

PRELIMINARY ASSESSMENT OF THE QUALITY OF ASA RIVER WATER, NORTH CENTRAL NIGERIA: IMPLICATIONS FOR IRRIGATION

O. A. Omotoso^{*1}, O. J. Ojo², K. O. Olojoku¹, M. T. Alebiosu¹, M. A. Yusuf¹
O. O. Kobiowu¹

¹Department of Geology and Mineral Sciences, University of Ilorin, Ilorin, Nigeria

²Department of Geology, Federal University Oye-Ekiti, Nigeria

*deletoso2002@yahoo.co.uk; *+2348067780267 (Corresponding author)

Abstract

The preliminary assessment of quality of Asa river water, north central Nigeria was carried out using ICP-MS, AAS and volumetric analytical methods in order to assess its suitability for irrigation purposes. The relative abundance of cations and anions in the water samples are $\text{Ca}^{2+} > \text{Na}^+ > \text{K}^+ > \text{Mg}^{2+}$ and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ respectively and the dominant water type is Ca-HCO₃. Most of the range of values of irrigation parameters computed are within the recommended limits. SAR falls within excellent range of <10; MAR and SSP fall below recommended value of 50; PS falls below the recommended limit of 3 meq/l; KR falls below 1; RSC falls below 2.5 meq/l and CIA gives an indication of ionic base exchange between Ca, Mg, Na and K ions of the water and the rock types respectively. Under specific ion toxicity, Cl⁻, Na⁺ and Boron fall below recommended limits of 106 ppm, 69 ppm and 0.7 ppm respectively. However, the range of HCO₃⁻ in the water is from 0.59 to 2.69 meq/l (average=1.37 meq/l). About 50 % of the water samples (taken from the southern part of the river) is greater than 1.5 meq/l above the prescribed limit. Consequently, the range of pH recorded (range=7.3 to 8.8; average=8.0) cut across slight-moderate-severe according to the degree of restriction on use, making the water unfit for irrigation purposes. This can lead to reduction in the yields of plants/crops. Respective average values of Fe and Mn in the analyzed water (4.8 and 1.6 ppm respectively) are above FAO (1985) standard for irrigation water. Gibbs' diagram and correlation coefficients of the ions suggest the source of ions from chemical weathering of the aluminosilicate minerals (in the rock types and sediments in the study area), precipitation, leaching of secondary salts and anthropogenic influences from the catchment area. Hence, based on the values obtained for HCO₃⁻, pH, Mn and Fe, the water is unfit for irrigation practices.

Keywords: Asa River water, irrigation, weathering indications, irrigation water quality, Gibbs' diagram

1.0 Introduction

The practice of irrigation is a common phenomenon across the globe most especially in the developing world. Due to global warming, the annual rainfall has dropped drastically and thus really affecting all year-round cultivation of land for crop productions in some areas. Desert encroachment is on the increase. To worsen the situation the available surface water and groundwater are indiscriminately being contaminated as a result of industrial waste discharge, mechanized farming practices and uncontrolled urbanization to mention a few. Consequently, the yield of crops is somehow being affected adversely. Hence, there is the need to evaluate or assess the quality of irrigation water before its application. This research therefore presents the quality of Asa River water in north central Nigeria for irrigation practices.

The Study Area

The study area is situated within latitude $8^{\circ} 16' 45.97''$ E and $8^{\circ} 37' 40.2''$ N and longitude $4^{\circ} 16' 45.97''$ E and $4^{\circ} 53' 49.20''$ E (Ilorin Topographical Sheet 223 N.W). Various agricultural practices (like crop productions and fish farming- including fish ponds) and industrial activities are being carried out in the area. Figure 1 presents the location map of the study area showing the sampling points. The study area is established on the Precambrian Basement Complex Rocks comprising: granite, granite gneiss, banded gneiss and migmatites (Annor et al., 1996; Alao and Ige, 2003; Omotoso et al., 2011). Moreover, Omotoso et al., 2011 further reported that the gneisses are foliated with light and dark bands and the main minerals are suspected to be quartz, feldspar and mica as observed from the petrographic analysis of rock samples. Quartzite veins cut across one another as observed from the field mapping. Structurally, lineations, foliations, joints, fractures and folds are the main features observed on the rocks. Figure 2 presents the Geological map of Nigeria.

2.0 Methodology

Sampling of Water and Analysis

Water samples were randomly collected from designated points along the river by scooping with clean plastic container. Figure 1 shows the sampling points. Water samples were collected in January, 2017 at the peak of dry season. Random sampling method was used for water sampling because of limited accessibility to certain area along the river bank. The water samples for cation analysis were acidified with nitric acid to reduce the chemisorption of the metal ions into the surfaces and prevent their hydrolysis and precipitation. The water samples for anions analysis were not acidified with nitric acid. To prevent contamination from metallic containers, plastic containers were used for the water samplings. The temperature, Total Dissolved Solid (TDS), Hydrogen ion concentration (pH), Electrical Conductivity (EC) and Geographical Positioning System (GPS) measurements of the water samples were taken in-situ and the values recorded accordingly using thermometer, TDS meter, pH-meter and Electrical Conductivity meter (Hanna instruments) respectively. Water samples were taken to the laboratory and analyzed for cations and anions using ICP-MS, AAS and volumetric analytical methods respectively. AAS was used to analyze SO_4^{2-} , and volumetric analytical method was used to analyze HCO_3^- , and CO_3^{2-} . In addition, some rock and sediment samples were taken to compute their weathering indications on the water phase.

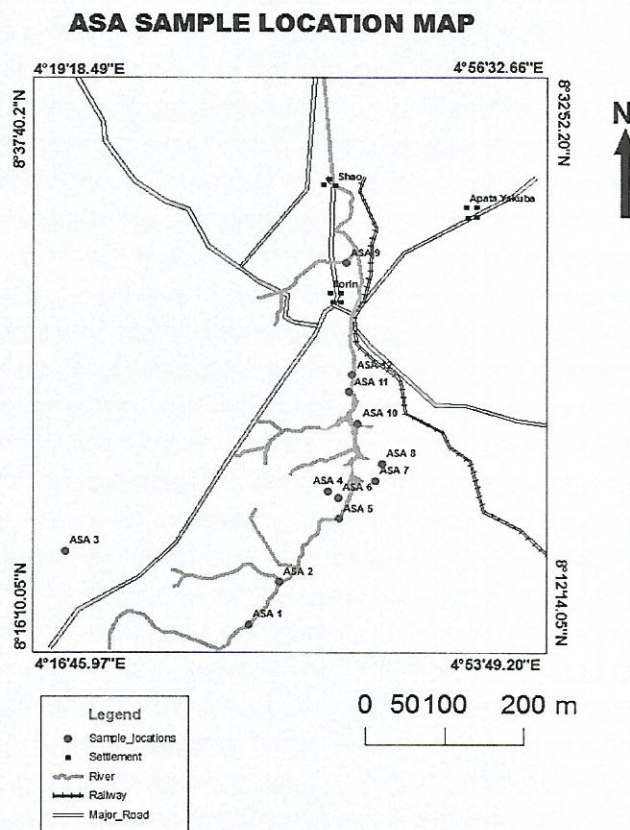


Fig. 1: Location map of the study area showing sampling points

Data Evaluation

As part of data evaluation, statistical summary and correlation analysis were used to establish the interrelationship between the parameters. The following parameters: Total Hardness (TH), Sodium Adsorption Ratio (SAR), Sodium Percentage (SP), Residual Sodium Carbonate (RSC), Magnesium Adsorption Ratio (MAR), Kelly Ratio (KR), Permeability Indices (PI), Potential Salinity (PS) and Chloro-alkaline Indices 1 and 2 (CAI-I, II), were calculated for the water samples as follows;

