Hydrochemical Evaluation of Groundwater in Akure Area, South-western Nigeria, for Irrigation Purpose

Yinusa A. Asiwaju-Bello[1,2], Franklin O. Olabode[1], Omolara A. Duvbiama[1], Jeremiah O. Iyamu[1], Adeyemi A. Adeyemo[1] and Miriam T. Onigbinde[1].

[1]Department of Applied Geology,
Federal University of Technology,
P.M.B. 704, Akure, Nigeria.

[2]Corresponding author: (ayoasiwajubello@futa.edu.ng; +2348036672708).

ABSTRACT

Groundwater samples from 103 dug wells in Akure area, south-western Nigeria were tested for their temperature, total dissolved solids, electrical conductivity, pH, and major dissolved ions in order to determine their irrigation quality potentials.

Based on the analyses, parameters like permeability index, sodium adsorption ratio, soluble sodium percentage, residual sodium carbonate, Kelley's ratio, magnesium adsorption ratio and chloro-alkaline index were calculated. The results were presented as spatial distribution maps for interpretations and further deductions.

Results showed that relative concentration of cations and anions are in the order of $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ and $HCO_3^{--}>Cl^{-}>SO_4$. 92.3 % of samples gave positive Chloro-Alkaline Index ratios, signifying direct ion-exchange of Na/K in water with Mg/Ca in the host rock. Evaluation and comparison of calculated values of the parameter indices indicate generally good to permissible uses of the groundwater for irrigation.

Keywords: irrigation, groundwater, quality index, ion exchange

1.0 INTRODUCTION

Surface water is a ready source of water in the hydrologic setting all over the world and it is the most abundant of all types of water but is usually prone to pollution and contamination from domestic, sewage and industrial wastes. It includes water from streams, rivers and ponds. Though it can be recycled and processed for industrial use, this treatment and management could be expensive. The alternative to surface water is the groundwater which is usually sourced from shallow hand-dug wells, springs and boreholes.

Groundwater accounts for about 96 percent of the global fresh water but it is not evenly distributed. It provides a reasonable constant supply which is not completely susceptible to drying out during dry season unlike surface water. All over the globe, groundwater has been of continuous and tremendous use in irrigation and industries both in urban areas ad in rural communities. It is conveniently available at point of use and possesses excellent quality that requires little or no treatment in most cases.

Groundwater occurrence is restricted in areas underlain by crystalline basement rocks of Precambrian age. Such rocks are generally igneous and metamorphic which, in their unaltered form, are characterized by low porosity and permeability. Porosity in basement rocks is by induction through weathering and fracturing.
Human activities can alter the natural composition of groundwater through the disposal or dissemination of chemical and microbial matter at the land surface and into soils, or through injection of wastes directly into ground water. So groundwater chemistry is important in determination of the water's suitability for different uses.
Akure metropolis is the capital city of Ondo State which lies in the south-western part of Nigeria. Groundwater is the major source of water for domestic, industrial and agricultural purposes by the inhabitants of the area. This study is focused on the evaluation of groundwater's suitability for irrigation.

1.1 Climate, Vegetation and Topography of the Study Area

Akure, the capital of Ondo State is located in the south-western part of Nigeria within latitudes 07°12´ and 07°19´N and longitudes 005°8´ and 005°17´E (Figure 1). The main rain-bearing system affecting the area is embedded in the easterly wind current. The available rainfall data of Akure show that rain falls in every month of the year but the months between March and November receive most of the fall. At times, rainfall in excess of 40mm is recorded on a single day while the average annual rainfall is 1334mm (Ondo State Ministry of Economic Planning and Budget, 2010).
The annual mean maximum temperature is 33^{O}C and the mean minimum is 18^{O}C. Evaporation is usually low from June through September, ranging from 3.3mm to 4.0mm per day. Sunshine duration is short (2.7 to 2.9 hours per day) during the month of July to September, while the relative humidity ranges from 5.0 to 90%, depending on the season (Ondo State Ministry of Lands, Housing & Environment, 2000). Rainfall serves as the major source of groundwater recharge in the area.
Vegetation in the study area is of rainforest type which consists of grasses and scattered trees. The landforms in the area consist of hills and plains. The hill can be found in the north eastern part of the study area. Elevation increases southward as the topography becomes more rugged. The hills are made up of fractured rocks (Faniran, 1970).
Relief of the area ranges between 315m and 402m above sea level (Figure 1). The drainage pattern is mainly dendritic which is a reflection of the homogeneity and resistance of the rocks present.

1.2 Geologic and Hydrogeologic Settings

The study area lies within the basement complex of south-western Nigeria (Rahaman, 1976). The dominant rock types in the area are migmatite-gneiss, porphyritic granite and granite gneiss. These rocks are covered by mantle of weathered regoliths, the thickness of which varies from place to place. The rocks are unsuitable for accumulation of groundwater unless they are highly weathered, fractured and/or jointed (Acworth, 1987). The major river in Akure is Ala River. It is the major source of water runoff within the township. There are other smaller rivers, such as Owuruwu, that also add to runoff in the town.

1.3 Previous Works

Various workers have evaluated the geochemical significance of groundwater for irrigation purposes. The regional groundwater quality in Jilh Aquifer, Saudi Arabia was characterised for agricultural use (Saeed *et al.*, 2001) and the results showed that overall concentration of all the ions was very high, but the sodium hazard in the aquifer was low. Low SAR and high EC in all the wells indicated that the water from these wells could be used for irrigation purposes with appropriate leaching.

