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Water Quality Assessment of Selected Wells in the Farmer-led Irrigation System in Anloga District, Volta Region, Ghana

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Abstract: *Increased groundwater extraction for irrigation is leading to the intrusion of saline seawater into many wells in some communities in Anloga District, Volta Region, Ghana, with resultant adverse effects on crop productivity. This study investigated the water quality of selected wells in four communities of the district for their suitability for irrigation. Water samples were collected from 10 representative wells, purposively selected out of 60, to determine the pH, electrical conductivity, total dissolved salt by means of a pH/EC/TDS/Temperature portable meter, and the concentrations of sodium, potassium, calcium, magnesium, sulphates, chlorides, bicarbonate and nitrate, using standard chemical laboratory procedures. The geochemical characterization of the sampled water sources was carried out using the Piper trilinear diagram, and revealed the dominance of Na-Cl facies of the groundwater in Tegbi, Whuti and Anyanui, suggesting seawater encroachment connected with groundwater abstraction. The water samples from wells in Woe indicated the Ca-Mg-Cl-SO_4 mixed type and are considered suitable for irrigation. About 50% of the sampled wells could be classified under the high salinity-low sodium hazard (C3-S1), 20% are under very high salinity-medium sodium hazard (C4-S2), another 20% under very high salinity-high sodium hazard (C4-S3) and 10% under medium salinity-low sodium (C2-S1) classes. These wells are prone to salinity, and farmers' discretion is recommended through the adoption of conditional use of the irrigation water such as growing of salt-tolerant crops.*

Keywords: *Irrigation, Wells, Water Extraction, Salinity, Anloga District*

1. INTRODUCTION

Groundwater has been described as the hidden wealth of nations, and nature's water insurance, accounting for about 49% of all water abstracted for home use and 43% of all water used for crop irrigation globally, mitigating half of the losses in agricultural yield resulting from drought [1]. In Africa, groundwater is a precious natural resource that provides reliable water supplies to millions of people [2]. Relatively abundant groundwater resources exist in Ghana, with more than 56,000 groundwater abstraction systems, which represent less than 5% of the average annual groundwater recharge in most of its river basins [3].

Already, surface water is vulnerable and scarce in many places, so groundwater plays an important role in economic development and human survival. Many small-scale vegetable farmers use shallow groundwater for irrigation in many parts of Ghana. Official statistics do not always reflect this use of groundwater for irrigation by small scale farmers, instead, there is a focus on the larger-scale, often state-run irrigation schemes which do not report irrigation with groundwater independently from the surface water irrigation data. This is likely because in most of sub-Sahara Africa there is a general view that groundwater yields are simply not sufficient for agricultural development.

Groundwater is a significant source of drinking water and irrigation [4]. Therefore, ensuring its quality is crucial as high-quality water is essential for domestic and irrigation purposes [5]. The quality of groundwater is influenced by both geogenic and anthropogenic factors in a specific area [6]. Geogenic factors include atmospheric precipitation, recharge area quality, and subsurface geochemical processes. Anthropogenic activities such as mining, agriculture, domestic and industrial waste, and solid waste dumping also impact groundwater quality [6].

The influx of seawater into fresh groundwater in coastal aquifers, amplified by an increase in water abstraction and rising sea levels increases vulnerability to saltwater intrusion [7, 8, 9]. Seawater intrusion connected with groundwater abstraction has been reported in many coastal aquifers some parts of world, for example, the United States of America (USA), and the degree of seawater intrusion varied significantly among localities and hydrogeological settings [10, 11, 12].

The rising sea levels push seawater into coastal freshwater aquifers, resulting in salinization that adversely impacts the quality of the water abstracted from the groundwater [13]. Under normal conditions, freshwater moves towards the sea, preventing seawater encroachment into coastal aquifers. An interface exists between the freshwater and seawater, sustained by the denser seawater underlying the freshwater [9, 12]. As groundwater is abstracted from the coastal aquifer through pumping, the lowered water levels in the aquifer cause seawater movement toward the freshwater zones of the aquifer. The encroaching seawater tends to decrease the freshwater storage in the aquifers through salinization [9, 12]. Hence, the encroached groundwater may not conform to agricultural water-quality standards without treatment [10].

The high salinity levels of groundwater in some tube wells and open wells in the Anloga District, and their use for irrigation purposes, have necessitated an overall assessment of the quality of groundwater in the study area. Salinization of groundwater can decrease soil and crop productivity [14].

Scanty information exists on the effects of well water qualities for irrigation in the Anloga District, Volta Region, Ghana. With reported cases of low yield of irrigated crops in the area, it became necessary to investigate the qualities of the irrigation water abstracted from shallow wells in the area with a view to evaluating their effects on crop production. Anloga District is situated near the Keta Lagoon, which connects to the Gulf of Guinea, which is part of the Atlantic Ocean [15]. This further necessitates the investigation of possible salinization of the wells through seawater intrusion. The objective of this study, therefore, is to assess the salinity levels and suitability of groundwater for irrigation in salt-prone communities of Anloga District, Volta Region, Ghana, during the dry season when irrigation activities are carried out.

2. METHODOLOGY

2.1 Study Area

The Anloga District is located within longitudes 5°47'N and 0°53'E. While it is not directly adjacent to the open sea, it is situated near the Keta Lagoon which connects to the Gulf of Guinea, which is part of the Atlantic Ocean (Figure 1). The district is within Ghana's dry equatorial climatic region [15]. It has a mean monthly temperature of 30 °C in the warmest month, March, and about 26 °C in the coldest month, August [16]. The annual rainfall is less than 900 mm with an uneven distribution over the year. Rainfall is bimodal, with the major season starting in April and peaking in June and the minor season from September to November [17]. Rainfall is erratic, unreliable, and usually in a few heavy showers during the minor season, and the harmattan dominates from November to February with winds from the northeast, which gives rise to a long dry season [16]. Some of the prominent communities in the district include Tegbi-Kpota, Tegbi-Xekpa, Tegbi-Agbedrafor, Anloga-Avume, Woe-Abiwukorfe, Whuti, Dzita-Agbledomi, and Anyanui.

Figure 1: Anloga District in Volta Region, Ghana

The groundwater geology of Anloga comprises Cenozoic and Mesozoic sediments, including coastal sea sand, sandy clay gravel, marine shale, unconsolidated alluvial sediments, glauconitic sandstone and limestone [18]. Soils on the sand spit are internally well drained with groundwater occurring within 1 m [19]. As shown by Asomaning *et al*. [17] in Figure 2, the groundwater consists of a thin local freshwater lens superimposing salty groundwater. The uncultivated soil is denoted as U while the farmland soils are denoted by F.

Groundwater from the shallow freshwater aquifer that underlies the sand bar is used for domestic purposes and irrigation of horticultural crops, majorly shallot, okra, tomato, pepper, cassava, maize, carrot, and spring onion [20]. The groundwater is abstracted through open hand-dug well and shallow tubewells, and these wells are scattered in all the farmlands. The sprinkler irrigation system is widely practiced. Farmers with open wells lift water manually from them to spray on their crops, and those with tubewells use electric motor pumps which are connected to the sprinkler system to irrigate the crops. As the human population increases in the area and more farmers sinks wells for irrigation purpose, the intense groundwater abstraction seems to be combing up saltwater into the wells, especially at the peak of the dry season in some of the communities in the study area. Farmers and Agricultural Extension Workers of the District Agricultural Department have severally complained of this challenge in different fora.

