NSUK Journal of Science & Technology, Vol. 7(1): pp. 13-24, 2020 Print: ISSN: 2756-696X
On-line: ISSN 2756-6951
**Website: www.nsukjst.org.ng**

# HYDROCHEMICAL ASSESSMENT OF SURFACE AND GROUNDWATER QUALITY IN SISIN BAKI, FARIN RUWA AND ENVIRONS, PART OF KURRA SHEET 189 SW, NORTH CENTRAL NIGERIA

***Ma'aji, U. M., Kana, M. A. and Iliya, M. M.**

Geology and Mining Department, Nasarawa State University, Keffi
***corresponding author: usmanmaaji66@nsuk.edu.ng**

**ABSTRACT**

The study area, Sisin Baki, Farin Ruwa and environs are located in Wamba Local Government Area of Nasarawa State in Kurra sheet 189 SW, North Central Nigeria. It is bounded by Latitudes $09^0$ 00' 00" N to $09^0$ 07' 30" N and Longitudes $08^0$ 35' 00" E to $08^0$ 45' 00" E, covering an area of about 253 $km^2$. It is underlain by the Basement Complex rocks of north-central Nigeria generally undulating with many reliefs which are influenced by the geology. The topography is characterized by many high mountains and some low lands drained by rivers and streams which are used for agriculture. Twenty-seven (27) samples of both surface water (streams and rivers) and groundwater (boreholes and shallow wells) were collected from the study area following the standard procedure as prescribed by APHA (1995) guidelines. Various physical parameters ($T^0C$, pH, TDS, EC, TH) and chemical parameters such as major anions ($Cl^-$, $SO_4^{2-}$, $CO_3^{2-}$, $HCO_3^{2-}$), and cations ($Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$) were analysed using standard procedures. The dominant ions were in the order of Mg > Ca > $HCO_3$ > Na > Cl > K > $SO_4$. The results showed that the groundwater in the area is predominantly suitable for drinking. The assessments of water studied for irrigation show that almost all the water sources of the study area are suitable for irrigation purposes.

***Keywords:*** *Water quality, NSDWQ, WHO, Anion, Cation, Permissible limits*

## INTRODUCTION

Water is the most valuable resource for sustaining life on earth. Water is used in different ways: for drinking, bathing, washing (domestic uses), and hydropower generation, in agriculture, irrigation, recreation and transportation. It is therefore very important to ensure the quality of groundwater for every human being, animals and plants for good health and survival (Chapman, 1996). The demand for freshwater resources has been increasing gradually due to population growth. Consequently, the use of underground water resources as a source of freshwater has increased drastically over a short period. Surface water from streams, rivers and shallow groundwater and a few boreholes are currently being used for agricultural purposes in the study area. Agricultural activity results in the intense use of both surface and groundwater, which in turn can have significant effects on their qualities (Kastridis and Kamperidou, 2015; Knight *et al.,* 2013; Huang *et al.,* 2013; Trabelsi *et al.,* 2012).

### Study Area

Sisin Baki and Farin Ruwa areas are underlain by the Basement Complex rocks of Northcentral Nigerian. It lies within Latitudes $9^o$ 00' 00" N to $9^o$ 07' 30" N and Longitudes $8^o$ 35' 00" E to $8^o$ 45' 00" E, covering an area of about 253 $km^2$ (Figure 1). The rocks covering these areas comprise of granitic gneiss, biotite gneiss, porphyroblastic gneiss and banded gneiss. These are the Basement Complex rocks of the Older Granite suites.

### Geology and Hydrogeology

Sisin Baki and Farin Ruwa areas are underlain by the Basement Complex rocks of Nigeria. These comprise the Migmatite-Gneiss Complex, Older Granites and Younger Metasediments (Bala *et al.,* 2011). The predominant rock type is the migmatite-gneiss complex which consists of banded gneiss, biotite gneiss, granitic-gneiss, coarse-grained gneiss and porphyroblastic gneiss (Nigerian Geological Survey Agency, 2006, Figure 2).

Groundwater in the study area occurs within the weathered overburden and fracture systems of the unweathered or partly weathered rocks. An aquifer is located in the weathered mantle and fractured zones of rocks where porosity and permeability are adequate to allow a large quantity of water to accumulate. Groundwater yield in the study area is higher where thick overburden overlies fractured zones.

## METHODOLOGY

A total of twenty-seven (27) water samples were collected from eight (8) different locations for geochemical analysis. Nine (9) water samples were from hand-dug wells, six (6) from hand-pump boreholes and twelve (12) from streams and rivers. These water samples were carefully collected and packaged in rinsed plastic containers and then labelled. Few drops of concentrated solution of nitric acid were added to one group of the samples at the point of collection. The water samples were collected during the peak of the dry season (April, 2019). Measurements for temperatures ($T^0C$), electrical conductivity (EC), pH and total dissolved solids (TDS) were done by a potable three-in-one digital meter (Hanna-HI 8314 Membrane). The water samples were analyzed for various chemical constituents using standard methods prescribed by the American Public Health Association (APHA 1989, 1995). The elements of interest were major cations ($Na^+$, $Mg^{2+}$, $Ca^{2+}$ and $K^+$), major anions ($HCO_3^{-2}$, $Cl^-$, and $SO_4^{2-}$) and also other elements (P, $CO_3$,). The techniques for the analysis were Atomic Absorption Spectrophotometric (AAS), Flame Photometry and Titrimetric Methods. The correlation of analytical data and classification for suitability were assessed by plotting different graphical representations using Wilcox (1955), USSL (1954), Gibbs (1970), Doneen (1964) using Arc-GIS 10.3, Rock-Works 15, Aquachem 4.0, and Surfer 11 software. Various physicochemical parameters such as pH (hydrogen exponent), TDS (Total Dissolved Solids), EC (Electrical Conductivity), TH (Total Hardness) and major cations ($Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$) and anions ($P^{3-}$, $SO_4^{2-}$, $CO_3^{2-}$, $Cl^-$ and $HCO_3^{2-}$) were analysed using standard procedures. The results of major constituents were compared with the water quality standards prescribed by the World Health Organisation (WHO, 2008) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015). From the analysed samples, different indices such as Percentage Sodium (%Na), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Magnesium Adsorption Ratio (MAR), Kelley's Ratio (KR) and Permeability Index (PI) were characterized in the study.

## RESULTS AND DISCUSSION

### Drinking and Domestic Suitability

To assess the surface and groundwater qualities for drinking, domestic, industrial and other public uses, hydro-chemical parameters of the study area were compared with the guidelines prescribed by the World Health Organization (WHO, 2008) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) (Table 2). All the physical parameters are below the permissible limit set by the WHO (2008) and the NSDWQ (2015) standards for drinking water quality as well as all the chemical parameters.