Groundwater quality in some selected areas in Bangladesh was evaluated for long term irrigation purposes (Shahidullah *et al.*, 2008). The results showed that some of the wells may not be suitable for drinking and industrial purposes with respect to the high Fe concentration. SSP and SAR irrigation indices have a linear relationship and high correlation coefficient of 0.97. They concluded that groundwater of the Bangladeshi area can be safely used for long term irrigation purposes. The irrigation quality of water in Jaffna, Sri Lanka was determined based on salinity, sodium and bicarbonate hazards (Nishanthiny *et al.*, 2010). 20.6% of the tested wells have good and 35.3% have unsuitable irrigation water qualities, respectively.

The most important dissolved ions that will influence irrigation water quality were determined for groundwater in Yola Area, Nigeria (Obiefuna & Orazulike, 2010). The results from the various irrigation indices showed that the groundwater will neither cause salinity hazards nor adverse effect on the soil properties of the study area.

2.0 MATERIALS AND METHODS OF STUDY

Water samples were collected from 103 randomly selected shallow dug-wells in the study area. Parameters like Temperature, EC, TDS and pH were measured *in-situ* using EC/pH/TDS-Temperature meter. Water samples from wells were bailed using plastic bailer, from depth of a few metres below the water table.

2.1 Analytical Methods

Well water samples collected were analysed in the Geochemistry Laboratory of the Department of Applied Geology, Federal University of Technology, Akure, Nigeria.

Sodium and Potassium concentrations were determined using a flame photometer while Calcium and Magnesium concentrations were determined by EDTA titration. Chloride was measured using silver nitrate titration and bicarbonate was measured with acid-base titration while Sulphate was measured using colorimeter-spectrophotometer.

For irrigation water quality tests, parameters like Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Kelley's Ratio (KR), Permeability Index (PI), Magnesium Adsorption Ratio (MAR), Sodium Adsorption Ratio (SAR) and Chloro-Alkaline Indices (CAI) were all calculated using established standard equations (Richards, 1954; Schoeller, 1962; Kelley, 1963; Doneen, 1964; Todd, 1980; Gupta, & Gupta, 1987; Raghaunath, 1987). These equations are:

$$PI = \frac{Na^+ + \sqrt{[HCO_3^- \times 100]}}{Ca^{2+} + Mg^{2+} + Na^+} \quad (1)$$

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

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

$$RSC = HCO_3^- - Ca^{2+} \quad (4)$$

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})} \quad (5)$$

$$MAR = \frac{Mg^{2+} \times 100}{(Ca^{2+} + Mg^{2+})} \quad (6)$$

$$CAI = \frac{[Cl^- - (Na^+ + K^+)]}{Cl^-} \quad (7)$$

where all the ionic concentrations are expressed in meq/litre.

3.0 RESULTS AND DISCUSSION

Summary of calculated values of the different parameter indices for rating irrigation groundwater quality are presented in Tables 1 to 7.

3.1 Salinity Hazard

Water with high salinity is toxic to plants and poses a salinity hazard. Soils with excessive concentrations of salts (calcium, magnesium, potassium and sodium) portend 'physiological' drought condition and reduce the osmotic activities of the plants. TDS values for all the samples (Table 1 & Figure 2) were within permissible limit (<1,000mg/l) for irrigation use which fall under the non saline category as shown in Table 2 (Robinove *et al.*, 1958).

Electrical Conductivity, as an irrigation quality index, measures total salinity of the soil. The EC ranges from 40 to 1600 (Table 3), with 68.9% of the samples falling into the excellent, low saline signifying low salinity hazard; 27.2% falling into good, moderately saline, signifying medium salinity hazard; and the remaining 3.9% falling into the fair/doubtful, highly saline signifying high salinity hazard. Based on standard classification systems (Richards, 1954; Todd, 1980; Eaton, 1950; Wilcox, 1950; Ayers & Westcot, 1985), 96.1% of the samples were considered safe for irrigation purpose while the remaining 3.9% were considered safe only with permeable soil having moderate leaching (Tables 4, 5 & 6).

3.2 Sodium Hazard

Irrigation water containing large amounts of sodium produces the undesirable effects of changing soil properties and reducing soil permeability. The Soluble Sodium Percentage (SSP) values obtained range from 2.60% to 56.02% (Table 3 and Figure 2) indicating low alkali hazards and good (Class II) to excellent (Class I) irrigation qualities (Wilcox, 1950). Applying modified Wilcox quality classification of irrigation waters, 79.6%, 19.4% and 1% of the well waters (Table 6) have excellent, good and permissible irrigation water qualities, respectively (Todd, 1980). This means that all the samples are suitable for irrigation purpose.

Continuous usage of water having a high SAR leads to a breakdown in the physical structure of the soil (Nagarajah, *et al.*, 1988). The SAR of all the groundwater obtained in the study area ranges from 0.03 to 0.36 (Tables 1, 5 and Figure 2). They are classified as excellent and fall under the category of C1SI, indicating low alkali and signifying high suitability for irrigation purpose (Figure 3).

3.3 Bicarbonate Hazard

This is expressed in terms of Residual Sodium Carbonate (RSC) as shown in equation (4). There is tendency for calcium and magnesium to precipitate from water having high concentrations of bicarbonates thus increasing the relative proportion of sodium in the water in form of sodium bicarbonate (Sadashivaiah, *et al.*, 2008). Infertile land can also be caused by irrigated water influenced with high deposition of sodium resulting from high concentration of bicarbonates (Eaton, 1950).

The RSC levels range from -0.06 to 9.83 meq/l (Tables 1, 7 and Figure 2). Most (79.6%) of the samples have RSC levels less than 1.25 and these waters are considered safe and excellent. Few samples (20.4%) gave RSC levels higher than 2.5 making them inappropriate for irrigation purposes (Eaton, 1950; Wilcox, 1950; Ayers & Westcot, 1985).

