Assessment of Groundwater for Irrigation Purpose in Ife North Local Government area, Southwestern Nigeria

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Abstract

The analysis of water quality characteristics provides valuable information useful in water resources management. This study assessed the quality of water samples from Ife North Local Government Area, Southwestern Nigeria, with a view to establishing their suitability for irrigation purpose. A total of 52 water samples were collected and analyzed during the dry season for the major cations (sodium, calcium, magnesium and potassium), anions (chloride, sulphate and bicarbonate), and physico-chemical parameters (temperature, pH, total dissolved salts and electrical conductivity). Based on these analyses, irrigation quality parameters such as sodium adsorption ratio (SAR), percentage of sodium (Na%), magnesium hazard (MH), permeability index (PI), residual sodium carbonate (RSC) and Kelly's ratio (KR) were computed. The electrical conductivity of the water samples varied from 78.00 to 1041.00 µS/cm with a mean value of 443.83 µS/cm and the total dissolved solids varied from 0.10 to 1.17 mg/l with an average value 0.44 mg/l. The salinity hazard result shows no degree of restriction on the use of the water for irrigation. Sodium concentration in the samples varied from 2.40 to 31.80 mg/l with an average value of 14.13 mg/l, indicating no degree of restriction for sensitive crops on the use of the water for irrigation. Based on the US salinity diagram, the water samples are predominantly of the C2-S1 class representing 57.69% of the total number of samples followed by C1-S1 and C3S1 classes at 28.85% and 13.46% of the samples, respectively; hence all the samples are suitable for irrigation. The Na% varied from 4.94% to 50.44% with a mean value of 25.42%, indicating no degree of restriction on the use of the water for irrigation. The obtained Cl^- ion concentration varied from 0.2 meq/l to 4.43 meq/l with a mean value of 1.74 meq/l representing slight to moderate degree of restriction on the use of this water in irrigation. The MH values range from 0.04% to 61.70% (with a mean value of 21.69%); only one sample has a value above the acceptable limit of 50%. Using the PI, 24 water samples fell under Class 1 and the remaining 28 samples fell under Class 2; therefore, the water samples are suitable for irrigation. The calculated RSC values varied from -1.37 to 0.21meq/l with a mean value of -0.52 meq/l, thus making the water suitable for irrigation purpose. The KR values for the study area are all less than 1, except one value, and therefore the water in the study area is suitable for irrigation purpose. In general, the water samples in the study area are suitable for irrigation purpose.

Keywords: salinity hazard, Kelly's ratio, basement complex, irrigation farming, alkaline soil, Ipetumodu

1. Introduction

Irrigation is the artificial application of water to the land or soil. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and vegetation of disturbed soils in dry areas and during periods of inadequate rainfall (Snyder & Melo-Abreu 2005). Irrigation water is supplied to supplement the water available from rainfall and the contribution to soil moisture from groundwater; and in many areas of the world the amount and [illegible] d to supplement with irrigation (Osunbitan et al. 2005).

The Ife region is underlain by crystalline basement complex rocks, which cover about 50% of the total land areas of Nigeria (Hubbard 1968). Rocks found in these areas are pre-Cambrian in age and lie within the zone of Pan African reaction (Rahaman 1975). The climate of southwestern Nigeria is characterized by two distint seasons: wet and dry seasons. The wet season lasts from April to October while the dry season lasts from November till March (Hayward & Oguntoyinbo 1987). According to Oke & Aladejana (2012), in order to alleviate the challenges of food insecurity in Nigeria, irrigation farming must be given serious attention. In a study conducted by Osunbitan et al. (2005), it was concluded that the groundwater supply could meet the water requirements demand on a small-scale irrigation project in the areas underlain by the basement complex with Ile-Ife as a case example. The suitability of groundwater from Ife North Local Government Area for drinking purpose has been studied by Oluyemi et al. (2011) and Jeje & Oladepo (2014). However, the area has large expanse of agricultural land. This study assesses the water quality in Ife North with respect to irrigation practice so as to determine the suitability of the water for irrigation purpose.

