GEOTECHNICAL AND HYDROGEOCHEMICAL PROPERTIES OF WEATHERED BASEMENT AROUND BAUCHI METROPOLIS, NE NIGERIA.

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ABSTRACT

The investigation of the weathered basement around Bauchi metropolis has been carried out. The objectives of this study were to determine the erodibility of the soil, evaluate its chemical characteristics and heavy metals content of groundwater, its hydrogeochemical controls and suitability for drinking. A total of thirteen soil samples from different locations were used for geotechnical analysis. The geotechnical result indicated mean plasticity index of 17.20%, mean optimum $9.30cm^3$, moisture content of 7.67% at mean maximum dry density of $2.50g/cm^3$. A mean cohesion values of $0.25cm^2/kg$ and a mean angle of internal friction value of 30.80^o suggesting very erodible of the soil. Nine groundwater samples were collected from the Bauchi. Field measurements of physical parameters were preceded by chemical analyses of the samples for major ions concentrations and bacteriological content. The groundwater has pH ranging from 6.90 to 7.10 implying that the groundwater sources are alkaline. The mean values for chloride, sulphate and iron are 158.89mg/l, 95.78mg/l and 8.70mg/l respectively. While the mean value for hardness is 381.29mg/l. These parameters indicate presence of mineral suphate, corrosion and very hard water therefore should be treated before use. Generally, erosion control structures in the area should be made of materials that should resist staining, corrosion and incrustation.

Keywords: Weathered, Sediment, Basement, Hydrogeochemical, Geotechnical, Water, Bauchi.
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INTRODUCTION

The study area falls within latitudes $10^{\circ}00'$ and $10^{\circ}30'$ N and longitudes $9^{\circ}30'$ and $10^{\circ}00'$E. It is bounded to the south-east by Alkaleri to the west by Tafawa Balewa, to the north by Ganjuwa. It is easily accessible by the Bauchi – Jos link road, Bauchi – Kano link road and Bauchi – Maiduguri link road. The study area is located in high relief. As a result run-off is relatively high and infiltration rate is low. The groundwater storage which is already limited by geological factors is further reduced by adverse climatic conditions.

Crystalline rocks weather more easily and deeply under humid conditions. More water is available for storage under favourable rainy environments. Hence, in the Bauchi area underlain by crystalline formation, groundwater and surface water are scarce and problematic. Experience all over the World has shown that the rate of failure of boreholes is usually highest in the basement complex terrains. This is due mainly to an inadequate knowledge of shallow aquifers which results from in-situ weathering and/or denudation basement rocks. It is only around the late 1950's that geophysical techniques have been realized as a very reliable tool to solve this sort of exploration problem (Hazell et al., 1988). The hydrogeochemical investigation of the sub-surface water is very important in determine the chemical characteristics and content of heavy metals in the groundwater. Some geotechnical parameters were also measured with a view of providing lacking geotechnical information on the weathered basement rocks of the study area.
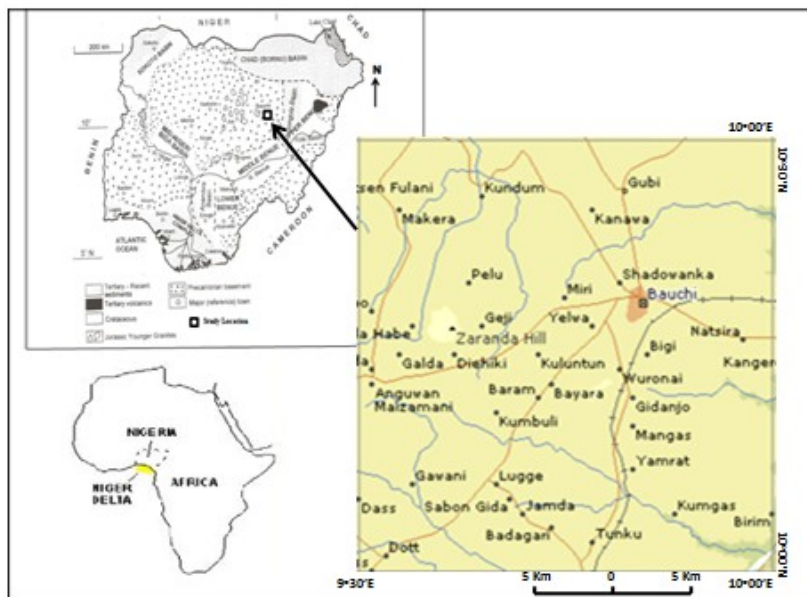

Fig. 1: Map showing location of the study area (In-set: Geological map of Nigeria and Africa).

