DOI: https://dx.doi.org/10.4314/gjpas.v31i2.4

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES SPECIAL ISSUE VOL. 31, 2025: 173-186
IN HONOUR OF PROFESSOR BARTH NWOYE EKWUEME ON HIS RETIREMENT
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA ISSN 1118 – 0579, e-ISSN: 2992 - 4464



# ASSESSMENT OF THE CONCENTRATION OF CHEMICAL ELEMENTS AND WATER QUALITY INDEX OF SHALLOW GROUNDWATER IN PARTS OF MANGU AREA, NORTH CENTRAL NIGERIA

**MANGS, A. D., DIBAL, H. U. AND POBES, F. D**

(Received 7 November 2024; Revision Accepted 5 December 2024)

## ABSTRACT

The study area Mangu and environs in Central Plateau State, is defined by latitudes $9^{O}.28^{1}$ to $9^{O}.36^{1}$ and longitudes $8^{O}.51^{1}$ to $8^{O}.57^{1}$. The inhabitants of the area depend mostly on groundwater from hand dug wells and boreholes (hand pumps) for most domestic and small-scale irrigation activities. These groundwater sources are located close to pollution point sources which may serve as threat to their quality. The aim of the study was to determine concentration and water quality indices of groundwater sources in the area. Twenty groundwater samples were collected in the dry season from shallow sources used for drinking and other uses. Physical parameters – pH, TDS, conductivity, and temperature) – were determined in the field with the HACH KITS. Major and trace elements were determined with the use of Inductively Coupled Plasma Optical Emission Spectrophotometer and anions ($HCO_3$, Cl and $NO_3$) by titration methods, while $SO_4$ was determined using double UV-visible spectrophotometer (Hitachi model 2000). Concentration of physical parameters and major elements vary for the different sources but are higher for most of the shallow groundwater sources within the Mangu Central Area, where the population is dense and human activities are high. The trace elements are, however, generally low for all sources. Gibbs plot indicates the source of elements in the water to be dominantly from rock weathering dominance. Factor analysis and water types suggest sources of elements to be from both rock-water interaction and anthropogenic activities. The contribution of anthropogenic activities is confirmed by the high concentration of chloride, nitrate, and sulphate. Effluent discharges from the Mangu Abattoir, septic tanks and pit latrines and indiscriminate disposal of solid wastes, could be responsible for the high concentrations. The Water Quality Index ranged from 7.36 - 66.55 and classified the water as 30% excellent, 50% good, 15% poor and 5% unsuitable for drinking. The waters are generally hard and not suitable for laundry purpose but may be beneficial for optimal function of the heart. This work recommends the determination of bacteriological content of the waters, owing to the high content of nitrate, chloride, and sulphate in some of the sources.

**KEYWORDS:** Hach Kits, Indiscriminate disposal, Inductively Coupled Plasma Optical Emission Spectrophotometer.

## INTRODUCTION

Access to safe sources, sufficient water and sanitation is a basic human need and is essential to human wellbeing (UN, 2006); but presently, billions of people around the world continue to suffer from poor access to water, sanitation and hygiene (UNICEF/WHO, 2019).

Good quality groundwater is important to the national economy development and the environment of any society, where it is mostly used as a source of drinking water as well as for agriculture, and industries. Natural groundwater is never chemically pure, as minerals, organic solids and gases are found dissolved in it to some extent (Fetter, 2007).

**Mangs, A. D.,** Department of Geology, University of Jos
**Dibal, H. U.,** Department of Geology, University of Jos
**Pobes, F. D.,** Department of Geology, University of Jos

Because it is underground and out of sight, various chemical species infiltrate the ground through leaching from waste dumps, chemical fertilizers, and septic systems (Schwartz and Zhang, 2002). Once leachates enter groundwater, they can be difficult to detect by taste or smell, and difficult to remove. Species in groundwater occur either in ionic or uncharged (un-ionic) molecular forms (Garrel and Christ, 1965). Groundwater charged with carbon dioxide may dissolve some minerals and incorporate chemical elements in them. Dissolved constituents in groundwater are classified according to relative abundance (concentration) as major, minor and trace constituents Mangu and environs depend mostly on groundwater from hand-dug wells and boreholes for most domestic and small-scale irrigation activities. These groundwater sources are located close to point sources of contamination, dominated by pit latrines, abattoir effluent and septic tanks. The aim of the study is to access the concentration of chemical elements and the water quality index of Mangu area.

**Description of the study area**

The study area is located within the basement complex of North Central Nigeria. It lies approximately between latitudes $9°28^{11}$ and $9°36^{11}$ and longitudes $8°51^{11}$and $8°57^{11}$, with a total surface area of approximately 24 $km^2$. Settlement villages that make up the study area include; Shidyel, Jwakras, Angwan Sarki, Gindiri Road, Kwata, Quarter-one, Gindiri Junction, Angwan Mata, Derkon, Rampiya, Angwan Mission, Dawo, Federal Low-cost, amongst others (Fig 1), all in Mangu town of Mangu Local Government Area of Plateau State. Two major rock types characterized the study area: porphyritic biotite granite and fine-grained biotite granite (Fig 1c). Minor intrusions of dolerite and aplititic dykes are also common within the two rocks. Groundwater is mostly obtained in the weathered overburden and fractures within these rocks (Schoeneich and Garba 2004). Wells are mostly full, almost reaching to the surface at the peak of the rainy season from July to August and lowest at the peak of the dry season from March to April. Inhabitants of the area obtain water from individual hand-dug wells and bore holes provided by the Government and Non-Governmental Organizations.