Sodium Adsorption Ratio (SAR):

SAR was calculated using the following equation given by Richard (1954) as:

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

(Concentrations are in meq/l)

Percentage Sodium (SSP)

The soluble sodium percentage was also calculated by the following equation (Todd, 1995):

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} * 100$$

(Concentrations are in meq/l)

Residual Sodium Carbonate (RSC)

RSC was calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose (Aghazadeh and Mogaddam, 2010) and is determined from the following equation:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

(Concentrations are in mq/l)

Magnesium Adsorption Ratio (MAR):

MAR was calculated using the following equation (Raghunath, 1987):

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100$$

(Concentrations are in meq/l). Values < 50 is generally considered suitable for irrigation purposes while values > 50 is regarded as unsuitable.

Kelly Ratio (KR):

The Kelly's Ratio was determined by employing the following equation (Kelly, 1963) as:

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

(Concentrations are in meq/l). Values > 1 is considered unsuitable for irrigation purposes while values < 1 is considered suitable.

Potential Salinity: This is determined using: $PS = Cl^- + (SQR(SO_4^{2-}))$

(Concentrations are in meq/l; $PS < 3$ meq/l is suitable for irrigation water-Donnen, 1964).

Weathering Indications

Some rock and sediment samples from the study area were subjected into geochemical analysis in order to compute their weathering indications to delineate the effect of weathering on the water phase. The weathering indications of rocks and sediments of the study area were computed using Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA) and Chemical Index of Weathering (CIW) as suggested by Nesbitt and Young (1982) having their respective formula as follows: $CIA = [Al_2O_3 * 100 / (Al_2O_3 + CaO + Na_2O + K_2O)]$, $PIA = (Al_2O_3 - K_2O) / (Al_2O_3 + CaO + Na_2O - K_2O) * 100$ and $CIW = (Al_2O_3 / (Al_2O_3 + CaO + Na_2O)) * 100$. The CaO was assumed to be derived from silicate fraction since carbonate and apatite were negligible. Fresh rocks or minerals such as albite, anorthite or K-feldspars have CIA up to 50%, fresh basalts have between 30 and 45% while granite and granodiorites range from 45 to 55% and fresh muscovite having values up to 75%. The clay minerals which are weathered products of fresh rocks have higher values, illites and montmorillonites have a range from 75 to 85%, kaolinites have up to 100% (Nesbitt and Young, 1982).

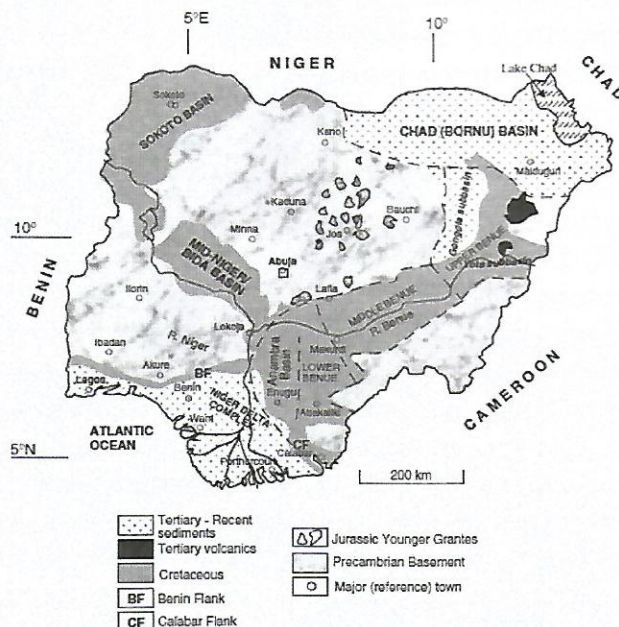


Fig. 2: Geological map of Nigeria showing study location (After Obaje, 2009)

3.0 Results and Discussion

Compositions of Major Ions

Table 1 presents the descriptive summary of the major ions in the water of the study area. The process of weathering really contributes some ions into the water phase (surface water or groundwater) thereby increasing the concentration of ions in the water phase (Naseem et al., 2010). Geological lithologies, water-rock interaction and relative mobility of ions are the main factors controlling the geochemistry of both surface water and groundwater (Yousef et al., 2009; Naseem et al., 2010). The geochemistry of surface water can be discussed by means of its major ions. On the average, the relative abundance of ions in the study area in ppm is $\text{Ca}^{2+} > \text{Na}^+ > \text{K}^+ > \text{Mg}^{2+}$ and $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ for cations and anions respectively. The relative higher values for bicarbonate could be as a result of industrial estates in the area in which carbon dioxide combines with atmospheric moisture to produce weak carbonic acid (acid rain) and the acid rain reacting with aluminosilicate feldspars mineral in granite gneiss forming bicarbonate ions. More so, the various agricultural practices in the area (bush burning, fertilizer applications, manuring etc.) also relatively increase the Ca ions in the water.

Na⁺ and K⁺

The Na ion concentration in the studied water samples ranged from 6.13 to 18.5 ppm (average= 10.3 ppm) fall within the permissible limit for agricultural purpose (irrigation in particular). Relative to Na ions, K ions has a lower average value of 5.1 ppm (range=1.56 to 14.26 ppm) and the K/Na ratio is 0.5. The relatively lower average value in the water phase suggests that K ions are also sourced from weathering of granitic rocks in the area as supported by the low correlation matrix with HCO_3^- (0.41). The strong correlation matrix between Na and Cl (0.74) suggest contributions from various anthropogenic activities in the study area (fertilizer applications, discharge from the industries, municipal wastes, animal and human wastes, etc.) and this is supported by the average value of Na/Cl (2.0) as well as that of K/Na (0.5).

Ca²⁺ and Mg²⁺

The Ca and Mg ions are very significant in appraising the magnitude of sea water contribution. The high Ca/Mg ratio (3.2) is a clear indication that there is no evidence of sea water intrusion in the study area (Hem, 1989; Naseem et al., 2010). The estimated average value of Ca/Mg ratio is 3.2 depicting complexity in their sources due to interaction with rocks and the climate of the study area (Naseem et al., 2010). Ca and Mg ions in the water samples ranged from 7 to 24.6 ppm (average=12.3 ppm) and 2 to 8.4 ppm (average=3.9 ppm) respectively. Naseem et al., 2010 reported that Ham and Liu (2004) used the variation in the composition of water (Mg/Ca versus Na/Ca) to distinguish limestone, dolomite and silicate rock sources of ions. The average values of Na/Ca and Mg/Ca (molar ratios) are 0.9 and 0.3 respectively showing their plots on the igneous rocks zone (i.e. Mg/Ca falls within range of 0.5 and 10; Na/Ca falls within the range of 0.1 and 10 according to Han and Liu, 2004). The correlation values between Na/Ca and Mg/Ca (0.8 and 1 respectively) also support same sources of ions.