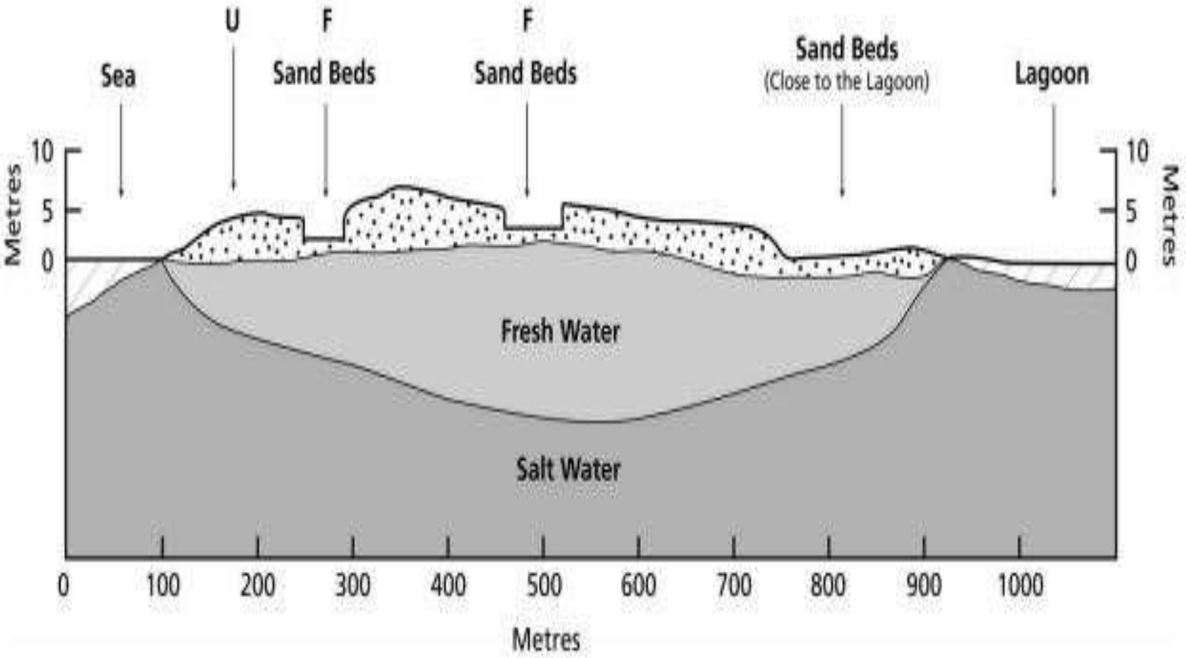

Figure 2: Cross section of the fresh groundwater and the sand beds through the Keta sand spit

2.2 Well Selection and Water Sample Collection

Prior to the selection of the water wells for this study, a reconnaissance survey and a focus group discussion between the International Water Management Institute (IWMI) team, Ghana, and the Farmer-based Organizations (FBOs) were carried out to identify communities with complains of farmlands threatened by saltwater intrusion. Four communities including Tegbi, Woe, Anyanui, and Whuti, were purposively selected for assessment of their groundwater as their farmlands seemed to be systematically prone, mainly due to their locations, being either very close to the Atlantic Ocean or near the fringes of a section of the Keta lagoon (Figure 1). Preliminary in-situ water quality tests were carried out in 60 wells from volunteered farmers in the four communities using the MI 806 pH/EC/TDS/Temperature portable meter (Milwaukee Instruments, Inc., USA). The survey, focus group discussion and the in-situ salinity mapping are reported in Igbadun *et al*. [21].

Ten wells with relatively high salinity parameters were purposively selected from the sixty wells further analysis during the dry season. Three wells were sampled in each of Tegbi and Anyanui, and two in each of Woe and Whuti. The pH, Electrical Conductivity (EC) and Total Dissolved Solid (TDS) were monitored in-situ on monthly basis from December 2021 to March 2022. At the peak of the dry season (Mid-February) when the level of water abstraction for irrigation was highest, water samples were collected from each well for laboratory analyses to understand the scales of the physiochemical parameters at peak dry season and water abstraction. Sampling was done using sterilized high-density polyethylene bottles of 350 ml rinsed with distilled water at the collection point. Drops of nitric acid were added to the water samples meant for metal analysis. The samples were carefully labelled, stored in an ice chest with ice, and transported to the Council for Scientific and Industrial Research (CSIR) -Water Research Institute's laboratory in Accra, Ghana, for analyses. The water samples were analysed for sodium, potassium, calcium, magnesium, chloride, sulphate, phosphate, nitrate, calcium hardness, magnesium hardness, total hardness and bicarbonate. The samples were collected in triplicates from each sample point, and the water temperature was measured at each sampling time.

2.3 Samples Analyses

The pH, electrical conductivity (EC) and total dissolved salts (TDS) of the samples were measured monthly from December 2021 to March 2022 (during the dry season) with MI 806 pH/EC/TDS/Temperature portable meter (Milwaukee Instruments, Inc., USA) in order to establish the water quality trend within this period. The flame photometric method was used to determine the sodium (Na) and potassium (K) concentrations. The flame photometer was calibrated with the standard stock of Na and K solution of 30 ppm concentration, with various other instrumental parameters adjusted to fine-tune the flame [22, 23, 24]. Ethylenediaminetetraacetic acid (EDTA) titration was used to determine Ca and Mg as described by [25, 26]. Chloride (Cl^-) was analyzed with the argentometric method; The Hydrogen carbonate (HCO_3^-) was determined from the titration method of alkalinity using 0.01M HCl, Phenolphthalein, and methyl orange indicators; Nitrate (NO_3^-) was determined by colorimetric method; Sulphate (SO_4^{2-}) was determined using the turbidimetric method and spectrophotometric method for PO_4 [27]. Total Hardness (TH) was calculated using Equation (1) [28]. Cationic concentrations were expressed in mg/L.

$$TH = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+} \tag{1}$$

The values of each of the EC, TDS, SAR, Na, Cl, NO_3^-, HNO_3^-, and pH were compared to the Food and Agriculture Organization (FAO) guidelines for irrigation water [29] to assess the quality of the water samples for irrigation purposes. Sodium Adsorption Ratio (SAR) was calculated to evaluate the suitability of the water quality for agricultural purposes. The SAR was calculated with Equation (2) [30]:

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

where, Na^+, Ca^{2+} and Mg^{2+} are the concentrations of sodium, calcium, and magnesium ions in meq/L. The SAR results were plotted on the United States Salinity Laboratory (USSL) diagram for classifying irrigation waters and interpreted. The soluble sodium percentage (SSP), magnesium adsorption ratio (MAR), Kelly's ratio (KR), and sodium percentage (%Na) were calculated using Equations (3), (4), (5), and (6) as expressed by [28], [31], [32], [33], respectively; all the cation concentrations are in meq/L.

$$SSP = \frac{(Na^+ + K^+)\times 100}{Ca^{2+}+Mg^{2+}+Na^+ + K^+} \tag{3}$$

$$MAR = \frac{Mg^{2+}\times 100}{Ca^{2+}+Mg^{2+}} \tag{4}$$

$$KR = \frac{Na^{2+}}{Ca^{2+}+Mg^{2+}} \tag{5}$$

$$\%Na = \frac{Na^+\times 100}{Ca^{2+}+Mg^{2+}+Na^+ + K^+} \tag{6}$$

where, K^+ is sodium concentration and all other cations are as previously defined in Equation (2).