***pH***

pH value is defined as the logarithm of the reciprocal of the $H^+$ ion concentration. It determines the nature of the solution whether it is acidic or alkaline. The strength of water is represented by pH and is controlled by $CO_2$, $CO_3^{2-}$ and $HCO_3^{-2}$ concentrations (Hem, 1991). The acceptable limit of pH for drinking water varies from 6.5 to 8.5 (WHO, 2008), 6.5 to 9.5 (NSDWQ, 2015), as presented in (Table 1). The pH values of surface and groundwater samples in the study area range between 2.65 and 5.5 which indicate that the water samples are slightly acidic. These values can slightly affect the taste of the water for domestic uses.

***Total Dissolved Solids***

Estimation of Total Dissolved Solids (TDS) helps in testing the suitability of water for drinking, agriculture and industrial purposes. TDS is the sum of potassium, calcium, sodium, magnesium, carbonates, bicarbonates, chlorides, organic matter, phosphate and other particles. The mineralization (TDS) of surface and groundwater in the study area ranges from 93.6 mg/l to 134.4 mg/l with an average of 114 mg/l. This is even below the permissible limit of WHO (2008) and NSDWQ (2007) Standards for Drinking and Domestic Use (Table 1). Based on TDS values the entire water within the study area is excellent for drinking and other domestic uses.

***Total Hardness (TH)***

Parameters such as $Ca^{2+}$ and $Mg^{2+}$ were considered to assess the water quality and geochemical process. The equation prescribed by Todd (1980), Ragunath (1987) and Hem (1991) which has been used to determine the total hardness (TH) in ppm is as thus: TH = 2.497 $Ca^{2+}$ + 4.115 $Mg^{2+.}$ Hardness due to bicarbonate of calcium or magnesium is termed as temporary hardness. The hardness due to chlorides, sulphates and nitrates of calcium and magnesium is considered as permanent hardness which results in a greater amount of soap consumption. It leads to the calcification of arteries in human being as well as affects the water supply system by forming scale (Saleem *et al.,* 2018). The total hardness of the study area ranges from 5.72 to 16.34mg/l with a mean concentration value of 11.03 mg/l. According to WHO (2008) and NSDWQ (2015), the permissible limit is 500 mg/l and 150 mg/l respectively (Table 2), and the range fall within 0 and 75 which make them excellent for irrigation purposes (Table 3).

***Electrical conductivity (EC)***

Electrical conductivity is a measure of the capacity of a substance or a solution to carry an electric current. The electrical conductivity measured in the study area ranges from 156 - 200µS/cm, with an average of 178µS/cm. This range falls within the permissible limits of the Nigerian Standards for Drinking Water of WHO (2008) and NSDWQ (2015), whose permissible limits are 1500 mg/l and 1000 mg/l respectively (Table 2). In other words, the water is suitable for irrigation purposes as it is below 250mg/l which is good and has low salinity hazard (Table 3).

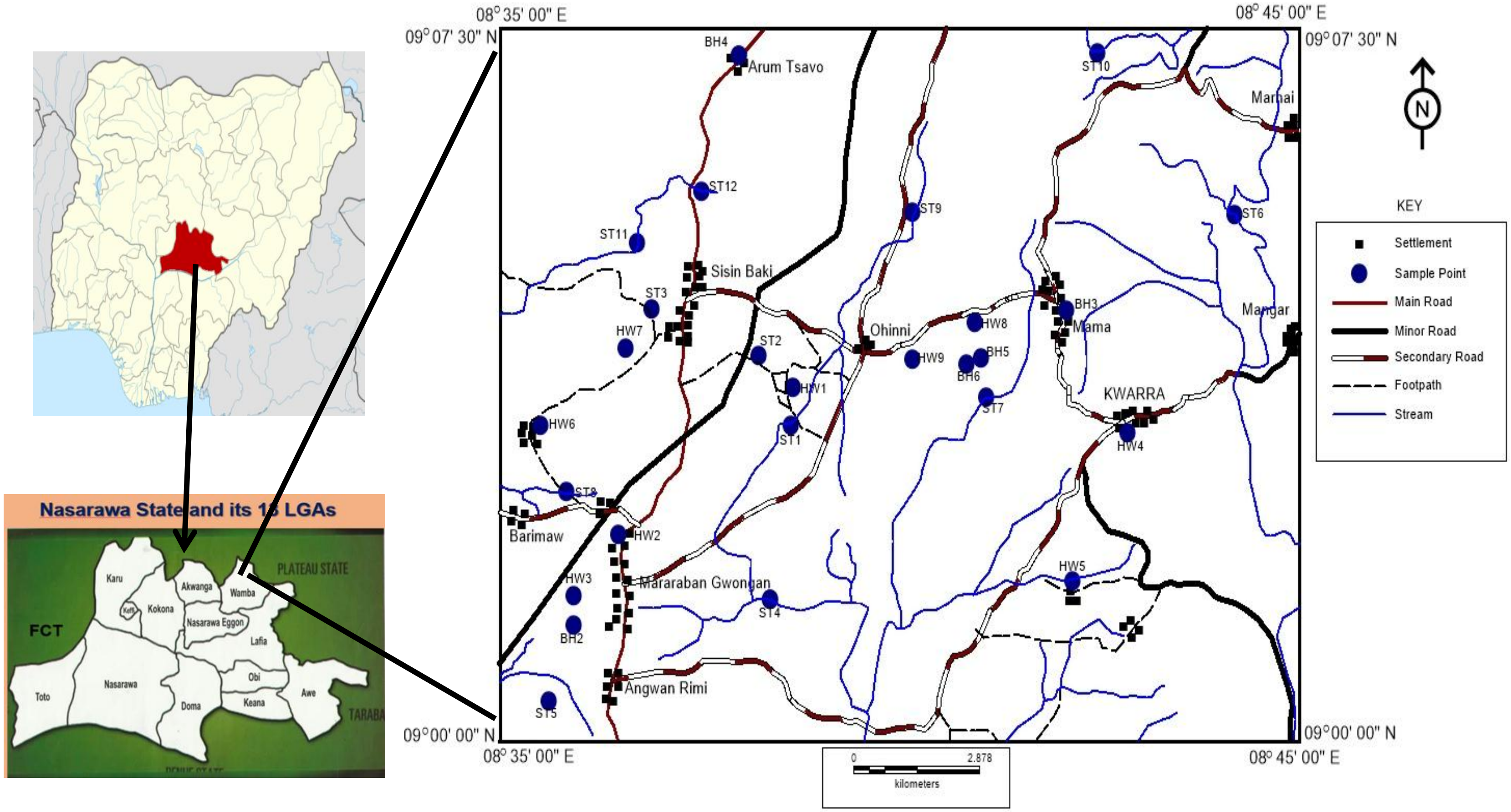



Figure 1: Location Map of Sisin Baki, Farin Ruwa and Environs showing Sample Points (Extracted and Modified from Topographical Map of Kurra Sheet 189 SW, Produced by Federal Survey Agency, 2006)

