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HYDROGEOLOGICAL AND GEOTECHNICAL STUDY OF BAUCHI AND ENVIRONS, NORTHEAST NIGERIA.

G. I. OBIEFUNA and A. NUR

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ABSTRACT

Hydrogeological and geotechnical investigations around Bauchi area have been carried out. The results of the investigations indicate the occurrence of two aquifer units namely; the unconsolidated weathered overburden aquifer unit and the fractured basement aquifer unit. The hydraulic parameters of the aquifer units indicate a hydraulic conductivity value that ranging between 0.93×10^{-3} m/s to 8.93×10^{-3} m/s and a mean value of 3.47×10^{-3} m/s. An average linear groundwater velocity of 3.80 m/yr and a specific discharge of about 1.71 m/yr were recorded. The geotechnical investigation indicates a mean plasticity index of 17.2%; mean optimum moisture content of 9.30% and a mean maximum dry density of 2.5 g/cm^3. The shear strength test indicated a mean cohesion value of 0.25 kg/m^2 in a mean angle of internal friction of 30.1°. From the results of this study recommendations that will serve as useful guide in erosion control and groundwater prospecting in the area were made.

INTRODUCTION

The study area is located in high relief area and is underlain by the weathered basement rocks. As a result run-off is relatively high and infiltration rate is low. The groundwater storage, which is limited by geologic factors, is further reduced by adverse climatic condition. Thus soil erosion has become problematic and is ravaging the landscape of the study area. It has also affected the agricultural, infrastructural and socio-economic aspects of both urban and rural development in the area. It was this exigency that prompted the carrying out of soil test analyses on the study area where erosion is devastating with a view of providing lacking geotechnical and hydrogeological information about the genesis and expansion of gullies. The study area Bauchi and environs, falls within latitudes 10° 00′ N and 10° 30′ N and Longitudes 9° 30′ E and 10° 00′ E (Fig.1). Alkaleri bounds it to the east, to the west it is bounded by Tafawa Balewa; to the south by Alkaleri and to the north by Ganjuwa. It is easily accessible by Bauchi-Jos, Bauchi-Kano Bauchi-Maiduguri link roads. There are numerous footpaths and tracks that provide access to hilly and other remote areas within the study area.

The study area is characterized by highlands and flat topography. The low lying areas are characterized by patches of granite outcrops while the entire western parts are characterized by chains of mountains with elevation ranging from 675 meters to 1025 meters a.m.s.l. Isolated outcrops of Bauchite granites, fayalite-quartz-monzonite and undifferentiated migmatites and gneisses occur in the eastern, western and northern parts of the study area.

It is drained by network of streams, which take their source from the mountainous area and flow to join rivers Gongola and Hadejia in the eastern and northern low plain areas. These streams include rivers Delimi and Zaranda, which drain the south extreme and flows northwards to join Hadejia whereas Rivers Ran, Waya Rakyamro, Rafin Lugge and Rafin Bagel drain the western highlands and flow eastwards into River Gongola around the study area. Rambaya River draining the northern part flows towards the northwestern part to join River Zaranda that subsequently flows northwards to join River

G.I. OBIEFUNA, Department of Geology, Federal University of Technology, Yola, Nigeria.
A. NUR, Department of Geology, Federal University of Technology, Yola, Nigeria.