According to Pillai & Khan (2016), irrigation practice is mainly dependent on water quality, type of soil and type of crop. The parameters which can be utilized to verify the suitability of water for irrigation are the salinity index as measured by the electrical conductivity, sodium hazard as measured by the sodium adsorption ratio, SAR (Richards 1954), sodium percentage, Na% (Todd 1980), chloride hazard as measured by the Cl^- ions (Hassan 2017), magnesium hazard, MH (Szabolcs & Darab 1964), permeability index, PI (Doneen 1964), residual sodium carbonate, RSC (Eaton 1950) and Kelly's ratio, KR (Hassan 2017). These parameters have been applied in discussions on suitability of groundwater samples for irrigation purpose in various literatures such as Ramesh & Elango (2012), Ibraheem & Khan (2017), Hassan (2017) and Kurdi & Eslamkish (2017). The expressions for these parameters are given in the following equations:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (1)$$

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

$$MH = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \quad (3)$$

$$PI = \frac{(Na^+ + \sqrt{HCO_3^-}) \times 100}{Ca^{2+} + Mg^{2+} + Na^+} \quad (4)$$

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (5)$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (6)$$

2. Materials and Methods

2.1 Description of the study area

The study was conducted in Ife North Local Government Area of Osun State, Nigeria between December, 2012 and January, 2013. Ife North is one of the present 30 Local Government Areas in Osun State (Figure 1). It is therefore, one of the 774 Local Government Councils so recognized by the constitution. The Local Government is made up of the historical seven sister towns (known as *Origbomeje*) comprising Ipetumodu, the headquarters, Edunabon, Moro, Yakoyo, Ashipa, Akinlalu and Isope (which had fused with Ipetumodu). The vegetation of Ife North Local Government Area is characterized by rainforest ecosystems which form part of the rich fauna and flora of the state. The major economic activities in the area are farming and the public sector which are basically government owned schools (Jeje & Oladepo 2014).

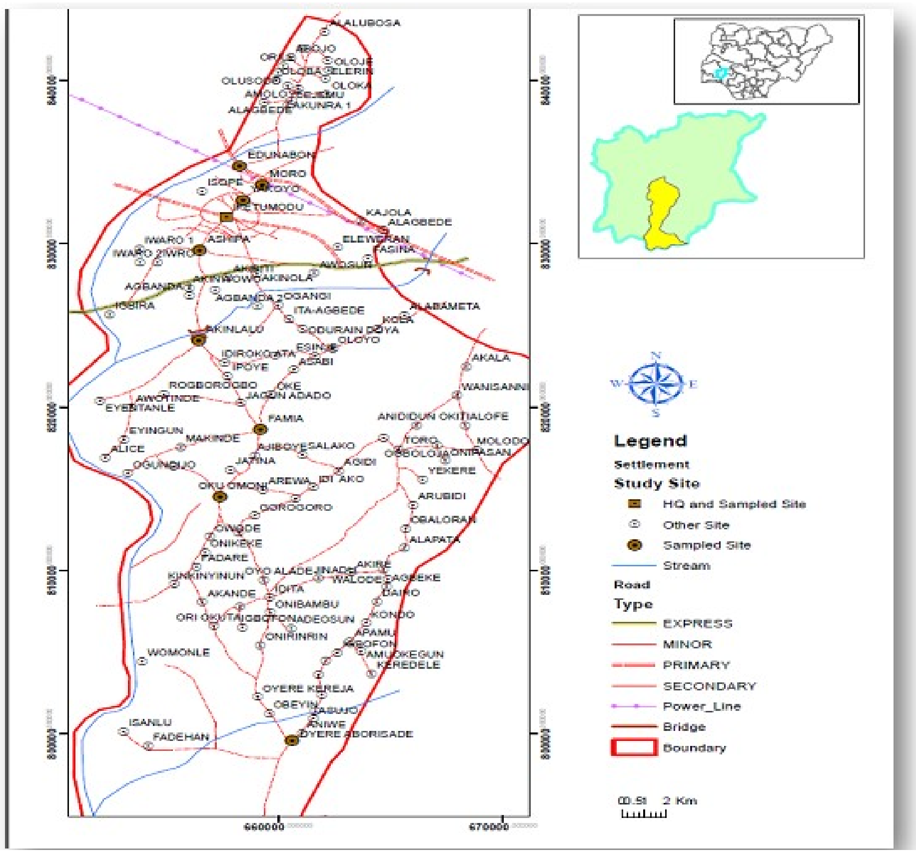

Figure 1: Map of the study area (Jeje and Oladepo, 2014)

