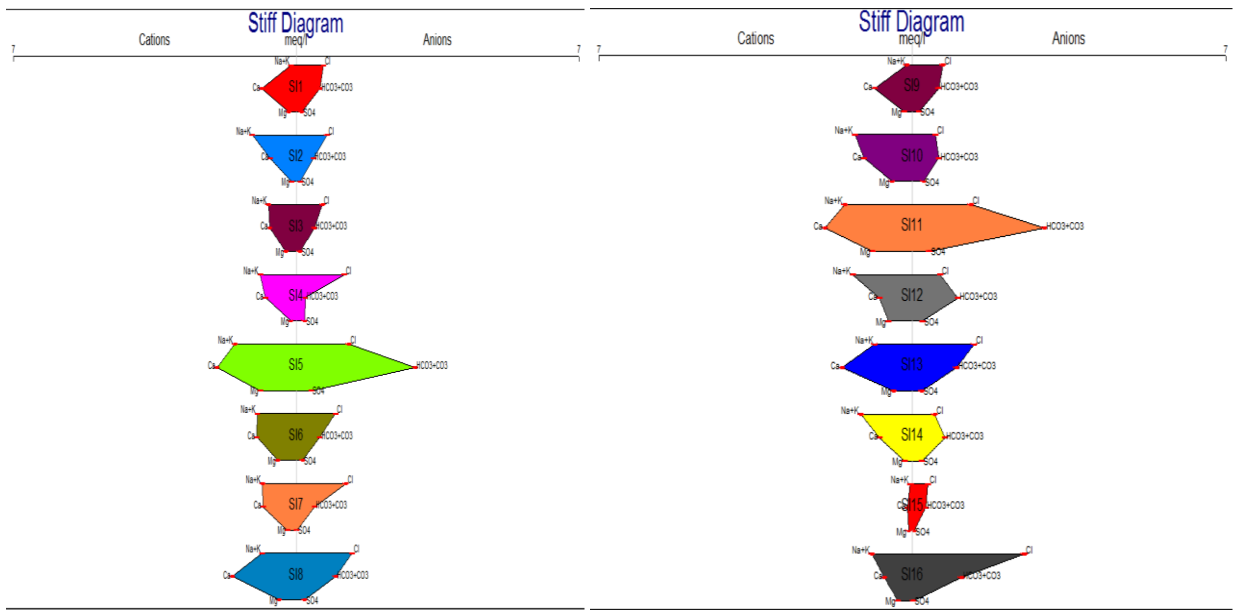


**Figure 4: Stiff pattern of the water samples in the study area.**

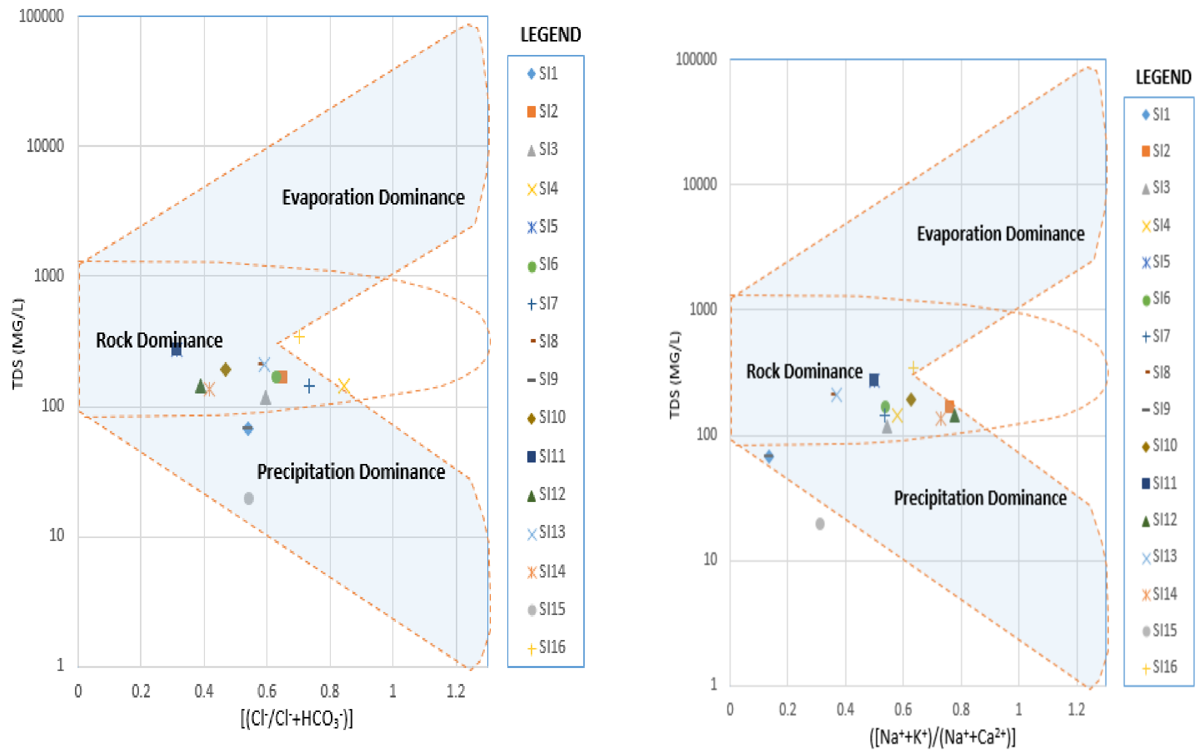


**Figure 5: Gibb's plot showing position of the water samples in the study area.**

**D. Water Quality Assessment for Irrigation Purpose**

The quality of water for various uses, including drinking by humans and animals, irrigation of crops, and other similar activities, will be determined by the concentration and composition of soluble salts in the water. When it is anticipated that salinity buildup will be an issue in an irrigated agricultural area, the quality of the water is an essential component that must be considered in order to ensure the sustainable use of water for agricultural irrigation (Zaman, 2018).

**Sodium Absorption Ratio (SAR):**
Because a high sodium concentration in irrigation water may increase soil hardness and diminish permeability, Sodium Absorption Ratio is significant in analysing the quality of groundwater for the purpose of irrigation. This is because this can inhibit the delivery of water that is necessary for the growth of crops. Mathematically, SAR can be expressed as

$$\mathrm{SAR} = \frac{\mathrm{Na}^+}{\sqrt{\frac{1}{2}\ (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})}}$$

The groundwater samples in the study area have SAR values that ranged from 0.109 to 1.27 with mean value of 0.86. The SAR values show the water samples are suitable for irrigation purposes as classified by (Mandel and Shiftan, 1991) which classed SAR value greater than 10 as unsuitable for irrigation purposes. The salinity hazard of the samples were also evaluated using the US salinity laboratory (1954) shown in (Figure 6). The samples plotted dominantly on C2 and S1 which corresponds to medium salinity levels and low sodium hazard.

**Sodium Percentage (Na %):**
Since sodium reacts with soil to reduce its permeability, measuring the sodium level of groundwater is crucial for categorising irrigation water. When the sodium concentration in irrigation water is high, the clay particles absorb sodium ion, pushing out $Ca^{2+}$ and $Mg^{2+}$ ions. A decrease in permeability occurs when sodium in water is exchanged for $Ca^{2+}$ and $Mg^{2+}$ in soil (Ayuba *et al.,* 2016). The Sodium Percentage could be expressed mathematically below as:

$$\mathrm{Na\%} = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} Na^+ + K^+} \times 100$$

