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RESEARCH ARTICLE

ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION IN THE ODA RIVER BASIN, EJISU-BESEASE, GHANA

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ABSTRACT

Hydrochemical study is a useful tool to identify the suitability of groundwater for irrigation purpose. Groundwater samples were collected from fourteen piezometers from the various locations in the study area to assess the quality of groundwater for irrigation use. To achieve this objective, concentrations of physicochemical parameters were analysed and interpreted with different irrigation indexes like Sodium adsorption ratio (SAR), ECw, Percent sodium, Magnezium hazard and Kelly's ratio. The various parameters estimated showed that electrical conductivity values ranged between186 to 638 µS/cm, TDS values were less than 500mg/l, SAR values varies from 0.34 to 0.86 meq/l, Na % values ranges from 20.55 % to 44.09 %, MH values ranged between 25.86 % to 55.29 % and KR varying between 0.13 and 0.44. The hydrochemical study of the area revealed that alkaline earths exceed alkalis and weak acids exceed strong acids in groundwater which presented a Ca-Mg-HCO_3 groundwater type. Results from the groundwater chemistry of the boreholes plotted on the USSL diagram and the Wilcox diagram indicated that the groundwater is of good quality for irrigation. The study unraveled the mechanism controlling groundwater chemistry as the chemical weathering of rock-forming minerals and evaporation.

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INTRODUCTION

Human and ecological use of groundwater depends on ambient water quality. The concentration and composition of dissolved constituents in water actually determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Generally the suitability of groundwater for agriculture and domestic purposes largely depends on the site specific with possible temporal variations caused by climatic conditions, as well as the residence time of water within the aquifer materials and anthropogenic activities (Oladeji *et al.*, 2012; Ewusi *et al.*, 2013). Irrigation water quality is related to its effect on soils and crops and its management. High quality crops can be produced only by using high quality irrigation water keeping other inputs minimal (Islam and Shamsad, 2009). Much work has been done on quality of irrigation water (Kankam-Yeboah *et al.*, 1997; Opoku-Duah *et al.,* 2000; Odeh *et al.,* 2009; Achak *et al*., 2011; Srinivasa, 2013; Ayandurai, 2013; Khan *et al.,* 2013) to assess its suitability for irrigation, industrial and domestic purposes. The drastic increases in population, modern land use applications (agricultural and industrial), and increase demand for water supply has increase pressure on the globally essential groundwater resources in terms of both its quality and quantity (Dar, 2011). The quality of irrigation water depends on the concentration of dissolved salt within the recommended permissible limits. The use of poor quality of water for irrigation will have ramifications on both plant and soil. The problems associated with the use of poor quality water include reduction in infiltration rate and toxicity due to certain ions and excessive nutrients (Ayers and Westcot, 1994). In certain conditions, especially where there is accumulation of sodium ions in the soil structure due to

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extended use of irrigation water, could cause deterioration in the soil physical properties, and thereby results in the decrease of the crop yield (Oladeji *et al.*, 2012). Since physico-chemical composition of groundwater is a measure of its suitability as a source of water for agriculture (irrigation), industrial and domestic purposes, it is necessary to evaluate the hydrochemical characteristics of groundwater and this present study seeks to assess the quality of groundwater for irrigation purposes in the Ejisu-Besease Oda River basin.