2.2 Sample collection and analysis

The water samples were collected from raw water sources (wells, boreholes and rivers within the study area). Fifty-two (52) samples of raw water were collected to determine their physico-chemical parameters. Water samples were collected in clean polyethylene bottles. The temperatures of the samples were determined on the field immediately after sampling by using a mercury-in-glass thermometer. Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were determined titrimetrically using standard EDTA, while Chloride (Cl^-) was determined by standard $AgNO_3$ titration. Bicarbonate (HCO_3^-) was determined from total alkalinity by titration with H_2SO_4. Sodium (Na^+) and Potassium (K^+) were determined by flame photometry; Nitrate (NO_3^-) and Sulphate (SO_4^{2-}) were determined using colorimetric method. The total dissolved solid (TDS) was determined by gravimetric method (dried at 105^OC). The pH was determined by using pH meter (Extech Instruments, Model 407227) while Electrical Conductivity (EC) was determined by using conductivity meter (DBK Instruments, Model 5008/3).

3. Results and Discussion

Table 1 shows the descriptive statistics of the physicochemical parameters observed in the study area. Table 2 shows the irrigation water quality parameters of the water samples which were computed by using Equations 1 to 6.

Table 1: Statistical summary of water quality parameters for the 52 samples

Parameters	Min	Max	Mean	Standard deviation
Ca^{2+} (mg/l)	4.56	58.49	26.42	±13.71
Mg^{2+} (mg/l)	0.01	15.3	3.87	±3.31
Na^{+} (mg/l)	2.4	31.8	14.13	±7.40
K^{+} (mg/l)	1.5	68.25	8.67	±11.23
HCO_3^{-} (mg/l)	12	122	68.23	±31.62
EC (µS/cm)	78	1041	443.83	±265.60
NO_3^{-} (mg/l)	0.21	5.93	2.37	±1.41
SO_4^{2-} (mg/l)	0.47	63.06	20.55	±14.71
Cl^{-} (mg/l)	7	154.95	60.85	±45.56
pH	6.9	8.9	7.4	±1.28
TDS (mg/l)	40	260	137.14	±63.18
Temp (°C)	26	31.3	26.52	±0.73

3.1 Salinity hazard

The most significant water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (Oke & Aladejana 2012). The electrical conductivity (EC) of the water samples varied from 78.00 to 1041.00 µS/cm with a mean value of 443.83 µS/cm and the total dissolved solids (TDS) varied from 0.10 to 1.17 mg/l with an average value 0.44 mg/l. The salinity hazard result shows no degree of restriction on the use of the water for irrigation, indicating no effect on the plant growth and no possibility to salt build-up in the soil (Ayers & Westcot 1985).The primary effect of high EC is the reduction in the osmotic activity of plants and thus interference with the absorption of water and nutrients from the soil (Tatawat & Changel 2008).

3.2 Sodium hazard

Sodium content is the most troublesome of the major constituents and an important factor in irrigation water quality evaluation. Excessive sodium leads to development of an alkaline soil that can cause soil physical problems and reduce soil permeability. Sodium concentration in the samples varied from 2.40 to 31.80 mg/l with an average value of 14.13 mg/l, indicating no degree of restriction for sensitive crops on the use of this water for irrigation (Ayers & Westcot 1985). Sodium hazard is also usually expressed in terms of the SAR. The SAR of the samples varied from 0.14 to 1.37 with mean value of 0.68. The SAR values of the samples were less than 10 and fell into the excellent class of irrigation water (Hassan 2017). Therefore, the water in the study area is free from sodium hazard and suitable for irrigation purpose. Soil permeability is reduced by irrigation with water high in sodium (Rao 2006). Therefore, the best measure of the likely effect of salinity on soil permeability is the SAR of water considered together with its EC. In this respect, the US salinity diagram (Figure 2) which is based on the integrated effect of EC (salinity hazard) and SAR (alkalinity hazard) has been used to assess the suitability of water for irrigation. From Figure 2, 15 of the water samples fell under class C1S1, indicating low salinity with low sodium water, which can be used for irrigation purpose on all types of soil; 30 of the water samples fell under class C2S1, indicating medium salinity with low sodium water, which can be used for irrigation on almost all types of soil without risk of exchangeable sodium; the remaining 7 water samples fell under class C3S1, indicating high salinity with low sodium water, which can be used for irrigation on almost all types of soil with only a minimum risk of exchangeable sodium (Richards 1954).

