APPRAISAL OF SOME ASPECTS OF GROUNDWATER RESOURCES OF BAUCHI AREA, BAUCHI STATE, NIGERIA

BY

ANIYA F.M. UMAR

A Thesis submitted to the Postgraduate School in partial fulfillment of the requirements for the award of Master of Science Geology (Hydrogeology) degree in the Department of Geology, Faculty of Science, Ahmadu Bello University, Zaria, Nigeria

Department of Geology
Ahmadu Bello University
Zaria.

July, 1987

D E C L A R A T I O N

I declare that this Thesis has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree. Information derived from the unpublished and published work of others has been acknowledged in the text.

Signature of Candidate

July, 1987

C E R T I F I C A T I O N

This Thesis entitled Appriasal of some Aspects of Groundwater Resources of Bauchi Area by Aniya, F.M. Umaru, meets the regulations governing the award of the degree of Master of Science Geology (Hydrogeology) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Schoeneich — Date: 3.12.1987
Dr. K. Schoeneich
Chairman, Supervisory Committee

for Michael Woake — Date: 3/12/87
Dr. E. Wozny
Member, Supervisory Committee

[signature] — Date: 7/12/87
Head of Department

[signature] — Date: 9-2-88
Dean, Postgraduate School

D E D I C A T I O N

To my Father and Mother

To late Enock Yohanna and

late Bitrus Alasoh

ACKNOWLEDGEMENTS

Special recognition and gratitutde is due Dr. Schoeneich of the Department of Geography, University of Jos, my Lecturer and Supervisor. He not only read and corrected the manuscript but also accompanied me during the last round of the field work. Any one who has done a project of this type will understand the magnitude of his contributions.

I am indebted to Dr. Ike, the Head of Department of Geology; to Dr. Abbaa, Dr. Okujeni and Mr. Woakes who through their instruction, contributed to my background in Geology; and to all other lecturers in the Department who helped me in various ways. I am grateful in particular to Mr. Woakes who offered useful suggestions during the work and also read and corrected grammatical errors in the manuscript. I thank Dr. Mudiare of the Department of Agricultural Engineering whose excellent lectures increased my knowledge in Hydrology.

I wish to express my appreciation to my employer, Abubakar Tafawa Balewa College, Bauchi, through its financial support this work become possible.

Data on boreholes with hydrogeological observations, chemical and bacteriological analyses of water samples and general information on the Gubi Dam and water supply scheme of Bauchi town were all received from the Bauchi State Water Board (BSWB) through the use of their files, reports and oral interviews. Great acknowledgements are due in particular to the geologists and water engineers of the BSWB. The Bauchi State Agricultural Development Programme (BSADP) provided additional data on boreholes. Climatological data were received from the meteorological section of the Bauchi Airport and population figures were made available by the National Population Bureau, Bauchi.

I must mention with gratitude Askira, Jude and Nuhu my colleagues in geological fraternity with whom we discussed a variety of wide ranging geological and non-geological topics.

I thank especially, Mr. and Mrs. Baru, Doris, Ezekiel, Vincent, Enock, Edward, Lamech, Bitrus, Santaya, Esther and many others who assisted me in different ways.

Finally, but most importantly, I thank God Almighty and the Father of our Lord Jesus Christ.

A B S T R A C T

Fractured crystalline rocks and the overlying overburden, which is derived mainly from the in-situ decomposition of the former, are the two types of geologic environment in which groundwater occur in Bauchi area. The overburden is the most important and its thickness varies from 0 to about 75 meters.

Groundwater table elevation ranges from less than 533 to about 655 meters above sea level.

Transrnissivities of the overburden vary from place to place and range from about 1.03 x 10^{5} to 1,6 x 10^{-4} m/s. Estimates of the permeabilities of the overburden also vary and range from about 214+ x 10^{-7} to 5.86 x 10^{-6} m/s. Yields of boreholes vary greatly from 1.4+ to 29.50 m^3/h, specific capacities of boreholes lie between 0.06 to 2.32 m^3/h/m with a mean of 0.65 m^3 /h/m.

Principal ions in the water are calcium and bicarbonate. The water is generally hard; it is suitable in chemical quantity for drinking, irrigation and some industrial purposes. Faeces from pit latrines and septic tanks placed below ground surface are the main sources of groundwater contamination.

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A B B R E V I A T I O N S

ABU ... Ahmadu Bello University

BSADP ... Bauchi State Agricultural Development Programme

BSWB ... Bauchi State Water Board

gph ... Gallons per hour

HQ ... Headquarters

K ... Permeability

km^2 ... Square Kilometers

m ... meter

masl .... meters above sea level

mg Eq/L .. Milligrams equivalent per Liter

mg/L ... Milligram per liter

m^3/h ... Cubic meters per hour

min ... minutes

ml ... Milliliter

mm ... millimeter

MPN ... Most Probable Number

m/s ... Meter per second

m^2/s ... Meters Squared per second

M.Sc. ... Masters of Science

Q ... Yield

r ... Correlation Coefficient

S ... Storage Coefficient

SAR ... Sodium Adsorption Ratio

SWL ... Static Water Level

T ... Coefficient of Transmissibility.

A B B R E V I A T I O N S (CONTD.)

TDS ... Total Dissolved Solids

US or USA .. United States of America

WHO ... World Health Organization

WRECA ... Water Resources and Engineering Construction Agency

% ... Percent

^{o}C ... Degrees Centigrade

π ... Pie or 3.14

INTRODUCTION

1.1 Purpose of the Work

Bauchi is the capital town of Bauchi State in Nigeria. The population of the area has increased from 61,673 in 1963 to about 129,213 in 1986. The growth in population and industry has increased demands on the water resources of the area.

The purpose of this work, although primarily a research project in the partial fulfilment of a Master of Science Degree in Geology, Ahmadu Bello University, Zaria, is also intended to aid the planning, development and management of the groundwater resources in the area.

1.2 Scope of the Work

The scope of the work includes the collection of field and available data and the analyses of data obtained to define the occurrence, distribution, movement, availability, quality and use of groundwater in Bauchi area. The existing water supply scheme in the area has also been surveyed and summarised in this work.

1.3 Field Work

Three separate field trips were embarked on during the course of the study. The first involved the location

of some of the boreholes drilled in the area; this was done in August, 1986. The selection and location of 57 suitable hand-dug wells and the measurement of water levels in them at the end of the rainy season (that is end of October and beginning of November, 1986, respectively), was carried out during the second round of the field work. The third round of the field work included the measurement of water levels in these hand-dug wells about the end of the dry season, and the mapping of aquiffers; this was done during the first week of April, 1987.

1.4 Borehole Numbering System

All the boreholes given in appendix VIII are numbered with prefix. Examples are A-8, Ag - 1, BA - 24, Fg - 1, NE - 7, NW - 7, P - 4, and U - 2. The prefix A means Army barracks; Ag, School of Agriculture; BA, Bauchi; Fg, Federal Government Girls College; P, Polytechnic; and U, University. NE and NW means north-east and north-west of sheet 149 respectively. Thus, borehole NE - 7 refers to the seventh borehole drilled in the area covered by the north-eastern part of sheet 149; such boreholes were drilled by the BSADP under its rural borehole programme.

The boreholes numbered with prefix BA belong to the BSWB while others belong to the respective institutions or establishments where they were drilled.

1.5 Scale of Presentation

The isopach map of the overburden (figure 6), map of aquifers and location of water intakes (figure 7) and maps of configuration of water table (figures 9 and 10) are presented on a scale of 1:50,000. The geological and hydrogeological sections (figures 6 and 11 respectively) have horizontal scale of 1:50,000; but the vertical scale have been exaggerated.

The structural map of part of the study area with an original scale of 1:50,000; the graph showing the effect of climate on fluctuations in water levels in an observation well, figure 2; and figure 8 showing fluctuations in water levels in two other observation wells, were also reduced from their originally drawn scales to fit in the A4 size paper. The scales of other figures were selected for convenience in presentation.

1.6 Previous Work

One of the first geological investigations in Bauchi area was carried out by Bain (1926). He described the rocks in general terms as a "gneissose granite

complex containing remnants of still older gneisses". He gave detail descriptions of some of the rock outcrops in Bauchi and its surroundings.

Up to the year 1948, water supply for Bauchi town was obtained from about a hundred hand-dug open wells, Schroeter (1974). Owing to the need for improvement in water supplies, the Geological Survey of Nigeria drilled the first borehole in Bauchi in 1948.

Tait (1957) investigated sources of water for the Nigeria Railway Corporation. Test pits around the railway station area showed groundwater at depths of 4.6 to 5.9 meters. He then suggested a borehole supply in the area. In what seems to be a follow up of Tait's work, Cole (1959) carried out a resistivity survey to the south and south-east of Bauchi town determining depths to unweathered rock varying between 14.6 to more than 45.7 meters. On the basis of this, he proposed a plan showing the location of four boreholes.

Pearson (1966) writing on the additional water supply for Bauchi town, divided the area into three small basins - Shedawanka to the north-west, Barkumbo to the north-east and Tambarin to the south of Bauchi town.

In what can be described as the first detailed hydrogeological investigations of Bauchi town, Schroeter (1974) identified the main aquifer to be the weathered mantle material which is developed on the crystalline rocks. He also produced two maps, one showing depths to water table in the Old Township area and the other showing relief of groundwater table and directions of groundwater flow. The configuration of relief of water table produced in this study is similar to that of Schroeter. Schroeter's work covered only the Old Township area and the immediate surroundings which is only about 20 percent of the present study area. Ine lack of sufficient available data and the relative low demand of water at the time seem to be the limiting factors in his areal coverage and to the scope of his work.

Edok - Eter Ma..dilas Ltd. (1976) carried out hydrogeological and geophysical investigations of Bauchi area for the BSWB. The report contain some hydrogeological cross-sections from results of resistivity surveys, and the structural map of the area drawn from aerial photographs. The average depth of the overburden in Gudum area south of Bauchi town was given as equal or less

than 20 meters. The average thickness of overburden material in the Tambarin Valley was reported to be approximately 35 meters, and greater or equal to 35 meters in the northern part of Barkumbo Valley. An average depth of 23 meters for the overburden in the study has been proposed in this work based on logs of boreholes.

The most recent published results of geological mapping of Bauchi area is that of Eboral (1976).

CHAPTER 2

PHYSIOGRAPHIC FEATURES

2.1 Location and Areal Extent

The location of the study area, Bauchi and its surroundings, is shown in figure 1. Its coordinates are 10^{o} 15' N to 10^{o} 26' 30.1" N and 9^{o} 43' 38.3" E to 9^{o} 54' 13.8" E. It covers 420 km^2 on the topographic map 1:50,000 sheet 149 Bauchi NW and NE.

2.2 Relief

The area is characterised by a hilly topography. Elevations range from 533 to 783 meters above sea level.

Hills may be isolated with conical, elongate or irregular shapes. Others occur in a chain forming a ridge with a serrated outline.

Flattish and gently sloping lands lie between the hills. Outcrops of crystalline rocks occur scattered throughout the area and along some stream courses.

The Barkumbo Valley North-east of Bauchi town lies between two roughly parellel bedrock ridges with a NE trend.

2.3 Climate

Bauchi lies within the Sudan Savanna region. The main characteristic climatic feature is a division of

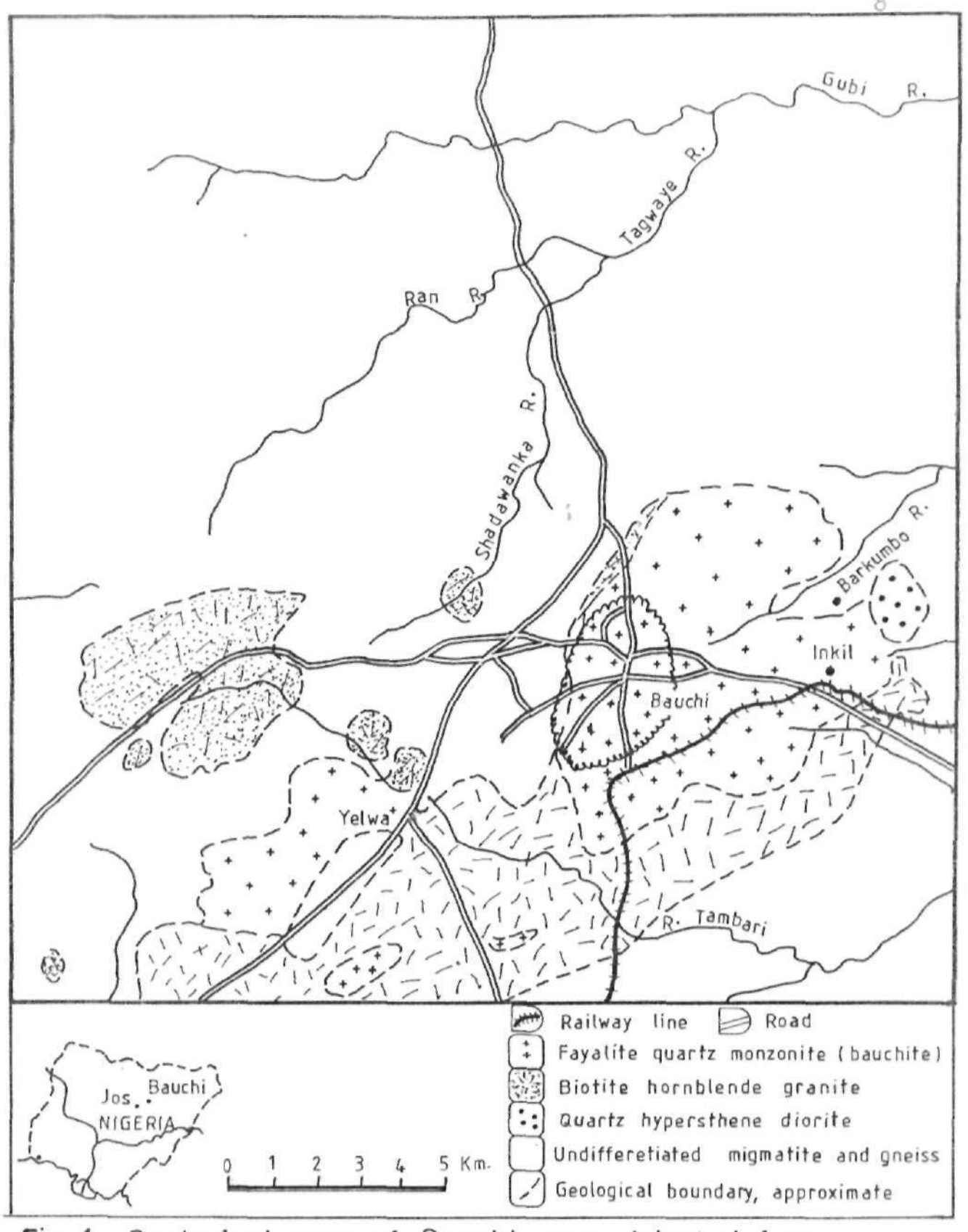


Fig. 1 Geological map of Bauchi area. Adapted from M. I. Eborall (1976).

the year into two seasons, the wet and dry seasons.

Rainfall occurs from mid April to October. The peak of the rainy season during which more rain fall occurs is July and or August. The distribution of monthly total of rainfall (for three years 1979 to 1981) at Bauchi Airport Meteorological Station is shown in figure 2. Figure 3 is the histogram of distribution of mean monthly rainfall for ten years from 1976 to 1985. Also detailed records of rainfall for the same period are given in appendix 1. The mean total annual rainfall for a ten-year period (1976 to 1985) is 932.24 mm.

Typically large variations in annual rainfall may occur from year to year for a given place. For example, at the Bauchi Airport where average rainfall for ten years is 932.24 mm, only 779mm and 725.6mm rain fell in 1983 and 1985 respectively.

Yearly extremes in temperature range from 11.5^{o}C at night during the cold harmattan season to 38^{o}C during the day in April and May. High temperatures occur between mid - February and May and temperatures are low during the cold harmattan season from mid - November to mid - February. The distribution of monthly

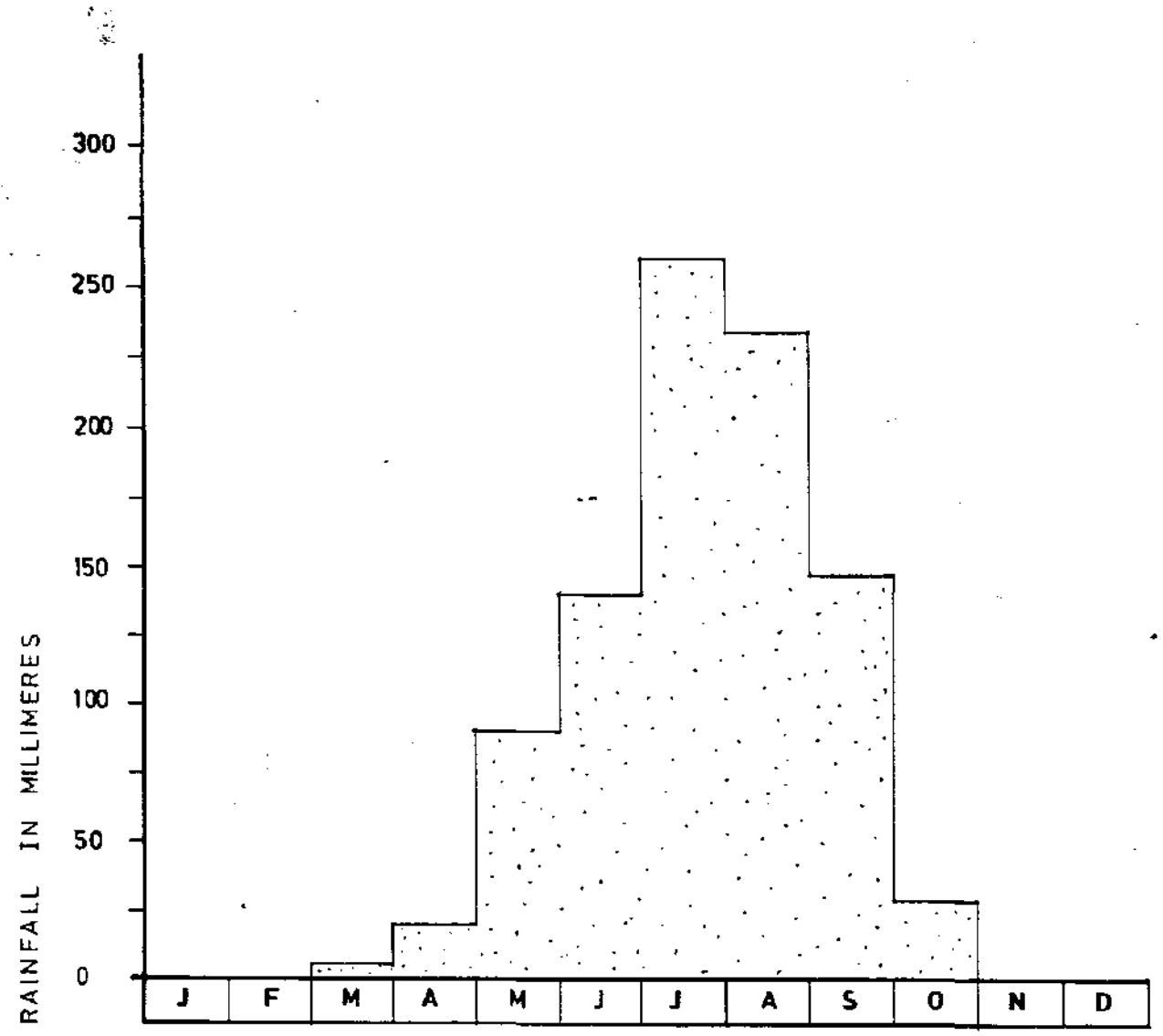


FIG. 3 HISTOGRAM OF MEAN MONTHLY RAINFALL IN MILLIMETRES AT BAUCHI AIRPORT FROM 1976 TO 1985.

means of minimum and maximum temperatures recorded at Bauchi Airport for the period 1979 to 1981 is shown in figure 2. Appendices II and III contain records of monthly means of maximum and minimum temperatures respectively from 1976 to 1985.

