HYDOGEOCHEMICAL ASSESSMENT OF SURFACE WATER AND GROUND WATER QUALITY IN AGBOWO-OROGUN AREA OF IBADAN, SOUTHWESTERN NIGERIA

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ABSTRACT

The Agbowo-Orogun area of Ibadan, which is within the basement complex of southwestern Nigeria, is underlained by banded gneiss of the migmatites-gneiss complex. A total of thirty-five water samples, made up of thirty-two from groundwater and three from surface water, were analyzed for their physico-chemical characteristics with the aim of assessing their quality and usability.

Results of some physico-chemical parameters show average values of 8.61 pH; 749.49μs/cm EC; 218.50 mg/l TDS; 84.40 turbidity; 323.14 pt/co unit colour; 54.94 mg/l Na^+; 49.75mg/l Ca^{2+}; 28.24mg/l Mg^{2+}; 23.54 mg/l K^+; 1.05 mg/l Fe^{2+}; 229.14 mg/l HCO_3^-; 128.23 mg/l Cl^-; 14.86mg/l NO_3^-; 7.30mg/l SO_4^{2-}; 4.60 mg/l PO_4^{3-} and 1.31mg/l F. Average values of total hardness (TH) and sodium absorption ratio are 230.68 mg/l and 1.95 respectively. The relative abundance of cations is in the order of $Na^+>Ca^{2+}>Mg^{2+}>K^+>Fe^{2+}$ while those of anions are; $HCO_3^->Cl^->NO_3^->SO_4^{2-}>PO_4^{2-}>F^-$. R-mode factor analysis shows five factor loadings and bi-log plots of TDS versus $Na^+/(Na^+ + Ca^{2+})$ all indicate that the bulk of the chemistry of the water is modified by weathering of the associated rocks.

Six water groups were identified, based on characterization using the piper trilinear diagram. These include; Ca-(Mg)-Na-HCO_3, Ca-(Mg)-Na-Cl-(SO_4)-HCO_3, Ca-(Mg)-HCO_3, Ca-Mg-(SO_4)-HCO_3, Ca-(Mg)-SO_4 and Na-(K)-HCO_3 thus reflecting diverse effects of bedrock lithologies, base exchange processes, precipitation and weathering. Both water sources are in general, slightly alkaline with low to medium sodium hazards. The pH, Ca^{2+} and SO_4^{2-} are within the permissible limits of WHO standard for both water sources. Concentrations of Na^+, NO_3^-, Cl^-, HCO_3^- conductivity and TDS are higher than maximum permissible limits for the surface water and may be attributed to anthropogenic effects. However it can be observed that both the groundwater and surface water sources are suitable for agricultural purposes while the groundwater in particular, is acceptable for domestic uses.

KEYWORDS: Water quality, physico-chemical characteristics, Agbowo, SW Nigeria

INTRODUCTION

Nigeria is one of the nations benefiting from the United Nations' Children Education Funds (UNICEF) Water and Environmental Sanitation (WES) initiative. Of the nations' over one hundred million population, only thirty-nine percent have access to safe water (Kola-Olusanya 1998) This also means that over sixty million of the population relies on water from sources that are largely suspect. Ibadan, a city in the southwestern part of Nigeria, is one of the largest urban centers in Africa, with a population of 1.3 million as at 1991 census and estimated population of 1.76 million in 2001, based on average growth rate of 3%. The city with a total area of about 540km², is characterized by a high population density of about 3,250 persons per km² in comparison to the national average of 137 persons per km². However as observed by Tijani et al. (2004), the rapid population growth of the town is not in particular linked with industrialization but to the age long role as a regional administrative capital since the colonial era, coupled with massive rural urban migration

As in many urban centers in developing countries, the city is also characterized by poor land-use planning, lack of proper sewage and waste disposal systems as well as high traffic congestion. Consequently, many households, especially within the congested central portion of the metropolis do not have appropriate waste disposal facilities. As a result, direct discharge of sewage water and dumping of domestic wastes into the drainage channel is a common practice. Most of the surface water sources in this area are affected by these discharges. In addition, about two-thirds of households in Ibadan depend entirely or partially on groundwater for domestic purposes. Since most of these wells derive their waters from shallow wells, there is the need therefore to examine the potential health hazards that might result from using water from these shallow wells.

Although, there is no up-to-date data on the daily water supply, demand and use, empirical observations have shown that domestic needs account for a substantial part of the water need in the area. This is attributed to the low number of factories, which would otherwise have required substantial quantities of water. In addition, the Ibadan inhabitants have had to look for alternative sources such as streams, rivers, etc to meet their water demands. These water sources are exposed to anthropogenic and industrial pollutants. Hence there is the need to assess the quality of water in the area. This study therefore examines the quality and usability of potable water sources in the area.