Table 2: Irrigation water quality parameters of the water samples

Sample Number	Location	SAR	%Na	PI	MH	KR	RSC
1	Ipetumodu	0.46	19.23	82.37	24.15	0.33	-0.04
2		1.37	39.99	66.84	36.81	0.93	-1.22
3		0.57	21.11	74.17	1.47	0.33	-0.25
4		0.17	11.39	98.69	13.71	0.17	-0.21
5		1.25	36.92	79.46	0.04	0.73	-0.26
6		0.24	11.33	73.99	3.99	0.15	-0.31
7		0.92	28.68	59.48	4.56	0.51	-1.36
8		1.29	36.58	70.76	1.25	0.7	-0.81
9		0.8	25.84	71.66	20.94	0.47	-0.4
10		0.67	17.34	62.48	30.31	0.37	-0.74
11		0.51	12.03	63.6	4.8	0.29	-0.79
12		0.82	25.93	65.17	4.27	0.44	-0.85
13		0.78	35.47	113.65	37.73	0.81	0.21
14		0.92	34.4	82.56	33.97	0.72	-0.32
15		1.06	28.21	59.78	40.84	0.59	-1.37
16		0.81	28.52	60.77	18.48	0.52	-1.19
17		0.69	25.89	60.38	23.05	0.47	-1.1
18		0.78	26.86	79.09	1.44	0.45	0.01
19		0.93	33.62	75.76	25.35	0.71	-0.64
20		0.64	33.42	106.9	28.53	0.68	-0.08
21		0.65	27.66	77.99	20.69	0.5	-0.47
22		0.88	26.47	72.6	1.25	0.48	-0.32
23		1	29.74	61.12	3.8	0.51	-1.28
24		0.77	23.31	60.07	0.97	0.36	-0.99
25	Moro	0.42	25.32	119.52	33.6	0.5	0
26		0.56	36.15	118.9	37.51	0.88	-0.14
27		0.18	11.66	98.8	18.64	0.18	-0.21
28		0.14	4.97	73.33	31.73	0.1	-0.16
29		0.48	14.96	54.58	6.75	0.28	-1.24
30	Yakoyo	0.73	29.23	77.59	32	0.73	-0.55
31		0.71	26.31	73.64	15.15	0.48	-0.57
32		1.01	36.13	83.74	33.97	0.78	-0.28
33	Oyere	0.74	24.71	65.19	24.65	0.45	-0.85
34		0.6	23.6	76.05	43.68	0.45	-0.34
35		0.41	20.01	81.3	19.63	0.35	-0.41

Table 2: Irrigation water quality parameters of the water samples (cont'd)

Sample Number	Location	SAR	%Na	PI	MH	KR	RSC
36	Edunabon	0.72	37.96	122.09	27.79	0.84	0.1
37		0.65	24.27	68.22	19.23	0.42	-0.72
38		0.62	26.16	100.57	30.7	0.6	-0.06
39		0.39	28.23	149.8	22.12	0.64	-0.03
40		0.16	6.4	80.96	20.22	0.13	-0.29
41		0.76	23.38	69.35	41.46	0.5	-0.58
42		0.68	23.19	73.97	53.59	0.49	-0.3
43		0.93	50.44	143.1	22.12	1.53	0.04
44	Akinlalu	0.78	30.58	64.81	61.7	0.85	-0.79
45		0.66	23.76	65.37	25.67	0.45	-0.88
46		0.52	18.8	64.32	16.04	0.29	-0.59
47	Famia	0.72	24.86	64.63	12.32	0.41	-0.84
48		0.55	31.6	126.72	26.69	0.7	0.01
49	Okuu Omoni	0.7	22.36	68.08	11.68	0.41	-0.66
50	Ashipa	0.52	23.88	96.1	35.46	0.47	-0.02
51		0.43	18.38	57.99	27.23	0.32	-0.97
52		0.32	11.68	56.55	3.96	0.17	-0.91

