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INFLUENCE OF BEDROCK ON THE HYDROGEOCHEMICAL CHARACTERISTICS OF GROUNDWATER IN NORTHERN PART OF IBADAN METROPOLIS, SW NIGERIA

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ABSTRACT

The influence of the country rock (bedrock) on the hydrogeochemical characteristics of groundwater in the northern part of the Ibadan metropolis were assessed.

Forty water samples (twenty boreholes, ten hand dug wells and ten surface water) were analyzed for their physical and chemical components while ten rock samples of both weathered (saprolites) and unweathered (fresh) for the country rock in Ibadan were analyzed for their chemical and mineralogical changes. The saprolites and hand dug well samples were taken from the same location in order to identify their relationship.

Mineralogical analysis shows that quartz, iron and opaque minerals increase from fresh to weathered rock samples but the reverse is the case of other minerals like feldspar, biotite and hornblende while clay minerals were only noticed in the weathered rocks.

Elemental gain and loss analysis of the altered gneisses and quartzite indicated leaching of SiO_2, Na_2O, K_2O and CaO and gain P_2O_5 and Fe_2O_3 from fresh to weathered rock samples Al_2O_3 is taken as constant. Water chemistry show that sodium, potassium and chloride ions occur in higher concentration compared to those of calcium, magnesium, bicarbonate and sulphate. Using piper diagram, four water groups were identified which are alkali rich ($Na^+ + K^+$), mixture of all cations ($Na^+ + K^+$, Ca^{2+}, Mg^{2+}), chloride rich (Cl^-) and mixture of anions (Cl^-, HCO_3^-, SO_4^{2-})

Comparison between the chemistry of water and the plots of elemental gain and loss show that high concentration of a particular element in the water sample is equivalent to the loss of the same rock sample. A plot of TDS against $Na^+ / Na^+ + Ca^{2+}$) ratio (boomerang) confirms the fact that groundwater in the case study area acquire their dissolved ions from the effects of chemical weathering of the underlying bedrock.

INTRODUCTION

Chemical composition is one of the principal criteria for assessing the quality of water. Geology, particularly rock types, their weathered products and precipitation from rainfall contribute greatly to the chemistry of surface and ground waters. This in essence determines their suitability for human consumption, domestic applications such as drinking water for domestic animals, irrigation of agricultural lands and also its many usages in the manufacturing industries.

When igneous and metamorphic rocks are exposed to water and atmospheric gases at or near the surfaces of the earth, the minerals they contain, decompose selectively and at very fast rates.

Several works on water quality especially in the basement complex have been discussed with the effects of the environment and man on the quality of water being emphasized. Examples of such works are those of Azeez (1972) and Ako (1990) and Raji and Alagbo, (1997)

The study area falls within the northern part of Ibadan, Southwestern Nigeria. It lies between latitude 3° 45E and 4° 03E and longitude 6° 45N and 7° 20N. The relief of the study area falls within two basic units which are the high ridges and low lying terraces which give rise to undulating feature of the environment. Three major rivers B Orogun, Ogunpa and Ona drain the study area. Orogun River flows from the northeastern direction and empties into the Eleyele reservoir while Ona flows towards the western part before it is joined by the Ogunpa River (Fig. 1). The area falls within the humid and sub-humid tropical climate of southwestern Nigeria. The moist monsoon wind from the Atlantic Ocean ushers in the wet season between early April and November. The vegetation is of the rainforest type, however larger portion of the area have been cleared for residential and commercial purposes, allowing only sparse vegetation.