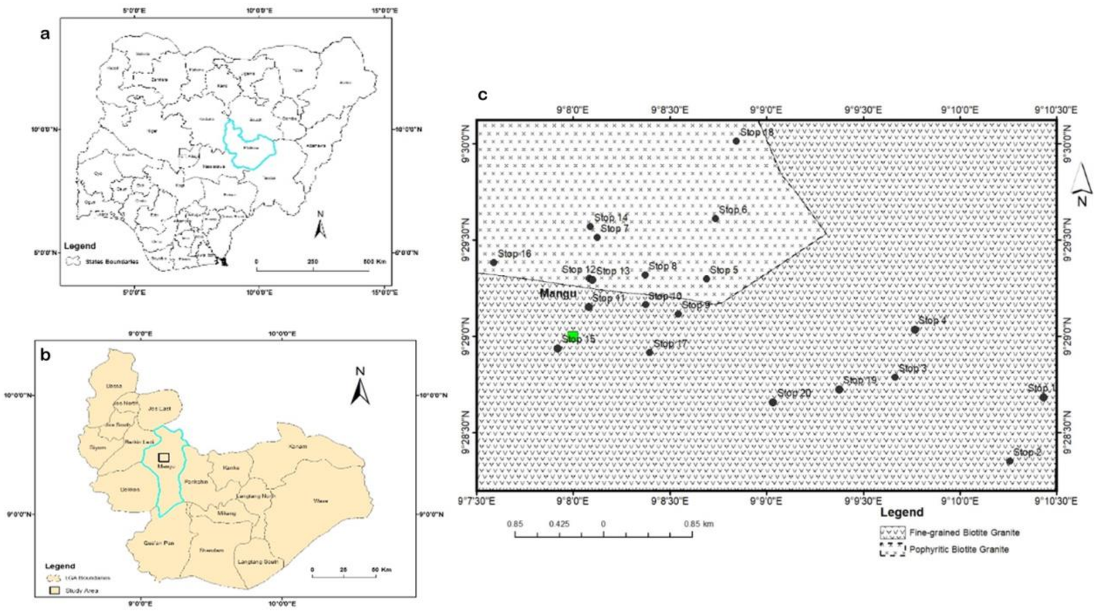


**Figure 1(a-c). Geological Map of the Study Area**

**METHODOLOGY**

The method employed in this work was based on description of field sampling of groundwater (Freeze and Cherry, 1979). Shallow groundwater samples (hand-dug wells and bore holes) were collected from twenty (20) locations in Mangu town and environs (Fig 1c). The sample bottles were first washed with distilled water and 1% $HNO_3$ and rinsed again with distilled water and allowed to dry in oven at 25$^oC$ for 24 hours. At each location the bottles were rinsed with the sampled water before collection. Two (2) water samples were collected in a 250 ml capacity plastic bottle, one for cations analysis and the other for anions. The one for cations analysis was acidified with 2 drops of nitric acid ($HNO_3$) to avoid bacterial growth and to keep the ions in solution. The water samples from hand-dug wells were collected using a plastic bucket tied to a rope (Davies, 1994). A meter tape was used to determine the depth to water level in hand dug wells only. Field parameters (pH, temperature and conductivity) were determined using the HACH pH/temperature meter. This was done by dipping the meter into the sampling container (bucket) immediately after collection and the reading was taken after few (1 -2) minutes when the value stabilized.

**Sample Preparation and Laboratory Analysis**

Two drops of concentrated nitric acid was added to each sample prevent any absorption and precipitation of some ions in the samples collected. The bottles containing all the water samples were wrapped and sealed with a masking tape.

The Inductively Coupled Plasma Optical Emission Spectrophotometer was used to analyse major cations and trace elements. The un-acidified water samples were analysed at the University of Jos, Department of Geology for chloride, bicarbonate, and nitrate using titrimetric method with the HACH Kits, while sulphate was determined using double UV-visible spectrophotometer (Hitachi model 2000)

**Determination of Water Quality Index (Wqi) in the Study Area**

Water Quality Index values were calculated based on the index proposed by Horton, (1965) and Brown *et al*., (2004). In this index, ten (10) parameters were used. They are pH, $HCO_3$, Mg, K, $SO_4$, Ca, Na, TDS (Total Dissolved Solids), EC (Electrical Conductivity) and Cl. Water Quality Index is computed following the three steps:

1. Assigning weight (wi) to the selected water parameters according to their relative importance in the overall quality of water for drinking purposes (weight may be from 1-5)
2. Computation of relative weight (Wi) of the chemical parameters using the following equations (1 – 4)
   Wi = wi / Σwi (I =1 to n) ------------------------ (1)
3. Assigning of the quality rating scale (qi) for each parameter, as below:
   Qi = (Ci / Si) * 100 -------------------------------- (2)

where qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and Si is the guideline value as giving by WHO (2011).

For computation of WQI, the sub index (Si) is first determined for each chemical parameter, as given below:

SIi = Wi * qi ---------------------------------------- (3)

WQI = ΣSIi 1 – n ----------------------------------- (4)

## RESULTS AND DISCUSSION

**Concentration and Distribution of Major Elements and other Water Quality Indices in the Study Area**

The physico-chemical parameters of water samples collected from hand-dug wells and boreholes in the study area are presented in Table 1.

The distribution of these parameters is shown in Figures (3- 10). The static water levels measured in the study area had depths ranging from 3.4 to 14.0 m in the hand-dug wells. The pH of water samples ranged from 5.71 to 8.24, indicating slightly acidic – alkaline waters. Total dissolved solids (TDS) in the area ranged from 32 – 723 mg/l, Quarter-one (Stop 8), having the highest value of 723 mg/l (Fig 3). The Electrical Conductivity of water in the study area ranged from 57 to 1032.9 us/cm and temperature ranged from 24.2-34.1 $^{O}$C. Temperature of waters reflect the ambient temperature of the area at the time of sampling. Calcium concentration in water samples of the area ranged between 4.19 and 150.03 mg/1, with Quarter-one (Stop 8) (Fig 4) having the highest calcium concentration of 150.03 mg/1. Magnesium concentration ranged from 0.91 – 40.32 mg1/, Kwata (Stop 7) has the highest magnesium concentration. Sodium concentration in the study area ranges between 6.71 and 214.26 mg/1. Quarter-one (Stop 8) has the highest concentration as 214.26 mg/l. Potassium concentration ranged from 0.60 – 40.27 mg/l. Bicarbonates in groundwater of the study area ranged from 30 -150 mg/, the highest value was recorded in Na'atika Garden (Stop 1). Sulphate concentration in groundwater ranged from 3.25 -27.5 mg/1; Na'atika Garden (Stop 1) has the highest sulphate concentration of 27.5 mg/1. Chloride concentration in water samples of the area ranges between 5.00 and 315.00 mg/1; w2w Quarter-one (Stop 8) having the highest value of 315.0 mg/l

