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Water Quality Assessment of Jalingo Area, North-Eastern Nigeria

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ABSTRACT

Water of good quality for domestic, industrial and agricultural purposes is very essential to public health and overall wellbeing of the people. Domestic and agricultural activities are carried out within the study area without considering the geochemical and biological processes that occur in the groundwater zone. The water quality of Jalingo Area NE Nigeria was investigated with the aim of determining its suitability for domestic, industrial and agricultural purposes. A total of 50 water samples were collected from surface water and groundwater sources which were analysed using standard methods: Atomic Absorption spectrophotometry for cations and conventional titration for anions. The water was characterized employing chemical indicators such as pH, sulphate, chloride and nitrate and the results indicate that most groundwater samples and some surface water samples are largely suitable for human consumption. Most of the surface water samples revealed total coliform bacteria values above the international permissible limits whereas most of the groundwater samples indicate values that are less than the international permissible limits. The chemistry of the different water sources suggests that alkaline earths (Ca+Mg) significantly exceed the alkalis (Na+K), and weak acids (HCO_3+CO_3) exceed the strong acids (CI+SO_4) suggesting the dominance of CO_3 weathering followed by silicate weathering. Hydrogeochemical studies disclosed the Ca^{2+}-SO_4^{2-} , Ca^{2+}-CI^-, Na^+-HCO_3^- and Na^+-Cl^- as the dominant ion types for surface water samples and Na^+-HCO_3^{2-} and Ca^{2+}-HCO_3 as the major ions for groundwater samples. The homogenous composition of groundwater indicates a common origin and source whereas the non-homogenous composition of surface water samples reveals active groundwater mixing and significant water-rock interaction, the irrigation indices determined revealed 642 values of TDS (<421 mg/l), SAR (<10), EC (<750 µS/cm) and TH (<250 mg/l) obtained for most of the water sources are found to be within the safe permissible limits for irrigation. However, some samples which displayed values of MAR (> 50%), PI (<25%), KR (>1.00) and SSP (>75%) suggest salinity hazards and should be treated before use. The groundwater samples are generally slightly acidic, largely soft, with fairly low to moderate concentrations of dissolved solids that fall within the international limits for drinking domestic and irrigation. The concentration of nitrate in about 71% of the water samples is higher than the recommended limits of 0.3 mg/l and 10 mg/l respectively should be treated before use.

Keywords: Water quality, Irrigation indices, Aquifer units, Jalingo area NE Nigeria

INTRODUCTION

Groundwater is a natural resource found beneath the earth Surface in soil pore spaces and fractures of rock formations called aquifers. Geochemical processes occurring within the groundwater and reactions with dissolved minerals control groundwater quality. Groundwater quality may be affected by natural factors, such as geological and geochemical processes. Geogenic sources are one of the causes of the variations in chemical composition of groundwater which changes in space and time (Brindha and Elango, 2012; Kraiem *et al.,* 2013). The evaluation of groundwater resources for development requires an understanding of the hydrogeological and geochemical properties of an aquifer. Groundwater in its natural state is being renewed by different processes such as reaction with atmospheric gasses and minerals within the geological formations. Geochemical processes occurring within the groundwater and reactions with dissolved minerals have a profound effect on water quality. Groundwater quality may be affected by natural factors, such as geology and geochemical processes. It also depends on the parent rock, intensity of weathering, residence time and external factors such as precipitation and temperature. Hydrogeochemical processes, such as weathering, dissolution, mixing and ion exchange control the concentration of major and minor ions in groundwater (Zhu and Schwartz, 2011; Rajesh *et al.,* 2012; Ankidawa *et al*., 2019; Seli *et al*., 2019). Therefore, increased understanding of the chemical processes affecting groundwater chemistry in Jalingo area will give an insight into the hydrogeology of the area. Currently groundwater in the study area is intensively used for irrigation purposes and for other human activities such as industrial and domestic activities. Despite its importance little is known about the natural processes that govern the chemical composition of groundwater or the anthropogenic factors that presently affect them (Garcia *et al.,* 2001). This work therefore intends to assess and interpret the water quality of Jalingo area. Quddus and Zaman (1996) studied the irrigation water quality of some selected villages of Meherpur District of Bangladesh and argued that some of the following ions such as calcium, magnesium, sodium, bicarbonate, sulphate, chloride, potassium, boron and silica are more or less beneficial for crop growth and soil properties in little quantities. Sarkar and Hassan (2006) investigated the water quality of a groundwater basin in Bangladesh for irrigation purposes and observed that standard water quality indices such as pH, EC, SAR, RSBC, MAR, PI, KR and TDS are within the acceptable range for crop production. Raihan and Alam (2008) presented a pictorial representation of groundwater quality throughout the Sunamganj District that allowed for delineation of groundwater based on its suitability for irrigation purposes. Brindha and Elango (2012) and Kraiem *et al.* (2013) gave details of the geochemistry of fluoride rich groundwater in weathered granitic rocks of Southern India as well as geochemical characteristics of Arid Shallow Aquifers in Chott Southwestern Tunisia respectively. These geological, hydrological and water quality appraisal lacked in depth hydrogeochemical framework of the groundwater occurrence in Jalingo area. Therefore, a study of the water quality and hydrogeochemical framework of groundwater occurrences would present a better understanding of the chemical processes affecting Jalingo area and would give an insight into the hydraulic characteristics and distribution of the aquifers in the area for effective management and future development.

The Study Area

The study area is part of Jalingo Sheet 215 NE which falls largely within Jalingo Local Government Area of Taraba State, Northeastern Nigeria. It has an aerial extent of about 219 Km^2 and located within Latitudes 8° 52′N to 9° 00′ N and Longitudes of 11°18′ E to 11° 26′ E. The area is well linked by road networks such as the Yola-Jalingo Road, Jalingo-Wuro Sambe road, Jalingo-Kona Road, Jalingo-Sunkani road and Jalingo-Wuro Musa road. Prominent villages within the study area include Wuro-Musa, Wuro-Sambe, Wuro-Goffe, Pantinapu and Kona. There are numerous footpaths and tracks that provide access routes to the villages and hamlets (Figure 1). The study area is characterized by highlands and flat topography. The low-lying areas are characterized by patches of laterites and granitic outcrops. The northern and northeastern parts are characterized by chains of mountains with elevation ranging from 600m to 3000m above the sea level. Isolated outcrops of basement rocks are found in the northwestern part of the study area. The study area is drained by two major rivers such as Rivers Lamurde and Mayo-Goi with network of streams which are tributaries of these rivers (Figure 1). The study area falls within the sub-tropical region and has two main seasons. These are the wet season which runs between April and October and the dry season which lasts from November to March. These seasonal climatic conditions are controlled by the inter-tropical convergence zone (ITCZ). The mean monthly rainfall varied from 759mm to 859mm (TSMOI, 2015). The mean monthly temperature range between 27°C to 37°C (TSMOI, 2015).

The Geology of the Study Area

The study area is underlain by Basement Complex rocks which are Precambrian to Paleozoic in age. The major lithologic units are the Older Granites, the Undifferentiated Metasediments and the Migmatite-Gneiss Complex. In most of the area, the unconsolidated weathered overburden materials consisting of clays, sandy clays, laterites and sands cover these rocks. The unconsolidated weathered overburden materials are of two types namely: the alluvium and the alluvium. However, outcrops of Older Granites consisting of granites, granodiorites and pegmatites occur towards the eastern, southern and northern parts of the study area (Figure 2). The undifferentiated metasediments are also found in the study area whereas the Migmatite-Gneiss Complex rocks are found in Kona area in the northern part and Barkin Dutse in the southwestern parts of the study area. The rocks have been fractured due to tectonism resulting in the occurrence of fissures, joints, and faults zones. The fault zones trend in the NE-SW and N-S directions.