Continuous usage of waters with RSC greater than 1 leads to salt build up which may hinder the air and water movement by clogging the soil pores and lead to degradation of the physical condition of soil. Negative RSC values as shown in some samples (Table 1) indicate that sodium build up is unlikely since sufficient calcium and magnesium is in excess of what can be precipitated as carbonates in the locations of those samples.

3.4 Magnesium Hazard

This is expressed in form of Magnesium Adsorption Ratio (MAR) as shown in equation (6). Magnesium content of water is one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters but higher magnesium content will adversely affect crop yields as the soils would become more saline (Joshi, *et al.*, 2009). The values of MAR for all the groundwater samples vary from 0.096% to 128.554% (Tables 1, 7 and Figure 4) with 98.05% of the waters having MAR less than the acceptable limit of 50% (Ayers & Westcot, 1985). These samples are considered safe but the remaining 1.95% of the samples has MAR higher than the acceptable limit of 50%. Those few samples with high MAR are considered unsuitable for irrigation purposes as they will harm the soil.

3.5 Permeability Hazard

Permeability index (PI) is used to assess probable influence of water quality on physical properties of soils (Doneen, 1966). The soil permeability is affected by the long term use of irrigated water and the influencing constituents are the total dissolved solids, sodium bicarbonate and the soil type. The PI values range from 3.13% to 40.39% (Table 1 and Figure 4) and the results indicate that groundwater in the study area fall within class I and class II (Doneen, 1966) which make the water suitable for irrigation purposes.

3.6 Kelley's Ratio

The level of Na^+ measured against Ca^{2+} and Mg^{2+} is known as Kelley's ratio, and it is used to rate irrigation waters (Kelley, 1940; Paliwal, 1967). All the tested samples classified as good because all the KR values fall within the permissible limit of 1, indicating the good quality of the groundwater for irrigation purpose (Tables 1, 7 and Figure 4).

3.7 Chloro-alkaline Indices (CAI)

The Chloro-alkaline indices (CAI) indicate the ion-exchange between the groundwater and its host environment (Aghazadeh & Mogaddam, 2010). The Chloro-alkaline indices used in the evaluation of Base Exchange are calculated using the Equation (7) and the results are shown in Table 1 and Figure 4.
Ion-exchange is said to be direct when the indices of exchange between Na/K in groundwater and Mg/Ca in host rock are positive. The exchange is considered as indirect when indices are negative. 92.3% of the samples gave positive Chloro-Alkaline index ratios, reflecting dominance of direct ion-exchange of Na/K in the water with Mg/Ca in the host rock. The remaining 7.7% of the samples gave negative ratios.

4.0 CONCLUSION

The results of the physiochemical analyses of groundwater from shallow hand-dug wells in Akure metropolis south-western Nigeria and the calculated irrigation water quality indices show that the groundwater is generally safe and suitable for long term irrigation uses. Overall, 91.80% of the tested waters fall into the excellent to good irrigation quality categories while the remaining 8.20% fall into permissible to unsuitable irrigation categories.

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Table 1: Calculated Irrigation Water Parameter Indices.

S/No	Well Location Lat N07°..; Lon E005°.	CAI	SAR	MAR%	PI%	SSP%	KR	RSC	TDS mg/l $CaCO_3$	EC µs/cm
1	N...15.9'; E...12.95'	0.79	0.1	7.18	11.36	8.89	0.06	0.91	43	87
2	N...14.97'; E...12.13'	0.82	0.79	41.1	6.37	15.11	0.1	1.37	247	495
3	N...14.22'; E...12.47'	0.71	0.19	7.82	10.36	19.32	0.13	0.59	63	127
4	N...14.45'; E...11.67'	0.82	0.22	30.66	6.31	13.99	0.09	1.67	262	525
5	N...17.15'; E...11.5'	0.83	0.17	11.84	6.12	10.56	0.07	0.53	163	326
6	N...17.92'; E...11.65'	0.87	0.12	5.46	13.15	10.23	0.09	0.76	53	106
7	N...16.28'; E...11.8'	0.58	0.16	37.5	11.1	19.72	0.09	1.87	91	183
8	N...16.45'; E...11.38'	0.60	0.15	43.73	11.76	13.74	0.09	2.76	99	198
9	N...16.88'; E...12.68'	0.74	0.08	4	11.84	6.68	0.05	0.91	39	79
10	N...17.4'; E...12.57'	0.80	0.08	7.82	11	16.72	0.06	0.59	52	105
11	N...15.17'; E...11.87'	0.85	0.27	69.53	6.51	10.68	0.09	9.37	494	988
12	N...15.57'; E...10.58'	0.68	0.12	24.22	12.68	17.71	0.07	3.22	70	140
13	N...17.23'; E...9.22'	0.72	0.11	18.86	12.22	14.29	0.06	4.8	115	229
14	N...18.38' E...8.03'	0.69	0.07	2.82	10.18	13.82	0.04	0.97	20	40
15	N...18.43' E...8.37'	0.81	0.08	10.99	15.99	10.53	0.05	2.59	50	99
16	N...17.58'; E...9.67'	0.48	0.06	26.98	9.32	24.18	0.04	1.22	84	168
17	N...18.23'; E...10.08'	0.44	0.03	21.92	10.71	15.38	0.01	5.27	95	189
18	N...18.03'; E...9.5'	0.93	0.11	21.6	5.39	5.57	0.05	-0.17	130	261
19	N...18.8'; E...9.22'	0.74	0.06	19.95	12.64	12.31	0.03	3.45	67	135
20	N...17.05'; E...9.7'	0.65	0.08	32.23	13.75	16.62	0.41	2.36	62	125
21	N...16.18'; E...9.82'	0.88	0.06	2.93	9.33	10.88	0.04	0.6	46	93
22	N...16.85'; E...8.85'	0.69	0.13	33.42	8.4	7.7	0.05	7.25	181	362
23	N...16.65'; E...9.22'	0.68	0.11	14.56	12.24	14.01	0.06	2.02	73	147
24	N...16.25'; E...10.17'	0.76	0.2	28.28	8.73	13.92	0.1	1.85	118	235
25	N...16.08'; E...10.7'	0.71	0.15	24	8.89	15.02	0.08	1.77	155	312
26	N...15.45'; E...10.02'	0.81	0.2	34.63	8.33	15.9	0.11	0.99	120	241
27	N...15.7'; E...9.87'	0.83	0.24	34.15	8.4	15.39	0.13	1.62	194	387