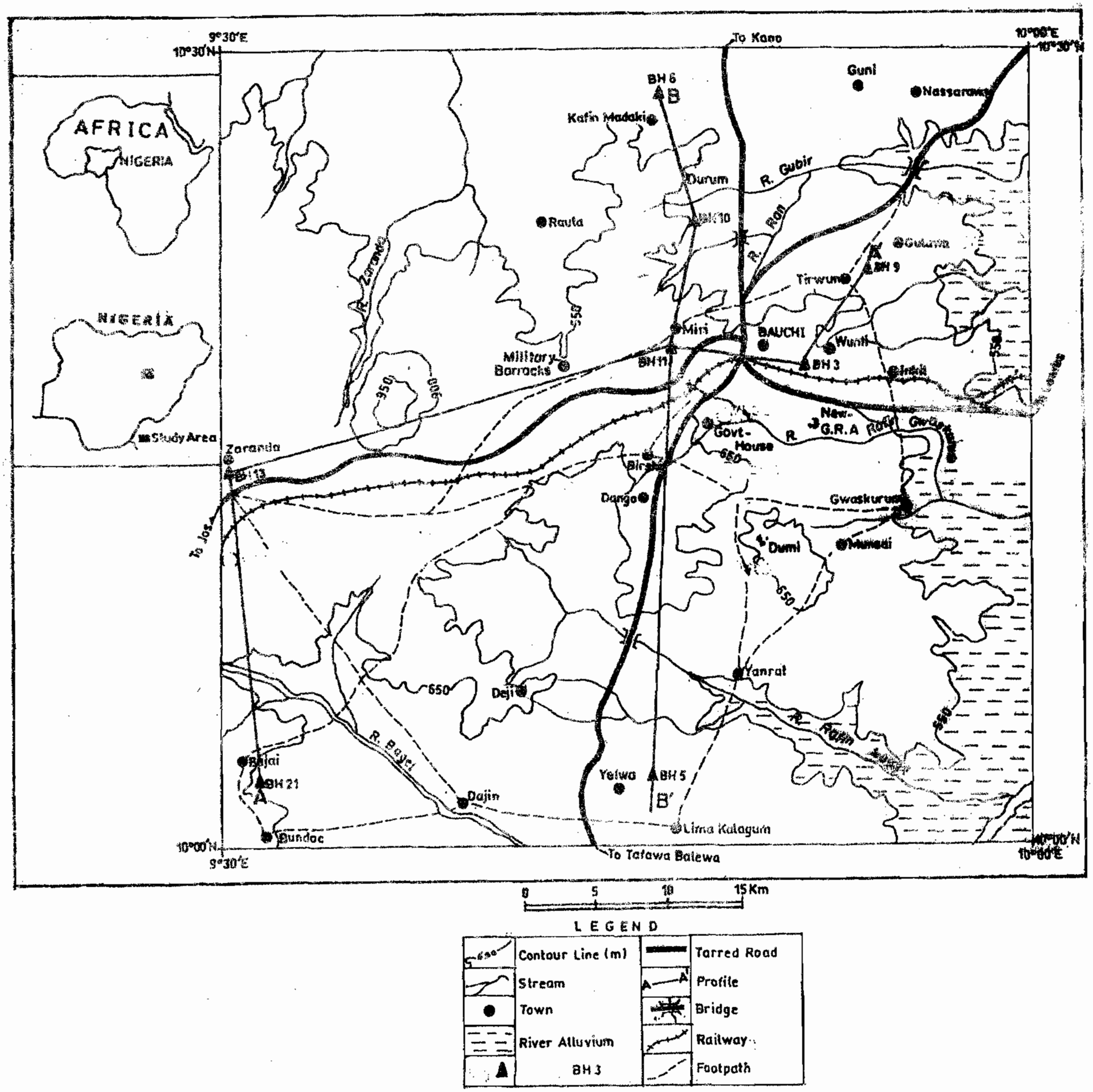

FIG. 1: MAP OF THE STUDY AREA SHOWING TOPOGRAPHIC FEATURES, DRAINAGES, ACCES ROADS AND BOREHOLE LOCATIONS

(After Bauchi State Agricultural Development Board (B.S.A.D.B) 1984).

Hadejia. Most of the rivers are seasonal except rivers Gongola and Hadejia, which are perennial. They exhibit trellis and dentritic drainage patterns, which are characteristic of areas with homogeneous resistant rocks (Oyawoye 1970).

The prevalent vegetation is Savanna and it has two distinct seasons; a dry season, which lasts from November to April, and a wet season, which lasts from May to October (UBRBDA) 1987-1994 Year Book). The mean maximum daily temperature ranges from 25° C to 34.5° C and the mean annual rainfall is about 1023.3 mm, most of which falls between the months of July to September (Table 1). Most of the previous works in area are mainly regional (Carter et al. 1963; Du Preeze and Barber 1965; and Kiser 1968) and describe the geology and chemical quality of groundwater in the northeastern Nigeria. Ali et al (1993) and Nur and Obiefuna (200 , gave some details on the geophysical and hydrogeophysical aspects of Bauchi area.

The main objective of this study area is to assess the results of hydrogeological as well as geotechnical parameters obtained from soil tests to infer the sub-surface processes that are likely to result in gulling in the study area.

GEOLOGY OF THE STUDY AREA

Rocks of the Crystalline Precambrian Basement complex rocks of Nigeria underlie the study area. The major lithologic units are: the Bauchite (fayalite-quartz-monzonite), the biotite-hornblende granite, the porphyroblastic biotite-granite, granulites and undifferentiated migmatites and gneisses (Fig. 2). In most parts of the area, unconsolidated weathered overburden materials consisting of laterites, clays, sands and gravels cover these rocks. The unconsolidated weathered overburden materials are of two types namely: - the Alluvium and the Elluvium. However, outcrops of Fayalite-quartz-monzonite (Bauchite) and Biotite-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 fractured zones exist in places. The prominent fault zones trend towards the NE-SW and N-S zones (Oyawoye 1970).

Undifferentiated Migmatite and Gneisses.

These are mixed rocks of mainly two sources-the pre-existing host rock and a rather

Table 1. Mean Monthly Rainfall Data (in mm) for Bauchi area for 1987/1988 to 1993/1994 Water Year (Upper Benue River Basin Development Authority 1987 – 1994 Year Book)

Water year	April	May	June	July	August	September	October	November	December	January	February	March	Total	No. of Raining Days
1987/88	68.8	90.9	143.3	173.[illegible]	275.[illegible]	155.0	[illegible]	00.[illegible]	[illegible]	00.0	00.5	01.8	920.7	62
1988/89	26.6	100.0	77.6	192.3	324.7	140.8	57.4	00.0	00.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1989/90	05.9	106.7	100.5	284.7	262.3	87.0	29.7	00.0	00.0	00.0	00.0	00.0	876.6	55
1990/91	85.9	149.1	103.3	283.1	244.1	35.9	19.1	00.0	00.0	00.0	00.0	26.5	949.6	82
1991/92	48.4	50.2	177.5	328.0	357.6	233.5	28.1	02.7	00.0	00.0	00.0	02.4	1229.4	75
1992/93	14.9	81.3	236.1	231.5	337.7	179.5	60.6	00.0	00.0	00.0	00.0	00.0	1141.9	89
1993/94	106.9	58.4	55.4	225.3	367.4	295.7	44.2	00.0	00.0	00.0	00.0	00.0	1174.3	69
Total	356.2	638.6	894.7	1708.5	2190.5	1132.2	248.3	02.7	00.0	00.0	00.5	32.7	[illegible]	494
Mean	50.9	91.2	127.8	244.1	312.0	161.7	35.5	00.4	00.0	00.0	00.1	04.7	1023.3	70.6