## Table 1: Physico – chemical parameters in waters of the study area

| SSymbol | UUnit | SStop 1 Naatika Garden Bungha | S Stop 2 Anointed Drink Bungha | SStop 3 Gyaghat | SStop 4 GSS Mangu | SStop 5 Angwan Sarki | SStop 6 Al Zira oil | SStop 7 Kwata | SStop 8 Quarter-One | SStop 9 Good Morning Market | SStop 10 Mwaghavul Community Bank | SStop 11 Angwan Mata | SStop 12 Mishkagham Mangu Palace | SStop 13 MMishkagham kam Palace | SStop 14 Derkon_ Angwan Mata | SStop 15 Rampiya | SStop 16 INEC Office | SStop 17 Angwan Mission | SStop 18 Allah Na Kowa Hospital | SStop 19 Pobest Drill Bungha | SStop 20 Widow hood Centre |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DDate | | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 | 02/04/2020 |
| LLongitude | | $9^{o}10^{0}$ 26'' | $9^{o}10^{0}$ 15.5'' | $9^{o}9^{0}$40.4'' | $9^{o}9^{0}$46'' | $9^{o}8^{0}$41.4'' | $9^{o}8^{0}$44.2'' | $9^{o}8^{0}$7.5'' | $9^{o}8^{0}$22.4'' | $9^{o}8^{0}$32.7'' | $9^{o}8^{0}$.22.6'' | $9^{o}8^{0}$4.8'' | $9^{o}8^{0}$500'' | $9^{o}8^{0}$5.9'' | $9^{o}8^{0}$5.4'' | $9^{o}7^{0}$55.20'' | $9^{o}7^{0}$35.40'' | $9^{o}8^{0}$23.80'' | $9^{o}8^{0}$50.70'' | $9^{o}$ $9^{0}$22.50'' | $9^{o}9^{0}$2.00'' |
| LLatitude | | $9^{o}28^{0}$4.1'' | $9^{o}28^{0}$21.1'' | $9^{o}28^{0}$47.3'' | $9^{o}29^{0}$02'' | $9^{o}29^{0}$17.8'' | $9^{o}29^{0}$36.6'' | $9^{o}29^{0}$30.7'' | $9^{o}29^{0}$19'' | $9^{o}29^{0}$6.9'' | $9^{o}29^{0}$9.8'' | $9^{o}29^{0}$9'' | $9^{o}29^{0}$17.9'' | $9^{o}29^{0}$17.5'' | $9^{o}29^{0}$34.1'' | $9^{o}28^{0}$56.2'' | $9^{o}29^{0}$22.9'' | $9^{o}28^{0}$54.9'' | $9^{o}$ $30^{0}$ 70'' | $9^{o}$ $28^{0}$43.40'' | $9^{o}28^{0}$39.4'' |
| TTDS | Mg/l | 134.00 | 72.00 | 32.00 | 82.00 | 92.00 | 59.00 | 497.00 | 723.00 | 157.00 | 279.00 | 366.00 | 404.00 | 217.00 | 261.00 | 91.00 | 148.00 | 46.00 | 132.00 | 144.00 | 82.00 |
| CConductivity | Uhmo /cm | 191.40 | 102.85 | 45.70 | 117.10 | 131.40 | 84.30 | 710.00 | 1032.90 | 224.30 | 398.60 | 522.90 | 577.10 | 310.00 | 372.90 | 130.00 | 211.40 | 65.70 | 188.60 | 205.70 | 117.10 |
| **TTem**pt | °C | 31.1 | 32.1 | 29.3 | 27.1 | 31.10 | 31.10 | 29.90 | 25.30 | 28.30 | 28.50 | 27.20 | 28.40 | 34.10 | 26.30 | 32.00 | 24.20 | 27.30 | 29.10 | 29.40 | 27.50 |
| Elevation | M | 1088.00 | 1103.00 | 1128.00 | 1123.00 | 1139.00 | 1130.00 | 1125.00 | 1141.00 | 1156.00 | 1122.00 | 1139.00 | 1136.00 | 1122.00 | 1122.00 | 1149.00 | 1110.00 | 1158.00 | 1123.00 | 1135.00 | 1124.00 |
| SWL | M | 5.00 | 7.30 | NA | 7.00 | 7.00 | 4.60 | 5.80 | 6.90 | NA | 5.50 | 7.00 | 14.00 | 5.30 | 6.00 | 3.40 | 4.30 | 6.20 | 7.70 | 6.40 | 3.20 |
| pH | None | 7.51 | 6.64 | 6.3 | 7.64 | 5.80 | 6.22 | 6.22 | 6.34 | 6.52 | 5.71 | 6.88 | 32.00 | 7.31 | 6.60 | 7.11 | 6.58 | 6.27 | 6.71 | 7.95 | 8.24. |
| Ca | Mg/l | 25.18 | 15.89 | 1.19 | 27.95 | 15.69 | 15.01 | 130.22 | 150.02 | 37.54 | 54.43 | 104.47 | 113.19 | 48.15 | 67.41 | 13.66 | 43.47 | 7.73 | 30.08 | 32.69 | 19.52 |
| Mg | Mg/l | 5.52 | 2.77 | 1.13 | 0.91 | 3.18 | 3.73 | 40.32 | 23.69 | 4.81 | 8.09 | 29.26 | 31.64 | 18.99 | 22.71 | 4.45 | 4.67 | 1.16 | 12.72 | 13.41 | 6.08 |
| Na | Mg/l | 50.16 | 14.21 | 6.71 | 5.56 | 21.49 | 10.02 | 81.96 | 214.26 | 24.77 | 69.73 | 48.79 | 47.68 | 10.13 | 24.11 | 25.33 | 29.00 | 7.76 | 11.31 | 17.50 | 10.03 |
| K | Mg/l | 2.12 | 46,06 | 3.69 | 10.81 | 6.46 | 2.98 | 10.75 | 40.27 | 3.81 | 8.96 | 3.88 | 3.87 | 2.01 | 3.06 | 3.10 | 0,60 | 6.47 | 2.99 | 4.54 | 2.55 |
| $HCO_3$ | Mg/l | 120.00 | 50.00 | 35.00 | 64.00 | 30.00 | 65.00 | 95.00 | 65.00 | 35.00 | 35.00 | 150.00 | 55.00 | 115.00 | 80.00 | 45.00 | 90.00 | 50.00 | 95.00 | 100.00 | 90.00 |
| $SO_4$ | Mg/l | 27.50 | 4.00 | 3.25 | 5.50 | 3.50 | 3.40 | 23.50 | 15.20 | 4.00 | 5.00 | 23.00 | 23.25 | 7.52 | 2.25 | 54.00 | 6.75 | 3.90 | 3.80 | 3.52 | 4.00 |
| Cl | Mg/l | 10.00 | 25.00 | 10.00 | 10.00 | 10.00 | 25.00 | 5.00 | 205.00 | 315.00 | 110.00 | 95.00 | 120.00 | 60.00 | 75.00 | 15.00 | 40.00 | 5.00 | 25.00 | 20.00 | 5.00 |