28	N...15.42'; E...11.1'	0.75	0.23	20.43	4.13	17.03	0.1	-0.67	289	579
29	N...15.03'; E...10.87'	0.74	0.17	22.38	5.55	14.39	0.09	-0.23	136	273
30	N...14.55'; E...10.35'	0.70	0.13	18.04	6.47	10.24	0.07	0.09	115	230
31	N...14.57'; E...9.48'	0.61	0.14	28.98	12.85	19.94	0.06	1.43	182	366
32	N...15.83'; E...8.02'	0.85	0.07	15.362	10.2	8.71	0.04	0.59	41	82
33	N...15.3'; E...8.7'	0.79	0.14	41.76	8.34	8.8	0.07	1.11	161	322
34	N...15.7'; E...9.2'	0.75	0.22	26.23	8.3	13.25	0.13	5.48	104	207
35	N...14.27'; E...8.8'	0.71	0.11	16.05	5.86	11	0.04	9.83	147	294
36	N...15.07'; E...9.37'	0.75	0.08	38.37	6.76	6.9	0.03	0.61	286	571
37	N...15.22'; E...11.48'	0.48	0.36	128.55	7.23	29.42	0.11	9.83	803	1600
38	N...12.77'; E...10.38'	0.70	0.06	21.49	5.89	9.15	0.02	0.62	102	204
39	N...12.12'; E...10.68'	0.90	0.04	38.4	10.21	2.6	0.02	5.6	155	309
40	N...13.63'; E...10.07'	0.71	0.08	12.24	5.57	6.14	0.04	-0.33	52	104
41	N...13.53'; E...10.88'	0.81	0.15	1.87	9.07	14.86	0.9	0.34	68	137
42	N...13.55'; E...11.38'	0.70	0.11	8.05	18.13	30.72	0.1	1.01	36	72
43	N...14.55'; E...11.02'	0.80	0.19	32.13	4.37	12.49	0.8	-0.25	222	444
44	N...13.55'; E...11.95'	0.86	0.22	23.01	6.16	14.77	0.12	-0.06	175	350
45	N...12.2'; E...11.63'	0.81	0.09	14.28	8.17	8.94	0.06	0.11	60	121
46	N...12.55'; E...12.47'	0.85	0.08	12.7	5.11	8.23	0.03	-0.51	65	113
47	N...12.8'; E...11.58'	0.82	0.1	11.57	8.39	14.12	0.06	0.11	63	125
48	N...13.37'; E...12.33'	0.79	0.04	13.95	7.93	7.93	0.02	0.25	51	102
49	N...13.08'; E...12.22'	0.87	0.13	20.74	4.09	7.58	0.05	-0.75	179	358
50	N...17.47'; E...8.97'	0.86	0.22	26.52	6.25	12.02	0.1	0.72	339	678
51	N...17.43'; E...8.55'	0.78	0.04	9.43	8.36	10.62	0.02	0.25	49	99
52	N...17.47'; E...10.8'	0.82	0.1	14.81	9.94	9.68	0.06	1.14	65	128
53	N...16.47'; E...10.98'	0.81	0.12	30.35	9.36	8.26	0.06	1.62	122	245
54	N...17.82'; E...10.6'	0.88	0.08	11.58	16.21	9.01	0.05	3.31	91	182
55	N...15.30'; E...13.16'	0.64	0.19	15.44	5.78	14.04	0.08	0.99	182	364
56	N...15.51'; E...13.39'	0.82	0.1	23.15	3.71	5.26	0.03	1.5	74	149
57	N...15.70'; E...13.56'	0.45	0.2	38	11.83	25.54	0.16	0.7	379	759
58	N...15.79'; E...14.58'	0.45	0.02	26.83	11.83	19.24	0.01	0.53	60	121
59	N...15.50'; E...14.59'	0.02	0.15	29.45	13.81	32.59	0.13	0.7	29	59
60	N...13.02'; E...13.20'	0.33	0.16	42.3	8.83	16.95	0.1	0.84	35	71
61	N...14.04'; E...13.31'	0.25	0.1	1.68	19.93	30.52	0.09	2.13	101	203
62	N...14.60'; E...13.39'	0.66	0.1	38.05	13.55	11.52	0.06	2.78	36	75
63	N...15.59'; E...14.94'	0.43	0.27	22.86	14.42	27.16	0.19	2.04	102	204
64	N...15.17'; E...14.98'	0.77	0.15	0.73	15.01	17.76	0.1	1.79	82	165
65	N...15.25'; E...15.50'	0.50	0.12	21.07	12.36	15.81	0.08	1.16	97	195
66	N...15.78'; E...15.06'	0.38	0.13	25.62	9.28	15.43	0.07	1.54	50	101
67	N...15.87'; E...15.44'	0.48	0.13	11.31	7.22	22.63	0.08	-0.06	88	176
68	N...15.53'; E...15.88'	-0.40	0.17	17.12	6.28	10.64	0.06	2.34	422	844
69	N...16.85'; E...13.36'	0.41	0.09	20.17	17.97	21.89	0.07	1.41	162	324
70	N...17.01'; E...13.50'	0.45	0.07	1.24	6.54	11.91	0.04	-0.4	45	90