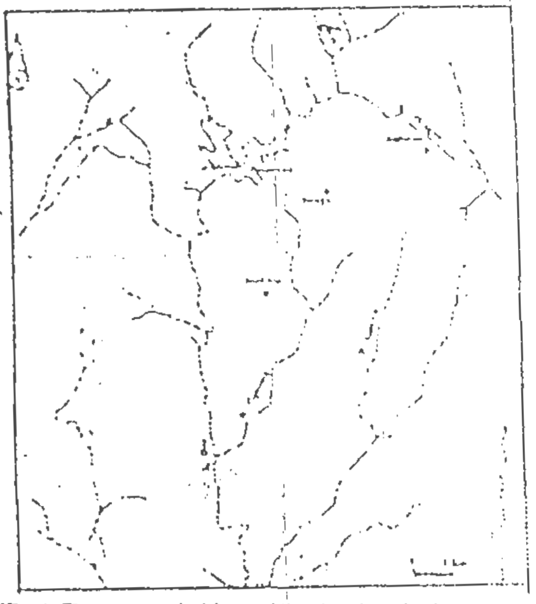

Fig.1 Topographic Map of Ibadan North showing the drainage pattern

GEOLOGIC AND HYDROGEOLOGIC SETTING

The area lies within the basement complex of southwestern Nigeria. The rocks are classified into major and minor types (Akintola and Filani 1982). The major types are quartzites, banded gneiss, augen gneiss, granite gneiss and migmatites. The minor ones include pegmatite, aplites, quartz veins, dolerite dykes and amphibolites (Fig. 2). In most cases, the rocks are overlain by the weathered regolith.

Banded gneiss constitutes over 75% of the rocks in and around Ibadan while augen gneiss and quartzite share the remaining in almost equal halves. Banded gneiss is characterised by well defined bands in which quartzofelspathic minerals alternate with ferromagnesian minerals. They are predominantly medium grained. Gneisses are seen to be well banded around Agbowo area, granitic towards Orogun and show augen-character within the University of Ibadan Campus.

Quartzites occur as elongated ridges striking NW B SE. They are mostly massive, dominantly made up of quartz, outcropping along Total Garden B Gate Road, and Oje B Bere Road. Fractures are more obvious in the quartzites of the Western axis of Ibadan. Generally, they are concordant to the bedding of the rocks but discordant fractures also occur. The fault traces vary in size from a few centimeters to hundreds of meters. There is a greater occurrence of folds in the southern part of the area. The regional strike of the foliation in Ibadan is roughly in the N-S direction.

Pegmatites and quartz veins occur as concordant and discordant bodies within the major rock types and vary both in length and width. The pegmatites are often pale-pink in colour while the quartz veins are white or grey. The dolerite dykes occur as discordant intrusive bodies cutting into the country rocks.

Basement rocks are commonly considered as poor aquifers because of their crystalline nature which leads to low porosity and permeability. However, appreciable porosity and permeability are developed through fracturing and weathering of the rocks (Davis and Deweist, 1966). This makes an otherwise barren rock to function as a groundwater aquifer. Also, the availability of groundwater depends on the extent of weathered overburden and the presence of joints in the underlying rocks (Acworth, 1987). Groundwater occurrence in the study area is essentially semi-confined to unconfined occurring under water table conditions and highly influenced by infiltration and percolation of precipitations.

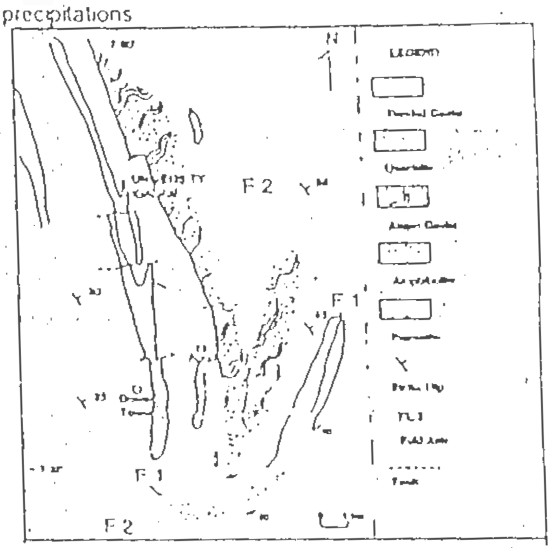

Fig. 2: Geological map of Ibadan (after Jones et. al. 1963)

METHODOLOGY

Forty water samples, ten fresh rock samples and ten weathered rock samples were collected. The water samples are made up of ten samples from the streams, ten from hand dug wells and twenty from boreholes (Table 1).