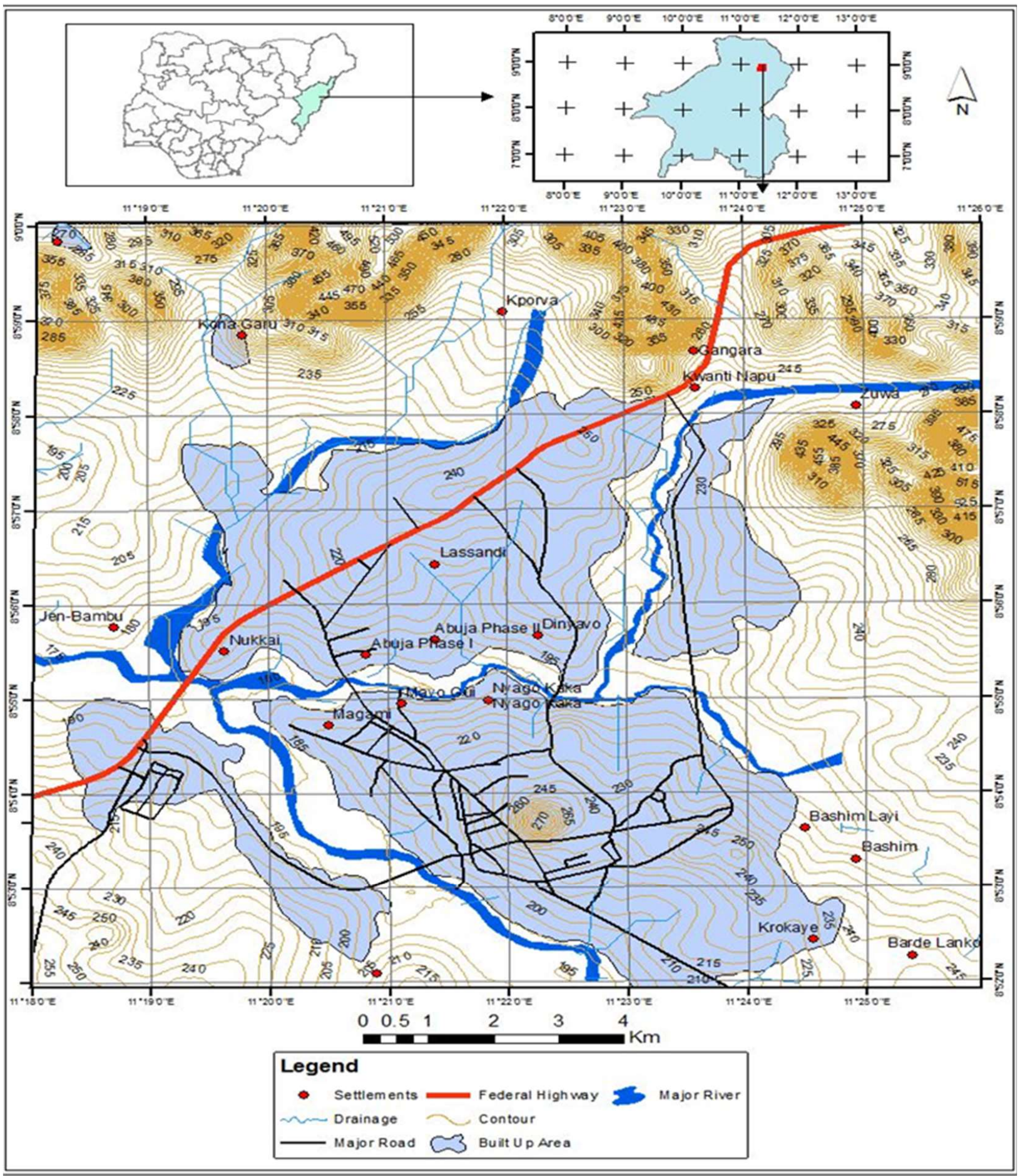

Figure 1: Topographical map of the study area

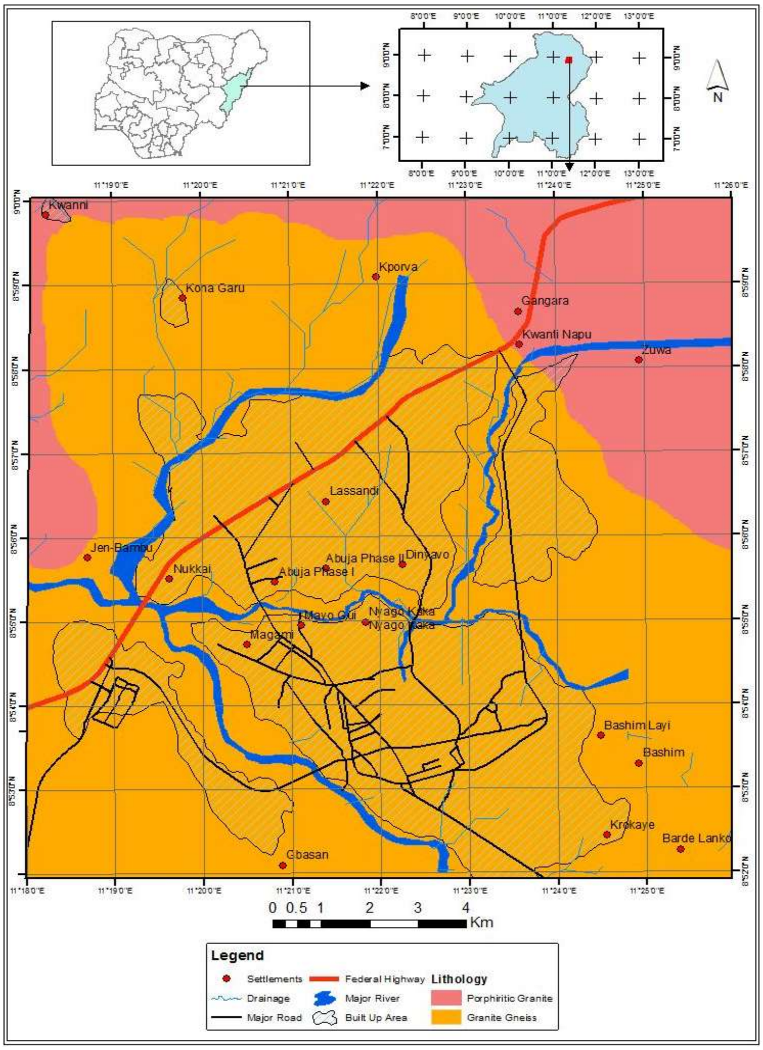

Figure 2: Geologic map of the Study Area

METHODOLOGY

Reconnaissance field trips were made during which the sources and causes of groundwater pollution were located and plotted on the map (Figure 3). Detailed measurement of physical parameters (characteristics) of the water samples at various locations within the study area in the field using the water quality monitoring kits called Horari WQ 431. A total of fifty (50) water samples were collected randomly which comprises hand dug wells, tube wells, boreholes (both motorized and hand pump) and surface waters. The samples were collected in a pre-washed polyethylene bottles (with detergents, dilute HNO_3 and doubly deionized distilled water respectively) for the chemical and the biological characteristic analysis at the "UNICEF" Laboratory in Jalingo, Taraba State of Northeastern Nigeria. The water samples collected in the study area were taken to the UNICEF Laboratory Jalingo, Taraba State Rural Water Supply and Sanitation Agency for chemical and biological analysis. The chemical and biological characteristics (parameters) were analyzed employing standard methods. Atomic Absorption Spectrophotometer model WQ 431 for anions and conventional titration for cations. The major cations analyzed included Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, Cu^{2+}, Fe^{2+}, Zn^{2+} and Mn^{2+} while the major anions measured included Cl^{-}, SO_4^{2-}, HCO_3^{-}, NO_3^{2}. These were analyzed by Spectrophotometer Model WQ 431. Ions measured in milligram/litre were converted to milliequivalent/litre and anions balanced against cations as a control check on the reliability of the analyses result. The biological parameters measured are Dissolved oxygen, Total Coliform Bacteria and Faecal Coliform Bacteria. The results of the measured parameters were compared with the Standard Organization of Nigeria (NWQS, 2007) and World Health Organization (WHO,2013) recommended limits to determine their suitability for domestic. Microbiological analyses of water samples were performed as described in standard methods for the examination of drinking water (WHO, 2013; APHA-AWWA, 2005). Total and faecal coliforms were determined by the most probable number per 100 ml sample using membrane filtration techniques (APHA-AWWA, 2005).