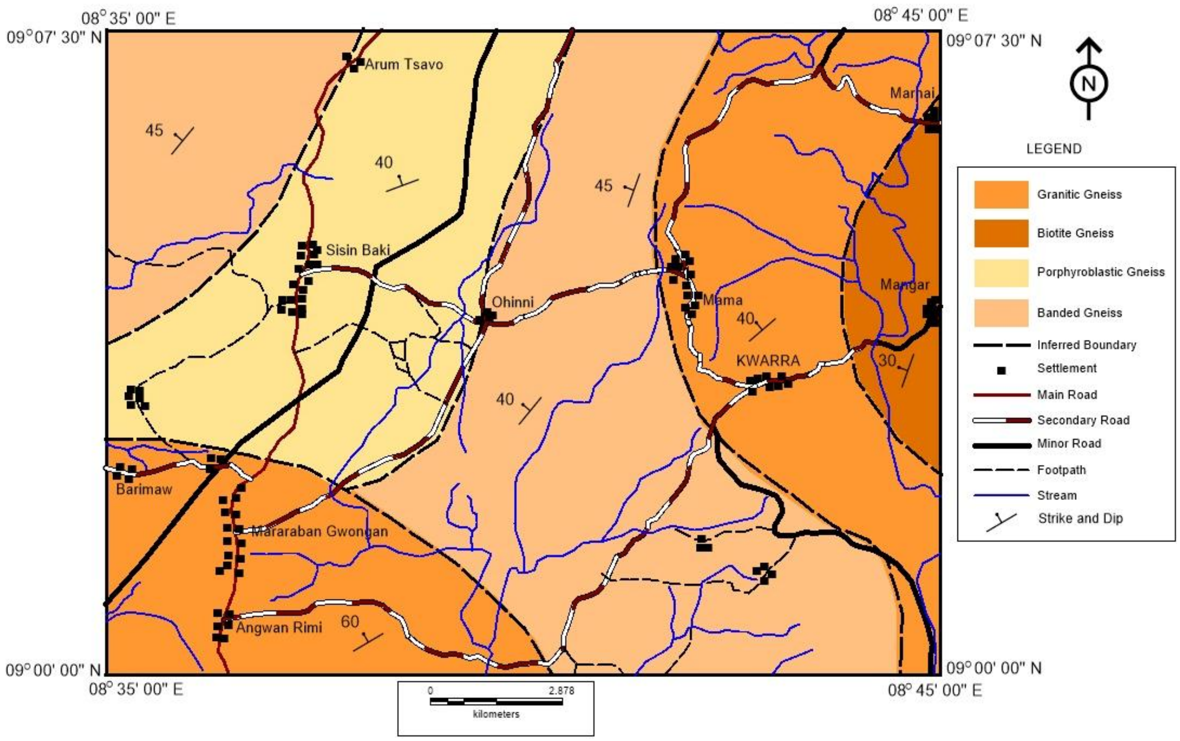



Figure 2: Geological map of Sisin Baki, Farin Ruwa and Environs (Extracted and Modified from Nigerian Geological Survey Agency, 2006)

Table 1: Physico-Chemical Parameters of Groundwater samples (mg/l) of Sisin Baki, Farin Ruwa and Environs

| S/N | Samp. ID | Location | Temp | pH | EC | TDS | Na | K | Ca | Mg | P | CO3 | $HCO_3$ | Cl | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HW 1 | Chinni 1 | 27 | 3.17 | 180 | 108 | 1.3 | 0 | 26 | 25.2 | 0.15 | 33.44 | 68 | 1.1 | 1.231 |
| 2 | ST 1 | Chinni 2 | 26 | 3.2 | 177 | 106.2 | 0.6 | 0 | 20 | 20.4 | 0.11 | 29.50 | 60 | 0.9 | 1.224 |
| 3 | ST 2 | Chinni 3 | 27 | 2.96 | 187 | 112.2 | 1.1 | 0 | 20 | 18 | 0.11 | 23.60 | 48 | 0.9 | 1.226 |
| 4 | ST 3 | Chinni 4 | 24 | 2.8 | 156 | 93.6 | 0.5 | 0 | 18 | 19.2 | 0.12 | 26.06 | 53 | 1 | 1.228 |
| 5 | ST 4 | Chinni 5 | 23 | 2.65 | 166 | 99.6 | 0.8 | 0 | 22 | 21.6 | 0.13 | 22.13 | 45 | 0.9 | 1.234 |
| 6 | BH 1 | Barmo | 25.6 | 3.1 | 184 | 110.4 | 4.1 | 0 | 18 | 12 | 0.1 | 13.77 | 28 | 0.9 | 0.08 |
| 7 | HW 2 | Barmo | 27.8 | 3.07 | 188 | 112.8 | 0.5 | 0.5 | 18 | 10.8 | 0.1 | 17.70 | 36 | 1 | 0.08 |
| 8 | ST 5 | Angwam Rimi | 30 | 2.8 | 198 | 118.8 | 1.4 | 0 | 24 | 13.2 | 0.1 | 21.63 | 44 | 1 | 0.08 |
| 9 | HW 3 | Maraba Gongon | 32.3 | 2.92 | 200 | 120 | 2.3 | 0.3 | 20 | 12 | 0.1 | 19.67 | 40 | 1.1 | 0.08 |
| 10 | BH 2 | Maraba Gongon | 28.7 | 2.8 | 195 | 117 | 2 | 1 | 22 | 12 | 0.1 | 21.63 | 44 | 1.3 | 0.08 |
| 11 | HW 4 | Well 1 | 25.7 | 3.15 | 181 | 126.7 | 5 | 0.7 | 10 | 13.2 | 0.1 | 13.77 | 28 | 0.5 | 0.08 |
| 12 | HW 5 | Well 2 | 26.1 | 3.22 | 182 | 127.4 | 1.7 | 0.3 | 16 | 13.2 | 0.11 | 17.70 | 36 | 0.5 | 0.16 |
| 13 | ST 6 | Stream 1 | 27.3 | 2.93 | 192 | 134.4 | 0 | 0 | 26 | 33.6 | 0.11 | 7.87 | 16 | 0.5 | 0.08 |
| 14 | ST 7 | Stream 2 | 25.4 | 3.12 | 182 | 127.4 | 1 | 0.3 | 30 | 37.2 | 0.11 | 9.83 | 20 | 0.7 | 0.08 |
| 15 | BH 3 | Borehole | 28 | 4.5 | 185 | 129.5 | 3.1 | 0.5 | 22 | 25.5 | 0.1 | 23.60 | 48 | 1 | 0.12 |
| 16 | ST 8 | JS 1 | 27.5 | 2.96 | 191 | 114.6 | 0.8 | 0 | 26 | 33.6 | 0.11 | 27.54 | 56 | 1.7 | 0.04 |
| 17 | HW 6 | JS 2 | 30.2 | 2.97 | 195 | 117 | 1.2 | 0.8 | 20 | 14.4 | 0.11 | 19.67 | 40 | 1 | 0.12 |
| 18 | HW 7 | JS 3 | 24 | 3.33 | 170 | 102 | 4.8 | 1.7 | 20 | 15.6 | 0.11 | 19.67 | 40 | 0.9 | 0.16 |
| 19 | HW 8 | Mama 1 | 25.6 | 3.31 | 179 | 107.4 | 4.8 | 1.3 | 2.6 | 25.2 | 0.11 | 19.67 | 40 | 1.2 | 0.08 |
| 20 | HW 9 | Mama 2 | 26.9 | 3.06 | 180 | 108 | 0.7 | 0 | 22 | 22.8 | 0.11 | 19.67 | 40 | 1 | 0.08 |
| 21 | BH 4 | Mama 3 | 25.4 | 3.12 | 183 | 109.8 | 1.7 | 0.3 | 14 | 14.4 | 0.1 | 13.77 | 28 | 1.4 | 0.12 |
| 22 | BH 5 | Mama 4 | 23.5 | 3.17 | 178 | 106.8 | 2 | 0.4 | 18 | 14.4 | 0.1 | 11.80 | 24 | 1.6 | 0.16 |
| 23 | BH 6 | Arum Tsavo 1 | 28 | 4.5 | 170 | 112 | 0.7 | 0 | 14 | 14.4 | 0.1 | 13.77 | 28 | 0.9 | 0.08 |
| 24 | ST9 | Arum Tsavo 2 | 27 | 5 | 168 | 109 | 0.7 | 0 | 16 | 14.4 | 0.1 | 17.70 | 36 | 0.9 | 0.08 |
| 25 | ST 10 | Arum Tsavo 3 | 28 | 4.5 | 173 | 115 | 0.5 | 0 | 20 | 14.4 | 0.1 | 9.83 | 20 | 0.5 | 0.04 |
| 26 | ST 11 | Arum Tsavo 4 | 28 | 5.5 | 175 | 118 | 1 | 0.2 | 24 | 19.2 | 0.11 | 23.60 | 48 | 1 | 0.16 |
| 27 | ST 12 | Arum Tsavo 5 | 28 | 4.5 | 169 | 117 | 1.1 | 0 | 20 | 19.2 | 0.1 | 13.77 | 28 | 0.6 | 0.08 |