Previous work in the area involving groundwater investigation dates back 1928 when the Geological Survey of Nigeria commenced the hydrogeological investigation in Nigeria. They undertook the actual exploitation of groundwater for rural communities by means of hand-dug and concrete-lined wells. Then in 1947 the exploitation aspect of the water supply work was handed over to the public works department but the responsibility for making systematic studies of the distribution of groundwater remained with the Geological Survey.

Carter et al. (1963), published maps and description of the geology of parts of Northeastern Nigeria which includes the Adamawa, Bauchi, and Borno province. This forms the basis for further groundwater studies around the area. Subsequently, Du Preeze and Barber (1965) and Kiser (1968) gave some details on the chemical quality of groundwater of the old Northern Nigeria which includes the study area.

Finally, Ali et al. (1993) carried out a geophysical study of the Basement structure of Barkumbo Valley of Bauchi area of Nigeria. The present study is an integrated study that will include the geotechnical investigation that will assist the government in finding solutions to the perennial water problems that is bedeviling the area.

GEOLOGY OF THE STUDY AREA

The study area is underlain by rocks of the Precambrian crystalline Basement Complex of Nigeria. The major lithologic units are: the Bauchite (Fayalite-quartz-monzonite); the biotite-hornblende-granite; the porphyroblastic biotite-granites, granulites and undifferentiated migmatites and gneisses (Fig. 2). In most part of the area, these rocks are covered by the unconsolidated weathered overburden materials consisting of laterites, clays, sands and gravels.

AGE	FORMATION	COMPLEX	LITHOLOGY	DESCRIPTION / UNIT
PRECAMBRIAN	BASEMENT COMPLEX	PAN AFRICAN OLDER GRANITES		Alluvium
				Fayalite-Quartz-Monzonite (Bauchite)
				Biotite-Hornblende-Granite
				Quartz-Hyperstene-Diorite
				Undifferentiated Migmatite & Gnesses

Fig. 2: Showing sediments formed from the weathered basement rocks in the study area.

The unconsolidated weathered overburden materials are of two types namely; the Alluvium and the Elluvium. However, outcrops of fayalite-quartz-monzonite (Bauchite) and biotete-hornblende-granite occur at two locations such as Idi and Lush hills.

Outcrops of these rocks show that they have been fractured due to tectonism. Thus fractures, fissures, joints and fracture-zones exist in places. The prominent fault zones trend towards the NE-SW and N-S zones as illustrated by Oyawoye (1970).

River Course Alluvium

The low-lying plains of the study area are essentially mantled by   lateritic pebbly soils resulting from in-situ weathering of the crystalline rocks. Where exposed by erosion, the soil profile consists of a laterite topsoil underlain by a clay horizon which in turn is underlain by partially weathered parent rock materials. Talus and deposits of alluvial pebbles and sands are abundant. The talus is found on the alluvial deposits of river channels and the river banks.

The Hadejah valley around the northern part of the study area and it's tributaries have alluvial flood plains and the Gongola valley around the eastern part which also are underlain mainly by unconsolidated coarse to medium grained sandy materials, clays and silts. From the observation it was found that at higher altitudes these sediments are coarse grained and fine towards the low-lying plains.

Elluvium

The elluvium consists essentially of gravels and sands which are very good aquifers and have given very high yields to wells. The processes in the formation of deep weathering which led to the development of lateritic profiles as the overburden form the elluvium. The parent materials – migmatites, gneisses which are cut by pegmatite, aptite and quartz veins are weathered to varying degrees and depths. The depth of weathering varies from 34 to 129m. It was found that water bearing zones are mainly found in the fractures of the poorly decomposed rock; intergranular permeability in moderately decomposed coarse-grained igneous and metamorphic rocks and fractured pegmatites, aptite and quartz veins within highly and moderately decomposed gneisses and migmatites.