Evaporation is the process by which water passes directly into the vapour state. It can occur from water surfaces and from transpiration from vegetation. The total loss of water from evaporation and transpiration from land surface and its vegetation is called evapotranspiration.

In Bauchi, evaporation rates are high particularly during the dry season. Daily water surface evaporation obtained from the U.S. Class A Pan raised above ground surface ranges from about 5.28mm in July to about 14.20 in May. The distribution of monthly means of daily water surface evaporation for a period of three years is shown in figure 2.

Eagleson (1970) observed that potential evapotranspiration is closely achieved from measurements using shallow evaporation pans. Potential evaporation is the amount of water loss due to evaporation and

transpiration when supply of water is unlimited. The record of water surface evaporation from pan measurement is given in appendix IV.

2.4 Drainage

Drainage is dendritic in pattern. The streams flow radially from two main elongate water-sheds; one from Bauchi to Miri and the other from Miri to the north of Miri. Thus the two water-sheds form an L-shape with its corner at Miri.

The main streams in the area are: the Tambarin which flows from the south-west to the north-east corner of the map area; the Barkumbo north-east of Bauchi town; the Shadawanka and Ran meet to form the Tagwaye; and the Gubi which runs from the north-west to the north-east of the area. Both the Gubi river and Tagwaye discharge into the Gubi Dam. These streams are all perenial but their head courses and smaller tributaries are dry during the dry season.

2.5 Vegetation

The vegetation is of Sudan Savanna type, generally devoid of thick forest but consists of grass, shrubs and scattered trees. Shrubs form the dominant vegetation.

The trees and shrubs are generally few and smaller on hills and their slopes. Grassy vegetation persists throughout the year in stream valleys where moisture is always available.

2.6 Geological Setting

Bauchi and its surrouncings is situated on the basement complex of Nigeria, made up of crystalline rocks. The complex consists almost entirely of granites, diorites, bauchites, migmatites and gneisses. Their distribution is shown on the geological map of the area in figure 1.

The oldest rocks of the area are the gneisses and Older Metasediments believed to be Birrimean in age. Oyawoye (1970) and McCurry (1976). Through the processes of metamorphism, migmatization and granitization that took place during at least two tectono-metamorphic cycles, the rocks were largely converted into migmatites and geisses with some relics of the original gneisses McCurry (1976). The basement complex was later intruded by a series of intermediate and acid plutonic rocks during the Pan African Orogeny (McCurry 1976). These plutonic intrusions form what is now known as the Older Granites.

The volcanic rocks which intruded some parts of Northern Nigeria after the Pan African Orogeny slightly affected this area. This is indicated by the presence of basalts encountered at depths of 47.2 and 30 meters in boreholes BH 102 (Bigi) and NE-1 (BSADP premises) respectively. Also some boreholes logs quote among other things "basic rock", "mafic dyke", "weathered mafic rock". These 'basic' or 'mafic' rocks are probably basalts. The possibility of basalt intrusions is even greater when the fact that the neighbouring Jos Plateau, an area with a series of volcanic intrusions, is taken into consideration. The basalts are not seen exposed on the surface.

Fractures within the rocks probably developed during the early tectonic cycles that affected the basement complex and during the tectonics related to the granite and basalt intrusions and during the cooling of these intrusions.

Recent alluvium, resulting from the weathering and erosion of hills and decomposed rock material developed in-situ on the basement complex, cover a larger part of the crystalline basement complex.

CHAPTER 3

GROUNDWATER RESOURCES

3.1 Types of Aquifers

There are two main types of aquifers in the study area, fractured crystalline rocks and weathered crystalline rocks (overburden) which overlie the crystalline rocks.

3.1.1 Fractured Crystalline Aquifer (Primary aquifer)

Fractured crystalline rocks underlie all parts of the area. The rock types that form the crystalline basement and their occurrences are shown on the geological map of the area in figure 1. The greater part of the crystalline rocks are buried beneath overburden material. The crystalline rocks can be encountered in drilled wells or hand-dug wells at variable depths. Outcrops of these fresh rocks may occur as flat masses on the surface, in some stream channels or as hills..

The capacity of the crystalline rocks to store, allow movement and yield water chiefly depends on the extent, pattern, size, openness and continuity of the fractures and the degree to which these fractures are hydraulically connected. Tabular water bodies which

fill fractures vary in thickness and may just be filaments of water which are usually of supercapillary size and subject only to rapid flow. The character of the fracturing in crystalline rocks is determined by the physical properties of the rock and the geological processes or phenomena that have acted upon them.

Fracturing in the study area is due to jointing, faulting and shearing probably associated with the Pan African orogeny and the late intrusions of volcanics into the basement and their subsequent crystallization. These processes can result in the formation of both surficial, shallow and deep fractures.

Fracture permeability decreases with depth as joints, faults and other fractures close due to the weight of overlying material (Davis and DeWiest, 1966). Freeze and Cherry (1979) have pointed out that rocks maintain much of their brittle character to depths of some kilometers below the surface and therefore fracture permeability can exist to great depths. Evidence commonly quoted is the flow of water into some mines and tunnels at great depths and large enough to supply water to wells in some cases. Freeze and Cherry (1979) went on further to declare that "in crystalline rocks

dry mines are the exception rather than the rule".

Fractures in impervious rocks control the permeability of the rock and Hilchie (1978) estimates the permeability of fractures to be a function of fracture width, that is:

$$K = 50{,}000{,}000 \times (\text{width})^2$$

K = Permeability in darcys and width in inches.

This estimate of fracture permeability indicates the reason why fractures though contributing only a small porosity, can completely control water movement.

Most of the fracture zones are usually buried beneath the overburden material from which it mainly receives its recharge, and it requires more detailed methods of geological investigation in order to delineate them. Figure 4 is a structural map of some part of the study area showing the major fractures within the crystalline basement. The map was plotted from aerial photographs taken in 1963. The map shows that the basement generally has a low percentage of fractures although zones of highly fractured rocks occur. Four main directions of fracturing can be discerned: NNW - SSE, NNE - SSW, one approximately N - S, and the other SW - NE direction.

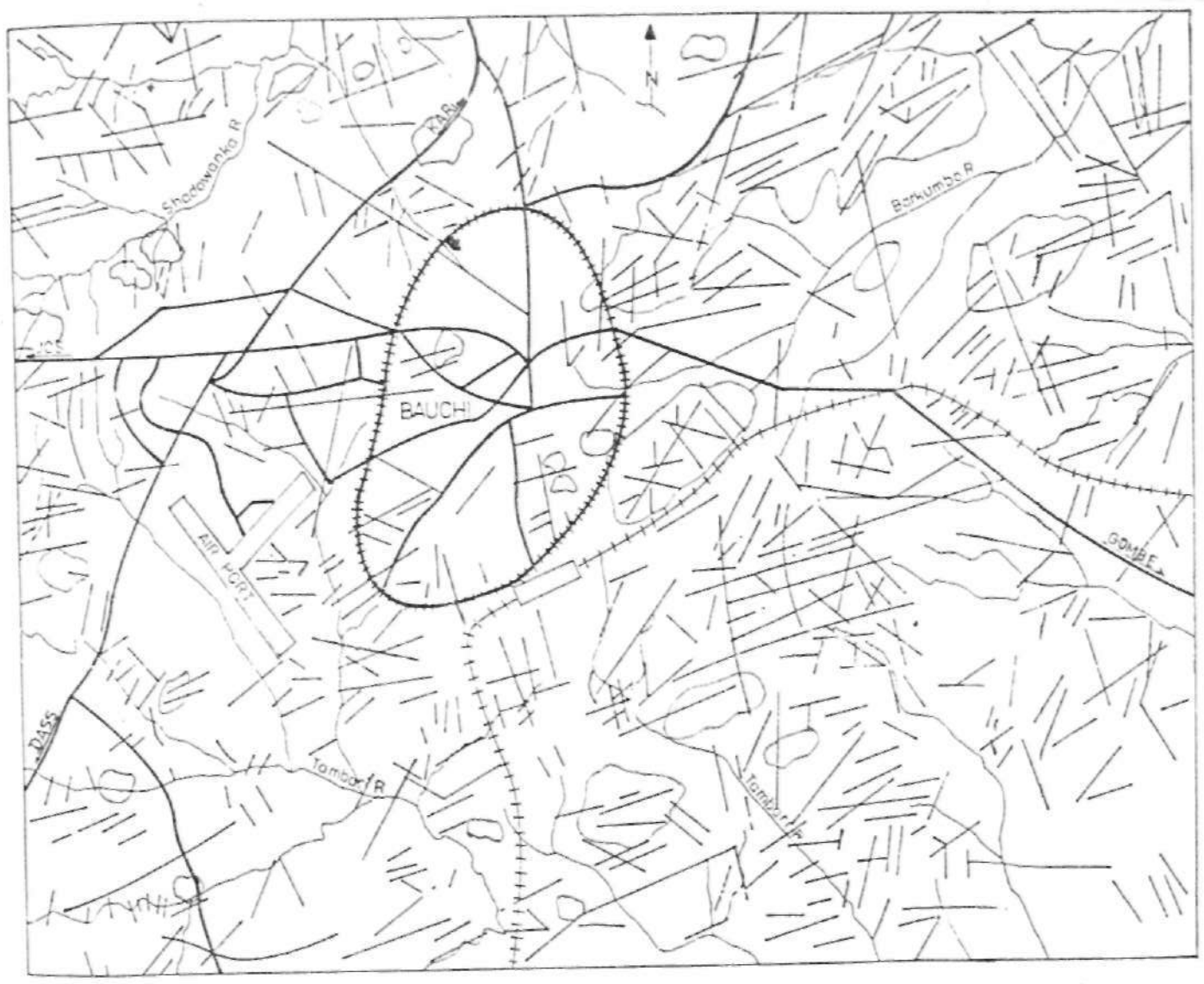


Fig. 4 Structural map of Bauchi area
(plotted from air photos)
Adapted from Edok – Eter
Mandilas Ltd. (1976).

Boreholes that penetrate the zones of fractures will have increased yields. Borehole BA 21 taps water only from the crystalline rocks and has a yield of 13.64 m^3/h.

In general, however, yields of wells in crystalline rocks are low and when they have high yields, the yields often decreases quickly with time; usually the cause is insufficient storage of groundwater near the well (Davies and Dewiest 1966).

The occurrenc e and distribution of the fractured crystalline aquifer at the surface and at shallow (inferred) depths is shown in figure 5.

3.1.2 Overburden (Secondary) Aquifer

This unit consists mainly of in-situ decomposed crystalline rocks. At shallow depths, the in-situ decomposed rocks are characteristically clayey, brown to reddish brown ferruginous and lateritic. They are fairly dense but not cemented and usually have some dessication cracks. The decomposed rocks overlie the crystalling rocks and are largely covered by a thin layer of surficial material consisting mainly of sands, gravels, silts, clays and local inter-mixes of these materials. These materials were derived from the

weathering of adjacent hills; the weathered materials were transported and deposited in lower lands and stream valleys. The thickness of these surficial materials range from zero to about three meters but may reach considerable depths in some few areas. Because of its small thickness, it will be considered together with the in-situ decomposed rocks as one water bearing unit, that is the overburden aquifer. The overburden can therefore be described as a secondary aquifer since its materials are derivatives of the crystalline rocks or primary aquifer. The geological section showing lithological units of the overburden layer is shown in figure 6.

The occurrence and movement of water in the overburden depends on its thickness, the severity of decomposition and the hydraulic characteristics of the materials that constitute it. The degree of decomposition is largely a function of fracturing of the parent rocks and to some extent on the mineralogical composition of the parent rocks. Because of the areal variation in the degree of fracturing and mineralogical composition of the parent rocks, the hydraulic characteristics of the resulting overburden aquifer vary from place to place.

Fracture zones in crystalline rocks are areas of more weathering than unfractured areas. Thus the overburden developed in-situ in fractured zones will have higher permeabilities and boreholes sited in such areas will yield more water. Correlation of the structural map figure 4 and map of location of boreholes figure 5 (both on a scale of 1:50,000) show that 18 boreholes are located on fractures and have an average yield of 11.79 m^3/h while 42 boreholes are not located on fractures and have an average yield of 7.32 m^3/h. Examples of the boreholes located on fractures are BA 2, BA 20, BA 24, BA 53, BA 64 and BA 70 (with yields of 12.55, 15.91, 15.91, 12.20, 11.37 and 9.51 m^3/h respectively).

The overburden, though a secondary aquifer, is the major source of groundwater in the study area and most of the boreholes so far drilled are completed within this unit. The overburden forms small groundwater basins which are isolated between underground domes and ridges and which outcrop as fresh rocks. Depths to unweathered bedrock (thickness of the overburden) vary from place to place and range from 0 to 75 meters. The average thickness of overburden material from the logs of 34 boreholes which penetrated the unweathered rocks is about 28 meters. Average values

of 30 to 40 meters in "drift covered basement rocks" in Nigeria has been reported by Faniran (1972). The isopach map of the overburden is shown in figure 7. The map was drawn from records of borcholes that penetrate the crystalline rocks and those completed within the overburden. In drawing the map, hills were regarded as outcrops of crystalline rocks where there are no overburden cover. The boreholes (whose records were used in constructing the map) are few and not evenly distributed. Therefore the map is only a first approximation.

Saturated thickness of the overburden varies in response to fluctuations of the water table. The whole thickness of the overburden may be saturated in some places, like marshes, during the rainy season.

Yields of wells are variable and depends on the thickness of the overburden and its hydraulic characteristics. The yields of boreholes completed within this unit range widely from 1.14 to 29.50 m^3/h with an average of about 8.1 m^3/h. A limited number of high yields have been obtained in some boreholes. For example, borehole numbers BA 82 located in the Barkumbo Valley has a yield of 29.50 m^3/h (6490 gallons per hour) and

BA 15 around the Airport area has a yield of 22.73 m^3/h (5,000 gallons per hour).

84 boreholes have drawdown data. The drawdowns in the boreholes vary greatly and range from 3.14 to 36 meters. Of the 84 boreholes, 34 have drawdowns between 0-10m, 40 have drawdowns ranging from 11-20m, 9 have drawdowns varying between 21-30m and 4 have drawdowns greater than 30m.

The distribution of the overburden is shown in figure 5. They are more extensive to the southern and north-western parts of the study area.

3.2 Recharge and Movement of Groundwater

The aquifers are recharged mainly by infiltration directly from rainfall. The amount of recharge depends on the permeability of the materials at the ground surface, vegetation cover, intensity of rainfall and on the moisture content of the materials infiltrated.

Discharge from the aquifers occurs naturally through springs, some stream courses and by evapotraspiration where the water table is at or near the land surface. Discharge also occur at cliffs of quarry sites and to wells and boreholes in many places.

The general directions of groundwater flow in saturated parts of the overburden aquifer can be determined by water table contours. Groundwater flows in the direction of decreasing head; that is from areas of recharge to points of discharge as streams, springs and wells. The directions of groundwater flow are indicated by arrows, see figures 9 and 10.

3.3 Water Table

The water table is the level at which water stands in wells and boreholes that penetrate the zone of saturation. In fractured impervious rocks the water table is the surface at contact between the water body in the fractures and the overlying ground air that projects into the fractures to the water - air contact. The water table is interrupted by the impervious rock between the fractures. Interconnections in fractures may extend over large areas or the water in a single fracture may be disconnected with the water in adjacent openings.

Figure 2 shows a hydrograph of water table in an observation well, BA 65 located in Gudum area. Fig. 8 shows hydrographs of water table for two observation wells BA 116 and BA 79 located in Bigi and

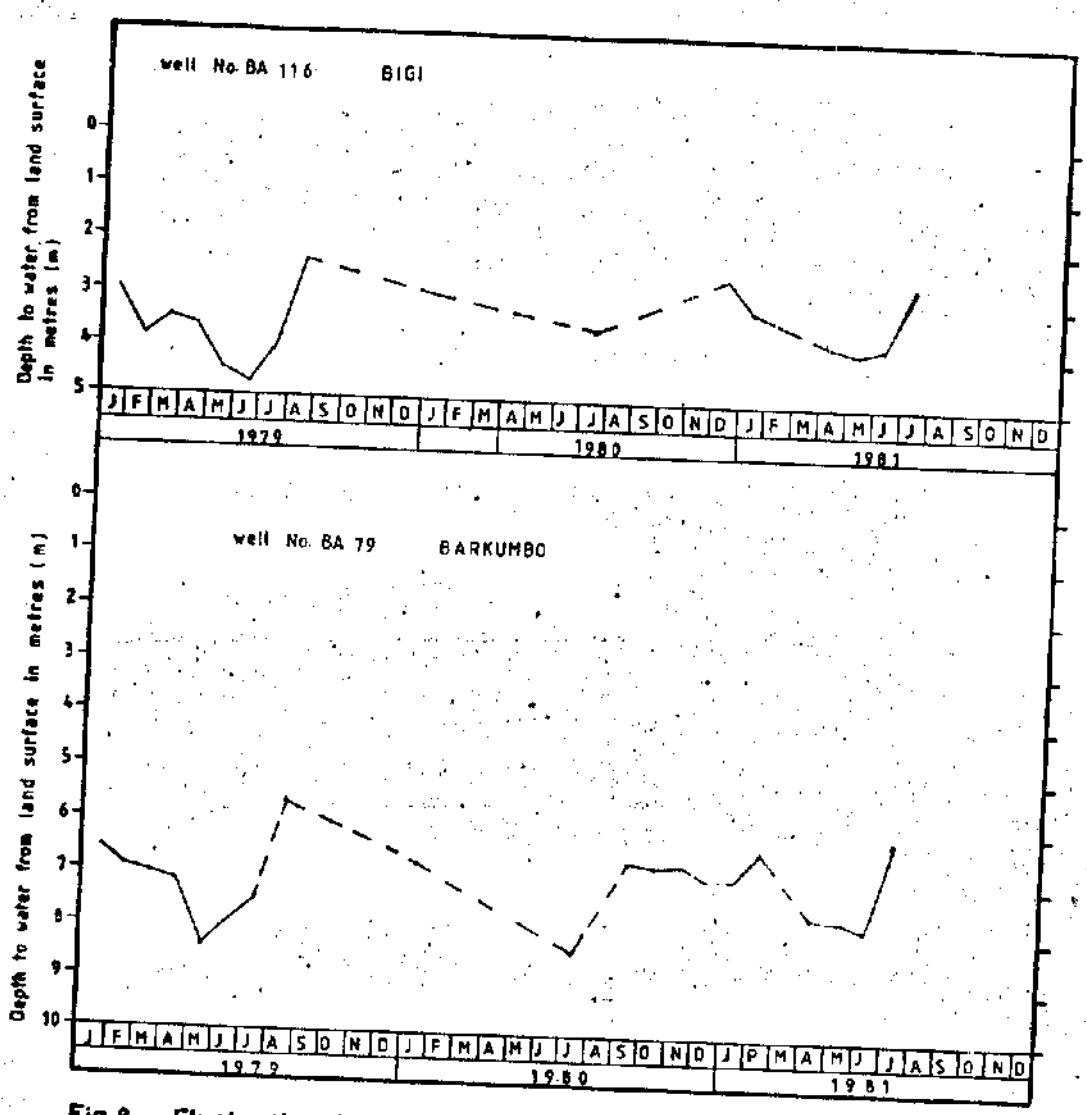


Fig.8 Fluctuation in water levels in two Bauchi State water Board observation wells.

