GROUNDWATER OCCURRENCE IN DAMATURU AND ITS ENVIRONS YOBE STATE, NORTH EASTERN NIGERIA

BY

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M.Sc/SCIEN/01126/2006-07

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY ZARIA NIGERIA, IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN APPLIED GEOLOGY (HYDROGEOLOGY)

DEPARTMENT OF GEOLOGY
FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY ZARIA
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JUNE, 2011

DEDICATION

This Research Work is dedicated To Allah (S.W.T) *our creator for showing me this moment in my life. Also to my late mother Mama Bintu Mustafa, may Allah (SWT) grant her Aljannat -firdaus, Ameen.*

DECLARATION

I declare that the work in this dissertation entitled ‘‘Groundwater occurrence in Damaturu and its environs Yobe State, north-eastern Nigeria’’ has been done by me in the Department of Geology, Faculty of Science, Ahmadu Bello University Zaria, under the supervision of Dr. S.A. Alagbe and Dr. U.A. Danbatta.

All information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any University.

Kachalla Musa _____ _____

Signature Date

CERTIFICATION

This dissertation entitled "Groundwater occurrence in Damaturu and its environs Yobe State, northeastern Nigeria" by Kachalla Musa meets the regulations governing the award of degree of Master of Science in Applied Geology (Hydrogeology) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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ACKNOWLEDGEMENT

In the name of Allah most gracious most merciful. All praises are due to Almighty Allah (S.W.T) for sparing my life to see the conclusion of this programme. My appreciation goes to my lecturers and supervisors in the department; these include Dr. S.A. Alagbe who is my major supervisor and had help me greatly in realizing this work, Dr U.A. Danbatta is my minor supervisor and has assisted me greatly with literatures and a lot of constructive criticisms which helped me shape my work to this standard. The critical observations and comments of both my supervisors have assisted in no small measure in the completion of this work.

I must express my thanks to Professor P. M. Zaborski who was the immediate past HOD, Professor Garba, Professor E. C. Ike, Professor K. Schoeneich, Dr. M. L. Garba, Dr. A. E. Ikpokonte, Dr. E. A. Bala, Dr. A. A. Ibrahim, Malam A. Yusuf, Malam I. Hamidu and Mr J. Ayok. They have been of tremendous help to me in one way or the other.

I will not forget the contribution of the members of my family towards actualizing this dream, starting with my Father (Baba Musa) and all my younger sisters and brothers. To my little kids – Baba, Abubakar Sadiq and Al-ameen and their supportive and caring mother Fatima, I appreciate your consistent prayers and patience throughout my tedious stay in Zaria.

May Allah reward my ever supportive and caring friends such as Arc. Haruna, Engr. Abubakar Barma, Mohammad Usman Dapchi (in whose car we undertook my fieldwork), Baba Samaila, Abdulmumin, Sadiq and Aminu Abdullahi Chiromari, for all their contributions toward the success of this thesis. I am also grateful to all my other

friends too numerous to be mentioned here that have contributed in one way or the other.

I also appreciate the assistance of my office senior colleague in person of Baaba Habu- new Head of Department Planning Research and Statistics and that of Muhammad Usman Audu I thank you. my collegue Musa Mohd Zanna who assisted me immensely on the analysis of my water samples am grateful. To Habu CS, Mohd Amshi and many others too numerous to mention here, I say thanks for all your concern and assistance.

Here in ABU Zaria, my class mates such as Mr. Guideal Roland (from Chad Republic) has been a wonderful friend and helpful to this work, Maryam Tafida of Shell Petroleum, Ibrahim Laaro, Anzaku of the FRSC, and Musa Kizito have been good friends. To members of our extended families included Dr. Abdulrahman Muhd, Dr. Abdulrahman Mustafa, Rabiu Adamu (Mutum Rabiu), Habu T. Abba, Dr. Baa Goni, Bana Wali, Sidi Waru, and Zanna Barma; I acknowledged your encouraging supports and prayers.

I will not conclude this acknowledgement without recognizing the support I enjoyed from my Programme Manager of the African Development Bank - Assisted Rural Water Supply and Sanitation, Yobe State Sub-Programme; in the person of Engr Musa Haruna Chalimno (Sarki), my collegues in the programme Bukar Aji Bukar (Project Accountant), Muhd Dagona (Procurement Specialist), Fatsuma Bala Geidam (M & E Officer), Ali B. Mohd (Sanitation Officer) as well as Muhammad Maisaje, Abba Umar, Umar El-badawy, Ya'u Usman and Nasiru Yahaya.

I will finally wish to extend my appreciation to the General Manager Yobe State Water Corporation Eng. Usman Ahmed for his contribution to the successful completion of this work. To our senior colleague Dr. Abubakar Garba Iliya the current MD of Chad Basin Development Authority (CBDA) Maiduguri who excelled in his chosen profession and contributed immensely to the growth of water industries of Yobe State, I will not forget your assistance.

Any omission is unintentional and quiet regretful.

KACHALLA MUSA (2011)

ABSTRACT

Groundwater occurrence in Damaturu and its environs was studied from data of boreholes and hand dug wells in Damaturu town and its surrounding villages of Sindiri, Digmari, and Malmattari. Elevation of water level in hand dug wells and static water levels of boreholes as well as wells coordinates were used to construct the configuration of water table map. Groundwater level fluctuation in the water table (phreatic) aquifer, direction of groundwater flow, cross-sectional view of the sub-surface geology/lithology were determined. Two major groundwater depressions were established from the hydrogeological map, these was created due to over pumping of the aquifers of Chad Formation in the area. also groundwater ridge created by the River Damaturu and the large pond which subsequently changed the river regime from effluent to influent was established from a cross-section. Groundwater within the aquifers of Chad Formation is the singular source of fresh water in the study area. The Chad Formation consists of aquifers that are shallow (water table aquifer) and deep ones. Water levels measured reveal that water tables are shallower in areas with elevation less than 368 m above sea level and in the *fadama* areas at the surrounding village of Digmari. Groundwater flow is to the north-eastern direction. Negligible seasonal variation in water levels less than 2 m show little recharge of aquifer. A total of 15 water samples from boreholes, five water samples from hand dug wells and surface water in the large pond located at the central part of the study area were analyzed for their chemical contents. Major cations and anions analyzed both in hand dug wells and boreholes includes sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg),bicarbonate (HCO_3), chloride (Cl) and sulphate (SO_4).

Aquifer characteristics in the study area using borehole pumping test data as evaluated show that transmissivity (T) values of the aquifer from ten boreholes ranges from 4.1 x 10^{-1} m^2/day to 45.0 x 10^{-3} m^2/day with a mean value of 15.45 x 10^{-2} m^2/day. These values fall under moderate potentials as classified by Gheorghe standards. Hydraulic conductivity (K) ranges between 1.4 x 10^{-1} m^2/day to 9.3 x 10^{-3} m^2/day with a mean value of 5.07 x 10^{-3} m^2/day, and the values show that the hydraulic conductivity of the aquifer in the study area is good, going by Bouwers standards. The storage coefficient (S) as calculated for the 10 boreholes ranges from 1.1 x 10^{-1} to 6.4 x 10^{-1} with an average of 3.13 x 10^{-1}, confirming good performance of the confined aquifer in the study area.