The water samples were collected into 2 litres volume white plastic containers after being properly rinsed. Water samples were analysed on the day of collection at the Oyo State Water Corporation, Asejire laboratory. All the samples were collected over a fortnight between March 25 and April 10, 1997 and this period was a transitional one between the end of dry season and the beginning of the rainy season so the effects of surface run off and infiltration on the investigated samples are minimal and that of the underlying bedrock dominant.

The temperature of the water samples was measured on the spot of collection. Portable pH meter was used for pH measurement. Other properties of water such as color, dissolved oxygen, TDS, total alkalinity, hardness, chlorine demand, calcium hardness as well as anions and cations such as Ca^{2+}, Fe^{2+}, Cl^{-}, Mn^{2+}, Mg^{2+}, P, Si^{2+}, Pb, SO_4^{2-}, HCO_3^{-}, NO_3^{-} were analysed for in the laboratory using titration method

Ten fresh rock samples and their equivalent weathered samples were analysed to ascertain their mineralogical and chemical composition. Also, well logs data for the borehole analysed were obtained from Fountain Springs Nigeria Limited, Ibadan

Table 1: SAMPLE LOCATION, SOURCE AND ROCK TYPES WITHIN THE STUDY AREA

SAMPLE NO	ROCK TYPE	LOCATION	WATER SOURCE
01	Granite Gneiss	Oje	Borehole
02	Granite Gneiss	Agodi	Borehole
03	Granite Gneiss	Orogun	Borehole
04	Granite Gneiss	Orogun	Borehole
05	Augen Gneiss	Agbowo	Borehole
06	Augen Gneiss	U.I.	Borehole
07	Augen Gneiss	Polytechnic	Borehole
08	Banded Gneiss	Elenk	Borehole
09	Banded Gneiss	Apete	Borehole
10	Banded Gneiss	Sango	Borehole
11	Augen Gneiss	Sampga	Borehole
12	Augen Gneiss	Bodija	Borehole
13	Granite Gneiss	[illegible]	Borehole
14	Granite Gneiss	Olunloyo	Borehole
15	Augen Gneiss	Bodija	Borehole
16	Augen Gneiss	[illegible]	Borehole
17	Banded Gneiss	Bashorun	Borehole
18	Banded Gneiss	[illegible]	Borehole
19	Banded Gneiss	Bashorun	Borehole
20	Augen Gneiss	[illegible]	Borehole
21	Augen Gneiss	Adamasingba	Hand dug well
22	Granite Gneiss	Sabo	Hand dug well
23	Granite Gneiss	Premier	Hand dug well
24	Augen Gneiss	Sabo	Hand dug well
25	Banded Gneiss	Cocacola	Hand dug well
26	Banded Gneiss	Mokola	Hand dug well
27	Quartzite	Secretariat	Hand dug well
28	Quartzite	U.C.H	Hand dug well
29	Quartzite	Total Garden	Hand dug well
30	Quartzite	Agodi	Hand dug well
31	Quartzite	Gate	Stream
32	Quartzite	Yemetu	Stream
33	Quartzite	Oranyan	Stream
34	Quartzite	Onireke	Stream
35	Quartzite	Apete	Stream
36	Quartzite	Adeoyo	Stream
37	Quartzite	Oje	Stream
38	Quartzite	Oke Are	Stream
39	Quartzite	Akturo	Stream
40	Quartzite	Dere	Stream