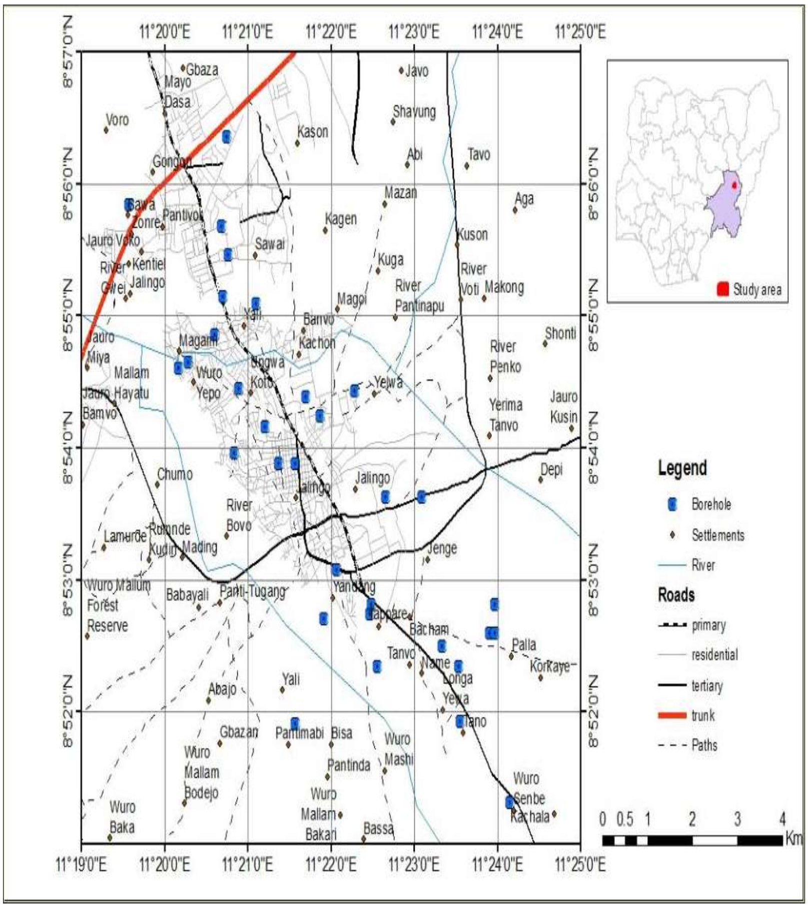

Figure 3: Map of the Study Area Showing Sample Locations

RESULTS AND DISCUSSION

Assessment of Groundwater Quality for domestic purposes

All the analysed parameters of the water samples of the study area with the exception of hydrogen ion concentration (pH) fall within the WHO (2013) recommended limits. Furthermore about 52.5% of these samples have pH values that are within the WHO (2013) recommended limits of between 6.5 and 8.5. These indicate that the samples are largely potable for human consumption and other domestic purposes. The assessment of some contamination indicators such as pH, sulphate, chloride and nitrate indicate that the shallow groundwater is largely suitable for human consumption. The concentration of iron in all the analysed samples is within the WHO (2013) recommended limits of 0.3mg/l and thus suitable for domestic purposes. All the surface water samples (pond water, stream water and river water) indicate total coliform values that are above the WHO (2013) permissible limit of 0 counts per 100 ml of water whereas 8 out of 17 samples revealed total coliforms that are above the NWQS (2007) recommended limit of 0 counts per 100 ml of water. Furthermore, all these samples have faecal coliforms that are above the NWQS (2007) and WHO (2013) limits of 0 counts per 100 ml. The shallow groundwater samples from tube wells and hand-dug wells indicated that 8 out of 15 samples have total coliforms that are within the WHO (2013) permissible limit of 0 counts per 100 ml of water whereas 14 out of 15 samples displayed total coliforms that are within the NWQS (2007) recommended limit of 10 counts per 100 ml of water. All the shallow groundwater samples revealed Faecal coliforms that above the NWQS (2007) and WHO (2013) and recommended limits of 0 counts per 100 ml. The groundwater consisting of boreholes demonstrated that 12 out of 18 samples have total coliforms that are within the WHO (2013) recommended limit of 0 counts per 100 ml of water whereas all the 18 water samples show total coliforms that are within the NWQS (2007) recommended limit of 10 counts per 100 ml of water. The study indicates that the surface water samples revealed more values of total coliforms and Faecal coliforms than the shallow groundwater samples which in turn displayed both the total coliforms and Faecal coliform values that are above those of the deep groundwater samples. Thus, the deeper the zone of occurrence of groundwater the lesser the pollution by coliform bacteria. The water samples from the surface water are more polluted than those of the shallow groundwater (Hand-dug wells, tube wells and boreholes). These indicate that both the Faecal and total coliform bacteria are filtered out as the water infiltrates through the underlying soil surface. Faecal and total coliform bacteria originate from domestic sewage, dumping sites, Abbatoir activities and defecation by animals of micro and macro species. Faecal pollution signifies poor sanitation management as well as unhygienic manner of living among people especially those living close to riverine areas. Pathogenic contamination of water bodies comes from aquaculture practices involving fertilization of ponds with cow and poultry manures and direct dumping of faecal matters into rivers (Obasohun *et al*., 2010; Ankidawa *et al*., 2019; Seli *et al*., 2019). Presence of microbial pollutants in drinking water could pose risks to public health by causing water borne diseases such as cholera, diarrhoea, typhoid, hepatitis dysentery and poliomyelitis (Meinhardt, 2006). The polluted well and surface water should be treated by disinfection/distillation so that bacteria and other harmful disease -causing microorganisms can be reduced or even completely eliminated. The wells should be covered and well casings should be water tight and extend at least 15cm above the ground surface, and should also be fitted with proper vermin proof cap.

Irrigation Purposes

The sodium adsorption ratio (SAR) is the proportion of sodium to calcium and magnesium which affect the availability of water to the crop. It gives a clear idea about the adsorption of sodium by soil. The sodium adsorption ratio of pond water is generally less than 5 whereas those of stream water samples are less than 1 and fall under the category C2S1 indicating low alkali hazards and excellent irrigation water. The SAR values of water samples are less than 1 (for Rivers Donga Bridge, Mayo-Goi and Mafindi) but ranges from 27 to 59 (for Rivers Mayo-Dassa, Wuro-Musa, Nukka and Lamurde). Thus, while Rivers Donga Bridge, Mayo-Goi and Mafindi fall under category C2S1 indicating low alkali hazards and suitable for irrigation the remaining samples (Rivers Mayo-Dassa, Wuro-Musa Nukka and Mafindi) fall under C1S4 indicating high alkali hazards. The sodium adsorption ratio of the shallow groundwater samples (tube wells and hand dug wells) and deep groundwater (boreholes) are generally less than 10 and fall within category C2S1 indicating low alkali hazards and excellent irrigation water. Sodium percent is an important factor for studying sodium hazard. It is also used for adjudging the quality of water for agricultural purposes. Thus, high percentage of sodium in irrigation water will cause stunted growth of plant and will reduce the permeability of soil (Joshi *et al.*, 2009; Ankidawa *et al*., 2019; Seli *et al.*, 2019). The soluble sodium percentage values of surface water in the study area ranges from 0.22 % and 62.33 % for pond water, 20.25% to 37.27% for stream water and 11.90% to 90.41% for river water samples indicate fair to excellent irrigation water (Wilcox, 1955). The SSP values of tube well water revealed values ranging from 52.50% to 66.10% whereas those of hand dug wells displayed values of 54.60 to 71.80% indicating fair irrigation water. The SSP values of deep groundwater (deep boreholes) revealed values of 15.04% to 74.40% indicating excellent to fair irrigation water. The concentration of residual sodium bicarbonate (RSBC) influences the suitability of water for irrigation purpose. One of the empirical approaches is based on the assumption that all calcium and magnesium precipitate as carbonate (Singh and Hasnain, 1998). Thus, based on this assumption, Eaton (1950) proposed the concept of residual sodium bicarbonate (RSBC) for the assessment of high carbonate waters. The water with high RSBC has high pH and land irrigated with such water becomes infertile owing to deposition of sodium carbonate as observed from black colour of the soil (Eaton, 1950). The residual sodium bicarbonate values of water samples from the study area vary from -0.09 meq/l to 6.37 meq/l with a mean value of 1.29. The residual sodium bicarbonate values are generally less than 2.50 meq/litre for both the pond water and stream water samples but ranges from 64.49 to 161.02 meq/l for the river water samples. Thus, both the pond water and the stream water samples are safe and suitable for irrigation purposes. The RSBC values of groundwater samples indicate 20 to 61.20 meq/l for tube well samples, 30.80 to 46.60 meq/l for hand dug well samples and 22.10 to 63.50 meq/l for borehole samples suggesting fair to poor irrigation water. Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yields as the soils become more saline (Joshi *et al.,* 2009). The values of the magnesium adsorption ratio (MAR) of both the pond water and stream water samples are generally below the acceptable limit of 50% (Ayers and Westcot, 1994) whereas those of river water samples are largely above 50%. Thus, while all the pond and stream water samples are considered suitable for irrigation purposes the river water samples with the exception of Rivers Mayo-Goi and Mayo-Dassa are considered unsuitable for irrigation purposes. All the shallow groundwater samples (tube wells and hand dug wells) and deep groundwater (boreholes) revealed MAR values that are generally less than the recommended limit of 50% and are therefore considered suitable for irrigation purposes. This is because high magnesium adsorption ratio causes a harmful effect to soil when it exceeds 50%. Most of the pond and stream water samples indicates Kellys Ratio (KR) values that are within the permissible limit of 1.00 whereas 4 out of 7 river samples revealed Kellys Ratio that are within the permissible limit of 1. Salts of calcium, magnesium, sodium and potassium present in the irrigation water may prove to be injurious to plants. Thus, when present in excessive quantities, they reduce the osmotic activities of the plants and may prevent adequate aeration. The TDS value of all the surface water samples is generally less than 300 mg/l whereas those of all the groundwater samples are less than 430 mg/l and thus non saline. They are hence considered good for irrigation. They are generally classified as excellent irrigation water according to Robinove *et al,* (1958). The soil permeability is affected by the long-term use of irrigated water and the influencing constituents are the total dissolved solids, sodium bicarbonate and the soil type. The soil permeability can be assessed based on the values of their permeability index (PI). Donnen (1964) gave a criterion for assessing the suitability of groundwater for irrigation based on the permeability index (PI). Accordingly, the permeability index is classified under Class I (>75%), Class II (25-75%) and Class III (<25%) order. Class I and Class II waters with 25% or more of maximum permeability waters are categorized as good for irrigation whereas Class III with 25% or less of maximum permeability waters are unsuitable. The pond and river water samples indicate maximum permeability index values that are generally less than 25% (Class III) whereas those of stream water samples belong to Class II with maximum permeability values between 25-75%. Thus, while the pond water and river water samples are categorized as unsuitable for irrigation, the stream water samples are good and suitable for irrigation purposes. All the borehole samples revealed maximum permeability values that are less than 25% (Class III) and are categorized as unsuitable for irrigation purposes whereas both the tube wells and hand dug wells indicate maximum PI values above 75% and are categorized as good and suitable for irrigation purposes. The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (EC). It is a measure of the degree of the mineralization of the water which is dependent on rock-water interaction and hence the residence time of the water in the rock (Eaton, 1950) The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the less water is available to plants; even though the soil may appear wet. Thus, because plants can only transpire water ("pure water"), useable plant water in the soil solution decreases dramatically as EC increases (Joshi *et al.*, 2009). This investigation revealed that 22 water samples fall within the low saline zone (< 250µS/cm) whereas 28 samples fall within the moderately saline zone (250 to 750µS/cm). The EC values of all the analyzed water samples from all the water sources are generally less than 750 µS/cm indicating low saline to moderately saline zone and are safe for irrigation under practically all conditions. Hard water is water that has high content of calcium and magnesium ions and sometimes other dissolved compounds such as iron. Calcium usually enters the water as either calcium carbonate in the form of limestone and chalk or calcium sulphate(anhydrite) in the form of other mineral deposits. Piper diagram confirms that most of the water sources are characterized by alkaline earth metals (Ca+Mg) which exceeds alkalis (Na+K), and the weak acids (CO_3+HCO_3) exceed strong acids (SO_4+Cl). In the present investigation, the pond water samples indicate hardness values that are generally less than 75 mg/l indicating soft water whereas stream water samples displayed hardness values ranging from 39 mg/l to 128 mg/l indicating soft to moderately hard water. The river water samples showed total hardness values of 3.87 mg/l to 127 mg/l suggesting soft to moderately hard waters. The tube well water samples revealed total hardness values of 85 mg/l to 210 mg/l indicating moderately hard to hard water whereas those of hand dug wells revealed values of 0 mg/l to 150 mg/l indicating soft to moderately hard water. The deep boreholes displayed values of 49 mg/l to 160 mg/l suggesting soft to moderately hard water.