Fayalite – Quartz – Monzonites (Bauchite)

Fayalite – bearing quartz- monzonites have been described in Bauchi area (Oyawoye, 1970). It contains quartz (72%), K- feldspar (14-72%) and plagioclase (4-52%). This unit is characterized by almost equal amount of alkali feldspars and plagioclase. It has dominant accessory minerals such as biotite and hornblende. In others, augites are present and are normally accompanied by hyperstene and olivine. The K- feldspars in monzonite is usually orthoclase (rarely microcline). Quartz occur in minor amounts. This unit is found around Guni, Wambai, Idi and Dumi hills in the central and northeastern area and some to the western portion (Fig. 1).

Biotite-Hornblende-Granite

In this rock unit the dominant minerals are biotite and hornblende. Other minerals found associated with them are muscovites, augites, sodium-rich amphiboles, pyroxenes and minor quartz or olivine. The biotite is often dark coloured and hornblende is green coloured. This can be found in Lush and Inkil hills. It covers parts of southeastern area and also outcrops at North and northwestern area of the map (Fig.1).

Quartz - Hyperstene – Diorite

This unit contains mostly of quartz in association with hyperstene and olivine. It has as sub-hedral granular texrure. It outcrops at the Northeastern extreme.

Undifferentiated Migmatite and Gneisses

These are mixed rocks of mainly two sources – the pre-existing host rock and a rather indefinite diffusion of other rock materials which are granitic in composition through the host rock. The host rock is usually the meta-sedimentary schists and the intruded materials include mostly granites, pegmatites and quartzite. They occur also mostly around the northwestern and southeastern portions and are less weathered than the schists.

MATERIALS AND METHODS

The samples were collected from thirteen different pits (Dumi, Dunglusi, New G.R.A, Zaranda, Gwalameji, Durum, Inkil, Wunti, Yelwa, Guni, Dandango, Shadawanka and Nassarawa) at varying depths of 2-3 meters using hand augar.

Laboratory analysis were carried out on the disturbed soil samples collected from the field in other to determine the geotechnical index properties. These were done in the Engineering Laboratory of Setraco Nigeria limited Company. The analysis carried out on the disturbed samples include; Liquid limit, plastic limit (Atterberg limit), Compaction test, Sieve analysis (Grading) and California bearing ratio.

According to Atterberg, 1911, a Swedish agricultural scientist who engaged in agriculture and ceramic proposed four states of soil consistency based on water content and stated that the liquid limit of a soil is the moisture content at which the soil passes from plastic state to liquid state as determined by the liquid limit test.

Particle size distribution refers to the percentage of the various grain sizes present in a rock as determined by sieving or sedimentation. It is one of the geotechnical index properties used to classify a soil based on size.

Soil engineers have established defined limit for the difference particle size found within a soil. The amount of particle size present is determined by mechanical analysis. Particles size distribution yield information on the size group of a sample's solid particles and relative proportion of the sizes, and this is a very important property which influences the engineering behavior of soil.

A total of nine water samples from hand-dug wells were collected from nine sampled localities (Yelwa, New G.R.A, Government House, Nassarawa, Wunti, Railway Quarters, Gombe Road (opp. FGGC), Army Barrack and Tirumn) for hydrogeochemical analysis. The samples were collected from hand-dug wells of different depth. The samples were taken to the laboratory for analysis. The use of Emission flame photometry was used during the analysis of sodium (Na), Magnesium (Mg), Iron (Fe), Zinc (Zn) and calcium (Ca). At the same time EDTA titrametric techniques were used with concentrated acid (HNO_3) for analysis of carbonates and hardness. In sulphate analysis spectrophotometer titration was used with Barium chloride ($BaCl_2$) and concentrated acid HNO_3 and for PH and chloride (Cl_2) analysis, colour comparator was used as the method.

For all the analyses, analytical reagent (Analar) grade chemicals were used. Laboratory equipment and facilities were decontaminated through proper cleaning and storage similarly, quality control of laboratory air through the use of functional cooling system (below 20°C) was

observed. The equipments were regularly calibrated using standard reference materials and solutions. In all the data verification and validation for ionic balance were carefully carried out.

