AQUIFER TYPES IN BAUCHI STATE
BASEMENT VS SEDIMENTARY

BY

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SIGNATURE AND DATE

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DEDICATION

This work is dedicated to the memory of my late Father,

MALLAM YAKUBU ABDUL,

who died just before I entered the University, my beloved Mother,

SADETU ALHAJI ENESI,

and my Sisters

HASSANATU YAKUBU,
HAJARATU YAKUBU,
JEMIATU YAKUBU,
RASHIDATU YAKUBU,

who through sweat financed my University Education. To them, I shall ever be grateful.

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I am most grateful to my Supervisor, DR.E.F.C.Dike, who saw to the successful completion of this research by making himself available at all times.

I am also very grateful to members of staff of the Geology Programme for their individual knowledge I received during the course of my study in the

ADDENDUM/ERRATUM

The bulk of the data used for this reasearch were obtained through my Supervisor from Water Survey's (Nigeria) Ltd, Bauchi State Agricultural Development Project (BSADP) and Bauchi State Urban Utilities Board - Water Division. I gratefully acknowledge this assistance.

Jimoh Aliyu Omeiza, Alhaji Enesi, Umoru Auru and my friend Jimoh Siyaka who at one time or the other rendered help financially or morally during my University education.

To all those whose names are too numerous to be mentioned here, I give my profound gratitude and wish them the best for their undertakings. Errors and ommissions in this work however remain my responsibility.

The water therefore is generally good for most uses.

Along the river valleys in the State, there is a great potential for use of groundwater within the alluvial deposits for irrigation purposes during the dry season.

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CHAPTER ONE

1 INTRODUCTION

1.1 Aims of Project

The importance of water to the development of any State such as Bauchi can not be over emphasised. The State therefore needs to fully explore and exploit its water resources; especially its underground water, to support its growing agricultural development programmes, its agro-based industries and its expanding population. The State being located in an area with long dry seasons (Oct.-May), short rainy seasons (June-Sept.) and an average high rate of evapotranspiration throughout the year requires planned water storage schemes to avert the perennial water shortages that affect most part of the State during the dry season.

This project is, therefore aimed at collecting data from various sources within the state and from the more than 1500 boreholes drilled in the State. These data will be systematically studied and interpreted such that useful suggestions and recommendations will be made toward a better understanding of the areal distribution, physical and the hyraulic characteristics of the various aquifers found within the state. The potential yield of these boreholes and the chemical quality of the groundwater will also be studied.

The research project is in itself a partial fulfilment of the award of Bachelor of Science (B.Sc.)

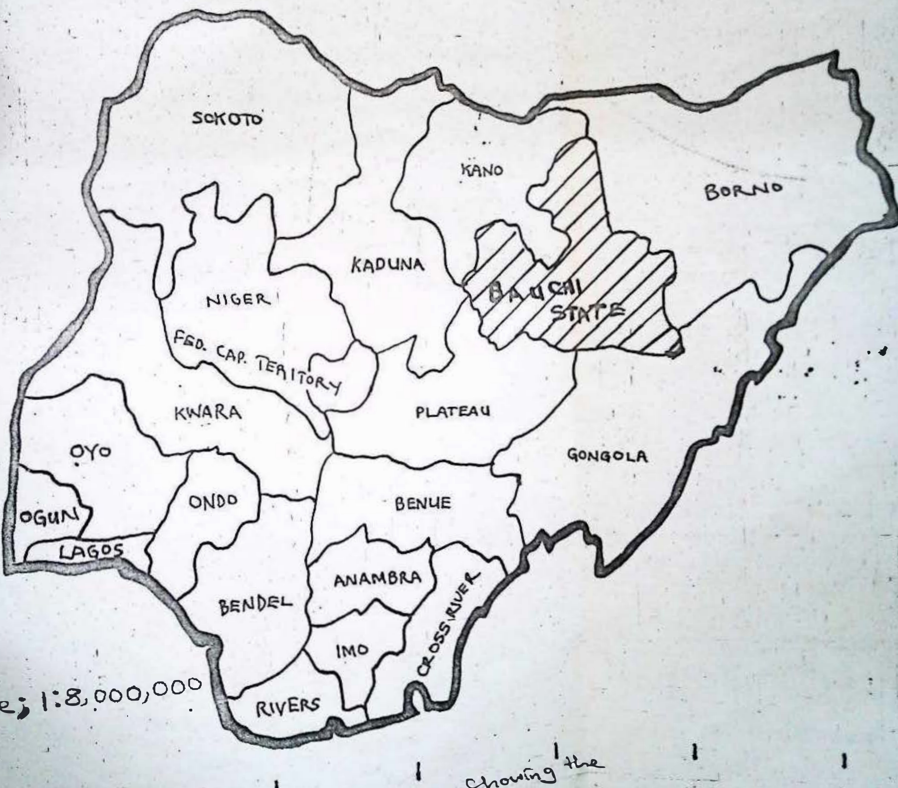

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FIG.1- Location map of Bauchi State. The map of Nigeria showing the (after Water Surveys, 1986)

...imate of Bauchi S...

The research project is in itself a partial fulfilment of the award of Bachelor of Science (B.Sc.) Applied Geology degree of the Abubakar Tafawa Balewa College, Ahmadu Bello University, Bauchi.

1.2 Location and Surface Area.

Bauchi State is located in the north eastern Nigeria between latitudes 12°39'N and 9°30'N and longitudes 11°50'E and 8°40'E. The state is bounded in the north by Kano State, to the west by Plateau State, Borno and Gongola States to the north-west as shown in Fig. 1.

The state covers an area of 66,510•045 square kilometers.

1.3 CLIMATE AND VEGETATION

The state is subjected to annual dry and wet seasons cycles. An intertropic front exert a principal control on the climate, while topographic features provide secondary variations. The intertropic front is the interface between dry tropical air crossing the Sahara and moist equatorial air from the ocean. The dry season is from October to May, and is characterised by an arid wind moving from the north-east of the sahara desert. During this period there is little cloud cover and temperatures vary from 32°c - 13°c in Bauchi Town (Water Survey's, 1987). The wet Seasons generally occur from June to September and are periods when the moist monsoonal air mass moves northward from the Gulf of Guinea. Table 1 summaries the climate of Bauchi State.

Towns	Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct.	Nov	Dec	Total
Bauchi	1956-1974	0.3	1.0	2.8	25.7	92.7	140.6	244.2	293.2	180.2	33.4	0.6	0.0	1014.8
	1985	0.0	0.0.	33.2	TR	122.3	108.4	152.2	162.2	145.6	1.7	0.0	0.0	725.8
	1986	-	-	-	98	119	217	452	-	-	-	-	-	
Toro	1956-1974	0.1	0.5	12.0	58.4	248.0	191.5	252.0	297.4	282.8	49.7	3.2	0.7	1356.3
	1986				98	119	217	452	113					
Gombe	1956-1974	0	0	4.6	34.5	86.3	140.9	181.5	207.1	173.6	41.4	1.9	0	871.8
Azare	1957-1974	0	0	0.2	10.9	52.7	88.7	187.8	288.6	116.7	17.1	0.3	0	763.0

Table 1 - Rainfall in Bauchi State (after Water Survey's report, 1987)

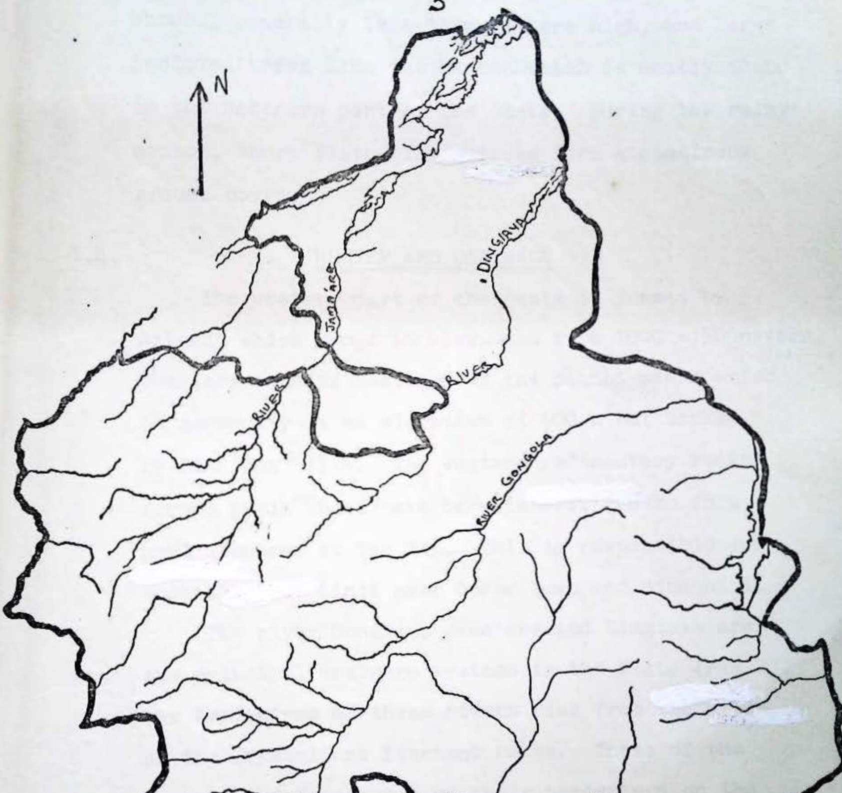

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FIG. 2— Location map Showing major river Systems (after Water Survey's 1987)

Vegetation in the state is typically that of the Sudan Savanah and is characterised by sparse shrubs, generally less than 2meters high, and large isolated trees like the baobao which is mostly found in the northern part of the state. During the rainy season, short feathering grasses form a continous ground cover.

1.4. RELIEF AND DRAINAGE

The western part of the state is formed by uplands which range in elevation from 1000 -1500meters. The terrain dips eastward to the Bauchi plain which is generally at an elevation of 600 m but broken by numerous hills. The eastern sedimentary rocks form a plain which have been lateritized to form hard ironpans at the top. This is responsible for such hills as Linji near Gombe town and Bima hill.

The river Gongola, Jama'are and Dingiaya are the principal drainage systems in the state (Fig.2). The headwaters of these rivers rise from the hills of the Crystalline Basement rocks. Those of the Gongola and Jama'are have their headwaters on the Jos Plateau, while the headwaters of Dingiaya lie within the Bauchi Plain. There are other smaller rivers found within the state, they include Yashi and Yuli both of which rise from crystalline basement rock. The Pai and Geji rivers have their headwaters in the Sedimentary rocks. The river Iggi rises on Crystalline basement rocks in Kano state and flows northeast along the state border of Burra, Ningi Local Government Area to Agwai Maji.

