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# Hydrogeochemical Characteristics of Groundwater Around Deba and Environs, Gombe Northeast

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## ABSTRACT

This study was conducted around Deba and environs with the primary goal of characterizing the groundwater sources in area for different uses. A total of 15 groundwater samples were collected from different sources and analyzed for major cations and anions. using the prescribed analytical methods. The results show a general trend of $Ca^{2+} > K^{+} > Mg^{2+} > Na^{+}$ for cations and $HCO_3^{-} > SO_4^{2-} > NO_3^{-} > Cl^{-} > CO_3^{2-}$ for anions. The salt content of the groundwater samples was evaluated from the total dissolved solids (TDS) which has a minimum value of 115mg/l and a maximum value of 144mg/l with a mean value of 129.5mg/l which falls within the excellent class of the UNESCO/FAO criteria. The pH value of the samples has a minimum value of 5.67 and a maximum 0f 6.47 with a mean of 6.07 which is within the permissible value of the WHO. The average values of the major cations are $Ca^{2+}$ - 23.44 to 29.17mg/l with a mean value of 26.30mg/l, $Mg^{2+}$ - 3.98 to 5.33mg/l with a mean value of 4.65mg/l, $K^{+}$ - 5.53 to 6.72mg/l with a mean value of 6.12mg/l, $Na^{+}$ - 0.38 to 1.26mg/l with a mean value of 0.81mg/l and anions are $CO_3^{2-}$ - 0 to 0.42mg/l with a mean value of 2.1mg/l, $HCO_3^{-}$ - 182 to 218mg/l with a mean value of 200mg/l, $SO_4^{-}$ - 20.12 to 27.55mg/l 23.83mg/l, $Cl^{-}$ - 7.49 to 17.56mg/l with a mean value of 12.52mg/l which are within the WHO permissible standards for drinking water. Also, a Piper/Trilinear plot of the hydro-chemical facies indicates that calcium is the dominant cation while bicarbonate is the dominant anion thus giving a Calcium - bicarbonate water type. These results show that groundwater from the study area is suitable for both drinking and irrigation purposes and hence is recommended for drinking water supply to meet the needs of the populace

**Keywords:** hydrogeochemical, characteristics, Groundwater, Deba.

## INTRODUCTION

Groundwater is a very key resource all over the world and its constituents is a very vital aspect as well. As the global demand for water continues to grow, understanding the composition of groundwater becomes increasingly important. The constituents of groundwater also directly impact its suitability for various uses and this composition varies significantly across regions, primarily due to geological differences and human activities within those regions.

This paper aims to investigate the factors influencing groundwater composition in Yamaltu/Deba as a study area, focusing on the interplay between geological characteristics and the water in the area. By analyzing the geochemical properties of groundwater samples, this study seeks to provide insights into how natural induced factors shape groundwater quality.

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These dynamics when understood is essential for developing sustainable groundwater management practices, particularly in regions with vulnerable water resources.

## GEOLOGY OF THE STUDY AREA

The study area is characterized by mainly sedimentary rocks such as sandstones, shales and limestones of the Pindiga formation of the Upper Benue Trough which were deposited during the following geological ages - Turonian-Coniacian. *(Ikusemoran Mayomi et al., 2018).*

The member of the Pindiga formation which is most dominant in the study area is the Kanawa member and the limestone in the area also contains evidence of fossils.

The Pindiga Formation directly overlies the Yolde Formation. It was deposited during the Cenomanian-Turonian times and it represents the full marine incursion into the Gongola sub-basin. Zaborski *et al.* (1997) subdivided the formation into three lithogenetic units, comprising of five members. These include: the lower most Kanawa Member composing of limestone-shale interbeds; the middle Deba Fulani, Gulani and Dumbulwa Members which are lateral equivalents and composed of dominantly sandstones minor mudstones; then the upper Fika Member composed of monotonous shale units with minor limestone beds intercalated.