Chloride ions

Chloride ion of about 70 ppm is required safe for crop production. However, it causes severe problem in crops at concentration > 350 ppm (Hopkins et al., 2007; Naseem et al., 2010). It has been reported that basaltic aquifer has higher Na/Cl molar ratio in contrast to typical rainfall values of 0.8 (Langmuir, 1997). The studied samples have value ranging from 1.1 to 3.0, suggesting some Na ions are derived from Na- bearing rocks or exchange with Ca ions. Also, surface or groundwater having values of HCO₃⁻ greater than that of Cl ions is an indication of natural water with no influx of pollution (Gholami and Srikantaswamy, 2009; Naseem et al., 2009). The ratio of HCO₃/Cl in the study water samples (8 to 36) depicts practically no contamination with Cl ions. A weak correlation matrix of HCO₃/Cl (0.4) has been established depicting weak relationship between the two ions. This also suggests that HCO₃ is from weathering of granitic rocks from the area of study and Chloride ions from various anthropogenic activities from the area same area of study. The range of Cl ions in the water samples of the study area is from 3 to 13 ppm (average= 5.5 ppm) far below the permissible limit making the water suitable for irrigation purposes.

Hydrochemical Facies and Water Type Determinations

The changes in hydro-geochemical phases of Asa river water, north central Nigeria was interpreted using various standard methods. The hydrochemical evolution of the river water can be understood by plotting the major cations and anions in the Piper Trilinear Diagram. The hydrochemical evolution can be described from the Piper plot, which has been divided into six sub categories viz. I: (Ca-HCO₃ type); II: (Na-Cl type); III: (Mixed Ca-Na-HCO₃ type); IV: (Mixed Ca-Mg-Cl type); V: (Ca-Cl type) and VI: (Na-HCO₃ type). The Piper diagram created for the Asa river area using the analytical data obtained from the hydrochemical analysis shows that the present study area is confined to the type 1(Ca-HCO₃). The values obtained from the Piper's plot reveals that the dominant cation is Ca²⁺, while the dominant anion is HCO₃⁻. Hence, the dominant hydrochemical facie of the sampled water is the Ca-HCO₃ facie (Figure 3). According to schoeller plot Ca²⁺ is the dominant cation while HCO₃⁻ is the dominant anion (Fig 4). The Stiff's pattern is used to determine the concentration of the dissolved ions as well as the types of ions present in the water samples. The shapes of the polygons are used to infer the extent of contamination of the water samples. The bigger the shapes of each plotted sample, the higher the concentrations indicating extent of water contamination/pollution. The result of the Stiff's pattern for the analyzed water samples indicates that Na⁺ + K⁺ and Ca²⁺ are the

dominant cations in all the samples. The dominant anions are the $\text{HCO}_3^- + \text{CO}_3^{2-}$. The shapes formed by the graph vary for all the water samples. The larger sized samples such as ASA 1, ASA 2, and ASA 3 denote higher amount of contamination while the smaller sized samples indicate lesser amount of contamination. Hence, the most suitable water samples recommendable for agricultural practices according to the Stiff pattern are samples ASA 4, ASA 6, ASA 7, ASA 10 and ASA 11 respectively (Figure 5). The Durov Diagram for the major cations and anions was plotted using Rockworks software as given in Figure 6. The plot indicates that most of the samples are in the reverse ion exchange phase, with few of the samples in the phase of mixing dissolution. It also indicates that HCO_3^- and $\text{Na}^+ + \text{K}^+$ are the dominant ions in the hydrochemical series and that the water is devoid of contamination/pollution.

Quality Evaluation for Irrigation Purposes

The suitability of surface water (e.g. lake, rivers, stream etc..) for irrigation purposes depends upon the effect of mineral constituents of water on both plants and soils irrigation (Ayers and Wascot; 1985; Singh et al., 2011). Table 1 presents the computed descriptive summary of irrigation water quality parameters in the study area. The parameters discussed below are important in assessing the suitability of water for irrigation purposes.

Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio (SAR) is considered a better measure of sodium (alkali) hazard in irrigation as SAR of water is directly related to the adsorption of sodium by soil/sediment and is a valuable criterion for determining the suitability of the water for irrigation. Excessive sodium content relative to the calcium and magnesium may deteriorate the soil/sediment characteristics, thereby reducing the soil permeability and inhibiting the supply of water needed for the crops. Na or alkali hazard could be expressed in terms of Sodium Adsorption Ratio (Gholami and Srikantaswamy, 2009; Naseem et al., 2010). The value of $\text{SAR} < 10$ is classified as excellent for irrigation water; values ranging from 10 to 28 classified as moderate and values > 28 are hazardous. In the present study area, the SAR values ranged from 0.49 to 1.2 (average=0.65) indicating the suitability of the water for irrigation in the area. Furthermore, the total concentration of soluble salts in irrigation water can also be expressed as low ($\text{EC} = < 250 \mu\text{S/cm}$), medium ($250 - 750 \mu\text{S/cm}$), high ($750 - 2250 \mu\text{S/cm}$) and very high ($> 2250 \mu\text{S/cm}$) and also classified as C-1, C-2, C-3 and C-4 salinity zone respectively (Richard, 1954; Singh et al., 2011). A high salt concentration (high EC) in water leads to formation of saline soil and a high sodium concentration results in the development of an alkaline soil. The plot of data on the United States salinity diagram (Figure 7) in which the EC is taken as salinity hazard shows that most of the water samples fall in the categories C1S1 and C2S1. This makes the water suitable for irrigation purposes.

Magnesium Adsorption Ratio (MAR)

It has been reported that in natural waters, Mg^{2+} in equilibrium state will definitely affect crop yields adversely (Nagaraju et al., 2006; Naseem et al., 2010). The MAR values above 50 is considered very harmful and unsuitable for irrigation purposes. In the analyzed water samples, the computed MAR values ranged from 30.6 to 36.8 (average=34.2) indicating the suitability of the water for the purpose of irrigation.

Soluble Sodium Percent (SSP)

Methods of Richards (1954) and Wilcox (1955) were adopted to classify and understand the basic character of the chemical composition of water, since, the suitability of the water for irrigation depends on the mineralization of water and its effect on plants and soil. Electrical conductivity and sodium concentration are very crucial parameters in the classifications of irrigation water. Water used for irrigation usually contains measurable quantity of dissolved substances such as salts originating from weathering of rocks, soils and anthropogenic activities. The salts affect the growth of plants, soil structures, permeability and aeration which eventually affect plant growth (Thorne and Peterson 1954; Ramesh and Elango 2011). The plot of analytical data on Wilcox (1955) diagram relating electrical conductivity to sodium percent shows that all the samples fall within excellent to good zone and this makes the water fit for irrigation without posing any problem to plants/crops yields.