RESULTS AND DISCUSSION

Mineralogical and Geochemical Analyses of Bedrock

The calculated average model percentages of the respective minerals indicates a higher occurrence in the fresh (unaltered) rocks of plagioclase, K- feldspar, biotite and hornblende (Table 2A). The weathered rock samples (saprolites) have higher abundance of clay minerals (mainly kaolinite, sericite), iron (as Fe_2O_3) and opaque minerals (Table 2A). Quartz is enriched in the weathered rocks

The absence or reduced presence of plagioclase, K B feldspars, hornblende, biotite in the altered (weathered horizons) rocks indicate leaching and chemical transformation of these minerals into clay. This is evidenced from the appreciable clay present in the weathered horizons. The leached minerals are dissolved in the subsurface water under confined pressure and temperature. This will ultimately alter the chemistry of the water and may impact positively or negatively the groundwater resources

The result of chemical analysis of ten altered and ten equivalent, unaltered rock samples from the study area were used (Table 2B) and according to Krauskopf (1979), to calculate and plot the percentage gain and loss of the individual elements in the altered rocks (Fig. 3) Al_2O_3 was assumed to be constant due to its limited solubility at pH of between 6 to 8

The result shows that the alteration is accompanied with percentage gain in iron and phosphorus and corresponding loss in sodium, potassium and calcium which are the elements which constitute the feldspars (Figure 3)

These are directly related to the mineralogical analysis results and are in accordance with the fact that the changes in the chemical compositions of progressively weathered saprolites must reflect what is happening to the primary minerals as a result of the chemical weathering, on the other hand, however, there is very little loss of SiO_2. The losses are generally less than 1%. This is due, to the stability of quartz, although silica is leached out of the rocks, the amount lost is little compared to the retained insoluble quartz.

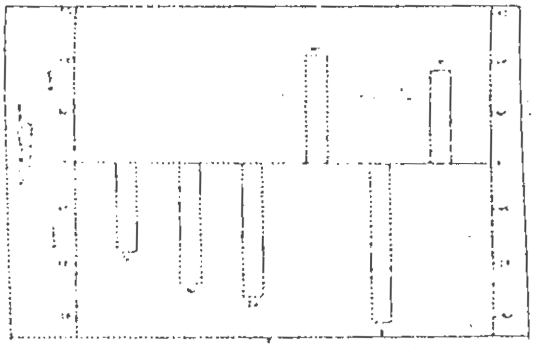

Fig. 3. Elemental gain and loss in the altered rock types in Ibadan

Water Chemistry

For the boreholes samples, (Fractured bedrocks) average concentrations of Na+ and K+ are 31.05ppm and 10.5ppm respectively while those of Ca^{2+} and Mg^{2+} are 12.9mg/L and 3.0mg/L respectively (Table 3).

Chloride is the dominant anion with an average concentration of 89mg/L. The average concentrations of SO_4^{2-} and HCO_3^{-} are 10.5mg/L

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and 20mg/L respectively.

In case of waters obtained from hand dug wells (weathered zone), average concentration of Na+ and K+ are 38ppm and 21ppm respectively. While those of Ca^{2+} and Mg^{2+} are 28.8mg/L and 3.6mg/L respectively. $C1^-$ is 114mg/L, SO_4^{2-} is 23.4mg/L and HCO_3^- is 47.3mg/L