CHAPTER TWO

GENERAL GEOLOGY OF BAUCHI STATE

2.1 Previous Work

Geologic work in the state dates back to the early part of this century when Falconer(1911) did a reconnaissance mineral Survey of Northern Nigeria. He first recognised Kerri-Kerri Sandstone and believed it to be Eocene in age.

In 1928 the geological Survey of Nigeria commenced hydrogeological investigation in Nigeria and also undertook the actual exploration of groundwater for rural Communities by means of hand dug, concrete-lined wells. Carter, Barber and Tait (1963) described the general geology of Bauchi. They recognised an acient Crystalline Basement, represented mainly by granitic rocks, overlain by Sedimentary and volcanic rocks.

Du Preez and Barber (1965) worked on the distribution and chemical quality of groundwater in Northern Nigeria while Schroeter (1974) described the hydrogeological conditions found in Bauchi Town and its surrounding area. He concluded that water is found in the superficial weathered mantle derived from the crystalline rocks of the Basement Complex, which form an aquifer of poor quality.

The 1986 Water Survey's unpublished report on shallow aquifers for lowland irrigation in Bauchi state for Bauchi State Agricultural Development Programme (BSADP) described the physical characteristics and areal extent of all the lowland aquifers (Fadama). While the reports by Edok-Eter-Mandilas Ltd (1978,1983) for Bauchi State Water Board investigated the various aquifer types in the state with Complete borehole logs.

The current research work will be aimed at upgrading the information currently available on the state aquifers and presenting their characteristics. There is a wealth of data currently available on these aquifers, the present work will present them in a more concise and systematic way.

2.2 Outline geology and Stratigraphic sequence

The terrain underlain by crystalline rocks comprises about 45% of Bauchi State almost entirely within one perimeter, which includes all of the western, much of central, part of the north, and forming an inlier at Kaltungo in the eastern part of the state.

Most of these crystalline rocks belong to the Basement Complex of Nigeria which are thought to be mostly Precambrian in age (Oyawoye, 1970). They are predominantly migmatites, bauchites, granites, quartzites and gneisses.

These Basement Complex was intruded by the Younger Granites Suites of Nigeria to form ring Complexes such as Zaranda and Ningi ring Complexes. In the South eastern part of the state, there is an outcrop of basalt which form part of the Longuda Plateau.

The eastern part of the state is predominantly underlain by sedimentary rocks. The oldest, Late Aptian - Late Albian Bima Sandstone is the first high energy phase in the development of the Benue Trough and Comprises mainly fluvial and alluvial sediments. It lies directly on the Crystalline Basement, accounting for about 7% of the area of Bauchi state. Overlying this is the Yolde formation, a transitional marine sequence with an areal cover of about 4%. This Yolde formation which predominatly is shaley tend to confine the Bima sandstone aquifer below it.

Overlying the Yolde is the Gongila formation with the thick Fika shale directly above the Gongila formation. Lying conformably on the Fika shale is the Gombe sandstone.
This sandstone represents a nearshore marine and deltaic deposit on the flank of the Benue Trough. It occupies about 4% of Bauchi state area. The Pindiga formation is equivalent to the Gongila formation and Fika shales.

Lyinging unconformably on the Gombe sandstone is the Kerri Kerri formation. It is a Lower Tertiary (Paleocene) continental deposit covering about 29% of the area of Bauchi state.

The lacustrine deposit of the Chad formation covers the northern part of the state accounting for 11%

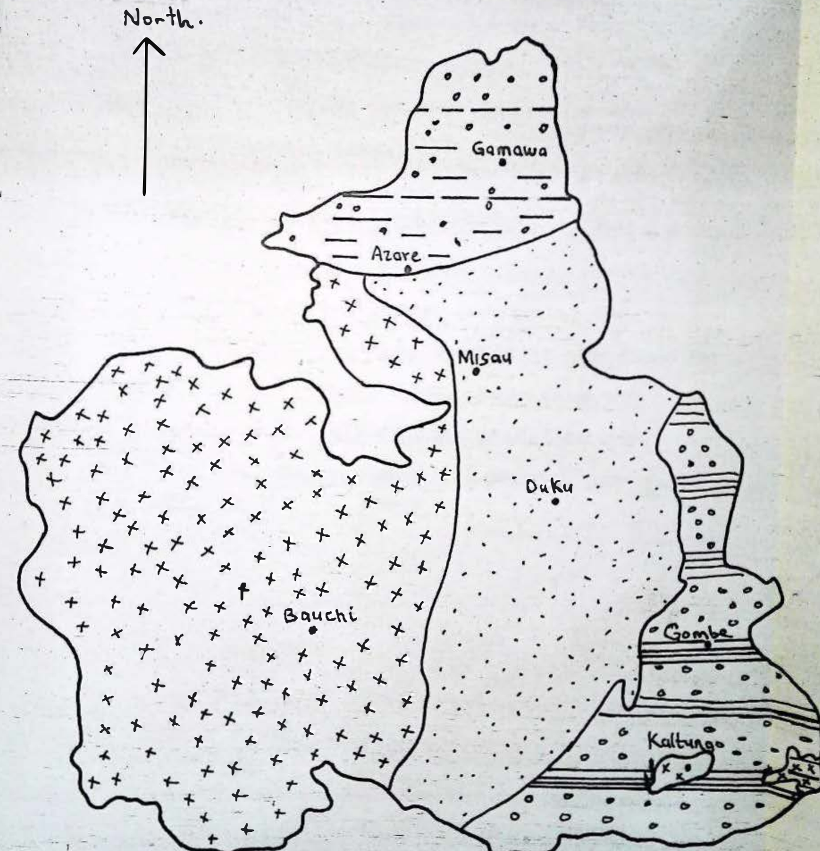
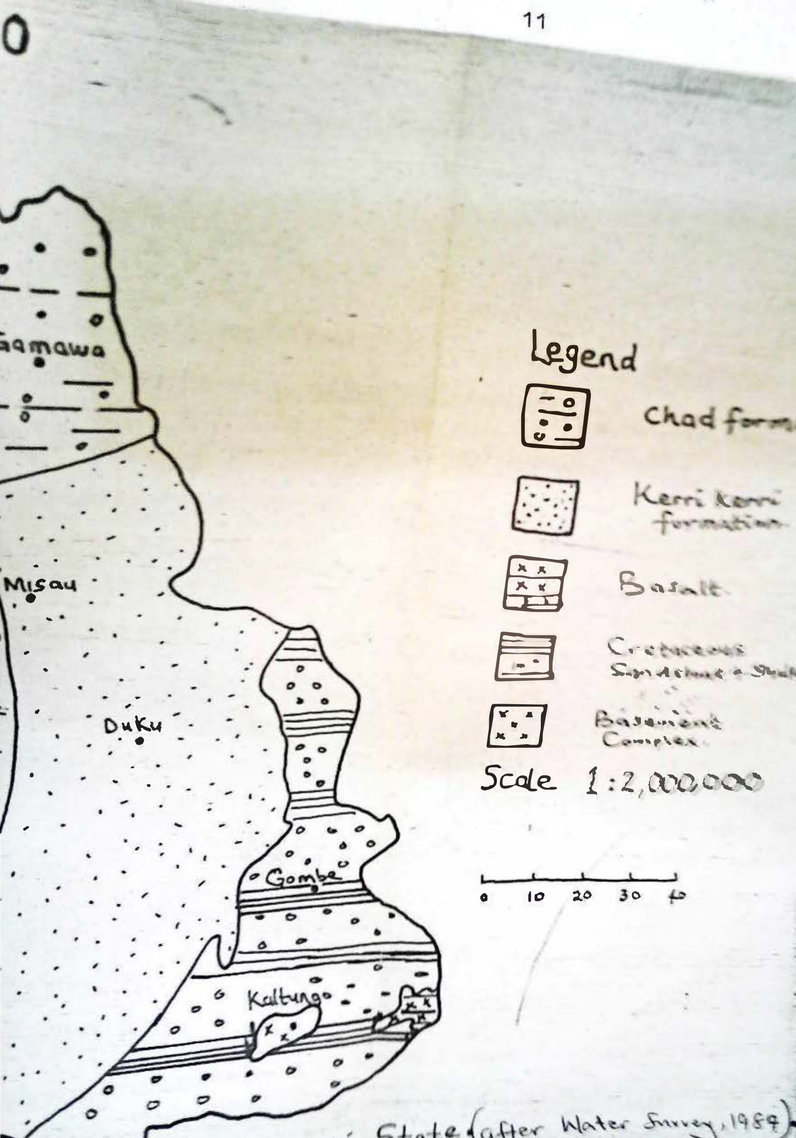


FIG. 3 — Major geologic units of Bauchi State.



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state.

The lacustrine deposit of the Chad formation covers the northern part of the state accounting for 11% of the area of the state (See fig.3)

Found along major river valleys in the state are Recent alluvial deposits. They form low lying plains adjacent to both sides of these rivers. They form very good aquifers during the dry season for the traditional irrigation schemes.

In the crystalline terrain, the superficial deposit is formed by the weathered mantle which are few meters thick, much thicker in some places, but rarely exceeding 60 meters. The mantle form an aquifer of poor quality Schroeter (1974), sustaining the numerous hand dug well found in this area. Overlying the sedimentary rocks are laterite and ironstone cap. Table 2 shows the stratigraphic sequence of the state.

CHAPTER THREE

AQUIFER TYPES

Northeastern Trough Dadiya	GONGOLA TROUGH Pindiga – Gombe	Gongila – Gombe (ZAMBUK RIDGE — ASHAKA.)	CHRONOLOGY
		Chad Formation	Pleistocene
Longuda Basalts		Bu Basalt	Pliocene
	Kerri Kerri formation		Miocene Paleocene
	Gombe Sandstone		U Maestrichtian
	Pindiga formation	Fika Shale	L Maestrichtian
	Pindiga formation	Fika Shale	Campanian Santonian
Lamaja Sandstone Numanha Shale Sekule Limestone Jessu formation Dukul Formation			Coniacian
Lamaja Sandstone Numanha Shale Sekule Limestone Jessu formation Dukul Formation		Gongila Formation	U / M / L Turonian
Yolde Formation	Yolde Formation	Gongila Formation	U / M / L Cenomanian
			U / M Albian

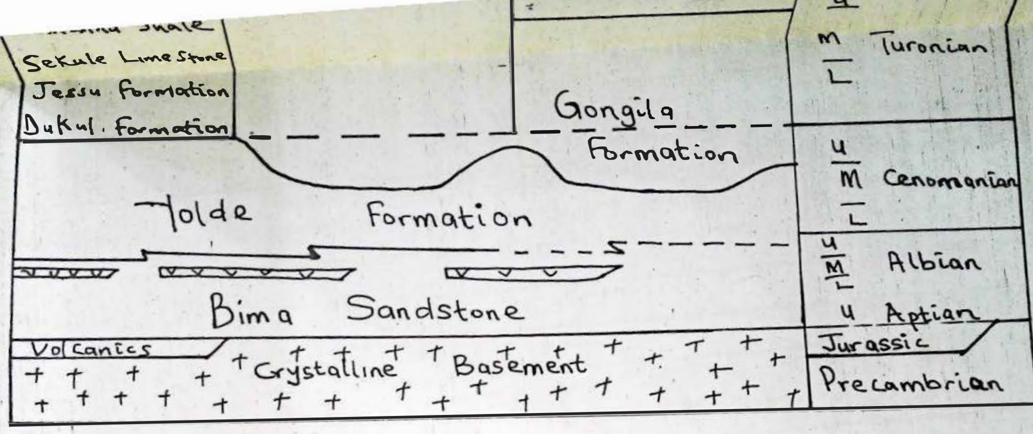

Table 2 — Correlation of Mesozoic and Cenozoic of NE Benue and Gongila Troughs, after Popoff et al (1986)

CHAPTER THREE

AQUIFER TYPES

3.1 BASEMENT AQUIFERS

3.1.1 INTRODUCTION

A large part of the state is underlain by Basement rocks. These Basement Complex rocks include granites, gneisses, migmatites, bauchites and quartzites. They underlie the sedimentary rocks in the state and rise to the land surface in the uplands to the west which continue into the Jos Plateau highlands. The Crystalline Basement rocks normaly do not contain water. However, when they are weathered, fractured, jointed and fissured they have been found to contain appreciable amount of water. They form poor quality aquifers (Schroeter, 1974) because of the restrictive nature of weathering, fracturing, jointing and the clayey materials that result.