Barkumbo Valley respectively. Fluctuations in water level in BA 65 are large compared to those in BA 116 and BA 79. Fluctuations of hydrograph give a general insight into the drainage and storage capacity of the aquifer. Large fluctuations are generally associated with small storage capacities and large unsteady subsurface flows, while small fluctuations point to large storage capacity.

In general water level rises with increase in precipitation and declines with decrease in precipitation. The water table does not respond immediately with on set of rains in this area, see figure 2. The first rains at the beginning of the wet season, April and May and sometimes early June do not appear to affect the water table especially in some areas where it is deep (see figure 2). This can be explained thus: infiltrating water from precipitation has to percolate to join the groundwater and for the water level to start rising percolation rate must exceed rate of drainage from the aquifer.

Measurements in hand-dug wells (appendix V) and in observation wells (appendix VI) show that the water

table in Bauchi area is generally shallow below ground surface and it ranges from less than one meter in the rainy season to about 11 meters in April. When referred to sea level, the water table elavation ranges from about 533 to about 655 meters above sea level. See figures 9 and 10 for maps of water table at the end of the rainy seaoson and dry season respectively.

3.3.1 End of rainy Season

The water table map at the end of the rainy season is based on the static water levels in hand-dug wells measured at the end of October and beginning of November (1986) and on the surface altitudes of stream channels. Water levels measured in boreholes, at the time they were drilled in previous years, were also used in drawing the map. In this case only boreholes that were drilled in October or November, were used. This consideration is based on the assumption that fluctuations in water level from year to year at a given place and time is small.

Figure 11 is a hydrogeological cross section showing the two aquifers in the study area and the position of water table at the end of the rainy season.

The section also shows that the water table is a subdued version of the land surface.

3.3.2 Dry Season

Water levels in hand-dug wells measured in April range from 1.5 to 11 meters below ground surface. The water table map is shown in figure 10. The map is based on the water levels in hand-dug wells measured during the first week of April 1987 and the surface altitude of stream channels whose courses contain water. It is also based on the fact that the water table is relatively shallow in stream valleys or channels.

In both water table maps contours across hills are broken because of the uncertainty of whether or not the fractures within the crystalline rocks contain water.

CHAPTER 4

AQUIFER AND BOREHOLE CHARACTERISTICS

4.1 Aquifer Test

In the majority of boreholes so far drilled in Bauchi area the only available data for evaluating aquifer performance are yield and drawdown. Pumping test records are available for twenty-one boreholes completed within the overburden aquifer. The results of these tests have been used to estimate some hydraulic characteristics of the aquifer.

No observation wells were constructed or used for the purpose of the pumping tests and all measurements during the tests were taken within the pumped boreholes.

In some of the boreholes tested the pumping test was carried out in a single - stage, some were in three stages while others were in four stages.

A single - stage pumping test is one during which a constant yield is maintained throughout the duration of the test. A three - stage pumping test is one during which three yields are used. Thus the test is started with a small yield and held constant for, say, one hour; the yield is then increased and also held

constant for another, say, three hours after which the yield is increased for the second time and kept constant to the end of the pumping test. For a four - stage pumping test, the above procedure is carried on to a fourth quantity of yield.

In all the test, the duration of pumping was short and range from one hour to 8 hours.

4.2 Aquifer Characteristics

The hydraulic characteristics (or aquifer characteristics) depend on its ability to transmit and store water and is defined mainly by three quantities namely: Coefficient of Transmissivity (or Transmissivity) Coefficient of Storage (or Storativity) and Coefficient of Permeability (or Permeability).

4.2.1 Transmissivity

Todd (1980) defined Transmissivity of an aquifer as "the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient" and as such is the product of Permeability and the saturated thickness of the aquifer, and can be written as:

$$T = Kb \quad \ldots\ldots\ldots\ldots \quad (4.1)$$

where,

T = Transmissivity with units of area per unit time for example, m^2/day or m^2/s.

K = Permeability with units of velocity, for example, m/s

b = Saturated thickness, with units of length, for example, meters.

Estimates of Transmissivities of the aquifer of the overburden at the various locations in three well fields (Bigi, Barkumbo Valley and Gudum) were made using borehole recovery measurements. The Transmissivities vary from place to place and range from 1.03 x 10^{-5} to 1.6 x 10^{-4} m^2/s. The computed values of the Transmissivities against each borehole in which the test was conducted are given in Table 1.

For the calculation of Transmissivities, Jacob's modified non-equilibrium method was used. The relevant formula is:

$$s' = \frac{2.303Q}{4\pi T} \log \frac{t + t'}{t'} \quad \ldots\ldots\ldots \quad (4.2)$$

where,

s' = residual drawdown in meters

Q = yield in m^3/h

TABLE I

HYDRAULIC CHARACTERISTICS OF THE OVERBURDEN AQUIFER IN BAUCHI AREA

Borehole No.	Yield m^3/h	Saturated Thickness (b) Of the aquifer in meters	Average Transmissivity (T) of the aquifer m^2/s	Average Permeability (k) m/s of the aquifer penetrated
51	11.37	38.18	$5.3x10^{-5}$	$1.39x10^{-6}$
53	12.20	31.23	$1.6x10^{-4}$	$5.12x10^{-6}$
56	5.46	23.66	$2.6x10^{-5}$	$1.10x10^{-6}$
57	5.46	13.46	$3.1x10^{-5}$	$2.30x10^{-6}$
58	6.66	28.12	$5.9x10^{-5}$	$2.10x10^{-6}$
60	13.50	23.91	$1.4x10^{-4}$	$5.86x10^{-6}$
62	7.27	25.55	$3.8x10^{-5}$	$1.49x10^{-6}$
64	11.37	25.15	$9.2x10^{-5}$	$3.86x10^{-6}$
70	9.56	35.06	$5.7x10^{-5}$	$1.63x10^{-6}$
74	6.75	40.44	$2.6x10^{-5}$	$6.43x10^{-7}$
77	5.73	20.08	$2.3x10^{-5}$	$1.15x10^{-6}$
82	10.91	26.88	$1.05x10^{-4}$	$3.91x10^{-6}$
84	29.50	38.13	$1.05x10^{-4}$	$2.75x10^{-6}$
85	6.77	25.35	$2.30x10^{-5}$	$9.07x10^{-7}$
101	7.40	51.90	$1.95x10^{-5}$	$3.76x10^{-7}$
102	5.40	48.10	$1.03x10^{-5}$	$2.14x10^{-7}$
106	10.46	42.60	$6.62x10^{-5}$	$1.55x10^{-6}$
117	9.43	34.23	$1.49x10^{-4}$	$4.35x10^{-6}$
118	7.96	41.26	$4.72x10^{-5}$	$1.14x10^{-6}$
119	6.27	30.56	$5.60x10^{-5}$	$1.83x10^{-6}$
120	6.55	41.88	$2.4x10^{-5}$	$5.73x10^{-6}$

t = time or duration of pumping in minutes

t' = time of recovery measurements in minutes

T = as defined earlier

The formula is derived by mathematical treatment of the Theis equation.

In the above method of procedure for analysis of recovery data is to plot the residual drawdowns, s', in meters on the coordinate scale of a semilog paper and the corresponding values of the time ratio $(t + t')/t'$ on the logarithmic scale.

The slope, $\Delta s'$, per log cycle and the Transmissivity, T, are related by:

$$T = \frac{2.303Q}{4\pi \Delta s'} \quad \ldots\ldots\ldots \quad (4.3)$$

Figure 12 is a worked example of calculating Transmissivity using recovery data for solution of the non-equilibrium method. The borehole recovery data used for this example is given in appendix VII.

4.2.2 Storativity

The storativity of an aquifer is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to the surface. Under

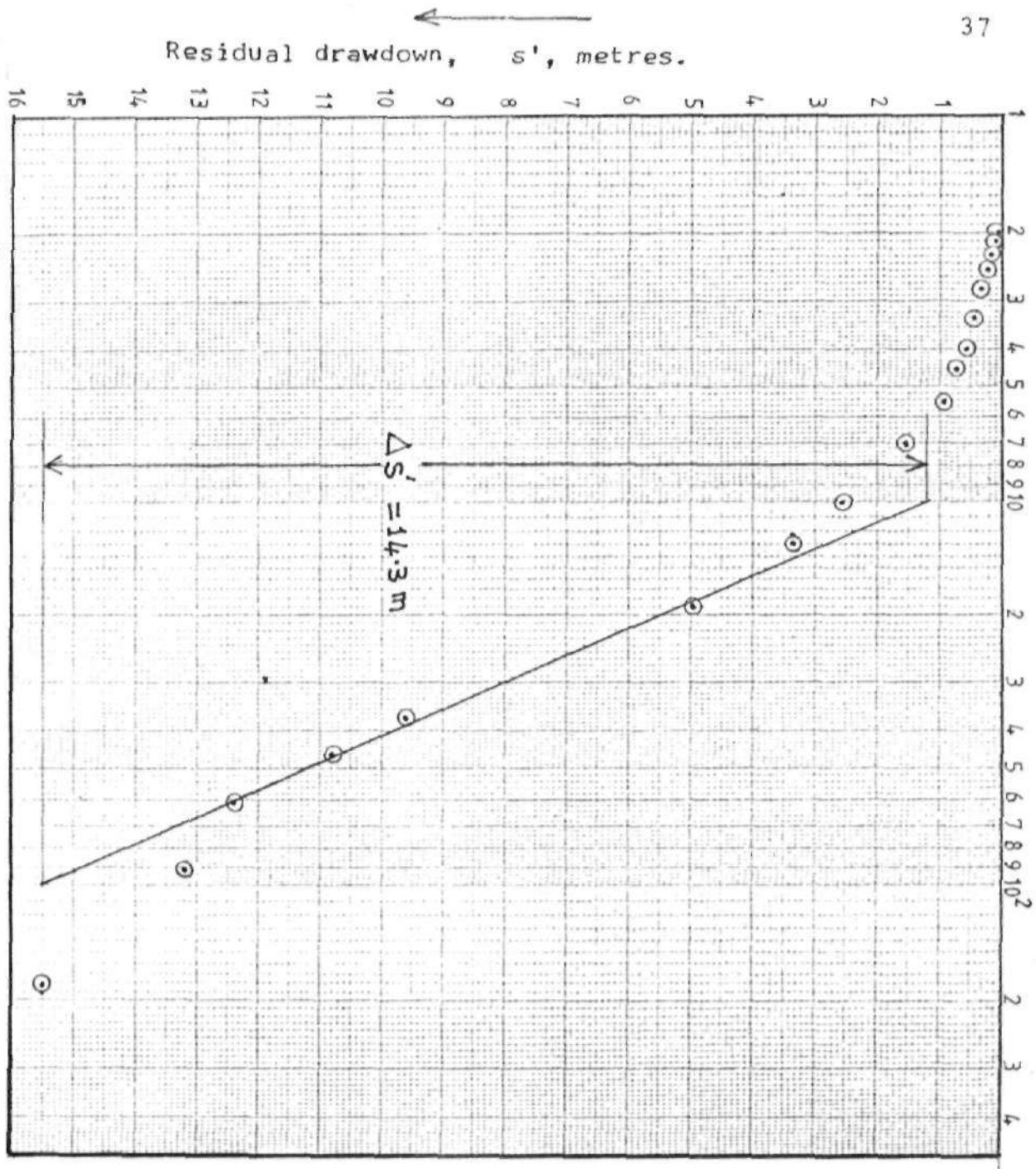


Fig.12 **Well Recovery** test method for the solution of the nonequilibrium equation.

BOREHOLE NO. 84 (SINGLE STAGE TEST)

SWL = 8.50 m/h

Yield = 29.50 m^3/h

Slope per log cycle $\Delta s'$ = 14.3 m

Transmissivity, **T**.

$$= \frac{2.303 \times 29.50}{4 \times 3.14 \times 14.3 \times 3600} \ m^2/s$$

$$= 1.05 \times 10^{-4} \ m^2/s$$

t = duration of pumping, 180 min.

t'= time of recovery measurement.

water-table (unconfined) conditions, such as those of the Bauchi area, the storativity is equal to the specific yield of the aquifer material dewatered during pumping.

The storativity can not be determined by the use of analysis of recovery data. It is an important parameter because it indicates how much water can be removed by pumping or draining from the aquifer.

The specific yields of the overburden aquifer material were also not determined because laboratory test of samples of the aquifer material was not carried out due to lack of facilities.

4.2.3 Permeability

Permeability of an aquifer is defined as the rate of flow of fluid in the aquifer. The relation between Permeability and Transmissivity is given in equation (4.1), from which:

$$K = \frac{T}{b} \quad \ldots\ldots\ldots \quad (4.4)$$

Using the above equation, the average Permeabilities of the aquifer material at various borehole locations were estimated for the value of the saturated thickness of the aquifer during the pumping test.

The Permeabilities vary and range from 2.14×10^{-7} to 5.86×10^{-6} m/s. See table 1 for the average Permeabilities of the overburden aquifer at various borehole locations.

The range of Permeabilities for the overburden aquifer stated above, falls within the range of Hydraulic Conductivities quoted as "moderate to low" and whose representative geologic materials are given as "fine sand, silt, clay and mixtures of sand, silt and clay" Todd (1980). It can easily be seen from the logs of the boreholes given in appendix VIII, that the representative geologic materials quoted above constitute most of the materials for the overburden aquifer of the Bauchi area.

Also the range of estimated Permeabilities for the overburden aquifer of Bauchi area represent porosities of 30-35 percent (The Open University Course Team, 1970). Thus, in the absence of any laboratory determinations of porosities of the overburden material in Bauchi area, a rough average of 30-35 percent can be assumed. Porosity is the percentage volume of rock occupied by pore space.

4.3 Borehole Characteristics

4.3.1 Depths

The depths of the boreholes are between 15 to 91.4 meters. Depths of 98 boreholes are known and about 80 percent of these lie between 20 to 50 meters below ground surface. Of the 98 boreholes depths, 64 were completed or finished within the overburden and 34 penetrated the unweathered crystalline rocks. The depth distribution of the boreholes is shown in figure 13.

4.3.2 Yields

Yields of 92 boreholes are available. The yields vary widely from 1.14 to 29.50 m^3/h with an average of 8.1 m^3/h. 70 percent of the boreholes yield between 0-10 m^3/h.

Most of the boreholes tap water from the overburden while others tap from both the overburden and the crystalline rocks. Only one borehole, BA 21, taps water solely from the crystalline rocks.

Figure 14 is a histogram showing the distribution of yields of 92 boreholes drilled in the area. Because most of the yields are small and only a limited

number of high yields occur, the histogram of yields, is skewed to the right.

However, the yields obtained are considered good under the prevailing geological circumstances.

4.3.3 Specific Capacities

The Specific Capacity of a well is the ratio of the yield of the well to its drawdown, or

$$\text{Specific Capacity} = \frac{\text{Yield}}{\text{Drawdown}} .$$

It is expressed as volume per unit time per unit depth of drawdown; for example, cubic meters per hour per meter of drawdown ($m^3/h/m$) as used in this work. Specific Capacity depends on the Transmissivity of an aquifer and the well construction factors, such as screen type, well diameter, degree of aquifer penetration and completeness of well development. Thus, it describes the productivity of both the aquifer and well in a single parameter. The greater the Specific Capacity the better the well.

The Specific Capacity of a well is not constant; it decreases with decrease in yield and increase of time of pumping. Even for a constant yield, the Specific Capacity decreases slightly with increase in time of

pumping. Despite these limitations, it is still considered a useful concept.

Specific Capacities for 81 boreholes were calculated. They range between 0.06 to 2.32 $m^3/h/m$ with an average of 0.65 $m^3/h/m$. 85 percent of the boreholes have Specific Capacities between 0-10 $m^3/h/m$. Thus the histogram of the distribution of Specific Capacities is skewed to the right. See figure 15.

4.4 Relationship Between Borehole Depth and Yield; and Between Thickness of Overburden and Yield

Figures 16 and 17 are scatter plots showing the relationships between depth and yield and between thickness of overburden and yield respectively. From the scatterplots, it seems the relationships between the two sets of variables are not clear.

The Pearson Linear Correlation Coefficient (r) which is an index or measure of closeness of the linear relationship between two variables were determined. The r for depth and yield is 0.32 and the r for thickness of overburden and yield is 0.43.