Table 2: Range of chemical parameters and their comparison with WHO and NSDWQ standards for drinking water Quality

| Parameters | Authors' Results (2019) | WHO 2008 Permissible Limit | NSDWQ 2015 Permissible Limit | Undesirable Effect |
|---|---|---|---|---|
| EC (µS/cm) | 156-200 | 1,500 | 1,000 | - |
| pH | 2.65-5.5 | 6.5-9.5 | 6.5-8.5 | Taste |
| TH (mg/l) | 5.72-16.34 | 500 | 150 | Scale formation |
| TDS (mg/l) | 93.6-134.4 | 2,000 | 500 | Gastro-intestinal irritation |
| $K^-$ (mg/l) | 0-1.7 | 20 | - | Bitter taste |
| $Na^+$ (mg/l) | 0-5 | 400 | 200 | High blood pressure |
| $Ca^{2+}$ (mg/l) | 2.6-30 | 200 | - | Scale formation |
| $Mg^{2+}$ (mg/l) | 10.8-37.2 | 125 | 20 | - |
| $Cl^-$ (mg/l) | 0.5-1.7 | 500 | 250 | Salty taste |
| $SO_4^{2-}$ (mg/l) | 0.04-1.23 | 400 | 100 | Laxative effect |
| $NO_3^-$ (mg/l) | - | 45 | 50 | Methaemoglobinaemia |
| $HCO_3^-$ | 16-68 | 600 | - | - |
| $CO_3$ (mg/l) | 7.87-33.44 | 500 | 150 | - |
| $NH_4$ (mg/l) | - | - | - | - |
| P (mg/l) | 0.1-0.15 | - | - | - |
| DO (mg/l) | - | - | - | - |
| Temp ($^oC$) | 23-30 | - | - | - |

Table 3: Classification of groundwater for agricultural purposes (Doneen, 1964; Sawyer and McCarthy, 1967; Lloyed and Heathcote, 1985; Nagaraju *et al.*, 2006; Vasanthavigar *et al.*, 2010; Tiri and Boudoukha; 2010); Arif *et al.*, 2018

| Parameter | Range | Suitability for irrigation | % of Sample |
|---|---|---|---|
| **SAR (meq/l)** | 0 – 10 | Excellent (suitable for all types of crops and soil except for those crops sensitive to Na) | 100% |
| | 10 - 18 | Good (suitable for coarse-textured soil) | - |
| | 18 - 26 | Fair (harmfully for almost all soils) | - |
| | >26 | Poor (unsuitable for irrigation) | - |
| **RSC (meq/l)** | <1.25 | Good | 100% |
| | 1.25-2.5 | Medium | - |
| | >2.5 | Bad | - |
| **EC (µS/cm)** | <250 | Good (low salinity hazard) | 100% |
| | 250-750 | Moderate (medium salinity hazard) | - |
| | 750-2250 | Poor (high salinity hazard) | - |
| | >2250 | Very Poor (very high salinity hazard) | - |
| **TH (mg/l)** | 0-75 | Excellent | 100% |
| | 75-150 | Good | - |
| | 150-300 | Fair | - |
| | >300 | Poor | - |
| **TDS (meq/l)** | 200-500 | Excellent | 100% |
| | 1000-2000 | Good | - |
| | 3000-7000 | Fair | - |
| **%Na (%) or SSP** | <20 | Excellent | 100% |
| | 20-40 | Good | - |
| | 40-60 | Permissible | - |
| | 60-80 | Doubtful | - |
| | >80 | Unsuitable | - |
| **KI (meq/l)** | <1 | Excellent | 100% |
| | >1 | Poor | - |
| **PI (meq/l)** | Class I | Excellent (Max. permeability) | 55.6% |
| | Class II | Good (75% of Max. permeability) | 44.4% |
| | Class III | Fair (25% of Max. permeability) | - |
| **MR (%)** | <50 | Excellent | 15% |
| | >50 | Poor | 85% |

**Irrigation Suitability**

Using the assessed water quality parameters, the following other parameters were determined to check the quality of the water used for irrigation:

1. Soluble Sodium Percentage (SSP).
2. Sodium Adsorption Ratio (SAR).
3. Residual Sodium Carbonate (RSC).
4. Magnesium Adsorption Ratio (MAR).
5. Kelley's Ratio (KR).
6. Permeability Index (PI).