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ACRONYMS

DTWL - Depth to Water Level in Meters Below Ground Level

GPS – Global Positioning System

GL – Ground Level (masl)

GIS - Geographic Information System

Km – Kilometre(s)

Km^2 - Square Kilometre(s)

Km^3 – Cubic Kilometre(s)

litres/s/m – Litres per Second per Metre

Mb - Millibars (Unit for measurement of atmospheric pressure)

mbgl - Metre(s) below ground level

masl - Metre(s) above sea level

m – Metre(s)

m^2 - Square Metre(s)

m^3 – Cubic Metre(s)

m^3/a – Cubic Metre(s) per annum

m^3/d – Cubic Metre(s) per day

m/year – Metre(s) per year

PVC – Poly Vinyl Chloride

S.W.L – Static Water Level

T.D.D - Total Depth Drilled in Meters

CHAPTER 1

1 INTRODUCTION

1.1 BACKGROUND

People's lives and livelihoods depend on clean water, demand for clean and fresh water increases in line with the population growth of that area. People in many areas of the world lack the basic fresh, drinkable water essential to their survival, if they are to prosper, more secure and low cost water supplies are needed. Maintaining secure water supplies for drinking, industrial and agricultural activities would be impossible without groundwater, the largest and most reliable of all freshwater resources (Planetearth, 2005).

The rapid increase in population as well as the industrial and agricultural expansion of Damaturu and its surrounding environs has led to inadequate water supply to the growing number of inhabitants of the area and their animals. With great awareness of the problems of acute potable water supply faced by the teaming population of Damaturu and its environs, a programme known as Damaturu Water Supply Scheme was initiated by the Federal Government of Nigeria in conjunction with Yobe State Government in 2002. This was to exploit and provide adequate and safe water for human and animal consumption from the groundwater resources in three well fields in Damaturu for social and economic development of the people. The project reached a certain level and was stopped due to non funding from both governments, it would have solved the water supply problem of the area were it completed as planned.

It is therefore with the afore mentioned information of water supply history of Damaturu and environs in mind and the present acute water supply situation to the inhabitants and also the need to encourage and increase irrigation activities in the area, a study to investigate and asses the hydrogeological situation and provide detailed information of groundwater occurrence within the aquifer of Chad Formation was carried out. These information would be useful to the people and government for effective water management within the study area.

1.2 AIM OF THE STUDY

This study is aimed at carrying out a comprehensive study of the groundwater occurrence in the Chad Formation aquifers in Damaturu and its environs, based on information derived from measurements of water levels in hand dug wells during dry and wet seasons and Static Water Levels in boreholes. It is intended to serve as a database for reference purposes. It will also update available records. At the end of this work, the following is expected to be achieved:

i. Prepare inventory of water points (boreholes, hand dug wells, ponds) in the study area.
ii. Study all the geographical and geological features of the area. These include location and depth of occurrence of shallow and deep aquifers.
iii. Provide professional advice on how best to design tube wells free of contaminated water.

1.3 THE STUDY AREA

The study area, Damaturu and environs comprises Damaturu town, Sindiri, Malmattari, and Digmari, villages. Damaturu is the capital of Yobe State since 1991. The study area occupies an area of approximately 408 km^2 situated entirely within the Chad Basin, and

bordered by Gujba, Fune and Bursari Local Government Areas in Yobe State, and Ngamdu in Borno State respectively.

1.3.1 Location and Accessibility

The study area is located in the north eastern part of Nigeria some 130 km west of Borno State (Fig. 1). The area is located on the Federal Survey of Nigeria (F.S.N) Sheet 87 and its coordinates are $11^0$55'94" to $11^0$59'06"N and 11^0 41'71" to $11^0$43'12"E.

The study area has a number of trunk 'A' roads linking it to the neighbouring states of Borno, Adamawa, Jigawa and Bauchi and to the neighbouring Niger Republic. Some few untarred roads, footpaths and cattle tracks link the study area to surrounding villages and farms, these made the area highly accessible. Telephone services and networks are fully available in the study area thereby making communication very easy.

1.3.2 Relief and Drainage

The study area is generally flat with an average height of about 315 m above mean sea level (amsl). There is a large pond at the central part of Damaturu town, river Damaturu that drains the study area together with its tributaries passes through Damaturu and forms a dendritic drainage pattern. The river flows in the southwest-northeast direction cutting across the study area including the large pond, which forms part of the drainage system of the area. It is usually filled with water during the rainy season and many species of plants and insects thrive in it. The water in the pond is normally unfit for drinking because the residents around that area dump their waste in to it and also children whose homes are around directly defecate in the pond during dry season.