Location, physiography and drainage

The study area, lies between longitudes 3°54' and 3°55' E and latitudes 7°26' and 7°27'N. It covers an area of about 66km² within the Agbowo-Orogun area, the northeastern part of Ibadan (Fig.1). Generally in Ibadan, the scenery is dominated by three major landforms, such as the hills, plains and river valleys. The hills are the most striking features, though they constitute < 20% of the total surface area. The two main types of physiographic features are the quartzite ridges and gneissic inselbergs. The plains are the most extensive landform systems in the area with the elevations ranging between 180 and 210m above sea level. The cover essentially the areas between the hill bases and usually entrenched valley bottoms. The river valleys are the narrowest landforms in the environ and are characterized by conspicuous incision of the rivers into the flood plains or rivers beds. The area has an undulating relief. The major rivers in Ibadan metropolis are the Ogunpa, Ona and Alero. The area is characterized by dendritic and trellised patterns (Olayinka, et al., 1999).
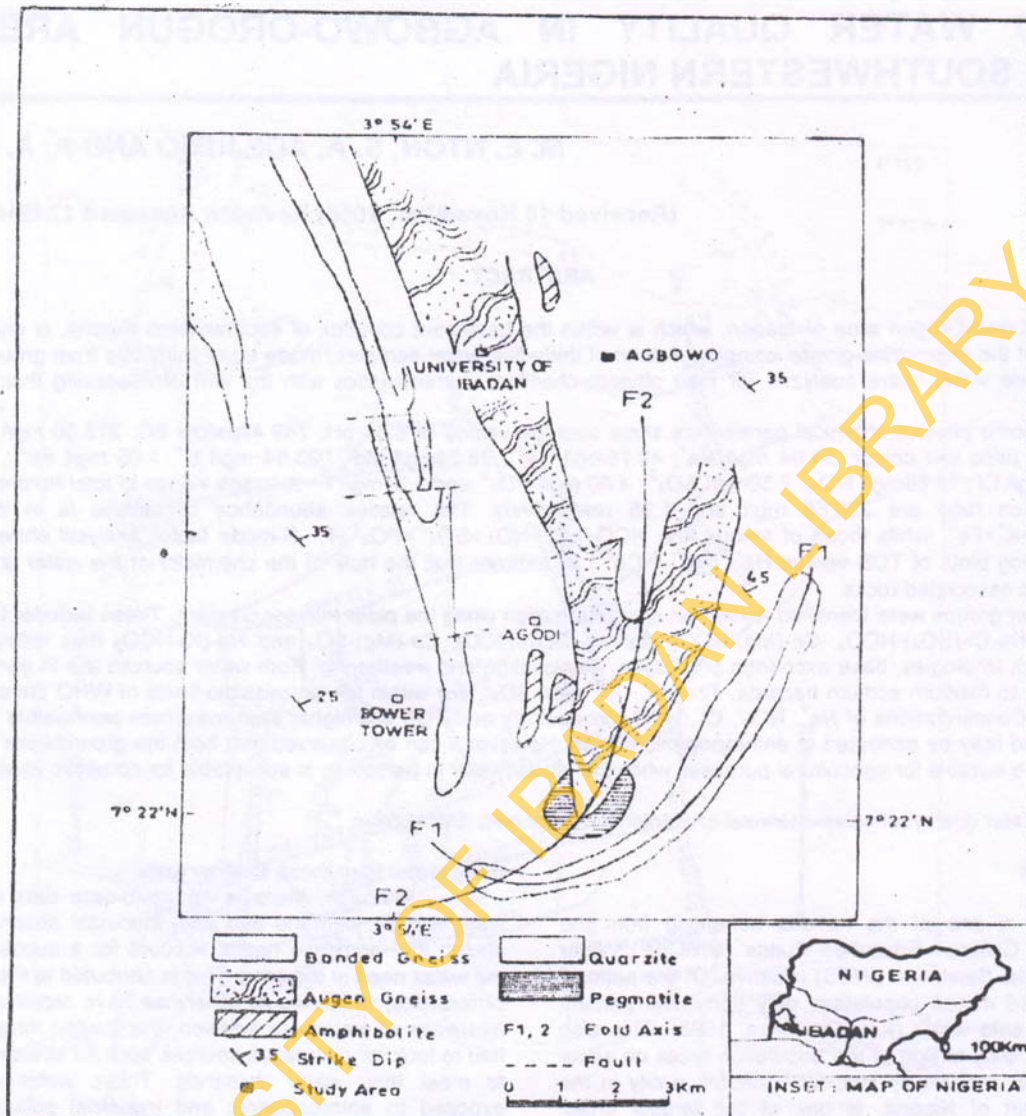
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Fig. 1: Geological map of Ibadan (After Grant, 1970)

The climatic zone of the southwestern Nigeria is within the West African Monsoonal type, characterized by two distinct seasons, namely the rainy and the dry seasons. The rainy season commences in April and lasts till October, while the dry season is from November to March of the following year. The former is characterized by high rainfall with an annual rainfall amount of about 1237mm. During the dry season, dry, dust-laden winds originating from the Sahara desert are experienced. The vegetation is characterized by typical rain forest, often modified by human habitation and cultivation (Duze and Ojo, 1982).

The study area lies within the Nigerian Basement complex, belonging to the Pan African mobile belt, (Jones and Hockey, 1964; Grant, 1970; Turner, 1983). The dominant rock types are banded gneiss, augen gneiss, quartzite and migmatites. These rocks are intruded by pegmatite, quartz veins, aplites and dolerite dykes (Olayinka et al., 1999).

Banded gneiss constitute >75% of the rocks in Ibadan, while augen gneisses and quartzite share the remaining quarter of the area almost in equal proportion. Other rock types in the area include amphibolites and pegmatite

(Fig.1). In the Agbowo -Orogun area, folded banded gneiss is the predominant rock type with regional strike in the NNW-SSE direction.

METHODOLOGY

Field sampling and determinations

A total of thirty five (35) representative water samples were collected from the study area. These comprise thirty two (32) from hand dug and three (3) from streams (Fig.2). At each location, an aliquot of the water to be sampled was used to rinse the plastic container to avoid contamination. The top film of the surface water and groundwater was also removed prior to collection. About 2 liters of water samples were collected at each location into a clean plastic container. In the field, temperature was determined directly using a thermometer while the turbidity of the water sample was determined using a Hatch Turbidity Meter. The samples were adequately labeled, acidified with concentrated nitric acid and preserved in a refrigerator for laboratory analyses.
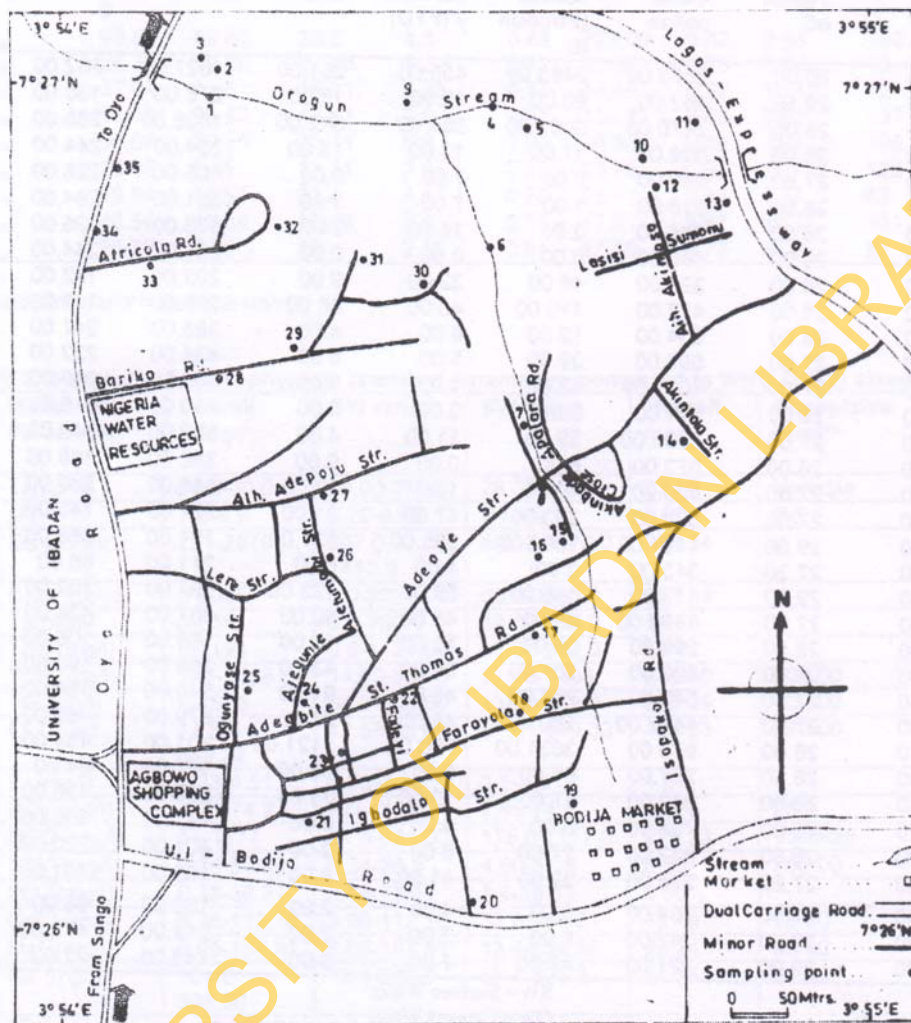
Fig 2: Road map of Agbowo/ Orogun showing drainage patterns and sampling points