Charge-balance error (CBE, %) estimation was carried out to determine the accuracy of the groundwater quality analysis. This is based on the electroneutrality condition of water in the natural ecosystem; that is, the sum of concentrations of all anions must be equal to the sum of concentrations of all the cations, the concentrations being expressed in meq/L. CBE (Equation 7) is the deviation from neutrality and is expressed as:

$$CBE = \frac{\sum cations - |\sum anions|}{\sum cations + |\sum anions|} \times 100\% \tag{7}$$

where, CBE is the charge-balance error, and $\sum$ cations (meq/L) and $\sum$ anions (meq/L) are the sums of cations and anions, respectively. The acceptable limit of the calculated CBE is ± 5 [34].

2.4 Salinity Classification of Irrigation Water

Salinity classification for irrigation water can be based on the classes developed by [35, 36] on almost all soils with little sodium hazard developing as shown in Table 1. A hydro-chemical classification of the groundwater samples was further carried out using the Piper's trilinear diagram [37] which plots the concentrations of the major cations and anions on a combination of cation and anion triangle that lie on a common baseline. The Piper diagram classifies the water samples on the basis of the hydro-chemical facies in the cation and anion triangles and in the diamond.

Table 1: Salinity classes standards of irrigation water

Salinity Classes of Irrigation Waters		Hazard
Salinity (mS/cm)	Salinity Class	
100 – 250	C1	Low
250 – 750	C2	Medium
750 – 2250	C3	High
>2250	C4	Very High

Source: USSL Staff [35]; Wilcox [36]

3. RESULTS

3.1 pH of Sampled Wells

The pH of the wells at the four locations from December 2021 to March 2022 are presented in Table 2. The pH values for the wells in Tegbi ranged from 7.31 to 8.31 during the study period. The lowest value (7.31) was recorded in well A3 in February and March, while the highest value (8.31) was recorded in well A1 in December. The pH data for Tegbi was most consistent in February with standard error (SE) of ±0.04. At Woe the pH ranged from 7.54 to 8.13. The lowest mean value (7.61) was recorded in March while the highest (8.08) was in January. The readings for March were the most consistent (SE = ±0.02). The wells in Whuti recorded pH range of 7.50 to 8.29. The lowest mean value (7.45) was obtained in December while the highest mean (8.05) was obtained in January. The results were most consistent in March (SE = ±0.02). The pH values for the wells in Anyanui ranged from 6.6 to 7.4. The minimum (6.37) and maximum (7.67) pH values were recorded in well A10 in February, and in well A8 in January, respectively.

Table 2: pH of sampled wells

Location	Well	Dec	Jan	Feb	Mar
Tegbi	A1	8.31	7.78	7.44	7.48
	A2	7.4	7.97	7.41	7.4
	A3	7.57	7.58	7.31	7.31
	Mean	7.76	7.78	7.39	7.40
	SE±	0.28	0.11	0.04	0.05
Woe	A4	7.59	8.02	7.74	7.59
	A5	7.64	8.13	7.54	7.62
	Mean	7.62	8.08	7.64	7.61
	SE±	0.03	0.06	0.10	0.02
Whuti	A6	7.39	8.29	7.61	7.5
	A7	7.5	7.8	7.54	7.54
	Mean	7.45	8.05	7.58	7.52
	SE±	0.06	0.25	0.04	0.02
Anyanui	A8	7.18	7.67	7	6.81
	A9	6.76	6.62	7.08	6.6
	A10	6.49	7.43	6.37	7.4
	Mean	6.81	7.24	6.82	6.94
	SE±	0.20	0.32	0.22	0.24

3.2 Electrical Conductivity (EC, µS/cm) of Sampled Wells

Table 3 shows the EC of the wells in the four locations during the period of the study. The EC ranged between 573 to 4017 µS/cm in Tegbi and the values were fairly constant for each of the three wells. The sampled wells at Woe recorded EC range of 1317 to 1600.0 µS/cm. The EC slightly increased from December 2021 and attained the highest value in February 2022 and then decreased. The EC of sampled wells at Whuti ranged between 2176.7 to 2823.3 µS/cm and was steady for each of the throughout the observation period. For the EC observations in the wells at Anyanui, the least and highest values were 1756.7 and 3781.7 µS/cm. The EC for well A8 increased from December to February where it peaked and decreased afterwards in March while the EC for well A10 decreased from December to February and increased in March. However, the EC for well A9 remained almost constant throughout the period.

3.3 Total Dissolved Solids (TDS, mg/L)

The total dissolved solids (TDS) of the sampled wells are as presented in Table 4. The values ranged from 380 to 2667 mg/l for the sampled wells at Tegbi. The TDS values were steady for each of the sampled three wells for the period of data collection. The TDS values for wells in Woe ranged from 870.0 to 1070.0 mg/l. The values slightly increased from December 2021 and peaked in February 2022, and then decreased. TDS of wells at Whuti ranged from 1436.7 to 1860 mg/l. The values were steady throughout the study period. The wells in Anyanui recorded TDS range of 1160.0 to 2496.7 mg/l during the study period. The TDS for well A8 increased from December to February where it peaked and decreased afterwards in March while the TDS for well A10 decreased from December to February and then increased in March. However, the TDS for well A9 remained almost constant throughout the period.

Table 3: Mean Electrical conductivity, EC (µS/cm) of sampled wells

Location	Well	Dec	Jan	Feb	Mar
Tegbi	A1	3950	1332	3920	4005
	A2	570	509	570	578
	A3	2140	1315	2050	1950
	Mean	2220	1052	2180	2178
	SE±	977	272	969	996
Woe	A4	1320	1052	1620	1550
	A5	1390	1084	1410	1445
	Mean	1355	1068	1515	1498
	SE±	35	16	105	53
Whuti	A6	2540	1209	2820	2750
	A7	2180	1237	2400	2155
	Mean	2360	1223	2610	2453
	SE±	180	14	210	298
Anyanui	A8	4480	2650	2820	2500
	A9	2500	1755	2850	1800
	A10	1760	3305	1780	2900
	Mean	2913	2570	2483	2400
	SE±	812	449	352	321

Table 4: Total dissolved solids, TDS (mg/L) of sampled wells

Location	Well	Dec	Jan	Feb	Mar
Tegbi	A1	2610	883	2600	2650
	A2	380	356	380	390
	A3	1410	909	1350	1300
	Mean	1467	716	1443	1447
	SE±	644	180	643	657
Woe	A4	870	728	1070	1030
	A5	920	751	940	960
	Mean	895	740	1005	995
	SE±	25	12	65	35
Whuti	A6	1680	846	1860	1810
	A7	1440	857	1590	1435
	Mean	1560	852	1725	1623
	SE±	120	6	135	188
Anyanui	A8	2960	1780	1870	1655
	A9	1650	1185	1880	1200
	A10	1160	2150	1180	1950

Mean	1923	1705	1643	1602
SE±	537	199	232	154

3.4 Cations and Anions of the Groundwater Samples

Table 5 gives the test results of the concentrations of selected cations and anions in the sampled wells in the four communities and the FAO standard irrigation water quality upper limits.