Correlation coefficients range between -1 for a perfect (negative) relationship through zero for uncorrelated variables to +1 for perfect (positive)

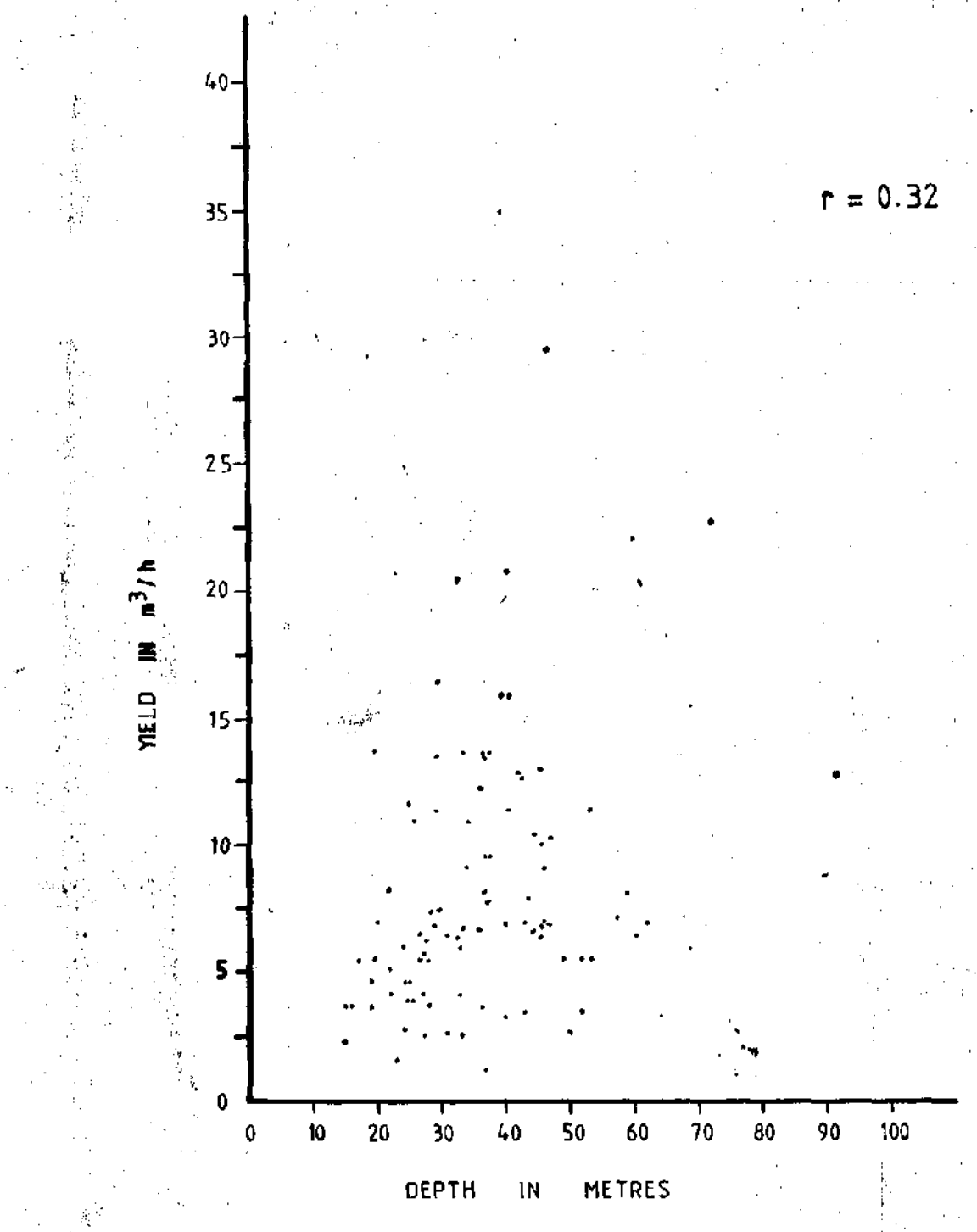


Fig. 16 Plot of yields against depths for 91 boreholes in Bauchi area.

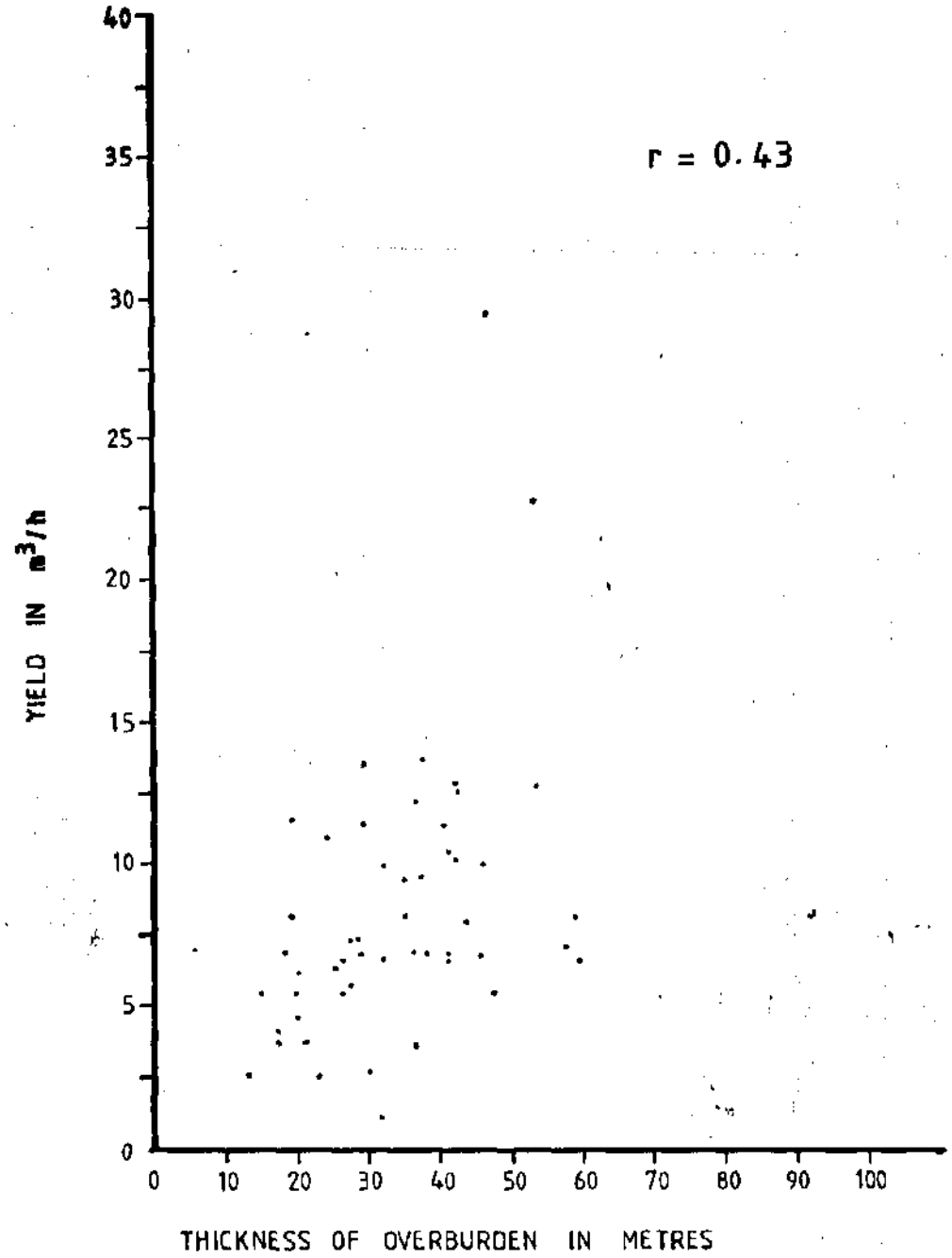


Fig. 17 Plot of yield and thickness of overburden for 51 boreholes in Bauchi area.

relationship. From the correlation coefficients obtained, the relationships between depth and yield and between thickness of overburden and yield are both weak or low. The relationship between thickness of overburden and yield is however stronger than the relationship between depth and yield.

Because of the weak relationships between depth and yield and between thickness of overburden and yield due probably to the heterogenous nature of the aquifers prediction of well yields for new borehole sites based on correlation studies is not reliable. The wells with high yields have depths of 30-48m. It may therefore be reasonable to assume that high yields are due to fracture zones.

CHAPTER 5

WATER QUALITY

5.1 Chemical Quality

Chemical analyses of seventeen water samples are given in appendix IX. The analysis of water sample from borehole BA 3 show that the principal ions are those of sodium, calcium, bicarbonate and chloride.

Because of the non-availability of sodium, potassium and bicarbonate data in nearly all the analyses the presentation of analytical results in the form of trilinear diagram is not possible. Schoeller Semi-logarithmic Diagrams (figures 18-21), have been used to illustrate the water chemistry.

The concentrations of the principal ions are expressed in milligram equivalent per litre (mg Eq/L) and are indicated or plotted on the logarithmic scale of a semilogarithmic paper. The points thus plotted are joined by straight lines. The Schoeller Diagram show the absolute value of each ion and also the concentration differences among the various water analyses represented on it. Curves of similar shapes indicate similar hydro-chemical compositions.

The analyses show that the pH ranges from 6.4 to 8.3, that is from slightly acidic to slightly basic.

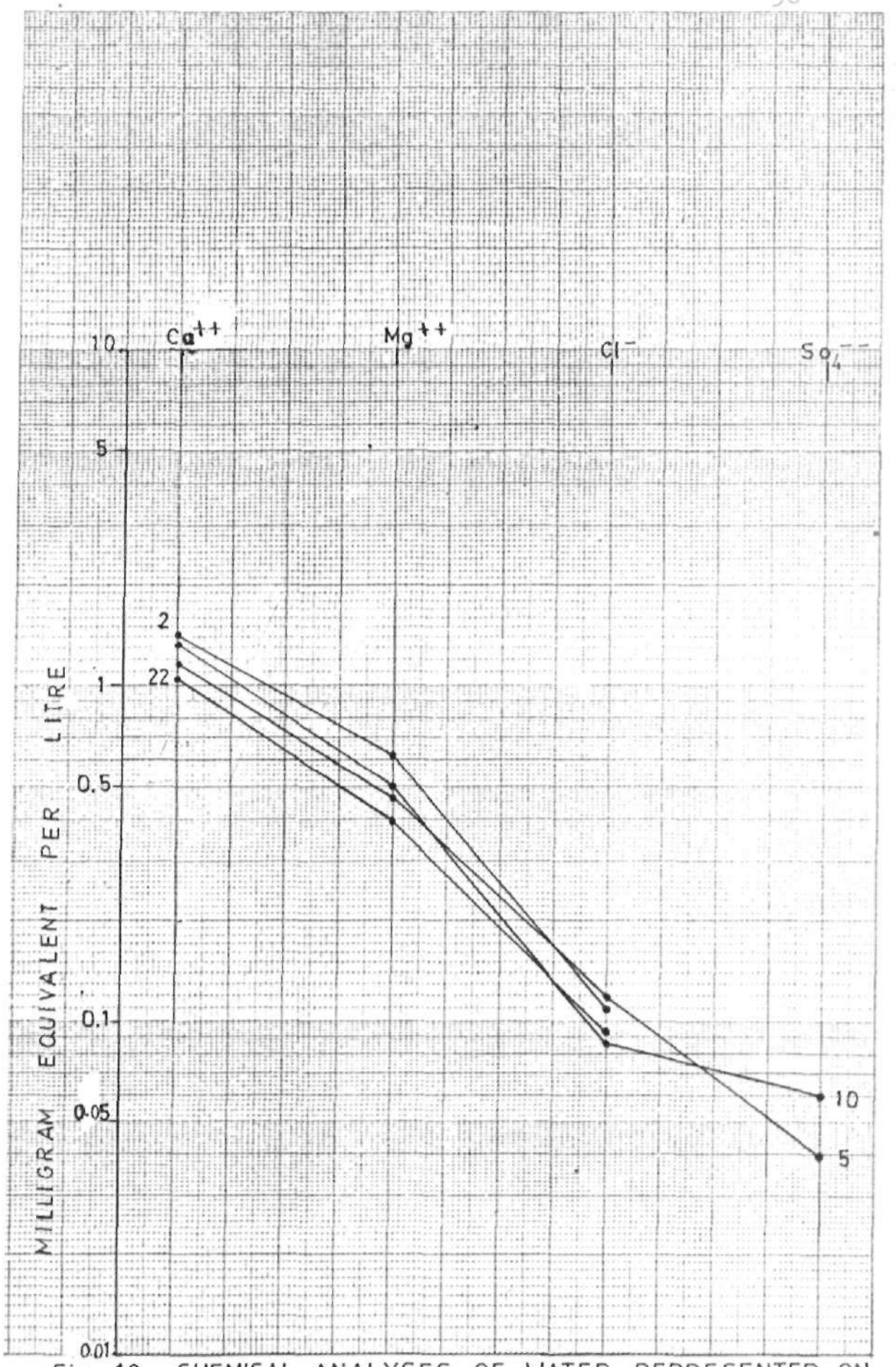


Fig. 18 CHEMICAL ANALYSES OF WATER REPRESENTED ON A SCHOELLER SEMILOG DIAGRAM. THE NUMBERS REFER TO THE BOREHOLES.

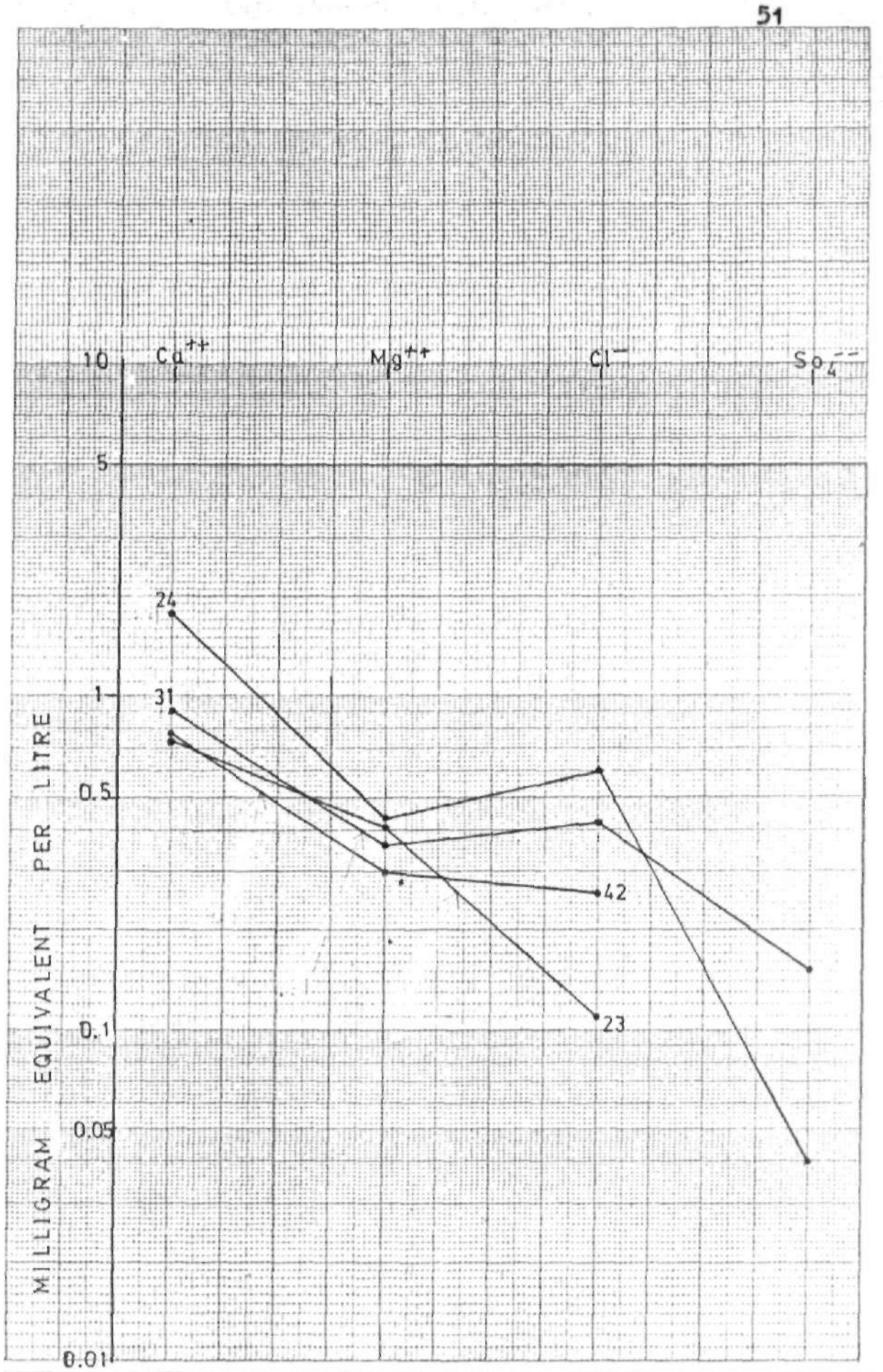


Fig. 19 CHEMICAL ANALSES OF WATER REPRESENTED ON A SCHOELLER SEMILOG DIAGRAM. THE NUMBERS REFER TO THE BOREHOLES.

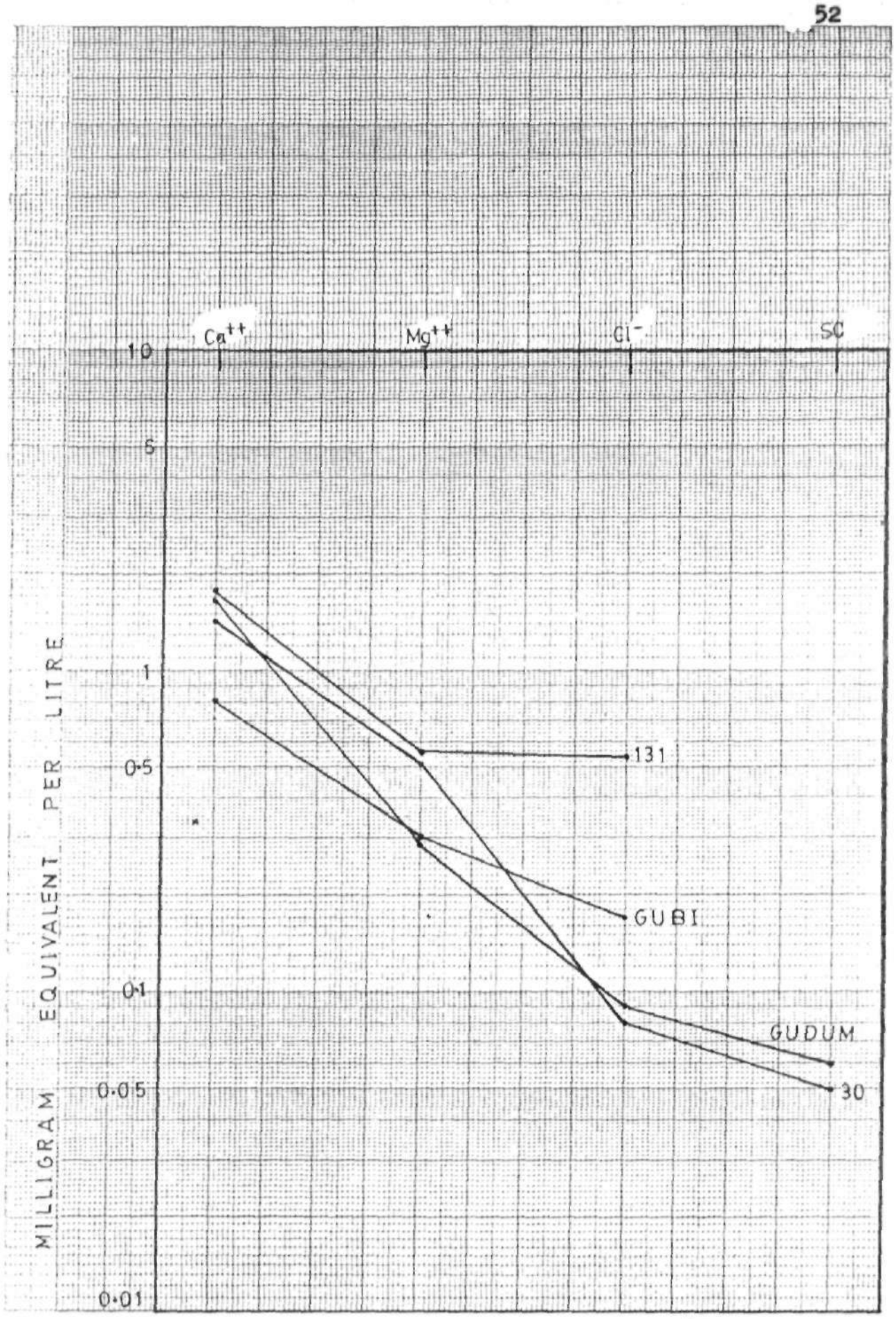


Fig. 20 CHEMICAL ANALYSES OF WATER REPRESENTED ON A SCHOELLER SEMILOG DIAGRAM. THE NUMBERS REFER TO THE BOREHOLES.