Laboratory study

The total dissolved and total suspended solids were analyzed by centrifugal method while total hardness was determined by titremetry. Cations (Ca, Mg and Fe) were determined by atomic absorption spectrometry (AAS) model 210VGP while Na and K were determined by Flame photometry method using photometer model Jenway PF97/L. The anions were analyzed using various methods. Chloride was analyzed by titration using Argentometric method. Fluoride was determined by SPANDS method calorimetrically, while nitrate was analyzed by colorimetric method using phenoidsulphanic acid. Bicarbonate ions were determined by calculations from phenolphthalein and total alkalinity. Determinations of the amount of sulphate were by turbidity method while that of phosphate was by colorimetry using vanado-molybdate method.

The laboratory analyses were conducted at the Geological Laboratory. Petroc Services Limited; Ibadan while detailed analytical protocols can be seen in Adejumo (2005).

Results and Interpretation

The results of physical and chemical parameters of the surface water and ground water samples are presented in Tables 1 and 2 respectively. The summary of the various parameters, their mean values as compared to the values of WHO (1993) standards is shown in Table 3. In the groundwater, the pH ranges from 8.20-8.90, temperature is from 26.0-29.0 $^{\circ}$C ; EC is from 207.0-1412.0 µs/cm, TDS ranges from143.0 to 556.0 mg/l and TH ranges from 84.0-556.0. Correspondingly, the surface water indicates the following ranges of parameters: pH, (7.70-8.70), temperature (28.0 to 30.0°C), Electrical conductivity (EC) varies from 462.0 to 2870µs/cm, TDS is from 276-1808 and TH (138.0-362.0).

Table: 1   Results of physical parameters of Surface water and Ground water in study area

Sample No.	Water Source	pH	Temp. oC	Cond µs/cm	Colour (Pt/count it)	Turbidity (FTU)	TSS	TDS	TH	SAR
1	SW	7.70	30.00	2583.00	2485.00	455.00	261.00	1627.00	362.00	12.30
4	,,	8.70	29.50	462.00	60.00	19.00	15.00	276.00	138.00	2.95
6	,,	8.70	28.00	2870.00	3065.00	855.00	542.00	1808.00	288.00	14.32
2	GW	8.70	26.00	608.00	17.00	13.00	13.00	384.00	244.00	1.90
3	,,	8.70	27.50	659.00	0.00	7.00	0.00	405.00	226.00	1.40
5	,,	8.60	26.50	915.00	1.00	7.00	1.00	561.00	284.00	0.31
7	,,	8.80	28.00	934.00	3.00	14.00	24.00	573.00	326.00	1.16
8	,,	8.60	29.00	460.00	0.00	0.00	0.00	284.00	244.00	0.77
9	,,	8.90	28.00	328.00	46.00	32.00	9.00	203.00	132.00	0.57
10	,,	8.70	26.00	412.00	110.00	40.00	36.00	255.00	148.00	1.04
11	,,	8.80	28.00	604.00	12.00	6.00	4.00	386.00	247.00	0.74
12	,,	8.80	27.60	697.00	39.00	5.00	8.00	434.00	222.00	0.90
13	,,	8.70	27.00	1013.00	43.00	1.00	3.00	642.00	330.00	1.07
14	,,	8.60	29.00	541.00	0.00	0.00	0.00	338.00	216.00	0.58
15	,,	8.20	27.00	1305.00	59.00	11.00	4.00	809.00	340.00	4.81
16	,,	8.40	28.00	573.00	6.00	0.00	0.00	358.00	168.00	0.55
17	,,	8.90	27.50	620.00	40.00	1.00	12.00	389.00	230.00	0.84
18	,,	8.60	27.00	528.00	233.00	47.00	91.00	327.00	140.00	1.62
19	,,	8.50	29.00	1134.00	1880.00	385.00	531.00	701.00	556.00	0.52
20	,,	8.40	27.30	343.00	0.00	1.00	0.00	211.00	88.00	0.75
21	,,	8.50	29.00	313.00	316.00	59.00	123.00	197.00	102.00	1.67
22	,,	8.30	27.00	1390.00	49.00	46.00	60.00	857.00	434.00	2.91
23	,,	8.60	28.50	299.00	26.00	10.00	16.00	188.00	106.00	1.04
24	,,	8.60	28.00	593.00	207.00	36.00	43.00	368.00	196.00	0.82
25	,,	8.80	27.00	549.00	244.00	46.00	91.00	344.00	184.00	1.67
26	,,	8.60	27.50	1412.00	180.00	48.00	27.00	879.00	466.00	2.21
27	,,	8.70	26.00	970.00	3031.00	760.00	1121.00	601.00	454.00	0.58
28	,,	8.60	28.50	207.00	64.00	6.00	53.00	187.00	84.00	1.45
29	,,	8.50	28.00	382.00	27.00	13.00	13.00	233.00	128.00	0.88
30	,,	8.70	29.00	765.00	0.00	8.00	0.00	491.00	308.00	0.65
31	,,	8.80	28.50	633.00	27.00	8.00	2.00	401.00	220.00	0.83
32	,,	8.80	27.20	298.00	37.00	11.00	8.00	186.00	101.00	0.68
33	,,	8.60	27.50	269.00	0.00	4.00	2.00	168.00	98.00	1.27
34	,,	8.60	29.00	342.00	6.00	3.00	2.00	214.00	172.00	0.87
35	,,	8.80	29.00	221.00	47.00	7.00	6.00	143.00	92.00	1.63

TH= Total Hardness (mg/l)
TSS= Total Suspended Solid (mg/l)
SAR= Sodium Absorption Ratio
SW= Surface Water
GW= Ground Water
TDS= Total Dissolved Solid

Table 2: Results of chemical characteristics of surface water and groundwater in the study area