Study Area

Besease is a predominantly farming area in the Ejisu Municipal District of the Ashanti Regionin Ghana. The site lies within Latitude1º15¹ N and 1º 45¹N and Longitude 6º15¹ W and 7º 00¹W. The study area covers about 72ha of the valley bottom lands at Besease (Figure 1). The climate of the study area is mostly related to the semi-humid type. The region is characterized with two distinct seasons, the wet season which begins from April and ends in October while the dry season extends from them on the of November to March. The wet season scan be categorized less than two rainy seasons. The major rainy season which ranges from mid-Marchto July and the minor rainy season starts from Septe mbertomid- November. The mean annual rain fall is 1420mm; mean monthly temperature is 26.5°C, the relative humidity ranges from 64% in January to 84% in August. The average monthly maximum and minimum evapotranspiration (ET_O) for the study area were 127.5mm and 64.7 mm and has anannual ET_O of 1230mm. The area is drained by the Oda River which is seasonal and whose basin is about 143km² (Kankam-Yeboah *et al.,* 1997). The study area is located in the moist semi-deciduous forest zone. Grass species prominently found in the valley bottom are *Santrocema trifolia, Chromolaeve ordorata, Imperata cylindrical, Mimosa pigra, Ceiba patendra, Centrosema pubescens and Mariscus flabelliformis*. Plantspecies like *Raphia hookeri (Raphia palm), Alstonia boonei, Malotus oppositifolius and Pseudospondias microcarpa* extends along the margins of the Oda River. Soils of the Ejisu- Besease can be found in the soil map of Kumasi area. The study are alies in the Offin soil series which are grey to light brown is h grey, poorly drainedalluvial sands and clays developed within nearly flat but narrow valley bottoms along streams. The series have very slow in ternaldrainage, very slow runoff, rapid permeability and moderate water holding capacity. The geology of the waters hed is relatively heterogeneous and mainly composed of Phyllites, quartzite, shale, Tarkwain and Voltaian-sandstone and limestone. The Phyllites which under lie 59% of the area consist of upper and lower Birimian rocks. Very few rock out crops were encountered in the survey as the rocks are deeply weathered. The weathered phyllite is soft and easily broken, recognizable pieces and is typically found at 2-3m below surface. Soils found within the Oda River catchment are grouped as those derived from granites, sandstones, alluvial materials, greenstone, andesite, schist and amphibolities. Specifically the soils are Orthi-ferric Acrisol, Eutric Fluvisol, Gleyic Arenosols, Eutric Gleysols and Dystri-Haplic Nitisol. The Besease aquifer is composed of heterogeneous sequence of layers which is dominated by sand, clayey and silts. The valley bottom is developed by small holder farmers who cultivate rice in the wet season and also grow vegetables like cabbage, lettuce, sweet pepper, cauliflower, cucumber and okra and other cereals like maize in the dry season when the water table is low.

Methodology

Water Sampling and Analytical Procedure

Fourteen water samples from installed piezometers were collected in clean plastic bottles for chemical analysis. At the time of sampling, bottles were thoroughly rinsed two to three times with the groundwater to be sampled. Samples collected were, stored in cooler boxes and transported to the laboratory where it was filtered using 0.45 millipore filter paper and acidified with nitric acid (Ultrapure Merck Brand) for cation analyses. For anion analyses, these samples were stored below 4°C. Major cations like Ca^{2+} and Mg^{2+} were analysed titrimetrically, using standard (0.02 N EDTA) and E.B.T indicator. Na^+ and K^+ were determined using flame photometer (Genway, PFP7). The chemical analysis was carried out as per standard procedures given in APHA (1995). HCO_3^- and Cl^- were determined by titrimetric method. Colorimetric spectrophotometer was employed to determine$SO_4^{2-}$and NO_3^- N. The concentrations were interpreted and calculated with irrigation indexes using the following formular as follows:

Sodium Adsorption Ratio

This was calculated using the equation (Raghunath, 1987) expressed as:

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

Where the ionic equations are expressed in meq/l.

Sodium Percentage

This was calculated employing the equation (Todd, 1995) expressed as:

$$Na\% = \frac{(Na^+ + K^+) \div (Ca^{2+} + Mg^{2+} + Na^+ + K^+)}{100}$$

Where the ionic equations are expressed in meq/l.

Kelly's Ratio

This was calculated employing the equation (Kelly, 1963) expressed as:

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

Where the ionic equations are expressed in meq/l.

Magnesium Hazard

This was calculated employing the equation (Szabolcs and Darab, 1964) expressed as:

$$KR = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100$$

Where the ionic equations are expressed in meq/l.

possible solubility processes of calcium carbonate rich deposit (Abd-Alrahman, 2011). Magnezium was found to vary from 8.7 to 21 mg/l. Sodium and Potassium concentrations ranges between 10.8 to 22 mg/l and 2 to 26.3 mg/l.