3.3 Sodium percent (Na%)

Water with Na% greater than 60 may result in sodium accumulations that will cause a breakdown of the soil's physical properties (Belkhir & Mouni 2012). The calculated results showed that Na% varied from 4.94% to 50.44% with a mean value of 25.42%, indicating no degree of restriction on the use of the water for irrigation. When the concentration of sodium ion is high in irrigation water, Na^{+} ion tends to be absorbed by clay particles, displacing $Mg^{2+}$and Ca^{2+} ions. This exchange process in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Ayers and Westcot 1985).The Wilcox diagram was used to relate Na% and EC. It is reported that salinity and sodicity are the principal water quality concerns in irrigated areas receiving such water. Saline-sodic irrigation water, coupled with limited rainfall and high evaporation, may increase soil sodicity significantly. In general, when sodium is an important component of the salts, there can be a significant amount of adsorbed sodium making the soil sodic (Wilcox 1948). Based on the Wilcox diagram (Figure 3), 46 of the raw water samples fell in the field of excellent to good and 6 fell in the field of good to permissible. The water is therefore suitable for irrigation purpose.

3.4 Chloride hazard

The most common toxicity is from chloride (Cl^{-}) in the irrigation water. Cl^{-} is not adsorbed or held back by soils, therefore it moves readily with the soil-water, is taken up by the crop, moves in the transpiration stream, and accumulates in the leaves. If the Cl^{-} concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Normally, plant injury occurs first at the leaf tips (which is common for chloride toxicity), and progresses from the tip back along the edges as severity increases. Excessive necrosis (dead tissue) is often accompanied by early leaf drop or defoliation (Alobadidy et al. 2010). The obtained Cl^{-} ion concentration of the samples varied from 7.00 mg/l (0.2 meq/l) to 154.95 mg/l (4.43 meq/l) with a mean value of 60.85 mg/l (1.74 meq/l) representing slight to moderate degree of restriction on the use of this water in irrigation.