Sample No	Water Source	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe^{2+}	Cl^-	F^-	NO_3^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}
1	SW	87.21	34.56	380.42	201	2.45	532.05	3.71	68.67	1167	44.6	26.84
4	,,	32.85	13.44	56.4	10.4	1.42	57.61	3.5	7.86	175	4.8	5.4
6	,,	72.96	25.34	395.2	220.38	3.15	549.32	4.51	74.2	1177	57.8	38.31
2	GW	52.83	26.88	48.2	16.8	1.96	59.39	2.1	9.64	354	11.2	6.2
3	,,	51.22	23.52	36.2	3.2	0.62	96.99	1.8	0.33	201	7.89	1.6
5	,,	67.36	27.74	10.4	1.6	0.57	115.8	0.87	41.86	166	2.7	0.64
7	,,	73.44	34.18	26.4	12.4	1.1	169.04	3.32	13.62	209	5.60	4.31
8	,,	64.32	19.97	19.45	4.8	0.68	55.43	0.93	<0.1	230	1.3	16
9	,,	32.64	12.1	10.6	1.8	0.45	22.77	0.65	13.73	157	0.24	0.79
10	,,	40.8	11.04	20.46	8.2	0.79	36.62	1.5	<0.1	179	2.3	1.82
11	,,	18.14	29.47	15.51	3.4	0.52	99.97	0.56	31.12	89	1.6	0.94
12	,,	53.12	20.93	21.64	5.8	0.9	113.82	0.73	7.42	164	0.59	0.61
13	,,	76.96	33.02	26.15	7.4	0.99	183.11	0.81	2.88	178	0.46	0.47
14	,,	56.16	18.48	18.66	5.07	0.71	89.08	1.42	14.4	114	2.4	2.71
15	,,	66.56	41.63	287	113.13	2.03	209.83	2.4	<0.1	547	3.13	21.41
16	,,	39.52	16.62	11.57	2.41	0.45	86.11	0.74	7.2	51	1.4	0.42
17	,,	51.52	24.29	21.22	6.39	0.94	90.07	1.21	<0.1	204	3.2	0.76
18	,,	24.08	13.15	28.51	7.42	0.97	53.45	0.67	<0.1	91	2.28	1.34
19	,,	42.72	107.81	19.91	6	0.96	278.32	0.55	10.52	184	1.4	0.38
20	,,	8.96	13.44	21	6.6	0.84	43.15	0.46	4.1	54	2.6	13
21	,,	19.68	8.35	21.64	5	0.68	37.61	0.64	4.21	55	0.94	3.71

22	,,	106.72	40.13	98.52	58.04	1.75	307.82	2.9	35.66	301	26.5	11.32
23	,,	21.12	11.81	27.4	22	0.99	37.21	1.8	6.87	86	4.6	0.84
24	,,	37.6	24.48	18.57	2.4	0.51	76.21	0.86	16.72	87	1.9	0.52
25	,,	32.48	24.67	36	19.2	0.94	76.21	1.2	ND	154	6.3	5.9
26	,,	112.16	44.54	77.51	46	1.64	381.06	1.62	40.53	621	13.5	13.4
27	,,	98.56	49.82	20.2	4.2	0.48	223.09	0.42	8.64	152	1.8	0.68
28	,,	25.76	10.08	17.48	3.2	0.71	32.66	0.23	7.53	73	1.3	2.1
29	,,	27.04	14.5	16.11	4.28	0.77	54.65	0.57	15.17	72	0.78	0.65
30	,,	64.16	35.42	18.61	3.6	0.81	133.82	0.63	3.65	137	0.45	0.52
31	,,	54.08	20.35	20.11	6.8	0.92	98.58	0.48	ND	156	2.3	0.46
32	,,	26.08	8.35	11.11	2.2	0.57	23.75	0.92	ND	129	4.7	0.53
33	,,	19.84	11.61	20.4	4.4	0.78	28.11	0.83	3.77	63	3.2	0.62
34	,,	46.56	13.34	18.46	3.4	0.71	17.81	0.67	<0.1	161	0.84	0.95
35	,,	26.72	6.05	26	2.18	0.61	17.58	0.73	24.81	82	0.93	0.83

GW = Groundwater; SW = Surface water

Table 3: Summary of hydrophysico- chemical parameters compared to WHO (1993) standard for drinking water

Measured Parameter	Overall Range	GW range	SW range	Overall mean	Acceptable level**	Max Permissible Level**
Temp °C	26.0-30.0	26.00-29.00	28.00-30.00	27.80	Variable	Variable
pH	7.0-8.9	8.20-8.90	7.70-8.70	8.60	6.6	9.5
EC µS/cm	221-2870	207.0-1412.0	462.0-2870.0	752.34		1400.00
Color (pt/co)	0-3065	0.0-3031.00	60.0-3065.0	353.14		
Turbidity	0-855	0.0-760.0	19.00-855.0	84.40		
TSS (rng/l)	0-1121	0.0-1121.00	15.00-542.0	89.17		
TDS (mg/l)	143-1808	143.0-857.0	276.0-1808	218.50	500.00	1000.00
TH (mg/l)	84-556	84.0-556.00	138.0-362.0	230.69	100.00	500.00
Cl⁻ (mg/l)	17.58-549.32	17.58-381.0	57.61-549.32	128.23	250.00	600.00
F- (mg/l)	0.23-4.51	0.23-3.32	3.5-4.51	1.31		
NO₃(mg/l)	<0.1-74.2	ND-41.86	7.86-74.2	14.86	25.0	50.00
HCO₃(mg/l)	51-1177	51.0-621.00	175.0-1177.0	229.23	Variable	Variable
SO₄²⁻(mg/l)	0.24-57.80	0.24-26.5	4.80-57.8	8.53	250.00	400.00
PO₄³⁻(mg/l)	0.38-38.31	0.38-13.4	5.4-38.31	4.60		
Ca²⁺(mg/l)	8.96-112.16	8.96-112.16	32.85-87.21	49.75	75.00	200.00
Mg²⁺(mg/l)	6.05-107.81	6.05-107.81	13.44-34.56	28.24	50.00	150.00
Na⁺(mg/l)	10.48-395.20	10.4-287.0	56.4-395.2	54.96	20.00	200.00
K⁺(mg/l)	1.80-220.38	1.6-113.13	10.4-220.38	23.54	10.00	12.00
Fe (mg/l)	0.45-3.15	0.45-2.03	1.42-3.15	1.05	0.3	1.0
SAR	0.31-14.32	0.31-4.81	2.95-14.32	1.95		

GW = Groundwater; SW= Surface water; ** After WHO (1993)

In the ground water, ranges of elemental concentrations are Cl⁻ (17.58-381.0), F⁻ (0.23-3.32), NO₃³⁻ (ND-41.86), Ca²⁺ (8.96-112.16), Mg²⁺ (6.05-107.81), Na⁺ (10.4-287.0) and K⁺ (1.6-113.13). In the surface water, corresponding values of elemental concentrations are, Cl⁻ (57.61-549.32), F⁻ (3.5-4.51), NO₃³⁻ (7.86-74.2), Ca²⁺ (32.85-87.21), Mg²⁺ (13.44-34.56), Na⁺ (56.4-395.2) and K⁺ (10.4-220.38).

