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Assessment of groundwater quality for drinking and irrigation: the case study of Teiman-Oyarifa Community, Ga East Municipality, Ghana

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Abstract

The suitability of groundwater quality for drinking and agricultural purposes was assessed in a predominantly farming and sprawling settlement in the Ga East Municipality (Ghana). Various water quality parameters were determined to assess groundwater quality of 16 wells in Teiman-Oyarifa community. Standard methods for physicochemical determinations were employed. Hand-dug wells, boreholes and pipe borne water samples were collected within the locality and analysed. Results showed the temperature range of 19.5^{o}C-26.7^{o}C, pH range of 4-7.4, conductivity range of 214-2830 µS/cm, total dissolved solids, 110-1384 mg/L, bicarbonate, 8.53-287.7mg/L, chloride, 28.41-813.8 mg/L, Flouride, below detection limit -0.4667mg/L, Nitrate 1.9-4625 mg/L, sulphate, 16.35-149.88mg/L. Results of analysis carried out using Atomic Absorption Spectrophotometry showed metal concentrations of Fe ranging from 0.212-3.396 mg/L, Mn 0.01-0.1 mg/L, Ca 0.39-9.97 mg/L. The ionic dominance for the major cations and the anions respectively were in these order; $Na^+>K^+>Mg^+>Ca^+$ and $Cl^->HCO_3^->SO_4^{2-}>NO_3^-$. Most of the samples analyzed were within the Guidelines set by both national and international bodies for drinking water. Most of the groundwater samples fell in the US Salinity Laboratory Classification of C2-S1(medium salinity-low SAR).

Keywords agriculture; dominance; groundwater; drinking; physicochemistry; salinity.

1 Introduction

Groundwater is the most important source of domestic, industrial and agricultural water supply in the world. Many communities in Africa depend heavily on groundwater. Exploitation of surface waters has reduced, ensuring an increasing reliance on groundwater abstraction due to increasing pollution with the concomitant rise in the cost of water treatment (Kortatsi, 2007). In Ghana, about 70% of total populations rely heavily on groundwater for drinking purposes (Kortatsi et al, 2008). Groundwater quality reflects inputs from the atomosphere, soil and water rock reactions as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes (Appelo and Postma, 1993; Zhang et al., 2011).

Suitability of water for various uses depends on type and concentration of dissolved minerals and groundwater has more mineral composition than surface water (Mirribasi et al., 2008).

The quality of groundwater is constantly changing in response to daily, seasonal and climatic factors. Continuos monitoring of water quality parameters is highly crucial because changes in the quality of water has far reaching consequencies in terms of its effects on man and biota.

In Ghana, groundwater resources are under increasing pressure in response to threats of rapid population growth, coupled with the establishment of human settlements lacking proper water supply and sanitation services (Anim et al., 2011). A number of factors influence water chemistry-Gibbs (1970) proposed that rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry of water. The influenceof geology on chemical water quality is widely recognized (Gibbs, 1970; Langmuir, 1997; Lester and Birkett, 1999). The influence of soils on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the soil and water (Hesterberg, 1998). Apart from natural factors influencing water quality, human activities such as domestic and agricultural practices impact negatively on groundwater resources.

Pollution of water bodies as a result of metal toxicity has become a source of concern among consumers. This concerns has become alarming in response to increasing knowledge on their toxicity to human health and biological systems. (Anazawa et al, 2004).

The toxicity of trace metals in water depends on the concentration of the metal below a certain level, which could be considered as essential for biochemical processes. However, in certain cases, high levels could bioaccumulate raising toxicity concerns.

Water quality data is essential for the implementation of responsible water quality regulations for characterizing and remediating contamination and for the protection of the health of humans and the ecosystem. Regular monitoring of groundwater resources thus play a key role in sustainable management of water resources.This study conducted seeks to serve as a prelimnary study to assess the groundwater quality in terms of drinking and agricultural uses for a rapidly developing community located in Ghana.

2 Materials and Methods

2.1 Location of study area

Teiman-Oyarifa is a rural community located within Ga East Municipality of the Greater Accra Region of Ghana. The Community is about 20km from the Central Business Area of Accra. It falls between latitude $5^o43'$ 60N and longitude 0^o11 0'W and is bounded in the west and north by the Akwapim-Togoland ranges on the south by the Gulf of Guinea. The terrain is generally flat and undulating with few isolated inselberg that seldom rise 70m above sea level. The climate is typically characterized by prevailing high temperatures with distinct variations in the duration, intensity, and seasonality of rainfall. The dry equatorial climate of the south-eastern coastal plains and the wet semi-equitorial climate are the two distinct climatic zones having two yearly rainfall patterns. The Major rains are between April and July, with its peak in June. The vegetation of the area is mainly coastal grassland and shrubs.