71	N...17.20’; E...13.28’	-0.01	0.21	0.1	10.18	31.73	0.17	0.04	64	128
72	N...17.23’; E...13.57’	0.53	0.23	17.01	11.76	16.85	0.13	2.74	42	86
73	N...16.84’; E...13.53’	0.69	0.13	24.62	4.26	6.52	0.04	1.79	98	196
74	N...13.91’; E...14.36’	0.78	0.06	9.43	11.38	11	0.03	4.78	83	167
75	N...13.83’; E...14.23’	-1.41	0.43	23.18	8.03	21.6	0.21	2.72	82	162
76	N...13.99’; E...14.15’	0.90	0.08	24.25	5.28	8.02	0.03	1.46	145	291
77	N...14.05’; E...13.91’	0.02	0.1	10.31	5.73	7.07	0.04	4.27	161	322
78	N...13.97’; E...13.79’	0.10	0.1	14.82	4.04	56.02	0.1	1.18	53	106
79	N...12.69’; E...15.55’	0.44	0.07	4.65	12.44	12.71	0.03	5.2	27	54
80	N...12.52’; E...15.48’	0.42	0.08	27.02	11.71	10.6	0.04	4.17	152	303
81	N...12.18’; E...15.62’	0.65	0.11	38.19	9.74	12.17	0.06	1.47	127	252
82	N...14.24’; E...13.61’	0.11	0.1	33.9	7.39	18.06	0.06	0.27	80	161
83	N...14.43’; E...13.72’	0.18	0.05	24.9	8.02	10.08	0.02	2.47	55	110
84	N...15.23’; E...13.42’	-0.07	0.15	24.47	8.21	23.4	0.1	0.27	145	291
85	N...17.59’; E...13.90’	0.41	0.18	31.35	7.64	20.32	0.11	0.51	68	137
86	N...17.47’; E...14.11’	-0.13	0.11	25.12	15.16	17.68	0.06	5.22	99	199
87	N...18.14’; E...14.06’	-0.34	0.19	17.98	10.49	30.27	0.14	0.44	89	179
88	N...17.86’; E...13.83’	0.16	0.04	21.07	16.96	15.62	0.02	1.94	57	114
89	N...17.59’; E...13.72’	0.38	0.12	22.02	8.26	19.98	0.07	0.74	57	114
90	N...17.27’; E...13.82’	-0.85	0.12	19.36	16.14	24.33	0.08	3.07	78	157
91	N...16.35’; E...16.60’	0.16	0.06	21.2	17.84	20.69	0.04	2.44	57	115
92	N...16.01’; E...16.63’	0.48	0.16	38.19	12.23	18.39	0.09	3.07	49	98
93	N...12.54’; E...13.06’	0.54	0.05	25.15	6.09	5.65	0.02	0.78	125	250
94	N...12.65’; E...13.27’	0.61	0.08	29.14	9.09	12.02	0.04	2.17	118	237
95	N...12.93’; E...13.04’	0.64	0.1	40.58	13.38	21.19	0.07	1.41	101	203
96	N...13.16’; E...13.07’	0.05	0.09	23.65	7.84	11.08	0.03	4.99	92	186
97	N...13.14’; E...13.34’	0.48	0.2	36.66	3.13	24.44	0.13	0.44	148	297
98	N...16.79’; E...14.66’	0.47	0.05	17.98	11.57	14.76	0.04	1.64	77	155
99	N...16.59’; E...14.75’	0.10	0.07	10.98	11.96	21.66	0.05	0.99	53	108
100	N...16.42’; E...14.98’	0.10	0.11	34.48	6.81	12.52	0.05	2.15	41	83
101	N...16.46’; E...15.27’	-0.33	0.11	20.7	6.47	10.04	0.05	1.64	115	231
102	N...16.20’; E...16.02’	0.31	0.14	8.37	17.01	22.72	0.11	1.64	174	348
103	N...16.24’; E...15.53’	0.21	0.05	24.18	9.71	16.84	0.03	1.22	88	175

Table 2: Range of Total Dissolved Solids for Irrigation Use (Robinove *et al.*, 1958).

CLASSIFICATION	TOTAL DISSOLVED SOLIDS (mg/l $CaCO_3$)	REMARKS
Non saline	< 1000	All samples in the study area fall in this zone
Slightly saline	1000-3000	NIL
Moderately saline	3000-10,000	NIL
Very saline	>10,000	NIL

Table 3: Summary of Physico-chemical Parameters of the Akure Groundwater

PARAMETER	RANGE	MEAN	STANDARD DEVIATION
pH	4.9-7.2	6.098	0.485
Temperature (^oC)	25.3-29.9	27.490	0.911
Electrical Conductivity (µs/cm)	40-1600	238.76	213.911
Sodium (meq/l)	0.013-0.452	0.1214	0.0801
Calcium (meq/l)	0.42-5.30	1.4171	0.74542
Potassium (meq/l)	0.0154-0.4590	0.1799	0.1424
Magnesium (meq/l)	0.0007-2.56	0.4678	0.47268
Bicarbonate (meq/l)	0.8-11.6	3.204	2.14494
Chloride (meq/l)	0.2-4.85	0.9418	0.76371
Sulphate (meq/l)	0.003-0.035	0.0152	0.009
TDS (mg/l $CaCO_3$)	20-803	119.30	119.990
Total Alkalinity (mg/l $CaCO_3$)	40-580	160.194	107.247
Total Hardness (mg/l $CaCO_3$)	0.72-740	166.709	119.279
Odour	Odourless	Odourless	Odourless
Acidity	180-1000	388.738	152.178
Eh	129-567	456.068	55.7301

Table 4: Limits of Some Parameter Indices for Rating Irrigation Water Quality (after Eaton, 1950; Wilcox, 1950; Ayers & Westcot, 1985).