Hydrogeochemistry

Four types of hydrogeochemical facies based on the classification given by Deutsch (1997) were identified for the surface and groundwater (pond water, streams, rivers, tube wells, hand-dug well and borehole samples) in the study area. These include HCO_3^-+CO_3^{2-}, Ca^{2+}+Mg^{2+}, SO_4^{2-} + CI and Na^++K^+ type. The stream water samples, and pond water samples revealed mainly Ca^{2+} and Na^+ as the major cations and SO_4^{2-} and CI^- as the major anions whereas river water samples indicate mainly Na^{+} and Mg^{2+} as the major cations and HCO_3^{-} and Cl^{-} as the major anions. The tube well displayed Na+ and Ca^{2+} as the major cations and CO_3+HCO_3 as the major anions. The water samples for hand-dug wells are characterized mainly by Na^{+} and Ca^{2+} as major cations and mainly by CO_3+HCO_3 as major anions whereas revealed borehole samples revealed Ca^{2+} as the major cations and CO_3+HCO_3 as the major anions. The homogenous composition between the hand-dug wells and boreholes appear to indicate a common origin and source whereas the non-homogenous composition of pond water, streams and rivers indicates active groundwater mixing and significant water-rock interaction. The water samples from pond water, streams, rivers, tube wells, hand-dug wells and boreholes are characterized mainly by HCO_3, SO_4^{2-} and Cl^{-} indicating active groundwater mixing and flushing, short residence time and fresh water with TDS values generally less than 260 mg/l. These results thus indicate that groundwater (both hand-dug well water samples tube well water samples and borehole samples) is less chemically evolved than the surface water (ponds, streams and river water samples) which probably has had a longer residence time in the subsoil before being discharged to the surface. Piper Trilinear Diagrams confirm that most of the water sources are characterized by alkaline earth metals (Ca+Mg) which exceeds alkalis (Na+K), and the weak acids (CO_3+HCO_3) exceed strong acids (SO_4+CI) in most of the water sources. Hence alkaline earths dominate bicarbonates indicating exchange of Na ions with alkaline earths resulting in base exchanged hardened water in places (Rao, 2002; Ankidawa *et al*., 2019).