RESULTS AND DISCUSSIONS

Geotechnics

Incipient gullies were observed in different parts of Bauchi and its environs which is underlain by the Basement complex rocks. The menace of this badland devestation was found in Federal Lowcost Housing Estate, Shadawanka, Zaranda and Tirumn. The Basement complex rocks of the area have undergone complete weathering or decomposition leading to about 4 to 7m thick unconsolidated weathered overburden- layer consisting of loose sands, gravels, silts and clays. The average depth of incision of these gullies observed is about 2.5 to 3m. It is the geotechnics of these areas that determine their susceptibility to gully erosion or their erodability.

Therefore, to determine the causes and to suggest solution to the problem, the geotechnical parameters or characteristics of the soils at thirteen locations using soil mechanic laboratory tests such as the liquid (LL) and plastic limits (PL), moisture content, specific gravity and shear strength tests were carried out (Table 1). While the result for the grain size analysis is in Table 2.

Table 1: Showing result of the Atterberg Limit.

Location	Sample NO.	Depth (m)	Atterberg Limit parameters (%)			MC (%)	Density (g/cm3)	Soil Description	Shear Strength	
			LL	PL	PI				θ	Cohesion
Dumi	AA1	5.00	32.60	23.40	9.20	8.10	2.40	Sandy-clay, coarse-medium	33.00	0.27
Dunglusi	AA2	7.00	41.50	24.00	17.50	13.60	2.60	Predominantly medium- coarse sand with some gravel	35.00	0.29
New G.R.A	AA3	4.00	40.60	17.70	22.90	10.00	2.40	Sandy gravel	33.50	0.25
Zaranda	AA4	0.02	28.60	*	28.60	5.80	2.40	Silty fine medium- coarse sand		
Gwalameji	AA5	0.02	24.10	17.60	6.50	5.70	2.60	Medium -coarse sand with some gravel		
Durum	AA6	0.05	34.30	16.30	18.00	6.10	2.50	Medium -coarse sand		
Inkil	AA7	0.03	28.30	*	28.30	5.90	2.50	Fine-medium coarse sand		
Wunti	AA8	0.05	33.80	17.70	16.10	10.50	2.50	Predominantly medium- coarse sand with some gravel		
Yelwa	AA9	0.02	23.40	*	23.40	6.20	2.50	Medium -coarse sand		
Guni	AA10	0.03	33.50	16.20	17.30	11.40	2.40	Sandy very silty clay	31.00	0.26
Dandango	AA11	0.02	26.00	16.50	9.50	3.80	2.50	Fine-coarse sand with some gravel		
Shadawanka	AA12	0.03	25.50	17.30	8.20	15.00	2.30	Sand Alluvium	25.00	0.22
Nassarawa	AA13	0.02	37.50	18.80	18.70	19.20	2.40	Sandy very silty clay	27.00	0.23
Total					224.20	121.30	32.00			
Average					17.20	9.30	2.50			

The LL and PL were used to obtain the plasticity index (PI) which is a measure of the plasticity of the soil. The values obtained ranges from 6.5 to 28.5% with a mean value of about 17.2% which indicates slight to medium plasticity. Thus the soil samples are soft and could be crushed by fingers and hence erodible.

The shear strength of the soil samples was also determined. Shear strength is the maximum internal resistance of the soil to movement of its particles by sliding or slipping. The forces that resist shear are the intergranular friction and the cohesion. The values of the cohesion obtained range from 0.22 to 0.29cm²/kg which is relatively low. Also, the shear angle of the internal friction ranges from 25 to 35°. The significance of the shear strength test is that the force due to run-off and the seepage flux are only resisted by the angle of internal friction since the value of cohesion is low.

Table 2: Showing the grain size analysis result of soil samples in the study area.