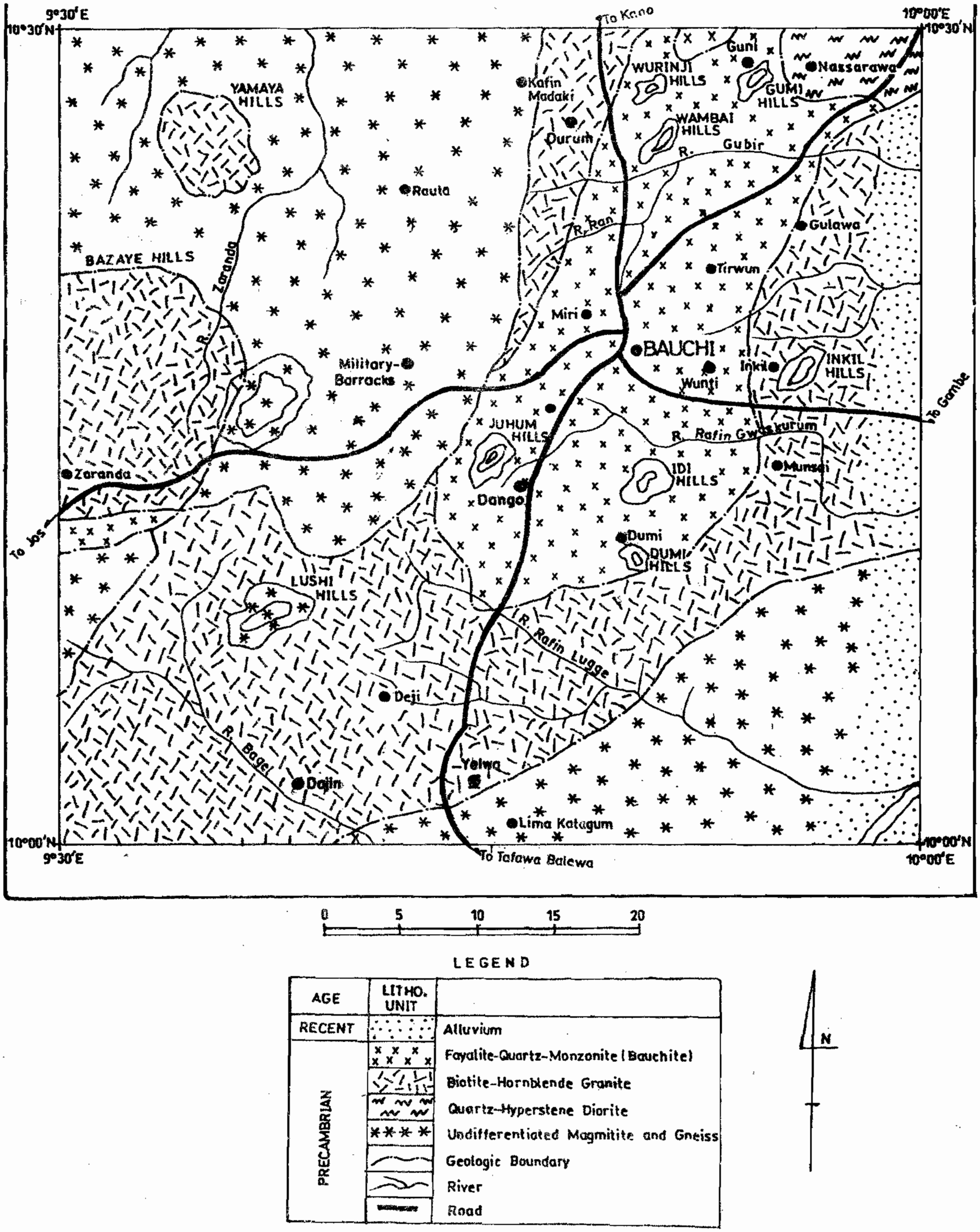

FIG. 2: GEOLOGIC MAP OF THE STUDY AREA (AFTER B.S.A.D.B. 1984)

Table 2. Hydraulic properties of some samples of the unconsolidated weathered overburden aquifer of the study area

S/No	Hydraulic Conductivity (m/s) x 10^{-3}					Transmissivity (m^2/s) x 10^{-3}				
	Location sample No.	1	2	3	4	5	1	2	3	4
1	Durni AA1	10.57	6.78	0.40	5.91	5.00	52.85	33.90	2.00	29.55
2	Tiruwn AA2	3.44	2.21	0.13	1.93	7.00	24.08	15.47	0.91	13.51
3	New GRA AA3	8.66	5.54	0.33	4.85	4.00	34.64	22.16	1.32	19.4
4	Zaranda AA4	14.71	9.43	0.56	8.23	10.00	147.10	94.30	5.60	82.30
5	Dajin AA5	8.34	5.35	0.32	4.67	26.00	216.84	139.10	8.32	121.42
6	Durum AA6	7.11	4.56	0.27	3.98	8.00	56.88	36.48	2.16	31.84
7	Inkil AA7	7.11	4.56	0.27	3.98	24.0	170.64	109.44	6.48	95.52
8	Wunti AA8	5.97	3.83	0.23	3.34	19.60	117.01	75.07	4.51	65.46
9	Yelwa AA9	3.85	2.47	0.15	2.15	15.00	57.75	37.05	2.25	32.25
10	Guni AA10	1.66	1.06	0.06	0.93	6.00	9.96	6.36	0.36	5.58
11	Dango AA11	3.31	2.12	0.13	1.85	9.50	31.45	20.14	1.24	17.58
12	Miri AA12	3.71	2.38	0.14	2.08	11.20	41.55	26.66	1.57	23.30
13	Nasarawa AA13	2.16	1.38	0.08	1.21	12.50	27.00	17.25	1.00	15.13
14	Total	80.90	51.65	3.06	45.10	157.10	12766.02	8150.37	482.87	7116.78
15	Mean	6.22	3.97	0.24	3.47	12.14	982.00	626.95	37.14	547.44