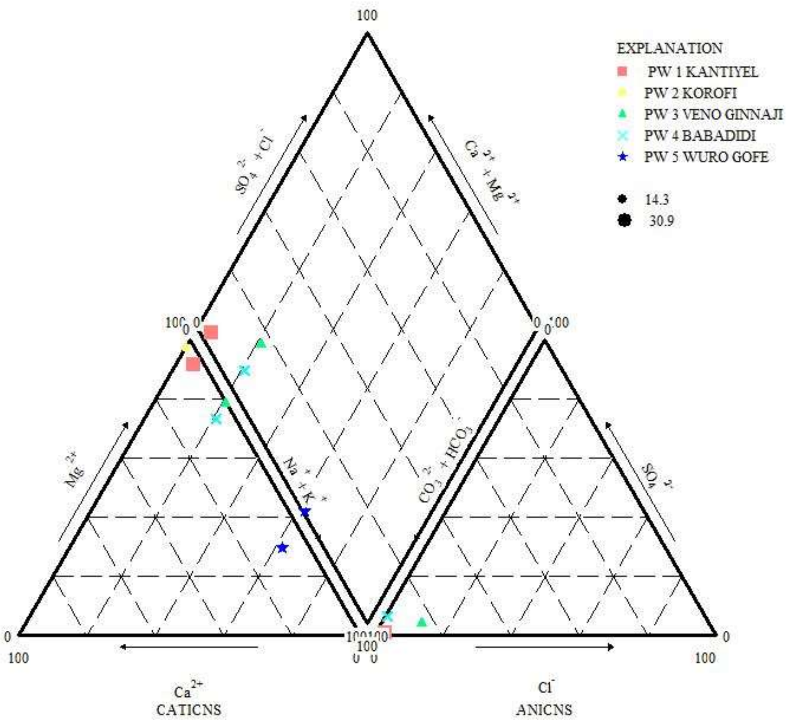

Figure 4: Piper Trilinear Diagram of Pond Water Samples of the Study Area

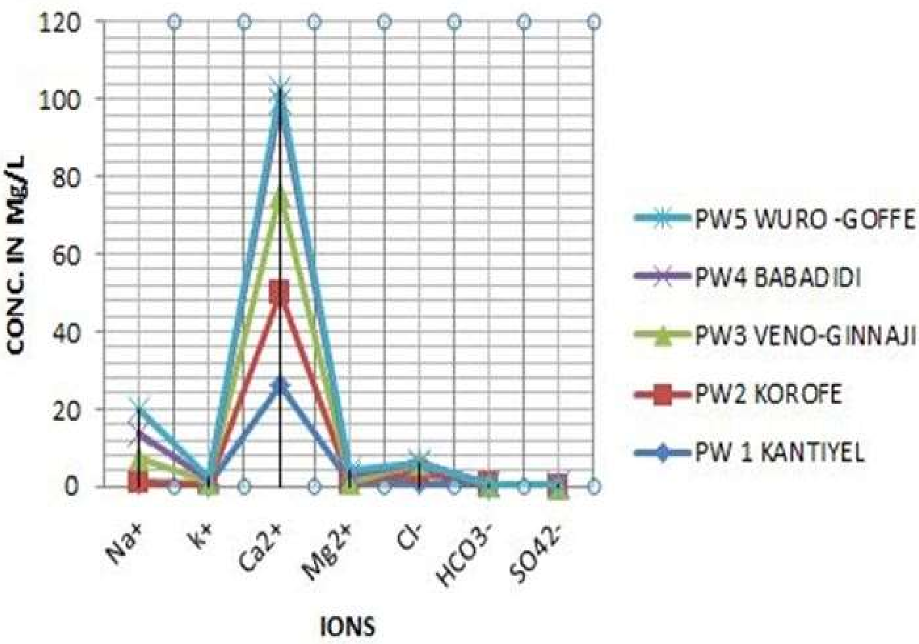

Figure 5: Schoeller semi-log plot of pond water samples of the study Area

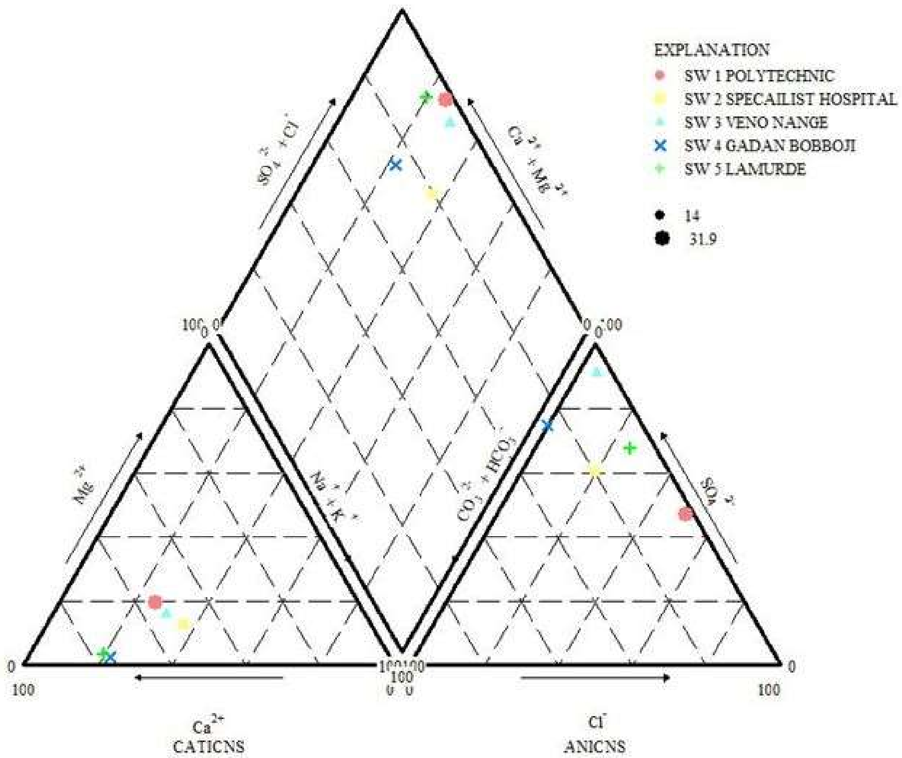

Figure 6: Piper trilinear diagram of stream water samples of the study area

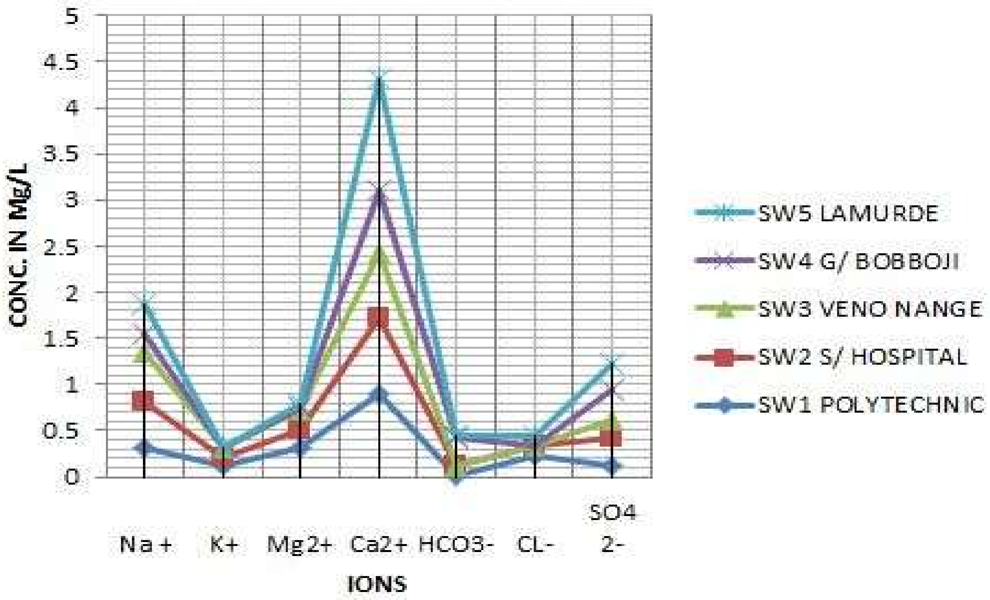

Figure 7: Schoeller semi-log plot of stream samples of the study area

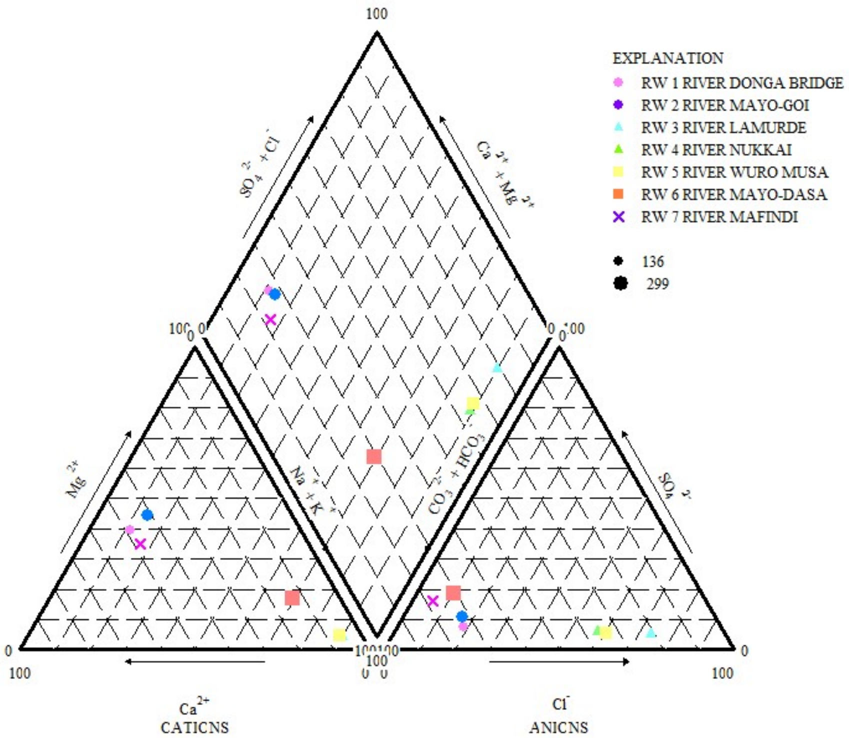

Figure 8: Piper trilinear diagram of river water samples of the study area

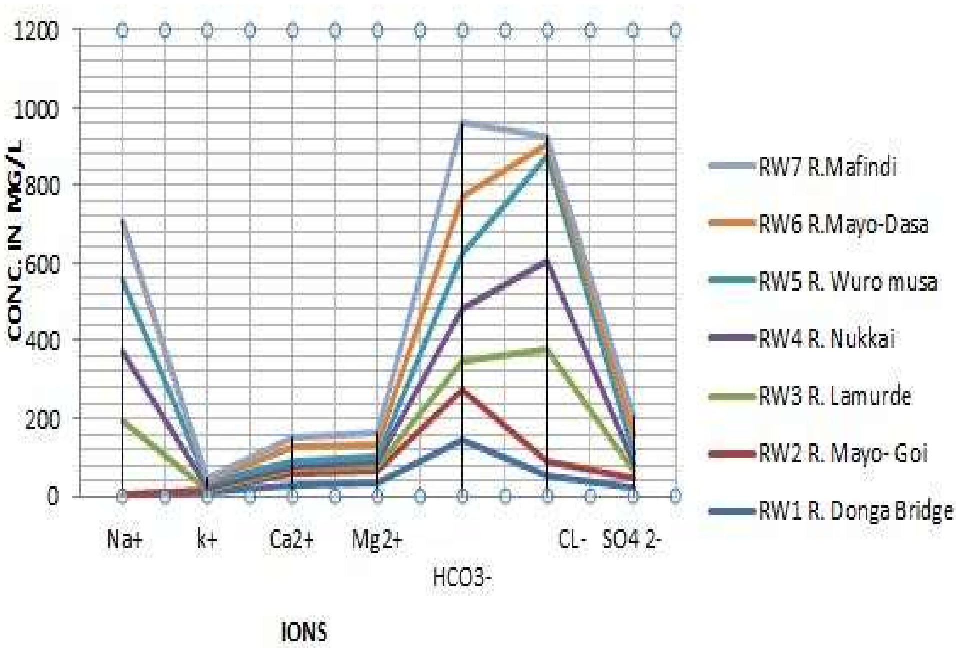

Figure 9: Schoeller semi-log plot of river samples of the study area

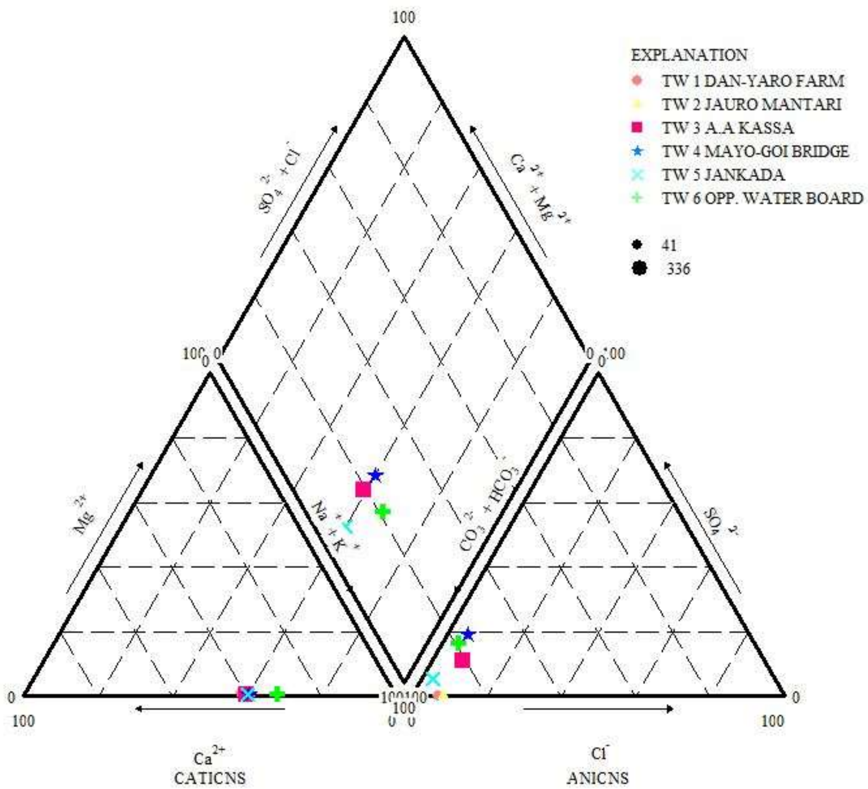

Figure 10: Piper trilinear diagram of tube well samples of the study area

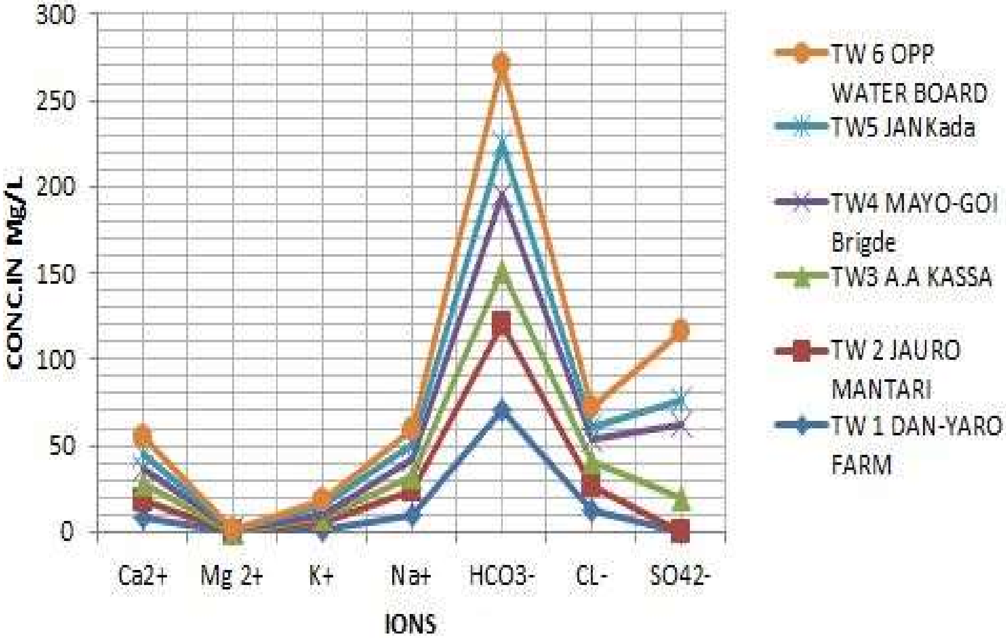

Figure 11: Schoeller semi-log plot of tube well samples of the study area

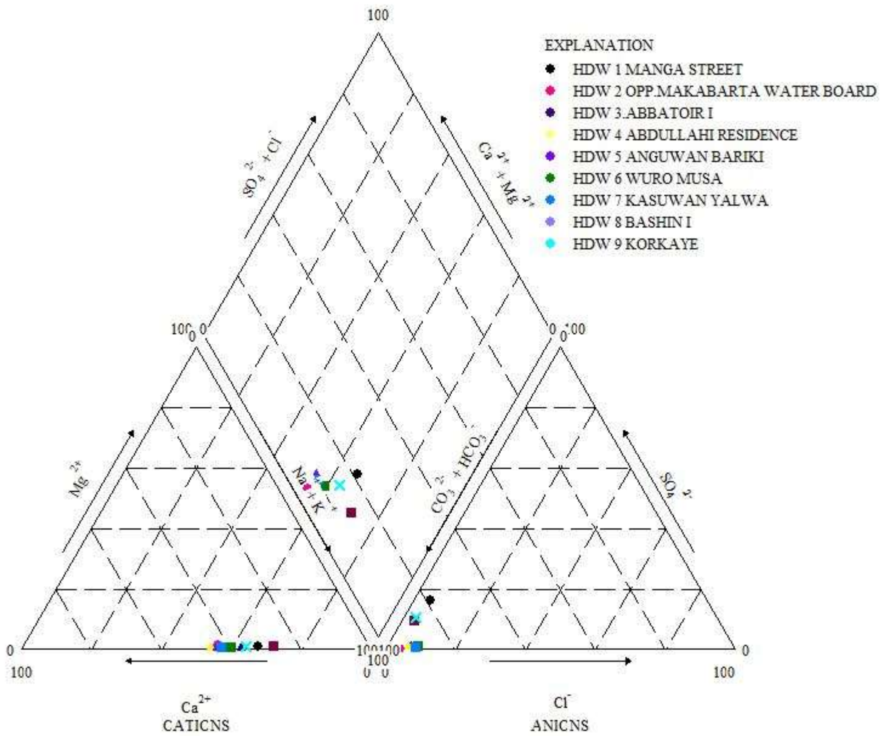

Figure 12: Piper trilinear diagram of hand=dug wells of the study area

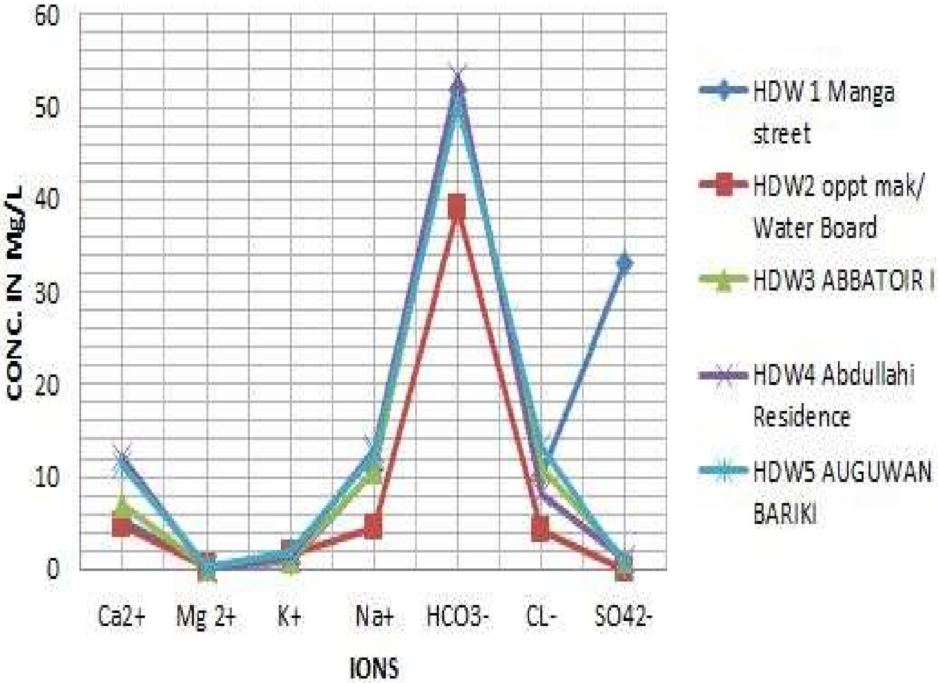

Figure 13: Schoeller semi-log plot of hand-dug well samples of the study area

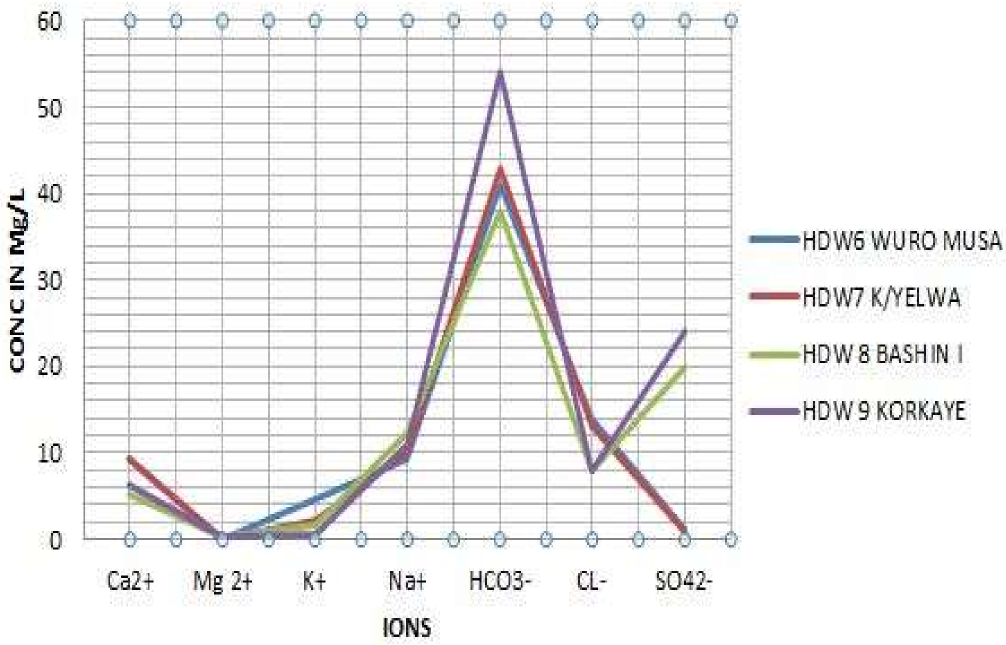

Figure 14: Schoeller semi-log plot of hand-dug well samples of the study area

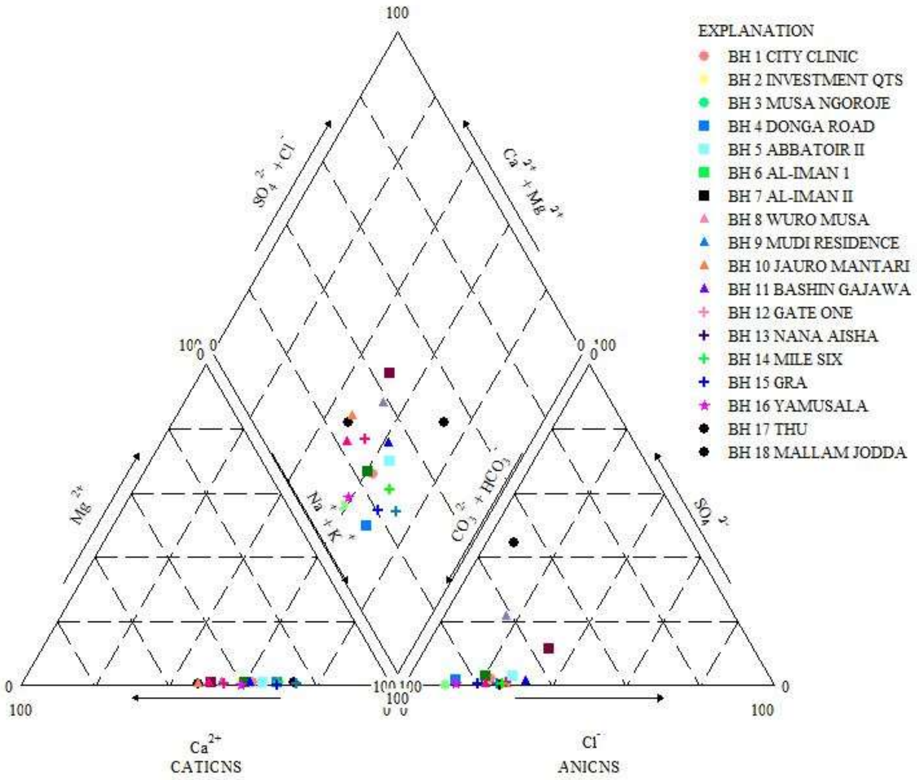

Figure 15: Piper trilinear diagram of borehole samples of the study area

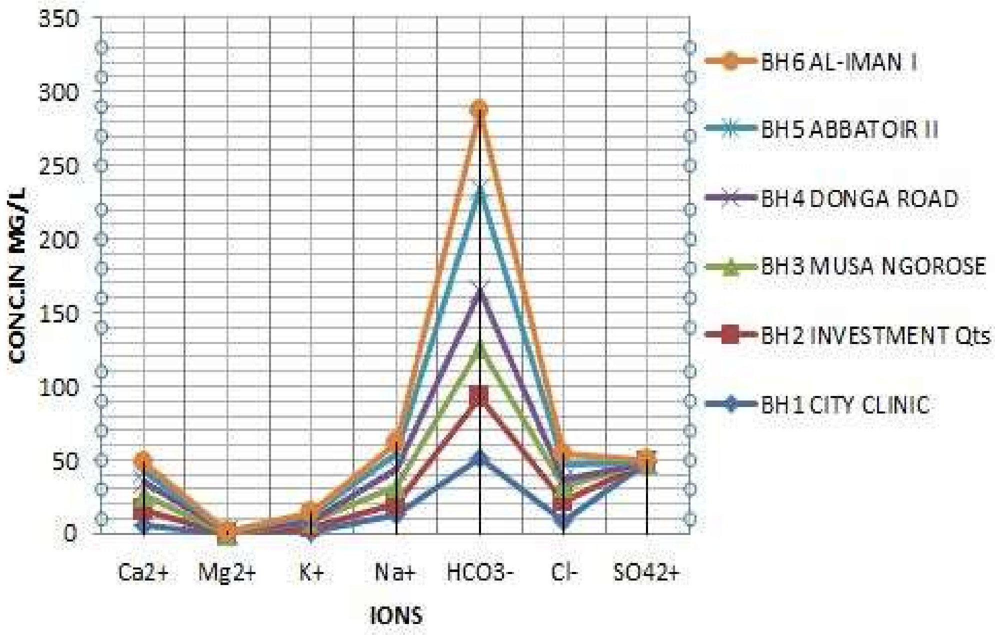

Figure 16: Schoeller semi-log plot of borehole samples of the study area

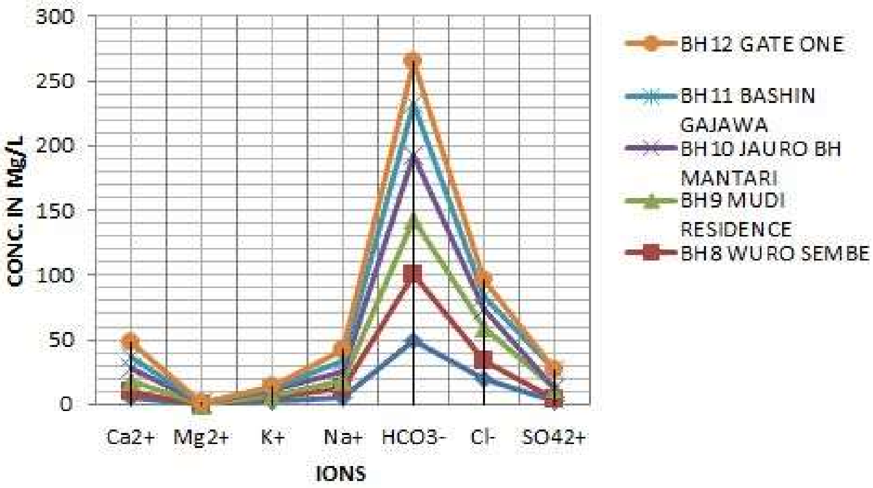

Figure 17: Schoeller semi-log plot of borehole samples of the study area

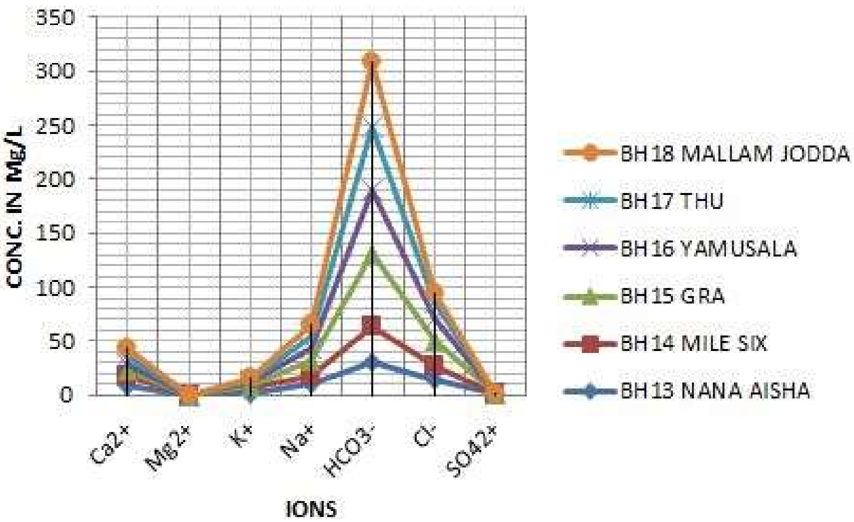

Figure 18: Schoeller semi-log plot of borehole samples of the study area

Ionic Ratios