2.2 Hydrogeology

The greater part of the study area is underlain by Dahomeyan formation. It comprises alternating bands of massive acidic and basic gneisses, schist and magmatites (Quist, 1976). The other geological units include the Togo series, the Accraian series, and the tertiary and recents sediments. The Togo series occurs mainly on the northwestern part of the study area and mainly consist of quartzites and phyllites. Other rock types include shale, sandstone, schist, and silicified limestones. The Accrarian series consist of sandstone, grits, and shales found in the vicinity of the city. Since the main rocks are inherently impermeable, groundwater in the study area is controlled by the development of secondary porosities such as fractures, faults, and associated weathered zones. The depth of weathering is highly variable and it is greater along the foothill of the

Akwapim-Togo ranges where it reaches 47m but least in the heart of the city, where it rarely exceeds 6m. The weathered zone acquifer and the fractured zone aquifer are the main aquifers in the study area and their yields are highly variable (0.7-27.5m^3h^{-1}) with a mean of 2.7m^3h^{-1} (WRI, 1996). The weathered zone aquifers are either phreatic or semi-confined but that of the fractured zone are mainly semiconfined or confined.

2.3 Sampling and analysis

Groundwater samples were collected from domestic and municipal boreholes at 16 sampling stations within the Oyarifa community (in June 2009). The samples were collected, put separately into acid cleaned high-density 1L polyethylene sampling bottles and analyzed according to strict sampling protocols described by Gale and Robins (1989). Water from the wells were pumped out for over 20 minutes, before abstracting the samples. Analysis of temperature, pH, electrical conductivity, and total dissolved solids were conducted on site with a portable HACH conductivity meter which was calibrated prior to taking of readings. The samples were transported in ice cooler on ice and stored at -4^{0}C, prior to analysis. Filtration of water samples was done using a Sartorius polycarbonate filtering apparatus and a 0.45µm cellulose acetate filtering membrane. Chemical analysis on the samples were conducted using standard procedures recommended by APHA- 1998. Hardness was measured by EDTA titrimetric method. Analysis of pH was conducted using a WTW model 523 pH meter. The pH electrode was calibrated with buffer solutions of pH 4, 7 and 10, prior to taking the readings. Analysis of Na^+ and K^+ ion concentrations were done using a Sherwood model 420 flame photometer. Chloride (Cl^-), sulphate ($SO4^{2-}$), nitrate (NO_3^-), fluoride (F^-) were measured using a single column Dionex DX-120 Ion chromatograph following protocols by the American Public Health Association (APHA, 1998). Samples for trace metal analysis were acidified to pH < 2 with 10% analytical grade $HNO_{3.}$ They were then acid digested using an ETHOS 500 model microwave and read using Varian AA240FS model Atomic Absorption Spectrophotometer in an air-acetylene flame at the Chemistry Department, Ghana Atomic Energy Commission. Analytical grade reagents were used for all analysis and replicate measurements were done to ensure reproducibility and good quality control.

3 Results and Discussion

The results of the research are presented in Table 1 below.

3.1 Groundwater quality and assessment for drinking

3.1.1 Physicals

Ground water quality assessment; carried out to determine suitability of water samples in terms of domestic and agricultural purposes. The portability of drinking water from domestic well samples is mainly based on recommended permissible limits for certain parameters described in WHO, 1996 and Ghana Standards Board limits for drinking water.

The pH values of groundwater samples ranged from 4 to7.4 as shown in Table 1. Most of the groundwater samples had pH values below the acidic limit of 6.5. pH values less than 6.5 are considered too acidic for human consumption and can cause health problems such as acidosis.. The acidic nature of most of the samples might be due to high mineral rich rocks making up the acquifers. This is evident in WW-1, which recorded the least pH of 4, showed extraordinarily high values of dissolved ions. The pH values of water from the study area were generally low. Eighty-eight percent of the wells had pH values lower than the safe limit for drinking water (6.5-8.5) as prescribed by WHO, 1996. The measured temperature values of the well water samples were between 19.5-26.7 ^{0}C. The electrical conductivity in water samples is an indication of dissolved ions. Thus the higher the EC, the higher the levels of dissolved ions in the sample. The Electrical Conductivity of all the samples ranged from 214 to 2830 µS/cm . The high levels of dissolved ions in WW-1 as shown in Table 1 might have been contributed by the higher electrical conductivity.