1. Hazen method (1893) 2. Harleman et al method (1963) 3. Uma et al method (1989)
4. Average values 5. Aquifer thickness (in meters)

indefinite diffusion of other rock materials which are granitic in composition through the host rock. The host rock is usually the metasedimentary schists and the intruded materials include mostly granites, pegmatites and quartzites. They occur mostly around the northwestern and southeastern portions and are less weathered than the schists.

Quartz-Hypersthene Diorite.

This unit consists mostly of quartz in association with hypersthene and olivine. It has a subhedral granular texture and outcrops at northeastern extreme.

Biotite-Hornblende Granites

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 olivines. The biotite is often dark colored and hornblende is green colored. This can be found in areas around Lush and Inkil hills. It covers parts of southeastern, northern and northwestern sectors of the study area (Fig2).

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 biotites and hornblende. In others, augites are present and are normally accompanied by hypersthene and olivine. The K-feldspars in monzonite is usually orthoclase

Table 3. Chemical analyses of water samples from the Unconsolidated weathered overburden groundwater

S/No.	Location	Sulphate (SO_4^{2-}) mg/l	Chloride Cl^{-1}	pH
1	HW1 Yelwa	95	150	7.00
2	HW2 New GRA	90	145	7.10
3	HW3 Government House	98	165	6.70
4	HW4 Nasarawa	94	175	7.40
5	HW5 Wunti	100	170	7.10
6	HW6 Railway Quarters	105	155	7.10
7	HW7 Gombe Road (opp.FGGC)	110	140	6.90
8	HW8 Military Barracks	85	185	7.00
9	HW9 Tirwun	85	180	7.2
10	Mean	95.78	158.89	7.1

(rarely microcline). Quartz occurs in minor amounts. This unit is found around Guni, Idi and Dumi hills in the central and northeastern area and some to the western portion (Fig.2).

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 led to the development of lateritic profiles as the overburden forms the elluvium. The parent materials migmatites, gneisses that are cut by pegmatite, apitite and quartz veins are weathered to varying degrees with depths. The depth of weathering varies from 34m to 129m. It was found that water bearing zones are mainly found in the fractures of the poorly decomposed rock; inter-granular permeability in moderately decomposed coarse-grained igneous and metamorphic rocks and fractured pegmatites, aplite and quartz veins within highly and moderately decomposed gneisses and migmatites.

River Course Alluvium

The low-lying plains of the study area are essentially mantled by lateritic pebbly soil resulting from weathering of the crystalline rocks. Where exposed by erosion, the soil profile consists of laterite topsoil underlain by 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 on river channels and riverbanks.

The Hadejia valley around the northern part and its tributaries have alluvial flood plains and the Gongola valley around the eastern part are also underlain by unconsolidated coarse to medium grained sandy materials, clays and silts. From careful observation it was found that at higher altitudes these sediments are coarse grained and fine towards the low lying plains.

Structural Trends in the Study Area.

All the rocks of the area are affected to varying extent by joints. In some instances the joints cut through the rock mass. In others, the joint planes run parallel of the rock mass. This results in onion weathering in which slice of the rock exfoliate and fall off the mass. In many places huge blocks of rocks fall off from the huge granite hills and ridges and settle at the lower