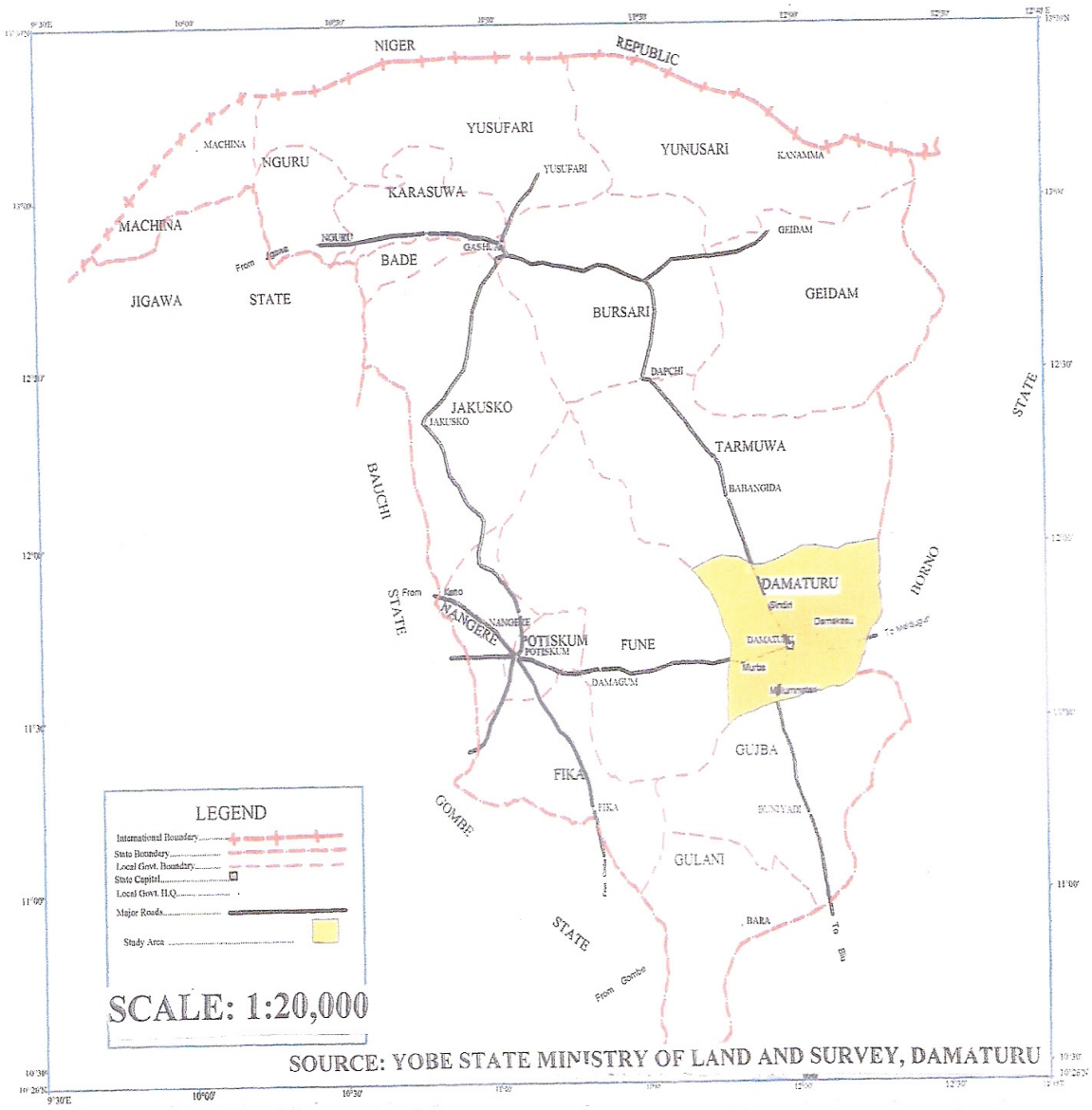


Fig 1: MAP OF YOBE STATE SHOWING THE STUDY AREA

1.3.3 Climate

The study area has a humid, tropical climate consisting of a single long dry season with its peak around April, followed by a shorter wet season with its peak in August. It is located on northern most Sudan Savannah which bordered the Sahel Savannah. Rainy season starts in June and ends in September, while the dry season starts in September and ends in May.

The data on rainfall (Appendix III) are presented in Figure 2 below; there are no precipitations from January to March in the study area. Rainfall starts from April to May and June, the peak of the rainy season is reached in August with much of the rain falling within that period. Towards the end of the year, no precipitation is recorded. From 2002 to 2008, the highest rainfall was recorded in 2005, although data for 2007 was not available at the time of this work. All the surface water that collects during rainy season in ponds and rivers dries up as soon as rainfall ceases. The high temperature in the study area leads to evaporation, while the loose nature of soil in the area leads to rapid percolation of water into the ground. The soil of the study area consists of a wide spread series of sand, clay, silt and sandy clay.

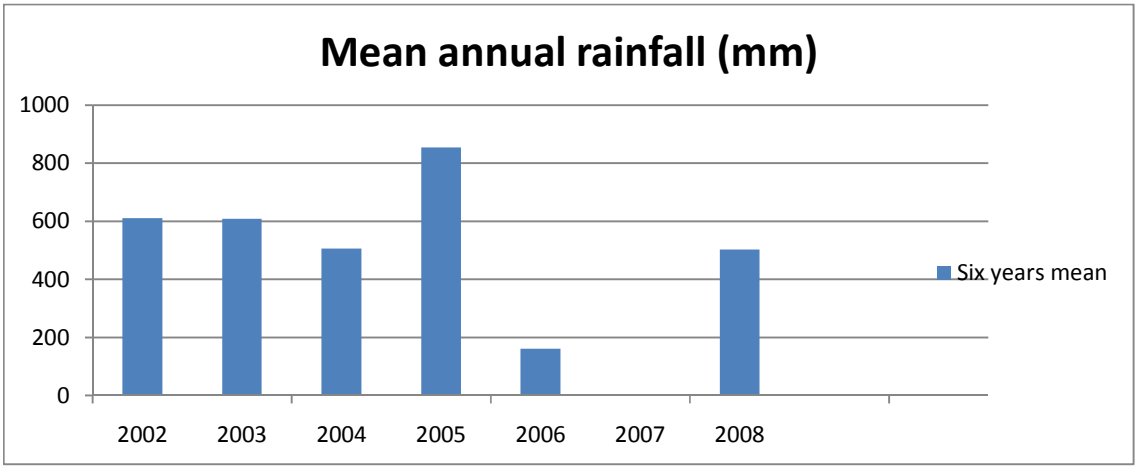


Fig. 2: Mean annual rainfall (mm) from 2002 to 2006 and 2008
(Source: Yobe State Agricultural Development Programme, 2010).
Average mean for 6 years = 540.32 mm/a.
Coordinates of Met Station: Lat. N11^{0}41.784 Long. E011^{0}56.864

1.3.4 Vegetation

The vegetation cover in the area consists of sparsely populated large trees such as baobabs, tamarind, neem with shrubs and grasses. Shrubs are visible throughout the year while grasses could not remain due to over grazing by animals and direct human use for thatched roofing, house fencing, cooking fuel, and crafts such as baskets weaving, mats and local fans. Typical examples of such grasses could be seen in Plate I where they surround a concrete lined well in the rainy season.



Plate I. Concrete lined well in Murba village, outskirt of Damaturu. Note the typical vegetation of the study area at the background (Photo: K. Musa, 2008) Coordinates: Lat. $11^0$42′ 08.5″ Long. $11^0$50′17.3″

1.3.5 People and Land use

The major ethnic groups in Damaturu and its environs are the Kanuri, Fulani, Hausa, Karekare, Bolewa, Bade, Ngizim, Babur and Shuwa-Arabs, these are the indigenous ethnic groups in Yobe State, while Igbo, Yoruba and people from the Niger Delta are other ethnic groups leaving in the area.

Most of the residents in the study area are civil servants and businessmen, while majority of those residing in the villages are peasant farmers and petty traders. Within the urban part of the study area (Damaturu/Maisandari), majority of the people are civil servants who practice farming during rainy season, a few have orchards, poultry farms and fish farms. This increases the economic viability of the people of the area greatly.

A multiple land use system is usually adopted by the people of this area, with the land cultivated during the short rainy season (June - September) during which variety of crops is grown. These include sorghum, millet and maize, cash crops grown include groundnut, beans, cotton and some few people cultivate gum Arabic for export. The *fadama* area within this study area (especially around Digmari) is cultivated for rice in small scale. Soil fertility is increased by adding fertilizer, animal waste, ash from dump sites and human waste. The land is also used for grazing of animals such as cattle, sheep, goat and camel. Crop production during rainy season and livestock rearing including the use of hay are the major source of livelihood of the rural populace of the area.

1.4 PREVIOUS WORKS

Falconer (1911) was the first to describe the Chad Formation and dated it as Pleistocene in age with a thickness of up to 840 meters. Raeburn and Jones (1934) named the Chad Formation as the “Chad Group” and dated it Quaternary in age. The dating of the Chad

Formation is based on vertebrate remains of the Lower Pleistocene. Barber and Jones (1960) then divided the Chad Formation into three water-bearing zones which were designated Upper, Middle and Lower aquifers. The Upper zone consists of wide spread series of inter-bedded sand, clay and sandy clay which extends from the surface to an average depth of about 60m but locally to 180m. Barber (1965) stated that the Chad Formation is essentially an argillaceous sequence with minor arenaceous horizons.

Du Preeze and Barber (1965) studied the distribution and chemical quality of groundwater of Northern Nigeria. The result indicated that the Upper aquifer is slightly acidic with high sodium bicarbonate, silica and low total dissolved solids. Investigation carried out by Beacon Services Limited (1979) subdivided the Upper zone aquifer into three units, an upper 'A' unit under water-table conditions and underlying 'B' and 'C' units which are semi-confined and/or confined. The work of Zanna (2005) investigated the concentration of fluoride in water samples from 39 boreholes and nine hand-dug wells in relation to dental fluoresis in Damaturu and found out that water from three boreholes have fluoride concentrations more than the WHO permissible limit.

Exploration carried out by Yusuf (2006), 37 Vertical Electrical Soundings (VES) in a geophysical arrays were conducted in Damaturu, where he found out that the third layer is the water bearing zone in the area. It has a mean thickness of 73m and resistivity value of 359Ωm and appears to continue laterally throughout the study area.