The range of sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) concentrations of the wells at Tegbi were between 38 to 490 mg/l, 61.2 to 117 mg/l, 6.29 to 72 mg/l and 6.2 to 11 mg/l respectively. The lowest concentration was recorded for well A2 for all the cations as compared to the other wells. The concentration for Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-) and Phosphate (PO_4^{3-}) ranged between 56.7 to 739 mg/l, 19.3 to 239 mg/l, 0.321 to 1.11 mg/l and 0.058 to 0.294 mg/l respectively.

Table 5: Physicochemical water quality parameters of wells in the study areas in mid-February 2022

Water Parameter	FAO Upper Limit	Tegbi			Woe		Whuti		Anyanui		
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Na^+	920	490	38	205	60	80	350	280	180	110	450
Ca^{2+}	400	108	61.2	117	144	122	101	103	125	40.4	92.2
Mg^{2+}	60.8	72	6.29	33.6	10.3	11	42.2	45.3	23.9	18.5	50.4
K^+	2	7.4	6.2	11	11	7.1	15	16	16	7.5	14
Cl^-	1050	739	56.7	258	144	150	581	501	209	179	521
$SO_4^{\ 2-}$	960	239	19.3	151	120	89	790	100	250	78	350
HCO_3	610	629	220	355	204	223	291	206	231	124	531
NO_3^-	10	0.76	0.32	1.11	1.01	0.83	0.54	0.54	0.45	0.44	0.44
$PO_4^{\ 3-}$	2	0.06	0.29	0.11	0.18	0.27	0.05	0.12	0.36	0.15	0.09

The unit for all water parameters is mg/L.

The Na^+ and Mg^{2+} concentrations in well A5 were more than that of well A4 by 33.3% and 6.8% respectively while the concentrations of Ca^{2+} and K^+ for well A4 were 18% and 54.9% more than well A5 respectively. The concentration for Cl^- and PO_4^{3-} were 4.2% and 50% more in wells A5 than A4 respectively whilst the concentration of SO_4^{2-} and NO^{3-} in well A4 was 34.8% and 21.1% more than the concentration in well A5 respectively.

The Ca^{2+}, Mg^{2+} and K^+ concentrations in well A7 were 2%, 7.3% and 6.7% more than the concentration in well A6 respectively whilst the Na^+ concentration in well A6 was 25% more than that of well A7. The concentration of Cl^- and SO_4^{2-} in well A6 was 16% and 690% more than that of the concentration in well A7.

The Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Potassium (K^+) concentrations for wells in Anyanui ranged between 110 to 450 mg/l, 40.4 to 125 mg/l, 18.5 to 50.4 mg/l and 7.5 to 16 mg/l respectively. The concentration for Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO^{3-}) and Phosphate (PO_4^{3-}) ranged between 179 to 521 mg/l, 78 to 350 mg/l, 0.44 to 0.45 mg/l and 0.09 to 0.36 mg/l respectively. The lowest concentration was recorded in well A9 for both cations and anions as compared to the other wells.

A statistical analysis of variance (ANOVA) for each water quality parameter across the sampled sources is shown in Table 6. The result shows that, for each parameter, there are variabilities in the values in each group and across the entire sampled sources but the differences are not significant at 5% probability level.

Table 6: ANOVA result for water quality parameters across sampled sources

Parameter	No. of samples	No. of sampled groups	F-stat	P-value	Conclusion
Na	10	4	0.7783	0.5476	NS
Ca	10	4	0.9968	0.4559	NS
Mg	10	4	0.9186	0.4865	NS
K	10	4	2.6040	0.1470	NS
Cl	10	4	0.9940	0.4570	NS
SO_4	10	4	0.9904	0.4583	NS
HCO_3	10	4	0.5690	0.6556	NS
NO_3	10	4	1.9230	0.2271	NS
PO_4	10	4	0.6317	0.6210	NS

NS: Not significant at P (0.05)

3.5 Charge Balance Error (CBE) Estimation

The charge balance error (CBE, %) of the sampled groundwater quality is presented in Table 7. The CBE ranged from 1.2 to 4.8% for all the wells, except for well A6 in Whuti which has CBE of 21.9%. The acceptable limit of the calculated CBE is ± 5 [34]. The positive CBE indicates that the water sample has a higher concentration of cations than anions. Hence, the water quality analysis report is acceptable except for A6. There is high consistency in the CBE values among 9 out of the 10 sampled wells, hence, the high CBE of well A6 may be attributed to systematic laboratory errors involving salt standards and dilutions for the sample.

3.6 Geochemical Facies of the Groundwater Samples

The geochemical facies of the groundwater samples are presented in the Piper trilinear diagram shown in Figure 3. Three groundwater types were identified from this diagram: Na-Cl type, mixed type (Ca-Mg-Cl), and the Mg-HCO_3 type, with Na-Cl having dominance over the other types. The results show that 70% of the sampled water sources are the Na-Cl type, 20% in the mixed class, and 10% type in the Mg-HCO_3 type. Two of the three (67%) wells sampled from Tegbi are the Na-Cl type and the third one (33%) is the Mg-HCO_3 type; the two (100%) sampled wells from Woe are the mixed type, and all the (100%) sampled wells from Whuti and Anyanui are the Na-Cl type.

Table 7: Charge balance error (CBE, %) of sampled groundwater quality

Location	Sampled wells									
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Tegbi	-4.8	-2.2	4.5							
Woe				4.8	4.4					
Whuti						-21.9	4.5			
Anyanui								4.9	-1.2	-3.4

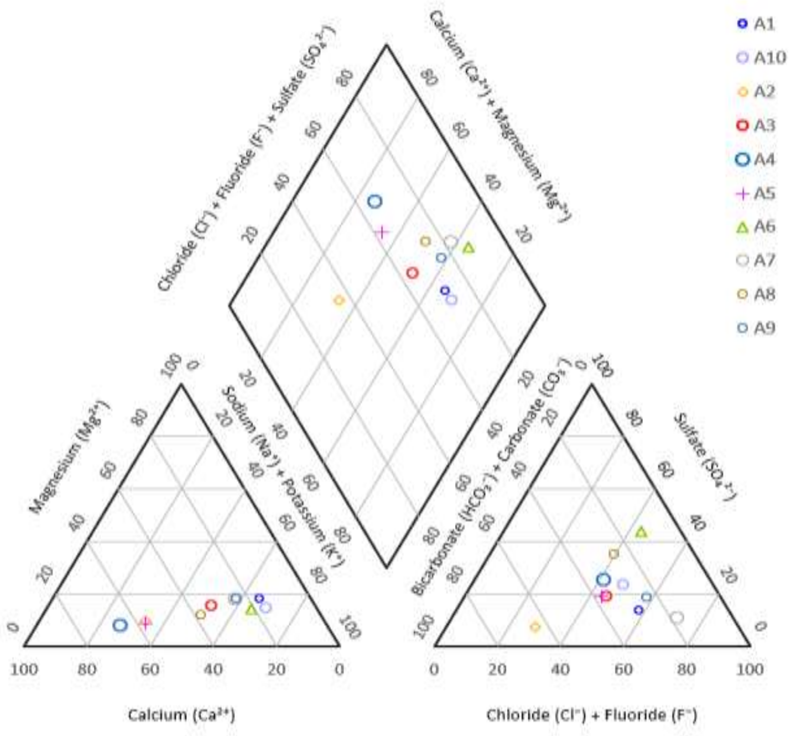

Figure 3: Piper trilinear diagram for groundwater samples

3.7 Derived Water Quality Parameters

The derived water quality parameters (Table 8), which are the sodium adsorption ratio (SAR), soluble sodium percentage (SSP), magnesium adsorption ratio (MAR), Kelly's ratio (KR), % sodium (%Na) and total hardness (TH) were computed from the values of the concentrations of ions.