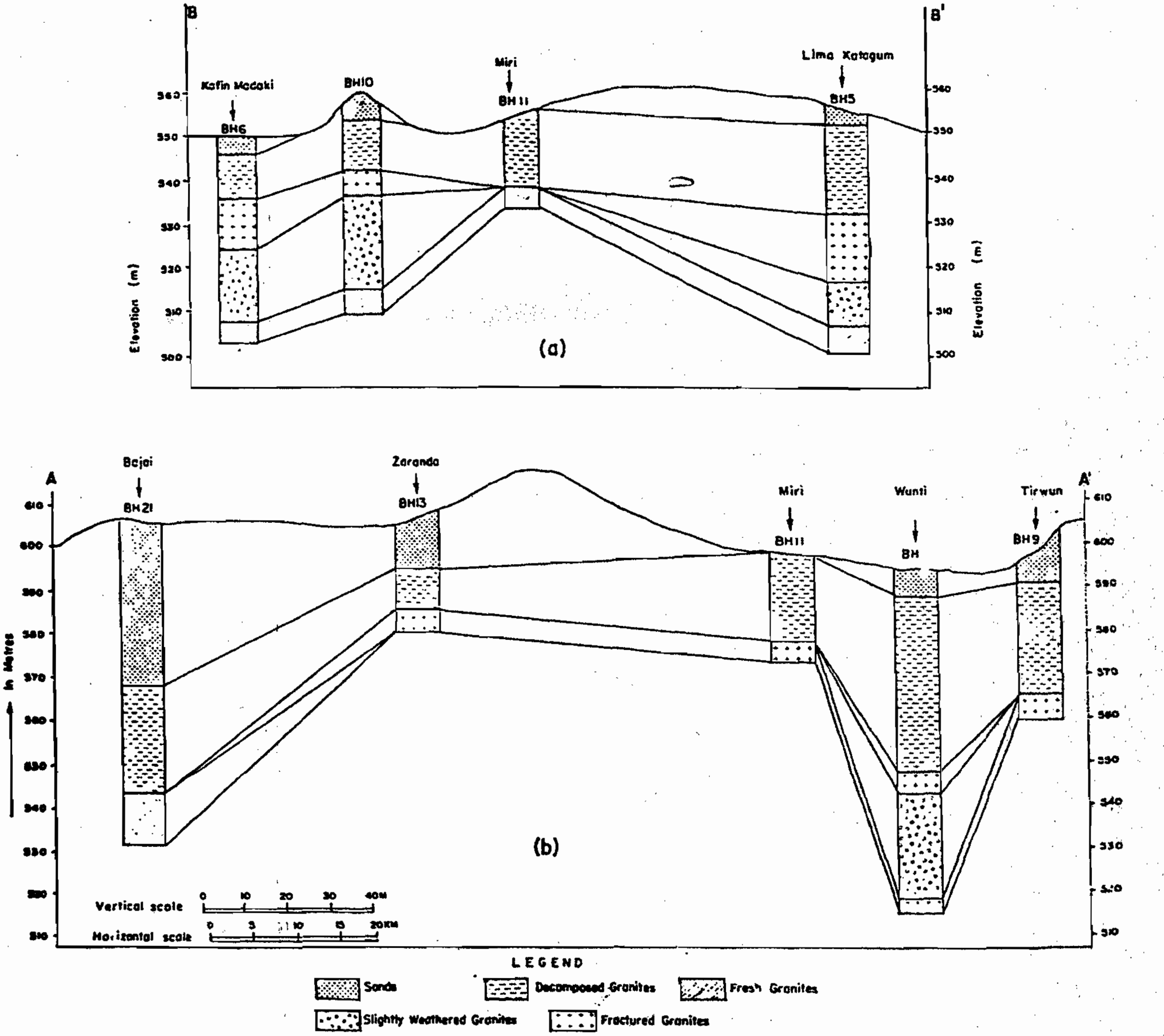

Fig.3a,b. Correlation of borehole lithologic logs in the study area (modified after Nur and Obiefuna (2003)

levels of the slopes or at the foot. The joints have different orientation but the most prominent directions are E-W and NE-SW. Most of the joints are closed and so are healed fractures on the rock mass. Others are however, open and so represent openings through which water percolates through the rocks bringing about in them the chemical weathering. Around the granitic rocks at Lush and Inkil hills, the joints seem not to go deep into the mass. The closed joints are filled essentially with quartzites, pegmatites, dolerites and materials of granitic composition.

Dolerite dykes are a prominent structure in the area and are observed to have intruded into probably pre-existing structures in the rocks. They have the same composition as basalts but differ only in the coarser textures. In some places they appear as swarms giving an impression of a fault zone. The most conspicuous directions of the dykes are also E-W and NE-SW, the former being the direction of flow of the main rivers. However, there are a number of observations that point to the possibility of faults being present. Firstly, the alignment of the main streams and river segments in the direction of the major structural trends. Rivers draining hilly terrains as in the study area readily exploit zones of fractures. The trellis drainage pattern of the two main rivers lends credence to this. Secondly, the presence of swarms of dolerite dyke is probably due with fault-like displacement of the host rocks in the course of intrusion.

HYDROGEOLOGY OF THE STUDY AREA

The meteorological data from the Upper Benue River Basin Development Authority Bauchi shown in Table 1 include the rainfall data for the area. Average annual precipitation occurring almost entirely as rainfall over a seven water year period (April to March) amounted to 3.11 x 109 m^3 volume of water. The value of actual evapotranspiration estimated from Turc (1954) formula from the mean annual rainfall is about 2.43 x 10^9 m^3/yr or 78 % of atmospheric precipitation. An estimate of the surface run-off of 4.35 x 108m^3/yr or 14 % of atmospheric precipitation was achieved employing Veisman (1972) rational formula. Bell (1983) has noted that infiltration can be estimated if the amount of run-off and evapotranspiration are known by subtracting these from the total precipitation. Accordingly when this is done for the study area an average infiltration value of 2.49 x 10^8 m^3/yr or 8.0 %.

Potential sources of surface water supply are rivers Gongola and Hadejia and their tributaries such as Rivers Delimi, Jauro and Zaranda. Others include Rivers Ran waya,