Dawoud and Abdulraouf, (2002) carried out investigation on the aquifers discharge using 29 productive wells and observed that about 10,000 m^3/day of water is abstracted from shallow alluvial groundwater aquifer. Groundwater flow model was calibrated to

evaluate aquifer potentiality and the effect on future withdrawal on deep aquifer systems. The main aquifer system in the area consists of two major layers; the upper layer is for the Chad Formation. The second water bearing layer is the Kerri-Kerri Formation, which is comprised of sandstone. This water bearing layer is not tapped, as all existing wells are tapping the upper Chad Formation layer. Goni, *et al*; (2000) showed that the groundwater level in shallow water table aquifer of the Chad Formation is rapidly declining at the rate of 1.1m/year.

1.5 STATEMENT OF THE PROBLEM

Field and desk research reveals that the water supply to Damaturu and its environs is inadequate. The rapid growth of the population of the town and its environs calls for harnessing all sources of water. The closest source of water to the populace is the groundwater that occurs in the Chad Formation. Due to acute shortage of water to the populace and the inability of the government to provide enough water to the people, proliferation and indiscriminate drilling of tube wells, hand augered wells without appropriate records and non-regulated is seen almost on a daily basis in all parts of the study area. Although this venture has created a lot of job opportunities to the teaming populace of the youth and also helped in providing water supply to people of the area, it is imperative to ensure good quality of water and its safety for drinking and domestic use. As such, a comprehensive study of groundwater in the Chad Formation aquifers needs to be undertaken.

CHAPTER 2

2 LITERATURE REVIEW

2.1 HISTORY OF WATER SUPPLY IN NORTH-EASTERN NIGERIA

The study of water supply situation in northeastern Nigeria started with the work of Falconer in 1911. Later in 1928, H. A. Cochran developed well sinking techniques and designed the concrete – lined well. The construction of concrete lined hand-dug wells for rural water supplies was undertaken in Bornu provinces as well as in Sokoto, Katsina and Kano Provinces of Northern Nigeria. The Native Authority offices were handling these projects and delivering to the rural areas. The government crews constructed dug wells of three to four feet in diameter and lined them with concrete rings down to beds of water–bearing sand. These wells were the sole sources of water supply to Maiduguri, the then capital of the defunct north-eastern State of Nigeria, and all other big towns across the region including the present study area. However, some of these wells dried up during the dry season when most of the surface ponds and rivers dry up (Miller *et. al., 1968*). The limitation of some of these hand-dug wells is their drying up during the dry season because of variations in weather conditions, seepages and lately over abstraction. Re-deepening them to intercept the dry season water table would have solved this problem.

Due to the interest spurred by the previous works of Falconer (1911), Cochran (1928), and Raeburn and Jones (1934) on the hydrogeology of northeastern Nigeria, exploitation of groundwater by boring holes started in 1950; and by 1952, the first borehole was drilled in Maiduguri.

Presently however, there is a record of over 100 boreholes owned by the Yobe State Water Corporation and Ministry of Water Resources that were drilled within the study area. These records are currently been gathered by the State Government and are to be plotted on GIS format and kept in an organized data bank of the water sector in the state for future use.

2.2 THE CHAD BASIN

Chad Basin is the largest area of inland drainage in Africa (Barber, 1965). It makes up a large part of the geotectonic continuum termed the West and Central African Rift system (Fairhead, 1986). The Chad Basin occupies an area of about 2,335,000km^2 extending into Nigeria, Cameroon, Niger Republic, Chad, Sudan, Libya and Algeria (Okosun, 1992), (Fig.3). Formations observed in the Chad Basin constitute also a major part of the study area. Names of formations although differ from one country to another, the compositions of the basin do not show a great change.

2.2.1 Regional Geology

About one tenth (1/10th) of the Chad Basin is situated in northern Nigeria and is known as the Bornu Basin. The Nigerian sector of the Chad Basin lies between latitudes 11^0 N and 13^0 43'38" N and longitudes 8^0 21'49" E to 14^{0}40'22" E (Fig.3**).** In the Bornu Basin, relief slopes gently from an elevation of 530m at the western margin to 240m in the Lake Chad (Miller *et.al., 1968).* The rivers drain northwards towards Lake Chad within broad, shallow valleys, which only retain surface water after the heaviest rains. However, sub-surface flow is common. Their flow supplies only five percent (5%) of the total input into Lake Chad (Miller *et. al., 1968*, fide Offodile, 2002). About 95% of the total water input into the Lake Chad comes from the Chari – Lagone River systems

(Miller *et al., 1968*), and the Lake lies in a shallow depression and its shoreline changes markedly in response to seasonal fluctuation in the level of water in the lake.

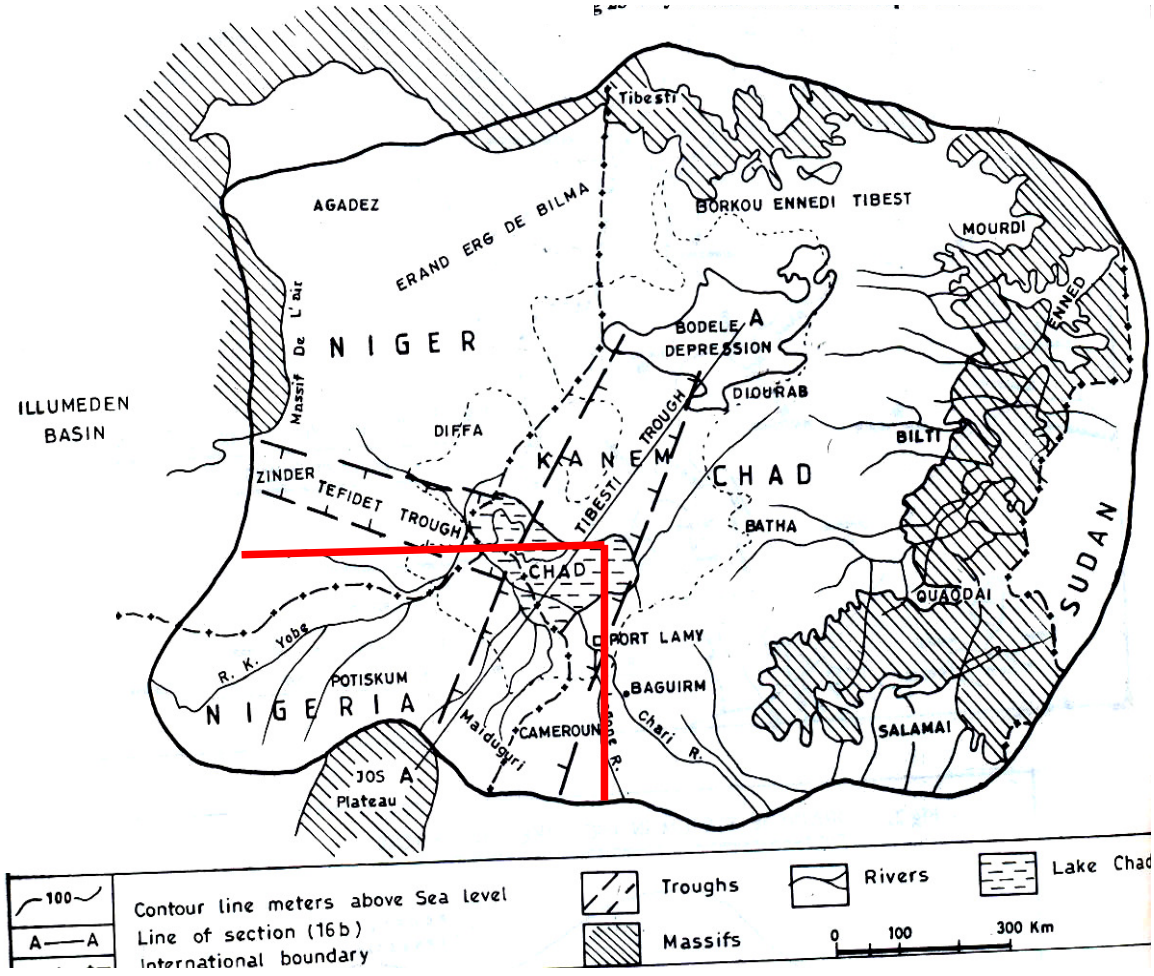


Fig. 3: Physical and structural map of the Chad Basin: inset-Nigerian sector (Modified after Offodile, 2002)