The SAR across the sampled wells ranged from 1.2 in well A1 (Tegbi) to 9.3 in well A10 (Anyanui). According to [35], water quality criteria for SAR is given as: SAR ≤ 10 is excellent, 10 – 18 is of good quality, 18 – 26 is of doubtful quality and > 26 is unsuitable for irrigation. The results in Table 8 show that the SAR of water from the sampled wells in Tegbi, Woe, Whuti, and Anyanui are less than 10, suggesting their suitability for irrigation.

The SSP was highest (65.3) in well A1 (Tegbi) and lowest (26.4) in well A4 (Woe). According to [28], water with SSP < 50 meq/L is considered suitable, while those with SPP > 50 meq/L are unsuitable. All the water sampled from Woe (SSP < 50), and the water from well A2 in Tegbi (SSP = 34) met the suitability criteria, as may be observed from Table 8. Except for well A1 in Tegbi, with SSP of 52.3, all the sampled wells had MAR< 50 across the four locations, suggesting that they are harmless for irrigation as suggested by Todd [28]. The KR ranged between 0.32 from well A4 in Woe to 2.23 from well A10 in Anyanui. All the sampled wells in Woe had KR < 1; wells A2 in Tegbi and A8 in Anyanui had KR of 0.46 and 0.95, respectively. Other wells had KR >1. A KR value above 1 suggests excessive sodium level [32]. Hence, all the wells in Woe are deemed suitable for irrigation.

The %Na range for the entire wells was 23.8 to 68.6%. Except for all the wells in Woe, and well A2 in Tegbi, the Na% values are above 40%. The irrigation water criteria for percentage sodium (%Na) as given by [36] are < 20 (excellent to good), 20 – 40 (good to permissible), 40 – 60 (permissible to doubtful), 60 – 80 (doubtful to unsuitable), and > 80 (unsuitable). Hence, samples from Woe are considered 'good to permissible' for irrigation. The samples from Tegbi (except well A2) have %Na between 40 to 60; this is 'permissible to doubtful'. Whuti and Anyanui have %Na between 60 to 80; this is considered 'doubtful to unsuitable'.

The total hardness (TH) of the sampled wells ranged from 177 mg/L in well A9 in Anyanui to 565 mg/L in well A1 in Tegbi. These values are above the desired TH range for irrigation water, which is between 50 and 150 mg/L or ppm [38].

Table 8: Derived water quality parameters of wells in the study areas

Location	**Well**	**Water quality parameter**					
		SAR mEq/L	**SSP (%)**	**MAR (%)**	**KR mEq/L**	**Na %**	**TH (mg/L)**
Tegbi	A1	9	65.3	52.3	1.88	65.2	565
	A2	1.2	34	14.5	0.46	30.5	179
	A3	4.3	51.3	32.1	1.03	50.4	430
	$\bar{X}$	4.8	50.2	33.0	1.1	48.7	391
Woe	A4	1.3	26.4	10.5	0.32	23.8	402
	A5	1.9	34.9	12.9	0.5	32.3	350
	$\bar{X}$	1.6	30.65	11.7	0.41	28.05	376
Whuti	A6	7.4	64.4	40.8	1.79	63.6	426
	A7	5.8	58.6	42	1.37	56.8	443
	$\bar{X}$	6.6	61.5	41.4	1.58	60.2	435
Anyanui	A8	3.9	50.1	23.9	0.95	47.6	410
	A9	3.6	59.4	43	1.35	54.7	177
	A10	9.3	69.3	47.4	2.23	68.6	437
	$\bar{X}$	5.6	59.6	38.1	1.5	57.0	341

$\bar{X}$ = Mean value of parameters for each groundwater source

4. DISCUSSION

4.1 pH

The normal pH range for irrigation water is 6.5 to 8.4 [29]. The pH values for the sampled water in the four communities indicate that the well waters were slightly alkaline, being just greater than 7. In Whuti, the pH values were within the same range observed by [39] for the same district. The pH values for all the wells fell within the FAO acceptable range for irrigation water [29].

4.2 Electrical Conductivity (EC)

The EC values in the study area ranged from 509 to 3750 µS/cm. This fell within the irrigation water classes of 'good to unsuitable' [40]. The lowest EC value was recorded in well A2 in Tegbi which was below 700 µS/cm and can be categorised as 'none' saline. The Well A10 in Anyanui had an EC value greater than 3000 µS/cm and can be categorised as 'severely' saline. The high conductivity observed in well A10 can be attributed to the periodic seawater intrusion into the wells [14, 39]. Also, areas with increased farming activities record high conductivities as a result of ions and metals being introduced from farmlands from the use of agrochemicals such as fertilizers [41]. Using such water for irrigation leads to physiological drought, meaning that less water will be available to the plant even though the soil may be wet [42, 43], which can affect the growth of the plant. The rest of the wells had EC values between 700 to 3000 µS/cm and can be categorised as slight to moderate saline.

4.3 Total Dissolved Solids (TDS)

The TDS ranged from 305 to 2250 mg/l. The lowest TDS value (305 mg/l) was observed in well A2 in Tegbi whilst the highest values (2250 and 2046 mg/l) were observed in wells A1 and A10 respectively. Well A10 also had the highest EC value. The absence of heavy industries in the area could account for the low TDS value recorded [41]. Similar observations were made by [41] in their studies of groundwater in the Northern Region of Ghana.

The normal TDS range for irrigation water is from 0 to 2000 mg/l. Wells A1 and A10 were above this range and considered 'not suitable for irrigation. In terms of the degree of restriction on use, well A2 can be categorised as 'none' whiles wells A3, A4, A5, A6, A7, A8 and A9 fell under the 'slight to moderate' category. Wells A1 and A10 can be categorised as 'severe' due to their high TDS values. The high TDS values can reduce water clarity, affect photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature [44].

4.4 Cations

The concentration of sodium in the water samples ranged from 38 to 490 mg/l. These values were within the FAO acceptable range of 0-920 mg/l for irrigation water. High sodium content in waters used for irrigation can cause displacement of exchangeable cations Ca^{2+} and Mg^{2+} by sodium from clay materials [14, 45]. Symptoms of sodium toxicity to plants are leaf burn, leaf scorch and dead tissues along the outside edges of leaves [46]. According to [47], the symptoms show on older leaves first. This starts from the outer edges of the leaf and moves inward gradually between the veins towards the leaf centre. Calcium is responsible for water hardness and may negatively influence the toxicity of other compounds [44]. Calcium concentration in the water samples varied from 40.4 to 144 mg/l. This was within the FAO acceptable limit for irrigation water [29].