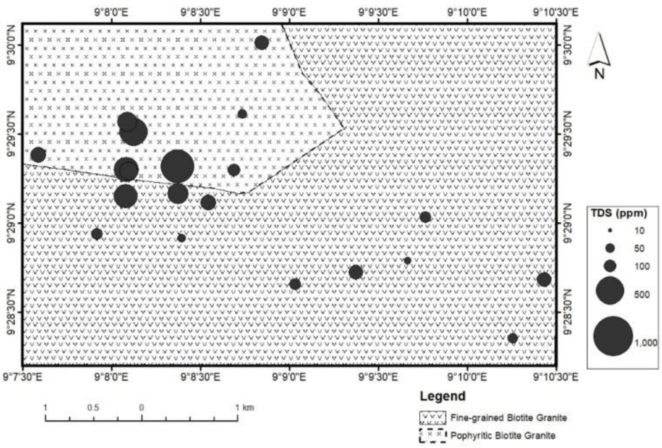


**Fig. 3: Distribution of Total Dissolved Solids in the study area**

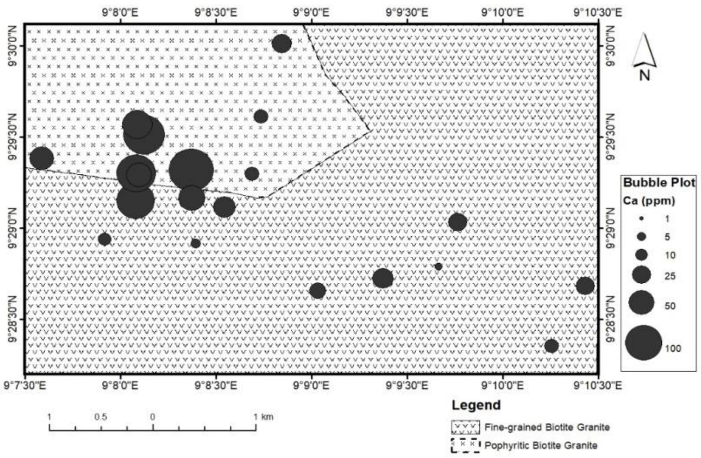


**Fig. 4: Distribution of calcium in the study area.**

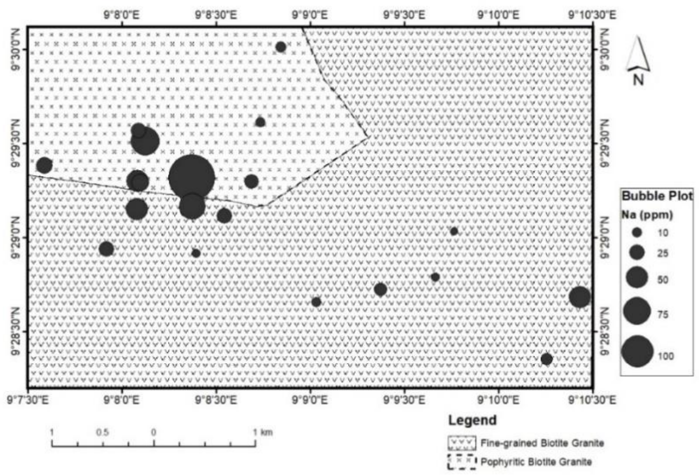


**Fig. 5: Distribution of sodium in the study area**

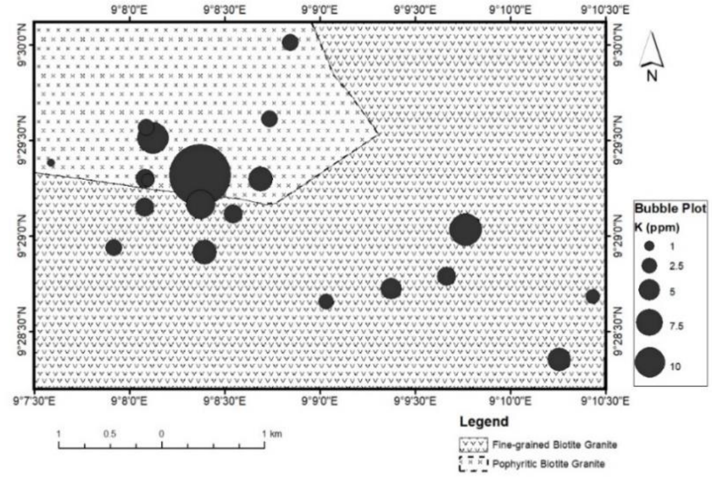


**Fig 6: Distribution of potassium in the study area.**

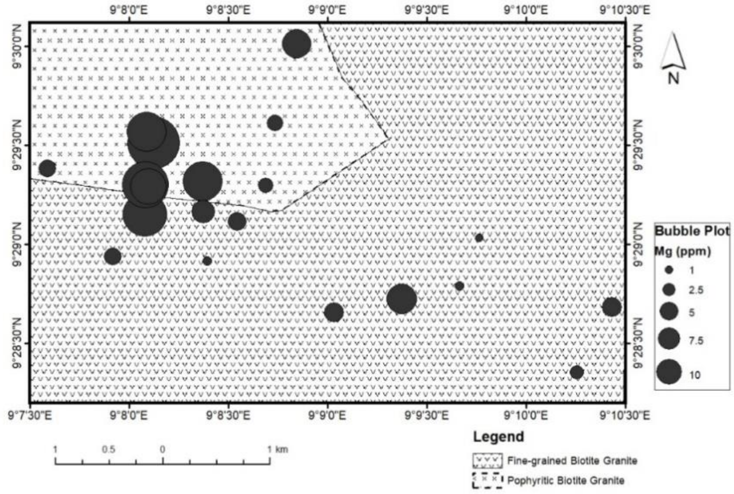


**Fig 7: Distribution of Magnesium in the study area**

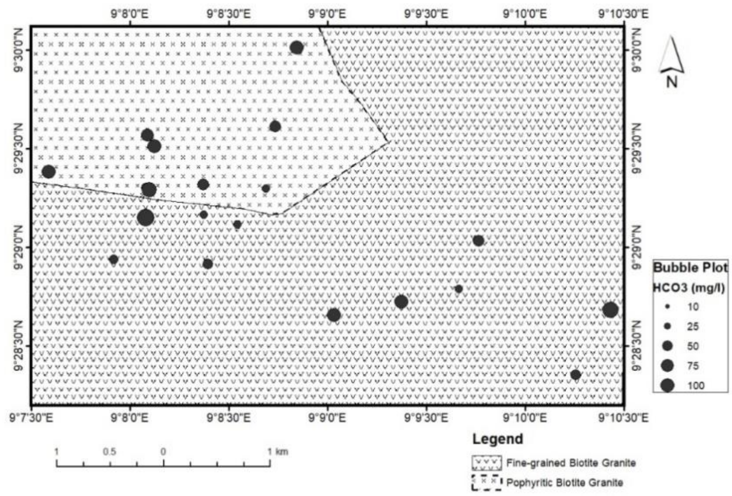


**Fig. 8: Distribution of bicarbonate in the study area**

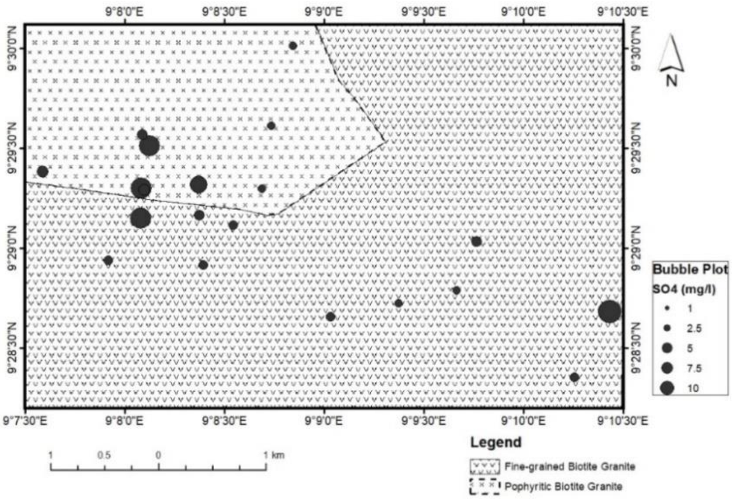


**Fig 9: Distribution of sulphate in the study area**

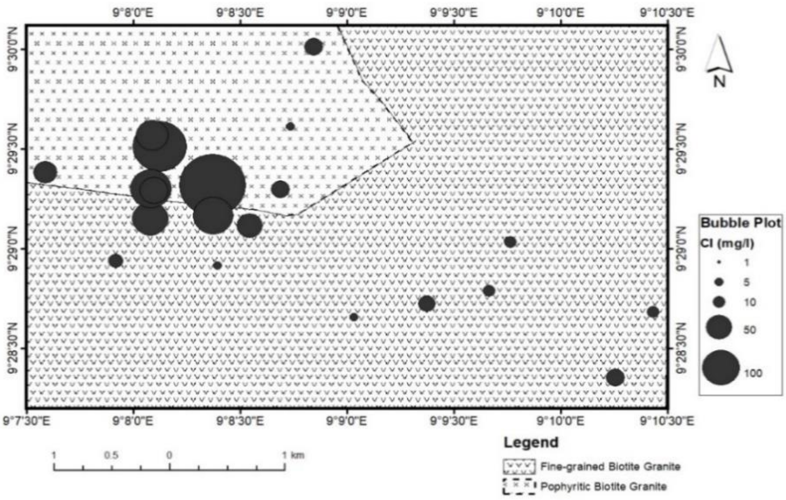


**Fig 10: Distribution of chloride in the study area**

**Factor Analysis**

To determine the control on the chemistry of waters in the hydrogeological environment and their possible sources, Principal Component Analysis (PCA) was carried out (Tables 3 and 4). The software Statistical Package for Social Sciences (SPSS) for windows was used. The interpretation of data is based on rotated factor loadings and rotated Eigen values. The extraction of factor was done with a minimum acceptable Eigen value of greater than one (1).