***Soluble Sodium Percentage (SSP or Na %)***

Sodium can be expressed in terms of percentage of sodium or soluble sodium percentage (% Na). Water for Irrigation is classified based on the reaction of sodium with the soil. For assessing the suitability of water for irrigation purposes, the percentage of $Na^+$ is widely used (Wilcox, 1955). To measure sodium hazard in soil, the term soluble sodium percentage (SSP) or Na% is used. Todd (1980) explained soluble sodium percentage (SSP) or Na% as (Eq. 1):

SSP or Na% = Na + K x 100 / (Ca + Mg + Na + K) (meq/l) (1)

The calculated values of Na% from the study area range from 0.00 – 12.93 which falls within the categories of water that is suitably excellent for irrigation purposes (Tables 3 and 4, and Figure 3). High Na% results from dissolution of minerals from rock weathering, and the addition of chemical fertilizers through irrigation waters (Subba Rao *et al.*, 2002).

***Sodium Adsorption Ratio (SAR)***

SAR is expressed in terms of sodium or alkali hazard of the water quality for irrigation purpose (Bhuiyan *et al.* 2015; Islam *et al.* 2016a and b). Excess amount of $Na^+$ and low value of $Ca^{2+}$ destroy the soil structure (Todd, 1980). The SAR value of irrigation water expresses the relative proportion of $Na^+$ to $Ca^{2+}$ and $Mg^{2+}$ (Arajhi *et al.*, 2015) and is calculated as (Eq. 2):

SAR = $Na^-$ / {(Ca + Mg) / 2} 0.5 (meq/l) (2)

However, the concentrations of Na, Ca and Mg ions in water are expressed as $Na^+$, $Ca^{2+}$ and $Mg^{2+}$, respectively (Ayers and Westcot, 1985). The calculated values of SAR range from 0.00 – 0.21 (Tables 3 and 4) which fall within the categories of water that is suitable for irrigation purposes (Figure 4).

Table 4: Parameters used for the evaluation of groundwater quality for irrigational practice (Na through $CO_3$ are in meq/l)

| S/N | Na | K | Ca | Mg | SO4 | Cl | HCO3 | CO3 | %Na | RSC | MR | KI | TH | SSP | PI | SAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.06 | 0.00 | 1.30 | 2.07 | 0.03 | 0.03 | 1.12 | 1.10 | 1.65 | -1.15 | 61.52 | 0.02 | 11.77 | 1.68 | 30.86 | 0.04 |
| 2 | 0.03 | 0.00 | 1.00 | 1.68 | 0.03 | 0.03 | 0.98 | 0.97 | 0.97 | -0.72 | 62.72 | 0.01 | 9.40 | 0.98 | 36.72 | 0.02 |
| 3 | 0.05 | 0.00 | 1.00 | 1.48 | 0.03 | 0.03 | 0.79 | 0.78 | 1.89 | -0.91 | 59.75 | 0.02 | 8.59 | 1.93 | 35.15 | 0.04 |
| 4 | 0.02 | 0.00 | 0.90 | 1.58 | 0.03 | 0.03 | 0.87 | 0.86 | 0.87 | -0.75 | 63.76 | 0.01 | 8.75 | 0.88 | 37.31 | 0.02 |
| 5 | 0.03 | 0.00 | 1.10 | 1.78 | 0.03 | 0.03 | 0.74 | 0.73 | 1.20 | -1.41 | 61.82 | 0.01 | 10.06 | 1.21 | 29.55 | 0.02 |
| 6 | 0.18 | 0.00 | 0.90 | 0.99 | 0.00 | 0.03 | 0.46 | 0.45 | 8.64 | -0.97 | 52.37 | 0.09 | 6.31 | 9.46 | 33.01 | 0.15 |
| 7 | 0.02 | 0.01 | 0.90 | 0.89 | 0.00 | 0.03 | 0.59 | 0.58 | 1.90 | -0.61 | 49.74 | 0.01 | 5.90 | 1.92 | 42.50 | 0.02 |
| 8 | 0.06 | 0.00 | 1.20 | 1.09 | 0.00 | 0.03 | 0.72 | 0.71 | 2.60 | -0.85 | 47.56 | 0.03 | 7.46 | 2.67 | 36.29 | 0.05 |
| 9 | 0.10 | 0.01 | 1.00 | 0.99 | 0.00 | 0.03 | 0.66 | 0.65 | 5.15 | -0.68 | 49.74 | 0.05 | 6.56 | 5.40 | 38.93 | 0.08 |
| 10 | 0.09 | 0.03 | 1.10 | 0.99 | 0.00 | 0.04 | 0.72 | 0.71 | 5.12 | -0.65 | 47.36 | 0.04 | 6.81 | 5.33 | 39.19 | 0.07 |
| 11 | 0.22 | 0.02 | 0.50 | 1.09 | 0.00 | 0.01 | 0.46 | 0.45 | 12.93 | -0.67 | 68.52 | 0.14 | 5.72 | 14.68 | 37.80 | 0.21 |
| 12 | 0.07 | 0.01 | 0.80 | 1.09 | 0.00 | 0.01 | 0.59 | 0.58 | 4.15 | -0.71 | 57.64 | 0.04 | 6.46 | 4.31 | 39.30 | 0.06 |
| 13 | 0.00 | 0.00 | 1.30 | 2.77 | 0.00 | 0.01 | 0.26 | 0.26 | 0.00 | -3.54 | 68.07 | 0.00 | 14.62 | 0.00 | 12.61 | 0.00 |
| 14 | 0.04 | 0.01 | 1.50 | 3.06 | 0.00 | 0.02 | 0.33 | 0.32 | 1.11 | -3.91 | 67.16 | 0.01 | 16.34 | 1.12 | 12.49 | 0.02 |
| 15 | 0.13 | 0.01 | 1.10 | 2.10 | 0.00 | 0.03 | 0.79 | 0.78 | 4.42 | -1.63 | 65.66 | 0.04 | 11.38 | 4.60 | 26.77 | 0.09 |
| 16 | 0.03 | 0.00 | 1.30 | 2.77 | 0.00 | 0.05 | 0.92 | 0.91 | 0.85 | -2.24 | 68.07 | 0.01 | 14.62 | 0.86 | 23.42 | 0.02 |
| 17 | 0.05 | 0.02 | 1.00 | 1.19 | 0.00 | 0.03 | 0.66 | 0.65 | 3.22 | -0.88 | 54.29 | 0.02 | 7.37 | 3.30 | 36.29 | 0.04 |
| 18 | 0.21 | 0.04 | 1.00 | 1.28 | 0.00 | 0.03 | 0.66 | 0.65 | 9.96 | -0.98 | 56.26 | 0.09 | 7.78 | 10.85 | 32.73 | 0.16 |
| 19 | 0.21 | 0.03 | 0.13 | 2.07 | 0.00 | 0.03 | 0.66 | 0.65 | 9.90 | -0.90 | 94.11 | 0.09 | 8.86 | 10.82 | 33.78 | 0.19 |
| 20 | 0.03 | 0.00 | 1.10 | 1.88 | 0.00 | 0.03 | 0.66 | 0.65 | 1.01 | -1.67 | 63.09 | 0.01 | 10.46 | 1.02 | 26.99 | 0.02 |
| 21 | 0.07 | 0.01 | 0.70 | 1.19 | 0.00 | 0.04 | 0.46 | 0.45 | 4.15 | -0.97 | 62.91 | 0.04 | 6.62 | 4.32 | 34.69 | 0.07 |
| 22 | 0.09 | 0.01 | 0.90 | 1.19 | 0.00 | 0.05 | 0.39 | 0.39 | 4.46 | -1.30 | 56.89 | 0.04 | 7.12 | 4.64 | 28.99 | 0.07 |
| 23 | 0.03 | 0.00 | 0.70 | 1.19 | 0.00 | 0.03 | 0.46 | 0.45 | 1.59 | -0.97 | 62.91 | 0.02 | 6.62 | 1.62 | 35.43 | 0.03 |
| 24 | 0.03 | 0.00 | 0.80 | 1.19 | 0.00 | 0.03 | 0.59 | 0.58 | 1.51 | -0.81 | 59.75 | 0.02 | 6.87 | 1.54 | 38.18 | 0.03 |
| 25 | 0.02 | 0.00 | 1.00 | 1.19 | 0.00 | 0.01 | 0.33 | 0.32 | 0.99 | -1.53 | 54.29 | 0.01 | 7.37 | 1.00 | 26.00 | 0.02 |
| 26 | 0.04 | 0.01 | 1.20 | 1.58 | 0.00 | 0.03 | 0.79 | 0.78 | 1.72 | -1.21 | 56.89 | 0.02 | 9.49 | 1.75 | 31.49 | 0.03 |
| 27 | 0.05 | 0.00 | 1.00 | 1.58 | 0.00 | 0.02 | 0.46 | 0.45 | 1.82 | -1.66 | 61.29 | 0.02 | 8.99 | 1.86 | 25.85 | 0.04 |