Table 1 Mean of Physico-chemical data of groundwater samples

Station	pH	Temp (oC)	Cond (μS/cm)	TDS (mg/L)	HCO3 (mg/L)	F (mg/L)	Cl (mg/L)	Na (mg/L)	K (mg/L)	TH (mg/L $CaCO_3$)	NO3 (mg/L)	SO4 (mg/L)	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Ca (mg/L)	Mg (mg/L)
WW-1	4	26.6	2830	1384	9.75	0.2097	813.8	667	184	21.59	4625	149.9	0.364	0.10	0.028	5.33	2.01
WW-2	4.6	26.7	419	220	17.07	0.1692	126.8	118.2	5.3	14.81	14.6	20.57	0.338	0.03	0.02	1.83	2.49
WW-3	6	26.3	543	285	8.53	0.4667	115.8	203	6.4	20.65	24.1	49.47	3.396	0.04	0.008	3.37	2.97
WW-4	5.5	26.1	214	110	24.38	0.0786	45	52.9	10.3	14.74	18.1	24.64	0.504	0.03	0.04	1.91	2.42
WW-5	5.9	25.6	258	130	43.89	0.0858	45.25	61.9	13.7	15.06	11.6	21.25	0.748	0.02	0.02	2.32	2.25
WW-6	5.9	20	244	130	68.27	0.1163	32.27	54.7	16.7	15.17	1.9	23.22	1.484	0.05	0.02	2.25	2.32
WW-7	5.5	19.8	232	124	43.89	0.0622	45.14	53.7	12.6	14.35	8.26	16.35	1.248	0.03	0.024	2.4	2.03
WW-8	6.6	20	467	250	195.1	0.1864	28.41	51.7	30.2	33.91	20.3	48.45	0.676	0.03	0.028	9.97	2.19
WW-9	6	19.5	337	183	95.1	0.2515	53.31	71.9	12.1	9.2	12.9	30.87	0.632	0.04	0.044	0.39	2.00
WW-10	5.7	20.3	314	165	41.45	0.2371	65.3	68.2	12.5	15.34	27.7	21.02	0.576	0.02	0.06	2.83	2.01
WW-11	5.8	20	323	171	78.03	<0.001	68.98	65.8	11.7	20.07	15.5	18.56	0.664	0.02	0.02	4.54	2.12
WW-12	5.4	20.5	308	162	287.7	0.0551	62.98	70.8	11.6	17.27	19.8	31.79	0.396	0.01	0.02	3.39	2.14
WW-13	7.4	20.3	322	171	87.78	0.2052	60.26	63	15.9	25.33	4.67	19.6	0.436	0.03	0.032	5.61	2.75
WW-14	5.9	20.2	257	133	9.75	0.1519	40.06	57.3	19.7	23.96	15.2	20.71	2.024	0.01	0.012	4.96	2.81
WW-15	5.1	20.9	458	243	39.01	0.1624	126.5	101.3	14.4	20.53	11.7	42.02	0.28	0.02	0.048	3.24	3.02
WW-16	5.2	26.5	568	260	43.89	0.0932	129	104.3	14.7	18.59	13.6	41.99	0.212	0.01	<0.001	2.73	2.86
Max	7.4	26.7	2830	1384	287.7	0.4667	813.8	667	184	33.91	4625	149.9	3.396	0.1	0.06	9.97	3.02
Min	4	19.5	214	110	8.53	0.0551	28.41	51.7	5.3	9.2	1.9	16.35	0.212	0.01	0.008	0.39	2.00
Mean	5.66	22.46	505.88	257.56	68.35	0.17	116.18	116.61	24.49	18.79	302.81	36.28	0.87	0.031	0.028	3.57	2.40
Stdev	0.77	3.10	629.40	305.20	74.72	0.10	189.29	151.71	42.91	5.77	1152.60	32.24	0.83	0.022	0.014	2.21	0.40

The TDS concentrations range were between 110.4-1384 mg/l as shown in Table 1. Groundwater samples were mostly fresh, with most of the wells having TDS values below the recommended value of 500 mg/l (WHO, 1996).