2.2.1.1 Lithology and Stratigraphy

The geologic history of the Bornu basin begins in the Upper Cretaceous (probably uppermost Albian) when over 1,000m of Continental sediments of the Bima Sandstone

was deposited unconformably on the Precambrian Basement (Barber, 1965). These beds are mainly restricted to the southwestern margin of the basin. The stratigraphic units represented in the Nigerian sector of the basin are shown in Table 1.

Table 1: Stratigraphic Sequence in the Chad (Bornu) Basin (N.E. Nigeria) (Modified after Matheis, (1976)

AGE	FORMATION	ENVIRONMENT
Pleistocene	Chad Formation	Lacustrine strata
	(unconformity)	
Paleocene	Kerri-Kerri Formation	Continental strata
Maastrichtian	(unconformity)	Estuarine deltaic strata
	Gombe Sandstone	
Senonian	Fika Shale	Marine strata
Turonian	Gongila Formation	Marine estuarine strata
Cenomanian	Bima Sandstone	Continental
	(unconformity)	
Pre-Cambrian	Basement Complex	

During the Turonian, there was an extensive transgression and the Gongila Formation, a mixed limestone/shale sequence was deposited. These beds are overlain by over 530m of marine shales belonging to the Fika Formation of Turonian to Senonian age. Towards the end of the Cretaceous (Maastrichtian), an estuarine-deltaic environment prevailed and the Gombe sandstone was deposited with intercalations of siltstones, shales and ironstones. These sediments probably attain a thickness of over 320m. They hardly extend far east into the Chad Basin. At the end of Cretaceous, there was a period of folding during which the Cretaceous beds were folded into a series of anticlines and synclines. These were later partly eroded creating an erosional unconformity at the base of the Tertiary deposits named Kerri-Kerri Formation and partly Chad Formation.

2.2.1.2 Geology of the Study Area

The study area lies within the Nigerian sector of the Chad Basin. The area is a part of the sediments of the Chad Basin comprising such rock types as sand and sandstone, clay/shale intercalations that formed the Chad Formation which dips concentrically at about 1.5m/Km. The Chad Formation varies rapidly both laterally and vertically and diatomite is often found within its clayey zones. Geophysical evidence revealed that the underlying basement is irregular and carries a major trough running WSW-ENE from Damaturu, which is joined by two minor troughs from the northwest. These are filled by Cretaceous sediments while on their flanks the Chad Formation overlies the Basement directly (Olayinka, *et al*., 1999; Raji and Alagbe, 2000).

The Chad Formation reached a thickness of 600 to 700 meters in the central part of the basin, but thins out rapidly towards the edges. Such a very abrupt reduction in thickness of sediments near the margins of the Plio-Quartenary basin could well be as a result of steep faulting in the basement rocks of the Chad depression. The gentle east-northwest dip of the Chad Formation towards Lake Chad is in conformity with the slope of the land surface (Barber, 1965).

2.2.1.3 Hydrogeology of the Study Area

The Chad Formation is a fresh water sedimentary sequence of Pleistocene age containing much groundwater. Barber and Jones (1960) demarcated it into three aquifer horizons, which is designated Upper, Middle and Lower aquifers.

The Upper Aquifer is composed mainly of fine sand, clay and silts partly inter-stratified with fluvial sands (Fig.4). The formation thickens towards Maiduguri axis and thins out towards Potiskum where the Kerri-Kerri Formation is exposed. Groundwater occurs in

the Upper Aquifer of the Chad Formation under water-table conditions, in perched aquifers, confined and semi-confined conditions at depths of less than 70 meters to 140 meters in the study area.

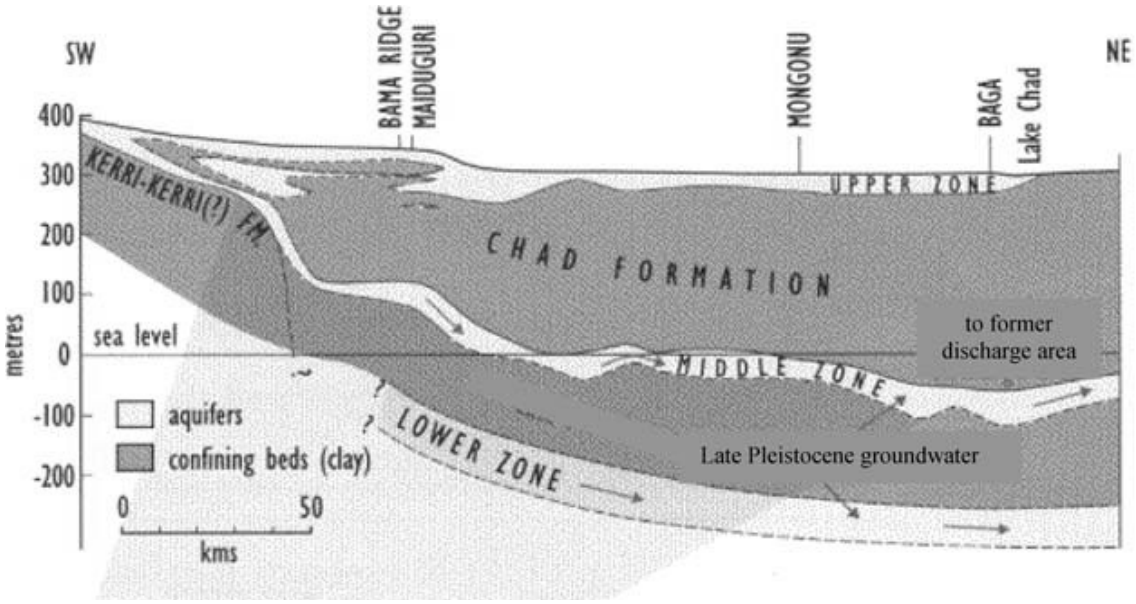


Fig. 4: Geologic cross section through the Chad Formation showing the Upper, Middle and Lower Zones aquifers (Barber and Jones, 1960)

Where it is confined, the pressure rise is not sufficient to produce artesian flow but rises above the aquifer. Recharge to the Upper area is by vertical infiltration of precipitation (Adegoke, 1985), while in the semi-confined horizons is likely via leakage through the hydrogeological 'windows' (Schoeneich and Askira, 1990). Groundwater movement in the Upper zone aquifer varies from place to place depending on whether there is any hydraulic gradient and the configuration of the intervening clayey hydraulic barriers (Consulints, 1976).