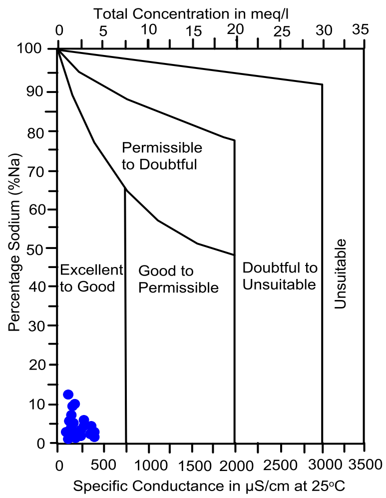
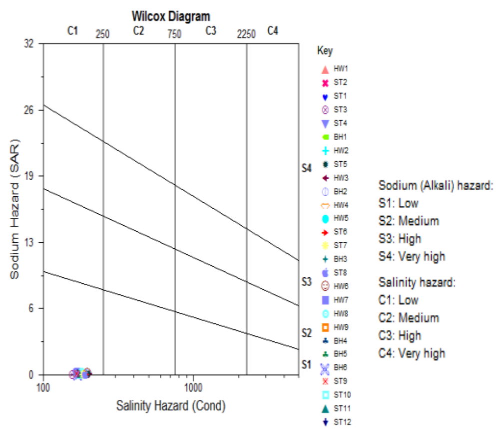



Figure 3: Classification of irrigation waters (after




Wilcox, 1948)

Figure 4: Classification of irrigation waters based on SAR (after Wilcox, 1962)

***Residual Sodium Carbonate (RSC)***

Considering the alkaline earths and weak acids, the residual sodium carbonate (RSC) is computed as per Ragunath (1987) and Rao *et al.*, (2012) as (Eq. 3):

$$RSC = (CO^{2-}_3 + HCO^{2-}_3) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

The RSC values in groundwater sample of the study area range from - 0.61 to -3.91. This is much less than 1.25meq/l, indicating that the waterfalls within safe quality categories for irrigation (Tables 3 and 4)

***Magnesium Adsorption Ratio (MAR)***

MAR also recognized as Magnesium Hazard (MH) and is calculated as per method suggested by Ragunath (1987) as (Eq. 4):

$$MR = Na + K / (Ca + Mg) \times 100 \text{ (meq/l)} \quad (4)$$

The calculated values of MR in the study area range from 47.36 – 94.11 %. This indicates that most of the water in the study area falls within the categories of water that is poor for irrigation (> 50) (Tables 3 and 4).

***Kelley's Ratio (KR)***

Excess amount of sodium over calcium and magnesium is measured by Kelley's Ratio (KR). To find out the suitability of groundwater for irrigation, Kelley's Ratio equation (Kelley, 1963) can be used as (Eq. 5):

$$KR = Na^{+} / Ca^{2+} + Mg^{2+} \text{ (mg/l)} \quad (5)$$

The calculated values of KR in the study area range from 0.00 - 0.14. Based on KR classifications, all samples collected from the study area are excellent for irrigation (Tables 3 and 4).

***Permeability Index (PI)***

Due to the long-term use of irrigation water, the permeability of soil gets influenced by sodium, calcium, magnesium and bicarbonate contents in the soil. Permeability Index (PI) of the groundwater samples was determined using the formula given by Doneen (1964) in the following equation:

$$PI = Na + (HCO_3)^2 / (Ca + Mg + Na) \times 100 \text{ (meq/l)} \quad (6)$$

The calculated values for PI in the study area range from 12.49 - 42.50. This indicates that water from the study area falls within the category of water that is excellent to good quality for irrigation (Figure 5; Table 3).

**Mechanism Controlling Groundwater Chemistry**

Gibbs' plots represent the ratios of $[Na^{+}: (Na^{+} + Ca^{2+})]$ for cations and $[Cl^{-}: (Cl^{-} + HCO_3^{-})]$ for anions as a function of TDS. These are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation dominance, rock dominance and evaporation dominance (Gibbs, 1970). Gibbs's plot of analytical data of groundwater samples from Sisin Baki, Farin Ruwa and environs clustered at the region of rock dominance (Figures 6a, and 6b). This might be attributed to chemical weathering of rock-forming minerals as the major driving force in controlling groundwater chemistry.