Table 3: SUMMARY OF WATER CHEMISTRY OF THE STUDY AREA

PARAMETERS	RANGE	MEAN	STANDARD DEVIATION	VARIANCE
Color (HU)	5 B 120	14.00	10.1	10.2
Temperature (°C)	22 B 30	24.7	1.1	[illegible]
pH	6.1 B 7.7	1.2	1.2	[illegible]
Dissolved Oxygen	1.5 B 6.6	4.9	[illegible]	[illegible]
Total Alkalinity	13.8 B 18.5	100	30.5	24.2
Total Hardness	45 B 165	72.5	12.4	53
Ca Hardness	30 B 150	[illegible]	34	34.5
Ca^{2+} (mg/L)	6.2 B 40	10.5	10.4	10.5
Mn^{2+} (mg/L)	0.01 B 0.2	0.10	0.54	[illegible]
Fe^{2+} (mg/L)	0.04 B 2.9	0.6	0.64	2.05
Mg^{2+} (mg/L)	1.3 B 6.2	[illegible]	1.62	1.64
Na^+ (ppm)	11 B 00	[illegible]	16.1	16.3
K^+ (ppm)	5.6 B 57.0	12.0	[illegible]	[illegible]
[illegible] (ppm)	2 B 26	10.2	4.6	[illegible]
HCO_3 (ppm)	11.5 B 70	37.2	19.9	[illegible]
NO_3 (ppm)	1.2 B 7.2	0.9	2.26	0.07
$C1^-$ (ppm)	2.0 B 212	[illegible]	[illegible]	[illegible]
SO_4^{2-} (ppm)	1 B 45	22.0	1.6	[illegible]
[illegible] (ppm)	0 B 20.70	6.07	[illegible]	[illegible]
[illegible] (ppm)	[illegible]	[illegible]	1.30	4.31
Cu (ppm)	0 B 0.06	0.02	0.017	0.015
Total Solid (ppm)	40 B 1500	[illegible]	321.0	[illegible]
Chlorine Demand (ppm)	0.0145 B 3.94	1.14	1.06	1.05

Finally, those taken from the stream (surface) Na^+ and K^+ concentration of 45ppm and 10ppm respectively. Ca^{2+} is 11.5mg/L while Mg^{2+} is 4.3mg/L, $C1^-$ which is the dominant anion is 98mg/L. The average concentration of SO_4^{2-} is 23mg/L and that of HCO_3^- is 55mg/L.

Generally pH values range from 6.1 B 7.7 while field temperature of water varies from 22°C to 33°C. Dissolved oxygen values from 3.5mg/L to 18.5mg/L total hardness ranges from 45mg/L B 165mg/L, Calcium hardness ranges from 30mg/L to 150mg/L. Also TDS value ranges from 40mg/L to 150mg/L while chlorine demand values is from 0.0145mg/L to 3.94mg/L.

The chemical parameter were plotted on the piper trilinear diagram to ascertain the genetic evolution of the water samples. Ions used for this plot were K+, Na+, Ca^{2+}, Mg^{2+} SO_4^{2-}, $C1^-$ and HCO_3^-.

From the plots, (Fig. 4) the several water samples can be grouped into four groups and these are.

- Alkali (Na^+, K^+)
- Mixture of all cations (Na^+ + K^+, Ca^{2+}, Mg^{2+})
- Chloride rich Cl
- Mixture of anions (Cl SO_4^{2-}, and HCO_3^-)

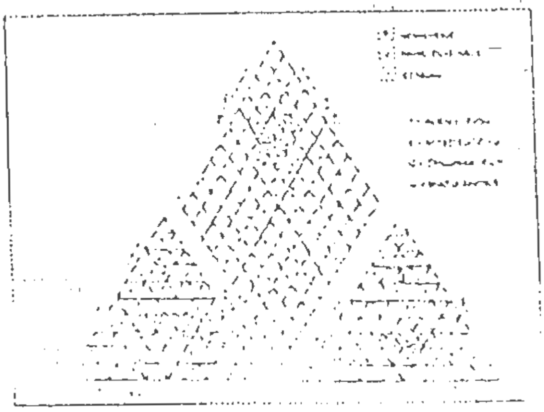

Fig. 4 Piper diagram used to classify water on the basis of its chemical composition

WATER CHEMISTRY AND BEDROCK RELATIONSHIP

The chemical composition of water depends primarily on the chemistry of the minerals making up the aquifer materials. In addition, the chemical character of water is modified by ion B exchange reactions during the percolation of precipitated water, uptake the recycling of nutrient element by plants and by the interaction such water have with municipal and industrial wastes and leachates in dumpsites.