TH ($CaCO_3$) for the samples ranged from 9.2 to 33.91 mg $CaCO_3$/L. Groundwater samples analyzed recorded TH values below the recommended limit of 500mg $CaCO_3$/L for drinking water by Ghana Standards Board. Such waters are soft waters and do not develop scales in water heaters, distribution pipes, and washing clothes with soap is easier. The Water Hardness Classification, according to WHO, 2004 follows this criteria; Soft (0-50mg $CaCO_3$/L), Moderate Soft(50-100mg $CaCO_3$/L, Slightly Hard (100-150mg $CaCO_3$/L), Moderate Hard (150-200 mg $CaCO_3$/L), Hard (200-300 mg $CaCO_3$/L) and Very Hard (over 300mg $CaCO_3$/L). From the WHO 2004 classification, the groundwater samples analysed were very soft and suitable for domestic use.

3.1.2 Ions and nutrients

The concentration of chloride in the groundwater samples ranged from 28.41 to 813.8mg/L as shown in Table 1. In drinking water, the concentration of chloride should not exceed 250mg/L as recommended by Ghana

Standard Board. However, about 94% of groundwater samples recorded lower chloride values (< 250mg/l). The amount of chloride ions recommended being acceptable by WHO (1996) is within 10 – 250 mg/L. Excess chloride above the background levels may be due to groundwater contamination as a result of seepage from septic systems, landfill, fertilizers or animals. Excess concentration of chloride in drinking water gives a salty taste and has a laxative effect on people not accustomed to it. Again, sample WW-1 with chloride level of 813 mg/L exceeded the recommended limits. The concentration of Na in the groundwater samples ranged from 51.7-667 mg/L (Table 1). In the study area, Na concentrations were within the safe limits of 200mg/L recommended limit for drinking water. The nitrate concentration of the samples ranged from 1.9-4625mg/L .

Nitrate in drinking water should not exceed 10 mg/l (WHO, 1996). All the samples recorded higher nitrate values with the exception of WW-6, WW-7 and WW-13. Excessive nitrate content in drinking water can cause health disorders such as methemoglobinemia, goitre, and hypertension (Baird and Cann, 2004).

One of the essential elements for maintaining normal development of healthy teeth and bones is Flouride. Lower concentrations of flouride usually below 0.6mg/l may contribute to dental caries. However, continuing consumption of higher concentrations, above 1.2mg/l however cause dental flourosis (Rao, 2006) and in extreme cases even skeletal flourosis (Dissanayake, 1991). Concentrations of fluoride in samples taken from the study area varied from below detection limit to 0.4667 mg/L (Table 1). There may therefore be the likelihood of the risk of dental caries, suffered by people who depend on this water source for drinking. The concentration of the various cations and anions were converted to milliequivalents per litre (meq/l). Groundwater samples analysed in the study area exhibited an overall ionic dominance of $Na^+>K^+>Mg^+>Ca^+$ for the major cations. On the other hand, for the major anions, the order was $Cl^->HCO_3^->SO_4^{2-}>NO_3^-$. This order was in contrast with the ionic dominance for freshwater which is in the order of Na>Mg>Ca>K and HCO3>SO4> Cl for freshwater (Burton and Liss, 1976).

3.1.3 Trace metals

Trace metals are needed by the body to satisfy its nutritional requirements. However, only minute quantities are required as high doses lead to health hazards which are sometimes lethal. Trace metals are widely distributed in the environment with sources mainly from weathering of minerals and soils (Merian, 1991; O'Neil, 1993). However, inputs from anthropogenic activities have increased the levels in the environment tremendously (Prater, 1975; Sayyed and Sayadi, 2011). The concentration of Iron in the samples ranged from 0.212-3.396 mg/L (Table 1). About 87.5% of all the groundwater samples had elevated Fe levels above WHO (1996) recommended limit of 0.3mg/L for drinking. The concentration of Manganese in the samples ranged from 0.01-0.1mg/L. All the samples analyzed fell within the WHO (1996) recommended limits of 0.1mg/L for Mn in drinking water. The concentration of Zn in the samples ranged from below detection limit to 0.06mg/L (Table 1).This concentration fell within the WHO (1996) recommended limit of 3.0mg/L for potable water.