Category	EC (µs/cm)	RSC	SAR	SSP(%)	REMARKS
I - Excellent	<250	<1.25	<10	<20	74.5% of the samples in the study area fall within this zone.
2 – Good	250-750	1.25-2.5	10-18	20-40	18.7% of the samples in the study area fall within this zone.
3 - Doubtful	750-2250	>2.5	18-26	40-80	6.8% of the samples in the study area fall within this zone.
4 – Poor	->2250	-	>26	>80	Nil

Table 5: Quality of Irrigation Water in Relation to EC (after Richards, 1954).

S/No	Electrical Conductivity, EC	Type of Water	Suitability for Irrigation	Remarks
1	Below 250	Low saline water	Entirely safe	68.9% of the samples in the study area fall within this zone.
2	250-750	Moderately saline	Safe under practically all conditions	27.2% of the samples in the study area fall within this zone.
3	750-2250	Medium to high salinity	Safe only with permeable soil and Moderate Leaching	Only 1% of the samples in the study area fall within this zone.
4	Above 2250			
i)	2250-4000	High salinity	Unfair for irrigation	NIL
ii)	4000-6000	Very high salinity	Unfair for irrigation	NIL
iii)	Above 6000	Excessive Salinity class	Unfair for irrigation	NIL

Table 6: Modified Wilcox Quality Classification of Irrigation Waters (after Todd, 1980).

Water Class	Na (%)	Electrical Conductivity (µS/cm)	Salinity Hazard	Remarks
Excellent	20	250	Low	74.3% of the samples in the study area fall within this zone.
Good	20-40	250-750	Medium	23.3% of the samples in the study area fall within this zone.
Permissible	40-60	750-2000	High	2.4% of the samples in the study area fall within this zone.
Doubtful	60-80	2000-3000	Very High	NIL

Table 7: Summary of Irrigation Quality Indices of the Akure Groundwater.

PARAMETER	RANGE	MEAN	STANDARD DEVIATION
KR	0.014-0.9	0.09	0.11949
MAR (%)	0.09-128.55	1.86	15.894
PI (%)	3.13-40.39	10.03	4.730
RSC (meq/l)	-0.04-9.83	22.88	2.077
SAR	0.02-0.35	0.13	0.094
SSP (%)	5.26-56.02	15.35	7.660
TDS (mg/l $CaCO_3$)	20-803	119.30	1197.990
EC (µs/cm)	40-1600	238.76	213.911

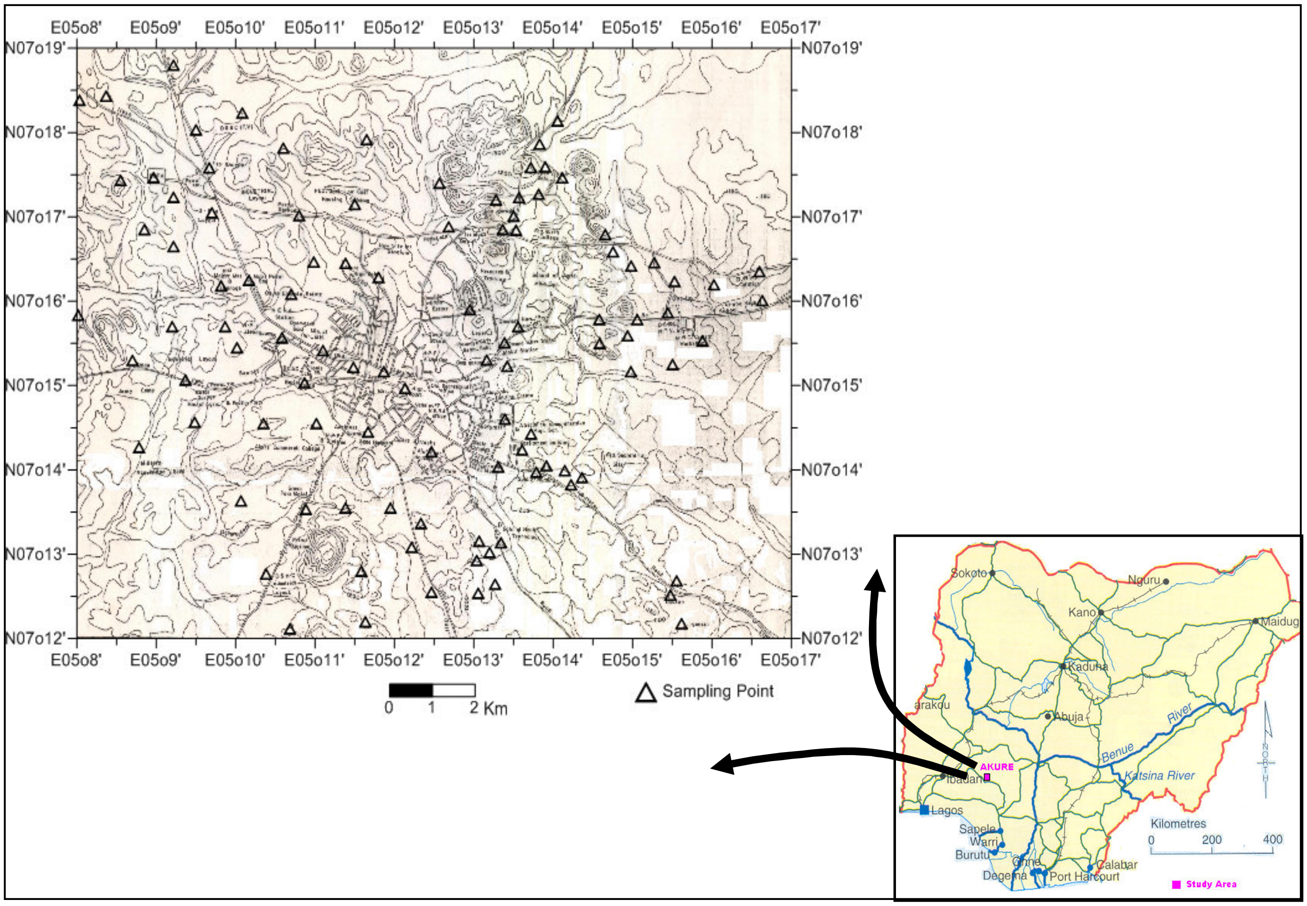

Figure 1: Topographical map of the study area showing the sampling points (*Inset is map of Nigeria*).