The ionic composition may be caused by many factors during chemical interaction. Thus, it is necessary to use the ionic ratios and plots to discriminate between them. The contribution of atmospheric sources to the dissolved salts has been discussed by many authors (Garrels and Mackenzie, 1971; Berner and Berner, 1987; Edet and Ekpo, 2008 and Obiefuna and Orazulike, 2011). Chloride is the most useful parameter for evaluating atmospheric input to water as it shows very little fractionation (Appelo and Postma ,1993; Ankidawa *et al*, 2019; Ngasoh *et al*., 2022). Sodium and chloride inputs are likely to be mainly from rainfall and thus reflect the ratio observed in seawater as indicated by the Na/CI ratio of 0.20 to 0.66. The lower Na/CI ratio (< 1) is due to the dominance of CI ions. Chloride ions are present in the groundwater as sodium chloride whereas chloride content exceeding sodium may be due to the Base Exchange phenomena or pollution by anthropogenic activities (Jones *et al.,* 1999). The ratios greater than one (1) are typically interpreted as released Na from silicate weathering reactions whereas ratio close to one (1) is related to halite dissolution (Meybeck, 1987). The analysed pond and stream water samples indicate Na/CI ratios that are largely above one (1) suggesting sodium released from silicate weathering whereas those of river water samples indicate ratios that are largely less than one (1) reflecting sodium released from halite dissolution. The analysed groundwater samples consisting of samples from tube wells, hand-dug wells and boreholes reveal Na/CI ratios that are largely below/close to one (1) suggesting sodium released from halite dissolution and/or contribution from rainfall. Cation exchange may account for a reduction in the Na concentration and halite dissolution may account for high concentration of Na and CI (Edet and Ekpo, 2008). The low concentration of potassium in natural water is a consequence of the tendency to be fixed by clay minerals and participate in the formation of secondary minerals (Matheis, 1982). The $Ca+Mg/HCO_3$ ionic ratio greater than one (1) suggest an excess of alkaline earth metals (Ca+Mg) over HCO_3 reflecting extra sources of Ca and Mg ions balanced by CI and SO4 and/or supplied by silicate weathering (Zang *et al*.,1995). Furthermore, an ionic ratio of $Ca+Mg/HCO_3$ less than 1 suggest