The ranges of chemical parameters in mg/l are as follows: Na⁺ (56.4-395.2), Ca²⁺ (32.85-87.21), Mg²⁺ (13.44-34.56), K⁺ (10.4-220.38), Fe²⁺ (1.42-3.15). Others are HCO₃⁻ (175.0-1170.0), Cl⁻ (57.61-549.23), NO₃⁻ (7.86-74.2), SO₄²⁺ (4.80-57.8), PO₄²⁻ (5.4-38.31), F⁻ (3.5-4.51). The mean concentration of the cations in both water sources are. in the order Na⁺ > Ca²⁺ > Mg²⁺ > K⁺ > Fe²⁺ while that for the anions is; HCO₃⁻ > Cl⁻ > NO₃⁻ > SO₄²⁻ > PO₄³⁻ > F.

Characterization of the water

Plots of hydrochemical parameters on Piper (1944) trilinear diagram based on Furtak and Langgurth (1967) classification (Fig.3) shows that 42.86% of the water is Earth Alkaline type, predominantly sulphate, while about 48.57% falls within Earth Alkaline water field (with higher alkali components). The remaining 8.57% belongs to Alkaline water type. This characterization has revealed the following six (6) important water facies.

(i) Ca- (Mg)-Na-HCO₃
(ii) Ca-Na-Cl- (SO₄)-HCO₃
(iii) Ca- (Mg)-HCO₃
(iv) Na- (K)-HCO₃
(v) Ca- (Mg)-SO₄
(vi) Ca-Mg- (SO₄)-HCO₃

EARTH - ALKALINE WATERS
a: predominantly HCO3
b: HCO3 - SO4
c: predominantly SO4

EARTH - ALKALINE WATERS (WITH HIGHER ALKALI COMPONENTS)
d: predominantly HCO3
e: predominantly SO4
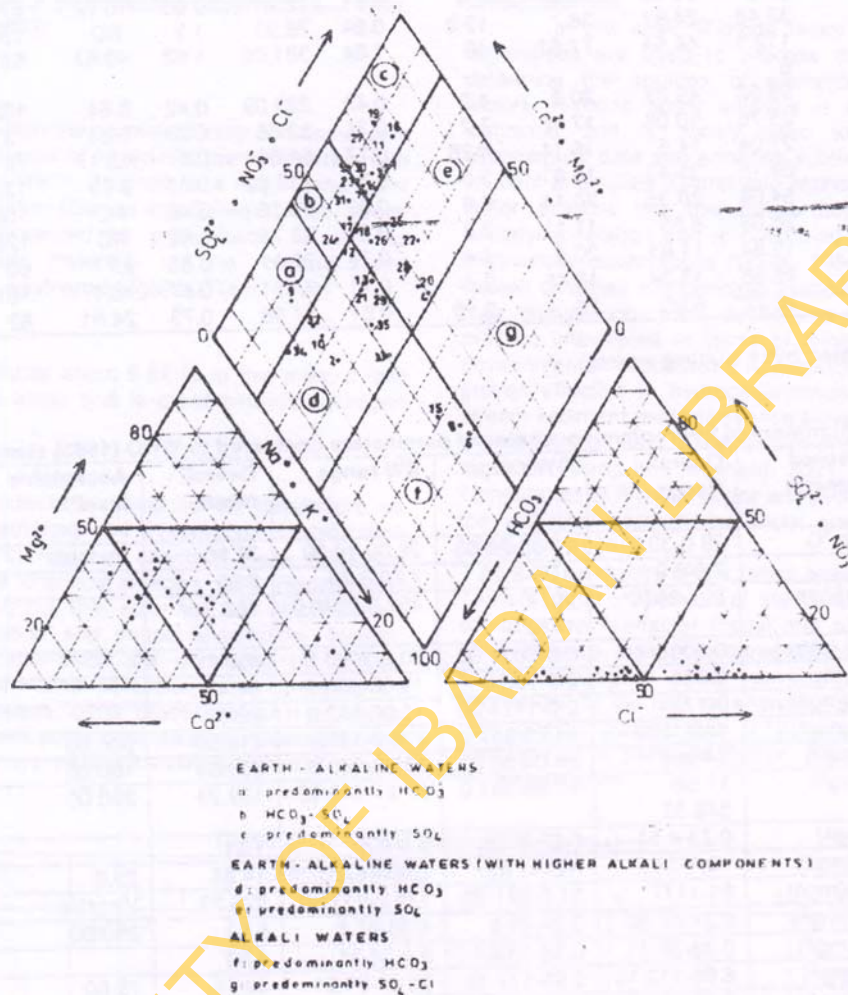
ALKALI WATERS
f: predominantly HCO3
g: predominantly SO4 - Cl

Fig 3: Trilinear piper diagram showing the chemical character of sampled water

Ca - (Mg) - Na - HCO₃

This water type constitutes about 28.57% in the study area. According to Lohnert, (1973), this type has appreciable amount of NaHCO₃ which is an indication of cation exchange water. One of the characteristics of this water type is the higher carbonate hardness as compared to the total hardness. This in effect means that there is more HCO₃ than the available alkaline earth metal ions (Ca²⁺ and Mg²⁺) in equivalent concentration (Lohnert, 1970). These excess bicarbonate ions then release the alkaline (notably Na⁺) into the solution by exchange reaction with the cation exchangers such as clay minerals and other selected minerals that form part of the aquifer materials thus enriching the water with NaHCO₃.

Ca - Na - Cl - (SO₄) - HCO₃

This constitutes about 20.0% of the water type. The occurrence of SO₄²⁻ distinguishes this water type from others. The SO₄²⁻ is a major constituent of atmospheric precipitation (Davies and Dewiest, 1966). The chemistry of this water type is therefore influenced by precipitation.

Ca - (Mg) - HCO₃

This water facie constitutes about 2..86% and belongs to the normal alkaline group. According to Amadi (1987), this water type is typical of Nigerian Basement Complex terrain with limited mixing, perhaps reflecting a primary stage of evolution of its groundwater system. Tijani (1994) reported such chemical composition is due to the dissolution of silicate minerals in the bedrock and aluminosilicates in the weathered regolith. Though not constituting a major proportion of the water facie, its contribution is related to the geology of the area.

Na - (K) - HCO₃

This water type constitutes about 8.57% in the study area. It is also referred to as alkaline water and is usually called *exchange water* due to the evolution through cation exchange process (Loehnert, 1970 and 1973). The presence of appreciable amount of clay materials (as cation exchanger) in the weathered overburden unit, and the apparently low flow velocity with the resultant relatively longer contact or residence time promoted the active cation exchange reaction as represented below.