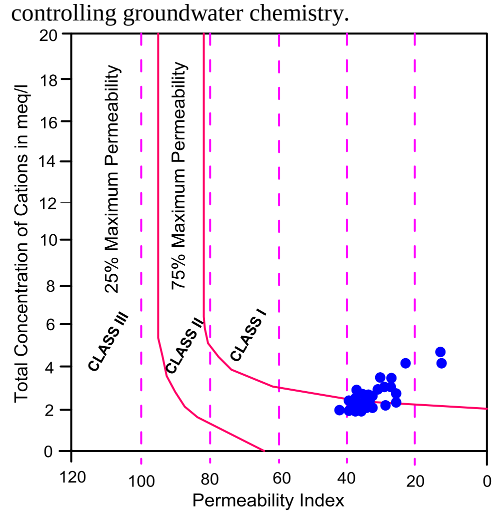
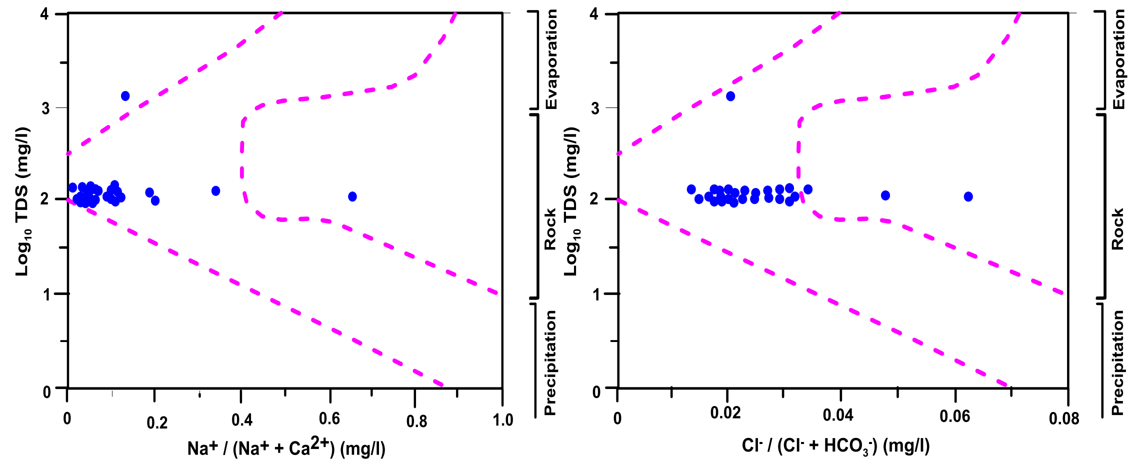



Figure 5: Classification of irrigation water based on permeability Index (PI) (Doneen, 1964).




Figures 6 (a and b): Controlling mechanisms for groundwater quality in the study area (after Gibbs, 1970)

**Groundwater Classification and Hydrogeochemical Facies**

As water flows through aquifers, it assumes a characteristic chemical composition as a result of interaction with the rock types. Hydrogeochemical facies is classified based on dominant ion using the piper's trilinear diagram. The concentrations of major ionic constituents of surface and groundwater samples in the study area were plotted on the piper trilinear diagram. These ions were in the order of abundance as Mg > Ca > $HCO_3$ > Na > Cl > K > $SO_4$ (Figure 7). Piper diagram is developed to display different types of waters and to define the composition of water into different classes. Piper diagram was used to conduct origin and hydro-chemical facies analyses of the sampling sites (Figure 8). Piper diagram shows that water of the study area is predominantly Mg-Ca-$HCO_3$ type (Figure 8).

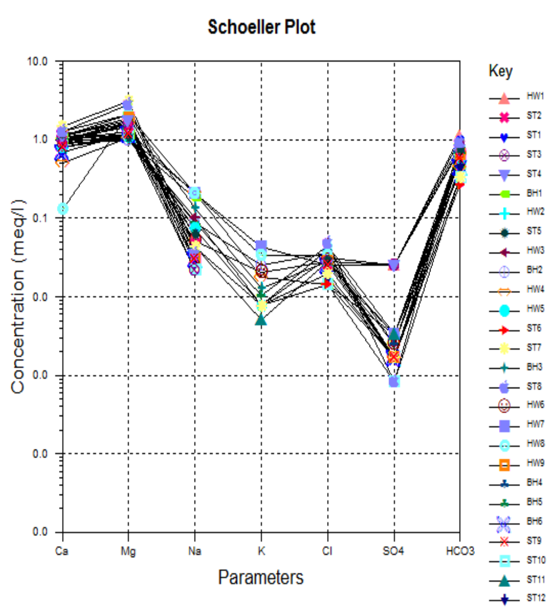



Figure 7: Concentrations of chemical parameters of water samples from the study area (after Schoeller, 1967)

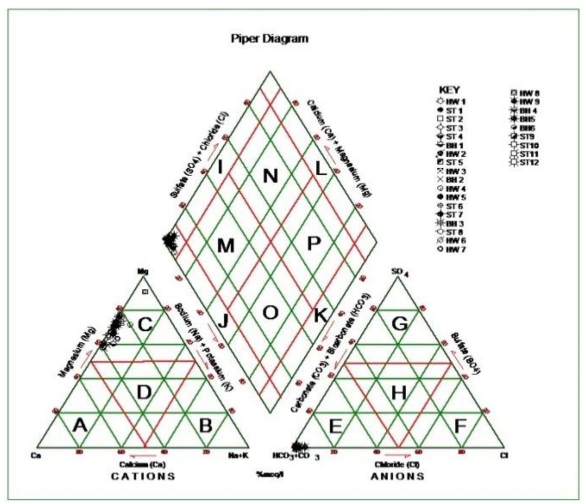



Figure 8: Type classification for water samples from Sisin Baki, Farin Ruwa and environs (Back and Hanshaw, 1965).

**CONCLUSION**

The hydrogeochemical assessment of the study area indicates that both the surface and groundwater are safe for drinking and irrigation purposes. Physical parameters such as $T^0C$, pH, TDS, EC, and chemical parameters such as major anions, $Cl^-$, $SO_4^{2-}$, $CO_3^{2-}$ and $HCO_3^{2-}$, and cations, $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$, have been analysed using standard procedures. The dominant cations and anions were in the order of Mg > Ca > $HCO_3$ > Na > Cl > K > $SO_4$. The functional source of the dissolved chemical constituents of surface and groundwater of the study area is rock dominance based on Gibbs' plot. Results of the groundwater quality of the study area reveal that pH; TH and TDS are safe for drinking purposes. Other elements are within the permissible limits. SAR and SSP values fall in the excellent category which makes the surface and groundwater suitably excellent for agriculture activities.

MAR also falls in poor categories. RSC, KR, and PI fall in suitable category which is good to excellent respectively. Above conclusion reveals that the groundwater of the study area is predominantly suitable for drinking and irrigation purposes.

**REFERENCES**


APHA (1989). Standard methods for examination of water and waste-water, 17th eds. American Public Health Association, Washington, DC.

APHA (1995). Standard methods for the examination of water and wastewater, 19th eds. American Public Health Association, Washington, DC.

Arajhi, A., Beecham S., Bolan N. S. and Hassanli A. (2015). Evaluation of soil chemical properties irrigated with recycled waste-water under partial root-zone drying irrigation for sustainable tomato production. *Agric Water Manag.,* 161:127–135. https://doi.org/10.1016/j.

Arif, A., Sughosh, M., Pardeep, S., Jitendra, P. and Khan A. H. (2018). Assessment of groundwater Quality, with special emphasis on nitrate contamination in part of Varanasi City, Uttar Pradesh, India. Applied Water Science (2018) 8:115 https://doi.org/10.1007/s13201-018-0759-x

Ayers, R. S. and Westcot, D. W. (1985). Water quality for Agriculture, FAO irrigation and drainage Paper 29 Rev I. UN Food and Agriculture Organization, Romeo.