The Middle Aquifer is the most extensive and important water bearing zone in the entire basin. It is separated from the Upper Aquifer by a clay layer of about 170 m thickness. The aquifers within this zone consist of fine to coarse grained sand. This sand is poorly

sorted and locally contains fine gravel as interconnected lenses, intercalated with clays and sandy clays. In addition, the clay beds in the middle zone commonly contain angular quartz grains, giving them a gritty texture. Groundwater occurs only under confined condition in the middle zone and throughout the 15,000 km^2 in the Chad Basin of Nigeria, the pressure is sufficient to cause artesian flow at the land surface. The piezometric surface contours of the Middle zone aquifer show a general NE direction of groundwater flow. The water of the Middle zone aquifer is of two broad types; sodium bicarbonate in the south and sodium sulphate in the north. It has salinity values from 156 to 2000 ppm (Oteze, 1988). Temperature of groundwater is between 39^0C and 45^0C.

The Lower aquifer is about 90 meters thick extending from 420 meters to 650 meters and has very limited lateral extent. It is separated from the Middle aquifer by thick clay deposit. It consists of sand, sandy clay, clayey sand and clay and it is thought that these deposits are lenticular. The sand varies from fine to coarse and is usually poorly sorted. The water in the zone is under sufficient pressure to produce artesian flows up to five meters of positive artesian head. The water is of sodium bicarbonate or sodium–calcium bicarbonate type and has a temperature of 48^0C to 50^0C.

The Kerri-Kerri Formation is a continental sequence of Paleocene age deposited under a wide range of environmental conditions, lacustrine and deltaic-type sediments being the most common. The formation is predominantly arenaceous, consisting loosely cemented sands and grits, clayey sandstone, massive clays and silts; bands of ironstone and conglomerate occur locally. It was laid down on an uneven surface of Basement Complex and Cretaceous rocks and the maximum proved thickness is over 180 meters.

The sediments are flat-lying and unfolded except in the north where they are gently down-warped beneath the Chad Formation. Groundwater mainly occurs under water-table conditions in Kerri-Kerri Formation. Occasional clay lenses give rise to perched aquifers in some localities. The saturated portion of the Kerri-Kerri Formation contains large quantity of water, though much of this is not readily available owing to the low permeability of the sediments due to interstitial clay and silt in the sandstones.

CHAPTER 3

3 METHODOLOGY

3.1 INTRODUCTION

This chapter describes the study design, sampling methods and the techniques used in data collection and analysis. The study involved collection of topographical map of the study area. Data for rainfall of the first three months (June, July and August) were analyzed for their physico-chemical parameters. These parameters were compared with those of some hand dug well water samples in the study area to know their concentrations and variations in the atmosphere and in the wells. Also, analyses of water samples from 15 boreholes spread across Damaturu and environs and large pond located at the central part of the study area were carried out.

Hand dug well's depths to water level at the peak of dry season and at the end of rainy season were located using Satellite Navigator and Water Level Indicator respectively. Boreholes records with locations (coordinates), static water level, design, lithology (Appendix V) and total depth were obtained and analyzed, all available and relevant borehole records were tabulated. Recently drilled boreholes/tube wells owned by both government and individuals whose static water levels, coordinates and elevations were recorded at the time of their development were also considered.

Pumping test data of 10 boreholes in the study area were used to compute the aquifer properties of transmissivity, hydraulic conductivity and storativity respectively using the Cooper Jacob's method for confined aquifers.

3.2 METHOD OF INVESTIGATION

The hydrogeological investigation of the study area was done in three stages which comprises field work, laboratory work and evaluation of the field and the laboratory data. A total of five water samples were taken from hand dug wells and 15 water samples from boreholes were used to analyze for chemical contents and qualities of groundwater. The field work covered a period of about seven months (September 2008 – April 2009). This period included both the end of rainy season (September) and peak of dry season (April) and it involved:

1. Taking coordinates and elevation of hand dug wells and boreholes using satellite navigator.
2. Measurement of water table of both end of rainy season and peak of dry season in hand dug wells and obtaining static water levels, coordinates and elevation in boreholes records.
3. Water sampling in selected boreholes and hand dug wells, surface water and rain water.

3.3 FIELD WORK

3.3.1 Water Level Measurement

Water level indicator was used to measure the water levels in wells and some boreholes whose pumps were not installed at the time of measurement while must were obtained from records. This instrument beeps a sound when the tip of the lowered probe touches water in the well. It consists of a calibrated tape in meters. Plate 2 shows the author measuring depth of well and its water level in a concrete lined well tapping the water table aquifer in the study area. This well is not more than 3.5m deep and its water level is around 1.7m. However, Plate 3 shows a dry concrete lined well at Sindiri with a depth

of 124.6m. This indicates that the water table aquifer has deepened at this location or has pinched-out.

3.3.2 Coordinates

Coordinates and elevations of each borehole and hand dug wells were recorded using Garmin satellite navigator. Also coordinates of the edges of the large pond was recorded so as to use it in locating the exact position of the pond on the map. It was calibrated to ensure accuracy in reading and was used to measure the exact locations of wells by recording its coordinates and elevations. The values obtained were used to plot water-table configuration maps of the peak of dry season by subtracting the water level measured in a well from the elevation of that well.



Plate 2. A productive concrete lined wells at Digmari. The author was measuring the water level (Photo: M. U. Dapchi, 2009)
Coordinate: Lat. $11^0 43' 35.2''$ Long. $11^0 55' 12.1''$

3.3.3 Water Sampling

Water samples were collected from selected boreholes and hand dug wells and also surface water in the large pond within the study area. Rain water samples of June, July and August were also collected. This was done in order to analyze their physical and chemical properties.

Each water sample from boreholes, hand dug wells and the pond were collected using rubber plastic container. Water pumped from boreholes were directly collected in containers, while in the case of hand dug wells and pond, the containers were lowered into the wells and pond to collect the sample and put into plastic sample bottle of 1 liter volume which was previously washed thoroughly with the same water for sampling. The bottle was firmly capped and taken to the laboratory. Rain water sample was similarly taken from the rain water that was falling directly from an open space and then put into sample bottle for the laboratory work. The water samples were preserved by adding concentrated nitric acid 35%, 2 mils on each 1000 mils equivalent to 1 liter of water sample. This preserves water in a sample bottle for at least 6 months although it lowers the pH of such water by 2.



Plate 3. A dry and abandoned concrete lined well of 124.6m deep at Sindiri (Photo: K. Musa, 2008) Coordinates: Lat. $11^0$49′05.2″ Long. $11^0$54′34.2″

3.4 LABORATORY WORK

3.4.1 Water Sample Analysis

Quality of water in boreholes, wells and pond were analyzed at the Yobe State Water Corporation's laboratory (YSWC LAB). Physical parameters such as colour, total dissolved solids (TDS), electrical conductivity and temperature were measured using TDS/Conductivity meter (HACH Model). Concentrations of major cations including calcium (Ca), sodium (Na), potassium (K), magnesium (Mg) and anions such as chloride (Cl), sulphate (SO_4) and bicarbonate (HCO_3) were measured by the use of spectrophotometer (DR 200 – HACH Model).

3.4.2 Analytical Procedure

Analyses for sulphate, chromium^{+6}, iron, manganese, chloride, nitrate, and flouride were carried out using different reagents ranging from sulfaver 4 sulfate reagent powder pillow for sulphate, chromium 3 reagent powder pillow for chromium, ferrous iron reagent powder pillow for iron, mercuric thiocyanate solution for chloride, nitrate reagent powder pillow for nitrate and SPADNS reagent for flouride. All of these elements have different wavelengths for measurement, programme numbers and reaction time on the spectrophotometer.