½ Ca^{2+}-HCO_3^- + Na- X → ½ Ca-X_2 + Na^+-HCO_3^- (X = Clay minerals as cation exchangers)

Such water type has been reported elsewhere in other parts of the Basement Complex of southwestern Nigeria (Tijani, 1994; Tijani and Abimbola, 2003)

Ca- (Mg)-SO₄

This water type falls within the normal alkaline and constitutes about 31.43% and is typical of Nigerian basement terrain with limited mixing (Amadi, 1987). Sulphate is a major constituent of atmospheric precipitation (Davies and Dewiest, 1966) hence this water type is influenced by precipitation as well as dissolution of silicate minerals in the bedrock and aluminosilicates in the weathered regolith (Tijani, 1994).

Ca-Mg- (SO₄)-HCO₃

This water type constitutes about 8.57 % in this area. It falls within normal alkaline water and is predominantly hydrogen carbonate sulphate.

Sources of Elements

Water chemistry, worldwide, is said to be dependent on precipitation, rock weathering and evaporation-crystallization processes (Gibbs, 1970). However effects of these controlling processes on different chemical species vary. Hudson and Golding (1970) pointed out that sulphate and chlorides are controlled by precipitation and evapotranspiration; sodium, magnesium, calcium and silica are controlled by mineral weathering while nitrate and potassium are controlled by plants uptake. Nonetheless, other processes such as cation exchange may also exert some considerable influence on the groundwater chemistry. Hence, the prevailing chemical character of any ground water system is usually not only a function of the character of recharging water, but also a function of the interaction with the aquifer system during subsurface flow.

In this work, R-mode factor analysis and elemental correlations are used to process the data in an effort to determine the sources of elements and their controlling factors. R-mode factor analysis is a multivariate statistical technique that is widely used to aid interpretation of geochemical data and enhance subtle but significantly single-element anomalies (Garret and Nichol, 1969). In other words, factor analysis has the simple objective of revealing an underlying relation that is presumed to exist within a set of multivariate observations (Davis, 1986). The analysis groups related variables into principal associations (factors) based on their mutual correlation coefficients and these associations may be interpreted in terms of mineralization, lithology and environmental processes. Application of this analysis has proven effective in hydrogeochemical, lithogeochemical and stream sediment reconnaissance survey as shown by a host of workers (Imeokparia, 1984; Elueze and Olade, 1985; Elueze et al., 2001; Meng and Maynard, 2001; Edet et al., 2003). The computation of R-mode factor analysis was done by employing the statistical package for social sciences software (SPSS) (Nie et al., 1975).

The results of the factor analyses are summarized in Table 4. After inspection of the various models that were computed, a five-factor model that accounted for 90.05% of data variance was considered to be most consistent with known geological and environmental processes and appropriate to the limit of analytical precision. Only variables with loading greater than 0.74 were considered significant members of a particular factor. These different factors are discussed below:

Table 4: R-Mode varimax factor matrix

Parameter	Factor Loading				
	1	2	3	4	5
TDS	0.832				
TSS			0.929		
Temp					0.974
Turb.			0.872		
Color			0.852		
TH		0.942			
K^+	0.958				
PO_4^{3-}	0.955				
SAR	0.951				
Na^+	0.946				
Mg^{2+}		0.848			
HCO_3^-	0.926				
Fe	0.906				
F-	0.835				
NO_3	0.741				
Cl-	0.752				
SO_4^{2-}				0.902	
Eigenvalue	9.36	3.29	3.01	1.23	1.06
% Total variance	46.8	16.43	15.34	6.15	5.31
Cum. %	46.8	63.3	78.6	84.7	90.05

Factor 1 (Na^+, K^+, Fe^{2+}, Cl-, HCO_3^-, SO_4^{2-}, Ec, TDS, SAR and NO_3^-)

This accounts for 46.8% of the total data variance. The high loading reflects geochemical interactions of transported foreign materials with that occurring within the study area. Na^+ and K^+ are transported in solution or in base exchange minerals occurring in clays from the adjoining geology. Much of the dissolve solids/pollutants in the water are traceable to hydrological processes. The electrical conductivity (EC), which is related to the overall component of the TDS, is similarly affected. Higher loading of Fe^{2+} may be associated with ferromagnesian minerals.

The HCO_3^- is the dominant anion in the water sample with a range 51-1177 mg/l (av. 229.23mg/l). It is abnormally very high

in the stream samples at locations 1 and 6, with respective values of 1167 and 1177mg/l. This is mainly due to CO_2 – charge recharge. Bicarbonate concentration in the water samples may also be due to seasonal changes associated with chemical reactions during rainstorm.

The presence of Cl^- may be associated with environmental and atmospheric precipitation (Elueze et al., 2001). Higher loading of SO_4^{2-} may be associated with organic input washed into the area from the nearby Bodija market. Equally higher loading of NO_3^-, in the stream samples, may be associated with the atmospheric influence, plants remains, agricultural practice as well sewage disposal (both animal and human) into the stream that drains through the area.

Factor 2 (Ca^{2+}, Mg^{2+} and TH)

This factor accounts for about 16.43 % of total variance. Calcium is both abundant in the earths' crust and extremely mobile in the hydrosphere, equally too, it is one of the most common ions in subsurface water (Davis and Dewiest, 1966). In this study, the higher loading for Ca may be released as weathering product of feldspars, amphiboles and pyroxenes. Mg may equally be attributed to the weathering of the above minerals or even clay minerals associated with the basement rocks. Total hardness in the water may be associated with practices from the nearby market. A typical example is the elevated value of 556mg/l from a borehole having sample number 19 which is near the Bodija market.

Factor 3 (TSS, Turbidity and Colour)

This factor accounts for 15.34 % of the total variance. Drinking water ideally has no colour. Colour in drinking water is usually due to the presence of colored organic matter associated with humus fraction of the soil. The stream samples

(1 and 6) show anomalous concentrations of 455 and 858 FTU respectively. Equally higher values of 385 FTU and 760 FTU for samples 19 and 27 respectively, may be associated waste dump input into the water system from the market. Colour is also related to turbidity. Most of the wells, having elevated values of turbidity may be associated with the routine fetching process that was ongoing at the time of sample collection. The equally high values of color and turbidity have accompanying influence on the total suspended solids and therefore justifying their association in this grouping.

Factor 4 (SO_4^{2-})

This factor contains one loading and accounts for 6.15 %. According to Hudson and Golding (1997) sulphate concentration is controlled by precipitation and evapotranspiration. This may be associated with findings from this study.

Factor 5 (Temperature)

This factor accounts for about 5.31% of the total variance. An average temperature of $27.80^{\circ}C$ was recorded for this area. It is known that water temperature is controlled by intensity of solar radiation, which reflects the temperature during the dry season, when the sampling was done. Temperature is an important factor in weathering process and its presence here supports this.