Grain Size Distribution B.S. Standard (% passing)			4	14	36	52	100	200	
Location	Sample	Depth	2.36	2.00	1.18	600	425	300	212	150	63
	NO.	(m)	mm	mm	mm	µm	µm	µm	µm	µm	µm
Dumi	AA1	5.00	79.00	72.90	50.80	24.60	15.10	9.10	5.50	2.80	0.30
Dunglusi	AA2	7.00	65.50	59.30	39.70	25.20	19.10	15.60	11.90	8.50	2.00
New G.R.A	AA3	4.00	78.50	68.20	42.10	22.80	15.80	11.40	7.70	5.00	1.00
Zaranda	AA4	0.02	77.20	71.30	54.20	29.90	14.40	2.10	0.60	0.20	0.03
Gwalameji	AA5	0.02	47.90	42.30	30.70	19.70	14.50	11.20	8.00	5.80	1.00
Durum	AA6	0.05	76.00	70.50	48.50	26.20	17.30	11.60	8.10	5.60	1.50
Inkil	AA7	0.03	57.70	52.90	42.30	27.50	19.20	13.80	8.10	4.10	1.50
Wunti	AA8	0.05	59.10	53.20	37.00	23.30	17.20	12.70	9.20	6.80	1.70
Yelwa	AA9	0.02	71.90	65.60	47.50	29.90	21.20	15.40	11.00	7.60	1.20
Guni	AA10	0.03	84.80	78.10	59.40	40.80	32.20	26.40	20.50	14.10	2.70
Dandango	AA11	0.02	64.90	60.20	47.50	32.00	22.50	17.40	12.20	8.30	2.10
Shadawanka	AA12	0.03	78.70	73.70	56.50	35.30	26.70	20.60	14.30	7.90	1.10
Nassarawa	AA13	0.02	86.00	80.20	61.20	40.10	30.30	23.70	17.10	11.70	1.40

The moisture content result ranges from 3.8 to 19.2% with an average of 9.3% which is low. This indicates that the amount of water content the soil can retain is small.

The specific gravity of soil samples was determined and it showed that the density in the medium to coarse samples is very high compare to fine particles. The density ranges from 2.3 to 2.6g/cm3 with an average of 2.5g/cm3. This is done to know the weight of soil samples and to determine the amount of water in which the soil particles can resist without loosen its shear strength and also its stability to loads and absorption of water.

The grain size result shows that texturally the soils are essentially gravels and sands and are greater than 50% on 200 percent passing (Table 2). The soil has indicated high percentage of gravels and sands which implies that the soil is very porous and very low interconnectivity among the particles and could absorb water easily via erodability of material.

Hydrogeochemistry

Hydrogeochemistry is the study of natural water chemistry. It deals with principles and properties that govern the behaviour of dissolved chemical constituents in groundwater. These dissolved chemical constituents occur as ions, molecules or solid particles. These constituents do not only undergo reactions, but also redistribution among the various ionic species or between the liquid/solid phases. These processes also help in the understanding of chemical evolutions that accompanies flow, hence the geochemical cycle of surface and ground water.

The geochemical cycle of surface and groundwater indicate the principal chemical changes involved in water as it travels through the hydrologic cycle from precipitation to groundwater. The chemical and biochemical constituents of groundwater determine its importance for industrial, agricultural or household use. The study of groundwater may yield important indications of the geologic history of the enclosing rock, the velocity and direction of groundwater movement and even the presence of hidden ore deposits. The mode of origin of particular water within the hydrologic cycle can also be determined.

Also, the chemical processes occurring in the groundwater region can affect the strength of geologic materials. If this is not detected, it may lead to failure of artificial slopes, mining excavation and other features of importance to mankind.

Hydrogeochemistry can be applied in various field of study such as agriculture, industries, mineral exploration, engineering works, environmental studies and in groundwater exploitation.

Some of these chemical constituents that affect geologic materials and/or engineering structures include pH values (acidity), chloride and soluble sulphate contents.

According to Du Preeze and Barber (1965), classification of water base on hardness was through the percentage of (CO_3) anion in the water such as 0 – 75% (soft), 75 – 150% (moderately hard), 150 – 300% (hard) and over 300% (very hard).

The coefficient of variation for chemical properties was done in relation to determine the differences and changes of various elements in different hand-dug well (Table 3).

Table 3: Coefficient of variation for chemical properties.