an excess of HCO_3 over alkaline earth elements (Ca+Mg) indicating the reaction of the feldspar minerals with carbonic acid in the presence of water which releases HCO_3 (Elango e*t al.,* 2003). This present investigation revealed a mean $Ca+Mg/HCO_3$ ratio of above one (1) for pond water (2360) and stream water (46.27) and mean ratio of less than 1 for river (0.161), tube well (0.228), hand-dug well (0.171) and boreholes (0.205). The $Ca+Mg/HCO_3+SO_4$ ionic ratio is used to determine the ion exchange processes. If ion exchange is dominant the $Ca+Mg/HCO_3+SO_4$ ionic ratio will be less than one (1) resulting in an excess of HCO_3+SO_4 (Fisher and Mulican, 1997). If reverse ion exchange is the process, the $Ca+Mg/HCO_3+SO_4$ ionic ratio will be less than one (1) resulting in an excess of Ca+Mg over HCO_3+SO_4 ions suggesting ions from weathering of silicates (Datta and Tyagi, 1996; Ankidawa *et al*., 2019; Seli *et al*., 2019). In the present investigation the $Ca+Mg/HCO_3+SO_4$ ionic ratio of pond water and stream water samples are generally above one (1) (with mean values between 2.91 to 145.09) whereas those of river, tube well, hand-dug well and boreholes are generally below one (1) (with mean values between 0.156 and 0.265).

CONCLUSIONS

The chemical composition of the shallow groundwater is strongly influenced by the interaction with the alluvial sediments/rock types and by anthropogenic activities and the residence time of groundwater. The different water sources include pond water, streams, rivers, tube wells, hand-dug wells and boreholes. Four types of hydrogeochemical facies based on the classification were identified for the surface and under groundwater within the study area. These include $HCO_3^{-}+CO_3^{2-}$, $Ca^{2+}+Mg^{2+}$, SO_4^{2-} + CI and $Na^{+}+K^{+}$ type the homogenous composition of groundwater (hand-dug wells and boreholes) appear to indicate a common origin and source whereas the non-homogenous composition of surface water (pond water, streams and rivers) indicates active groundwater mixing and significant