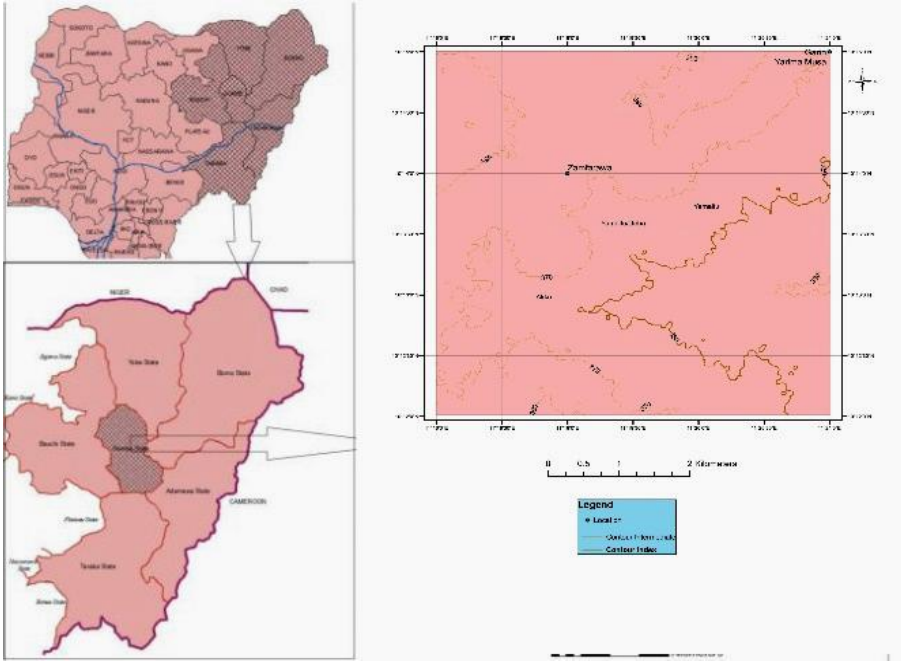

**Figure 1:** Location map of the study area.

## MATERIALS AND METHODS

Prior to setting out to the field, a topographical map of scale 1:25,000 was obtained in order to carry out desk examination of the study the area. A visit was also made to the area to carry out reconnaissance survey and among the things observed were the elevation, stream channels, accessible routes, rock formations available, road networks and a letter of introduction to begin the study of the area was submitted to the head of the study area.

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A total of thirty (30) groundwater samples were collected from random sampling points of observed wells, boreholes, solar pump, stream channels and lakes in the communities of the study area out of which fifteen (15) samples were acidified with about 5ml of Nitric acid ($HNO_3$). For each location that the samples were taken, the elevation of the area and GPS coordinate were, and the static water level for those samples gotten from the well were also taken.

At the end of the field sampling, the samples were sent to the Adamawa State Water Board at Adamawa state to be tested for physical/organoleptic, chemical/inorganic and micro-biological constituents using various methods/equipment at the laboratory.

The following parameters were determined: pH, Electrical conductivity, Temperature, Total dissolved salts, Turbidity, Major cations and anions, and coliform count.

**pH**: This measurement was carried out using handheld pH meter EXACT instrument model CT6021 to determine the acidity and alkalinity of the water samples. The Samples were left to reach room temperature and then the electrode of the pH meter was submerged into the container holding the sample and left for two minutes after which the reading stabilized on the pH meter and the value was recorded.

**Electrical Conductivity**: is a measure of the ability of water to conduct an electric current This was measured using a handheld conductivity meter EXACT instrument model CT3030. It also makes use of an electrode which was immersed in the sample and after few minutes it was removed and the electrode was cleaned and immersed again to ensure that the result was consistent with first one before recording.

**Temperature:** was measured using a handheld temperature meter EXACT instrument model CT6021 where an electrode was immersed into the water samples and the temperature reading from the thermometer was recorded.

**Total dissolved solids (TDS):** includes all inorganic and organic compounds that are present in the water in solution, it is the measure of the total amount of dissolved solids in the water and can be provide information about the potential presence of contaminants such as salts, metals and other pollutants**.** The TDS of the collected water samples was determined using handheld TDS meter EXACT instrument model CT3061. The protective cap of the meter was removed and it was put on then the sensor at the base of the meter was immersed in the water sample container up to the ribs section and then the meter was used to gently stir to dislodge any air bubbles. This was done for about 10 seconds in order for the reading to stabilize and then once the reading was seen on the screen the meter was lifted out of the sample, excess water that entered the meter was shaken off and the readings were taken.

**Turbidity (NTU):** this was measured using handheld turbidity meter HACH model 2100Q. The samples were collected in a sample cell which was cleaned afterwards to avoid fingerprints or water droplets from affecting our readings and placed in the turbidity meter then the lid was shut and the meter was powered on. After stabilizing for a while, the readings were displayed on the screen and were recorded.

**Major cations and anions:** All the major cations and anions were measured for using HACH digital spectrophotometer model DR3900**.** This is an electrical equipment. The sample is collected in a vial and after the meter is put on, the vial is placed into the meter and then measurement is started. The readings are displayed on the screen which were then recorded.

**Coliform Count**: is a measure of the presence of coliform bacteria /microbial constituent of water and is often an indicator of water contamination. The coliform count of the collected samples was determined by the use of handlens. The samples were prepared and placed in a petri dish and left for a few minutes to allow solidification after which the petri dishes were placed in an incubator and allowed for 24 hours. After the petri dishes were brought out of the incubator, they were placed on a colony counter and the observed to get the count of bacterial colonies.