A bi-log plot of TDS against the Na/(Na+Ca) ratio, as reported by Gibbs (1970) (Fig.4), indicates that the composition of majority of the groundwater falls within the center of Gibbs "boomerang" which is interpreted as related to weathering of the silicate mineral associated with dominant rock types. The surface water rock may have modified its chemistry as a result weathering and dilution of underlying rocks.
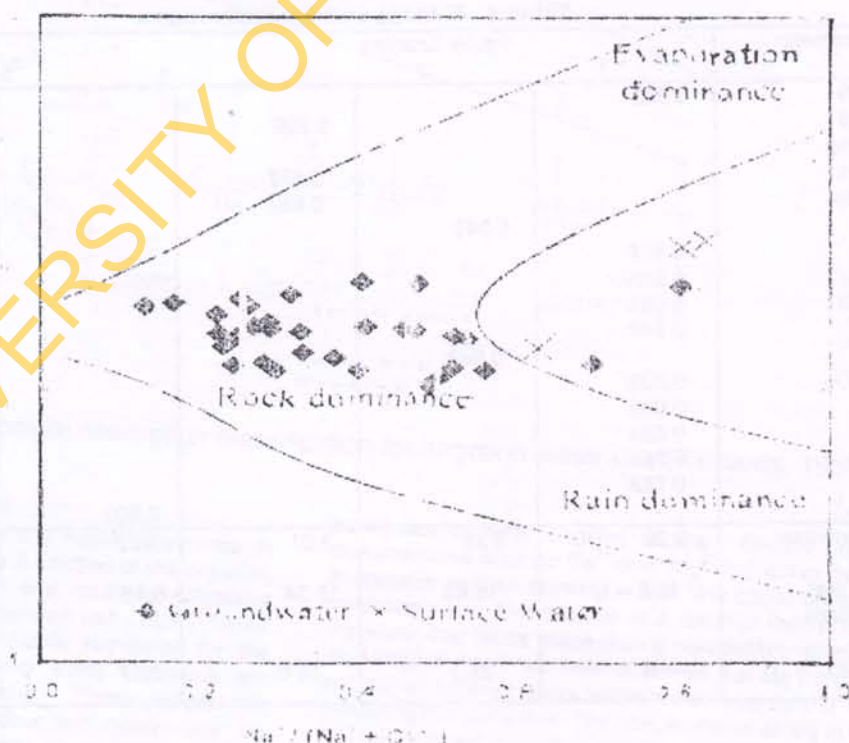

Fig. 4: Plot of Log TDS against Na/(Na + Ca) ratios (After, Gibbs, 1970)

Statistical correlation using product moment indicates positive correlation between some pairs of parameters among the major cations and anions with TDS (Table 5). There are very

strong correlations between TDS and EC (r = 0.99), TDS and Na+K (r= 0.94), TDS and HCO_3^- (r=0.93), TDS and NO_3^- (r=0.80), while there are relatively strong correlations between

NO_3 and Cl^- (r=0.78), TDS and Ca+Mg (r=0.76) Weaker correlations were obtained between Ca and HCO_3 (r=0.56) and Ca and Mg (r=0.48). These positive correlations are clear indications of the contribution of these ionic components to the overall mineralization. This is also supported by the relatively equal proportion (equivalent concentrations) of the major cations and anions in the analyzed water samples. There is a very strong correlation of electrical conductivity and total dissolved solid (r=0.99,Table 5). As reported by Richard (1954), such a correlation is an approximate relationship for most natural water.

Table 5: Correlation between some hydrochemical parameters of Agbowo water

Variable	Correlation coefficient
TDS and EC	0.99
TDS and Na+K	0.94
TDS and HCO_3^-	0.93
TDS and NO_3^-	0.80
NO_3^- and Cl^-	0.78
TDS and Ca+Mg	0.76
Ca and HCO_3^-	0.56
Ca and Mg	0.48
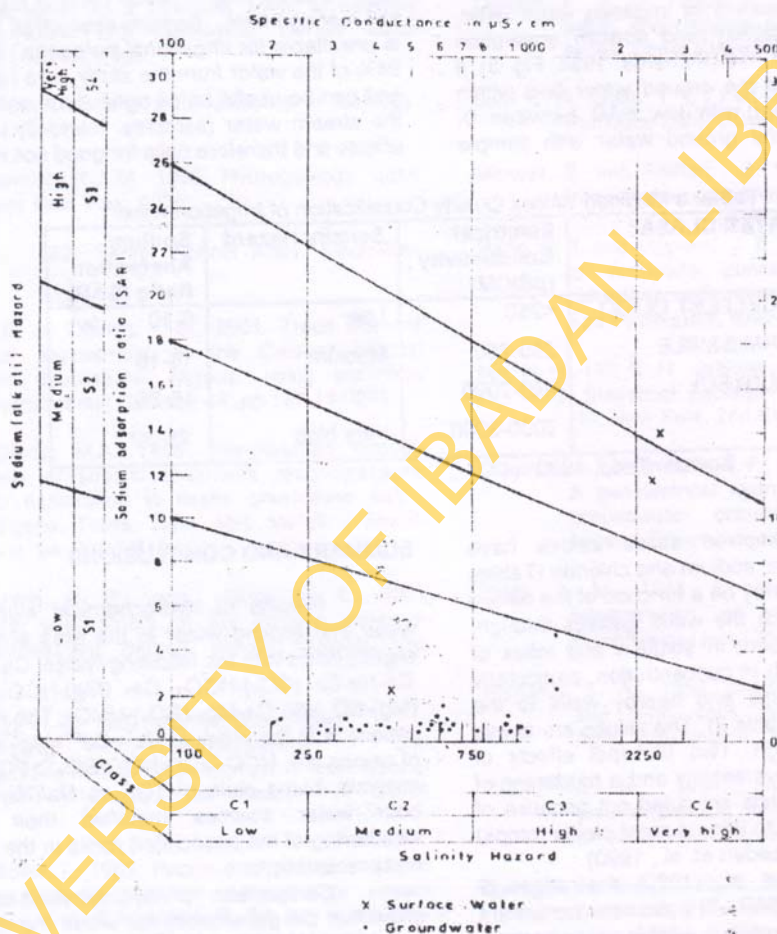
Fig 5: Salinity and Sodium absorption classification for irrigation water use (Richards, 1954)

WATER QUALITY AND USABILITY

The chemical character of any water determines its quality and utilization. The quality is a function of the physical, chemical and biological parameters and could be subjective since it depends on a particular intended use (Tijani, 1994). Hence, there are different water quality standards for the various uses (WHO, 1993). Drinking water standards are generally based on two main criteria: These include the presence of objectionable taste, odour and colour plus the availability of substances with adverse physiological (health) effects.