PCA classified the factor loadings as ‘strong > 0.75, moderate 0.75-0.50’ and ‘weak 0.50-0.30,’ respectively (Liu et al, 2003).

The three components extracted summed up to 82.21% of the total variance in the water samples (Table 2). The first component accounted for 52.41% of the total variance and has strong positive loading for $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $Cl^{-}$, $NO_3^{=}$, TDS, and EC (Table 3). The first three ions are from the rock types, which may be coming from feldspars and magnesium from hornblendes and biotite (Lekmang, 2021). However, chloride and nitrate may be from anthropogenic activities (Townsend and Whittemore, 2005).

**Table 2. Rotated Component Matrix of Physiochemical (Major and Physical Parameters) Data**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| **Component** | **Total** | **% of Variance** | **Cumulative %** | **Total** | **% of Variance** | **Cumulative %** |
| 1 | 7.338 | 52.418 | 52.418 | 7.338 | 52.418 | 52.418 |
| 2 | 2.876 | 20.545 | 72.963 | 2.876 | 20.545 | 72.963 |
| 3 | 1.295 | 9.253 | 82.215 | 1.295 | 9.253 | 82.215 |
| 4 | .967 | 6.909 | 89.124 | 0.12 | 0.83 | 99.972 |
| 5 | .693 | 4.953 | 94.077 | 0.03 | 0.22 | 99.994 |
| 6 | .379 | 2.704 | 96.781 | | | |
| 7 | .334 | 2.388 | 99.169 | | | |
| 8 | .053 | .380 | 99.549 | | | |
| 9 | .048 | .340 | 99.889 | | | |
| 10 | .012 | .083 | 99.972 | | | |
| 11 | .003 | .022 | 99.994 | | | |
| 12 | .001 | .006 | 100.000 | | | |
| 13 | 2.157E-9 | 1.541E-8 | 100.000 | | | |
| 14 | 8.582E-18 | 6.130E-17 | 100.000 | | | |

**Table 3. Component matrix of the major elements and physical parameters in the study area.**

| | Component Matrix | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Ca | **.980** | .087 | .047 |
| K | **.698** | -.395 | -.492 |
| Mg | **.830** | .327 | .325 |
| Na | **.884** | -.194 | -.241 |
| Alk | .237 | **.944** | -.085 |
| HCO3 | .237 | **.944** | -.085 |
| Cl | **.968** | -.184 | -.077 |
| Nitrate | **.864** | -.260 | .299 |
| SO4 | **.659** | .455 | .094 |
| TDS | **.997** | -.016 | -.010 |
| EC | **.997** | -.016 | -.010 |
| Temp | -.342 | .108 | .337 |
| pH | -.272 | **.680** | -.317 |
| $SiO_2$ | .114 | .011 | **.745** |
| | | | |

These ions also are responsible for the total dissolved solids in the water. The second factor constitutes 20.54% of the variance and has high positive loading for total alkalinity, and bicarbonate; and the third constitutes 9.25% of the total variance and has strong positive loading for $SiO_2$.

**The concentration of trace elements in the waters of the Area.**

.

These trace elements (Sr, Zn, Rb, Mn, Li, and Ba) showed substantial concentration in the waters of the area (Table 4), the rest are below detection limits. Strontium ranged from 39.45 to 1137.60 ug/l with a mean of 340.22 ug/l. The values of uranium, yttrium antimony, lead, sodium and copper were not so significant in the waters. Vanadium ranged from 0.30 – 21.10 ug/l, with a mean of 3.15 ug/l. zinc, barium, manganese, lithium and aluminum show some level of significance in the waters (Table 3)

**Table 4. Concentration of Trace Elements in the Water Types of the Study Area in µg/l**

| ID | Sr | U | V | Y | Zn | Sb | Rb | Pb | Nd | Mn | Li | Cu | Ce | Br | Ba |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stop1 | 174.56 | 0.26 | <0.20 | <0.01 | <0.50 | 0.23 | 2.57 | <0.20 | <0.01 | 1.70 | 52.3 | 0.20 | <0.01 | 8 | 22.34 |
| Stop2 | 63.34 | 0.21 | 0.30 | 0.99 | 6.10 | 0.88 | 30.96 | 3.50 | 1.53 | 74.67 | 2.00 | 0.60 | 0.45 | 14 | 139.79 |
| Stop3 | 39.45 | 0.07 | 0.50 | 0.02 | 5.70 | 0.80 | 2.95 | 1.30 | 0.02 | 0.85 | 10.30 | 9.60 | 0.04 | <5 | 80.64 |
| Stop4 | 130.77 | 0.55 | 0.60 | 0.18 | 3.60 | 1.89 | 37.89 | <0.2 | 0.27 | 33.01 | 0.60 | 0.40 | 0.23 | <5 | 114.46 |
| Stop5 | 205.48 | 0.12 | <0.20 | 0.17 | 5.50 | 1.25 | 7.16 | 0.30 | 0.08 | 2.06 | 6.40 | 5.00 | 0.10 | 23 | 641.50 |
| Stop6 | 185.88 | 0.03 | 3.10 | 0.02 | 4.20 | 1.67 | 0.59 | <0.2 | 0.02 | 0.77 | 6.80 | 0.30 | 0.05 | <5 | 158.16 |
| Stop7 | 798.98 | 2.10 | 2.30 | 0.46 | 17.60 | 3.20 | 4.35 | 0.60 | 0.09 | 2.85 | 26.40 | 1.50 | 0.13 | 189 | 335.50 |
| Stop8 | 1137.6 | 0.18 | 3.20 | 0.23 | 52.60 | 3.23 | 22.83 | 0.50 | 0.28 | 98.81 | 18.00 | 0.90 | 0.70 | 168 | 252.47 |
| Stop9 | 313.61 | 0.75 | 0.60 | 0.09 | 27.70 | 3.17 | 2.10 | 1.10 | 0.07 | 2.72 | 9.50 | 4.90 | 0.13 | 37 | 250.90 |
| Stop10 | 414.03 | 0.59 | 1.10 | 0.57 | 14.20 | 1.64 | 13.16 | 0.30 | 0.55 | 13.73 | 14.20 | 1.30 | 0.26 | 78 | 675.06 |
| Stop11 | 668.36 | 2.95 | 4.00 | 0.06 | 5.60 | 2.87 | 0.69 | <0.2 | <0.01 | 0.28 | 13.30 | 0.40 | <0.01 | 83 | 114.98 |
| Stop12 | 833.05 | 0.06 | 2.10 | 0.20 | 136.30 | 1.67 | 2.07 | 1.00 | 0.29 | 9.94 | 17.00 | 1.50 | 0.91 | 143 | 256.08 |
| Stop13 | 232.99 | 7.28 | 1.60 | 0.05 | 8.60 | 1.86 | 1.31 | <0.2 | 0.02 | 7.69 | 30.30 | 0.30 | <0.01 | 74 | 26.15 |
| Stop14 | 444.23 | 0.38 | 1.00 | 0.60 | 10.10 | 1.64 | 4.16 | 0.80 | 0.71 | 6.29 | 12.10 | 0.60 | 0.67 | 99 | 257.21 |
| Stop15 | 115.56 | 0.19 | 0.80 | 0.15 | 15.70 | 3.38 | 2.77 | 3.00 | 0.08 | 0.83 | 13.90 | 2.10 | 0.11 | 20 | 93.67 |
| Stop16 | 191.71 | 0.14 | 0.4 | 0.15 | 4.2 | 2.31 | 3.55 | <0.2 | 0.16 | 42.39 | 5.40 | 0.50 | 0.42 | 45 | 162.51 |
| Stop17 | 54.81 | 0.42 | <0.2 | 0.11 | 5.5 | 2.87 | 0.96 | 0.6 | 0.18 | 1.10 | 8.00 | 1.50 | 0.23 | <5 | 73.70 |
| Stop18 | 255.56 | 0.02 | 4.6 | 0.02 | 11.2 | 2.51 | 0.7 | <0.2 | <0.01 | 1.34 | 6.70 | 2.20 | <0.01 | 89 | 113.29 |
| Stop19 | 298.09 | <0.02 | 21.1 | 1.1 | 6.5 | 3.91 | 0.29 | 3.1 | 0.03 | 0.48 | 8.90 | 2.20 | 0.04 | 150 | 82.41 |
| Stop20 | 246.49 | 0.04 | 6.4 | 0.02 | 13.2 | 3.01 | 0.45 | 4.4 | 0.01 | 8.33 | 6.30 | 13.10 | 0.04 | <5 | 151.06 |