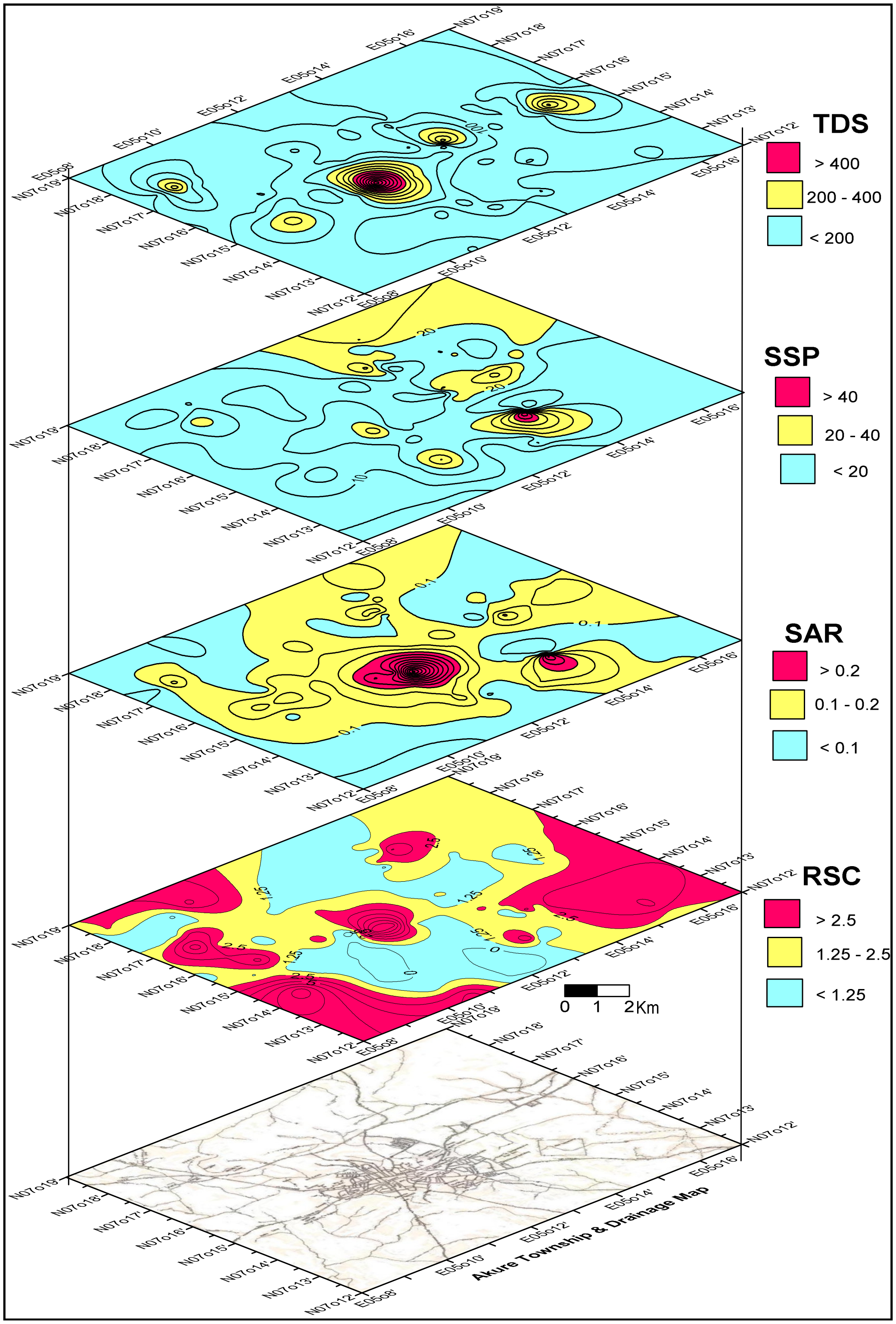

Figure 2: Spatial distribution of TDS, SSP, SAR & RSC values over the drainage area.