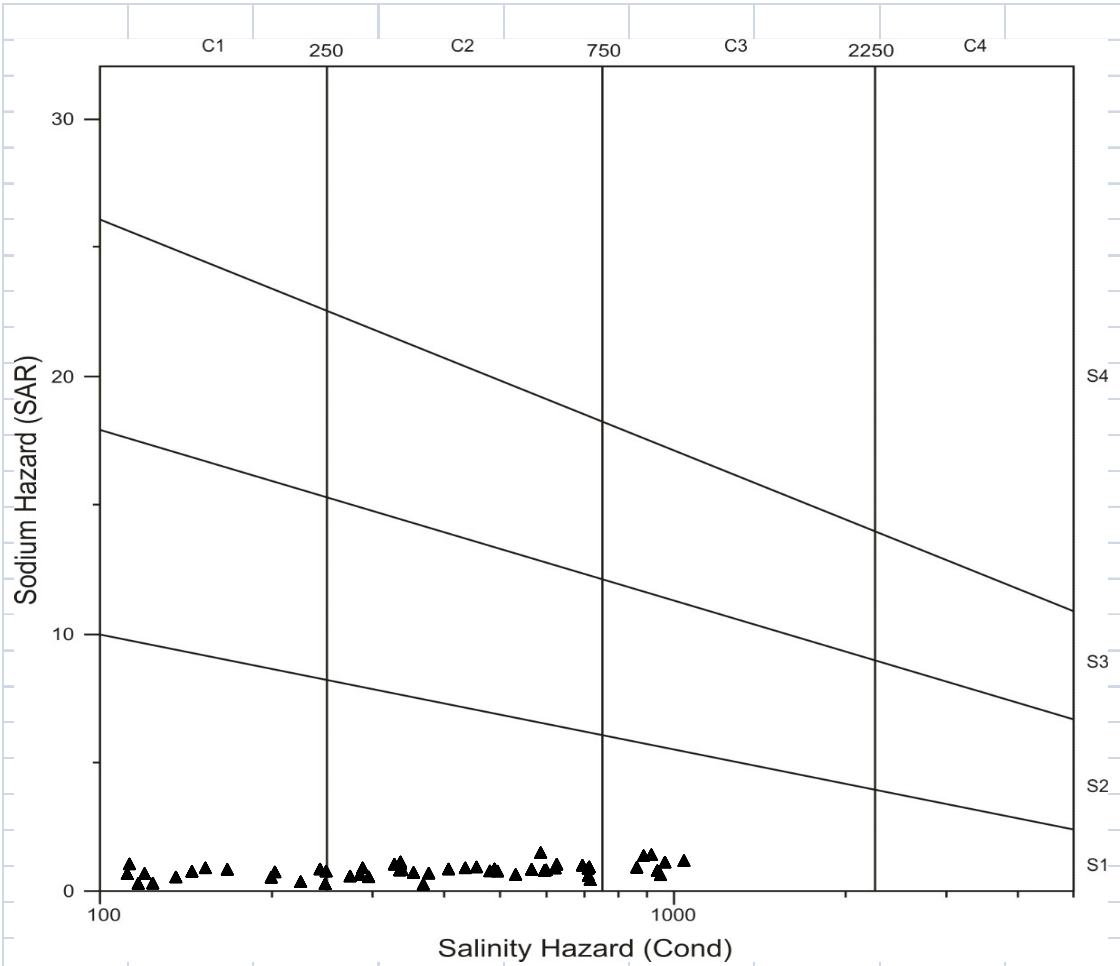

Figure 2: Classification of water samples based on the US salinity diagram

3.5 Magnesium hazard (MH)

Generally, Ca^{2+} and Mg^{2+} ions maintain a state of equilibrium in most waters. Both Ca^{2+} and Mg^{2+} ions are associated with soil aggregation and friability, but they are also essential plant nutrients. High concentration of Ca^{2+} and Mg^{2+} ions in irrigation water can increase soil pH, resulting in reduction of the availability of phosphorous (Al-Shammiri et al. 2005). Water containing concentrations of Ca^{2+} and Mg^{2+} ions higher than 10 meq/l (200 mg/l) cannot be used for agriculture (Alobadidy et al. 2010). The observed results show that none of the samples have Ca^{2+} and Mg^{2+} ions concentration exceeding 200 mg/l, thereby making them suitable for irrigation purpose. Another indicator that can be used to specify the magnesium hazard is the expression given in Eq. 3. According to this, high MH values (>50 %) have an adverse effect on the crop yield as the soil becomes more alkaline (Prasanth et al. 2012). The MH values range from 0.04 to 61.70% (with a mean value of 21.69%). From Table 2, only one sample has a value above 50%; this is from Edunabon (Sample 42).