## Generation of Ion Distribution Maps

The distribution of the major cations and anions as measured from the collected water samples of the study area was plotted on maps generated to show their spread in various areas. The software used to generate these maps Tatuk GIS calculator and SURFER 11 software and the process by which these maps were generated are as follows:

Firstly, the GPS coordinates were converted from degree minute seconds (DMS) to decimal degrees (DS) on the TatukGIS calculator.

**Table 1:** Converted GPS coordinate values in degree minutes of the study area for calcium ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $Ca^{2+}$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 28.99 |
| L7 | 11.34 | 10.24 | 27.38 |
| L1 | 11.34 | 10.23 | 24.89 |
| L8 | 11.35 | 10.25 | 23.44 |
| L9 | 11.32 | 10.23 | 25.22 |
| L2 | 11.32 | 10.23 | 27.98 |
| L14 | 11.32 | 10.24 | 29.02 |
| L10 | 11.31 | 10.23 | 25.16 |
| L3 | 11.35 | 10.24 | 25.97 |
| L4 | 11.34 | 10.24 | 29.17 |
| L15 | 11.33 | 10.24 | 28.15 |
| L11 | 11.31 | 10.22 | 26.73 |
| L5 | 11.34 | 10.24 | 24.51 |
| L12 | 11.33 | 10.23 | 26.63 |
| L6 | 11.34 | 10.24 | 23.55 |

**Table 2:** Converted GPS coordinate values in degree minutes of the study area for Magnesium ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $Mg^{2+}$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 4.23 |
| L7 | 11.34 | 10.24 | 3.98 |
| L1 | 11.34 | 10.23 | 4.81 |
| L8 | 11.35 | 10.25 | 5.03 |
| L9 | 11.32 | 10.23 | 4.73 |
| L2 | 11.32 | 10.23 | 5.28 |
| L14 | 11.32 | 10.24 | 4.87 |
| L10 | 11.31 | 10.23 | 5.14 |
| L3 | 11.35 | 10.24 | 5 |
| L4 | 11.34 | 10.24 | 4.39 |
| L15 | 11.33 | 10.24 | 5.27 |
| L11 | 11.31 | 10.22 | 5.08 |
| L5 | 11.34 | 10.24 | 4.81 |
| L12 | 11.33 | 10.23 | 4.66 |
| L6 | 11.34 | 10.24 | 5.33 |

**Table 3:** Converted GPS coordinate values in degree minutes of the study area for sodium ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $Na^{+}$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 0.506 |
| L7 | 11.34 | 10.24 | 1.03 |
| L1 | 11.34 | 10.23 | 0.419 |
| L8 | 11.35 | 10.25 | 1.19 |
| L9 | 11.32 | 10.23 | 0.367 |
| L2 | 11.32 | 10.23 | 0.403 |
| L14 | 11.32 | 10.24 | 0.392 |
| L10 | 11.31 | 10.23 | 0.516 |
| L3 | 11.35 | 10.24 | 0.537 |
| L4 | 11.34 | 10.24 | 0.603 |
| L15 | 11.33 | 10.24 | 1.1 |
| L11 | 11.31 | 10.22 | 0.445 |
| L5 | 11.34 | 10.24 | 1.07 |
| L12 | 11.33 | 10.23 | 0.37 |
| L6 | 11.34 | 10.24 | 1.26 |

**Table 4:** Converted GPS coordinate values in degree minutes of the study area for potassium ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $K^+$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 6.6 |
| L7 | 11.34 | 10.24 | 5.9 |
| L1 | 11.34 | 10.23 | 5.86 |
| L8 | 11.35 | 10.25 | 6.41 |
| L9 | 11.32 | 10.23 | 5.9 |
| L2 | 11.32 | 10.23 | 6.51 |
| L14 | 11.32 | 10.24 | 6.72 |
| L10 | 11.31 | 10.23 | 5.8 |
| L3 | 11.35 | 10.24 | 6.6 |
| L4 | 11.34 | 10.24 | 6.22 |
| L15 | 11.33 | 10.24 | 5.53 |
| L11 | 11.31 | 10.22 | 6.33 |
| L5 | 11.34 | 10.24 | 6 |
| L12 | 11.33 | 10.23 | 5.84 |
| L6 | 11.34 | 10.24 | 6.12 |

**Table 5:** Converted GPS coordinate values in degree minutes of the study area for bicarbonate ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $HCO_3^-$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 202 |
| L7 | 11.34 | 10.24 | 182 |
| L1 | 11.34 | 10.23 | 194 |
| L8 | 11.35 | 10.25 | 185 |
| L9 | 11.32 | 10.23 | 191 |
| L2 | 11.32 | 10.23 | 193 |
| L14 | 11.32 | 10.24 | 204 |
| L10 | 11.31 | 10.23 | 192 |
| L3 | 11.35 | 10.24 | 196 |
| L4 | 11.34 | 10.24 | 203 |
| L15 | 11.33 | 10.24 | 195 |
| L11 | 11.31 | 10.22 | 186 |
| L5 | 11.34 | 10.24 | 188 |
| L12 | 11.33 | 10.23 | 193 |
| L6 | 11.34 | 10.24 | 218 |