Table 4. Summary of results of soil tests

Gully Location	Depth (m)	Width (m)	Compaction: Optimum moisture content %	Compaction: Maximum dry density mg/m^3	Shear Strength: Angle of Shearing resistance (θ)	Shear Strength: Cohesion kg/m^2	Permeability m/sec x 10^{-2}	Atterberg Limit: Plastic limit %	Atterberg Limit: Liquid limit %	Atterberg Limit: Plasticity index %	Silt/clay content %	Soil classification
Dumi AA1	5.0	3.0	08.1	2.4	33.0	0.27	5.79	32.6	23.4	09.2	1.21	Sandy Gravel
Tiruwn AA2	7.0	2.5	13.6	2.6	35.0	0.29	0.19	41.5	24.0	17.5	4.44	Gravelly sand
New GRA AA3	4.0	1.6	10.0	2.4	33.5	0.25	4.75	40.6	17.7	22.9	2.43	Gravelly sand
Zaranda AA4	2.0	2.1	05.8	2.4	28.5	0.24	8.07	28.6	00.0	28.6	0.09	Gravelly sand
Dajin AA5	1.8	2.3	05.7	2.6	27.6	0.28	4.58	24.1	17.6	06.5	3.90	Gravelly sand
Durum AA6	4.5	3.2	06.1	2.5	34.0	0.26	3.90	34.3	16.3	18.0	2.75	Gravelly sand
Inkil AA7	2.5	1.8	05.9	2.5	32.0	0.23	3.90	28.3	00.0	28.3	2.53	Gravelly sand
Wunti AA8	4.7	1.5	10.5	2.5	30.0	0.25	3.27	33.8	17.7	16.1	4.02	Gravelly sand
Yelwa AA9	2.2	2.8	06.2	2.5	29.6	0.27	2.11	23.4	00.0	23.4	3.35	Sand
Guril AA10	2.9	1.7	11.4	2.4	31.0	0.26	0.91	33.5	16.2	17.3	4.91	Gravelly sand
Dango AA11	2.2	1.4	03.8	2.5	26.0	0.24	1.81	26.0	16.5	09.5	4.05	Gravelly sand
Miri AA12	2.4	1.3	15.0	2.3	25.0	0.22	2.04	25.5	17.3	08.2	2.94	Gravelly sand
Nasarawa AA13	2.0	1.2	19.2	2.4	27.0	0.23	1.19	37.5	18.8	18.7	3.87	Sand
Mean	3.3	2.0	09.3	2.5	30.1	0.25	3.27	31.5	14.3	17.2	3.11	Gravelly sand

kyamro, Rafin Lugge, Rafin Bagel and Rambaya. River Hadejia takes its rise from the western highlands and flows northeastwards and discharges into Lake Chad. It has its peak discharge between the months of August and July with minimum discharge in the month of March. There are two main aquifer units that have been identified based on hydrolithologic analyses of borehole logs, the nature of water table and geological reconnaissance. These are the unconsolidated weathered overburden aquifer and the fractured basement aquifer units. The unconsolidated weathered overburden aquifer unit is derived from the complete weathering and/or decomposition of pre-existing granitic rocks. They consist of residual soils such as gravels, sands, silts and clays and extend from Bajai to Tirwun and from Liman Katagum to Kafin Madaki. The thickness varies from 3m at Liman Katagum to 5m at with an average thickness of about 4.4m (Fig 3). The depth to static water level varies from 2.33 to 6.42m with an average of about 4.12m. The fractured basement aquifer unit varies from 14m at Liman Katagum to 52m at Bauchi with an average thickness of about 26.6m.

It directly underlies the unconsolidated weathered overburden aquifer unit. This investigation is confined to the unconsolidated weathered overburden aquifer since all the gullies identified are located within this aquifer. The hydraulic properties as determined from statistical methods (Hazen 1893, Harleman et al 1963 and Uma et al 1989) indicate a mean hydraulic conductivity, K, of 3.47×10^{-3} m/s and a transmissivity, T, of 5.47×10^{-1} m^2/s (Table 2). Comparisons were made for K to the Todd (1980) and T to the Gheorghe (1978) classifications. The values of K and T are relatively high.

An average storativity value of 8.6×10^{-5} was computed. The specific discharge is developed in overcoming friction on the joint surfaces and in pore spaces. It is called the Darcy Velocity (Vd) and equals the product of hydraulic conductivity and hydraulic gradient (i). It is based on Darcy's law and expressed mathematically as:

$$Vd = Ki \qquad 1)$$

where Vd = specific discharge

i = hydraulic gradient

The mean hydraulic conductivity value for the unconsolidated weathered overburden aquifer is computed as 3.47×10^{-3} m/s. This value when multiplied by the average hydraulic gradient, which was computed as 0.0057, gave a specific discharge value of 1.71 m/yr. The average linear groundwater velocity is a measure of the speed with which water moves through the pores or joints; and is obtained by dividing the specific discharge by the real or volumetric (average) porosity. The average linear groundwater velocity (Va) as given by Todd (1980) is:

$$Va = Vd/n \qquad 2)$$

where n = porosity

Va = average linear groundwater velocity.

Vd = specific discharge

The porosity of the unconsolidated weathered overburden aquifer is estimated based on Pettijohn (1975) at a value of 0.45. Thus using equation (2) an average linear groundwater velocity of 3.80m/yr was calculated, which confirms high seepage fluxes and pore pressures. There are two main groundwater flow systems that are identified in the study area. These include the local flow system occurring in the unconsolidated weathered overburden aquifer unit and the intermediate flow system occurring in the fractured basement aquifer unit. The first type of flow (unconsolidated aquifer unit) receives direct recharge from rainfall over its permeable soil cover. The flow comes from areas of higher elevation such as the undulating ridges and hills to areas of lower elevation such as rivers or stream valleys to the north and eastern side of the area. The distribution of hydraulic head in the unconsolidated weathered overburden aquifer indicates that a localized recharge area occurred towards the western portion around Zaranoa Nur and Obiefuna (2003).

The calculation of available groundwater reserve can be obtained through the following formula:-

$$Qa = b \times Sy \times A \qquad (3)$$

Where b = average saturated thickness of the aquifer

sy = specific yield at 19% for unconsolidated weathered overburden aquifer and 23% for fractured basement aquifer after Johnson (1967).