water-rock interaction. The ionic composition is caused by many factors during chemical interaction. Chloride is the most useful parameter for evaluating atmospheric input to water as it shows very little fractionation. Sodium and chloride inputs are likely to be mainly from rainfall and thus reflect the ratio observed in stream as indicated by the Na/CI ratio of 0.20 to 0.66. The lower Na/CI ratio (< 1) is due to the dominance of CI^- ions. Chloride ions are present in the groundwater as sodium chloride whereas chloride content exceeding sodium may be due to the Base Exchange phenomena or pollution by anthropogenic activities. The ratios greater than 1 are typically interpreted as released $Na^+$from silicate weathering reactions whereas ratio close to 1 is related to halite dissolution. The analyzed pond and stream water samples indicate Na/CI ratios that are largely above 1 suggesting sodium released from silicate weathering whereas those of river water samples indicate ratios that are largely less than 1 reflecting sodium released from halite dissolution. The analyzed groundwater samples, boreholes revealed Na/CI ratios that are largely below/close to 1 suggesting sodium released from halite dissolution and/or contribution from rainfall. The Ca+Mg/HCO3 ionic ratio greater than 1 suggest an excess of alkaline earth metals (Ca+Mg) over HCO3 reflecting extra sources of Ca and Mg ions balanced by CI and SO_4 and/or supplied by silicate weathering (Furthermore an ionic ratio of Ca+Mg/HCO_3 less than 1 suggest an excess of HCO_3 over alkaline earth elements (Ca+Mg) indicating the reaction of the feldspar minerals with carbonic acid in the presence of water which releases HCO_3. This investigation revealed a mean Ca+Mg/HCO_3 ratio and Ca+Mg/HCO3+SO_4 ionic ratio of pond water and stream water samples are generally above 1 (with mean values between 2.91 to 145.09) whereas those of river, tube well, hand-dug well and boreholes are generally below 1 (with mean values between 0.156 and 0.265),

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