**Table 6:** Converted GPS coordinate values in degree minutes of the study area for carbonate ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $CO_3^{2-}$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 1.2 |
| L7 | 11.34 | 10.24 | 0 |
| L1 | 11.34 | 10.23 | 1 |
| L8 | 11.35 | 10.25 | 0 |
| L9 | 11.32 | 10.23 | 0 |
| L2 | 11.32 | 10.23 | 0 |
| L14 | 11.32 | 10.24 | 0 |
| L10 | 11.31 | 10.23 | 0 |
| L3 | 11.35 | 10.24 | 0 |
| L4 | 11.34 | 10.24 | 0 |
| L15 | 11.33 | 10.24 | 2 |
| L11 | 11.31 | 10.22 | 0 |
| L5 | 11.34 | 10.24 | 2.1 |
| L12 | 11.33 | 10.23 | 0 |
| L6 | 11.34 | 10.24 | 4.2 |

**Table 7:** Converted GPS coordinate values in degree minutes of the study area for Sulphate ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $SO_4^{2-}$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 22.17 |
| L7 | 11.34 | 10.24 | 25.61 |
| L1 | 11.34 | 10.23 | 21.98 |
| L8 | 11.35 | 10.25 | 24.12 |
| L9 | 11.32 | 10.23 | 22.05 |
| L2 | 11.32 | 10.23 | 20.73 |
| L14 | 11.32 | 10.24 | 20.67 |
| L10 | 11.31 | 10.23 | 21.09 |
| L3 | 11.35 | 10.24 | 20.88 |
| L4 | 11.34 | 10.24 | 20.12 |
| L15 | 11.33 | 10.24 | 25.47 |
| L11 | 11.31 | 10.22 | 20.72 |
| L5 | 11.34 | 10.24 | 22 |
| L12 | 11.33 | 10.23 | 20.66 |
| L6 | 11.34 | 10.24 | 27.55 |

**Table 8:** Converted GPS coordinate values in degree minutes of the study area for Chloride ion distribution map.

| Sample Point | Longitude(X) | Latitude(Y) | $Cl^-$ (mg/l) |
|---|---|---|---|
| L13 | 11.33 | 10.24 | 9.67 |
| L7 | 11.34 | 10.24 | 10.44 |
| L1 | 11.34 | 10.23 | 9.43 |
| L8 | 11.35 | 10.25 | 11.87 |
| L9 | 11.32 | 10.23 | 8.86 |
| L2 | 11.32 | 10.23 | 9.08 |
| L14 | 11.32 | 10.24 | 9.46 |
| L10 | 11.31 | 10.23 | 8.72 |
| L3 | 11.35 | 10.24 | 9.22 |
| L4 | 11.34 | 10.24 | 8.58 |
| L15 | 11.33 | 10.24 | 12.47 |

| | | | |
|---|---|---|---|
| L11 | 11.31 | 10.22 | 7.49 |
| L5 | 11.34 | 10.24 | 10.88 |
| L12 | 11.33 | 10.23 | 7.82 |
| L6 | 11.34 | 10.24 | 17.56 |

Then the values were transferred to the surfer software to generate the maps using these procedures;

i. Open the surfer 11 software.

ii. Then open a new worksheet and input the converted GPS coordinate values. Input longitude values on the X axis of the worksheet and latitude values on the Y axis of the worksheet.

iii. Then input the concentration values of the element (mg/l) that corresponds to the GPS coordinates on the Z axis of the worksheet

iv. Save the worksheet as a BLN file (BLN – Golden software blanking)

v. Open a new plot on the surfer 11 software and then click on 'Grid'.

vi. Click on the recently saved worksheet and open.

vii. Click on 'Ok' to save grid file as '.grd'

viii. Minimize or close the grid details and then click on 'Map'.

On the pop-up options click on 'New' and then click on 'Contour map'.

The map is generated automatically and then you can include the scales and readings from the object and property manager box on the left side of the screen.