The concentration of Magnesium in the water samples varied from 6.29 to 72 mg/l. This was within the FAO acceptable limits of 0-68 mg/l for irrigation water except for A1 in Tegbi which was above the acceptable limit. According to [42], this can increase the pH of the soil. The area is also made up of sandstones and limestones which are highly consolidated and dip and thickens towards the coast in the southwest [48, 49]. The high Magnesium content observed in A1 can be attributed to the erosion of the limestone which is a major source of Magnesium in the groundwater as supported by [50].

The concentration of Potassium in the water samples ranged from 6.2 to 16 mg/l. These concentrations were above the FAO acceptable limits of 0 to 2 mg/l which could pose a threat if the water is used for vegetable production [29]. The high potassium content in the water may not be far fetch. According to [51], such may be associated with leaching of the element from organic and inorganic fertilizers used on the cropped fields which is a common occurrence. Summarily, the order of abundance of these cations is $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$.

4.5 Anions

The chloride concentration in the water samples varied from 56.7 to 739 mg/l. This was within the acceptable limits of 0-1050 mg/l by FAO [29]. The sulphate concentration in the water samples varied from 19.3 to 790 mg/l, which was within the acceptable limits of the FAO [29]. Nitrogen stimulates crop growth. It is usually available as nitrate and ammonium with nitrate occurring frequently in irrigation water. Nitrate is one of the common groundwater contaminants in farming areas [20]. The nitrate concentration in the water samples varied from 0.32 to 1.11 mg/l, which was within the acceptable limits of the FAO [29].

4.6 Sodium Adsorption Ratio (SAR)

The SAR values ranged from 6.5 to 53.5 among the sampled wells. The SAR values of the water samples below 10 are in the low-sodium water (S1) sodicity class and according to [35, 36] this class of water can be used for irrigation on almost all soils with little sodium hazard developing [36].

The salinity of the water samples ranged from 509 to 3750 μS/cm). The salinity of water sample A2 was between 250 - 750 μS/cm and fell in the medium-salinity water (C2) class). This type of water can be used for irrigation if a moderate amount of leaching occurs [36]. Water samples from wells A3, A4, A5, A8 and A9 had salinities between 750 to 2250 μS/cm and belong to the high-salinity water (C3) class [35, 36, 47]. This according to [36] cannot be used on soils with restricted drainage. Water samples from wells A1, A6, A7 and A10 had salinities greater than 2250 μS/cm and fell in the very high-salinity water (C4) category [35, 36, 47]. Category C4 waters are not suitable for irrigation under ordinary conditions but may be used under special circumstances [36].

On plotting the SAR and salinity values over the U.S. Salinity diagram (Figure 4), the water fell in the C2-S1, C3-S1, C4-S2 and C4-S3 classes. Class C2-S1 and C3-S1 indicate that the groundwater generally has low SAR and medium to high salinity hazards associated with them and supports findings by [52] in their studies. Groundwater classified as C2-S1 and C3-S1 may be considered as 'good' and 'medium' quality irrigation water respectively and can support the growth of medium to high salt tolerant crops. The significant intrusion of salt water into the freshwater lens as a result of increased abstraction of groundwater will increase groundwater salinity [52]. When this happens, the groundwater in C2-S1 and C3-S1 classification zones will move through C3-S1 and C3-S2 and plot in either zones C3-S3, C4-S3 or C4-S4. The current classification of groundwater in C4-S2 and C4-S3 zones in this study confirms this prediction by [52].

4.6 Geochemical Implications of Water Sample Sources

The dominance of Na-Cl facies of the groundwater in Tegbi, Whuti and Anyanui implied that the origin of Cl in the groundwater samples can be attributed to the encroachment of Na-Cl-rich seawater to the aquifer through seawater encroachment connected with groundwater abstraction [11, 12]. Saline water is known to have adverse effect on crop development as physiological drought occurs when the salt concentration of the soil becomes higher than that of the plant root cells through a reverse osmosis [53]. This could be a major factor in reduced growth and yield as reported by the farmers. The dominance of Mg-HCO_3 in a third part of the water sample from Tegbi could raise the sodium hazard of the water as there is a tendency for the magnesium to react with bicarbonate in the water or soil thereby precipitating as magnesium carbonate [54]. This would increase the relative proportion of sodium, thus raising the sodium hazard rating. The potential bicarbonate hazard value has been estimated to be 1.5 – 8.5 for the slight to moderate restriction for sprinklers [29]. The Ca-Mg-Cl-SO_4 mix in Woe community is not of much significance as it is dominant in $CaCl_2$ (Table 2) which is not known to be of particular adverse effects as calcium and chloride ions totally separate in water and becoming free ions, with calcium (Ca^{2+}) clinging to soils with high cation exchange capacity and being and being used up by the plants. The chloride (Cl^-) does not cling to the soil and could be freely leached out [55]. The geochemical facies of the Woe groundwater sources and its suitability for irrigation corroborates the results obtained for the SAR, SSP, MAR, KR and %Na which also consider the Woe groundwater sources suitable for irrigation.