3.1.2 WEATHERED BASEMENT AQUIFER

The upper part of the Basement can be weathered chemically to form regolith or mantle which may form an aquifer. The thickness of the weathered material varies widely but usually range from 10 - 40 meters. In granites, this thickness is irregular but generally more uniform in gneisses and migmatites.

Generally, the weathering profile consists of an upper zone of complete decomposition, intermediate zone of decomposition, and a lower zone of partial decomposition (fig.4). The main water bearing zone of partial decomposition where partial weathering has broken irregular bonding and created voids in which groundwater can be stored. Jones (1985) observed that this zone is the most productive aquifer because the zone has been broken down into sand -sizes and larger fragments and not yet subjected to severe weathering process. The weathered Basement has low water yield. This is because the decomposed mantle is often too thin (< 40m)

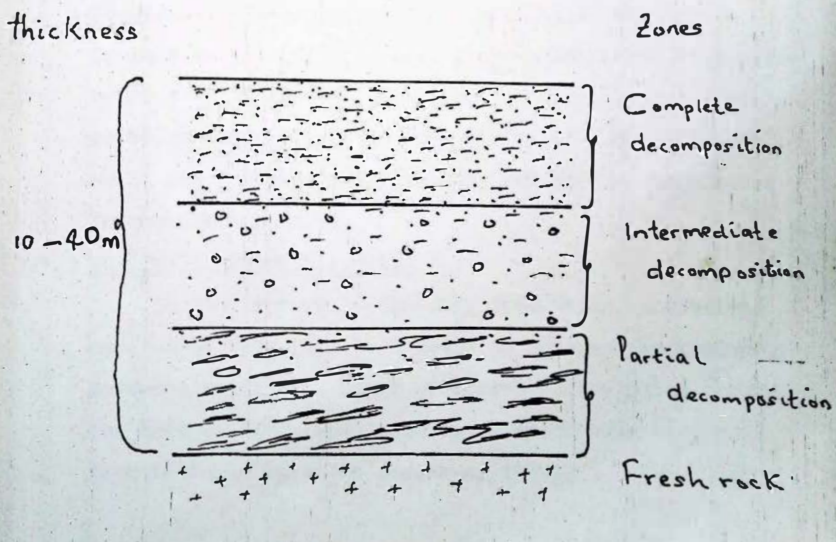

FIG. 4 — Weathering profile of a basement Complex rock. (Dike, 1986).

to harbour large quantities of water and is usually too clayey to be highly permeable. The common yield range from 1.7l.p.m. to 83.3 l.p.m. per well and the groundwater is marked by seasonal variation in level. Du Preez and Barber (1965), found out that carefully sited dug wells, especially along stream valleys usually provide adequate supply for village communities. Many of such wells have been constructed on weathered Basement. Examples are the various hand-dug and Concrete lined wells next to the student hostels in Yelwa Campus of the College.

In the foreland areas of the State where thin Sediments like the Chad formation and acient aeolian deposits overlie the weathered Basement, the zone of weathering is usually thick upto 40 meters and usually constitute a more uniform and productive aquifer. A typical example is at Azare, where borehole No 11 tapping water from weathered granite of the basement has a yield of 66lpm (880ghp) and transmissivity of $6.6 \times 10^{-5} m^2 ps$ while the borehole which is 54.3 meters deep terminated in the fresh bedrock.

3.1.3 FRACTURED BASEMENT AQUIFER

In addition to weathering, fracturing, intrusions and joints have also been found to enhance the status of Basement aquifers. Major groundwater flow paths occupy the main fracture and joint zones which have resulted from tectonic episodes (Mogekwu, 1987).

Away from the major fractures, a system of minor jounts which are localized and with geometry highly variable may have small groundwater circulation, but further away there is negligible groundwater circulation. These joints and fractures may be great in lateral extent and depth forming tight and open fissures (Du Preez and Barber,1965).

In the state, the fractures and joints are aligned stightly east of north and have characteristics symptomatic of tension (Water Survey's Report, 1986). One of these joint systems has been traced for 25 kilometers and it's heavily explioted. The density of the joints or fractures is highly variable, depending on the structure of the rock and the tectonic history of the area. Below the zone of fracture and joints, one encounters the zone of hard, fresh and unaltered bedrock. This zone produce little or no water due to the absence of weathering or fracturing. The fractured layer, constitutes a much better aquifer with dischange exceeding 66.7lpm in about 60 per cent of the wells drilled within the state (Wardrop Report, 1985). This yield very much depend on the type of rock and climatic conditions.

The aquifer characteristics of the basement rocks were critically examined using boreholes No.101 in Bauchi Town and No.6 at Liman Katagun. Both boreholes tap water from Basement aquifers at depths of 57.3meters and 54 meters respectively (Table 3).

The two boreholes were pump tested for six hours with 6 inches diameter Johnson stainless steel screens. While the yield at Bauchi borehole No 101 was 71.25lpm, the yield at Liman Katagun borehole No. 6 was 195lpm. Their transmissivities were 1.9×10^{-5} m^2/Sec. and 7.3×10^{-5} m^2/sec respectively. From the above and the data in table 3 , the aquifer characteristics of the basement rocks vary widely from place to place.

Fracturing of asement rocks usually create zones of weakness where thick weathered materials can be formed. These materials normally overlie the fractured zone (fig.5). This combination of two aquifer types usually give a more uniform and appreciable water yield compared to the previous aquifers discussed in 3.1.2 and 3.1.3. A typical example is the borehole drilled at the College's Kari Housing Estate. The borehole penetrates both the weathered and fractured basement aquifers to a depth of 52 meters. It has a provisional yield of 135l.p.m. to 146.3 l.p.m., recharged from perennial rainfall and nearby stream.

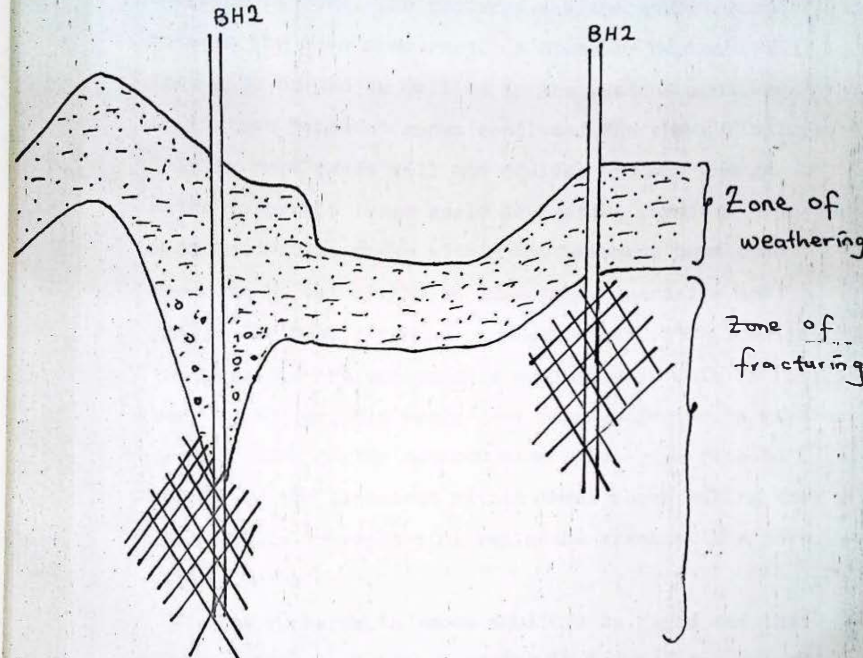

FIG.5 — Combination of weathered and fractured Basement aquifers. (after Dr. Dike, 1987)

Note: — Not to Scale.
BH ~ Borehole.

The water yield from the basement aquifers was generally found to be low and variable, depending on the type of rock, the recharge and the evapotranspiration rate in the area concerned. A Study by Mouton (1975) from 2500 boreholes drilled in the baement aquifers in African basement rocks confirmed the above findings. Only in rare cases will the aquifer produce enough water to permit large scale irrigation farming. The most productive rocks within the basement have been found to be metamorphosed limestone, quartzite and schist (Dr.Dike personnel communication, 1987a) while the granites are not usually productive. This is because metamorphic rocks have been subjected to strains and stresses during metamorphism which gave rise to foliation and lineament within these rocks making them susceptible to weathering while the granite is a more stable rock.

The recharge in these aquifers is rapid and the water table fluctuates tremedously between the rainy and dry seasons. The Basement aquifers form an important source of potable water in the rural areas of the State.