**Table 9:** Percentage of major cations and anions used to plot trilinear diagram.

| S/N | LOC. | Ca2+ | Mg2+ | $K^+$ | $Na^+$ | $CO_3^{2-}$ | $HCO_3^-$ | $SO_4^-$, | $Cl^-$ |
|---|---|---|---|---|---|---|---|---|---|
| 1. | L1 | 68.78 | 21.91 | 8.29 | 1.00 | 0.85 | 80.77 | 11.62 | 6.75 |
| 2. | L2 | 69.31 | 21.56 | 8.26 | 0.87 | 0 | 82.14 | 11.21 | 6.65 |
| 3. | L3 | 68.22 | 21.65 | 8.89 | 1.23 | 0 | 82.21 | 11.12 | 6.66 |
| 4. | L4 | 72.07 | 18.04 | 7.94 | 1.31 | 0 | 83.43 | 10.50 | 6.07 |
| 5. | L5 | 67.25 | 21.76 | 8.44 | 2.56 | 1.79 | 78.68 | 11.69 | 7.84 |
| 6. | L6 | 64.39 | 24.03 | 8.58 | 3.00 | 2.93 | 74.72 | 11.99 | 10.36 |
| 7. | L7 | 72.31 | 17.33 | 7.98 | 2.37 | 0 | 78.28 | 13.99 | 7.73 |
| 8. | L8 | 65.01 | 22.99 | 9.11 | 2.88 | 0 | 78.37 | 12.97 | 8.65 |
| 9. | L9 | 69.36 | 21.44 | 8.31 | 0.88 | 0 | 81.53 | 11.95 | 6.51 |
| 10. | L10 | 67.89 | 22.86 | 8.02 | 1.21 | 0 | 82.12 | 11.46 | 6.42 |
| 11. | L11 | 69.01 | 21.62 | 8.37 | 1.00 | 0 | 82.59 | 11.69 | 5.73 |
| 12. | L12 | 70.77 | 20.42 | 7.95 | 0.86 | 0 | 82.94 | 11.28 | 5.78 |
| 13. | L13 | 72.86 | 17.53 | 8.50 | 1.11 | 0.97 | 81.04 | 11.30 | 6.67 |
| 14. | L14 | 71.07 | 19.66 | 0.84 | 8.43 | 0 | 82.75 | 10.65 | 6.60 |
| 15. | L15 | 69.28 | 21.38 | 6.97 | 2.36 | 1.61 | 77.11 | 12.79 | 8.49 |

## GENERATION OF PIPER PLOT

The Piper diagram was plotted by using the Groundwater Chart (Gw_chart) software by inputting the calculated percentages of major cations - $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$ and anions - $CO_3^{2-}$, $HCO_3^-$, $SO_4^-$, $Cl^-$ of the non-acidified samples from the study area.

i. Open the software
ii. Go to chart type/convert and click on it.
iii. Select Piper diagram
iv. Enter preferred number of data points.
v. Select Data Type (Percentage or Concentration in Meq/L)
vi. Select percentages and enter the values of calculated percentages for each element.
vii. Click on plot and then save work.

## RESULTS AND DISCUSSIONS

### Major Cations and Anions Observed in the Study Area

**1. Calcium**: an important cation that affects the chemistry of groundwater is one of the major cations observed in the collected samples. Proper calcium levels enhance soil structure, aiding water absorption and root growth. The concentration of calcium within

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the study area ranges from 23.44mg/l to 29.17mgl with a mean concentration value of 26.305mg/l and is within the permissible limit of the WHO set standards.

From the colour scale on the distribution map (Fig 2), the areas that contain the most amounts of calcium are red, orange and yellow - Garin Waziri, Jauro Bubba, Garin Baraya, Basambo and Janawo. While the areas with the least amount of calcium are green, sky blue, dark blue and black - Zanfarawa, Jauro Shehu and some parts of Arda Shembi.

**2. Magnesium**: is an essential cation for plant growth which contributes to soil salinity. The concentration of magnesium in the study area ranges from 3.98mg/l to 5.33mg/l with a mean concentration value of 4.655mg/l which is within the permissible limit.

From the colour scale on the distribution map (Fig 3), the areas that contain the most amounts of magnesium are Garin Waziri, Jauro Bubba, Garin Baraya, and Basambo (colours white, red, orange and yellow) while the areas with the least amount of Magnesium are Janawo and Zanfarawa (colours green, sky-blue, dark-blue and black).

**3. Sodium:** It also falls within the permissible limits of set standards with values from 0.367mg/l to 1.26mg/l and a mean concentration value of 0.8135mg/l. Sodium is a highly reactive alkali metal.

The ion distribution map (Fig 4) of this cation shows that the distribution of sodium ion is very high around areas such as Zanfarawa, Arda Shembi, Jauro Sheu and some parts of Garin Waziri and less in the other areas, with a colour scale of white (the most abundant ion containing region), red, orange and yellow representing areas that contain abundant amounts of sodium ion in the study area and the areas that are coloured green, sky blue, dark blue and black (the least abundant ion containing region) are those areas with less concentration of sodium ion.

**4. Potassium:** is an important cation which supports various physiological processes in plants and enhance their resistance to diseases and stress when present in the right amount in the soil. The value of potassium in the study area ranges from 5.53mg/l to 6.72mg/l with a mean concentration value of 6.125mg/l. It falls within the permissible limits.