Most of the ions record higher concentrations in the hand dug wells (weathered zone) than in the boreholes (Fractured basement rock) (Fig. 5). This is expected as the water obtained from the wells had very close interaction with the minerals of the weathered horizons thereby leaching out the mobile ions into solution.

However, the water from the deep boreholes are obtained from fractures in the fresh bedrocks where the crystalline rocks contribute very little ions to the water they bear, as their mineral are held together and highly stable. The effect of the rock types and their weathered products as well as dilution effect from precipitation on the chemistry of the water samples from this area is evident, especially from the plot of TDS against Na^+/ Na^+ + Ca^{2+} ratio. From this boomerang plots, (Fig. 0) most of the water samples especially those of the hand dug wells (weathered zone) were plotted in the centre of the boomerang which shows that they are influenced by the chemical weathering of the underlying bedrock while a few plotted in the corner end of the boomerang indicates domination of meteoric precipitation. The comparison between elemental gain and loss (Fig. 4) in the weathered rock samples and chemistry of water samples especially those hand dug wells (weathered zone) shows that corresponding loss in sodium, potassium and calcium equivalent leads to a corresponding increase in these ions in the water samples. Consequently, the main source of these cations in the groundwater samples (especially the hand dug wells) results from chemical weathering of the feldspars, micas and other related minerals constituting the basement rock of the study area. Na^{+} and Ca^{2+} are most likely to be sourced from the incongruent dissolution of plagioclase to form kaolinite. Mg^{2+} and K^{+} is from weathering of biotite.

Finally, the higher concentration of Na^{+} (33ppm) and K^{+} (12.8ppm) in relation to that of Ca^{2+} (16.5mg/L) and Mg^{2+} (3.8mg/L) is in consonant with the reported average composition of these cations in the gneisses from the study area (Burke et al, 1976). The banded gneisses are reported to have average composition of MgO B 1.88% CaO B 4.01%, Na_2O B 4.78% and K_2O B 2.48% while the granite gneiss average content of K_2O is 6.2% and MgO of 0.1%.

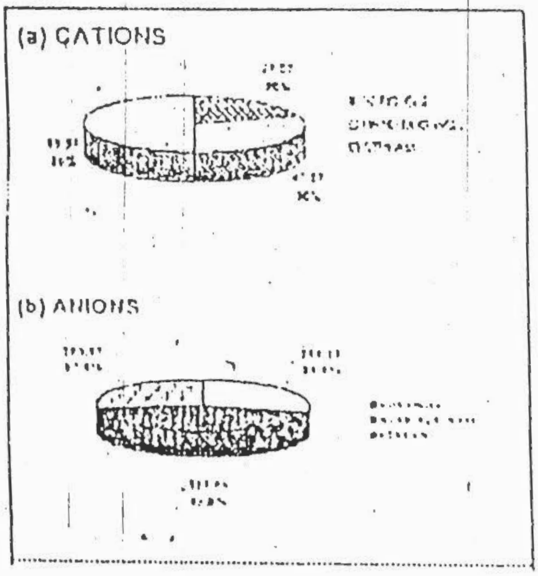

Fig. Percentage cations (A) and anions (B) concentration in different waters of the study area.

CONCLUSION

Water quality is governed by its chemical composition which depends primarily on the materials which have dissolved in it. When minerals get in contact with water, they are dissolved thereby altering the water chemistry which invariably affect the water quality with time.

The mineralogical analysis of fresh and weathered rock samples, their chemical analysis as well as the water samples from the study area confirm that chemical composition of the ground water especially those from weathered zone (hand dug wells) depends primarily on the chemical weathering of the underlying bedrocks.

The main rock type of the study area is the gneissic rocks from which minerals like plagioclase, biotite, and K-feldspar produce the high concentrations of Na^{+}, K^{+} and Ca^{2+} in the groundwater samples.

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