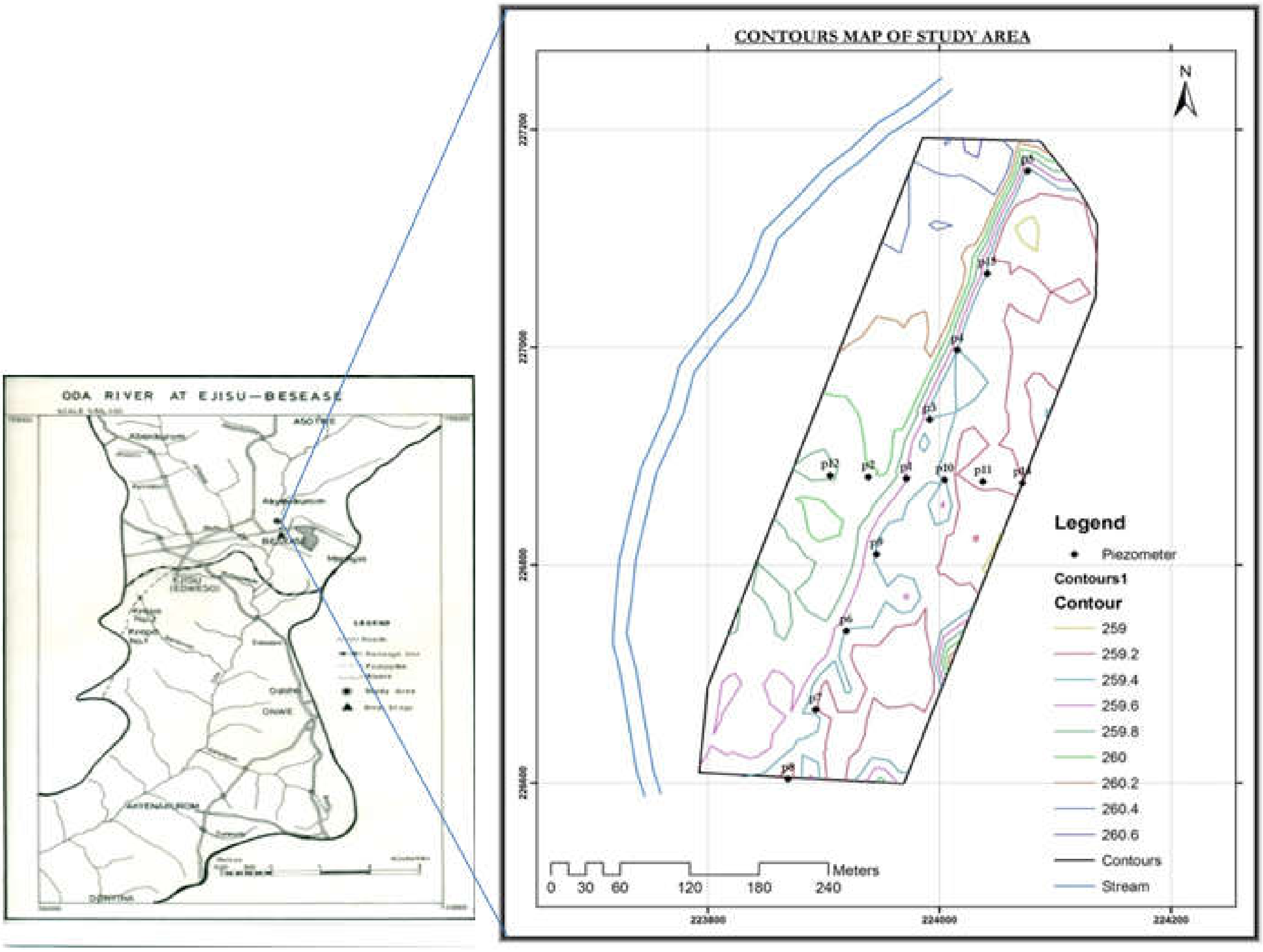

Figure 1. Map of Besease project site showing locations of water sampling points

RESULTS AND DISCUSSION

Hydrochemical Characteristics of groundwater

For assessing the suitability of groundwater for drinking, agricultural and industrial purposes, understanding the chemical composition of groundwater is necessary. The physico-chemical analysis of the shallow groundwater samples is presented in Table 1. The pH values at the Besease Wetlands exhibit slightly less acidic and alkaline behaviour which shows that groundwater is neutral with average value of 7.02. Electrical conductivity (EC) values of groundwater samples ranges between 186 to 638 µS/cm at 25°C which were found within the permissible limits (Ayers and Westcot, 1985). The higher value of EC at P14 suggests the enrichment of salt due to possible evaporation and groundwater flow direction effect and additional leaching derived from anthropogenic sources. Calcium ranges between 19 – 52 mg/l. The high Calcium content of the sample at P13 may be due to leaching and

Bicarbonate content ranges between 150 to 421 mg/l with an average of 268.2 mg/l. Bicarbonate represents the major sources of alkalinity. Bicarbonate was slightly higher indicating a contribution from carbonate weathering process. Chloride concentration in the groundwater samples of the area varies from 15.95 to 46.09 mg/l. The sulphate and nitrate content ranged from 17.29 to 44.19 mg/l and 37.2 to 130.2 mg/l respectively. High nitrate at P14 suggest greater mineralization of plant matter that has been buried under seasonal alluvial deposition. Also the range of values obtained for the total dissolved solids (TDS) is between 140.7 to 427.5 mg/l with a mean value of 234.28 mg/l. These values are less than the permissible limits of 1000 mg/l recommended by (WHO, 2006).