The Piper Trilinear Diagram (Fig. 11) is made of two triangles, one for plotting cations and the other for anions. The water types are deduced based on the diagram segmented by Back and Henshaw (1997).

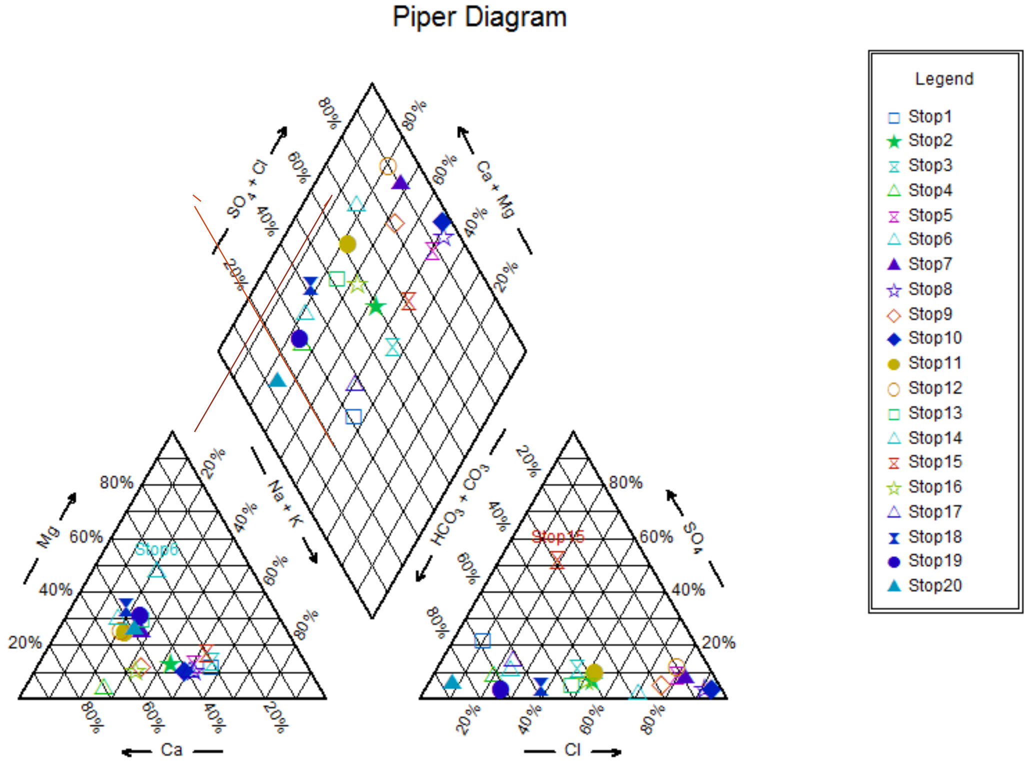


Fig 11: Piper Diagram of water types for all locations

Detailed compositions of the waters from the piper diagrams (Fig. 11) shows that the water types are predominantly ($Na^+$ - $Cl^-$ - $HCO_3^-$ – $SO_4^=$) and ($Ca^{2+}$-$Cl^-$ - $HCO_3^-SO_4^=$) water. Since sulphide and chloride mineralization have not been reported in the environment, the presence of chloride and sulphate may be the contribution of anthropogenic activities (Townsend and Whiteman, 2005).

**Gibbs Plot of the Water Samples in the Study Area**
Gibbs plots are the graphs of ratio of cations [($Na^+$ + $K^+$) / ($Na^+$ + $K^+$ + $Ca^{2+}$)] and anions [$Cl^-$/ ($Cl^-$ + $HCO3^-$)] against TDS. The plot is used to determine possible sources of elements in the waters. Gibbs (1970) proposed two diagrams to understand the hydrogeochemical procedures with reference to atmospheric precipitation, rock–water interaction, and evaporation over the administration of the geochemistry of groundwater. From the plots, all the samples of the study region fall within rock weathering dominance (Figs. 12 and 13).

**Water Quality Index (WQI)** Water quality index is a central parameter for finding out groundwater excellence and its aptness for human consumption (Mishra and Patel, 2001; Avvannavar and Shrihari, 2008)

WQI describes a method of ranking that gives the combined control of major water quality parameters on the whole excellence of water for human utilization (Singh et al., 2004; Singh et al., 2016). The standards for human consumption as suggested by WHO (1997) have been taken for the estimation of WQI. WQI standards are divided into five categories by Brown *et al.* (1972): Excellent (0-25), Good (26-50), Poor (51-75), Very Poor (76-100) and Unsuitable for drinking (>100).

The result of the WQI for samples from the study area is presented in Table 5. The WQI ranged from 7.36 - 66.55. Statistically, 30% of the water samples are excellent, 50% are good, 15% are poor and 5% are rated unsuitable for drinking (Table 5).