Back, W. and Hanshaw, B. B. (1965). Advances in Hydroscience In: Chemical Geohydrology, Vol. 2. Academic Press, New York, 49 p.

Bala, E. A., Eduvie, O. M. and Byami, J. (2011). Borehole depth and regolith aquifer hydraulic characteristics of bedrock types in the Kano area, Northcentral Nigeria

Bhuiyan, M. A. H., Ganyaglo S. and Suzuki S. (2015). Reconnaissance on the suitability of the available water resources for irrigation in Thakurga district of northwestern Bangladesh. *Appl Water Sci*., 5(3):229239. https ://doi.org/10.1007/s1320 1-014-0184-8

Chapman, D. (1996). Water quality assessments as a guide to use of biota, sediments and water in environmental monitoring, 2nd Edn., University Press, Cambridge.

Doneen, I. D. (1964). Notes on water quality in Agriculture. Published as a Water Science and Engineering. Paper 4001. Department of Water Sciences and Engineering, University of California.

Federal Survey Agency (2006). Topographical map of Kurra Sheet 189 SW. A Publication of the Surveyor-General of the Federation, Abuja, Nigeria.

Gibbs, R. J. (1970). Mechanisms Controlling World Water Chemistry. *Science*, 170(3962): 1088-1090.

Hem J. D. (1991) Study and interpretation of the chemical characteristics of natural waters, 3rd edn. Scientific Publishers, Jodhpur (Book 2254)

Huang G, Sun J, Zhang Y, Chen Z, Liu F. (2013). Impact of anthropogenic and natural processes on the evolution of groundwater chemistry in a rapidly urbanized coastal area of South China. Science of the Total Environment 463, 209-221.

Islam M. A., Zahid A., Rahman M. M., Rahman M. S., Islam M. J., Akter Y., Shammi M., Bodrud-Doza M., Roy B. (2016a). Investigation of the groundwater quality and its suitability for drinking and agricultural uses in the south-central part of the coastal region of Bangladesh. Expo health. https ://doi.org/10.1007/s1240 3-016-0220-z

Islam S.M.D., Majumder R. K., Uddin M. J., Khalil M. I., Alam M. F. (2016b). Hydro-chemical characteristic and quality assessment of groundwater in Patuakhali district, southern coastal region of Bangladesh. Expo Health. https://doi.org/10.1007/s12403-016-0221-y

Kastridis, A. and Kamperidou, V. (2015). Influence of the Land Use Changes on Alluviation of Volvi Lake. *Wet and Soil & Water Res*., 10, 2.

Kelley J. E. Jr. (1963). The critical path method resources planning and scheduling. *Ind Sched*, 13:347365

Knight, S. S., Locke, M. A. and Smith, Jr, S. (2013). Effects of agricultural conservation practices on Ox-bow lake watersheds in the Mississippi River alluvial plain. *Soil and Water Research*, 8: 113-123.

Lloyed, J. W.and Heathcote, J. A. (1985). Natural Inorganic Geochemistry Relation to Groundwater. Oxford Press.

Nagaraju A., Suresh S., Killkam K., and Hudson-Edwards K. (2006). Hydrogeochemistry of Water of Mangampeta Barite Mining Area, Cuddapah Basin, Andhra Pradesh, India. *Turkish Journal of Engineering and Environmental Science*, 30:203–219.

Nigeria Geological Surveys Agency (2006). Geological and Mineral Resources Map of Bauchi State. Published by the Authority of the Federal Republic of Nigeria.

NSDWQ (2015). Nigerian Standard for Drinking Water Quality. Approved By SON Governing Council.

Raghunath, H.M. (1987) Groundwater. Wiley Eastern Ltd., Delhi.

Rao, N. S., Subrahmanyam, A., Kumar S. R., Srinivasulu N., Rao G. B., Rao P. S. and Reddy G. V. (2012). Geochemistry and quality of groundwater of Gummanampadu sub-basin, Guntur district, Andhra Pradesh, India. *Environ Earth Sci.,* 67(5):1451–1471.

Saleem, M., Athar, H., Gauhar, M. and Mohd, W. (2018). Hydrogeochemical assessment of groundwater in shallow aquifer of greater Noida region, Uttar Pradesh (U.P), India. *Journal of Applied Water Science* (2018) 8:186 https://doi.org/10.1007/s13201-018-0828-1

Sawyer, G. N. and McCarthy, D. L. (1967). *Chemistry of Sanitary Engineers*, 2nd Ed., McGraw Hill, New York.

Schoeller, H. (1967). Geochemistry of Groundwater. An international Guide for Research and Practice, UNESCO, Chapter 15, pp 118.

Subba, Rao, N., Prakasa Rao, J., John Devadas, D., Srinivasa Rao, K. V., Krishna, C. and Nagamalleswara Rao, B. (2002). Hydrogeochemistry and Groundwater Quality in a

Developing Urban Environment of a Semi-Arid Region, Guntur, Andhra Pradesh. *India. Journal of the Geological Society of India*, 59: 159-166.

Tiri, A. and Boudoukha, H. (2010). Hydrochemical Analysis and Assessment of Surface Water Quality in Koudiat Medouar Reservoir, Algeria. *European Journal of Scientific Research*, 41(2):273–285.

Todd, D.K. (1980). *Groundwater hydrology*. Wiley, New York, pp 10–138

Trabelsi, R., Abid, K., Zouari, K., Yahyaoui, H. (2012). Groundwater salinization processes in shallow coastal aquifer of Djeffara plain of Medenine, South-eastern Tunisia. *Environmental Earth Sciences,* 66: 641-653.

USSL (United States Salinity Laboratory). (1954): Diagnosis and Improvement of Saline and Alkali Soils. Agricultural Handbook No. 60. USDA.

Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Rajiv-Gandhi, R., Chidambaram, S., Anandhan, P., Manivannan, R. and Vasudevan, S. (2010). Application of Water Quality Indices for Groundwater Quality Assessment. Thiru-manimuttar Sub-Basin, Tamilnadu, India. *Environmental Monitoring and Assessment*, 171: 595-609. http://dx.doi.org/10.1007/s10661-009-1302-1

Wilcox, L. V. (1948). Classification and Use of Irrigation Waters. U.S. Department of Agriculture, Washington DC, 962.

Wilcox, L. V. (1955). Classification and use of the Irrigation Waters, U.S. Department of Agriculture Circular No. 969, Washington, District of Columbia, 19 p.

Wilcox. L. V, (1962). The Quality of Water for Irrigation Use. US Department of Agriculture. Bulletin, 40.

World Health Organization (WHO) (2008). Guideline for Drinking Water Quality. 2nd Edition, Volume 2, Geneva, Health Criteria and Other Supporting Information, 940-949.