TABLE 3.1. RECORDS OF some BOREHOLE, SCREENED IN BASEMENT AQUIFER (Bauchi Water Board Records)

Location	Borehole number	Date of Completion	Total Depth(m)	Setting(m)	Screen Diameter(")	Openings	Static water level (m)	Yield (min)	Drawdown (m)	Remarks
Bauchi	101	18/6/78	57.3	28.95-41.1 47.24-51.2	6	50	6.30	71.2	36.90	Productive
Bauchi	102	6/6/78	53. 3	24.0- 41.1	6	50	6.85	75	20.90	"
Bauchi	62	2/12/76	28. 3	14.3- 26.5	6	50	3.50	120	14.25	"
Bauchi	119	17/8/78	32. 3	15.2- 19.2 25.3- 29.3	6	50	2.38	90	10.01	"
Toro	1	27/4/77	54. 2	21.0-27 .1 35.3- 45.4	4	50	7.85	51	30.29	"
Toro	2	4/5/79	39. 3	15.2- 31.0 34.1- 36.2	6	50	6.42	115.1	8.78	"
Dass	3	4/1/78	17	9-15	6	50	2.05	71.3	5.75	"
Liman Katagun	1	13/11/78	54	30-43	6	50	3.95	195	25.69	"
Ningi	1	25/6/77	51. 2	20.7-26.8 32.9-45.1	6	"	4.27	90	17.37	"
Bingi	7	8/11/78	48. 1	21.9-29.56 37.1-45.1	6	"	9.35	30	2.16	"
Kwankiyal	4	1/8/78	59	43-57	6	"	9.35	75	5.54	"
Yana	6	10/9/78	42	30-40	6	"	7.42	129.8	9.13	"
Shira	5	14/11/77	35. 4	19.2-21	6	"	9.12	63.8	8.73	"
Shira	5	27/11/77	60.37	20.1-34.1 22.5-47.3	6	"	3.09	30	14.64	"

3.2 SEDIMENTARY AQUIFERS

3.2.1 INTRODUCTION

The sedimentary aquifers found in the State are restricted to the eastern, northern and part of the central parts of the state, accounting for about 54 per cent of the total area of the state. These aquifers include the Bima sandstone, the Gombe sandstone, the Kerri Kerri formation, Chad formation and the alluvial deposits; the last is found along the major river valleys in the State. The age of the aquifers range from Upper Aptian/Albian for the Bima sandstone to Recent for alluvial deposits.

The physical, groundwater occurrence and the aquifer characteristics of each of these aquifers are discussed below.

3.2.2 BIMA SANDSTONE (UPPER APTIAN-UPPER ALBIAN)

The Bima sandstone is the oldest, most extensive and thickest of the Cretaceous sedimentary formations in the state. It crops out in the core of the large anticlines in the three depositional basins of the Benue, Chad and Gongola. Th Bima lies directly on an irregular floor of the Basement Complex ; fig 6. The sandstone is made up of alluvial, fluvial and lacustrine deposits, which contain comparatively coarser materials than any of the younger overlying formations.

The Bima sandstone was derived from a granitic terrain (Carter et al 1963), probably to the east of out crop (fig 6). Therefore, the lower beds are invariably coarser and more feldspathic than higher beds, which accumulated as the basin subsided and at greater distances from the granitic terrain. The sandstone itself is an alternation of sandstone and claystone. The sandy content decreases while the clayey content increases with depth towards the contact with underlying crystalline Basement rocks. The sand and gravel Bima beds are composed mainly of angular to subangular grains and rock fragments with a high proportion of feldspars. The colour of the sandstone varies from brown, red, pink to yellow, white and purple. The clay beds are mottled showing Variegated colours.

Falconer (1911) who first recognised this formation named it the Bima sandstone, although various other names have been suggested by different authors, his original name has been retained. In boreholes, the sandstone is multi coloured, with subangular quartz grains. The sandstone varies in thickness from 300-3000 meters (Carter et al,1963, Ako and Iyioriobhe,1986) The variation in thickness is due partly to the irregular relief of the Basement floor on which the Bima was laid down, and differential vertical movement within the basins during deposition. The maximum thickness occurs in the Lamurade anticline (Benue Basin) where over 3,000 meters of section is exposed, even though the base is not exposed.

Groundwater occurrence in the Bima sandstone is under water-table conditions in the outcrop area, but down dip it is confined beneath clay beds of the overlying Yolde Formation. The aquifer characteristics of the Bima vary much, depending on the primary porosity and permeability which in some places are drastically reduced as a result of breakdown of the abundant feldspars into clay minerals in the sandstone. This interstitial clay problem is very noticable in beds close to the contact with underlying asement rocks. These beds tend to have low yields than the upper beds of the formation which are generally characterised by higher yields. In addition, the Bima contains a number of faults and fractures (Ako and Iyioriobhe, 1986; Dike 1987, see fig.6) which may have contributed to the increased secondary porosity and permeability. These fractures have resulted from the Late Santonian folding that affected the Bima. Fractured Bima aquifer commonly have higher yields.

There are numerous hand-dug wells and boreholes tapping water from the Bima sandstone. Three of these boreholes (see Table 3) are screened in medium to coarse sands and tests from these boreholes indicate moderate yields with greater drawdowns as contact with the crystalline .sement is approached. This may be due to the reduction in the thickness of the water bearing sands and the increase of interstial clay content of these beds.

The Gombe wells 63/GO and 64/GO drilled east of Gombe Town and near the Railway Station respectively demostrate this relationship. The deeper borehole, 64/GO with depth at 311 meters yielded 264 lpm compared to the higher yield of 360 lpm from the shallower 63/GO well which terminated at a depth of 288 meters. There are several flowing artesian boreholes in Bima quifer, however, none flowed strongly enough to eliminate the use of a hand pump (Wardrop Consultant Report, 1985). Of the more than 100 boreholes drilled into the Bima during the BSADP borehole project in the State; yields of more than 400lpm were recorded in many wells while few of the boreholes had yields of 10lpm.

The Bima is recharged annually mainly at it's outcrop area, directly from precipitation and also by effluent seepage from streams. Lateral recharge is possible through the contacts with other formations but this may not be much. Once underground, the water moves eastwards away from the crystalline rocks into the overlying sedimentary formations.

3.2.3 GOMBE SANDSTONE (MAESTRICHTIAN)

The Gombe sandstone probably overlies the Fika shale on the western flank of the marine shale belt. This sandstone/shale sequence represents the return to a shoreline- Continental phase of deposition on the flank of the Benue trough in the Late Cretaceous. It is a sequence of estuarine and deltaic massive sandstone, siltstone, shales with iron stone top. The transitional basal beds of clay and siltstone are associated with rare coal layers while the upper layer of the sandstone is more sandy. Some of the upper sandstone horizons are heavily ferrugenised to sandy ironstone. The ironstone which vary in thickness, are vesicular or accretionary and are believed to have formed as a type of "iron pan" in extremely shallow water when sedimentation was almost at a standstill (Carter et al 1963). The sandstone which form the greater part of the formation are soft and light gray in colour when fresh but on exposure give rise to a dark red, flaggy debris. This reddish colour of the weathered sandstone is as a result of oxidation.

Falconer (1911) originally assigned the Gombe sandstone near Gombe and to the west of Tilde and Dukkul an Eocene age. The age was latter known to be wrong. Raeburn and Brynmor (1934) included the sandstone in their "Upper Sandstone Group", describing it from an area around Fika. In boreholes, the sandstone is grayish in colour, poorly cemented with sub-rounded - rounded quartz grains. The true thickness of the sandstone can not be determined due to folding and erosin (Barber et al, 1963). Ako and Iyoriohbe (1985) suggested a thickness of between 200 - 300 meters around Gombe area while boreholes 51/GO and 54/GO both around Gombe Town gave the thickness of the sandstone to be 211 meters and 214 meters respectively.

Groundwater occurs mainly in the soft sandstone and fine gravel to very fine sands. These sandstone form good aquifer with moderate yields.

In the outcrop area, the sandstone is under watertable conditions. The Gombe sandstone dips westward away from the Basement rocks to form subartesian aquifer in the basal beds. The confining strata being the intraformational clays (Du Preez and Barber, 1965). The aquifer characteristics of the sandstone is derived from it's primary porosity and permeability formed during deposition and subsequent modification during compaction.

A total of 125 boreholes were drilled into the sandstone through the Bauchi State Agricultural Development Programme (BSADP) between 1981 and 1985. Fifty-five of these boreholes tap water from very fine sand aquifer of the sandstone, which had to be controlled using a 75 mm thick fine sand pack. In many places within the sandstone, the water bearing zone can only be identified using down - the - hole resistivity profile (Wardrop Report, 1985). The yields from the sandstone aquifer varies considerably throughout the formation. The Wardrop report (1985) gave well yields exceeding 400 lpm and recorded few cases with yields of less than 10 lpm. A particularly poor area within the formation is an area west of Nafada where drilling in a group of four villages was unsuccessful. Borehole No.9 at Gombe Town which taps water from the sandstone aquifer has a test yield of 52.8 lpm while that of borehole No.51 has a test yield of 60.6 lpm. The boreholes have depths of 112 meters and 371 meters respectively.

The Gombe sandstone is recharged mainly at it's outcrop area, directly from precipitation and by infiltration of effluent seepage from streams while in flood during rainy seasons. This is proved