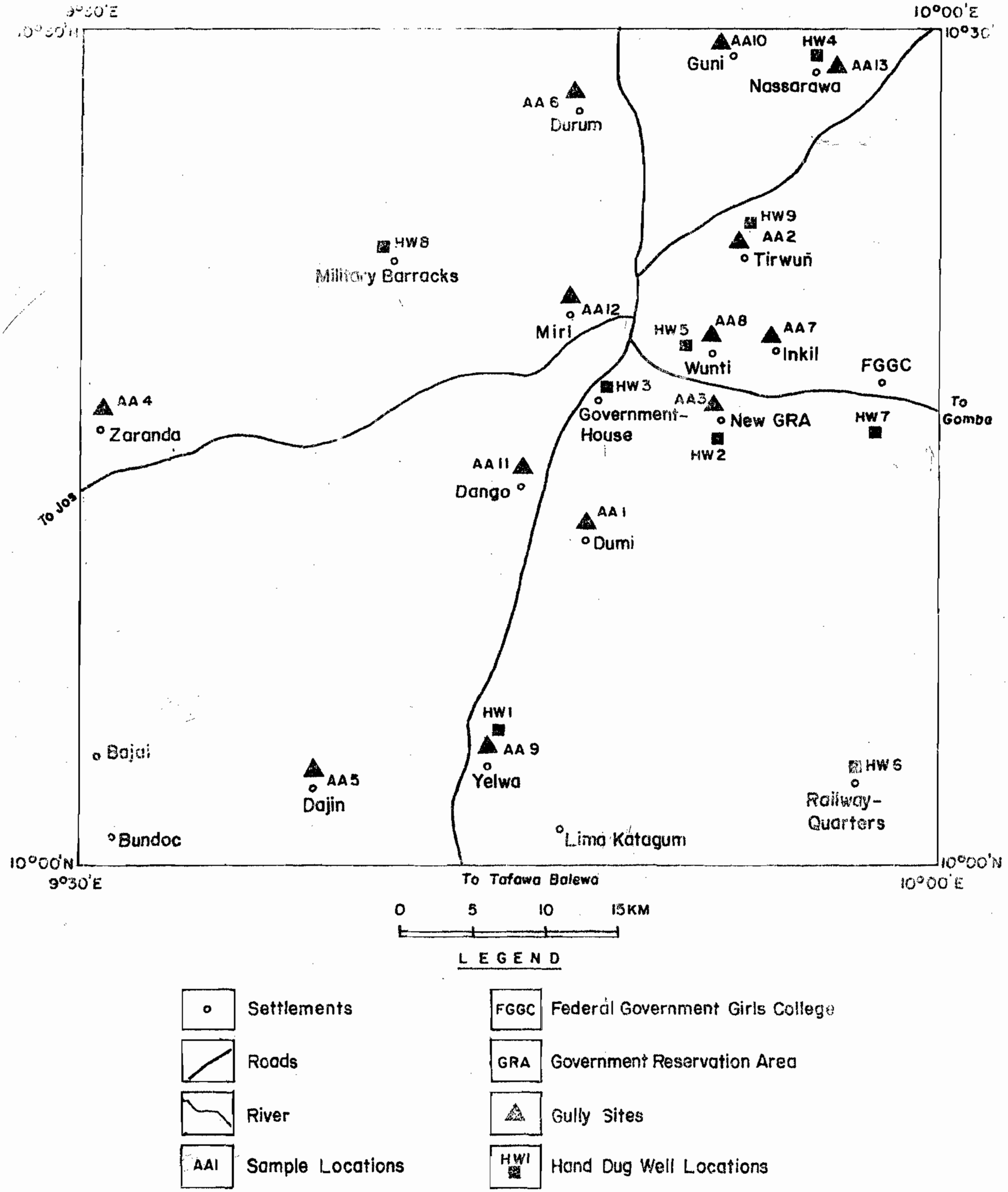

FIG. 4: MAP SHOWING GULLY SITES, WELLS AND SAMPLE LOCATIONS

Qa = groundwater reserve,
A = area.

Thus using equation (3) average groundwater reserves of 1.64×10^{10} m^3 and 2.09×10^{10} m^3 were obtained for the unconsolidated weathered overburden aquifer and fractured aquifer units respectively. Cementing materials can be affected by pH values (acidity), Chloride and sulphate contents of the groundwater that comes in contact with them. The pH values of the groundwater obtained range from 6.7 to 7.4 (Table 3). The chloride and sulphate contents indicate average values of 159 mg/l and 96 mg/l respectively. This is relatively high and capable of causing corrosion and incrustation of metallic objects and structures.

GEOTECHNICAL PROPERTIES OF THE WEATHERED BASEMENT

Incipient gullies were observed in different parts of Bauchi and its environs, which are underlain by the Basement complex rocks. The menace of devastation was found in the New GRA, Yelwa, Miri, Zaranda and Tiruwn (fig.4). The Basement complex rocks of the area have undergone considerable weathering or decomposition leading to about 4 to 7 meters thick unconsolidated weathered overburden layer consisting of loose sands, gravels, silts and clays. The average depth of incision of these gullies observed is about 2.2 m to 7.0 with width ranging from 1.2 m to 3.2 m. It is the geotechnics of these areas that determine their susceptibility to gully erosion or their erodibility.

Therefore, to determine the causes and to suggest solution to the problem the geotechnical parameters or characteristics of the soils at the thirteen locations using soil mechanic laboratory tests such as the liquid and plastic limits, the grain-size analysis, moisture content, specific gravity and shear strength tests were carried out. Table 4ab summarizes the results of the tests conducted on soil collected from the sites. The liquid and plastic limits were used to obtain the plasticity index, which is a measure of the plasticity of the soil. The values obtained ranged from 6.5% to 28.6 % indicating slight to medium plasticity. Thus the soil samples are soft and could be crushed by fingers and hence erodible.