Property	Coefficient of Variation (%)
Ph values	2.82
Sodium (Na)	17.32
Magnesium (Mg)	24.64
Hardness	9.96
Carbonate/Alkalinity	24.70
Sulphate (SO4)	8.88
Iron (Fe)	11.03
Zinc (Zn)	10.00
Calcium (Ca)	27.99

Table 4 indicates that the pH values of the groundwater are generally between 6.9 and 7.1 which is an indication that the water is neutral. The chloride concentration shows a mean value of 158.89mg/l which is relatively high and capable of causing corrosion and incrustation of metallic objects. Erosional control structures should be made with anti corrosion materials.

Table 4: Summary of the geochemical properties for all the zones.

Location	Sample NO.	pH Value (Mean)	Na (Mean) mg/l	Mg (Mean) mg/l	Ca (Mean) mg/l	Fe (Mean) mg/l	Zn (Mean) mg/l	Hardness (Mean) mg/l	Carbonate HCO$_3$/8CO$_3$ Alkalinity	SO$_4$ (Mean) mg/l	Cl$_2$ (Mean) mg/l
Yelwa	HW-1	7.00	55.00	85.00	26.00	7.30	0.10	414.95	15.00	95.00	150.00
New G.R.A	HW-2	7.10	50.00	80.00	30.00	8.50	0.10	404.35	15.00	90.00	145.00
Govt. House	HW-3	6.70	40.00	85.00	40.00	9.60	0.08	449.91	9.00	98.00	165.00
Nassarawa	HW-4	7.40	60.00	60.00	45.00	10.00	0.12	359.45	16.00	94.00	175.00
Wunti	HW-5	7.10	35.00	55.00	60.00	9.80	0.10	376.31	13.00	100.00	170.00
Railway Qtrs	HW-6	7.10	50.00	45.00	65.00	8.70	0.10	347.62	13.00	105.00	155.00
Gombe Road Opp. F.G.G.C.	HW-7	6.90	45.00	60.00	55.00	9.00	0.10	384.42	9.64	110.00	140.00
Shadawanka Barrack	HW-8	7.00	55.00	60.00	50.00	7.50	0.10	371.93	10.00	85.00	185.00
Tirumn	HW-9	7.20	60.00	45.00	55.00	7.90	0.10	322.65	14.00	85.00	180.00
Mean		7.10	50.00	64.00	47.33	8.70	0.10	381.29	10.89	95.78	158.89
Standard Deviation		0.20	8.66	15.77	13.25	0.96	0.01	37.99	2.69	8.51	14.95

The sulphate content of the groundwater indicates a mean value of 95.78mg/l and hence suggests the presence of sulphate bearing minerals such as pyrite, anhydrite or marscasite within the soil. Therefore, erosion control structures should be made with sulphate resistant cement since ordinary Portland cement is likely to be attached by the soluble sulphate present in the groundwater. The Iron content of the groundwater indicates a mean value of 8.7mg/l which is also very high and hence capable of staining metallic objects. The hardness of the groundwater shows a mean value of 381.29mg/l which indicates that the water is very hard and therefore should be treated before use.

Generally, erosion control structures in the area should be made of materials that should resist staining, corrosion and incrustation, etc.

CONCLUSION

The study area covered an extent of about 3,025km^2 and is underlain by the Older Granites and Granite – Gneiss complex of the lower Precambrain Basement complex. The uppermost 4 – 5m of these rocks have undergone complete weathering or decomposition leading to residual soils (the unconsolidated weathered overburden layer) consisting of sands, clays and gravels.

The geotechnical study indicates that the soil sample have plasticity index ranging from 6.5 – 28.8% with an average value of 17.20% which indicates slight to medium plasticity. Thus the soil samples are soft and could easily be crushed by fingers and hence erodible. Thus the soil has

little or no cohesion. Shear strength test was conducted and cohesion values range from 0.22 – 0.29cm^2/kg which is low. Also shear angle of the internal friction ranges from 25-35°.

The hydrogeochemical studies indicated that the water samples have total hardness ranging from 322.65mg/l to 449.91mg/l with an average value of 381.29mg/l. The value of Iron varies from 7.3mg/l to 10.0mg/l. The hydrogeochemical studies have also provided all the chemical characteristics of the underground water in the area in terms of elements and their concentrations. All these information will serve as useful guide in groundwater prospecting in the area.

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