Residual Sodium Carbonate (RSC)

RSC is a very useful parameter that has a great influence on the suitability of irrigation water (Bokhari et al., 1992; Naseem et al., 2010). It significantly influences the pH, EC and SAR of irrigation water. High concentration of RSC leads to an increase in adsorption of sodium on soil and also causes soil structure to deteriorate as it restricts water and air movement through soil. More so, excess sum of carbonate and bicarbonate in water over the sum of calcium and magnesium influences the suitability of water for irrigation. Waters having high concentration of bicarbonate, there is tendency for calcium and magnesium ions to precipitate as the water in the soil becomes more concentrated (Karanth, 1987; Singh et al., 2011). However, an excess quantity of sodium bicarbonate and carbonate is considered to be detrimental to the physical properties of soils as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate and this excess is denoted by Residual Sodium Carbonate (RSC).

In the study area, RSC ranged from 0.06 to 1.24 meq/l (average=0.42 meq/l) which is below the recommended limit of <1.25 meq/l. Hence, the water is fit for irrigation purposes on the basis of RSC

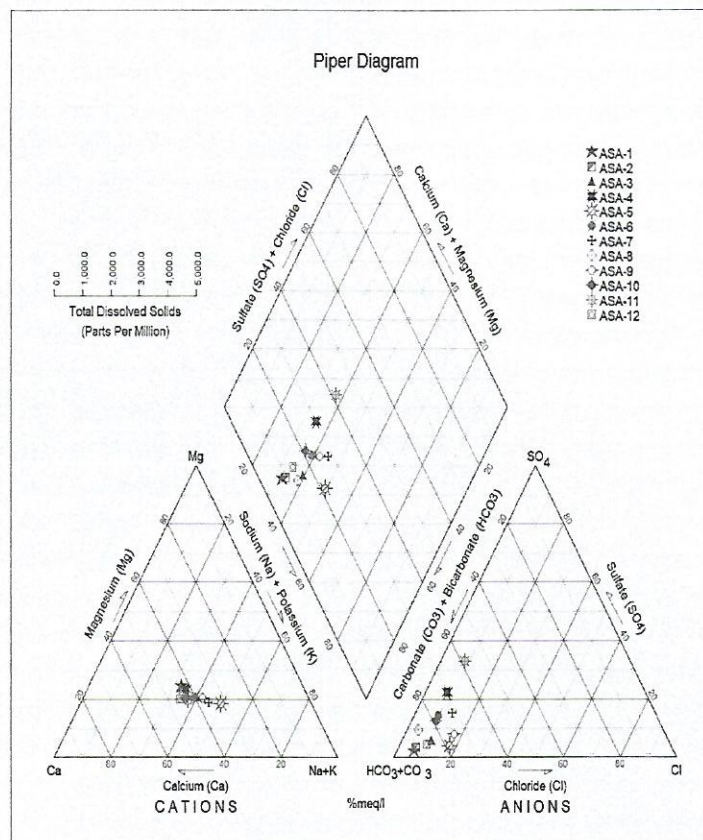


Figure 3: Piper Diagram for the analyzed samples

Total Dissolved Solids (TDS)

Salts of calcium, magnesium, sodium and potassium available in irrigation water may likely pose injury to plants (Obiefuna and Sheriff, 2011; Ishaku et al., 2011). Consequently, salts from the major ions when present in excess amounts may influence the osmotic activities of the plants and may also prevent adequate aeration. In the studied water samples, TDS ranged from 40 to 150 ppm (average=78.3 ppm). Most of the samples fall below recommended limit of 150 ppm, making the water suitable for irrigation purpose.

Kelly's Ratio (KR)

Naseem et al., 2010 reported that Kelly (1940) and Paliwal (1967) introduced an important parameter to evaluate irrigation water quality based on the level of Na ions measured against Ca and Mg ions. Water having Kelly's Ratio values <1 is suitable for irrigation while values >1 is considered unfit for irrigation purposes. In the studied water samples, KR ranged from 0.4 to 0.89 (average=0.5) indicating the good quality of the water for irrigation purposes.

Potential Salinity

The dissolved salts in irrigation water lead to several challenges to growers. Generally, salts reduce the osmotic potential of water, increases the energy that plants use to extract moisture from the soil/sediments and to worsen the case, making them more susceptible to wilting. Hence, there is the need to determine the Potential Salinity of irrigation water. The Potential Salinity computed for the water samples from the study area ranged from 0.29 to 0.79 meq/l (average=0.53 meq/l) which far below the prescribed limit making the water suitable for irrigation purposes.

Specific Ion Toxicity

It has been reported that certain ions alone, either as a result of their direct toxicity to plants or through their effect on water and soil chemistry, can be indicators of irrigation water quality. Examples of substances sometimes found in concentrations in water that are toxic to trees and shrubs include Na^+ , Cl^- and B. Values greater than 69 ppm, 106 ppm and 0.7 ppm for Sodium ion, Chloride and Boron respectively, have restriction on use as irrigation water. In the studied water samples, Na^+ , Cl^- and B ranged from 6.13 to 18.5 ppm (average=10.3 ppm); 3 to 13 ppm (average=5.5 ppm); and 0.008 to 0.012 ppm (average=0.009 ppm) respectively. All of the ions fall below the recommended limit making the water fit for irrigation purposes. HCO_3^- is another specific ion toxicity useful in determining the quality of irrigation water. Value greater than 1.5 meq/l has restriction on use as irrigation water (FAO, 1985). High concentration of carbonate and bicarbonate in water increases SAR index. When bicarbonate and carbonate ions react with calcium or magnesium they will precipitate as calcium carbonate (CaCO_3) or magnesium carbonate (MgCO_3) when the soil solution concentrates in drying conditions. The concentration of Ca and Mg ions decreases relative to sodium ions and the SAR index will be bigger. This could likely cause an alkalizing effect and an increase in pH. Consequently, when a water analysis indicates high pH level, it may be a sign of a high content of carbonate and bicarbonates ions (Lenntech, 2017).

In the studied water samples, HCO_3^- ranged from 0.59 to 2.69 meq/l (average=1.37). about 50 % of the water samples have more than 1.5 meq/l most especially at the southern part of the river where agricultural practices are prominent. But on the average, over 50 % have HCO_3^- values less than 1.5 meq/l. The relatively high concentration of HCO_3^- in some of the samples may be as a result of weathering of aluminosilicate minerals into the water system as also supported by the Gibbs diagram. High concentration of HCO_3^- reduces the yields of plants/crops and can also clog the nozzles of pesticide sprayers and drip tube irrigation systems with obvious effects. In addition, the activity of some pesticides, floral preservatives, and growth regulators is drastically reduced by high alkalinity (Mattson, 1995).