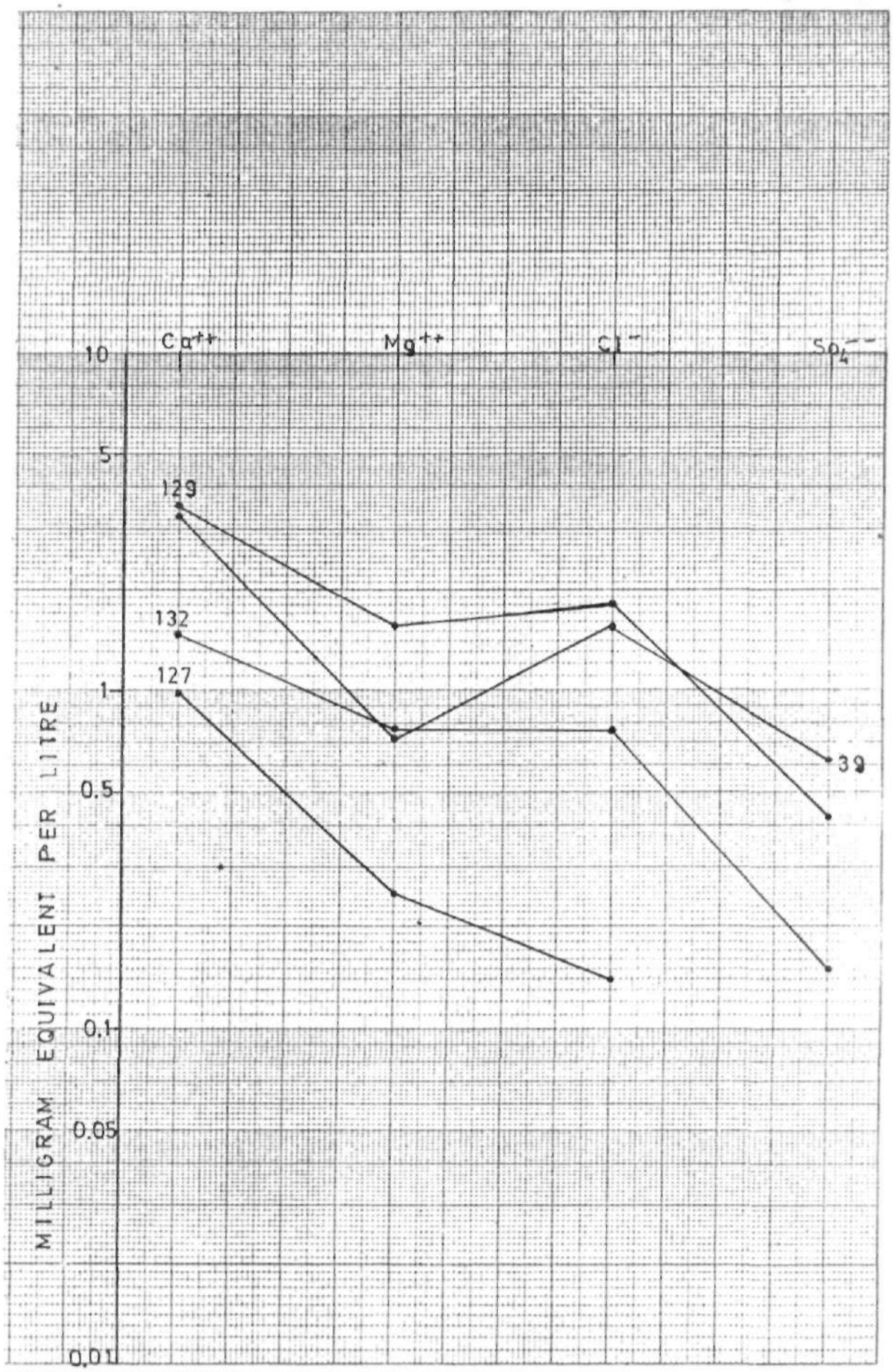


Fig.21 CHEMICAL ANALYSES OF WATER REPRESENTED ON A SCHOELLER SEMILOG DIAGRAM. THE NUMBERS REFER TO THE BOREHOLES

Hardness of the water has been given in nearly all the analyses. "Hardness of water relates to its reaction with soap and to the scale and incrustations accummulating in containers or conduits where the water is heated or transported" Bouwer (1978). Although hardness is expressed in terms of dissolved $CaCo_3$ content, it is due to several salts including carbonates, bicarbonates, sulphates, chlorides and nitrates of calcium and magnesium of which calcium bicarbonate is the commonest. Thus the total hardness of water is usually divided into carbonate and non-carbonate hardness. If the hardness as $CaCo_3$ exceeds the alkalinity as $CaCo_3$, the difference between the two is the non-carbonate hardness.

From analytical results, the hardness in most of the samples range from 60 to 120 mg/1; hardness within this range is described as moderate, Hem (1970). Few of the samples are however very hard with hardness greater than 180 mg/1. The hardness in all the analyses is mainly due to bicarbonate ions.

A complete analyses for the major ions from borehole BA 3 show that the water is essentially a sodium -

calcium - magnesium - bicarbonate water. Iron, sulphate, ammonium and nitrate are low in concentrations. Sulphate is absent in some of the analyses. Nitrate concentrations are relatively high in few of the analyses and may indicate polution. The low iron concentration will probably present no problems in the distribution mains. Total Dissolved Solids (TDS) range widely from 60 to 300 mg/L. Ionic concentrations fall within acceptable limits by World Health Organization (WHO) for domestic supplies. The Sodium Adsorption Ratio (SAR) determined from the analysis of water sample from borehole BA 3 show that the water is suitable for irrigation. Except for the hardness in some analyses, the water is suitable for most industrial purposes. See appendix XI for water standards.

5.2 Biological Quality

Pathogenic organisms excreted in the faeces of persons include bacteria and viruses. These organisms occur in some contaminated waters. It is therefore important that water contaminated with these organisms be disinfected before use.

Only a few pathogens are usually present in poluted waters, hence the high frequency of negative

laboratory tests could be misleading. For this and other reasons, bacteriological quality of water is based on testing for non-pathogenic indicator organisms mainly the Caliform group. Coliform bacteria are excreted in large numbers in the faeces of infected man and other warm blooded animals. The Coliforms are easier to detect and almost always greatly outnumber the pathogenic ones in faeces. Consequently, water contaminated by faecal polution is identified by the presence of Coliform bacteria. If they are absent it can generally be inferred that the pathogenic ones are also absent.

The Coliform test or count measures the Most Probable Number (MPN) of Coliform per 100 ml of water. A count of one Coliform per 100 ml is generally specified in many drinking water standards as the maximum permissible. Waters with MPN greater than one Coliform per 100 ml need sterilization before consumption.

Escherichia Cali is a typical Coliform bacteria and is of faecal origin. Thus, its presence in water is a confirmation of faecal polution.

Bacteriological examination of some water samples are given in appendix X. The number of micro-organisms

that grow on nutrient agar at 37°C exceed 200 in most of the samples. This test is however, of little significance in detecting the presence of faecal contamination since organisms of all types present in the sample capable of growing under the imposed conditions will be counted. However, large number of growth as seen in some of the analyses, may indicate faecal contamination; thus the presence of Coliforms as a confirmatory test for faecal contamination should further be ascertained.

In nine out of the twelve groundwater samples examined for bacteria, Coliform bacteria have been detected with the MPN exceeding the permissible limit. Furthermore, the presence of Escherichia Coli in five of the samples (that is from boreholes BA 22, BA 23, BA 30, BA 42 and BA 129) confirm faecal polution at the locations of these boreholes. It is interesting to note that these boreholes are infact located in residential areas where the sources of the faeces containing these Coliforms might be pit laterines and or septic tanks.

5.3 Sources of Groundwater Contaimination

Sewage and faeces placed below ground surface, mainly in septic tanks and pit latrines filter directly

downward to the water table, where it can migrate into the groundwater flow system. These are probably the main sources of groundwater contamination in the area.

Refuse, dumps, livestock and fowl waste disposed on land are leached into the ground. The leachate contain both inorganic and organic contaminants. Also rain storm carries contaminants into disposal basins where some of them percolate down to the groundwater.

Poorly abandoned wells and boreholes facilitate movement of contaminants into the groundwater. Agricultural activities through the application of fertilizers and pesticide are potential sources of groundwater contamination.

As seen in the bacteriological examination, groundwater in Bauchi area is vulnerable to contamination, particularly, faecal polution because the water table is shallow.

Contamination may be intermittent and may not be revealed by analysis of one water sample. Results of analyses provide information on the conditions that prevail at the time of sampling and a satisfactory result is not a guarantee that the conditions will persist in the future. Therefore periodic examination

is desirable to ascertain the nature, degree and possibly, the sources of the contaminants, and to take necessary action if contamination is evident.

CHAPTER 6

PRESENT WATER SUPPLY SCHEME AND WATER DEMAND

Water supply in the Bauchi area is derived from two sources, groundwater and surface water.

6.1 Groundwater

Groundwater is tapped through boreholes and hand-dug wells.

6.1.1 Boreholes

The first borehole in Bauchi area was drilled in 1948 by the Geological Survey of Nigeria and in that year, three boreholes were drilled. At present more than 150 boreholes have been sunk in the area. The majority of the boreholes were drilled by the BSWB; some through contract and others by its own drilling crew. Available records of some of the boreholes are given in appendix VIII. Of the boreholes so far drilled, only about 55 are in operation. Some have been abandoned while others have not yet been commissioned. The locations of 83 boreholes are shown in figure 5.

The BSWB manages 42 of the operational boreholes and 3.64 million liters of water per day is withdrawn from these boreholes. Some establishments have their own boreholes located within their premises; there are

eleven such boreholes. Also eight boreholes fitted with hand-pumps have been drilled under the BSADP rural borehole programme and are located in various localities, mostly villages. The total daily yield that is obtained from all the boreholes not owned by the BSWB is estimated as 1.46 million liters. This therefore means that the total daily yields from all operational boreholes is 5.10 million liters.

There are three methods in which water is withdrawn and supplied to the area from the boreholes.

In the first method, water is pumped from a group of boreholes located near each other into a booster station. A booster station consists of a relatively small underground storage device equiped with a pump house. Its function is to boost the flow of water into the distribution mains. There are five of such stations located at various places with storage capacities of 45,460 liters each. From a booster station water is then pumped either directly into the distribution mains or into large storage tanks located on high ground, mainly small hills. Water under gravity flows from the tanks through systems of distribution

mains to various places, for example, households and public taps. Three storage tanks are served by the booster stations. Two of these have storage capacities of 227,300 liters and are located to the north-east of Bauchi township, at Ibrahim Bako and Adamu Jumba housing estates, respectively. The third one is located on Jahun hill and has a storage capacity of 0.45 million liters,

The second method involves the use of mobile vehicle tankers owned by various government agencies, private establishments and individuals. In this method, water from boreholes is pumped directly into the tankers to be distributed to various points of need. This system has helped to a great extent where distribution mains are lacking, mainly nearby villages.

The third method by which water is taken from boreholes is found mainly in villages where the boreholes are fitten with hand-pumps. Water is drawn from the borehole directly into containers by the individuals by operating the pump.

Boreholes equipped with mechanical pumps need regular maintenance and are only available near or in Bauchi town.

6.1.2 Hand-dug Wells

Dug wells are the earliest and coomonest means through which groundwater is tapped. It has been the main source of water long before boreholes were drilled and still remains an important source of groundwater supplies to many people, households and villages.

The wells are shallow with the deepest ones reaching only about 14 meters. The earliest concrete - lined wells were dug by the former Native Authorityy. Most wells are now dug and owned by individuals.

Some of the wells, especially the deeper and properly sited ones yield relatively large quantities of water and contain water throughout the year. Many of the wells, however, contain little or no water during the dry season.

The total quantity of water yield from the wells is difficult to estimate but it will probably reach several thousand liters per day. The daily total yield of wells will be greater in the rainy seasons than in the dry seasons.

6.1.3 Groundwater Storage

The quantity of water in ground storage is one of the basic requirements in the proper planning,

development and management of groundwater resources.

The groundwater storage in the study area has not been determined in this study because of the absence of gauging stations that could have provided stream discharge records; lack of complete meteorological data; and absence of some aquifer test data and other facilities that can enable determination of the storage coefficient of the overburden aquifer.

It is hereby proposed that the present total daily pumpage from boreholes be used as the safe yield. Safe yield is the rate at which groundwater can be withdrawn without causing a long term decline of water level Bouwer (1978). The total daily pumpage from boreholes is about 5.10 million liters.

6.2 Surface Water

6.2.1 Gubi Dam

Gubi dam is located in the north-eastern part of the project area and about 11 kilometers north-east of Bauchi town. Work on the dam started in 1979. Construction of the dam has been through direct labour of the BSWB and contract has only been awarded for minor finishing touches.

The dam is sited at a point where three streams converge in the North-eastern part of the map area. The total catchment area of the streams that contribute to the lake has been given as 179 km^2 (BSWB, 1982).

It is an earth - zoned dam. BSWB record show the lake has a surface area of 590 hecters and the maximum flood level of the dam is estimated at 559.04 m asl. The total storage capacity of the dam at full supply level (that is at 557.0 m asl) is 38.4 million cubic meters of water and the dead storage level below which point water cannot be withdrawn is 545m asl. The total volume of water that can be withdrawn at full supply level (or active storage capacity at full supply level) is 35.15 million cubic meters. Active storage at any point is the quantity of water that is in storage between the elevation or level of that point and the dead storage level.

A treatment plant has been constructed through contract work near the dam and its maximum treatment capacity is 5.46 million liters per day. The size of the present treatment plant is small and was designed to treat water from a temporary impoundage while work on the dam was going on.

Chemical and bacteriological analyses of water from Gubi dam are given in appendices IX and X respectively. Because the quality of the water is good, commonly applied treatment processes, which are easy and within reasonable economic limits, are employed. The treatment required are in four stages and are summarised below:

Straining: Water from the dam is passed through metal screens that vary in coarseness (coarse to fine). The process removes possible floating or suspended debris and living organisms in the water.

Storage: Sedimentary particles which escape the straining process settle on the bottom of the storage or sedimentation tanks. The process is speeded by adding coagulant like alum, $Al_2 (SO_4)_3$, $7H_2O$ which flocculate the very fine clay particles.

Filtration: Water from storage reservoirs still contain dissolved constituents as well as finer particles and small organisms. The water is allowed to filter through a sand filter tnak with filter beds consisting of an upper layer of fine quartz sand and a lower layer of coarse sand and gravel. The fine layer acts as a microstrainer and traps finely suspended particles and small organisms;

it is about one meter thick. The lower layer is about 30 centimeters thick and here other bacteria complete the decomposition of any organic matter in the water.

Sterilization: Most of the bacteria in water are removed by filtration and the remainder are killed by adding chlorine. The quantity of chlorine added is such that it is not harmful but enough to kill the remaining bacteria.

Treated water is pumped from the treatment plant into two large storage tanks. One of the tanks is placed on a 15.2 meter tower situated along Maiduguri road; it has a capacity of 0.45 million liters. The other one has a capacity of 0.91 million liters and is located on a small hill west of Bauchi town. Water from these tanks under force of gravity flow through the system of distribution mains.

Construction of two additional storage tanks with capacities of 11.4 million liters each are nearing completion. Both reservoirs are situated on Wambai hill north-east of Bauchi township; these are expected to be served by the dam.

At the moment, about 100 km of pumping and distribution mains have been laid in and around Bauchi

town.

6.2.2 Streams

Some villages do not have the hand-pump-fitted boreholes or have no dug wells for their water supplies. Such settlements are often found along or near stream courses. These villages depend on streams whose reaches contain water even during dry spells. Examples of such villages include Dungulbi, Rusa and Tala all in the south-eastern part of the map area; all the people in these villages and their animals depend on stream water from tributaries of the Tambarin. Other examples of such villages are found in the north-eastern and north-western parts of the project area.

6.3 Water Demand

The present total water supply from boreholes and Gubi dam is about 10.564 million liters per day. Assuming that this supply were used only for domestic purposes, the consumption of water will be 81.7 liters per head per day. This figure is less than the average water consumption for domestic purposes in urban population for 34 African countries surveyed by WHO and is estimated at 100 liters per head per day.

The present total water demand is 22.73 million liters per day as estimated by the BSWB. This then means the present water supply of 10.564 million liters per day is only 46% of the total water demand.

6.4 Conjuntive Use of Groundwater and Surface Water

The problem of meeting water demand can be solved more effectively if the resources are treated as one single resource.

This means the use of groundwater and surface water should be complimentary to each other according to availability and demand for it. Conjuntive use provides the opportunity to develop the inherent advantages of both surface and groundwater reservoirs.

Groundwater reservoirs are significant because of their capabilities of storing large useable water, safe from loss by evaporation and less vulnerable to contamination from surface activities. On the other hand, surface supplies are more easily replenished and are usually desirable for providing large supplies to populated areas.

The present water supply scheme, whereby supplies are obtained from both boreholes and the Gubi Dam, is

desirable. However, because of the low yields obtained generally from boreholes and the greater potentials offered by the Gubi Dam, the tendency is that borehole supplies may be neglected or de-emphasized as time goes on. The results of bacteriological examination of water samples from boreholes show that the water is biologically contaminated, therefore treatment of groundwater is required if conjuctive use is to be continued.

SUMMARY AND CONCLUSIONS

Knowledge of the groundwater situation under natural conditions, the geologic framework in which it occurs and how the water enters and discharges from the framework have been presented in this work as basic requirements for making decisions for groundwater resources development and management.