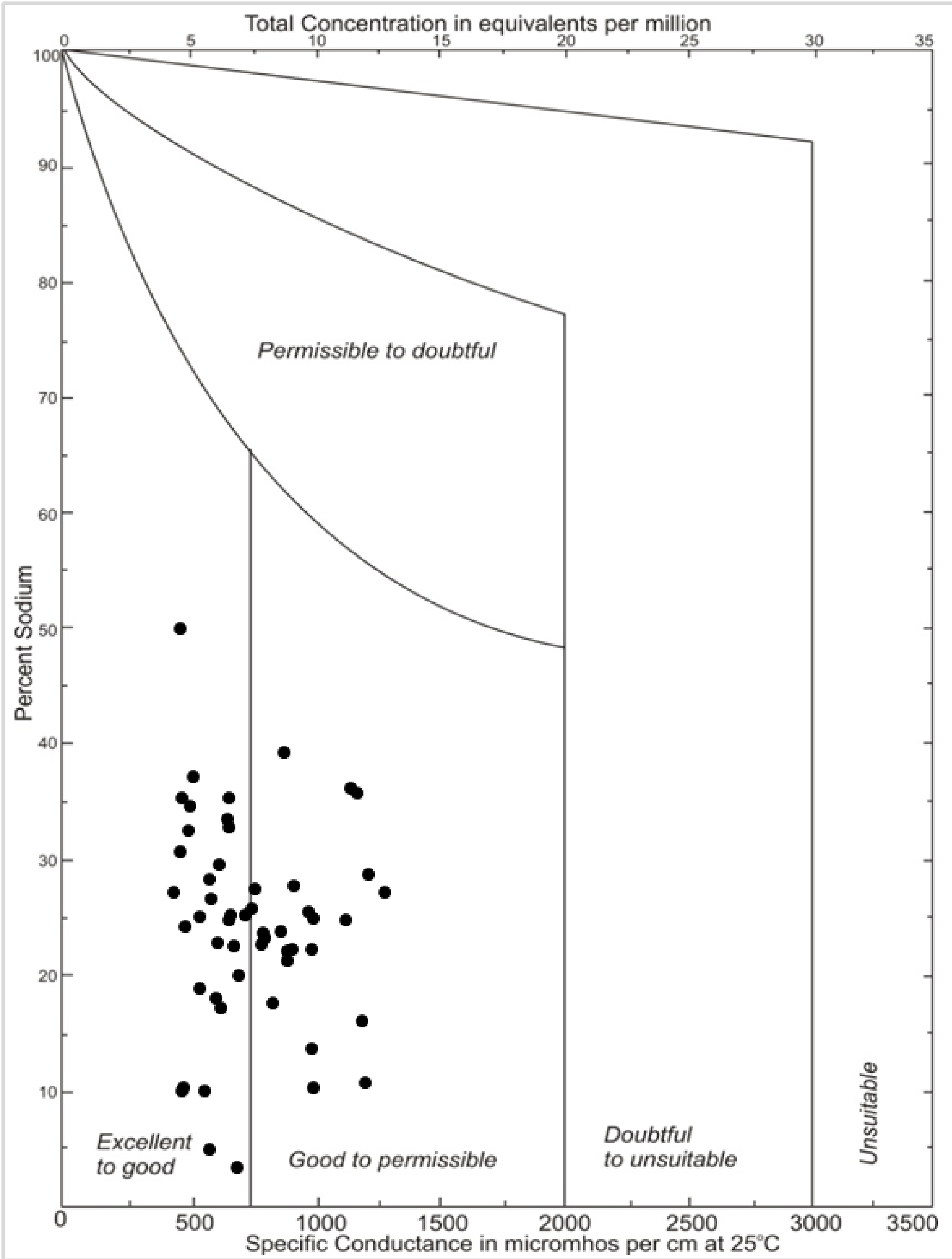

Figure 3: Classification of water samples based on the Wilcox diagram

3.6 Permeability index (PI)

Permeability of the soil is affected by the long term use of irrigation water. Hassan (2017) classified PI values as follows: Class 1 (PI>75%), Class 2 (25<PI<75%) and Class 3 (PI<25%). Class 1 and class 2 waters are categorized as good for irrigation with 75% or more of maximum permeability. Class 3 waters are unsuitable with 25% of maximum permeability. From Table 2, 24 water samples fell under Class 1 and the remaining 28 samples fell under Class 2. Therefore, the water samples are suitable for irrigation.

3.7Residual sodium carbonate (RSC)

In waters having high concentration of bicarbonates, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. Residual carbonate levels less than 1.25 meq/l are considered safe, waters with RSC of 1.25-2.50 meq/l are within the moderate range, and waters having RSC more than 2.5 meq/l leads to salt build-up which may hinder the air and water movement by clogging the soil pores and leading to degradation of the physical condition of soil (Nishanthiny et al. 2010). The calculated RSC values for the study area varied from -1.37 to 0.21meq/l with a mean value of -0.52 meq/l. The RSC values were less than 1.25 meq/l, hence the water is suitable for irrigation purpose.

3.8 Kelly's ratio (KR)

This is an important parameter based on the level of Na^+ ion against Ca^{2+} and Mg^{2+} ions. Values of KR greater than 1 indicate an excess level of Na^+ ion in water. Therefore, groundwater with KR<1 is suitable for irrigation (Hassan 2017). The KR values for the study area are all less than 1, except Sample 43 at Edunabon, and therefore the water in the study area is suitable for irrigation purpose.

4. Conclusion

The suitability of the raw water was investigated for irrigation purpose. The water quality indices employed in determining the suitability of those samples were chloride, SAR, MH, PI, KR, Na% and RSC. The results showed that the values of these indices in the waters of the study area were generally within the levels suitable for irrigation purpose.

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