Hydrogen Ion Concentration (pH)

pH is one of the parameters used in assessing the quality of irrigation water. Water with $\text{pH} < 7.0$ has restriction on use as irrigation water; water > 7.0 has slight-moderate-severe degree of restriction on use as irrigation water. In the study area, the pH of the water samples collected and analyzed ranged from 7.3 to 8.8 (average=8.0). however, the recorded pH values indicate that the water samples have some restrictions on use based on the elevated pH values. The high pH values is as a result of relatively high concentration of HCO_3^- in Asa river water which is brought about by the weathering of aluminosilicate minerals into the water system.

Chloro-Alkaline Indices (CAI)

It is essential to know the changes in the chemistry of water as it travels from one formation to another. CAI is a very important parameter which can be used to predict such behavior. Positive CAI values suggests substitution of Na and K ions in the water for Mg and Ca ions from the surrounding rocks through Base Exchange Reaction. CIA is negative when there is an exchange of Mg and Ca ions of the water with Na and K ions of the rock (Ishaku et al., 2011; Nagaraju et al., 2006; Omotoso and Ojo 2012). All the

studied water samples show negative CAI values suggesting that there has been an exchange of Mg and Ca ions of the water with Na and K ions of the country rock.

Iron and Manganese

Fe and Mn are part of the parameters to be considered in irrigation water (FAO, 1985). An irrigation water with Mn and Fe concentrations of > 1.5 ppm is severe and could pose a potential problem in irrigation practices. In the studied water, Fe and Mn ranged from 0.6 to 15 ppm (average=4.8 ppm) and 0.1 to 6.3 ppm (average=1.61 ppm) respectively. The average concentrations of these metals/elements in the studied water samples are above the recommended limits and are therefore a threat for irrigation practices in the area.

Source of Dissolved Ion and Weathering Indications

Gibbs diagram can be adopted to deduce the source of dissolved ions in the water. It is a plot of the total dissolved solids (TDS) against the cations and the anions respectively. It is used to predict the relationship between water composition and aquifer lithological characteristics (Gibbs, 1970). The three distinct fields of the Gibb's plot are; the precipitation dominance, evaporation dominance and rock dominance. The rock dominance field indicates the interaction between the rock chemistry and the chemistry of the percolating waters under the subsurface. Figure 9 present the sources of cations and anions in the sampled water respectively. Most the plotted ions fall within the rock dominance and precipitation dominance zones. This depicts the influence of chemical weathering and precipitations on the chemistry of the water in the study area. The correlation matrix of the ions in the water is presented in Table 2. Significant correlation of HCO_3^- with Ca (0.86), K (0.41), Mg (0.86), Na (0.79), shows chemical weathering in the rock types of the area. Cl^- and HCO_3^- show significant correlation with Ca, Mg, Na and K and this indicates the predominance of chemical weathering along with leaching of secondary salts (Prasanna et al., 2010). HCO_3^- shows good correlation to poor correlation with Na and K indicates weathering of potash feldspar. TDS shows good correlation with Ca^{2+} , K^+ , Mg^{2+} , Na^+ , HCO_3^- , Cl^- , SO_4^{2-} which indicate chemical weathering, leaching of secondary salts, and anthropogenic influences (Prasanna et al., 2010). Boron has moderate to good correlation with Ca^{2+} , K^+ , Mg^{2+} , Na^+ , HCO_3^- , Cl^- and TDS and this denotes chemical weathering of rock types, leaching of secondary salts and influence of anthropogenic activities in the area of study. The computed average Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA) and Chemical Index of Weathering (CIW) of rocks and sediments obtained during the research in the study area are: 62:63, 65:74 and 68:81 respectively. This shows that the rock and sediments in the study area have undergone intensive chemical weathering and the reflection of this is observed on the water phase. Some of the plagioclase in the rocks and sediments have been weathered and this has been dissolved into the water phase.