The most important water bearing unit in the study area is the overburden materials derived from the in-situ decomposition of the crystalline rocks and the erosion of adjacent hills. Poor and irregular hydraulic characteristics of this aquifer can be attributed to the clayey nature of the product of decomposition and the poor degree of sorting of the mixtures of the erosional products - sands, gravels, silts and clays. However, given the prevailing geological circumstances, the performance of the aquifer can generally be considered 'good'. There are few examples of high yielding boreholes.

Exploitable amount of water can be available in the fractures within the crystalline rocks and yields of boreholes can be improved if fracture zones are

located and tapped together with the overlying overburden.

The principal ions in the water are calcium and bicarbonate. The water is generally hard. Iron is low in concentration. The Total Dissolved Solids range from 60 to 300 mg/L. The water require treatment before drinking; it can be used for irrigation and some industrial purposes.

Groundwater occur under water table conditions about 3 to 6 meters below ground surface in many places. It is vulnerable to contamination. The main source of contamination is faecal pollution, as confirmed by the presence of Escherichia Coli in some of the samples examined.

To improve supplies from groundwater the attainment of full potential yields of boreholes will be dependent on:

(i) careful selection of new borehole sites, that is only after geological and geophysical investigations;
(ii) proper well design and construction;
(iii) careful and complete development of boreholes and
(iv) regular maintenance of operational boreholes.

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APPENDIX I

MONTHLY TOTAL OF RAINFALL (mm) STATION:
BAUCHI AIRPORT

JAN.	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MONTH/YEAR
0.0	0.0	0.0	73.3	106.0	125.1	230.7	165.0	211.5	90.7	0.0	0.0	1976
0.0	0.0	0.0	0.0	27.3	142.3	181.2	330.4	117.4	16.4	0.0	0.0	1977
0.0	0.0	TR	20.6	74.8	212.8	299.6	367.2	133.2	42.8	0.0	0.0	1978
0.0	0.0	TR	37.2	75.1	83.5	329.4	258.7	165.7	41.7	TR	0.0	1979
0.0	0.0	TR	0.5	111.6	121.3	314.1	146.6	82.5	40.3	0.0	0.0	1980
0.0	0.0	0.0	28.2	120.2	246.3	396.3	268.7	172.5	18.4	0.0	0.0	1981
0.0	TR	0.0	43.8	38.4	164.9	233.2	239.1	146.0	31.6	0.0	0.0	1982
0.0	0.0	13.0	TR	95.0	123.5	227.1	184.2	136.2	0.0	0.0	0.0	1983
0.0	0.0	6.8	19.3	148.7	77.8	239.0	227.8	164.0	10.3	0.0	0.0	1984
0.0	0.0	33.2	TR	122.3	108.4	152.2	162.2	145.6	1.7	0.0	0.0	1985
0.0	0.0	53.0	222.9	919.4	1405.9	2602.8	2349.9	1474.6	293.9	0.0	0.0	Total
0.0	0.0	5.3	22.3	91.9	140.6	260.3	235.0	147.5	29.4	0.0	0.0	Average

TR = trace.

APPENDIX II

MONTHLY MEANS OF DAILY MAXIMUM TEMPERATURE (°C) FOR A PERIOD OF TEN YEARS
STATION: BAUCHI AIRPORT

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	MONTH/YEAR
-	-	-	-	-	-	-	-	-	-	-	-	1976
-	-	-	-	-	-	30.0	28.5	30.5	32.4	32.2	29.2	1977
30.7	34.6	36.8	35.4	35.1	31.3	28.4	29.5	29.7	32.0	31.2	30.9	1978
31.6	34.7	36.7	37.0	33.8	31.2	29.9	29.3	29.7	32.5	33.3	29.5	1979
32.3	33.1	36.6	37.8	34.6	31.5	29.2	29.1	30.6	32.8	33.1	29.8	1980
29.0	33.2	36.4	37.8	34.2	32.0	28.8	29.6	30.3	33.2	30.8	31.8	1981
30.7	32.5	35.5	37.2	34.4	32.3	29.9	29.2	29.8	32.4	31.1	31.7	1982
24.9	34.1	34.4	38.1	37.2	31.8	30.0	29.7	30.6	33.1	33.7	32.3	1983
30.0	33.0	37.6	37.3	34.2	33.9	30.3	30.7	30.8	32.8	33.6	29.8	1984
32.9	31.1	36.5	36.3	36.4	32.6	29.4	30.3	30.7	34.0	34.3	29.8	1985

Dahh (-) indicate no recording was made.

APPENDIX III

MONTHLY MEANS OF DAILY MINIMUM TEMPERATURE (°C) FOR A PERIOD OF TEN YEARS

STATION: BAUCHI AIRPORT.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	MONTH/YEAR
13.4	19.0	20.1	22.6	22.0	20.5	19.5	19.0	-	17.1	15.3	13.9	1976
14.3	15.5	20.4	23.0	23.2	-	20.4	24.6	18.9	17.2	11.8	9.6	1977
11.9	17.3	21.0	24.3	22.7	21.5	20.7	19.7	19.0	20.0	15.0	13.3	1978
13.7	17.0	22.0	23.4	22.5	21.5	20.9	20.9	20.0	19.5	17.7	17.7	1979
13.9	17.1	20.8	23.8	23.1	22.0	20.8	20.1	20.3	19.5	15.4	13.6	1980
13.0	16.5	21.0	23.0	23.0	21.2	20.6	20.5	20.7	20.3	15.8	12.2	1981
14.5	17.0	22.1	23.8	22.5	21.5	19.8	20.3	20.4	20.4	14.6	13.5	1982
11.5	16.4	18.5	23.2	24.7	21.6	20.8	20.5	20.6	18.2	15.3	14.5	1983
13.1	17.0	22.3	23.9	22.3	22.4	20.3	20.7	20.2	20.6	16.6	13.6	1984
16.3	15.5	22.6	23.7	23.4	21.7	20.4	20.9	20.5	19.9	17.7	15.1	1985

APPENDIX IV

MONTHLY MEANS OF DAILY EVAPORATION (mm) FOR A PERIOD OF TEN YEARS. STATION: BAUCHI AIRPORT

JAN	FEB	MAR	APRIL	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	MONTH/ YEAR
-	-	-	-	-	-	-	-	-	-	-	-	1976
-	-	6.83	6.89	10.16	-	6.30	8.10	-	7.72	9.59	8.42	1977
9.49	12.00	14.23	10.63	9.50	7.70	5.28	6.23	6.33	6.48	7.04	8.16	1978
9.18	10.71	12.75	12.46	9.05	7.88	6.54	5.79	6.54	6.95	8.15	8.67	1979
9.69	10.71	12.75	13.28	9.72	7.61	6.05	6.20	6.32	7.42	9.69	8.67	1980
9.18	10.73	13.77	14.20	9.99	8.21	6.66	7.14	6.26	7.22	9.18	10.20	1981
9.18	10.71	12.75	12.68	8.38	8.05	8.03	6.69	6.40	9.69	8.67	9.18	1982
6.63	10.20	11.64	10.71	10.20	6.67	5.80	6.45	7.00	9.18	10.20	10.20	1983
10.20	10.71	13.00	12.88	11.94	10.24	7.70	6.32	6.45	7.47	8.16	8.16	1984
8.16	11.22	9.74	9.69	11.09	10.7	9.49	10.87	12.50	11.78	11.73	10.2	1985

Dash (-) indicate no record.

WATER LEVELS IN HAND-DUG WELLS IN BAUCHI AREA

Well No.	Locality	Coordinates	Elevation of Well m asl	End of rainy season Oct/ Nov - 1986		Dry Season - April, 1987	
				SWL (m)	Elevation of SWL m asl	SWL (m)	Elevation of SWL m asl
1	Opposite Jamma Pri. School	10° 17' 55.0" N 9° 49' 56.3"	604.0	1.50	602.5	5.40	598.6
2	Angwar Borno	10° 18' 12.2" N 9° 50' 33.4" E	621.0	0.50	520.5	4.80	616.2
3	Kofar Idi	10° 18' 39.5"N 9° 51' 21.7" E	620.3	1.50	618.8	5.80	614.5
4	North of BSADP premises	10° 17' 47.3"N 9° 48' 33.3" E	604.7	0.23	604.5	2.22	602.5
5	Miri Pr. school	10° 18' 34.6"N 9° 44' 41.8" E	658.4	3.30	655.1	10.32	648.1
6	Guka Village	10° 21' 20.0"N 9° 53' 30.8" E	573.2	2.00	571.2	8.60	564.6
7	Fafin Maka-ranta	10° 21' 30.7"N 9° 50' 28.0" E	589.2	3.80	585.4	6.80	582.4
8	Kura Village	10° 21' 36.8"N 9° 51' 59.5" E	612.6	1.50	611.1	dry	-

WATER LEVELS IN HAND-DUG WELLS IN BAUCHI AREA

Well	Locality	Coordinates	Elevation of well m asl	End of rainy season Oct/Nov. - 1986		Dry season April 1987	
				SWL (m)	Elevation of SWL m asl	SWL (m)	Elevation SWL m asl
9	Guru village	10° 19' 12.2" N 9° 47' 27.7" E	623.3	1.10	622.2	6.66	646.6
10	Bayan Dutse	10° 20' 0.0" N 9° 47' 30.0" E	619.4	2.60	616.8	6.84	612.6
11	Near Min. of lands & Survey	10° 18' 54.9" N 9° 50' 19.4" E	622.4	5.00	617.4	6.00	616.4
12	Near Karama hotel	10° 18' 55.8" N 9° 51' 33.0" E	615.7	2.36	613.3	6.00	609.7
13	Near old market round about	10° 18' 48.4" N 9° 50' 54.3" E	624.8	3.20	621.6	10.40	614.4
14	Kofar Turum	10° 19' 19.5" N 9° 51' 11.8" E	636.4	1.80	634.6	10.00	626.4
15.	Urban maternity	10° 19' 33.6" N 9° 50' 51.0" E	627.9	2.10	625.8	7.40	620.5
16	Kofar Dumi	10° 18' 13.1" N 9° 51' 21.5" E	620.9	3.86	617.0	5.50	615.4
17	Near Railway Industrial Clinic	10° 17' 46.8" N	615.7	0.20	615.5	3.00	612.7

APPENDIX V CONTD.

WATER LEVELS IN HAND-DUG WELLS IN BAUCHI AREA

Well No.	Locality	Coordinates	Elevation of well m asl	End of rainy season Oct/Nov. 1987		Dry season April, 1987	
				SWL (m)	Elevation of SWL m asl	SWL (m)	Elevation of SWl m asl
18	Railway gate	10° 17' 36.6" N 9° 50' 48.6" E	615.7	1.30	614.4	6.00	609.7
19	Kofar Jahun	10° 17' 23.6" N 9° 50' 21.7" E	605.0	0.90	604.1	3.30	601.7
20	Gwalga-furan	10° 17' 34.8" N 9° 48' 1.0" E	607.5	2.20	605.3	4.00	603.5
21	Imani Estate	10° 18' 43.4" N 9° 53' 6.6" E	595.0	1.60	593.4	3.00	592.0
22	Sabon Kaura	10° 17' 7.8" N 9° 47' 12.3" E	618.7	1.30	617.4	6.20	612.5
23	Miri Village	10° 18' 14.9" N 9° 44' 42.6" E	649.2	3.00	646.2	5.86	643.3
24	Inkil Police check point	10° 18' 20.4" N 9° 53.' 23.5" E	594.4	3.00	591.4	5.70	588.7
25	Kofar Nasa-rawa	10° 18' 18.0" N 9° 49' 53.3" E	603.5	2.30	601.2	6.16	597.3
26	Dumi Village	10° 17' 10.9" N 9° 52' 15.1" E	615.0	2.20	612.8	5.41	609.6

APPENDIX V (CONTD.

WATER LEVEL IN HAND-DUG WELLS IN BAUCHI AREA

Well No.	Locality	Coordinates	Elevation of well m asl	End of rainy season Oct/Nov. 1986		Dry season April, 1987	
				SWL m	Elevation of SWl m asl	SWL (m)	Elevation of SWl m asl
27	Dumi-Anguwan Joji	10° 16' 43.0" N 9° 52' 32.9" E	592.0	3.20	588.8	5.20	586.8
28	Refin Zurfi	10° 15' 46.0" N 9° 46' 58.7" E	620.0	3.15	616.9	4.20	615.8
29	Gwallameji near borehole	10° 15' 28.8" N 9° 46' 38.0" E	618.7	2.10	616.6	4.30	614.4
30	Birshi Gandu old settlement	10° 16' 14.0" N 9° 45' 26.4" E	643.1	6.30	636.8	7.90	635.2
31.	Birshi Gandu new settlement	10° 16' 19.9" N 9° 46' 23.2" E	640.0	4.50	635.5	7.85	632.2
32	Yelwa Tudu	10° 16' 11.3" N 9° 47' 49.1" E	605.6	1.79	603.8	5.40	600.2
33	Lushi Village	10° 15' 57.5" N 9° 48' 41.2" E	591.3	3.20	588.1	5.50	585.8
34	Gwallaga Village	10° 15' 57.3" N 9° 49' 46.1" E	582.1	5.39	576.7	7.45	574.7
35	Bigi	10° 15' 57.8" N 9° 50' 40.3" E	582.2	3.60	578.6	5.20	577.0

APPENDIX V CONTD.

WATER LEVELS IN HAND-DUG WELLS IN BAUCHI AREA

Well No.	Locality	Coordinates	Elevation of well m asl	End of rainy season Oct/Nov., 1986		Dry season April, 1987.	
				SWL (m)	Elevation of SWL m asl	SWL (m)	Elevation of SWL m asl
36	Bigi haye	10° 15' 14.9" N 9° 50' 34.5" E	579.1	3.20	575.9	5.00	574.1
37	Gudum Village, east of Gudum hill	10° 16' 25.4" N 9° 51' 42.9" E	594.4	4.08	590.3	5.25	589.2
38	Gudum Village foot of hill	10° 16' 13.9" N 9° 51' 16.1" E	594.4	5.32	589.1	6.00	588.4
39	Wutin Dada Pr. school	10° 19' 5.5" N 9° 46' 1.0" E	637.9	4.27	633.6	6.84	631.1
40	Lafiyari village	10° 19' 33.7" N 9° 45' 14.8" E	648.2	7.12	642.1	8.00	641.2
41	South-west of Lafiyari village	10° 19' 14.3" N 9° 45' 1.6" E	649.2	5.62	643.6	7.80	641.4
42.	Rafin Tambari	10° 18' 0.1" N 9° 46' 25.6" E	624.8	2.41	622.4	5.75	619.1
43	Tafawa Balewa Estate	10° 19' 31.7" N 9° 51' 27.3" E	630.9	3.10	627.8	5.40	625.5
44	Army Barracks	10° 19' 43.1" N 9° 49' 18.7" E	603.5	1.82	601.6	5.60	597.9

APPENDIX V CONTD

WATER LEVELS IN HAND-DUG WELLS IN BAUCHI AREA

Well No.	Locality	Coordinates	Elevation of well m asl	End of rainy season Oct/Nov., 1986		Dry season April, 1987	
				SWL (m)	Elevation of SWL m asl	SWL (m)	Elevation of SWL m asl
45	Shadawanka Village	10° 20' 17.7" N 9° 49' 3.6" E	595.9	3.96	591.9	5.00	590.9
46	Zamfara Village	10° 20' 21.1" N 9° 45' 57.8" E	631.5	5.23	626.3	6.00	624.7
47	Tirwun-Maiduguri Road	10° 20' 40.9" N 9° 52' 26.8" E	601.9	2.13	599.8	4.60	597.3
48	Guni, foot of Guni hill	10° 20' 33.7" N 9° 52' 22.7" E	590.7	9.16	581.5	10.30	580.4
49	Sabon Kaura	10° 21' 59.0" N 9° 47' 3.6" E	592.2	4.23	587.8	6.10	586.1
50	Mafin Dinya	10° 21' 39.9" N 9° 48' 18.6" E	602.0	4.52	597.5	5.71	596.3
51	Anguwar Kanawa	10° 15'12.3" N 9° 44' 47.6" E	624.8	8.28	616.5	9.56	615.2
52	Tirwun north	10° 21' 20.5" N 9° 53' 36.7" E	576.1	4.21	571.9	6.40	569.7
53	Old Maiduguri Rd Water Board Quarters	10° 19' 59.0" N	608.1	0.50	607.6	1.50	606.6

APPENDIX V CONTD

WATER LEVEL HAND-DUG WELLS IN BAUCHI AREA

Well No.	Locality	Coordinates	Elevation of well m asl	End of rainy season Oct/Nov.,1986		Dry season April, 1987	
				SWL (m)	Elevation of SWL m asl	SWL (m)	Elevation of SWL M asl
54	Budum Village	10° 21' 50.9" N 9° 54' 5.2" E	567.0	4.23	562.8	7.14	559.9
55	Miri (1) NE of Guru	10° 19' 40.8" N 9° 48' 1.2" E	617.2	3.48	613.7	6.26	610.9
56	Kano motor Park	10° 20' 42.9" N 9° 50' 46.0" E	603.5	5.48	598.0	7.25	596.3
57	Old Post office	10° 19' 9.1" N 9° 49' 25.3" E	615.7	1.62	614.1	4.75	611.0

APPENDIX VI

WATER LEVELS IN THREE OBSERVATION WELLS IN BAUCHI AREA

MONTH/ YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MONTH/ LOCALITY
1979	4.44	5.28	5.43	5.75	7.19	8.20	7.76	3.73	-	-	-	-	Gudum
1980	3.74	-	-	-	-	-	7.40	-	2.61	3.04	2.89	3.96	"
1981	3.97	5.21	-	6.54	6.84	9.68	5.12	-	-	-	-	-	"
1979	6.54	6.96	7.05	7.15	8.40	7.95	7.47	5.67	-	-	-	-	Barkumbo
1980	6.78	-	-	-	-	-	8.40	-	6.64	6.73	6.70	6.99	"
1981	6.99	6.48	-	7.64	7.72	7.89	6.20	-	-	-	-	-	"
1985	-	-	-	-	-	-	-	-	-	7.08	7.15	-	"
1979	2.96	3.80	3.44	3.53	4.42	4.07	3.93	2.30	-	-	-	-	BIGI
1980	2.96	-	-	-	-	-	3.53	-	-	-	-	2.55	"
1981	3.12	3.39	-	3.80	3.94	3.86	2.63	-	-	-	-	-	"
1985	-	-	-	-	-	-	-	-	-	-	3.30	-	"

APPENDIX VII

PUMPING TEST OBSERVATION

Borehole No.84

SWL - - - - - -- -- - 8.50m

Yield - -- - - -- - 29.50 m^3/h

Duration of Pumping, t ------ 180 minutes.