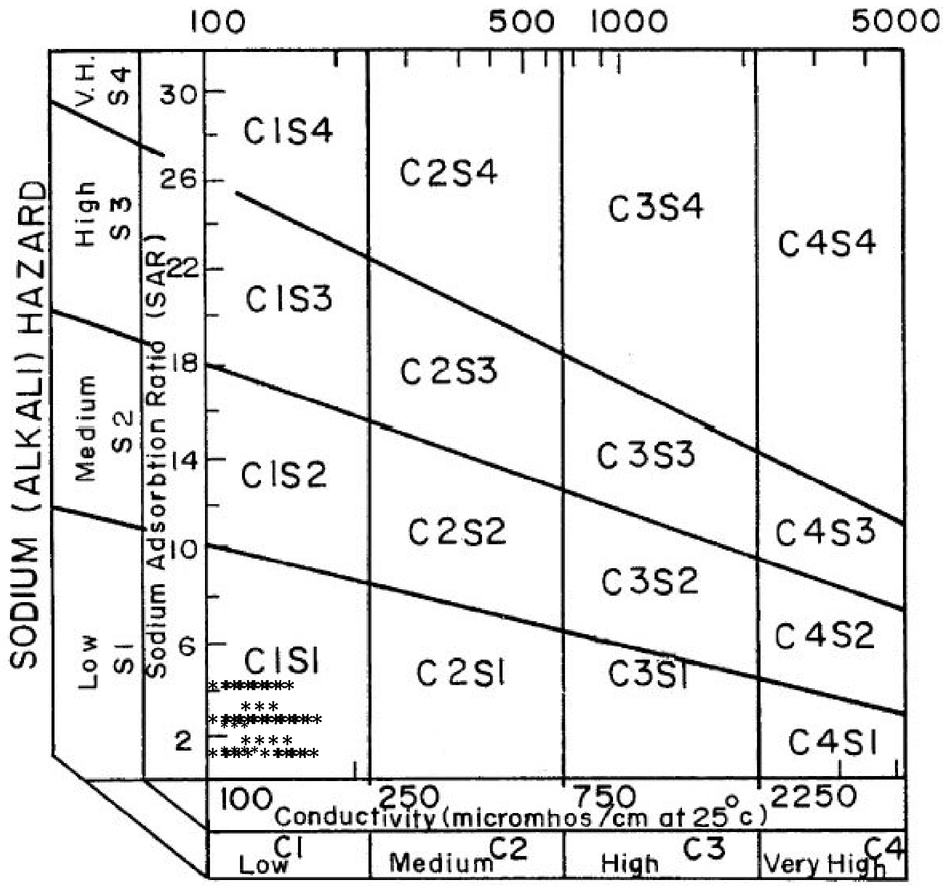

Figure 3: Classification of the water samples using S.A.R. and Salinity Hazard. (after U.S Salinity Laboratory, 1954). **(*** * * are plots of Akure groundwater on the diagram*)**

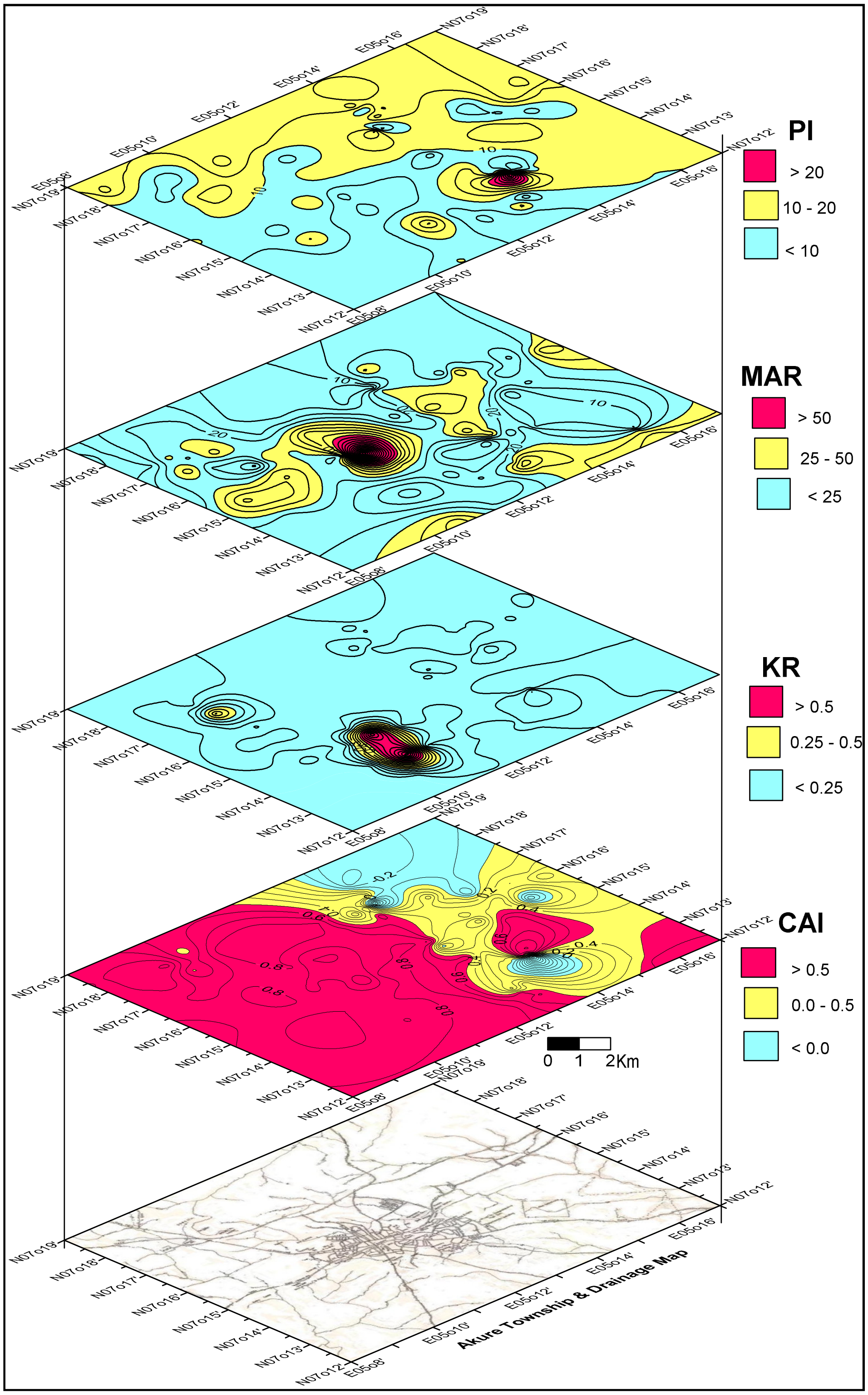

Figure 4: Spatial distribution of PI, MAR & CAI values over the drainage area.