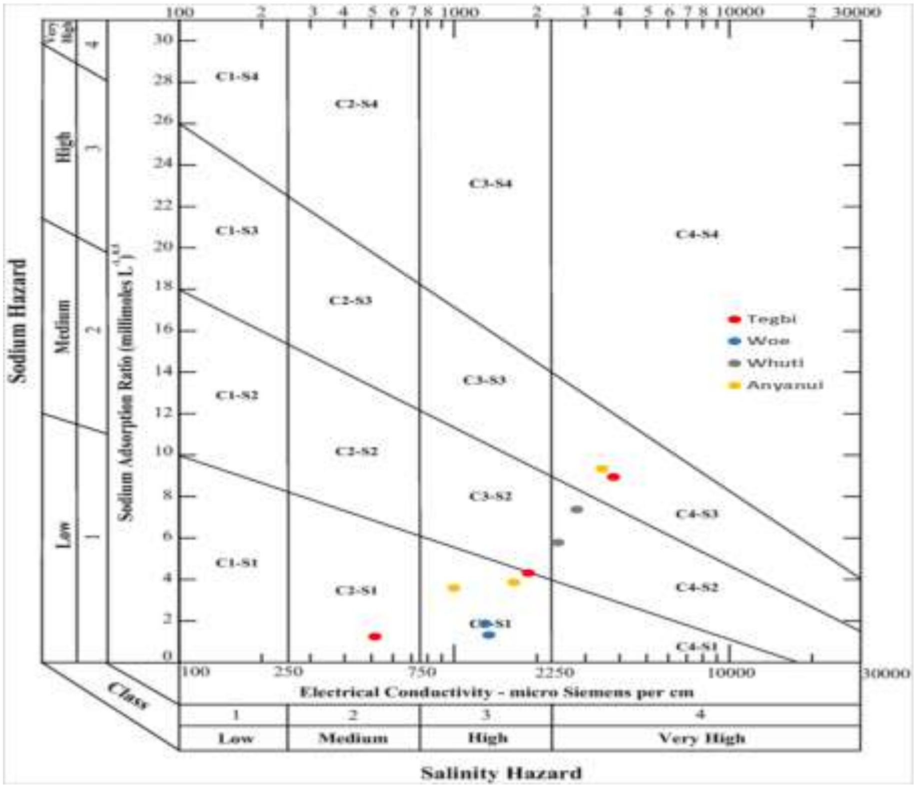

Figure 4: Classification of the sampled water for irrigation purposes

5. CONCLUSION

The physicochemical properties of the water samples used for irrigation in the Anloga District were compared to the FAO water quality standards for irrigation, on which basis the water quality of 50% of the well sampled can be categorized under the high salinity-low sodium hazard (C3-S1) Wilcox's classification. Their use for irrigation should be discrete and should be used for crops that are moderate to highly tolerant to saline water, such as carrot and spring onion. 20 % of the wells are under the very high salinity-medium sodium hazard (C4-S2) class, while another 20 % belong to the very high salinity and high Sodium (C4-S3) classification. The groundwater quality for Woe is considered suitable for irrigation based on the geochemical classification of the water sample which is the Ca-Mg-Cl-SO_4 mixed type. The irrigation water quality of the wells in Tegbi, Whuti and Anyanui are considered to be critical because of the dominance of sodium chloride in the water. Farmers using these wells for irrigation should be more discrete in their use because of their high salinity. Conditional use of such irrigation water should be adopted, for example, the water can be used to irrigate crops that have high tolerance to salinity, like beetroot.

REFERENCES

[1] Mahed, G. (2023). Africa's vast underground water resources are under pressure from climate change - how to manage them. The Conversation newsletter, September 3, 2023. https://theconversation.com/africas-vast-underground-water-resources-are-under-pressure-from-climate-change-how-to-manage-them-209609

[2] Adelana, S. M. & Macdonald, A. M. (2008). *Groundwater research issues in Africa*. CRC Press.Akoto, O., Teku, J. A., & Gasinu, D. (2019). Chemical characteristics and health hazards of heavy metals in shallow groundwater: case study Anloga community, Volta Region, Ghana. *Applied Water Science*. 9(36): 1-9. https://doi.10.1007/s13201-019-0914-z
[3] IWMI (2010). Agricultural Water Management National Situation Analysis Brief. AgWater Solutions Project (January), International Water Management Institute (IWMI), Colombo, Sri Lanka.
[4] MacDonald, A. M., Bonsor, H. C., Dochartaigh, B. É. & Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. *Environmental Research Letters, 7*(2), 024009.
[5] Sadat-Noori, S. M., Ebrahimi, K. & Liaghat, A. M. (2014). Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer, Iran. *Environmental Earth Sciences, 71*(9), 3827-3843. https://doi.10.1007/s12665-013-2770-8
[6] Abed, M. F., Zarraq, G. A. & Ahmed, S. H. (2021). Hydrogeochemical Assessment of Groundwater Quality and its Suitability for Irrigation and Domestic Purposes in Rural Areas, North of Baiji City-Iraq. *Iraqi Journal of Science*. *62*(7): 2296-2306. https://doi:10.24996/ijs.2021.62.7.18
[7] Mustafa, S., Slater, S. & Barnett, S. (2012). Preliminary investigation of seawater intrusion into a freshwater coastal aquifer – Lower South East. Technical Report, Science, Monitoring and Information Division, Department of Environment, Water and Natural Resources (DEWNR), Government of South Australia, 2012/01.
[8] Werner, A.D., Bakker, M., Post, V.E.A., Vandenbohede, A., Lu, C., Ashtiani, B.A., Simmons, C.T. & Barry, D.A. (2013). Seawater intrusion processes, investigation and management: recent advances and future challenges. Advances in Water Resource, 51(3): 3-26. http://dx.doi.org/10.1016/j.advwatres.2012.03.004
[9] Lenntech (2024). Seawater intrusions in groundwater. Retrieved July 16, 2024 from https://www.lenntech.com/groundwater/seawater-intrusions.htm
[10] Edwards B.D. and Evans K.R. (2002). Saltwater intrusion in Los Angeles Area coastal aquifers - the marine connection. United States Geological Survey (USGS) Factsheet 030-02, 2002. Retrieved June 22, 2024 from https://pubs.usgs.gov/fs/2002/fs030-02/fs030-02.pdf
[11] Barlow, P.M. & Reichard, E.G. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeol J*. 18: 247–260. https://doi.org/10.1007/s10040-009-0514-3
[12] USGS (2024). Seawater intrusion – Sustainable Groundwater Management (SGMA). California Water Science Centre, United States Geological Survey (USGS). Retrieved July 21, 2024 from https://ca.water.usgs.gov/sustainable-groundwater-management/seawater-intrusion-california.html
[13] NRC, 2011. Saltwater Intrusion and Climate Change: A primer for local and provincial decision-makers. Natural Resources Canada (NRC). Retrieved July 29, 2024 from https://www.princeedwardisland.ca/sites/default/files/publications/saltwater_intrusion_and_climate_change.pdf
[14] Asare, R., Sakyi, P. A., Fynn, O. F., & Osiakwan, G. M. (2016). Assessment of Groundwater Quality and its Suitability for Domestic and Agricultural Purposes in parts of the Central Region, Ghana. *West African Journal of Applied Ecology, 24*(2), 67-89.
[15] Oppong Danso, E., Abenney-Mickson, S., Sabi, E. B., Plauborg, F., Abekoe, M., Kugblenu, Y. O., & Andersen, M. N. (2015). Effect of different fertilization and irrigation methods on nitrogen uptake, intercepted radiation and yield of okra (Abelmoschus esculentum L.) grown in the Keta Sand Spit of Southeast Ghana. *Agricultural Water Management*, *147*, 34-42. doi:10.1016/j.agwat.2014.07.029
[16] Awadzi, T. W., Ahiabor, E., & Breuning-Madsen, H. (2008). The Soil-Land use System in a Sand Spit Area in the Semi-Arid Coastal Savanna Region of Ghana – Development, Sustainability and Threats. *West African Journal of Applied Ecology*, *13*, 181-194.
[17] Asomaning, S. K., Abekoe, M., Dowuona, G., Borggaard, O., Kristensen, J., & Breuning-Madsen, H. (2015). Sustainable long-term intensive application of manure to sandy soils without phosphorus leaching: a case study from Ghana. *Acta Agriculturae Scandinavica*, Section B — Soil & Plant Science. doi:10.1080/09064710.2015.1058413
[18] Gyau-Boakye P. & Dapaa-Siakwan S. (2000). Groundwater as sources of rural water supply in Ghana. *J Appl Sci Technol*. 5(1 & 2): 77–86
[19] Asomaning, S. K., Abekoe, M. K., & Dowuona, G. N. (2018). Phosphorus sorption capacity in relation to soil properties in profiles of sandy soils of the Keta sandspit in Ghana. *West African Journal of Applied Ecology, 26*(1), 49-60.
[20] Akoto, O.; Teku, J.A. & Gasinu, D. (2019). Chemical characteristics and health hazards of heavy metals in shallow groundwater: case study Anloga community, Volta Region, Ghana. *Applied Water Science*. 9: 36, https://doi.org/10.1007/s13201-019-0914-z
[21] Igbadun, H.E., Cofie, O.O. & Kpapko-Sraha, M.A. (2021). Salinity Status of Open and Shallow Tube Wells in Farmer-Led Irrigation System in Anloga District of Ghana. *International Water Management Institute Technical Report submitted to Ghana Agricultural Sector Investment Programme (GASIP). August 2021.*
[22] APHA (1985). Standard methods for the examination of water and wastewater, 15th edn. American Public Health Association, Washington, DC, USA.