RECOVERY MEASUREMENT

Time of recovery measurement t' (min)	Dynamic water Level (m)	Residual drawdown S' (n)	$\frac{t + t'}{t'}$	Remarks
1	24.00	15.50	181	Single stage test
2	21.70	13.20	91	
3	20.90	12.40	61	
4	19.30	10.80	46	
5	18.10	9.60	37	
10	13.48	4.90	19	
15	11.85	3.35	13	
20	11.05	2.55	10	
30	10.06	1.56	7	
40	9.47	0.97	5.5	
50	9.22	0.72	4.6	
60	9.07	0.57	4	
80	8.92	0.42	3.3	
100	8.82	0.32	2.8	
120	8.75	0.25	2.5	
140	8.67	0.17	2.3	
160	8.60	0.10	2.1	
180	n 8.57	0.07	2	Completion

APPENDIX VII

RECORD OF SOME BOREHOLES IN BAUCHI AREA

LOcality	Borchole No.	Coordinates	Date Completed	Total depth (m)	Screention (m) From	Screention (m) to	SWL in (m) below ground surface	Pumped yield m^3/h	Draw down(m)	Lithological description & depth (m)
SE of GGSS	BA 1	-	4-1-79	19.81	-	-	4.27	13.64	9.45	-
Old G.R.A	BA 2	10° 18' 37.2" N 9° 49' 27.3" E	11-3-48	42.37	21.95	42.67	4.27	12.55	-	0-21.3 dg, 21.3-27.4 g, 27.4-39.6 dg, 39.6-42.4 sc.
Old G.R.A.	BA 3	-	7-2-48	53.04	-	-	-	11.37	-	-
South of Wunti market	BA 4	10° 18' 48.4" N 9° 50' 1.6" E	14-2-53	91.44	18.30	31.70	3.35	12.73	65.84	0-53.5 dg, 33.5-53.3 sdg, 53.3-91.4 g.
Old G.R.A.	BA 5	10° 18' 41.8"nN 9° 49' 30.3 E	6-3-53	45.72	-	-	5.18	10.00	-	0-1.5 clay soil 1.5-7 hdg, 7.6-21.3 dg. 21.3-45.7 sdg.
Old G.R.A.	BA 12	10° 18' 35.2" N 9° 49' 21.0 E	-	60.05	-	-	10.67	5.46	23.46	-

g - granite. dg - decompsed granite. hdg - highly decomposed granite.

sdg - slightly decomposed granite. sc - sandy clay.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date completed	Total depth (m)	Screen position (m) From	to	SWL (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description & depth (m)
SE of GGSS	Ba 13	10° 20' 3.9" N 9° 51' 0.1" E	-	32.92	-	-	4.27	20.46	25.30	-
Airport area	BA 15	10° 17' 54.1" N 9° 49' 19.6" E	6-8-69	40.58	-	-	25.30?	18.18	20.73	-
Near Airport	BA 16	-	-	45.41	-	-	-	6.36	-	-
Old G.R.A.	BA.17	-	-	33.83	-	-	5.49	13.68	15.24	-
Old G.R.A.	BA 18	-	-	36.58	-	-	-	13.64	-	-
Near Airport	BA 19	10° 18' 5.6" N 9° 49' 29.1" E	13-3-70	36.58	-	-	31.39 ?	13.50	20.12	-
Near Airport	BA 20	10° 17' 45.9" N 9° 49' 13.8" E	-	39.62	-	-	18.59 ?	15.91	-	-
Near Coops	BA 21	-	14-1-71	37.49	-	-	4.27	13.64	12.19	0-1.52 top soil 1.52-37.5 granite

? = doubtful.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Bofehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	to	SWL (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description & depth (m)
Near Airport	BA 22	10° 18' 45.1" N 9° 49' 36.5" E	-	-	-	-	-	5.68	-	-
Near Airport	BA 23	10° 17' 55.8" N 9° 48' 55.0 E	21-6-71	29.26	-	-	-	16.37	18.90	-
Fadamar reke	Ba 24	10° 18' 36.9" N 9° 49' 58.3" E	3-3-71	40.84	-	-	2.44	15.91	47.07	-
Kofar Wambai	BA 26	10° 18' 54.9" N 9° 51' 24.8" E	3-6-75	29.90	18.30	24.38	1.16	7.36	22.70	0-183 ssc, 18.3 - 24.4 s, 24.4-27.4 sc, 27.4-29.9m
FGGC	Fg -1	10° 19' 19.6" N 9° 52' 31.6" E	1975	46.63	-		10.67	6.82	-	-
Kofar Wambai	BA 27	10° 18' 48.4" N 9° 51' 26.8" E	1976	36.58	19.81	27.43	2.41	3.64	-	0-19.8 ssc, 19.8-27.4 ssg, 27.4-36.6 sc.

ssc = silty, snad and clay. s = sand. sc = silty clay, m = monzonite

ssg = silty sands and gravels.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description & depth (m)
Kofar Wambai	BA 28	10° 18' 49.2" N 9° 51' 31.4" E	6-4-76	36.50	16.76	33.53	1.60	8.18	-	0-12.2 ssgc, 12.2-15.2 ssg, 15.2-18.3 sc, 18.3-35.0 ssg, 35.0-36.5 fm.
Kofar Wambai	BA 29	-	30-4-76	26.00	8.00	24.00	2.50	10.91	17.00	0-8 sgc, 8-24 wm, 24-26 fm.
Kofar Wambai &	BA 30	10° 18' 47.5" N 9° 51' 40.5" E	17-6-76	72.00	18.00	60.00	1.80	22.73	22.90	0-41 ssgc, 4-53. wm, 53-70 fissured dyke, 70-72 wm.
Old G.R.A.	BA 31	10° 18' 23.7" N 9° 49' 26.1" E	9-6-76	28.00	5.00	23.00	2.20	3.64	8.4	0-5 ss+c, 5-8 hwb, 8-2 fwb, 21-28 fb.
Old G.R.A.	BA 34	-	24-10-76	16.00	-	-	0.76	3.64	4.57	-

ssgc = silty, sandy gravelly clay. ssg = silty sand and gravels. sc = silty clay.

fm = fresh monzonite. wm - weathered monzonite. ss+c = silty sand with clay nodules,

hwb = highly weathered basement. fwb = fairly weathered basement. fb = fresh basement.

sgc = silty gravelly clay.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (m) below ground surface	Pumped yield m3/h	Drawdown (m)	Litholdgical description & depth (m)
Kofar Turum	BA 35	-	25-11-76	33.00	-	-	0.60	2.27	7.01	0-16 sgs, 16-19 hwb, 19-23 mwb, 23-33 fb.
East of meat factory	BA 36	-	10-1-77	24.38	13.00	22.00	1.83	4.55	4.27	-
Bakin Kura	BA 38	-	8-1-77	49.00	-	-	4.00	5.46	9.11	-
Bakin Kura	BA 39	10° 19' 23.9" N 9° 50' 22.2" E	2-3-77	46.00	-	-	3.00	9.09	13.00	-
SE of GGSS	BA 40	-	29-1-77	31.00	-	-	1.00	2.73	12.00	0-11 scs, 11-12 g+s, 12-13 swb, 13-31 fb.
South of GGSS	BA 41	10° 19' 57.4" N 9° 50' 50.6" E	7-2-77	37.00	-	-	1.00	1.14	19.00	0-2 c+g, 2-2 wg, 32-37 fg.

sgs = silty gravelly sand. hwb = highly weathered basement, mwb = moderately weathered basement.

fb = fresh basement. scs = silty clayey sand. g+s = gravels with sand. c+g = clay with gravels

wg = weathered granite. fg = fresh granite.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description & depth (m)
Specialist Hospital	BA 42	10° 19' 21.2" N 9° 49' 51.7" E	14-3-77	22.00	-	-	1.40	5.11	5.70	-
T. C. Yelwa	BA 44	-	26-4-77	34.00	-	-	2.20	9.09	11.80	-
Sululu	BA 45	10° 19' 15.8" N 9° 48' 25.2" E	30-6-77	31.00	12.00 24.00	17.00 26.00	3.11	6.36	8.90	0-18 gs, 18-22 wr, 22-26 gs, 26-31 fg.
Sululu	BA 46	10° 19' 22.3" N 9° 48' 29.3" E	18-7-77	25.00	10.00	15.00	2.60	4.55	6.40	0-8 cs, 8-10 wg, 10-18 s+g, 18-20 swg 20-25 fg.
East of Yelwa	BA 47	10° 16' 29.7" N 9° 48' 45.8" E	24-8-78	43.00	9.00 30.00	12.00 40.00	0.10	6.82	7.30	0-11 sandy soil 11-24 ss, 24-30 cs, 30-39 cg, 39-41 md, 41-43 fg.

gs = gravelly sand. wg = weathered granite. fg = fresh granite. cs= clayey sand

s+g = sand with gravels. swg = slightly weathered granite. ss = silty sand cg = clayey grit.

md = mafic dyke.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	to	SWL in (m) below ground surface	Pumped Yield m^3/h	Drawdown (m)	Lithological description & depth (m)
Gudum	BA 51	10° 16' 3.3" N 9° 51' 19" E	21-9-76	40.23	24.40 32.30	30.50 40.23	4.05	11.37	16.35	0-0.9 l, 0.9-1.8 hwg, 1.8-3.0 sc, 3.0-28.0 hwg+s+p 28.0-36.6 mwg, 36.6-4023 swg.
Gudum	BA 53	10° 16' 2.4" N 9° 51' 35.0" E	18-10-76	36.58	22.30	34.40	5.35	12.20	9.57	0-0.9 l, 0.9-9.1 hwg, 9.1-30.5 mwg 30.5-36.5 swg.
Gudum	BA 56	10° 15' 35.3" N 9° 51' 7.5" E	14-11-76	26.21	12.20	24.4	2.55	5.46	13.95	0-10.1 hwg, 10.1-25.3 mwg, 25.3-26.2 swg
Gudum	BA 57	10° 15' 24.6" N 9° 51' 7.5" E	3-11-76	19.81	6.70	18.90	6.35	5.46	8.68	0-3.0 l, 3.0-11.0 hwg, 11.0-14.0 mwg 14.0-16.8 Quartz vein, 16.8-19.8 swg.
Gudum	BA 58	10° 15' 29.6" N 9° 51' 28.9" E	9-12-76	33.22	19.20	31.39	5:10	6.66	13.60	0.30 l, 3.0-10.1 hwg, 10.1-32.0mwg, 32.0-32.2 swg.

l = Laterite. Sc = silty clay. s+p = sand and pebbles. hwg = highly weathered granite.

mwg = moderately weathered granite. swg= slightly weathered granite.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description
Gudum	BA 60	10° 15' 29.6" N 9° 51' 28.9" E	10-11-76	29.26	14.90	27.10	5.35	13.50	5.81	0-2.1 hwg+c, 2.1-16.2hwg, 16.2-28.0 mwg, 28.0-29.2swg.
Gudum	BA 62	10° 15' 38.4" N 9° 51' 37.2" E	12-12-76	28.35	14.30	25.50	2.28	7.27	14.25	0-0.9 1, 0.9-3.9 wg+c, 3.9-12.2 hwg, 12.2-27.1 mwg, 27.1-28.3 swg.
Gudum	BA 64	10° 15' 50.19"N 9° 51' 37.2" E	18-11-76	29.30	15.90	28.00	3.50	11.37	9.10	0-0.9 1, 0.9-6.1 wg+c, 6.1-12.2hwg, 12.2-28.0 mwg, 28.0-29.3 swg.
Lushi	BA 66	10° 16' 22.1" N 9° 48' 39.2" E	26-1-77	61.57	36.30 48.20	42.40 59.40	3.50	6.82	35.50	0-4 wg+c, 4-14.9 hwg, 14,9-48.1mwg, 48.1-49.4 ms, 49.4-50.3 mwg, 50.3-51.2 ms, 51.2-59.4 mwg, 59.4-61.5 swg.

hwg+c = highly weathered granite with clay. wg = weathered granite. mwg = moderately weathered granite.

swg = slightly weathered granite. ms = mica schist. wg+c = weathered granite with clay.

APPENDIX VIII CONTD

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen Position (m) From	To	SWL in (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description & depth (m)
Lushi	BA 68	10° 16' 3.3" N 9° 51' 46.2 E	30-3-77	58.33	36.90	53.30	3.00	8.18	33.00	0-2.1 bs, 2.1-5.2 s+c, 5.2-12.2 s+p, 12.2-34.1 wp, 34.1-40.2 gw , 40.2-51.2 wd, 51.2-58.8 swd.
Barkumbo	BA 70	10° 20' 4.7" N 9° 53' 40.8" E	10-2-77	37.18	17.70	30.80	2.13	9.56	10.65	0-0.9 top soil, 0.9-12.2 hwb, 12.2-20.1 mwb, 20.1-22.3 dd, 22.3-27.1 mwb, 27.1-37.2 swb
Barkumbo	BA 74	10° 20' 31.9"N 9° 53' 45.8" E	2-2-77	45.72	16.20 30.18	24.10 36.30	5.28	6.75	19.64	0-14.0 hwb, 14.0-16.2 mwb, 16.2-22.3 hwb, 22.3-23.2 mwb, 23.2-45.7 swb.
Barkumbo	BA 77	10° 20' 23.7"N 9° 53' 50.7" E	23-2-77	27.13	13.12	25.30	7.05	5.73	16.15	0-2.1 clay, 2.1-21.0 mwg, 21.0-27.1 swg.

bs = brown soil. s+c = sand and clay. wp = weathered pegmatite, gw = weathered gabbro.

swd = slightly weathered dolerite. dd = dolerite dyke. hwb = highly weathered bauchite.

mwg = moderately weathered granite. swg = slightly weathered granite. mwb = moderately weathered bauchite.

swb = slightly weathered bauchite.

APPENDIX VIII CONTD.

R RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (M) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description & depth (m)
Barkumbo	BA 82	10° 19' 58.2" N 9° 53' 52.4"E	1-3-77	34.14	11.90	28.0	3.30	10.91	7.71	0-4 hwb, 4-15.2 mwb, 15.2-26.2 mwa, 26.2-30.2 swb, 30,2-34.1 fb.
Barkumbo	BA 84	10° 20' 9.7" N 9° 54' 10.5"E	7-3-77	46.63	26.50	44.50	8.50	29.50	25.30	0-16.2 hwa, 16.2-41.1 mwa, 41.1-46.6 swqd.
Barkumbo	BA 85	10° 19' 52.5" N 9° 53' 44.1" E	17-2-77	28.65	14.90	27.10	3.30	6.77	22.33	0-17.1 hwb, 17.1-27.1 mwb, 27.1-28.6 swb.
Bigi	BA 101	10° 15' 12.3" N 9° 49' 24.5" E	18-6-78	57.30	29.00 47.20	41.20 51.20	5.40	7.14	36.90	0-26.2 s+c+p, 26.2-34.1 hwg, 34.1-49.1 mwg, 49.1-57.3 swg.
Bigi	BA 102	10° 15' 18.1" N 9° 49' 32.7" E	6-7-78	53.34	24.00	40.20	5.25	5.41	20.19	0-24 cssp, 24-34.1 hwg, 34.1-43.3 mwg, 43.3-47.2 swg, 47.2-53.3, fesh basalt.

hwa = highly weathered applite. mwa = moderate weathered applite. swqd = slighty weathered quartz diorite.

s+c+p = sand, clay and pebbles. cssp = alternating layers of clay, silt, sand and some pebbles. fb = fresh bauchite.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCH AREA

Locality	Borehole No.	Coordinates	Date Completed	Total Depth (m)	Screen position (m) From	Screen position (m) To	SWL in (m) below ground surface	Pumped yield m^3/h	Drawdown Yield (m)	Lithological description & depth (m)
Bigi	BA 106	10° 16' 11.5" N 9° 50' 11.5" E	29-4-78	44.50	17.10 35.36	27.10 43.3	1.95	10.46	12.80	0-9 csg, 9-18 hwg, 18-33 mwg, 33-41 swg, 41-44 fg.
Bigi	BA 117	10° 16' 32.0" N 9° 50' 22.2" E	17-7-78	37.19	16.10	32.30	2.96	9.48	4.97	0-2.1 sand, 2.1-7.9 wg, 7.9-17.1 mwg, 17.1-18.0 hwg, 18.0-35.1 swg, 35.1-37.1 fg.
Bigi	BA 118	-	29-7-78	43.28	16.20	32.30	2.98	7.96	13.87	0-2.1 clay, 2.1-6.1 hwg+c, 6.1-9.1 hwg, 9.1-13.1 clay granite wash and some pebbles, 13.1-31.1 mwg, 31.1-43.2 swg.
Bigi	BA 119	10° 16' 12.3" N 9° 49' 41.8" E	17-8-78	32.31	15.20 25.30	19.20 29.30	1.75	6.27	10.01	0-3 clay and silt, 3-6.1 fg, 6.1-14.0 mwg, 14.0-20.1 swg, 20.1-27.1 fg, 27.1-30.1 gv, 30.1-32.3 swg.

fg = fresh granite. hwg+c = highly weathered granite with clay. gv = granite vein.

see previous pages for more explanation.

APPENDIX VIII CONTD

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

207135

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	Screen position (m) To	SWL in (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description, depth (m)
Bigi	BA 120	10° 16' 27.1" N 9° 49' 41.8" E	30-9-78	44.20	18.00 36.3	28.00 40.20	2.32	6.55	25.57	0-4 sc, 4-7 cg, 7-9.1 sg, 9.1-22.3 hwg, 22.3-31.1 mwg, 31.1-41.1 swg, 41.1-44.20 fg.
B.T.C. Yelwa	BA 121	10° 16' 25.4" N 9° 48' 2.9" E	28-3-78	17.00	5.00	14.00	1.00	5.46	6.00	0-2 gravelly soil, 2-5 hwg, 5-15 swg, 15-17 fg.
B.T.C. Yelwa	BA 122	10° 16' 23.7" N 9° 48' 17,8"E	11-4-78	19.00	4.50	15.00	1.20	4.55	7.80	-
B.T.C. Yelwa	BA 123	-	24-5-78	15.00	-	-	1.00	2.27	9.00	-
South of B.T.C Yelwa	BA 124	10° 16' 13.6" N 9° 48' 24.3" E	13-6-78	15.00	7.00	13.00	4.80	3.64	4.00	-
South of B.T.C Yelwa	BA 125	10° 16' 17.2" N 9° 48' 5.4" E	24-7-78	19,00	10.00	16.00	3.00	3.64	6.00	0-7 Laterite, 7-10 wg+c, 10-17 wg, 17-19 fg.