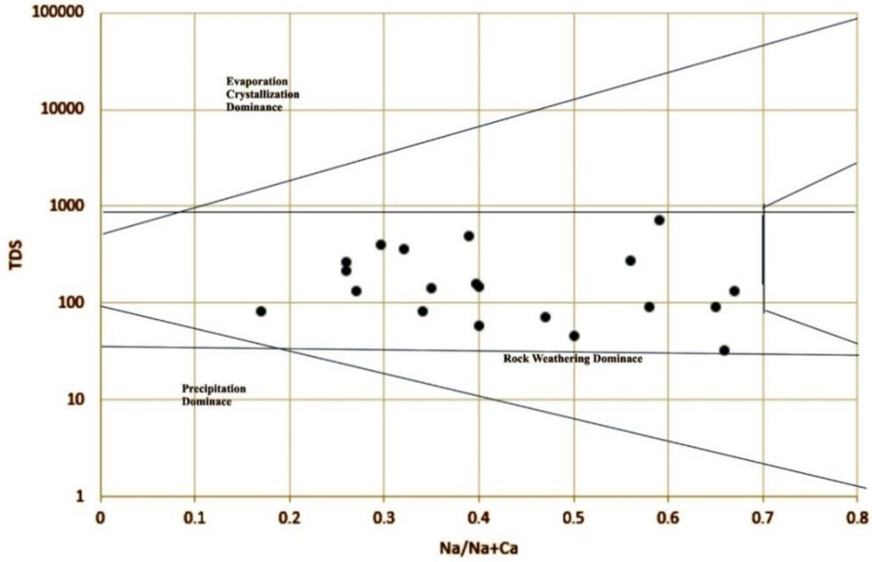


**Fig 12: Gibbs Plot of cations vs TDS showing rock weathering dominance as the major contributor of elements in the waters**

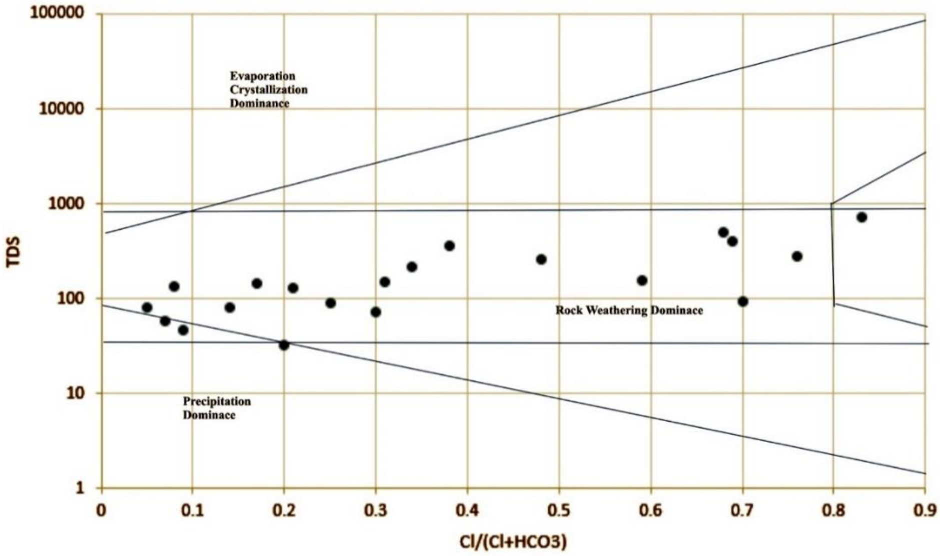


**Fig 13: Gibbs Plot of anions vs TDS showing rock weathering dominance as the major contributor of elements in the waters**

**Concentration and Sources of the Elements in the Waters**

Compositions of groundwater are determined by various factors such as natural and anthropogenic (Nelson, 2002). Major natural factors that control groundwater composition include rock type, residence time and the chemical state of groundwater (Schwartz and Zhang, 2002). From this study, the Gibbs plot point to rock–water interaction as the main contributor to the composition of water in the area. However, the factor analysis, apart from indicating that the composition of the waters, is from the rock types, the high concentration of $Cl^-$ and $NO_3^-$ in the waters indicate a contribution from anthropogenic activities.

The water types in the study area, which are predominantly $Ca\text{-}HCO_3 – Cl – SO_4$ and $Na\text{-}HCO_3 – Cl – SO_4$ confirm both the rock types and anthropogenic activities as sources of elements in the waters. Sources of chloride, nitrate and sulphate may be from septic tanks, pit latrines and indiscriminate disposal of solid wastes within the communities. They are especially high in the central area around the Kwata (Stop 7) and Quarter-One (Stop 8), located close to the market area and the Mangu abattoir, which must have influenced the compositions of these ions in the waters owing to large human activities that take place in the area

**Table 5: Water Quality Index of Water Samples in the Study Area**

| ID | WQI | Remarks |
|---|---|---|
| Stop 1 Naatika garden Bungha | 26.57 | Good |
| Stop 2 Anointed Drink Bungha | 35.75 | Good |
| Stop 3 Gyaghat | 33.35 | Good |
| Stop 4 GSS Mangu | 29.29 | Good |
| Stop 5 Angwan Sarki | 58.05 | Poor |
| Stop 6 Al Zira oil (Gindiri road) | 7.32 | Excellent |
| Stop 7 Kwata (Mangu market) | 66.55 | Poor |
| Stop 8 Quarter-One | 126.55 | Unsuitable |
| Stop 9 Good morning market | 29.65 | Excellent |
| Stop 10 Mwaghavul Community Bank | 36.23 | Good |
| Stop 11 Angwan Mata | 25.39 | Excellent |
| Stop 12 Mishkagham Mangu Palace | 46 | Good |
| Stop 13 Mishkagham Kam Palace | 22.09 | Excellent |
| Stop 14 Derkon Angwan Mata | 22.09 | Excellent |
| Stop 15 Rampiya | 12.67 | Excellent |
| Stop 16 INEC Office | 22.08 | Excellent |
| Stop 17 Angwan Mission | 40.35 | Good |
| Stop 18 Allah Na kowa Hospital | 20.33 | Excellent |
| Stop 19 Pobest Drill (Opposite Hariz Petroleum) | 47.26 | Good |
| Stop 20 Widowhood Centre | 52.67 | Poor |

**Water Quality (Domestic Use)**

Individual water quality parameter compares well with the WHO (2011) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2010) except for areas whose water pH fall below the 6.5 lower limits recommended by both the WHO (2004) and the NSDWQ (2010). The calculated water quality index generally indicated good water quality for drinking, except for three areas: locations 5, 7 and 20, which are classified as poor. Trace elements in the study area generally occur in concentration below their WHO (2011) permissible limits. Hence, they do not pose any threat to human health. However, based on Sawyer and McCarty's (1967) classification, the hardness of the water in the study area ranges from 15.07- 489.92 mg/1, with the following percentages: 35% slightly hard water, 20% very hard water, 30% moderately hard water and 10% hard water and 5% as soft. Samples from Kwata (Stop 7), Quarter-One (Stop 8), Mwaghavul Community Bank (Stop 10), Angwan Mata (Stop 11), Mishkagham Mangu Palace (Stop 12), Mishkagham Kam Palace (Stop 13) and Derkon (Stop 14) are not suitable for laundry, due to their high degree of hardness. Calcium and magnesium are the two critical elements responsible for the hardness of water (Todd, 1980). Their effects on health have been studied in different parts of the world (Kozisek, 2012; Wajtaszek and Pieniak, 2012) and it is reported that inadequate intake of calcium and magnesium in water may increase the risk of developing cardiovascular diseases, cancer, and diabetes (WHO, 2009). The protective effect of magnesium in drinking water on decreasing the incidence of Type 2 diabetes among young adults has been confirmed by (Kousa *et al*., 2012). Although hypertension is multifactorial in origin, adequate calcium intake has been associated with lowered risk of elevated blood pressure in some studies. From this study, therefore, the inhabitants of the study area may be protected from certain cardiovascular diseases owing to the hard nature of their water. This study, however, differs from an earlier one carried out (Dibal et al., 2018), which indicated low intake of both calcium and magnesium in the drinking water of the Central Plateau, of which the study area falls.