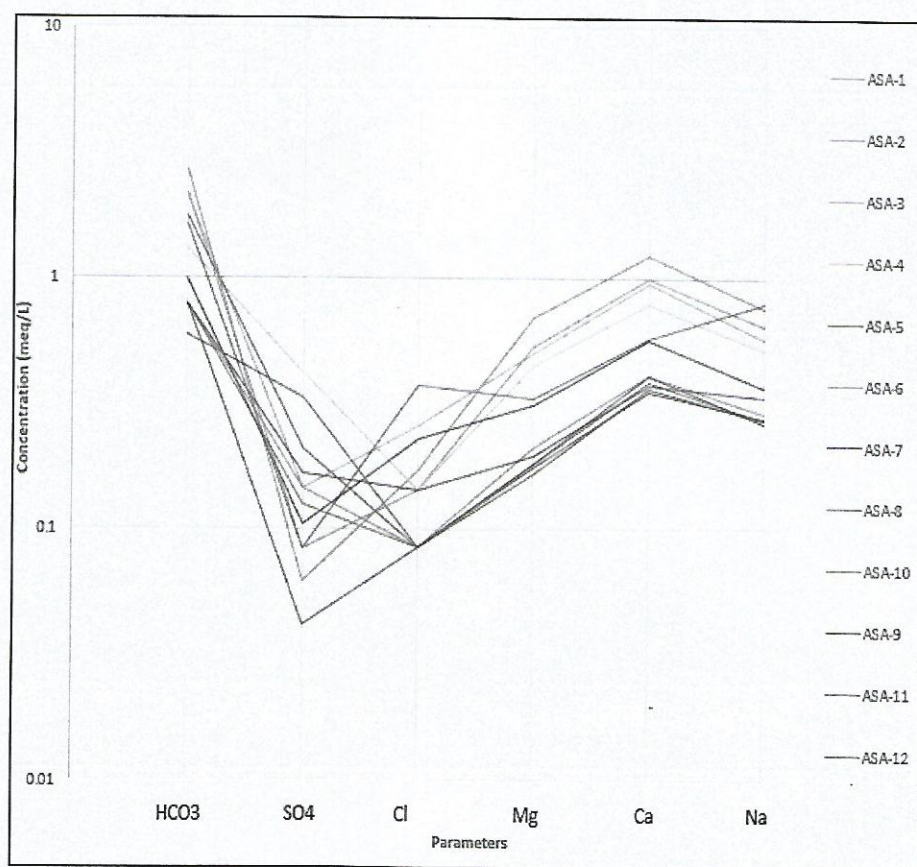
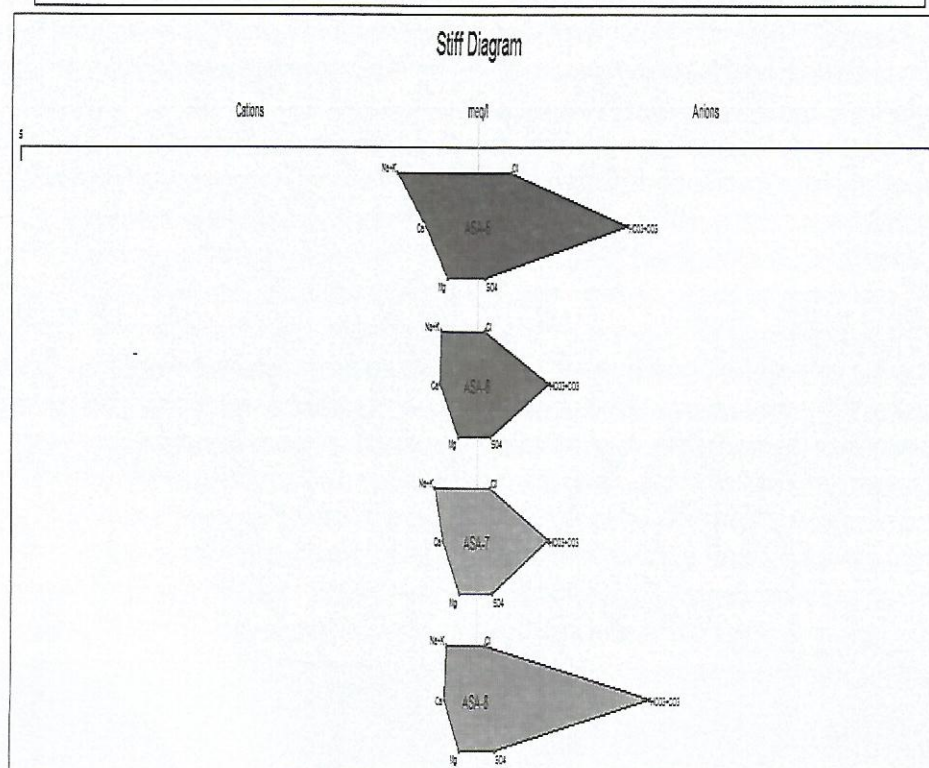
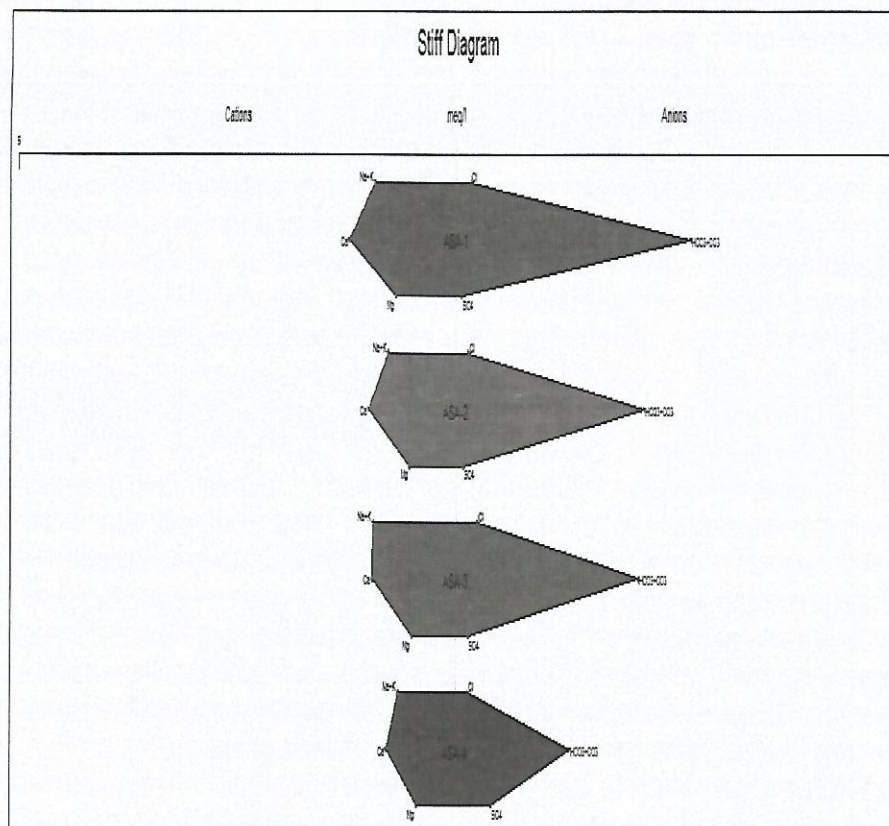