The Na % of the water samples ranged from 10.59% to 58.71% with a mean value of 37.8%. According to (Ayuba *et al.*, 2016), Na% < 20% is classed as excellent, 20 – 40% classed as good, 40-60% classed as permissible, 60- 80% is doubtful while greater than 80% is classed as unsuitable. This classification indicates the water samples fall within excellent to permissible.

**Magnesium Hazard (MH)**
The presence of magnesium in soil and water would have a negative impact on the quality of those resources and make the soil unfit for cultivation for the purposes of calculating the magnesium hazard ratio. A magnesium concentration in a water sample that is greater than 50 percent will cause the water to be toxic to plants (Rajmohan and Elango, 2005), it can be mathematically expressed as:

$$\mathrm{MH} = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100$$

Table 4 shows that all water samples are suitable for irrigation purposes as Magnesium Hazard ratio percentage is greater than 50%.

**Kelly Ratio (KR)**
When deciding if groundwater is acceptable for irrigation, Kelly's ratio is can be employed. Kelly's ratio was first determined by comparing sodium to calcium and magnesium in 1951. Kelly's ratios greater than one (1) indicate that groundwater is unsuitable for use in irrigation systems. In the area under study, Kelly's ratios for water samples vary from 0.098 to 1.03, with a mean of 0.55. All the samples except SI2 passed Kelly's Ratio and may be used for irrigation.

**Permeability Index (PI):**

It is possible to gauge whether or not water is suitable for irrigation by measuring its permeability index (PI). Long-term exposure to irrigation water (especially water with a high salt concentration) can alter the soil's permeability since the $Na^+$, $Ca^{2+}$, $Mg^{2+}$, and $HCO_3$ ions all have a role in this characteristic (Rawat et al., 2018). It can be calculated mathematically by;

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$$

Depending on the values of the PI, the irrigated water can be placed into one of three categories: Class I (more than 75%), Class II (25-75%), or Class III (less than 25%) (Marapatla and Reddy, 2018).The PI values of the water samples varied from 63.17% to 251.87% with a mean value of 89.77%, which can be categorized as class I and class II with over 90% falling under class I indicating that most of the samples are moderate to good in terms of suitability for irrigation purposes.