**CONCLUSION**

The concentration of elements and water quality index in the Mangu area have been studied. Results of Physico-chemical analysis of groundwater samples from the area showed that chemical parameters differ for individual sources. Concentration of the elements is higher in the Mangu central area than those sources that at the outskirt of the town. This may imply that human activities, which could have led to the increase of some of the elements, are limited in the areas at the outskirt, Gibbs plots indicates the concentration of elements in the waters to be mainly from the weathering of rocks that constitute the study area, while factor analysis and derived water types from modified Piper Diagram indicate weathering of rocks and anthropogenic activities as contributors of chemical elements in the waters. The Mangu area, which showed a high concentration of nitrate, sulphate and chloride, could be attributed to the central abattoir which discharges its effluent waters indiscriminately, septic tanks, pit latrines and surface disposal of solid wastes. These are responsible for the calculated water quality index ranges from 7.36 - 66.55 and is classified as 30% - excellent includes; Stops 6 (Al Zira oil Gindiri road), Stop 13 (Mishkagham Kam Palace), Stop 14 (Derkon Angwan Mata), Stop 15 Rampiya, Stop 16 (INEC Office), and Stop 18. 50% as good includes; Stop 1 (Naatika garden Bungha), Stop 2 (Anointed Drink Bungha), Stop 3 (Gyaghat), Stop 4 (GSS Mangu), Stop 9 (Good morning market), Stop 10 (Mwaghavul Community Bank), Stop 11 (Angwan Mata), Stop 12 (Mishkagham Mangu Palace), Stop 17 (Angwan Mission), Stop 19 (Pobest Drill, Opposite Hariz Petroleum)). 15% as poor includes; Stop 5 (Angwan Sarki), Stop 7 Kwata (Mangu market), Stop 20 (Widowhood Centre). The least is 5% and is rated unsuitable for drinking (Stop 8) Quarter-One. The waters of the study area are generally hard and are not suitable for laundry use, but inhabitants may be benefiting from the protective use of hard water against some cardiovascular diseases as indicated by several studies in different parts of the world.

**REFERENCES**


Avvannavar, S. M and Shrihar, S., 2008. Evaluation of water quality index for drinking purposes for river Netravathi Mangalore, South India. Environmental Monitoring Assessment. 143, 279 - 290

Back W, Henshaw, B.B., 1965. Advances in Hydrogeosciences. In: Chemical Geohydrology Academy Press New York II, 49.

Davies, T. C., 1994. Water quality characteristics associated with fluorite mining in the Kerio Valley area of Western Kenya. International Journal of Environmental Health Research 4, 165 - 175

Dibal, H.U., Justina, M.D., Yenne, E.Y., Fom, S.G and Daku, S.S., 2019. Calcium and Magnesium distribution in groundwater and food substances in parts of Central Plateau State, Northcentral Nigeria. Global Journal of Geological Sciences 17, 61 – 73.

Fetter, C.W., 2007. Applied Hydrogeology. 2nd Edition. CBS Publishers, New Delhi, Bangalore. Pune Kochi Chennai. 592.

Freeze, R.A and Cherry, J. A., 1979. Groundwater. Prentice–Hall Inc., Englewood Cliffs 7632, 604

Gabriel, R.M. and Christ, C.L., 1965. Solutions, Minerals and Equilibria. Freeman-Cooper, San Francisco, C.A, 450.

Gibbs, R.J., 1970. Mechanism controlling the world's water chemistry. Science 170, 1088–1090.

Horton, R. K., 1965. 'An index number system for rating water quality. Journal of Water. Pollution. Con. Fed. 37(3), 300–305.

Kousa A., Puustinen N., Karvonen M and Moltcanova E., 2012. The regional association of rising type 2 diabetes incidence with magnesium in drinking water among young adults. In: F. Kozisek (Eds.) Health and Regulatory aspects of calcium and magnesium in drinking water In: L. Razowska-Jaworek (Ed) Calcium and magnesium in drinking water; occurrence and significance for human health. International Association of Hydrogeologists selected papers. CRC Press, 135 – 145.

Kozisek, F., 2012. Health and regulatory aspect of calcium and magnesium in Drinking Water. In: L. Razowska-Jaworek (Ed) Calcium and magnesium in drinking water; occurrence and significance for human health. International Association of Hydrogeologists selected papers. CRC Press, 135 – 145.

Lekmang, I. C., 2021. Geochemistry of the basalts of Kerang Twin Volcanoes within the Panyam Volcanic Line, Jos Plateau, Central Nigeria: Implications for their origin and evolution. An Unpublished PhD Thesis, University of Jos, 179

Liu, C., Lin, K and Kuo, Y., 2003. Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Science of the Total Environment 313 (1 – 3), 77 – 89.

Mishra, P.C and Patel, R.K., 2001. Study of the pollution load in the drinking water of Rairangpur, North Orissa. Indian Journal of Ecological Planning 5 (2), 293 – 298.

Piper, A. M., 1944. A graphic procedure in the geochemical interpretation of water-analyses. Eos, Transactions American Geophysical Union, 25(6), 914-928.

Sawyer, C.N and McCarty, P.L., 1967. Chemistry for Sanitary Engineers. 2nd Ed. McGraw Hill, New York, 518.

Schoeneich, K and Garba, L., 2004. Geol. 405. Hydrogeology. Lecture notes for students of the Geology Department, Ahmadu Bello University Zaria.

Schwartz, F.N and Zhang, H., 2002. Fundamentals of Groundwater. John Wiley and Sons. Inc. 583.

Singh, K.P., Malik A., Mohan D. and Sinha, S., 2004. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River India), Water Resource 38, 3980–3992.

Singh, J. S., Kumar, A., Rai, A. N., and Singh, D. P., 2016. Cyanobacteria: a precious bio-resource in agriculture, ecosystem, and environmental sustainability. Frontiers in microbiology, 7, 529

Townsend M.A and Whittemore, D.O., 2005. Identification of nitrate and chloride sources affecting municipal well waters of the city of McPherson, Kansas Geological Survey Open File Report 2005-34, 1 – 24

United Nations., 2006. The human right to water and sanitation. International Decade for action "WATER FOR LIFE 2005 – 2015.

UNICEF/WHO, 2019. 1in 3 people globally do not have access to safe drinking water. News release, New York, Geneva.

WHO, 1984. World Health Organization Guidelines for Drinking Water Quality. Vol. 2, Health Criteria and Other Supporting Information, Geneva, 335

WHO, 1997. The world health report 1997: conquering suffering; enriching humanity. In The world health report 1997: conquering suffering; enriching humanity (pp. 162-162).

WHO, 2011. Guidelines for Drinking Water Quality. 4$^{th}$ edition, 186.

Wojtaszek, T., and Pieniak, M., 2014. Mineral water as a source of healthy minerals. Calcium and Magnesium in Groundwater: Occurrence and Significance for Human Health, 147.