Graphical Representation of Hydrochemical Data

Groundwater geochemical evolution can be understood by plotting the major cations and anions concentration on the piper trilinear diagram developed by Piper (1944).

Table 1. Chemical Constituent of Groundwater

Sample	pH	EC_{Ew} (µs/cm)	Ca^{2+}(mg/l)	Mg^{2+}(mg/l)	Na^{+}(mg/l)	K^{+}(mg/l)	HCO_3^-(mg/l)	NO_3^-(mg/l)	SO_4^{2-}(mg/l)	Cl^-(mg/l)	TDS	SAR	% Na	K' ratio	MH
P1	6.5	356	19	12.6	15.6	20	220	37.2	32.18	26.59	238.5	0.68	37.48	0.34	52.23
P2	6.7	215	23	13.5	17.3	23	330	68.2	28.34	18.43	144.1	0.71	37.25	0.33	49.18
P3	7.2	208	20	8.7	12.5	15	252	55.8	41.79	24.11	139.4	0.59	35.11	0.32	41.77
P4	7.4	329	37	14.3	16.8	2	186	86.8	44.19	15.95	220.4	0.59	20.55	0.24	38.92
P5	7.1	242.3	48	13	11.6	23.8	160	43.4	21.61	23.04	162.3	0.38	24.32	0.15	30.87
P6	6.9	318	45	18	10.8	24	209	80.6	17.29	21.27	213.1	0.34	22.53	0.13	39.74
P7	7.2	280	27	12.5	13	26	150	74.4	25.94	25.52	187.6	0.52	34.12	0.24	43.29
P8	7.3	590	25	10	18.4	28	421	99.2	20.65	29.42	395.3	0.79	42.28	0.39	39.74
P9	6.8	367	33	19.6	16.8	18	386	74.4	32.18	42.54	245.9	0.57	26.76	0.22	49.48
P10	7.2	420	28	21	22	22	195	111.6	43.23	18.43	281.4	0.77	32.72	0.31	55.29
P11	6.9	536	30	14	17.6	31	370	130.2	27.86	17.37	359.1	0.67	37.04	0.29	43.48
P12	7.1	210	29	12	10.5	17	280	43.4	34.58	46.09	140.7	0.41	26.81	0.19	40.55
P13	7.2	186	52	11	13.8	21	236	49.6	32.18	21.27	124.6	0.45	24.53	0.17	25.86
P14	6.8	638	22.4	9.72	19.3	26.3	360	93	18.73	19.14	427.5	0.86	44.09	0.44	41.71
Ave.	7.02	349.7	31.31	13.57	15.4	21.2	268.2	74.8	30.05	24.94	234.3	0.595	31.83	0.27	42.3