Fig. 4: Schoeller Diagram for the water samples



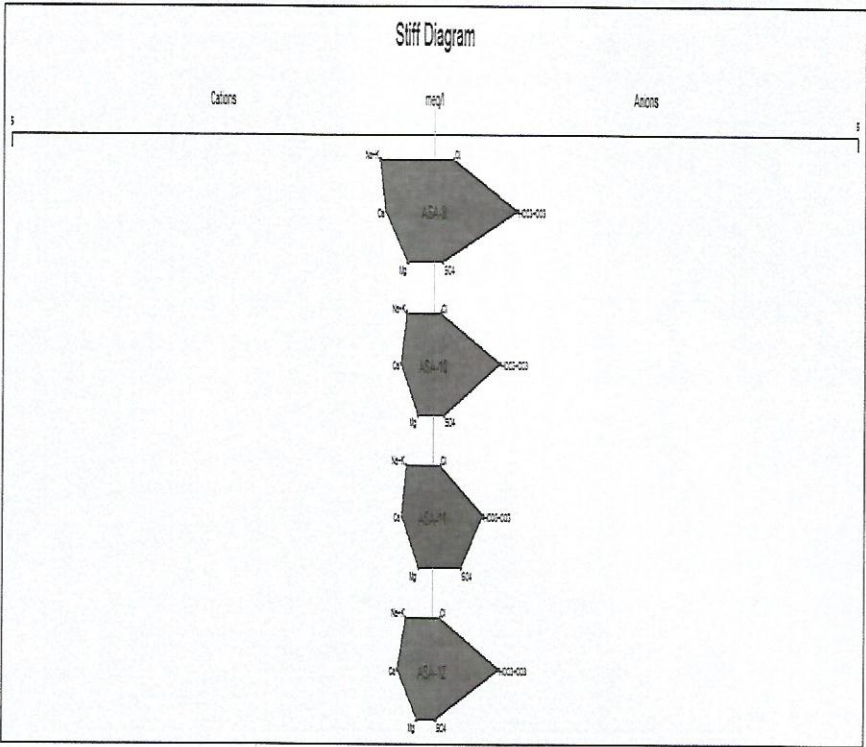


Fig 5: Stiff diagram for the analyzed samples

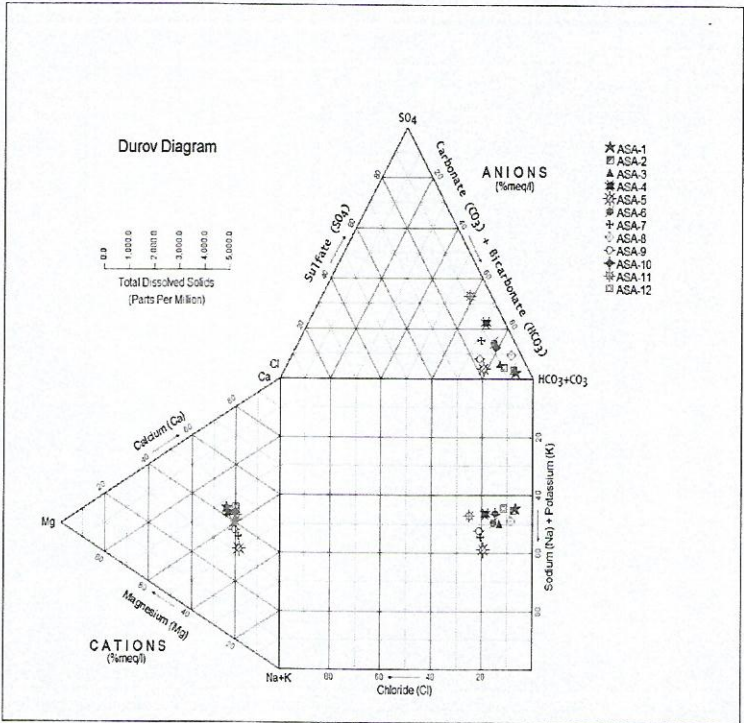


Fig 6: Durov diagram for the analyzed samples

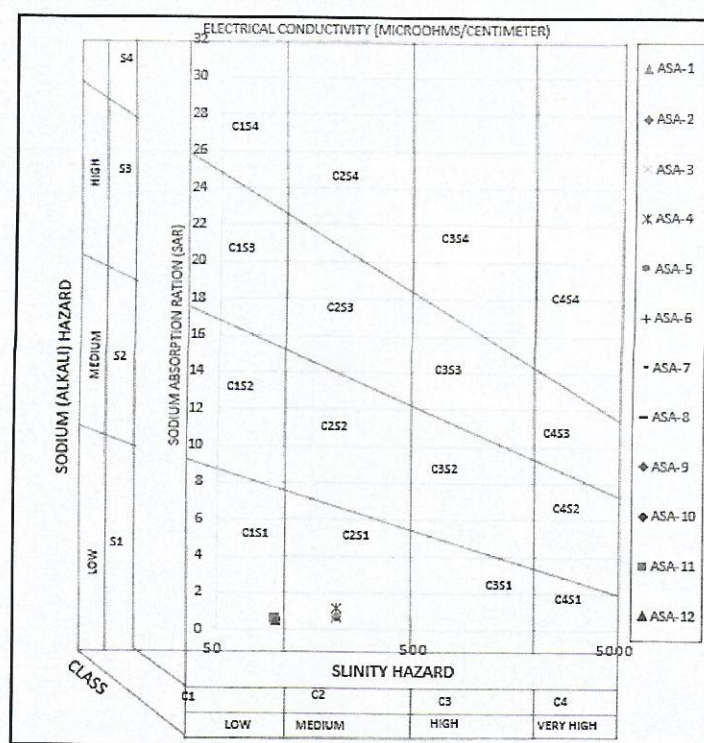


Fig. 7: US salinity diagram for classification of irrigation waters (after Richards, 1954)

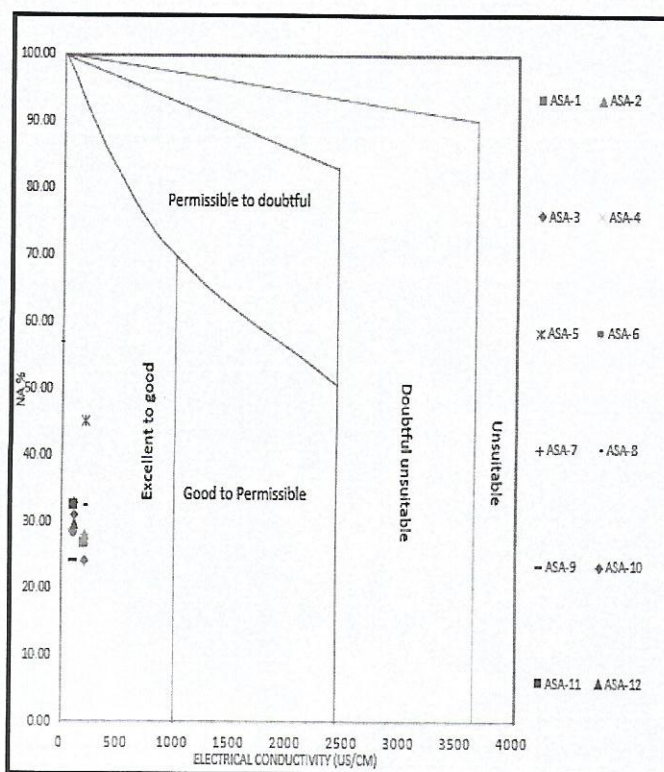


Fig.8: Plot of sodium percent Vs electrical conductivity (after Wilcox, 1955)