[23] Kadyampakeni, D., Appoh, R., Barron, J., & Boakye-Acheampong, E. (2018). Analysis of water quality of selected irrigation water sources in Northern Ghana. *Water Science & Technology Water Supply*, *18*(4), 1308-1317. doi:10.2166/ws.2017.195

[24] Ahluwalia V.K. (2023). Instrumental Methods of Chemical Analysis, https://doi.org/10.1007/978-3-031-38355-7_35

[25] Tucker B.B. & Kurtz L.T. (1961). Calcium and magnesium determinations by EDTA titrations. *Soil Science Society of America Journal*. 25(1): 27-29. https://doi.org/10.2136/sssaj1961.03615995002500010016x

[26] SI Analytics (2018). Determination of Calcium and Magnesium in Water. SI Analytics-Application report Titration. Retrieved August 1, 2024 from https://www.xylemanalytics.com/File%20Library/Resource%20Library/SIA/09%20Application%20Papers/UK/calcium_magnesium_EN.pdf

[27] APHA, AWWA & WEF (2012). Standard methods for examination of water and wastewater, 22nd ed. American Public Health Association, Washington, DC, USA.

[28] Todd D.K. (1980). Groundwater hydrology, 2nd ed. Wiley, New York, 535 pp.

[29] Ayers, R.S. & Westcot, D.W. (1985). *Water quality for agriculture*. FAO Irrigation and Drainage Paper No. 29, Rev. 1, Food and Agriculture Organization (FAO) of the United Nations, Rome.

[30] Richards, L. A. (1954). *Diagnosis and improvement of saline and alkali soils.* Washington DC. 160p: USDA Agricultural Handbook No 60., US Department of Agriculture.

[31] Raghunath, H. M. (1987). Groundwater (2nd Ed.). Wiley Eastern, New Delhi, India, 344-369.

[32] Kelley, W.P. (1963). Use of saline irrigation water. *Soil Science*. 95(6): 385–391.

[33] Yousefi, M., Najafi Saleh, H., Mohammad, A.A., Mahvi, A.H., Ghadrpoori, M. H., & Suleimani, H. (2017). Data on water quality index for the groundwater in rural area Neyshabur County, Razavi province, Iran, *Data Brief*. 15: 901–907

[34] Domenico, P.A. & Schwartz, F.W. (1990). *Physical and Chemical Hydrogeology*; Wiley: New York, NY, USA, 1990; 824

[35] USSL Staff. (1954). *Diagnosis and improvement of saline and alkali soils.* Washington DC, USA: USDA Handbook No 60.

[36] Wilcox, L. V. (1955). *Classification and Use of Irrigation Waters.* Washington D.C. USA: US Department of Agriculture.

[37] Piper, A.M. (1944). A Graphical Procedure in the Geochemical Interpretation of Water Analysis. US Geological Survey Groundwater, Note 12.

[38] Schiavon, M. & Moore, K.K. (2021). How to properly read irrigation water analysis for turf and landscape: ENH1352/EP616. 12/2021. https://10.32473/edis.ep616.2021

[39] Norvivor, F. A., Gordon, C., & Appeaning-Addo, K. (2017). Physico-Chemical Quality of Groundwater in Keta South, Ghana. *Journal of Health and Environmental Research, 3*(3), 51-56. doi:10.11648/j.jher.20170303.12

[40] Fipps, G. (2003). Irrigation water quality standards and salinity management strategies. *Texas FARMER Collection*.

[41] Salifu, M., Yidana, S. M., Anim-Gyampo, M., Appenteng, M., Saka, D., Aidoo, F., . . . Sarfo, M. (2017). Hydrogeochemical and isotopic studies of groundwater in the meddle voltarian aquifers of the Gushegu district of the Northern Region. *Appl Water Sci*, *7*, 1117-1129.

[42] Jadhao, S. M., Kadu, P. R., Pondkule, R. G., & Mali, D. V. (2016). Assessment of Irrigation Water Quality of Purna Valley of Vidarbha. *Journal of Soils and Crops,* 26(2), 375-382.

[43] Adams, S., Issaka, R. N., Quansah, G. W., Amfo-Otu, R., & Bagna, S. (2014). Assessment of Irrigation Water Quality of Tono Dam in Navrongo, Ghana. *Journal of Biodiversity and Environmental Sciences (JBES), 4*(3), 187-195.

[44] Arshad, M., & Shakoor, A. (2017). Irrigation Water Quality. *Water Int, 12*(1-2), 145-160.

[45] Islam, M. S., & Shamsad, S.Z. (2009). Assessment Of Irrigation Water Quality Of Bogra District In Bangladesh.

[46] Zaman, M., Shahid, S.A., & Heng, L. (2018). Irrigation Water Quality. In *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques* (pp. 113-131). Springer, Cham https://doi.org/10.1007/978-3-319-96190-3_5

[47] Nag, S. K., & Das, S. (2014). Quality Assessment of Groundwater with Special Emphasis on Irrigation and Domestic Suitability in Suri I & II Blocks, Birbhum District, West Bengal, India. *American Journal of Water Resources, 2*(4), 81-98. https://doi:10.12691/ajwr-2-4-2

[48] Jørgensen, N. O., & Banoeng-Yakubo, B. K. (2001). Environmental isotopes (18O, 2H, and 87Sr/86Sr) as a tool in groundwater investigations in the Keta Basin, Ghana. *Hydrogeology Journal,* 9, 190–201. https://doi.10.1007/s100400000122

[49] Yidana, S. M., Banoeng-Yakubo, B., & Akabzaa, T. M. (2010). Analysis of groundwater quality using multivariate and spatial analyses in the Keta basin, Ghana. *Journal of African Earth Sciences*. 58: 220–234. doi:10.1016/j.jafrearsci.2010.03.003

[50] Arabi, A. S., Funtua, I. I., Dewu, B. B., Garba, M. L., Okoh, S., Kwaya, M. Y., & Bolori, M. T. (2013). Assessment of Calcium and Magnesium Concentrations in Groundwater as Supplements for Sleep Related Ailments. *Journal of Applied Environmental and Biological Sciences, 3*(7), 29-35.

[51] Yadav, B.K. & Thaman, S. (2016). Water quality and potassium and sulphur contribution through groundwater irrigation in Bathinda district of Punjab. *Agricultural Research Journal*. 58:1014-1019. https://doi.10.5958/2395-146X 2021.00143.5

[52] Kortatsi, B. K., Young, E., & Mensah-Bonsu, A. (2005). Potential Impact of Large Scale Abstraction on the Quality of Shallow Groundwater for Irrigation in the Keta Strip, Ghana. *West African Journal of Applied Ecology*, 8(1): https://doi.org/10.4314/wajae.v8i1.45780

[53] Zondo, S. (2021). Desalination strategies for irrigated agricultuer. Research and Technology Bulletin, 2020/21-06. Agriculture and Rural Development, Republic of South Africa.

[54] A & L Canada Laboratories, Inc. (2007). Interpreting irrigation water analysis II. Plant nutrition and water quality. Factsheet No. 701.

[55] Lawn Care Academy, 2008. Calcium chloride uses – the myths and facts. https://www.lawn-care academy.com/calcium-chloride-uses.html