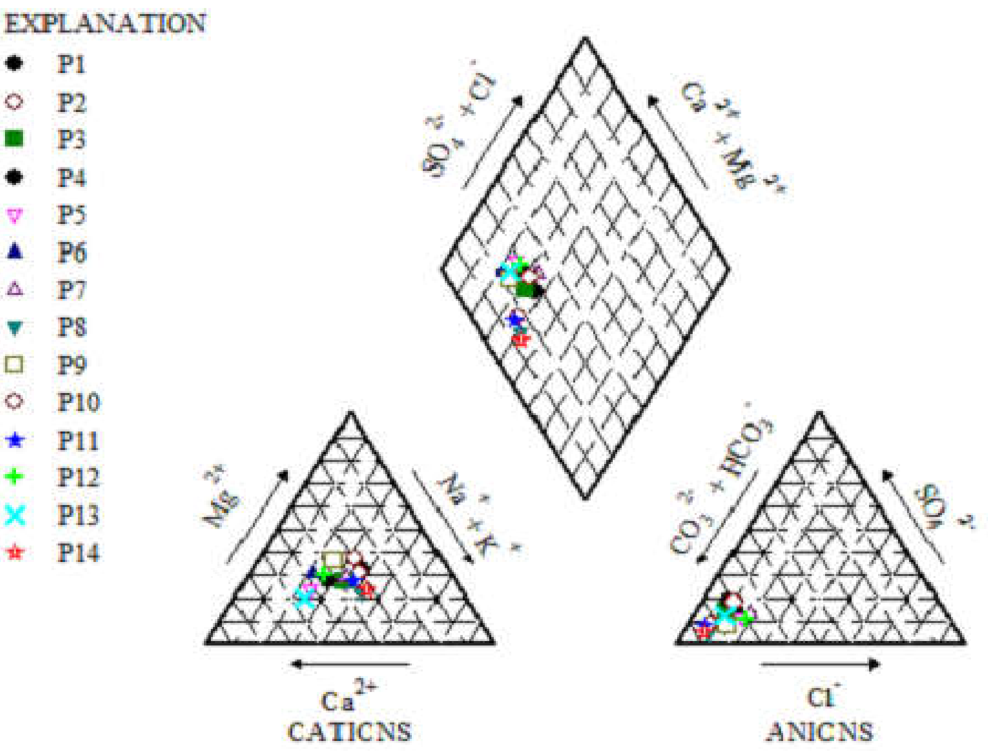

Figure 2. Piper Plots for Groundwater Samples

Table 2. Suitability for irrigation based on ECw

EC (µS/cm)	Salinity class	Suitability for irrigation	Percentage of Samples
<250	C1	Excellent (Low)	35.7
250-750	C2	Good (Medium)	64.3
750-2250	C3	Doubtful (High)	Nil
2250-5000	C4	Unsuitable (VeryHigh)	Nil

Table 3. Suitability for Irrigation based on SAR

SAR(meq/l)	Suitability for irrigation	Percentage samples
<10	Excellent	100
10-18	Good	Nil
18-26	Doubtful	Nil
>26	Unsuitable	Nil