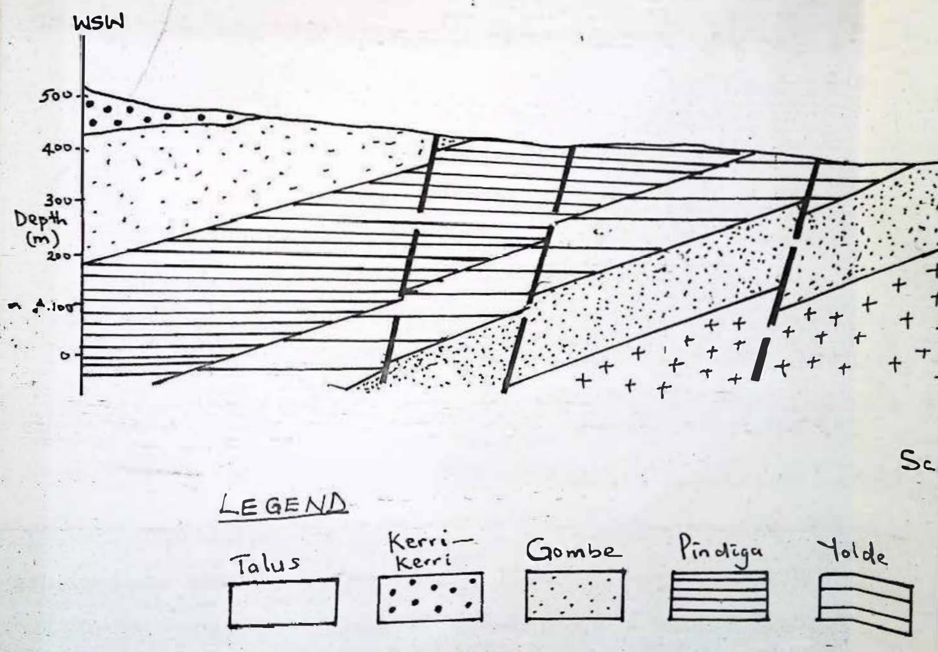

FIG. 6 — Geologic Section of the rocks in th
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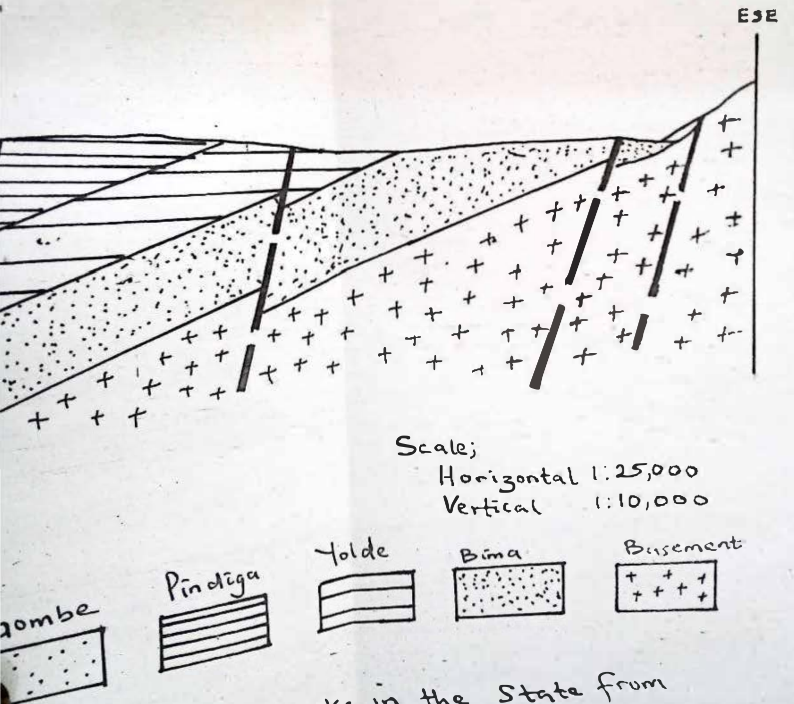

...ection of the rocks in the State from
...a (after Conred Consultant, 1978).

The Gombe sandstone is recharged mainly at it's outcrop area, directly from precipitation and by infiltration of effluent seepage from streams while in flood during rainy seasons. This is proved by the dramatic increase in the levels of water in hand dug wells that tap the aquifer immediately after the rainy season and the drastic drops after the rains stop. Once underground, the water moves west-ward into the overlying kerri-kerri formation.

3.2.4 KERRI KERRI FORMATION (Paleocene)

The Kerri Kerri formation lies unconformably on the eroded surface of the Maestrichtian Gombe sandstone, however, on the western part of the formation, (e.g. around Darazo area) the formation lies unconformably on an uneven surface of the Basement complex. The Santonian folding episode (Burke et al 1971), resulting from compressional forces in the Benue valley which affected the older Cretaceous sedimentary rocks did not affect the Paleocene Kerri Kerri formation. This is evident from the formation's gentle dip to the North-east below the Chad formation.

The formation consist of a wide range of clastic sediments with complex facics relationships deposited under fluvial, deltaic and marginal lacustrine conditions. The lithological association include sandstone, grit, clay and basal conglomerate with clay clasts (Ako and Osundu, 1986).

The sandstone range from fine to medium grained and are moderately well sorted. Carter et al (1963), observed that the formation appears to have derived its materials from a terrain of Cretaceous sedimentary rocks with subdued relief or from the Crystalline Basement rocks to the west of the formation. The colour of the formation vary widely, ranging from white; when the formation is dominated by clay to red, gray and black in sandstone with clay interbeds.

The Kerri Kerri formation was first recognised by Falconer (1911) who named it Kerri Kerri sandstone and believed it to be Eocene in age. Falconer's age was based on an anology, pointing out the similarities between the Kerri Kerri to "Lakoja" and "Sokoto" series then thought to be Eocene in age but which have since been shown to be of Upper Cretaceous age.
Adegoke et al (1978), confirmed the age of the formation to be Paleocene, based on palynological data. The thickness of Kerri Kerri formation is very variable, a thickness of 160 meters is recorded in the borehole 55/60 at Gombe Town while 60 meters is recorded in borehole No.44 at Darazo where the formation is very close to the Basement - rock contact. The variation in thickness may be due to the uneven surface on which the formation was deposited.

The water bearing zones of the formation are fine to coarse quartz sands, fine quartz gravel and lateritic or ironised gravel.

The thick layers of impervious Kaolinites found in the formation greatly reduce the water bearing capability of the kerri kerri. The kaolinite is however traversed by major widely - spaced joints aligned east of north which convey percolating water rapidly downwards from interbedded aquiferous sandstone (Water Survey's report, 1986). In unjointed areas, perched water table occur, while directional jointing causes rapid movement of groundwater to the south-southwest, along the core of a horse shoe shaped trough, to feed major spring at Wikki. It is possible that confined water occurs in the formation where it is overlain by impervious sediment of the Chad formation. The depth to water table varies within the formation, a range of 20 -110 meters was given in the 1985 Wardrop report. Thus change in depth depends on the topography of the area concerned and the drainage pattern. Because of caving problems associated with fine sands forming the Kerri Kerri aquifer in an area north of Alkaleri to Dukkul, 70 per cent of the boreholes completed for BSADP in the area were drilled with mud. In other places air was used.

The aquifer characteristics are derived from Dukkul borehole No. 1 and Chinade borehole No. 2. The boreholes were pump tested for a duration of 1 hour and 2 hours respectively. The yields were 71 lpm and 57.75 lpm from Dukkul and Chinade respectively. The aquifer transmissivity (T) was computed as $4.3 \times 10^{-4}\ m^2/s$ at Dukkul and $7.5 \times 10^{-}\ m^2/s$ at Chinade.

A drawn down of 1.67 meters was observed at Dukkul while 31.19 meters drawn down was observed at Chinade. In some areas, aquifers occur too deep (> 90 meters) making hand dug wells inpracticable. In an area in the vicinity of Dukkul aquifers occur 90 meters below the ground surface which was too deep for hand pump operated wells. Many villages in his area were therefore cancelled out of the borehole project. The Kerri Kerri Formation is recharged at it's outcrop area, directly from precipitation and by infiltration of effluent seepage from streams during the rainy seasons.

3.2.5 CHAD FORMATION (Plio-Pleistocene)

The chad formation comprises lacustrine and fluvital sediments that occupy most of Borno, northern Kano and northern Bauchi states, covering an area of 51,000 squar miles. The formation consists of sands, clays and slity clay and fine gravel, laid down on the floors of Kerri Kerri formation, Fika shale and in some places the Crystalline Basement. It forms a gently sloping featureless plain of a gradient of 1:10,000 (Wardrop report, 1985) which is drained to the north - east into the Chad Basin by the Jama'are River. Laterite cover appears to mark the transition from the Chad formation to the underlying older sediments of Kerri Kerri formation.

The Chad formation was first described by Raeburn and Brynmor (1934) and they named it "Chad Series".

However, since these sediments do not constitute a "Series" in the stratigraphic sense, the name Chad formation was later substituted.

The thickness of the formation varies widely, increasing from zero at the southern edge of the formation to as much as 240 meters on the northern boundary of the state, and thickens to 800 meters near the centre of the Basin (Kogbe, 1981 b). Barber (1965) observed thick consolidated sediments of the Chad formation to cover an extensive area near Azare where they over step the Kerri Kerri formation. At Azare, borehole No.11 penetrate 39.3 meters of the formation with the borehole terminating in the granite bedrock at depth of 49.4 meters. In boreholes the colour of the sediments vary from brown gray to mottled or buff depending on the environments of the sediments penetrated.

Three aquifer horizons have been identified within the Chad formation. They are an upper unconfined aquifer with limited areal extent, a middle confined aquifer with a proved lateral extent of about 20,000 square miles and a lower aquifer found at depths of 470-500 meters and so far has been proved only around the Maiduguri area. Groundwater in these aquifers occur under water-table conditions, in perched aquifers, and as confined and semi-confined water. The water bearing zones are sands and gravels with the piezometric depth ranging from 20 to 50 meters.

Numerous hand dug wells and boreholes tap water from these water bearing zones but in some areas hand dug well yields are low and depths to water excessive. However, borehole supplies depend on penetrating any of the permeable sand or gravel below the water table.

Yields from boreholes are generally good, with most of the boreholes having yields exceeding 400 lpm while only few had yield lower than 10 lpm. Borehole No.1 at Udubo has a yield of 375 lpm while borehole No.1 at Gamawa which is north of Udubo has a yield of 562.5 lpm with static water levels of 24.4 m and 19.7 meters respectively. The Udubo No.1 borehole with a depth of 163 m had a drawdown of 3.2 m after six hours of testing and a calculated transmissivity of 3.4×10^{-4} m^2/sec. Gamawa No.1 borehole drilled to a depth of 285.7 m recorded a drawdown of 0.89m after six hours of pumping and the transmissivity calculated as 3.4×10^{-3} m^2/sec. The aquifer characteristics although quite good in locally variable.

The Chad formation which outcrops in a wide track in the northern part of the state is recharged annually. It is mainly through mordern and fossil alluvnim of defunct and mordern drainage (Water Survey's report,1986), during the rainy seasons by infiltration of effluent seepage from streams and directly from precipitation.

Table 4 - Record of some boreholes Screened in Sedimentary aquifers.

Location	Borehole No	Date of Completion	Total depth	Screen Setting(m)	Screen Diameter(")	Screen Openings	Static water Level (m)	Yield (lpm)	Drawdown (m)	Remark
BIMA SANDSTONE										
Gombe	63/GO	1/4/78	288	189.48-244.82	6"	50	27.2	360	25.33	P
Gombe	64/GO	8/4/78	311	250.92-263.42 262-306	6"	50	17.25	264	36.04	P
Billiri Laushi	3/BI	30/1/79	108	21.3-30	6"	50	33.15	390	5.6	P
GOMBE SAND STONE										
Gombe	9/GO	-	112.2	-	6"	50	49.67	52.8	10.67	P
Gombe	55/GO	-	714	-	6"	50	43	40.2	-	P
KERRI KERRI FORMATION										
Dukkul	1	29/3/77	239.6	192-198 213.4-235.4	4"	50	43.6	63.75	1.67	P
Dukkul	5	7/6/78	297.9	-	6"	50	45.0	90	2.47	P
Alkaleri	1	5/11/77	81	45-49 59-63	6"	50	27.94	262.5	2.06	P
CHAD FORMATION										
Udubo	1	19/5/78	163.1	-	4"	50	24.4	370	3.2	P
Gamawa	1	3/1/78	72.6	-	4"	50	9.82	240	0.89	P

3.2.6 ALLUVIAL DEPOSITS (Recent)

Alluvial deposits are found in valleys of the major rivers in the State. These rivers are the Jama'are which drains the Chad formation into the Chad basin and the Gongola River which drains the Cretaceous and Kerr Kerri Sediments into the Benue river. The sediments consist of gravels, sands, silts and rarely clay with sands, and gravel being medium to coarse grained. The water bearing zones are the sands and gravels. In the largest rivers, the sediments are permanently and continously saturated with perennial subsurface flow, while in smaller ones, saturated alluvim occurs in permanent pockets. In Basement rock areas these alluvial deposits provide the main source of water for local communities. Alluvial deposits on the crystalline terrain are usually very porous and permeable, athough during the dry seasons, the water yields in these areas decline drastically.