3.2 Quality criteria for irrigation purpose

EC and Na^+ play a vital role in suitability of water for irrigation. Higher EC in water creates a saline soil. Harmful effects of irrigation water increases with the total salt concentration, irrespective of the ionic composition. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Thorne and Peterson, 1954). The salts apart from affecting the growth of plants also affect the soil structure, permeability and aeration which indirectly affect plant growth.

Sodium adsorption ratio (SAR), ratio of dissolved sodium (RDS) as %Na, or residual sodium carbonate (RSC) might equally be used for calculating a value which can be utilized as an index of ground water suitability for irrigation purposes (Shaki and Adeloye, 2006).

SAR is the most commonly used for evaluating groundwater suitability for irrigation purposes (Ayers and Westcot, 1985). It is normally expressed as Na content or alkali hazard which is normally expressed in Sodium adsorption ratio (SAR) (Rao, 2005). SAR is expressed as shown below (Hem, 1991):

$$SAR = \frac{Na^{+}}{\{[Ca^{2+} + Mg^{2+}]/2\}^{0.5}}$$

where the ion concentrations are expressed in meq/l, as shown above.

SAR values in irrigation waters have a close relationship with the extent to which Na is absorbed by soils. If water used for irrigation is high in Na and low in Ca, the ion exchange complex may become saturated with Na, which destroys soil structure because of dispersion of clay particles. As a result, the soil tends to become deflocculated and relatively impermeable. Such soils become very difficult to cultivate. The total concentrations of soluble salts in irrigation water can be classified as low (S1:<10), medium(S2:10-18), high(S3:18-26) and very high(S4:>26) (Rao, 2006). The zones (S1-S4) have the value of EC less than 250 µS/cm, 250-750 µS/cm, 750-2250 µS/cm and more than 2250 µS/cm respectively.

The US salinity lab's diagram (US Salinity Lab Staff, 1954) is used widely for rating irrigation waters, where SAR is plotted against EC. The analytical data plot is shown in Fig. 1.

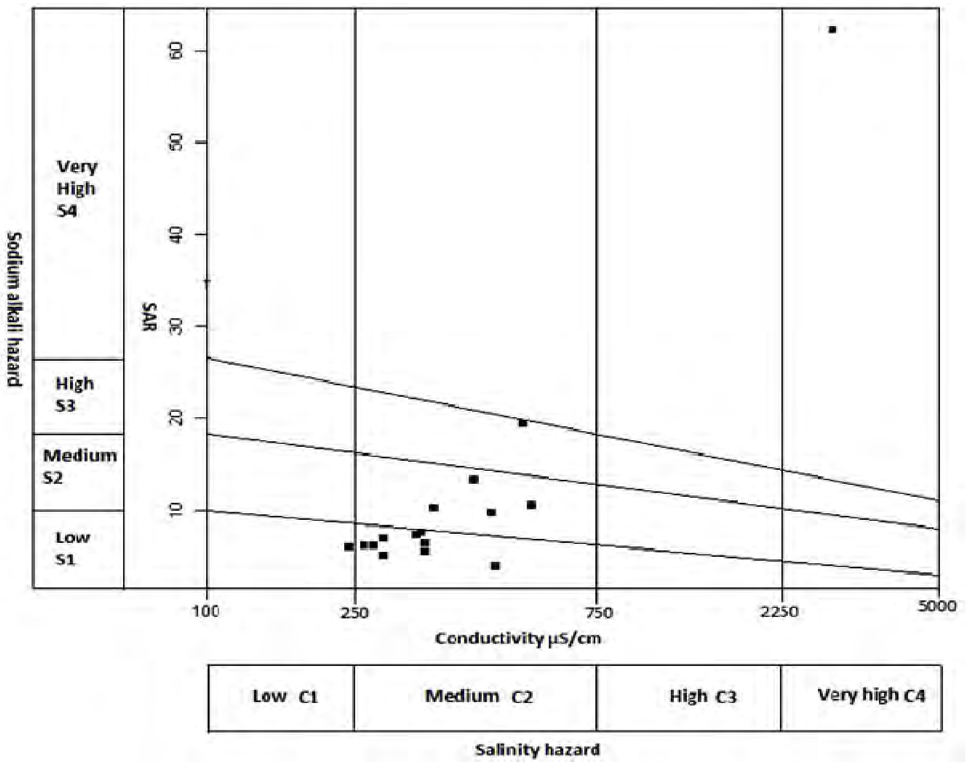

Fig. 1 Salinity diagram of groundwater samples from the study area

Fig. 1 is derived from Table 2 below, which refers to the table of classification of water samples based on salinity hazard and Table 3, which is classification based on USSL sodium hazard for irrigation.