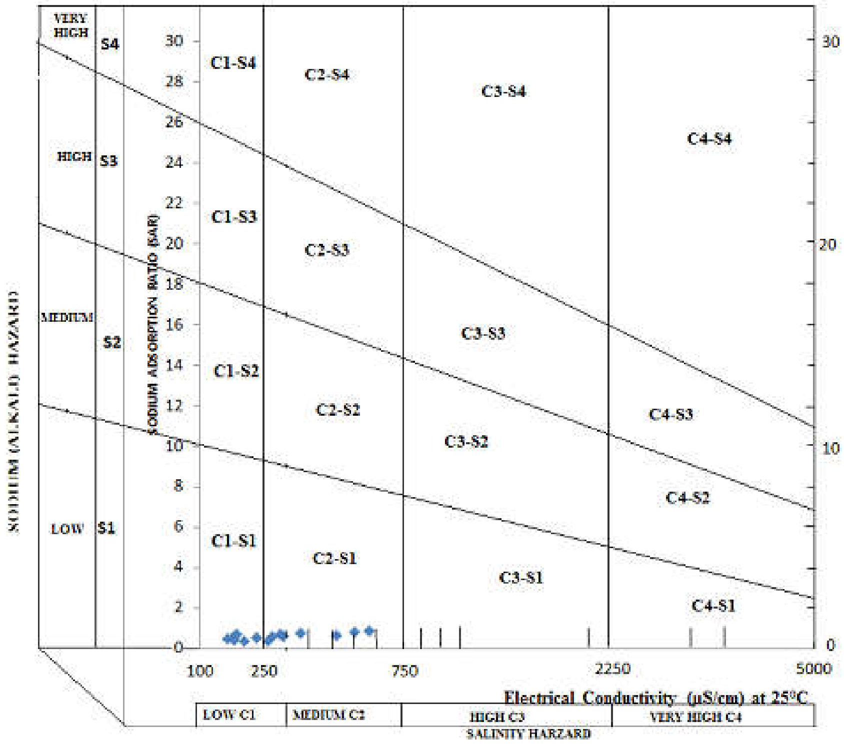

Figure 3. US Salinity diagram for groundwater samples at Besease inland valley bottom

Table 4. Suitability for irrigation based on Na %

Na %	Suitability for irrigation	Percentage samples
<20	Excellent	100
20-40	Good	Nil
40-60	Permissible	Nil
60-80	Doubtful	Nil
>80	Unsuitable	Nil