The physical parameters such as pH, EC, TDS generally fall within the acceptable limit of the WHO (1993) standard (Table 3). In particular, the stream water samples 1and 6 have EC and TDS higher than the maximum permissible value by 40.83% and 23.7% respectively on the average. These are purely due to anthropogenic factors. Equally, the chemical characteristics such as Ca^{2+} and Mg^{2+} are within the maximum acceptable limit for drinking water. The concentration of Mg is moderately low. This may be as a result of natural softening of the water that takes place during percolation, which results in exchange of Na. It has been observed that Mg concentration in excess of 500mg/l gives unpleasant taste to the water, thus rendering it unpalatable. The concentration of Mg in both water sources renders the taste palatable and therefore both sources are potable. K^+, Na^+, Fe^{2+}, Cl^-, SO_4^{2-} are within the acceptable limit. It is necessary to emphasis that Fe is abnormally high in stream samples 1 and 6 with average corresponding values of 2.45 and 3.15mg/l respectively. Also in wells located closer to the streams (2, 7 and 15, Fig. 2), respective values for Fe are 1.96, 1.10 and 2.03mg/l (Table 2). The source of iron may be through weathering of ferromagnesian minerals in the associated rocks and more importantly, through waste dump

into the streams. Such high concentration in both water sources which is above the permissible limit for drinking water and could pose problems to health particularly for the surface water.

Nitrate concentration for the surface water is above the maximum permissible value of WHO (1993) which renders it unfit for drinking purposes (Table 3). Arising from the work of Carroll (1962) the groundwater can be classified as fresh, based on the proportion of TDS which is between 0 - 1000mg/l while the surface water at locations 1 and 6 have TDS >1000mg/l and is within the slightly alkaline water class. The high values of TDS may be associated with the poor drainage of the stream.

On the other hand, irrigation water criteria are dependent on water conductivity (EC), sodium absorption ratio (SAR), type of plants, and amounts of irrigation water used, soil and climate Using the salinity and sodium absorption classification for irrigation water use (Richards, 1954, Fig. 5), it can be observed that 90 % of the ground water falls within medium to high salinity hazard with low SAR between 0-10. Two water sources from the ground water with sample numbers 28 and 35 (Fig 2, Table 1) fall within low salinity hazard. On the other hand, the surface water from locations 1 and 6 show very high salinity hazard with corresponding high electrical conductivity. Water from locations 28 and 35 (Fig.2, Table 1) have low salinity hazard and SAR between 0-10 (Fig.5) and could be termed excellent water class based on the modified Wilcox quality classification of irrigation water (Table 6).

Using Wilcox model (Table 6) as reported by Todd (1980), over 90% of the ground water falls within good to permissible class, while the surface water at locations 1 and 6 fall within doubtful class of irrigation classification. According to Mandel and Shiftan (1981), water-containing SAR of 0 to 10 can be applicable on all agricultural soils while, that having SAR range from 18 to 26 may produce harmful effects and calls for good soil management. Sodium absorption ratio range of 26 - 100 is unsuitable for irrigational purposes. Based on the above, > 94% of the water from the study area has SAR between 0 - 10 and can be useful on all agricultural soils with the exception of the stream water (samples 1 and 6) which produce harmful effects and therefore calls for good soil management.

Table: 6 Modified Wilcox Quality Classification of Irrigation water[a]

WATER CLASS	Electrical Conductivity (µS/CM)	Salinity Hazard	Sodium Absorption Ratio (SAR)
EXCELLENT GOOD	<250	Low	0-10
PERMISSIBLE	250-750	Medium	10-18
DOUBTFUL	750-2000	High	18-26
	2000-3000	Very high	26-30

Source: Todd, 1980

Locations with high total dissolved solids values have correspondingly high bicarbonate, sodium and chloride (Tables 1 and 2). The sources of these may be a function of the nature and type of rocks through which the water passes through, duration, materials already present in solution and influx of leachates from dump. Na is high in concentration, particularly in the samples from the streams and nearby wells to the streams (Locations 1,6 and 15,Table 2). The values are above the permissible level of 200mg/l. Two principal effects of sodium are a reduction in soil permeability and a hardening of the soil. In this study, such effects are ruled out because of low SAR. Hence, it can be used to irrigate most plants (crops) and on most soils (Hem, 1985, Leeden et. al., 1990).

Based on the work of Leeden et. al., (1990), the ranges of additional parameters such as SAR, TH, etc. are consistent with domestic supplies, recreation, wildlife propagation, irrigation and most industrial requirements for the groundwater. The observed chloride concentration of most of the water samples fall below the maximum permissible level of WHO (1993) (Table 3). It is higher in samples 1 and 6 that are from surface water and samples 18, 20 and 31, collected from ground water. Observed nitrate value for surface water samples streams (Locations 1 and 6) and the ground water at location 5, around the vicinity of the stream, are above the maximum permissible level of 50.00 (WHO, 1993). The source of most of this nitrate could be from sewage disposal and from animal dung drained in from the nearby market. It can be deduced that the stream water may is not fit for human consumption, based to nitrate content and colour.

The concentration of Ca in all the samples is below WHO (1993) maximum permissible level. According to Lehr et al., (1980), 1800mg/l of Ca in water has not been found to impair any physiological reaction in man but may affect the industrial and domestic uses. Again, the observed second order of Ca with a value of 49.75mg/l may be due to its abundance in the earth crust or as released by weathering products of feldspars, amphiboles and pyroxene.

SUMMARY AND CONCLUSIONS

Results of hydrochemical studies of both surface water and ground water in the area shows that the water is slightly basic with the following facies: Ca- (Mg)-Na-HCO$_3$, Ca-Na-Cl- (SO$_4$)-HCO$_3$, Ca- (Mg)-HCO$_3$, Na- (K)-HCO$_3$, Ca-(Mg)-SO$_4$ and Ca-Mg- (SO$_4$)-HCO$_3$. The relative abundance of cations is in the order of Na$^+$>Ca^{2+}>Mg^{2+}>K$^+$>Fe^{2+} while those of anions are; HCO$_3^-$>Cl$^-$>NO$_3^-$>SO$_4^{2-}$>PO$_4^{2-}$>F$^-$. R-mode factor analysis, bi-log plots of TDS vs Na/(Na+Ca) ratio show that both water sources modified their chemistry through weathering of the associated rocks in the area base exchange and precipitation.

Comparison of hydrophysico-chemical parameters show that the parameters fall within the maximum permissible limit of the World Health Organization (WHO, 1993). It can be deduced that the surface water in particular is slightly alkaline, unfit for drinking in the present form but could be developed to supplement existing ones. The ground water is fresh and portable though minor treatment such as boiling and filtration may be required. Both water sources can be utilized in agricultural practices. Further studies should include microbial investigation and heavy metal plus isotopic compositions, so as to ascertain other quality parameters and hence prescription of necessary treatment measures.

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