Sc = Silty clay. wg+c = weathered granite with clay. sg. = sands and gravels.

hwg = highly weathered granite. mwg.= moderately weathered granite. swg = slightly weathered granite

fg = fresh granite.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	Screen position (m) To	SWL in (m) below ground surface	Pumped Yield m^3/h	Drawdown (m)	Lithologi cal description & depth (m)
G.G.S.S.	BA 126	10° 20' 22.0" N 9° 50' 54.6" E	21-8-78	20.00	8.00	17.00	1.00	6.82	9.00	0-4 ssg, 4-7 hwr, 14-14 wr, 14-18 swr, 18-20 fr.
Bacas	BA 127	16° 19' 59.5" N 9° 50' 36.7" E	3-10-78	22.00	11.00	19.00	1.83	4.09	12.78	0-4 cs, 4-6 ss, 6-17 wg, 17-22 fg
Kofar Rariya	BA 129	10° 19' 32.7" N 9° 50' 14.8" E	14-12-78	25.00	11.00	19.00	0.77	11.69	6.34	0-7 hwg, 7-19 wg, 19-25 fg.
Bakin Kura	BA 130	-	18-12-78	23.00	-	-	1.00	1.61	19.00	-
Kofar Wambai	BA 131	10° 18' 46.7" N 9° 51' 20.7" E	9-4-79	47.00	8.00 23.00 35.00	11.00 29.00 41.00	3.00	10.23	17.00	0-4 sc, 4-23 hwb, 23-26 md, 26-33 wb, 33-47 swb.

ssg = sands and silt with gravels. hwr = highly weathered bedrock. wr = weathered bedrock

swr = slightly weathered bedrock. fr = fresh bedrock. cs = clayey sand. ss = silty sand.

APPENDIX VIII CONTD:

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	Screen position (m) To	SWL in (m) below ground surface	Pumped Yield m^3/h	Drawdown (m)	Lithological description & depth (m)
Bakin Kura	BA 132	10° 19' 26.2" N 9° 50' 27.1" E	12-1-79	22.00	7.00	16.00	1.70	8.18	10.70	0-2 sc, 2-12 hwg, 12-19 swg, 19-22 fg.
Specialist Hospital	BA 133	10° 19' 30.3" N 9° 49' 56.6" E	25-1-79	40.00	16.00	34.00	1.20m	6.82	16.00	0-8 cg. 8-12 gss, 12.32 hwg, 32-36 swg, 36-40 fg.
Near Air-port	BA 134	10° 18' 5.7" N 9° 49' 6.9" E	1979	24.00	11.00	21.00	4.40	7.91	12.06	0-4 cs, 4-10 wg+c, 10-19 wg+s, 19-23 fg, 23-25 wg+s.
Near Air-port	BA 135	-	1979	46.00	19,00	34.00	4.27	6.82	3.35	0-13 s+g, 13-17 gs+c, 17-27 hwb, 27-34 mwb, 34-38 swb, 38-46 fb.

Sc = silty clay, cg- clayey gravels. gss - gravels sand and silt. wg+c = weathered granite with clay, wg+s = weathered granite with sand. s+g - sand and gravels gs+c = gravels with sand and clay. fb = fresh basement.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (m) below ground surface	Pumped yield m^3/h	Drawdown (m)	Lithological description & depth (m)
NW of Baskin hill	BA 139	10° 17' 13.9" N 9° 46' 25.5" E	30-10-82	27.50	7.50	17.50	2.70	2.50	13.00	-
NW of Baskin hill	BA 141	10° 17' 32.3" N 9° 46' 18.6" E	21-1-83	43.00	17.00	40.00	2.70	3.40	16.65	-
East of Specialist Hospital.	BA 144	-	3-3-83	33.00	6.00	10.00	0.90	4.09	11.20	-
NW of Baskin hill	BA 145	10° 17' 2?.9" N 9° 46' 12.2" E	26-3-83	52.00	10.00	20.00	3.10	3.41	23.65	-
NW of Baskin hill	BA 146	10° 17' 19.6" N 9° 45' 52.7" E	9-4-83	52.00	11.00	21.00	2.15	5.46	11.00	-
Water Board Premises	BA 147	-	16-4-83	25.00	18.00	23.00	3.00	3.86	12.00	-
Fadar Mada	BA 148	-	30-4-83	40.00	6.00	10.00	2.20	3.18	11.30	-

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (m) below ground surface	Pumped Yield m^3/h	Drawdown (m)	Lithological description. & depth (m)
Tafawa Balewa Estate	BA 150	10° 19' 32.2" N 9° 51' 25.6" E	25-8-83	50.00	20.00	32.00	2.52	2.73	20.00	0-8 L, 8-30 wg, 30-50 fg (fractured
Tafawa Balewa Estate	BA 151	10° 19' 53.3" N 9° 51' 19.0" E	16-11-84	33.00	16.00	22.00	4.07	5.91	12.50	-
Near Airport.	BA 154	-	10-7-84	37.00	12.00	20.00	2.85	7.73	17.15	-
School of Agric	Ag-1	10° 17' 2.2" N 9° 48' 2.9" E	13-12-79	27.40	-	-	2.93	6.18	17.72	-
University Near stream	U-2	10° 16' 33.6" N 9° 47' 11.8" E	31-7-82	27.00	15.00	20.00	3.80	4.09	13.70	-
University	U-3	10° 16' 48.4" N 9° 47' 49.7" E	-	24.00	12.20	15.20	-	-	-	-
Polytechnic	P-4	10° 15' 9.0" N 9° 46' 5.1" E	27-10-83	24.50	10.50	16.00	2.30	3.86	7.60	-
Polytechnic	P-5	10° 15' 14.0" N 9° 46' 5.1" E	6-11-83	28.75	14.00	25.00	2.55	5.46	7.00	-

L = Laterite. wg = weathered granite. fg = fresh granite.

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCH AREA

Locality	Borehole No.	Coordinates	Date Completed	Total depth (m)	Screen position (m) From	To	SWL in (m) below ground surface	Pumped Yield m^3/h	Drawdown (m)	Lithological description
AArmy Barracks	A-6	10° 20' 10.5" N 9° 49' 38.2" E	1986	35.94	-	-	4.55	6.55	18.06	-
Army Barracks	A-8	10° 20' 0.0" N 9° 49' 35.2" E	1986	26.70	-	-	8.70	6.55	12.91	-
Army Barracks	A-10	10° 19' 29.4" N 9° 49' 18.7" E	1986	45.82	-	-	3.75	12.98	12.60	-

APPENDIX VIII CONTD:

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Screen position (m) From	To	SWL in (m) below ground surface	Yield m^3/H	Drawdown (m)	Lithologic description. & depth (m)
BSADP HQ	149 NE-1	10° 16' 50.1" N 9° 48' 47.4" E	17-4-82	-	-	-	-	-	0-15 highly to moderately decomposed granitic rock, 15-30 pd gn, 30-36 b slightly fractured 30-40 fm, 40-44fb.
Wutin Dada	149 NE-2	10° 19' 4.0" N 9° 45' 51.9" E	25-5-82	10.0	14.0	5.50	-	-	0-9 hdgn, 9-14mdgn
BSADP HQ	149 NE-3	10° 16' 49." N 9° 48' 38.4" E	3-12-82	26.0	41.0	3.55	12.84	27.8	0-3 L, 3-6 pdgn, 6-19 hdgn, with some pegmatite layers, 19-24 pdgn fractured, 24-36 pdgn, 36-42 mdp
Gwallameji	149 NE-5	10° 15' 18.1" N 9° 46' 41.4" E	25-2-85	14.0	18.0	3.88	-	-	0-1 L, 1-3 Lateritic clay, 3-6 hdgn 6-18 mdgn, 18-40 pdgn.

hdgn = highly decomposed gneiss. mdgn = moderately dedomposed gneiss. pdgn = poorly decomposed gneiss

fb = fresh basalt. L = Laterite. mdp = moderately decomposed pegmatite. fm = fresh migmatite.

b = basalt

APPENDIX VIII CONTD.

RECORDS OF SOME BOREHOLES IN BAUCHI AREA

Locality	Borehole No.	Coordinates	Date Completed	Screen position (m) From	To	SWL in (m) below ground surface	Yield m^3/h	Drawdown (m)	Lithologic description & depth (m)
Gurtu	149 NE-7	10° 18' 4.8" N 9° 45' 2.5" E	15-3-85	13.0	21.0	5.52	-	-	0-8 hdrx, 8-13 mdrx, 13-25 pdg + pdp
Zamfara	149 NE-9	10° 20' 28.6" N 9° 46' 9.2" E	16-385	13.0	25.0	12.36	-	-	0-1 top soil, 1-25 mdg
Tirwun	149 NE-9	10° 21' 14.6" N 9° 53' 6.2" E	9-3-85	13.0	25.0	6.20	-	-	0-1 top soil, 1.20 mdgn, 20-25 fgn
Miri	149 NW-7	10° 18' 54.8" N 9° 44' 49.7" E	28-5-82	10.0	18.0	7.05	-	-	0-14 highly to moderately decomposed biotite gneiss, 14-18 mdgn.

hdrx = highly decomposed crystalline rock. mdrx = moderately decomposed crystalline rock.

pdg = poorly decomposed granite. pdp = poorly decomposed pegmatite. mdg = moderately decomposed granite

fgn = fresh gneiss. mdgn = moderately decomposed gneiss.

APPENDIX IX

CHEMICAL ANALYSIS OF WATER SAMPLES

	CONCENTRATION IN mg/l							
Borehole no. or location	2	5	10	22	23	24	30	31
Date analysed	7-8-79	7-8-79	6-5-78	7-8-79	7-8-79	7-8-79	6-5-78	28-6-78
pH	6.9	7.9	8.1	7.5	6.9	7.5	8.3	7.5
Phenolphtalin Alkalinity ($Ca\ Co_3$)	1.0	2.0	0.5	1.5	nil	1.50	1.0	2.0
Methylorange Alkalinity ($Ca\ Co_3$	136.0	11.80	120	114.0	35.0	122.0	119.0	70.0
Total Hardness ($CaCo_3$	99.66	81.7	91.49	73.62	57.46	110.43	96.12	63.01
Calcium (Ca^{2+}	27.76	23.43	26.73	21.63	14.78	35.69	28.16	18.01
Magnesium (Mg^{2+}	7.45	5.7	6.08	4.82	5.04	5.26	6.34	4.43
Chloride (Cl^-)	4.0	5.9	3.10	3.3	3.9	21.10	3.0	14.8
Nitrite Nitrogen	Nil	0.01	0.003	0.007	nil	0.23	0.004	Nil
Nitrate Nitrogen	1.32	1.76	0.5	2.2	0.88	7.92	0.40	0.04
Ammonia Nitrogen	0.12	0.12	0.04	0.12	0.06	0.16	0.03	0.12
Sulphate (SO_4^{2-})	Nil	2.0	3.0	nil	nil	2.0	2.5	7.0
Iron (total)	0.03	0.08	0.05	0.02	0.07	0.02	0.09	0.02

Analysed by Water Resources and Engineering Construction Agency (WRECA), Kano State.

APPENDIX IX CONTD

CHEMICAL ANALYSIS OF WATER SAMPLES

Borehole no. or location	CONCENTRATION IN mg/L							
	2	5	10	22	23	24	30	31
Date analysed	7-8-79	7-8-79	6-5-68	7-8-79	7-8-79	7-8-79	6-5-78	28-6-78
Free Carbon Dioxide	nil	nil	nil	nil	13.20	nil	nil	nil
Dissoved Oxygen	nd	nd	nd	nd	nd	nd	nd	nd
Chemical Oxygen Demand	0.63	0.56	1.39	0.49	0.70	0.77	1.46	2.44
Silica (Sio_2)	nd	nd	72.5	nd	nd	nd	57.5	nd
Flooride (F^-)	nd	nd	0.93	nd	nd	nd	0.86	nd
Total Dissolved Solids	180	155	180	130	100	225	180	60
Suspended Solids	20	25	30	20	20	25	20	72
Consuctivity (micro ohm/cm	200	180	205	154	120	250	200	132

Analysed by Water Resources and Engineering Construction Agency (WRECA), Kano State

APPENDIX IX CONTD

CHEMICAL ANALYSES OF WATER SAMPLES

	CONCENTRATION IN mg/L							
Borehole no. or location	39	42	127	129	131	132	Gudum	Gubi dam
Date analysed	7-5-79	31-5-79	-	31-5-79	31-5-79	7-5-79	6-5-78	7-5-79
PH	6.4	7.1	7.3	6.9	7.5	6.9	7.9	7.3
Phenolphtalin Alkalinity ($CaCo_3$)	nil	nil	0.0	6.00	nil	nil	1.0	nil
Methylorange Alkalinity ($CaCo_3$)	141	81.0	91.0	182.0	119.0	116	119.0	83.0
Total Hardness ($CaCo_3$	201.11	61.05	78.0	250.5	116.72	115.7	96.12	54.0
Calcium (Ca^{2+})	66.33	15.14	19.8	69.18	35.69	29.9	32.88	16.22
Magnesium (Mg^{2+})	8.76	3.7	3.0	18.84	6.79	8.98	3.47	3.50
Chloride (Cl^-)	55.3	9.10	5.0	65.5	19.10	26.6	3.20	5.90
Nitrite Nitrogen	0.23	0.007	0.03	0.007	0.04	0.07	0.002	nil
Nitrate Nitrogen	14.08	1.32	3.52	2.2	6.60	3.52	0.40	0.88
Ammonia Nitrogen	Nil	0.10	0.001	0.18	0.14	nil	0.05	0.12

Analysed by Water Resources and Engineering Construction Agency (WRECA), Kano State.

APPENDIX IX CONTD

CHEMICAL ANALYSES OF WATER SAMPLES

	CONCENTRATION IN mg/l							
Borehole no. or location	39	42	127	129	131	132	Gubi	Gubi dam
Date analysed	7-5-79	31-5-79	-	31-5-79	31-5-79	7-5-79	6-5-78	7-5-79
Sulphate (SO_4^{2-})	30.0	nil	nil	20.0	0.02	7.0	3.0	nil
Iron (total)	0.52	nil	0.05	0.02	0.02	0.16	0.15	0.15
Free Carbon Dioxide	18.3	6.20	8.40	nil	7.87	11.48	nil	5.19
Dissloved Oxygen	nd	nd	nd	nd	nd	nd	nd	nd
Chemical Oxygen Demand	0.77	0.35	1.75	0.42	0.42	0.70	1.6	4.18
Silica (SiO_2)	nd	nd	nd	nd	nd	nd	70.0	nd
Fluoride (F^-)	nd	nd	nd	nd	nd	nd	0 .61	nd
Total Dissoved Solids	300	100	160	280	125	180	180	70
Suspended Solids	20	20	20	20	25	20	20	30
Consuctivity (micro ohm/cm)	320	112	175	290	150	205	210	104

Analysed by Water Resources and Engineering Construction Agency (WRECA) Kano State.

APPENDIX IX CONTD:

CHEMICAL ANALYSIS OF WATER SAMPLE

Location	Borehole no. 3	
PH	7.4	
NH_4^+	0.002	m/L
NH_4 organic	0.025	mg/L
Na^+	14.025	mg/L
K^+	trace	mg/L
Mg^{++}	12.75	mg/L
Ca^{++}	8.59	mg/L
Al^{+++}	nil	mg/L
Fe^{++} and Fe^{+++}	0.08	mg/L
Cl^-	nil	mg/L
F^-	0.6	mg/L
NO_3^-	0.5	mg/L
NO_2^-	nil	mg/L
SO_4^{--}	trace	mg/L
HCO_3^-	117.4	mg/L
CO_3^{--}	nil	mg/L
SiO_2	130	mg/L
Total Dissoved solids	283.97	mg/L
SAR	0.5	

APPENDIX X

BACTERIOLOGICAL EXAMINATION OF WATER SAMPLES

Date and time collected	6-8-79 7.10am	6-8-79 7.02am	29-5-79 6.42am	6-8- 79 6.55am	6-8-79 6.33am	6-8-79 7.22am	7-5-79 7.40am
Date and time examined	7-8-79 9.30am	7-8-79 9.30am	30-5-79 9.10am	7-8-79 9.30am	7-8-79 9.30am	7-8-79 9.30am	7-5-79 3.25pm
Location or Borehole no.	2	5	10	22	23	24	30
Nature of Sample	raw	raw	raw	raw	raw	raw	raw
PH	6.9	7.3	7.1	7.5	6.9	7.5	7.3
Growth on nutrient agar at 37°c for 2 days	250	>300	150	>300	>300	>300	25
Most probable number of coliform organism per 100ml	nil	16	nil	18	3	18	18
Most probable number of Escherichia Coli per 100ml	nil	nil	nil	3	3	nil	18
Free Chlorine mg/L	nil	nil	nil	nil	nil	nil	nil
Total Chlorine, mg/L	nil	nil	nil	nil	nil	nil	nil

Examined by WRECCA. Kano State.

APPENDIX X CONTD

BACTERIOLOGICAL EXAMINATION OF WATER SAMPLES

Date and time collected	7-5-79 7.07am	29-9-79 7.45am	29-5-79 7.22am	29-5-79 7.10am	7-5-79 7.15am	7-5-79 8.00am
Date and time examined	7-5-79 3.25pm	30-5-79 9.10am	30-5-79 9.10am	30-5-79 9.10am	7-5-79 3.25pm	7-5-79 3.15pm
Location or Borehole no.	39	42	129	131	132	Gubi dam
Nature of sample	raw	raw	raw	raw	raw	raw
PH	6.4	7.0	6.9	7.5	6.9	7.3
Growht on nutrient agar at 37°c for 2 days	100	>300	>300	>300	40	200
Most probable number of coliform organism per 100ml	nil	18	18	nil	18	18
Most probable numbers of Escherichia Coli per 100ml	nil	12	3	nil	nil	nil
Free Chlorine mg/L	nil	nil	nil	nil	nil	nil
Total Chlorine, mg/L	nil	nil	nil	nil	nil	nil

*Examined by WRECCA. Kano State.

APPENDIX XI CONTD

WATER STANDARDS

Sodium Absorption Ratio (SAR)

Two principal effects of Sodium (Na) in the soil are hardening of the soil and reduction in the soil permeability. Both are caused by replacement of Calcium (Ca) and Magnesium (Mg) ions by sodium ions.

The United States salinity Laboratory (1954) recommended the use of SAR as the basis for classification of irrigation water. The ratio is expressed as:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

This ratio is calculated from the concentration of the ions in milligrams equivalent per liter.

Recommended water classification based on SAR are:

SAR	Water class
10	Excellent
10 - 18	Good
18 - 26	Fair
26	Poor.

APPENDIX XI

WATER STANDARDS

International standards for Drinking water (WHO) 1971).

	Permissible (P.P.M)	Excessive (P.P.M)
Magnesium (Mg)	50.0	150.0
Calcium (Ca)	75.0	200.0
Iron (Fe)	0.1	1.0
Maganese (Mn)	0.05	0.5
Copper (Cu)	0.05	1.5
Zinc (Zn)	5.0	15.0
Flouride (F)	0.5	1.5
Chloride (Cl)	200.0	600.0
Nitrate (NO_3)	50.0	100.0
Sulphate (SO_4)	200.0	400.0
Total hardness	100 (as $CaCo_3$)	500 (as $CaCo_3$)
Total Dissoved solids	500.0	1,500.0
PH range	7.0 - 8.5	6.5 - 9.2

Toxic substances in drinking water (WHO 1971)

Substance	Maximum Permissible (mg/l)
Lead (Pb)	0.05
Selenium (Se)	0.01
Arsenic (As)	0.05
Cyanide	0.05