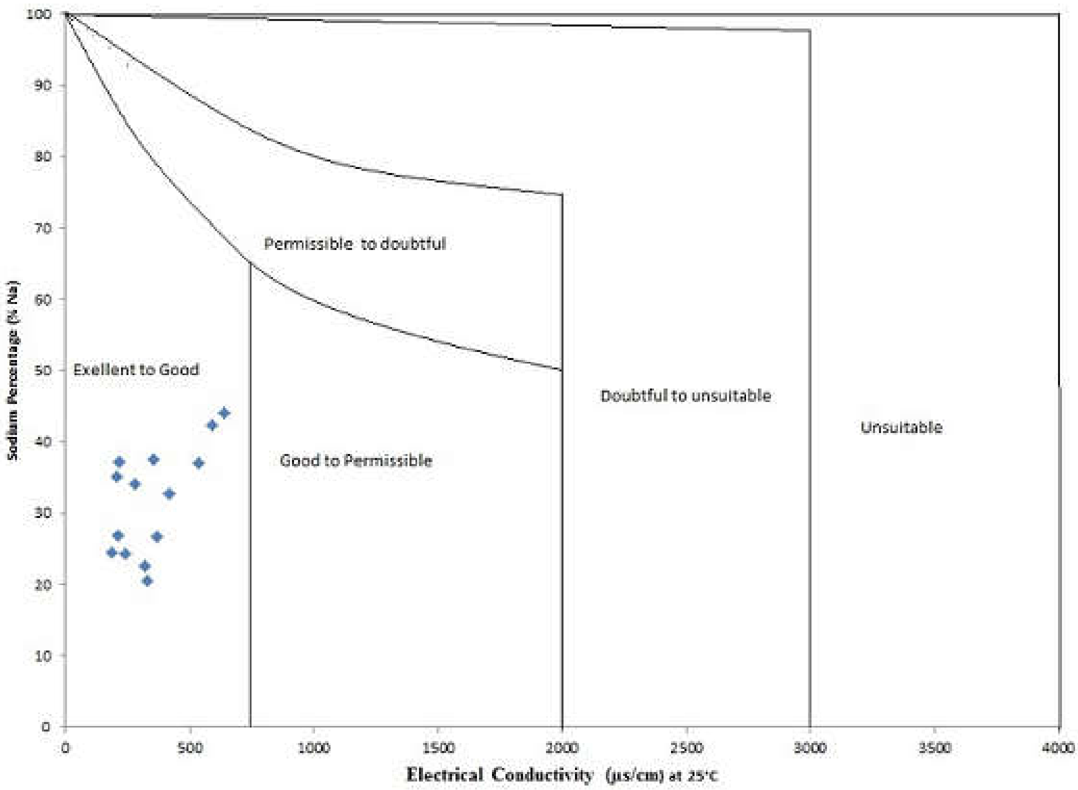

Figure 4. Wilcox diagram for classification of groundwater quality in the study area

The piper diagram combines three distinct fields for plotting, two triangular fields at the lower left and lower right respectively and an intervening field. Each apex of the triangle represents a 100 % concentration of one of three chemical constituents. Major ions are plotted in the two base triangles of the diagram as cation and anion percentages milligram per litre. The overall cations and anions are each considered as 100 %.The overall characteristic of the water is represented in the diamond-shaped field by projecting the position of the plots in the triangular fields. Different types of groundwater can be distinguished by their plotting position, occupying certain sub-areas of the diamond-shaped field. Piper–trilinear plots were made for the samples collected during the field visits. A perusal of hydrochemical character from Piper Trilinear Diagram (Fig.2) showed that alkaline earths (Ca^{2+} and Mg^{2+}) exceeded alkalis (Na^+ and K^+) and weak acids (HCO_3^- and CO_3^{2-}) exceeded strong acids (Cl^- and SO_4^{2-}) in the groundwater which presented a $CaHCO_3$ groundwater type which indicated sufficient recharge from fresh water.

Groundwater Quality Analysis for Irrigation

Electrical Conductivity

Suitable irrigation practices are invariably influenced by water quality, soil types and cropping practices. One of the important chemical constituents that affect the suitability of water for irrigation is the EC. If EC of irrigated water is high, it will affect root zone and water flow Srinivassa (2013) noted that the higher the EC, the lesser the water available to plants, even though the soil may show wet, because plants can only transpire ''pure'' water. Higher salt content in irrigation water causes an increase in soil solution osmotic (Ayers and Westcot, 1994). The EC classification in the study (Table 2) indicated that the overall water quality was excellent (35.7 %) to good (64.3 %) category.

SAR

One of the most important parameter for the determination of desirability of irrigation water is SAR. Excessive sodium content relative to calcium and magnesium reduces the soil permeability and thus inhibits the supply of water needed for the crops (Kumar *et al*., 2007). Na has the ability to disperse the soil, when present above a certain threshold value relative to the concentrations of total dissolved salts. Selvam *et al.* (2012) posited that if water used for irrigation is high in sodium and low in calcium content, then exchangeable calcium in soil may replace sodium by base exchange reaction in water. This can destroy the soil structure owing to dispersion of the clay particles. Osmotic activity is reduced by excess sodium which interferes with the absorption of soil water and nutrient. SAR values vary from 0.34 to 0.86 with an average of 0.60. All the groundwater samples fall under the excellent category (Table 3) which shows that groundwater within the study area is suitable for irrigation purpose.

USSL Diagram

The hydrochemical data plotted on the US salinity diagram (Fig. 3) proposed by US Salinity Laboratory Staff (1954) 64.3 % of the groundwater samples fell in the field of C2-S1, indicating water of medium salinity and low sodium, which can be used for irrigation in almost all types of soil with little danger of exchangeable Na^+. Also 35.7 % of the groundwater samples from P5 fell under C1-SI, indicating water of low salinity and low sodium content, which could be used for irrigation in all types of soils. A rise in conductivity values may reduce soil permeability especially if inadequate drainage facilities exist at the Besease site. Groundwater of this pH level is considered suitable for irrigation