It was observed that potassium ion is less abundant at Garin Waziri, Karo and Jauro Ali and abundant at areas such as Jauro Bubba, Garin Baraya, Basambo and Janawo. The regions that are coloured white (the most abundant ion containing region), red, orange and yellow on the ion distribution map (Fig 5) are those areas that contain abundant amounts of potassium ion in the study area. The areas that are coloured green, sky blue, dark blue and black (the least abundant ion containing region) are those areas with less concentration of potassium ion.

**5. Bicarbonate:** is a negatively charged ion that is an important component of groundwater for irrigation. Bicarbonate is formed when carbon dioxide dissolves in water and its presence in groundwater is due to the dissolution of carbonate minerals. High bicarbonate levels may lead to increased alkalinity in water, affecting soil pH and potentially hindering nutrient availability to plants. Bicarbonate in the study area ranges from 182mg/l to 218mg/l with a mean concentration value of 200mg/l which also falls within permissible limits.

It is most abundant in Jauro Sheu, Garin Baraya and Arda Shembi. On the ion distribution map (Fig 6), the areas that are coloured white (the most abundant ion containing region), red, orange and yellow on the ion distribution map are those areas that contain abundant amounts of bicarbonate ion in the study area. The areas that are coloured green, sky blue, dark blue and black (the least abundant ion containing region) are those areas with less concentration of bicarbonate ion.

**6. Carbonate**: is another important anion that forms from the dissolution of carbonate minerals. The range of carbonate is from 0mg/l to 4.2mg/l with a mean concentration value of 2.1mg/l. It falls within the permissible limit. Carbonate was only observed in four samples (L1, L5, L6, L13) not observed in the other samples.

Carbonate was also observed mostly around the areas of Jauro Sheu, Arda Shembi and some parts of Garin Waziri and Jauro Ali.

The areas that are coloured white (the most abundant ion containing region), red, orange and yellow on the ion distribution map (Fig 7) are those areas that contain abundant amounts of carbonate ion in the study area. The areas that are coloured green, sky blue, dark blue and black (the least abundant ion containing region) are those areas with less concentration of carbonate ion.

**7. Sulfate**: is an anion that also affects the suitability of water for irrigation. It comes from the dissolution of evaporite minerals. The range of sulfate in the study area is from 20.12mg/l to 27.55mg/l with a mean concentration of 23.835mg/l. It falls within permissible limits.

Sulfate is also very high in concentration in areas such as Arda Shembi, Garin Waziri, Jauro Sheu, Jauro Ali and some parts of Zanfarawa and is low in other regions of the study area.

The areas that are coloured white (the most abundant ion containing region), red, orange and yellow on the ion distribution map (Fig 8) are those areas that contain abundant amounts of sulfate ion in the study area. The areas that are coloured green, sky blue, dark blue and black (the least abundant ion containing region) are those areas with less concentration of sulfate ion.

**8. Chloride:** is another important anion to consider when evaluating groundwater for irrigation. It is present in groundwater due to its release from evaporites or salt deposits. Chloride helps to maintain a stable pH in groundwater. In the study area it ranges between 7.49mg/l to 17.56mg/l with a mean concentration of 12.525mg/l and is within permissible limits.

Chloride is also very high in concentration in areas such as Arda Shembi, Garin Waziri, Jauro Sheu, Jauro Ali and some parts of Zanfarawa and is low in other regions of the study area.

The areas that are coloured white (the most abundant ion containing region), red, orange and yellow on the ion distribution map (Fig 9) are those areas that contain abundant amounts of chloride ion in the study area. The areas that are coloured green, sky blue, dark blue and black (the least abundant ion containing region) are those areas with less concentration of chloride ion.

## Trilinear Diagram (Piper Plot/Diagram)

This is a graphical representation of the chemistry of water samples. Water samples shown on the Piper diagram can be grouped in hydro-chemical facies. The cation and anion triangles can be separated in regions based on the dominant cation(s) or anion(s) and their combination creates regions in the diamond shaped part of the diagram.

The trilinear diagram (Fig 1) of the hydro-chemical facies presents a dominant cation type (the calcium type) and it corresponds with the bicarbonate type and it is a magnesium bicarbonate type. This also tells us that the hydro-chemical facies demonstrate the presence of weak acids exceed strong acids, and alkaline earth metals exceed alkalis.