Jama'are Town which is located on the bank of the river Jama'are gets it water supply from alluvial sediments of the Jama'are river. Boreholes I and II located near the Jama'are river at Jama'are town both penetrated sand, fine gravels and clay at depths of 41 meters and 39 meters respectively. Johnson 6 inches stainless steel with 20 stots were placed in sand and gravel water bearing zones and then gravel packed in both boreholes.

A yield of 420 lpm was obtained from borehole I while that of borehole II yielded 480 lpm. During the rainy seasons when the river is in flood, the wells which have hydrantic continuity with the river may produce larger yields with small draw down (Water Survey's report, 1986) as the aquifer becomes fully saturated. Recent abandoned river channels characterised by gravels and sands provided secondary source of water and will become a potential source of water supply in the near future.

The quantity of water and the length of time the water is retained in these aquifers after surface flow ceases depend on porosity, permeability, thickness and the areal extent of the alluvim, and also the hydrantic gradient. In many deposits, especially those found along the major rivers in the State, water is retained throughout the year and the quantity may be large. The main disadvantage of alluvial aquifers, lies in the fact that they are usually unconfined, and liable to pollution from the surface.

Recharge is seasonal and stream flow is supplimented by post - rain release of water from silty alluvium.

CHAPTER FOUR

BASEMENT Vs SEDIMENT RY AQUIFER TYPES

4.1 INTRODUCTION

The fundamental differences that exist between basement and sedimentary aquifers arises from the different modes of origin of their parent rocks, and the post-formational events that affect these rocks. The rocks of the Basement Complex are basically hard and with inter-locked crystalline texture due to crystallisation from molten magma or recrystallisation during metamorphism. On the other hand, sedimentary rocks are formed from the products of weathered materials derived from pre-existing rocks such as igneous and metamorphic rocks. The post-formational activities such as tectonism and diagensis that affect these rocks play a major role in determining their aquifer characteristics.

The hard, crystalline Basement rocks normally do not form aquifers, but after their formation, weathering and toctonism can however create openings which act as conduits for water storage and movement. In the case of sedimentary rocks, post-depositional cementation and compaction can drastically reduce the initial porosity and permeability of the rocks. The final differences between these two aquifer types are related to porosity and permeability, depth to aquifers, aquifer thickness and areal extent, and yields from aquifers.

4.2 POROSITY AND PERMEABILITY

The porosity of a rock is the ratio of the void spaces in that rock to the bulk volume of that rock and this is usually measured in percentage. Water can therefore be stored in rocks if there are available void spaces. Such void spaces include crevices joints, fissures, fractures, and solution cavities as well as original pore spaces between grains. The void spaces between the composite mineral grains of sedimentary rocks give rise to primary porosity. In enhancing the aquifer potentials of crystalline Basement rocks, secondary porosity must be created within these rocks. This porosity is due to post-deformational geologic features that affect the rocks. Such features include tectonism, weathering and intrusion. As shown in Table 5, the porosities of these aquifer types are remarkably different. In the Basement aquifers, the porosity is generally low compared to those of sedimentary rocks.

ROCK TYPES	POROSITY (%)		
	Min	Max	Average
Granites, Schist, and gneiss	0.02	1.85	0.8
Slate, Shale	0.49	7.55	3.85
Marble & dolomite	0.53	13.36	4.85
Sandstone	4.8	28.28	15.89
Sand (clean)	26.0	47.0	35.0
Sand (uniform)	35.0	40.0	38.0
Clay	44.0	47.0	45.0

Table 5 - Porosity of Rocks (after Meinzer, 1923)

Another major difference that exists between these aquifer types is in their permeabilities. The permeability of a rock can be defined as the ease with which water can be transmitted through the rock economically. As shown in Table 6, Sedimentary rocks such as clean sands and gravels have high permeabilities while the permeabilities for unweathered clay and Basement rocks are very low.

Hydraulic conductivity, meters/day

10^{4} 10^{3} 10^{2} 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5}

Relative hydraulic conductivity

Very high High moderate Low very low

REPRESENTATIVE MATERIALS

Unconsolidated deposits

Clean gravel - Clean sand and - Fine Sand-Silt, Clay, mixture-

Massive sand and gravel of sand, silt and clay-clay

Consolidated Rocks

Vesicular and Scoriaceous Clean sandstone and [illegible] sandstone-

Massive basalt cavernous fractured igneous and shale, mudstone-

igneous and limestone and dolomite metamorphic rocks meta.rocks

Table 6 - Hydraulic Conductivities for various classes of geological materials (after Todd, 1959)

The low values of porosity and permeability in Basement rocks are directly related to the tight nature of the fractured or jointed rock and the clayey nature of the weathered mantle. This eventually leads to low yields in these rocks.

DEPTH TO AQUIFERS

The depth to aquifers varies widely within the State depending on the terrain and rock formations. In Basement rocks, this depth depends on the density of joints or fractures and the intensity of the weathered zone. A depth of less than 40 meters is typical for Basement aquifers while sedimentary aquifers may be found at depths ranging from 50–500 meter (Master Surveyor's report, 1985 and Table 7)

[illegible]	AQUIFER		
[illegible]	[illegible]	Max. depth(m)	Max. thickness (m)
[illegible]	sand from weathering	–	40
	fractured rock	40	50
[illegible]	sandstone	500	300
[illegible]	–	500	300
[illegible]	sand + sandstone	300	40 – 80
[illegible]	sand + sandstone	200–300	40 – 70
[illegible]	gravel + sand	–	10 – 30

Table 7 – [illegible] aquifer types in Bauchi State with depths and thicknesses

[illegible] borehole project, a depth range of [illegible] obtained in the Basement while [illegible] 150 – 250 meters was found typical [illegible] sedimentary terrain.

4.3 DEPTH TO AQUIFERS

The depth to aquifers varies widely within the state depending on the terrain and rock formations. In Basement rocks, this depth depends on the density of joints or fractures and then intensity of the weathered zone. A depth of less than 40 meters is typical for Basement aquifers while sedimentary aquifers can be found at depths ranging from 50-500 meter (Water Survey's report, 1986 and Table 7)

Geological formation	AQUIFER Nature	Max.depth(m)	Max thickness (m)
Basement Complex	sand from weathering	-	40
"	fractured rock	40	50
Bima sandstone	sandstone	500	300
Gombe "	"	500	300
kerri kerri formation	sand + sandstone	300	40 - 80
Chad "	sand + sandstone	200-300	40 - 70
Recent alluvium	gravel +sand	-	10 - 30

Table 7 - Main aquifer types in Bauchi State with depths and thicknesses

In the BSADP borehole project, a depth range of 15-70 meters was obtained in the Basement while a depth range of 50 - 150 meters was found typical of the Sedimentary terrain.

Using 56 out of the boreholes drilled during the drought relief programme in the State, a depth range of 12 to 66 meters, with an average depth of 29.47 meters was computed for Basement aquifers. For the sedimentary aquifers, a depth range of 20 meters to 81.5 meters and 28 meters to 72 meters were calculated for kerri kerri and Chad formations respectively. The average depthsto aquifers in these formations are 44.89 m for Kerri Kerri while 45.5 meters was computed for the Chad formation.

In the present study, fifty boreholes from the two aquifer types, (Basement and Sedimentary) were studied for comparative purposes. In the Basement rock, the aquifer depth ranged from 14 - 52 meters with average depth of 30.15 meters. In the sedimentary rocks, aquifer depth ranged from 25meters to 262. 10 meters, with calculated average depth of 48.72 meters.

From the above data, the depth to basement aquifers are generally shallower than those of sedimentary aquifers. In basement rocks, aquifers are resistricted to the weathered, fractured and jointed zones usually occupying a relatively thin ($<$ 40 m) upper part of the rocks.

4.4 AQUIFER YIELDS

The water yields of an aquifer depends mainly on it's permeability (tranmissivity), the development of the well and the water storage capacity of the aquifer.

if permeability of an aquifer is high, such as in well rounded, well sorted and clean sandstones, wells tapping such an aquifer generally have high yields. However, water yields from weathered rocks are normally low because of the clayey nature of the weathered mantle. Examples include borehole No.101 in Bauchi and borehole No.1 at Toro both drilled into Basement rocks have tested yields of 71.5 lpm and 51 lpm respectively.

The water storage of an aquifer depends on it's lateral extent and thickness. Most of the sedimentary aquifers in the state are known to be laterally extensive and thick, whereas, basement aquifers are by their nature laterally discontinous. Therefore, water yield from sedimentary rocks in the state are normally higher than those of basement aquifers. Boreholes 63/GO and 64/Go both drilled into sedimentary rocks at Gombe Town gave tested yields of 360 lpm and 264 lpm respectively. When these are compared to Basement aquifer yields it can easily be seen that Sedimentary aquifers generally have more yields than Basement aquifers. Well development is the method adopted after the well must have been drilled to enhance better yield from the well. Since all wells drilled went through development stage, differences in the yield as a result of this development depend on the technique used.

Monton (1975), observed that of 2,500 boreholes drilled in the Basement rocks of Africa, that most of them have water quantity which is not great and only in rare cases will the aquifer produce enough water for large scale irrigation farming. In most cases, boreholes drilled into Sedimentary aquifers have yieldsexceeding 400 lpm although in rare cases yields of less than 10 lpm can occur. In Basement aquifers, the reverse is the case (Wardrop Report,1985). Normally the weathered manlte may form an aquifer of poor quality.

In the present study, fifty boreholes each from the two aquifer types, Basement and Sedimentary were studied for comparative purposes. In the Basement aquifer, the yield range from 3.7lpm to 246lpm from boreholes at Shira No.1 and Darazo No.5 respectively. While values of 101.7lpm from borehole No.3 at Lanzai and 562.5lpm from borehole No.3 at Misau were observed for Sedimentary aquifers. The average water yield computed from borehole data was 143.4lpm and 366lpm for basement and sedimentary aquifers respectively.

These data conclusively demonstrate that sedimentary aquifers in the state are generally more productive than basement aquifers. The low figures for basement aquifers is related to its lower porosity and permeability, and its restricted lateral extent and thickness.

4.5 COST OF DRILLING AND PRODUCING AN AQUIFER

The cost of drilling a borehole in the State depends on many factors but the main onces include the depth of the well, cost of materials and the nature of formation(s) penetrated.