Table 2 Classification of water samples based on salinity hazard

Salinity hazard class	EC(μS/cm)	Water class	Number of samples
C1	100-250	Excellent	3
C2	250-750	Good	12
C3	750-2250	Doubtful	0
C4	>2250	Unsuitable	1

Table 3 Classification of water based on USSL sodium hazard for irrigation

Sodium hazard class	SAR in equivalalent per mole	Water class	Number of samples
S1	<10	Excellent	11
S2	10-18	Good	3
S3	18-26	Doubtful	1
S4	>26	Unsuitable	1

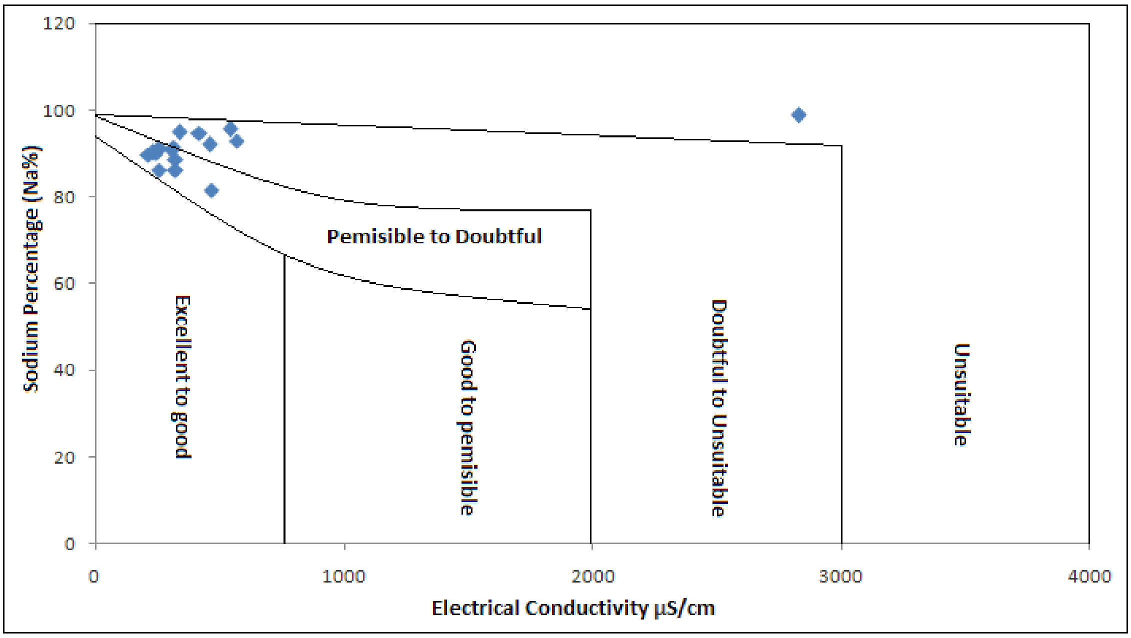

Fig. 2 Position of water samples on the Wilcox plots

Wilcox (1948) used percentage sodium and electrical conductance in evaluating the suitability of groundwater for irrigation. The Percent Sodium is computed with respect to the relative proportions of cations present in water, where the concentrations of ions are expressed in meq/l using the formula

$$\%Na^+ = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)}$$

Excess Na^+, combining with carbonate, leads to formation of alkali soils, whereas with chloride, saline soils are formed. Neither soil will support plant growth (Rao, 2006). Generally, $\%Na^+$ should not exceed 60% in irrigation waters. The Wilcox diagram showing the position of the water samples is represented by Fig. 2.

4 Conclusion and Recommendation

The groundwater samples from Teiman-Oyarifa community was assessed for their quality in terms of their potential for drinking and irrigation. The results revealed that groundwater in the study area were mostly acidic. Most of the water samples recorded TDS values less than WHO maximum allowable levels. Sodium ion concentration was generally high compared to other cations. The amounts of iron in the water samples were higher than recommended maximum allowable levels. Iron is a major component of all the wells and probably originated from the parent rocks. The measured concentrations of zinc in all the water samples were below WHO maximum permissible levels. Sodium adsorption ratio (SAR) values suggests suitability of groundwater from the study area for irrigation. This research may serve as a preliminary study to provide baseline information that may direct future water quality assessment studies in the study area.

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