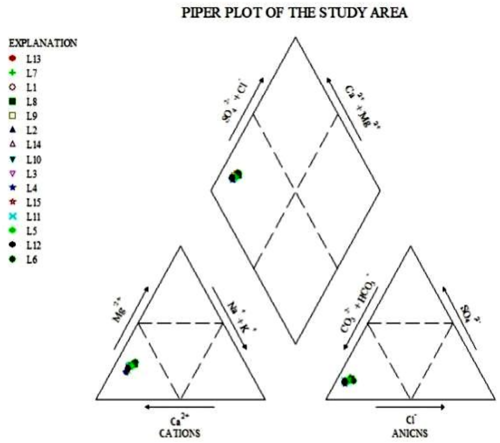

**Figure 2:** Trilinear/Piper diagram of the study area

For the dominance of the Bicarbonate type of the samples collected from the study area observed on the trilinear diagram, this indicates that the region has carbonate rocks present especially limestone which can be seen from the geology of the area and as water flows through these rocks, it dissolves minerals from these carbonate rocks in the environment which increases the concentration of bicarbonate ($HCO_3^-$).

On the cation triangle, from our trilinear diagram it is observed that the most dominant cation type is the calcium type. This is also as a result of the geology of the area. The presence of carbonate rock formations such as limestone and gypsum in the area leads to dissolution of these carbonate rocks when there is flow of water and then calcium gets dissolved and enters the water system.

## CONCLUSION

The aim of this paper is to assess and understand the hydrogeochemical properties of groundwater in Yamaltu/Deba area and environs and from the conducted study the hydrogeochemical characteristics of groundwater in the study area shows that the major anions and cations fall within permissible standard limits when compared with the WHO (2011) set guidelines and the UNESCO/FAO (1973) criteriafor parameters

The major cation and ion being calcium ($Ca^{2+}$) and Bicarbonate (($HCO_3^-$ ) deduced from the plotted trilinear diagram of the study area and their abundance in the groundwater is majorly due to the presence of carbonate rocks such as limestone in the study which reacts with water as it flows through the area.