The depth of well is dependent on the level of occurrence of the water bearing zones in the formation penetrated. In Basement terrain, the depth to this zone is generally less than 70 meters, whereas in Sedimentary terrain depths greater than 100 meters occur very frequently. This would then mean that it would cost more to drill into deep seated Sedimentary rocks than into Basement rocks. The cost of material will depend on the type of materials being used for construction and quality of such materials. It was found out that in deep wells, as it's always the case in Sedimentary rocks, more screens and blind casings are required in well construction than will be needed in Basement rocks. The choice of materials include either the use of polyvinyl chlorice (PVC) or Stainless Steel materials as screens or as blind casing.

Where a high water yield is a pre-condition for well construction, the more costly Johnson stainless screens are preferred to the cheaper PVC screens. This is because the Johnson screen are more efficient and can achieve greater yield.

The use of locally crushed gravels to the more resistant, well rounded imported gravels can drastically affect the cost of well construction especially in terms of foreign exchange alhough the use of the later will enhance longer life of the well. It is because of t his cost effectivencess that most boreholes presently being drilled in the state are gravel packed with local gravels.

In well consolidated sandstone formations, it will require more money, energy and time to drill a well than in loosely weathered materials of the Basement rocks. These reasons therefore indicate that boreholes constructed in Sedimentary rocks cost more than those in Basement rocks.

Before the introduction of Second-Tier Foreign Exchange Market (SFEM) it costed ₦5,000:00k more to construct a well in sedimentary formation than in Basement rocks. There is a marked difference in cost of borehole construction in the state. Edok-Eter-Mandilas and Water Board boreholes on average cost upwards of ₦40,000. However the BSADP boreholes project with 1205 successful boreholes costed an average of ₦17,000. This low price was due to the large number of wells drilled, the use of PVC for casing and screens in a majority of these wells, and the fact that completion for village boreholes with hand pumps only needed small water yields to be successful. Also most wells were aborted at depth greater than 90 meters.

The same conditions apply to the present extension of this programme by another programme of 200 village boreholes at estimated cost of ₦3.4 million i.e ₦17,000 per borehole. The cost of drilling wells during the drought relief programme in 1985 may have been cheaper. Since the wells were constructed in emergency to alleivate the water scarcity in the northern part of the state.

4.6 AQUIFER DURABILITY

Aquifer durability is dependent on such factors as well completion method adopted, the maintenance of the well and pollution of the aquifer. Well completion which invōlve such things as placement of screens and Casing, cementation of casing and gravel pack. The choice of material for any of these may determine the life of the well completed into an aquifer. The use of polyvinyl chloride (PVC) screens and casing in the State is to cut the cost of producing boreholes but it is a known fact that with time PVC may be damaged which can then lead to the failure of the boreholes. On the other hand if more water yield is expected and well depth exceed 60m, the more costly steel Casing and the Johnson stainless steel screens are used. This will not only enhance more efficiency of the borehole, it will also lead to increased life vis-a-vis PVC screens and casing.

The maintenance of a well can also go a long way in prolonging it's life span. To achieve this, a good management of the aquifer is necessary. Normally wells in the State are inspected twice a year for maintenance. In some cases wells arbituary break-down due to lack of spare parts for maintenance. The good management of an aquifer will definitely prolong the life of the aquifer. Good aquifer management guards against all forms of surface pollution. The susceptible aquifers are the alluvial aquifers which are usually unconfined, and close to urban and industrial areas of the State.

The yearly recharge of aquifers in the State is very important for long well life. If recharge is less than extraction, artifical recharge should be instituted to suppliment this deficit. If this is not done, mining may result which may eventually lead to the deterioration of these aquifers.

Some wells tappings water from basement and sedimentary aquifers in northern Ghana are still effective after 12 years since completion and development (Mr. Stephen, Wardrop, personnal communication), and may continue to do so for more years with proper maintenance. In the State (Mr. Gabriel, Personal communication), observed that some boreholes constructed in the state during the colonial era (over 20 years ago) are still functioning due to proper maintenance over these years.

During the course of this project, the oldest borehole out of the 100 boreholes examined is No 64 Bauchi borehole which was completed on 18th November, 1976.

This borehole is still functioning today and will probably continue to do so for many years to come through proper maintenance.

CHAPTER FIVE

CHEMICAL QUALITY OF GROUNDWATER IN THE STATE

.1 INTRODUCTION

In recent years it has been found that the chemical quality of groundwater alomost rank in importance with quantity and this is especially true when considering the use of water for domestic, irrigation and industrial purposes. The term "Chemical quality of water" can be defined as the combined physical, chemical, biological and the dissolved solid content of the water.

Since groundwater is never found in its purest state in nature, it becomes imperative to critically examine the chemical qualities of the groundwater found in the different aquifers in the state.

The chemical qualities of groundwaters are controlled mainly by climate, and geological conditions merely cause local variations (Du Preez and Barber, 1965). This is in accordance with Schoeller's (1959) view on the zonation of groundwater in respect of climate, where he showed that bicarbonate waters are produced under temperate and tropical conditions whereas sulphate waters develop under desert conditions. Therefore, the relatively low salinity of the groundwater in the state could be as a result of climate.

With few exceptions, the groundwater in the State is of good quality and suitable for most uses such as drinking and irrigation on all types of soild. The chemical analysis of groundwater from the different aquifers in the State is shown in Table 8 and the detailed discussion of these aquifers follow below.

5.2 BASEMENT AQUIFERS

From available data, the waters from Basement Complex aquifers are calcium or soduim bicarbonate types and most of them contain less than 200 part per million (ppm) dissolved solids. The presence of abundant nitrate in some of these waters is probably due to pollution.

Apart from the pollution harzards, these water are good for drinking, washing, irrigation on all types of soils, and most are suitable for industrial use.

AQUIFERS	BASEMENT		BIMA/ GOMBE		KERRI KERRI		CHAD		ALLUVIAL	
	CONCENTRATION EXPRESSED IN PER PAR MILLION									
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Total Soluble Solids	44	242	92	528	42	116	180	1065	98	180
Magnesium (Mg^{2+})	0.2	5.0	0.2	10	0.4	3.0	1.2	36.5	1.6	3.0
Calciu (Ca^{2+})	1.4	52	1.12	76.55	2.4	14	3.7	70	10	17
Soduim (Na^{+})	3.0	31.4	2.9	144	2.1	6.6	4.0	218	3.1	10.2
Potassuim (K^{+})	nil	13.2	1.0	30.5	2.0	17	2.8	23.2	2.8	5.2
Chlorine (Cl^{-})	0.5	8.0	2.5	44.5	0.4	1.5	3.0	120	2.0	4.0
Sulphate (SO_4^{-2})	nil	nil	nil	140	nil	nil	nil	330	nil	trace
Bicarbonate (HCO_3^{-})	9.2	99.1	6.1	413.5	1.5	10.7	66	354	15.2	41.2
Carbonate (CO_3^{-2})	nil	6.1	nil	nil	nil	nil	nil	13.7	nil	nil
Silica	28	80	2.0	80.5	10	20	22	130	22	24
PH	6.1	8.3	5.3	7.2	5.0	5.7	5.9	8.6	7.1	8.0
Sample No	8		12		4		76		3	

Table 8 - Range of Main Chemical Characteristics

(Modified from Du Preez

5.3. BIMA SANDSTONE

The groundwater from the sandstone is either Soduim or Calcium bicarbonate type containing little or no Sulphate. The dissolved solids range from 184 ppm to 496 ppm while the PH is between 6.1 and 7.2. Samples from wells that penetrated the Bima sandstone are found to be soft, moderately hard and hard in the hardness table. The high salinity of these waters may have resulted from wells penetrating the younger overlying marine Sediments of Yolde and Fika shales.

In terms of uses, the waters are useful for drinking although some of them might have limited use for washing because of their hardness. Generally the waters are suitable for irrigation on all types of soil except when the sodium content is extremely high. As for industrial purposes, their use is limited mainly because of hardness, alkalinity and the high salinity.

5.4 GOMBE SANDSTONE

The analysed waters from Gombe sandstone indicate a calcium bicarbonate - rich type and low in dissolved solids. At Gombe Town, boreholes No. 9 and No.29 tapping waters from the sandstone indicate a PH commonly less than 7 with a bicarbonate concentration of less than 2.0ppm.

Water from the sandstone can be used for drinking, washing and for industrial purposes. In irrigation, the waters are suitable in all types of soils.

5.5

KERRI KERRI FORMATION

Groundwaters from this formation showed a total dissolved solid content of between 110 and 240mgpl (Compagnia report; 1976). The waters show a low Salinity of Sodium - Calcium bicarbonate type, sometimes ferrnginous and high in Carbon dioxide but the chemical quality is generally good. As the aquifer in most places is unconfined, some of it's waters may show high concentration of nitrate which is an indication of pollution. If unpolluted, the waters from the formation are good for drinking, and can be used for irrigation on any type of soil. It's suitability as industrial water is generally very high because it is low in dissolved solid, low in salinity, and PH is almost neutral.

The best known spring in the State, the Wikki spring, emerges from the Kerri Kerri formation. The chemical analysis of the spring water is shown in Table 9. The spring's water temperature is generally higher than normal.

Table 9 - Chemical analysis of Wikki Spring waters (After Du Preez and Barber, 1965)

	p.p.m
Chloride (Cl)	1.0
Fluoride (f)	0.1
S,O_2	18.0
Total alkalinity as $CaCo_3$	11.5
Total hardness as $CaCo_3$	7.5
[illegible] hours)	60.0

.6 CHAD FORMATION

The chemical quality of waters from the formation vary according to the three different aquifer zones. This variation is summarised in Table 10. The waters from the western part of the Calcium - Sodium bicarbonate type and sulphate is usually absent. Some of the waters show concentration of nitrate which is an indication of pollution. They are low in dissolved solids and slightly alkaline because of the moderate PH.

Table 10 - Chemical analysis of water from the Upper, middle and Lower aquifer zones of Chad formation (Modified from Du Preez and Barbar, 1965).

AQUIFER ZONES	UPPER		MIDDLE		LOWER	
	Concentration in per par million					
	Min	Max	Min	Max	Min	Max
Salinity	267	289	194	1065	177	318
Silicar Content	93	130	21	117	9	36.4
PH	6.3	6.5	5.9	7.1	nil	nil
Alkalinity($CaCO_3$)	152	176	98	292	130	130
Total hardness ($CaCO_3$)	73	110	18	320	Soft	
Principal Cations	K^+, Ca^{2+}, Na^+ mg^{2+}		Na^+, K^+ Ca^{2+}, mg^{2+}		nil	
Principal anoins	$B1CO_3^-$, Cl^{2-} SO_4^{2-}, NO_2^{2}		$B1CO_2^{2-}$, SO_4^{2-} Cl^{2-}		nil	

5.7 ALLUVIAL DEPOSITS

Since in most areas, the aquifers are non-confined, the water from these deposits are therefore susceptible to pollution from human, animal and industrial waste. Apart from these harzards, the water from these aquifers are generally low in dissolved solids and usually soft.