Percent Sodium

Sodium content is generally in terms of percent sodium or soluble sodium Percentage. Excess sodium in waters produces undesirable effects of changing soil properties and reducing soil permeability. A set of proportion of air and water in the pore spaces is required for the proper growth of plants. Khan and Abbasi (2013) observed that the sodium content of water react with the soil and accumulate in the pore spaces thus reducing it permeability. In all natural waters percent of sodium content is a parameter to evaluate its suitability for agricultural purposes. Sodium combining with carbonate can lead to the formation of alkaline soils, whereas sodium combining with chloride form saline soils (Wilcox 1955). Soils of this nature do not support plant growth. The computed values of percent sodium (%Na) ranged from 20.5 % to 42.28 % with the mean value of 31.82 % (Table 4) which shows that groundwater samples are below the threshold of 50 percent. The result indicates that water has no sodium hazard and fit for irrigation as far as sodium percent is concerned.

Wilcox Diagram

Wilcox (1955) employed sodium percent and electrical conductivity in assessing the suitability of groundwater for irrigation purposes. Groundwater samples of the study area were plotted in the Wilcox's diagram (Wilcox 1955) to classify the water for irrigation, in which EC_w is plotted against Na %. Figure 4 shows that all the groundwater samples are excellent to good for irrigating croplands.

Table 5. Suitability for irrigation based on KR

KR	Suitability for irrigation	Percentage samples
<1	Suitable	100
>1	Unsuitable	Nil

Table 6. Suitability for irrigation based on MH

MH	Suitability for irrigation	Percentage samples
<50	Suitable	85.7
>50	Unsuitable	14.3

Kelly's Ratio (HR)

Kelly *et al.* (1940) have opined that the sodium problem in irrigated water could be taken into consideration on the bases of the values of Kelly's ratio. Groundwater having kelly's ratio more than one is considered not suitable for irrigation purposes. The calculated Kelly's ratio for all the groundwater samples in the study area varies from 0.13 to 0.44 with an average value of 0.27. All the groundwater samples had KR values less than one (Table 5) which indicates that groundwater of the Besease wetlands in the Oda River basin is of good quality for irrigation purpose.

Magnezium Hazard (MH)

Although Magnezium and Calcium concentrations are ensential for plant growth but may be associated with soil aggregation and friability (Khodapanah *et al*., 2009). Excess of magnizium affects the quality of soils which is the cause of poor yield of crops (Ayyandurai, 2013). $MH > 50$is considered harmful and unsuitable for irrigation use. In the study area the MH values range between 25.86 % and 55.29 % (Table 1). The results show that 85.7 % of the groundwater samples have $MH < 50$ and are classified as suitable for irrigation use whiles 14.3 % are undesirable for irrigation (Table 6).

Conclusion

The hydrochemistry of the groundwater quality studies revealed that alkaline earths (Ca^{2+}-Mg^{2+}) exceeded alkalis (Na^{+}-K^{+}) and weak acids (HCO_3^{-}-CO_3^{2-}) exceeded strong acids (SO_4^{2-}-Cl^{-}) in groundwater thus giving a Ca-Mg-HCO_3 groundwater type. It was found out that the dominant HCO_3^{-} and Ca^{2+} indicated that recharging water is of limestone aquifer. The results shows that 64.3 % of the groundwater samples fell in the field of C2-S1, indicating water of medium salinity and low sodium, which can be used for irrigation in almost all types of soil with little danger of exchangeable Na^{+}. Analysis of groundwater from the fourteen piezometers showed an overlap of the physico-chemical parameters and water chemistry results indicating that the groundwater is of good quality for irrigation. It can be concluded that the mechanism controlling groundwater chemistry is the chemical weathering of rock-forming minerals and evaporation.

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Conflict of Interest

The studies reported in this publication, were supported by a grant from the Ministry of Food and Agriculture (MoFA), Ghana. The author is a lecturer at the University of Energy and natural Resources, Ghana. The terms of this arrangement have been reviewed and approved by the University of Energy and natural Resources at Sunyani in accordance with its policy on objectivity in research.

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