**Table 4: The irrigation parameters of water samples of the study area.**

| Sample ID | Na % ratio | Kellys Ratio | MHR (%) | PI | SAR |
|---|---|---|---|---|---|
| SI1 | 10.594 | 0.098 | 18.029 | 76.451 | 0.141 |
| SI2 | 58.714 | 1.033 | 15.363 | 93.328 | 1.270 |
| SI3 | 42.954 | 0.672 | 28.166 | 84.784 | 0.906 |
| SI4 | 49.638 | 0.869 | 15.469 | 75.003 | 1.165 |
| SI5 | 34.725 | 0.381 | 31.238 | 71.265 | 0.909 |
| SI6 | 40.031 | 0.566 | 32.005 | 70.201 | 0.960 |
| SI7 | 44.678 | 0.726 | 20.649 | 80.236 | 1.041 |
| SI8 | 29.601 | 0.368 | 21.080 | 63.177 | 0.736 |
| SI9 | 10.594 | 0.098 | 18.029 | 76.451 | 0.141 |
| SI10 | 45.384 | 0.635 | 29.888 | 69.142 | 1.118 |
| SI11 | 34.725 | 0.381 | 31.238 | 71.265 | 0.909 |
| SI12 | 51.118 | 0.774 | 42.249 | 88.305 | 1.234 |
| SI13 | 29.601 | 0.368 | 21.080 | 63.177 | 0.736 |
| SI14 | 55.864 | 0.934 | 19.381 | 96.618 | 1.258 |
| SI15 | 18.538 | 0.174 | 44.268 | 251.875 | 0.109 |
| SI16 | 48.713 | 0.851 | 34.491 | 105.149 | 1.177 |
| Average | 37.842 | 0.558 | 26.414 | 89.777 | 0.863 |
| Min | 10.594 | 0.098 | 15.363 | 63.177 | 0.109 |
| Max | 58.714 | 1.033 | 44.268 | 251.875 | 1.270 |

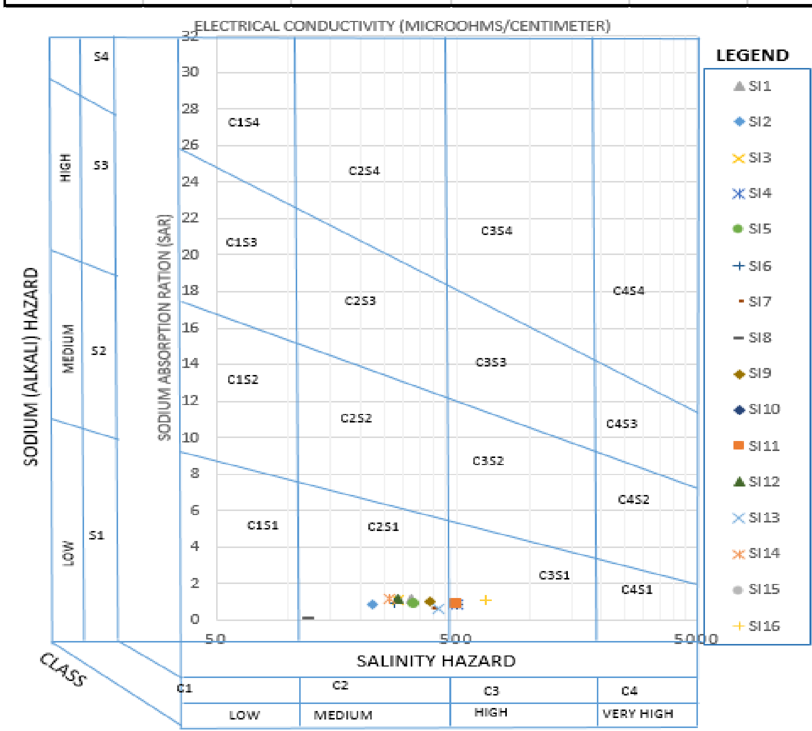

**Figure 6: Wilcox plot of water samples of the study area.**

## V. CONCLUSION

Physiochemical and hydrochemical properties of groundwater samples from Kurudu area of Abuja, north central Nigeria, have been carried out. The physicochemical parameters of the water samples are within the acceptable limit recommended by WHO (2011). Water samples exhibit dominant cation ranged in the order of $Ca^{2+}$> $Na^{+}$> $K^{+}$> $Mg^{2+}$ while the dominant anion varied in the order of $HCO_3^{-}$> $Cl^{-}$> $SO_4^{2-}$> $NO_3^{-}$respectively. The water in the study area is classified fresh according to total dissolved solid values. Results of hydrochemistry suggest that the samples consist of four hydrochemical facies of Na-Cl type, Ca-$HCO_3$ type, Na-Ca-$HCO_3$ type and mixed CaMgCl water type with dominantly mixed CaMgCl water type which is a result of linear mixing processes of water.

According to Gibb's diagram, chemical weathering of rock-forming minerals is principally responsible for the high concentration of ions seen in the water samples. All samples clustered heavily on C2 and S1 on the Wilcox diagram, indicating moderate salinity and a low sodium risk.With a few notable exceptions like pH, most parameters were found to be within safe drinking water levels when compared to WHO (2011) criteria. All of the groundwater samples appear to be fit for irrigation according to irrigation indicators including the Magnesium Hazard ratio, the kelly ratio, the percentage of sodium, and the permeability index.

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