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.

According to Coulomb's law, the shear strength is given by;

$$S = C + P \tan \theta \qquad 4)$$

Where S = Shear Strength
C= Cohesion
P = Effective pressure
Tan θ = Coefficient of friction
θ = Angle of internal friction.

The shear strength test indicated values of cohesion ranging from 0.22 kg/m^2 to 0.29 kg/m^2 in an angle of internal friction ranging from 25^0 to 35^0. 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. The compaction test shows that the optimum moisture content ranges from 3.8% to 19.2%, while the maximum dry density ranges from 2.3 mg/m^3 to 2.6 mg/m^3. 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 losing their shear strength and its stability to load and water absorption. The maximum dry density values are generally low signifying that the soil is not compact but loose. As earlier pointed out the high hydraulic conductivity measurements indicate high permeability. Permeability is a measure of the capacity of a soil to permit the passage of water and it has the dimension of velocity (cm/sec). The environmental setting in the area such as highlands flat topography and scarp slopes make the rainwater not taken up by the soil as infiltration to flow as run-off thereby detaching particles because of their low shear strength (Onwuemesi 1990). The sparse vegetal cover exposes the soil surface to direct impact of rainfall as well as viscous drag of run-off.

CONCLUSION.

Hydrogeological and geotechnical investigations of the weathered basement rocks of Bauchi area were made for the purpose of inferring the surface and sub-surface processes that contribute to the formation of gullies in the area. Specific discharge value of 1.82 m/day and average linear groundwater velocities of 4.21 m/year were computed for the two-aquifer units. These values indicate moderate seepage force which is however in conformity with moderately high hydraulic conductivity (K) and transmissivity (T) values recorded. Most of the waters tested indicate pH ranging from 6.7 to 7.4. The water is of the chloride type and is generally of good quality and also suitable for both agricultural and industrial proposes. The results from of the investigation have shown that the control of gullies in the area must be done through an integrated approach. The approach involves agronomic or massive aforestation effort aimed at protecting the soil from the direct impact of raindrops as a first step. The second step requires some engineering methods, which can be used to modify the slope characteristics in an attempt to check the amount and velocity of run-off. Finally drainage is an important factor in reducing the high pore pressures and seepage forces associated with this area. Draining the soil using appropriate methods can help to increase the shear strength and reduce the susceptibility of the soils to erosion.

REFERENCES.

Ali, S., Shemang, E.N. and Likkason, O. K., 1993. The Basement structure in Barkumbo Valley, Bauchi Nigeria; A revelation from seismic refraction and D.C. Resistivity Studies. Jour.of Mining and Geology, Vol.29 No.2: 47-51.

Bell, F.G., 1983. Fundamentals of Engineering Geology Butterworths Pub. London. 211-257.

Carter, J.O., Barber, W., Tait, E.A. and Jones, G. P.,1963. The Geology of parts of Adamawa, Bauchi and Borno provinces in Northeastern Nigeria. Geological survey of Nigeria Bull. 30: 35-53.

Du Preeze, J.W. and Barber, W., 1965. The distribution of Chemical Quality of Groundwater in Northern Nigeria. Geol. Survey of Nigeria Bull.36: 19-33, 94-97.

Gheorghe, A., 1978. Processing and synthesis of Hydrogeological data, Abacus press, Turnbridge Wells Kent.

Harleman, D.R.E., Mehborne, P.E. and Rumer, R.A., 1963. Dispersion, permeability correlation In porous media Jour. Hydraulic Div. Amer. Soc. of Civil Engineers. No HY2, Vol.89:67-85.

Hazen, A., 1893. some physical properties of sands and gravels. Mass state Board of Health 24th Annual

Johnson, A., I 1967. Specific yields compilation of specific yield for various materials. U.S. Geological Survey water supply paper 16, 62-D. Report.

Kiser, R. T., 1968. Chemical Quality of Water in Northern Nigeria. Geological Survey of Nigeria Open File Report.

Nur, A. and Obiefuna, G.I., 2003. Hydrogeoelectrical Studies in Bauchi and Surroundings Northeastern Nigeria Journal of Environmental hydrology. USA (in press).

Onwuemesi, A.G., 1990. Hydrogeophysical and Geotechnical investigations of the Ajalli Sandstone in Nsukka and Environs with Reference to Groundwater Resources and Gully Erosion problems. Water Resources-Journal of the Nigerian Association of Hydrogeologists vol.2 No.1: 70-76.

Oyawoye, M.O., 1970 The Basement Complex of Nigeria, In African Geology Whiteman, A.J. and Dessauvagie, T.F. (Eds.) University Press Ibadan. 91-97.

Pettijohn, F. J., 1975. Sedimentary Rocks (3rd Ed.) Harper and Row, New York.

Todd, D.K., 1980. Groundwater Hydrology J. Wiley and Sons, New York.

Turc, L., 1954 Methods of Measuring Evapotranspiration MC Graw-Hill Book Coy. Inc. New York.

Upper Benue River Basin Development Authority UBRBDA (1981-1990) Hydro-meteorological Year Book.

Uma, K.O., Egboka, B.C.E. and Onuoha, K.M., 1984. New Statistical grain-size method of evaluating the Hydraulic conductivity of sandy Aquifers. Jour. of Hydrology 108: 343-366.

Veisman, W.T.,1972. Introduction to hydrology. Mc Millian Pub.London.