They are generally suitable for most purposes such as drinking, washing , industrial usage and for invigation. However, water found adjacent to limestone areas such as Ashaka have high dissolved solid content and their hardness may be fairly high.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The research has confirmed the presence of aquifers in basement rocks, Bima and Gombe Sandstones, Kerri Kerri and Chad formations and as well as in Recent alluvial deposits. While the basement aquifers are laterally and vertically restricted in terms of extent, the sedimentary aquifers are laterally extensive with great thickness. In most places, the Sedimentary aquifers are confined by overlying clay beds as compared to the non-confined nature of the basement aquifers. Existing borehole data suggest that subartesian aquifers are present in sedimentary rocks athough the pressure heads are too small to eliminate the use of hand pumps. The non - confining nature of Basement aquifers aid non - development of artesian aquifers.

In the Basement Complex rocks, fracture zones sometimes yield sufficient waters to boreholes, especially near stream valleys where weathered mantle is very thick. In areas between these fracture zones, the water yield is practically negligible if there is any yield at all.

In the Bima sandstone, the aquifer occurs in the upper part of the sandstone. The lower part; near the Basement is generally clayey, so yield to boreholes are generally low and drawdown high.

In the upper part, the clay content become more abundant as one moved westward and up-dip and therefore yields are considerably reduced.

The Gombe sandstone forms a very good aquifer locally in the State. In its outcrop area, water is obtained through the use of hand-dug wells from perched water - table.

The Kerri Kerri formation has an extensive areal cover in the State. It's aquifer potentials are very high, with most of the boreholes yielding over 400 l.p.m. of water. Very limited water was being tapped from this aquifer prior to the BSADP borehole project. This will soon change as the state's population and industrial development increase. The Kerri kerri aquifer however acts as a potential source of water to numerous hand-dug wells for villages and communities.

The Chad formation which extend through Bauchi, Kano, and Borno states has three aquifer horizons. These are the lower, middle, and upper aquifer horizons athough the lower one has only been proved below Maiduguri town in Borno State.

Generally in the State, the Bima sandstone is the most exploited aquifer followed by Gombe, kerr kerri and Chad formation aquifers. The bias toward the Bima may be due to its large areal extent in the state, its thickness; about 300 meter within the state, and the coarse nature of the sandy zone which has high porosity and permeability.

The least exploited is the Chad formation aquifers. This may be because the formation is mostly resistricted to the extreme northern part of the State where neither Urban population nor industrial development exists. The increasing population and development of this part of the state may soon change this trend. The alluvial aquifer in the state is currently under studies to find our it's aquifer potentials. This will help to determine the usage of it's water for large scale irrigation or as portable water to communities that live along river banks.

The chemical qualities of groundwater in all these aquifers are generally good to excellent. but where exception do take place may be due to local conditions. Most of the waters are bicarbonate type and where excess soduim occurs renders the water invaluable for irrigation. The formation near bedrock contact are usually mineralised with high dissolved solids. This is what happen near the base of the Bima sandstone and the Kerri Kerri - Basement contact west of Darazo town. The chemical quality of water from Recent alluvium is generally good but it is very susceptible to pollutants from human, animal and industrial wastes.

6.2 RECOMMENDATIONS

As suggested by . Dike (1987) good management of the water resources of the state is very imperative. If such a management is set up in the state, it should be enpowered to oversee the exploration and exploitation of these aquifers in the best interest of the state.

Long term planning should be effected such that the life span of these aquifers can be prolonged.

Observation wells which are presently concentrated at Azare in the northern part of the State, should be extended to other parts so that water levels, pressure measurements are made at intervals every year. Exploratory boreholes should be constructed in the eastern part of the State. These wells should be located in such a way as to penetrate most of the Sedimentary aquifers and terminate in the jointed Basement rocks. This will be done primarily to obtain better characteristics of these aquifers, the exact definations of their thickness, contact relationships and transmissivities.

When new boreholes are drilled in artesian or subartesian areas, each well should be provided with automatic shot off devices, demestic water supply facilities and recording flow-meters to measure the quantity and rate of water use from boreholes tapping the various aquifers. Boreholes should therefore not be allowed to flow uncontrolled. In addition chemical analyses of water should be made for all new boreholes.

In the western part of the State where well siting has proved to be very difficult, dam construction on any of the rivers in this area may be the only alternative way of supplying portable water to the people in the area. On the alternative, a system of of boreholes can be drilled into the alluvium of major rivers.

Water is then pumped from these boreholes to these communities through a system of pipe-line network as done for Dukkutown from the Gongola river.

All new boreholes constructed in the State should be gravel packed completely to prevent the common break-down of boreholes in the State. In the alluvial acuifers, wastes should be disposed off far away from the rivers or alluvial deposits. This will prevent the pollution of the aquifers.

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APPENDICE

le 11 - Log of BH No..101 from Bauchi Aquifers- Basement. Edok - Eter Mandilas, 1978

al depth 57.3m, drilling commenced on 10th June,1978 completed on the 18th June.

ithologic description	Thickness (m)	Depth (m)
op Soil	2.1	2.1
and,Clay,and some fine pebble	24.1	26.2
ighly weathered granite	11.0	37.2
oderately weathered granite	11.9	49.1
Slightly weathered granite	8.2	57.3

able 12 - Log of BH No.1 at Liman Katagum (Edok - Eter Mandilas, 1978) Aquifer:-Basement.

Total depth 54m, drilling Commenced on 26th August,1978 and completed on 10th Sept.1978.

Lithological Description	Thickness (m)	Depth (m)
Brown Clay	9	9
Highly weathered granite	12	21
Moderately weathered granite	21	42
Slighly weathered granite	8	50
fresh granite	4	54

Table 13 - Log of borehole No. 63/60([illegible], 1977) in Gombe Town, aquifer in Bima Sandstone.

Total depth 288m, drilling Commenced on and Completed on 1st April, 197[illegible]

Lithologic description	Thickness (m)	Depth (m)
- Sand, medium; dark brown, poorly sorted with round quartz grains	2	2
- Sand, Coarse to very coarse, yellow whitish, well sorted, subangular quartz grains; Subrounded.	15	17
- Sand, Clayey; violet, unsorted, white; subrounded hyaline quartz grain	5	22
- Sandstone, Coarse, white - pinkish, poorly Cemented, fairly sorted; whitish-yellow, subangular quartz grains	6	28
- Sandstone, Coarse, Silty yellow - pinkish, well cemented, unsorted, white - Yellowish, Subangular quartz grains	11	39
- Sandstone, Coarse, whitish - Yellowish, poorly Cemented, well sorted white angular quartz grains.	3	42
- Sandstone, medium, Silty, yellow - violet, fairly cemented, well sorted, white-yellowish, angular quartz grains	8	50
- Sandstone, Coarse, white -Yellowish, poorly cemented, well sorted angular quartz grains	4	54
- Clay and Sand, violet -.yellowish, Subrounded quartz grains and few feldspar	2	56
- Sandstone, Coarse, white Clay, violet-yellowish, poorly sorted white Subrounded quartz grains.	12	68

Table 13 - Log of BH No.63/GO at Gombe Town, continued

Lithologic description	Thickness (m)	Depth (m)
- Sand, Coarse, white - yellowish, well sorted, white-yellowish, subangular quartz grains, few feldspar,pink, hyaline subrounded	12	68
- Sandstone, Coarse, Clayey poorly clayey, Yellowish - Violet, well cemented, unsorted	18	84
- Sandstone, Coarse, whitish, poorly cemented, well sorted, white subangular quartz grains	8	94
	6	98
- Sandstone, with Claystone interbeds, violet to greenish well rounded unsorted	26	124
- Sandstone, wellwith claystone interbeds, greenish, well cemented, unsorted	24	148
- Sandstone, Coarse, white-greenish, poorly cemented, farily sorted, white, hayaline, subangular quartz grains	2	150
- Sanstone with claystone interbeds, green-violet, well cemented,unsorted	13	160
- Sand, medium to fine, white-greenish, fairly sorted,whitish quartz grains	5	168
- Sandstone, clayey, green-violet, fairly cemented	8	176
- Sand, Coarse - Medium, white - greenish, well sorted	18	194
- Claystone and sandstone, violet, well cemented, unsorted	36	230

Fig. 13 - Log of BH 63/GO at Gombe town continued.

Lithologic description	Thickness (m)	Depth (m)
- Sandstone, Coarse, greenish, poorly cemented, white subrounded quartz grains	3	233
- Claystone and sandstone, dark, violet faily cemented, poorly sorted.	7	240
- Sandstone, Coarse, Clayey, violet, white quartz grains	6	246
- Sand, Coarse, whitish, well sorted subangular quartz grains.	9	255
- Sand, medium to fine, with clay, violet, poorly sorted, white quartz grains.	3	258
- Sand, Coarse, subangular white quartz grains.	23	281
- Sandstone, Coarse to find, with silt, grey - greenish, unsorted, subangular quartz grains.	2	283
- Sand, Coarse, white, well sorted, white, hayaline, subangular quartz grains, traces of pyrite	5	288

Table 14 - Log of BH No.5 at Dukku town ; Aquifer, kerri kerri (after Edok-Eta Mandilas, 1978)

Lithology description	Thickness (m)	Depth (m)
- Top soil of reddish clay, silt and small small sand	9.1	9.1
- Medium to Coarse and and some clay stone	7.1	16.2
- Whitish clay with sand	3	19.2
- Medium to coarse sand, pebbles and reddish clay	13.1	32.2
- Coarse sand to fine pebble and whitish clay	47.3	79.6
- Whitish plastic clay with sand	10.0	89.6
- Blackish clay with Carbonaceous material	18.0	107.6
- Alternating layers of gray and blackish clay/sandstone	26.4	134
- Grey Clay	12.0	146.0
- Darkish clay with little lignite	14.0	160.0
- Lignite	1.8	161.8
- Fine sandstone, Grey clay and fine to Coarse sand.	9.2	211.3
- Alternating layer of sandstone and darkish clay	15.2	226.5
- Lignite	0.9	227.4
- Alternating layer of darkish clay and carbon material	7.1	234.5
- fine Sandstone	14	248.5
- Alternating layers of darkish clay and Carbonaceous material	26.2	274.7
- Fine Sandstone	2-1	276.8
- Blackish clay with some layer of Sandstone	21.1	297.9

Table 15 - Log of BH No.1 at Jama'are
after Preussag, 1982

Lithologic description	Thickness (m)	Depth (m)
- Mud, reddish brown over burden	3	3
- Clay, reddish brown	6	9
- Sand, medium to Coarse grained yellowish grey	15	24
- Sand, Clayey, medium to Coarse reddish brown	3	27
- Sand, Coarse, gravelly, reddish brown	6	33
- Clay dark grey	3	36
- Sand, fine - Coarse grained, generally whitish	5	41