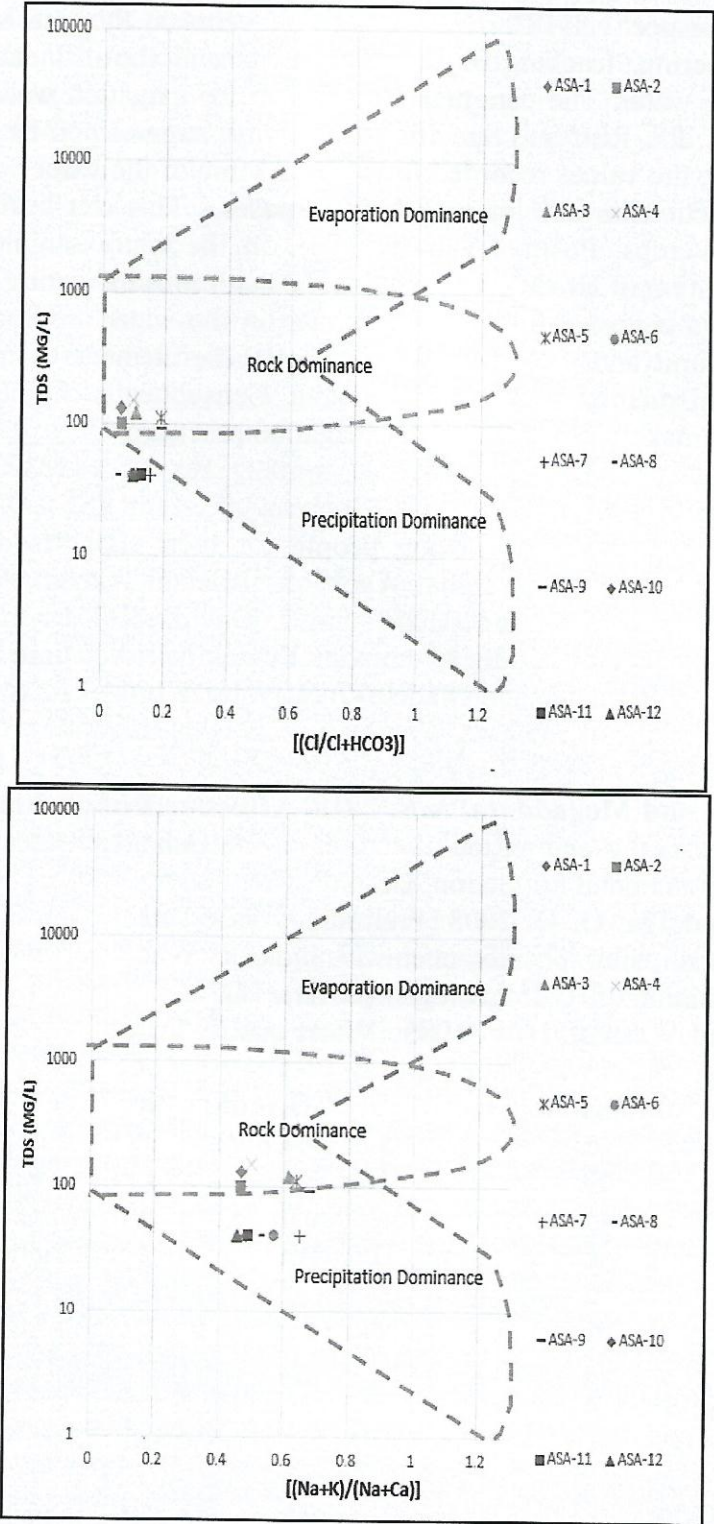


Fig. 9: Mechanism governing surface water chemistry (Gibbs, 1970)

4.0 Conclusions

The Asa river water was evaluated for its suitability for irrigation purposes. The hydrochemistry displays $Ca^{2+} > Na^{+} > K^{+} > Mg^{2+}$ and $HCO_3^{-} > SO_4^{2-} > Cl^{-}$ trend respectively for cations and anions. The dominant hydrochemical facies of the water is Ca-HCO₃ water type. In the Gibbs' diagram, the ions fall within the category of rock and precipitation dominance depicting the sources of ions from both weathering of aluminosilicate minerals from granite-gneiss and contributions from precipitations within

the study area respectively. Correlation analysis between the ions shows the impact of chemical weathering, leaching of secondary salts and the influence of anthropogenic activities on the water. The parameters computed for irrigation water quality (i.e. SAR, MAR, SSP, KR, PS, RSC and Specific ion toxicity) suggest non-hazardous effect of the water. However, the values recorded for pH and some of the values of HCO_3^- pose some degree of restriction on use for irrigation purposes. This can lead to reduction in the yields of plants/crops. Positive value of RSC in the water samples signify relatively higher concentration of HCO_3^- over the alkaline earth ions indicating ionic base exchange process. Average concentrations of Fe and Mn in the water are above the FAO (1985) recommended limit and the elevated values of these elements could cause a potential problem on the irrigation practices in the area. Consequently, higher values of HCO_3^- , pH, Mn, and Fe make the water unfit for irrigation practices.

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Table 1: Descriptive summary of the major ions and the irrigation water parameters

	AVERAGE	MIN	MAX	SDV	VAR	MEDIAN
Parameters						
Ca ²⁺ (ppm)	12.34	7.01	24.55	6.05	36.57	9.8
K ⁺ (ppm)	5.1	1.56	14.26	3.89	15.15	4.62
Mg ²⁺ (ppm)	3.95	2	8.39	2.14	4.58	3.15
Na ⁺ (ppm)	10.32	6.13	18.5	4.67	21.84	8.08
CO ₃ ²⁻ (ppm)	0	0	0	0	0	0
HCO ₃ ⁻ (ppm)	83.33	36	164	42.15	1776.97	70
Cl ⁻ (ppm)	5.5	3	13	3.12	9.73	5
SO ₄ ²⁻ (ppm)	7.67	2	20	5.38	28.97	6.5
Fe, ppm	4.80	0.58	15.02	5.14	26.40	2.30
Mn, ppm	1.61	0.05	6.26	1.88	3.52	0.94
TDS, ppm	78.33	40	150	42.6	1815.15	65
pH	7.98	7.3	8.8	0.5	0.25	7.85
SAR	0.65	0.49	1.2	0.2	0.04	0.59
SSP	38.48	32.62	49.43	4.98	24.8	37.85
MAR	34.17	30.63	36.75	1.94	3.75	34.43
PS (meq/l)	0.53	0.29	0.79	0.14	0.02	0.54
KR	0.5	0.4	0.89	0.14	0.02	0.46
EC, μ S/cm	150	100	200	52.22	2727.27	150
RSC, meq/l	0.42	0.06	1.24	0.37	0.14	0.22
Cl ⁻ (meq/l)	0.15	0.08	0.37	0.09	0.01	0.14
Na ⁺ (meq/l)	0.45	0.27	0.8	0.2	0.04	0.35
HCO ₃ ⁻ (meq/l)	1.37	0.59	2.69	0.69	0.48	1.15
B, ppm	0.0093	0.008	0.012	0.0014	0.0000021	0.009
CIA-1	-1.95	-3.02	-0.65	0.71	0.5	-1.74
CIA-2	-0.11	-0.17	-0.05	0.03	0.0011	-0.11

Table 2: Correlation Matrix of some of the measured parameters

Parameters (ppm)	Ca	K	Mg	Na	HCO3	Cl	HCO3- ppm	SO4	TDS, Mg/L	B
Ca	1.00									
K	0.56	1.00								
Mg	1.00	0.56	1.00							
Na	0.80	0.34	0.83	1.00						
HCO3	0.86	0.41	0.86	0.79	1.00					
Cl	0.37	0.49	0.41	0.74	0.40	1.00				
HCO3- ppm	0.86	0.41	0.86	0.79	1.00	0.40	1.00			
SO4	-0.18	-0.12	-0.16	-0.25	-0.28	-0.27	-0.28	1.00		
TDS, Mg/L	0.84	0.56	0.86	0.82	0.68	0.61	0.68	0.11	1.00	
B	0.84	0.56	0.86	0.82	0.68	0.61	0.68	0.11	1.00	1.00

Parameters (ppm)	Ca	K	Mg	Na	HCO3	Cl	HCO3- ppm	SO4	TDS, Mg/L	B	Fe	Mn
Ca	1.00											
K	0.56	1.00										
Mg	1.00	0.56	1.00									
Na	0.80	0.34	0.83	1.00								
HCO3	0.86	0.41	0.86	0.79	1.00							
Cl	0.37	0.49	0.41	0.74	0.40	1.00						
HCO3- ppm	0.86	0.41	0.86	0.79	1.00	0.40	1.00					
SO4	-0.18	-0.12	-0.16	-0.25	-0.28	-0.27	-0.28	1.00				
TDS, Mg/L	0.84	0.56	0.86	0.82	0.68	0.61	0.68	0.11	1.00			
B	0.84	0.56	0.86	0.82	0.68	0.61	0.68	0.11	1.00	1.00		
Fe	0.17	0.67	0.20	0.18	-0.01	0.54	-0.01	0.27	0.57	0.57	1.00	
Mn	0.68	0.80	0.65	0.48	0.53	0.44	0.53	-0.04	0.67	0.67	0.52	1.00