However the physical parameters such as colour, temperature, turbidity and electrical conductivity do not require reagents for their detection, only programme numbers and their wavelengths numbers were used.

3.5 EVALUATION OF FIELD DATA

Field groundwater level data were used in plotting the configuration of water table map comprises; water table contours, flow directions, cross section and depth to water table.

3.5.1 Contour Maps of Water-table

Topographical maps of the study area (Damaturu Sheet 87 NE and SE) were acquired for the study. Locations on the base map of boreholes and hand dug wells were determined. The hydrogeological map was produced by manual plotting. The contour map plotted was for the aquifer tapped by the hand dug wells and boreholes in the area. A total of 20 hand dug wells and 15 boreholes were measured in the entire study area.

3.5.2 Preparation of Hydrogeological Maps

The depth to water levels measured in hand dug wells and static water levels in boreholes were subtracted from the values of their elevations, the resultant values were used to plot the map manually which produces points of equal water table elevation

(Water table contour lines or isohypes). The map is used in studying the configuration of the water-table, cross section and direction of groundwater flow.

3.5.3 Cross-section

Two points AB were joined with a straight line cutting across at least two boreholes to show the cross sectional view of the sub-surface geology/lithology of the area. Lithologs for 9 boreholes were correlated to view the variation in depth of the aquiferious zones within the study area.

3.5.4 Thickness of Dry Zone

The thickness of dry zone along river channel in the study area was taken to be zero on the assumption that at the end of rainy season (September) water was still flowing in the river. Assumptions were also made in the case of the peak of dry season (April) that water level along the dry river channel has dropped to about 5m below the dry bed.

3.5.5 Chad Formation Shallow and Deep Aquifers

The aquifers in Chad Formation within the study area varied with depth, shallow aquifers or water table aquifers are found between 3-50m, these are the aquifers predominantly tapped by hand dug wells in the study area. Deep aquifers below 100m could only be found in boreholes, their characteristics were determined by evaluating pumping test data of some boreholes obtained from the Yobe State Water Corporation, Damaturu. The deep aquifers are confined in most cases and are encountered below 100m. Meddle aquifer however, is mostly encountered around 190 m to 200 m in this study area.

CHAPTER 4

4 RESULTS AND DISCUSSIONS

4.1 HAND DUG WELLS, BOREHOLES AND LARGE POND IN THE STUDY AREA

Figure 5 shows the plot of the distribution of boreholes, hand dug wells, a large ponds, river Damaturu and streams in the study area.

Some hand dug wells visited were no longer in use because of the availability of water from boreholes to the residents. Boreholes own by both government and individuals are available throughout the study area. The large pond which is a depression situated at the centre of Damaturu town is fed by River Damaturu, large body of water collects during the rainy season from the river and surface run-off, it dries up at the peak of dry season (April) due to high rate of evaporation, while some percolates down probably recharging the shallow aquifer in the area.

4.1.1 Configuration of Water Table Map

In Figure 5, a large and elongated water table depression lying in the SW – NE direction was created at the northern part of the study area and another depression at the southern part closed to the first one was created as well, these was due to over pumping of the Chad Formation aquifers in the area. A ridge in water table was also created by the River Damaturu which as a result of excessive exploitation of groundwater, changed its regime from effluent to influent one. So also the large pond though fed by the river and surface run-off, it also contribute to the groundwater.

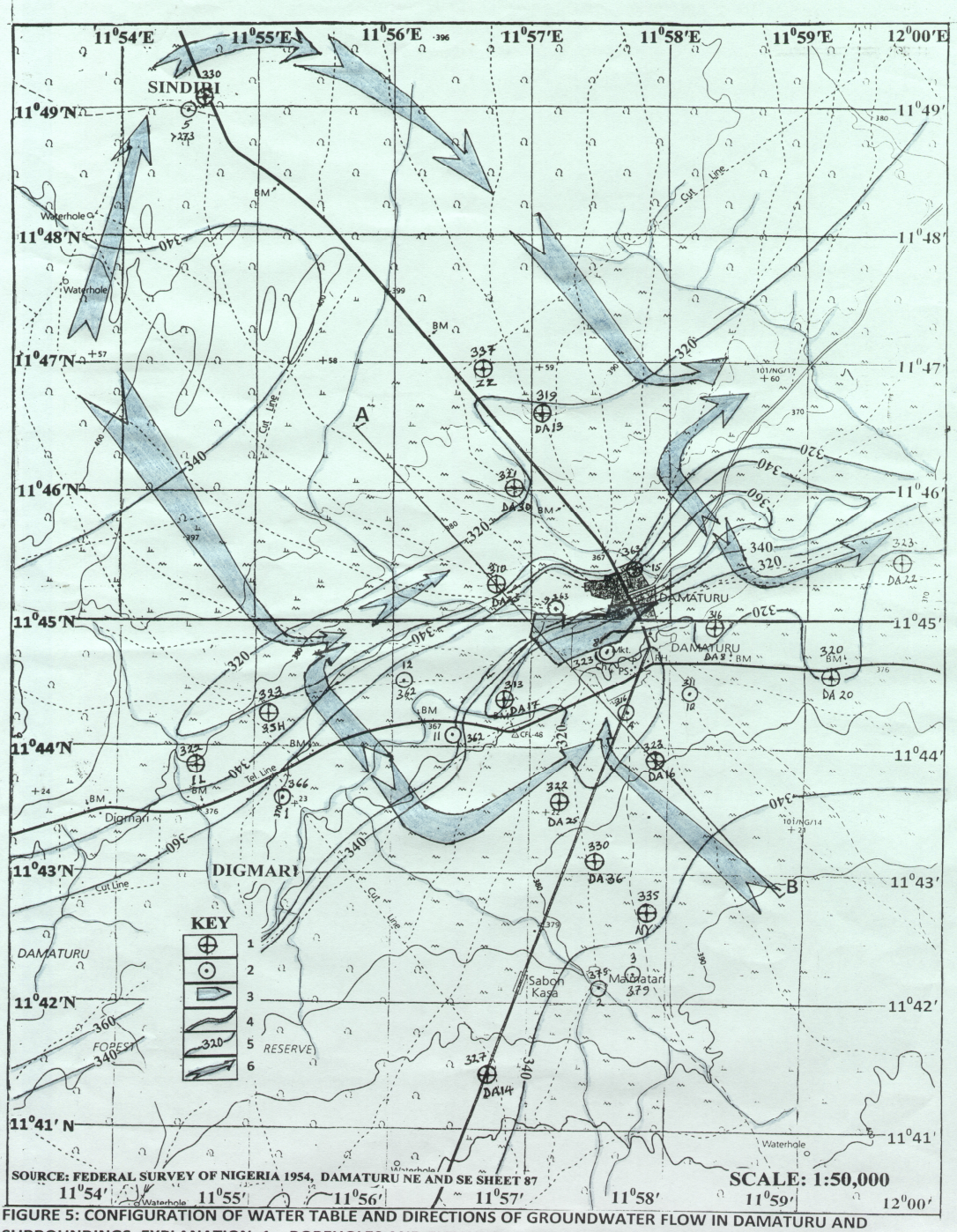


FIGURE 5: CONFIGURATION OF WATER TABLE AND DIRECTIONS OF GROUNDWATER FLOW IN DAMATURU AND SURROUNDINGS. EXPLANATION: 1 – BOREHOLES AND ELEVATIONS OF STATIC WATER LEVEL IN METERS ABOVE SEA LEVEL, 2 – HAND DUG WELLS AND ELEVATION OF WATER TABLE IN METERS ABOVE SEA LEVEL, 3 – LARGE POND IN DAMATURU, 4 – INFLUENT RIVER DAMATURU, 5 – WATER TABLE CONTOURS IN METERS ABOVE SEA LEVEL, 6 – DIRECTION OF GROUND WATER FLOW

4.1.2 Direction of Groundwater Flow

The map show groundwater movement indicated by the arrows drawn perpendicular to the groundwater table contours in blue colours. Groundwater in the study area flows from the higher groundwater elevation contours (360 m) to lower groundwater elevation contours (320 m) and largely towards the north-eastern direction.