### Cation Distribution Maps

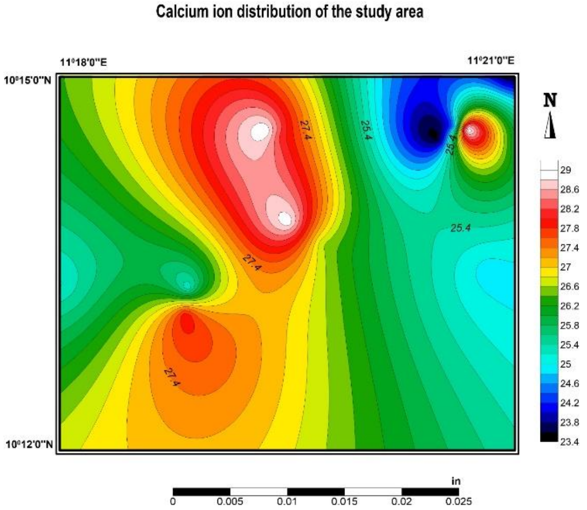

**Figure 3:** Calcium ion distribution

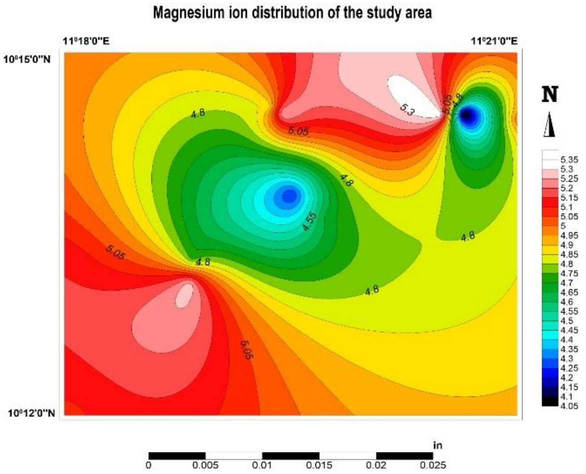

**Figure 4:** Magnesium ion distribution

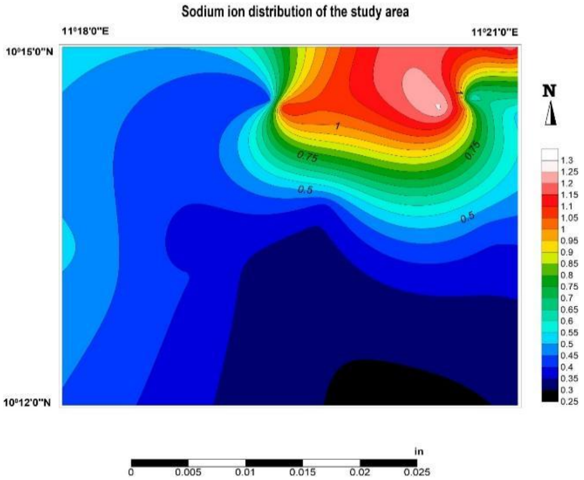

**Figure 5:** Sodium ion distribution

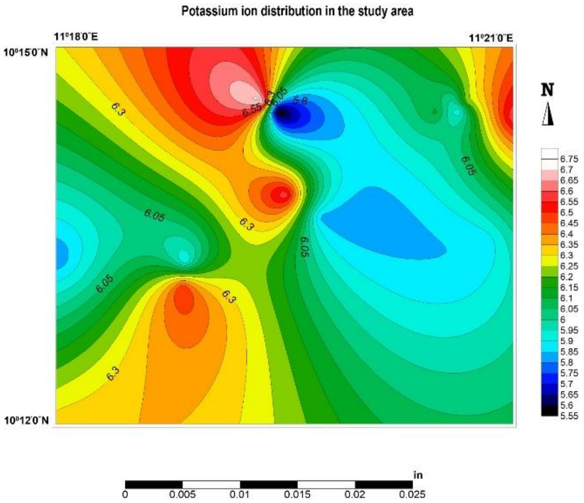

**Figure 6:** Potassium ion distribution

## Anion Distribution Maps

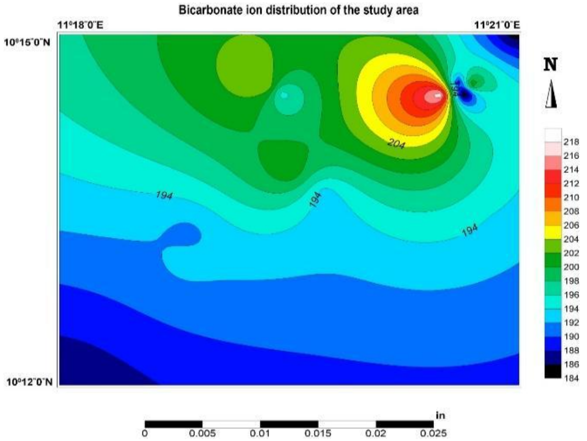

**Figure 7:** Bicarbonate distribution map

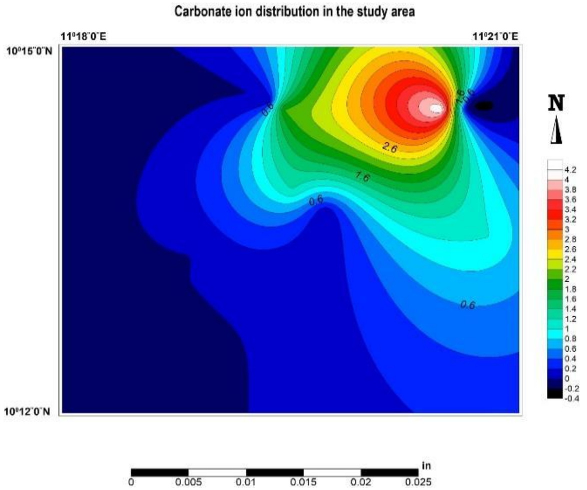

**Figure 8:** Carbonate distribution map

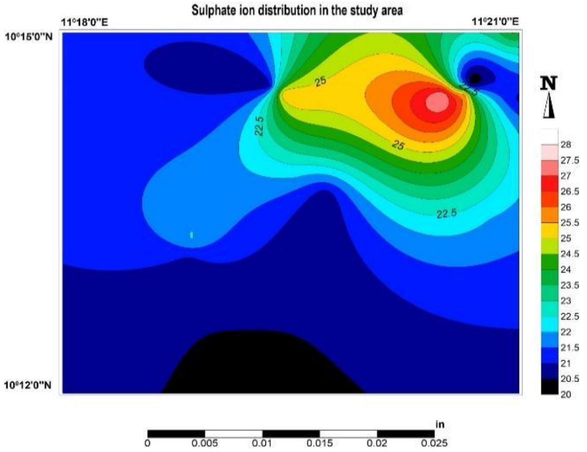

**Figure 9:** Sulphate distribution map

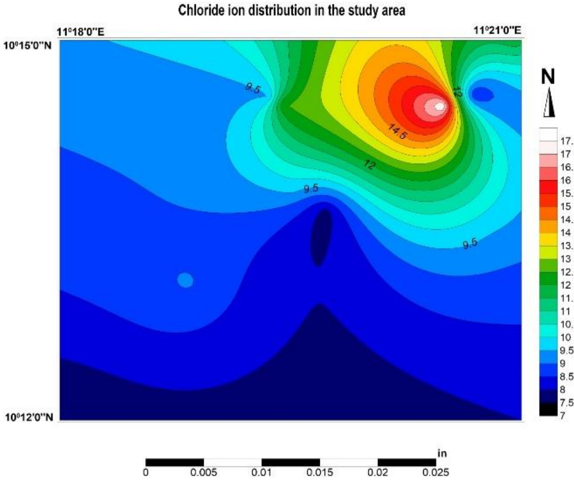

**Figure 10:** Chloride distribution map

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