4.1.3. Cross-section

Figure 6 is the cross-sectional view of the area cutting across two boreholes, River Damaturu and the large pond showing the water table ridge created by the river and also the two water table depressions created due to over pumping of groundwater.

Borehole numbers DA 25 and DA 16 were on the cross section line AB, DA 25 has a total depth drilled of 137 m but was located at a lower elevation of about 370 m above sea level while DA 16 has a total depth drilled of 141 m above sea level but located at a higher elevation of 380 m above sea level. From their screen position, they are apparently tapping from the same aquifer with a little variation of depths. The lithology in both boreholes were the same with slight variation of thickness.

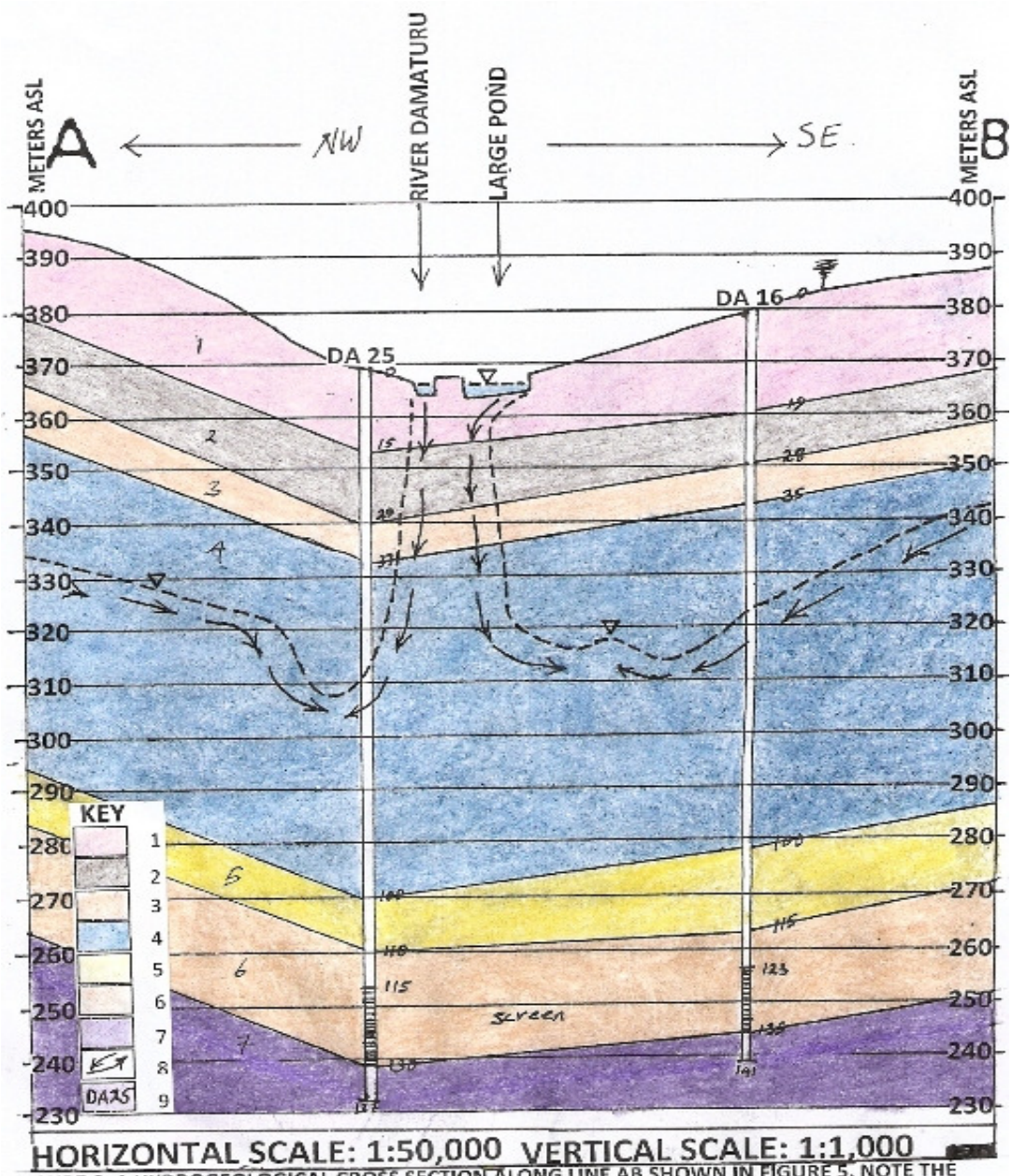


FIGURE 6: A HYDROGEOLOGICAL CROSS SECTION ALONG LINE AB SHOWN IN FIGURE 5, NOTE THE INFLUENT RIVER DAMATURU AND THE INFLUENT LARGE POND FED BY THE RIVER AND SURFACE RUNOFF FROM DAMATURU TOWN. PLEASE ALSO NOTE THE WATER TABLE RIDGE CREATED BY THE RIVER AND TWO WATER TABLE DEPRESSIONS CREATED BY OVER PUMPING OF THE CHAD FORMATION AQUIFER. EXPLANATION: 1 – LOOSE TOP SOIL, 2 – CLAY,LIGHT BROWN, 3 – MEDIUM GRAINED SAND, BROWNISH, 4 – CLAY INTERCALATED WITH FINE GRAINED SAND, GRAYISH, 5 – CLAY, YELLOWISH DARK GRAY, 6 – MEDIUM TO COARSE GRAINED SAND, BROWNISH, 7 – SHALE, BLUE BLACK, 8 – DIRECTION OF GROUND WATER FLOW, 9 – BOREHOLE

4.1.4 Borehole Correlation

9 boreholes lithologs of the study area were used for correlation. Figure 7 show the picture of the sub-surface geology of the entire study area. The aquifers are the major concern of this correlation, they are shown in different depths in each borehole.

The uppermost sand unit seen in this correlation is the water table aquifer which starts from about 25 m and are usually taped by hand dug wells, although most of the hand dug wells

located in areas with lower elevations of about 367 m above sea level and the fadama areas do not reach that depth (Plate 2).

The predominant aquifer taped by most boreholes in this study area is the upper aquifer found around the depth of 91 m to 170 m in different wells from the correlation. It has various thickness ranging from 15 m to 25 m. The aquifer's static water levels in boreholes measured within the study area ranges from 45 m to 60 m having average of 58 m, it has a good yield, and satisfactory aquifer characteristics (Table 11).

The last aquifer so far penetrated by some boreholes within the study area is the aquifer encountered between 190 m to 250 m. this is so far the deepest aquifer recorded within the study area.

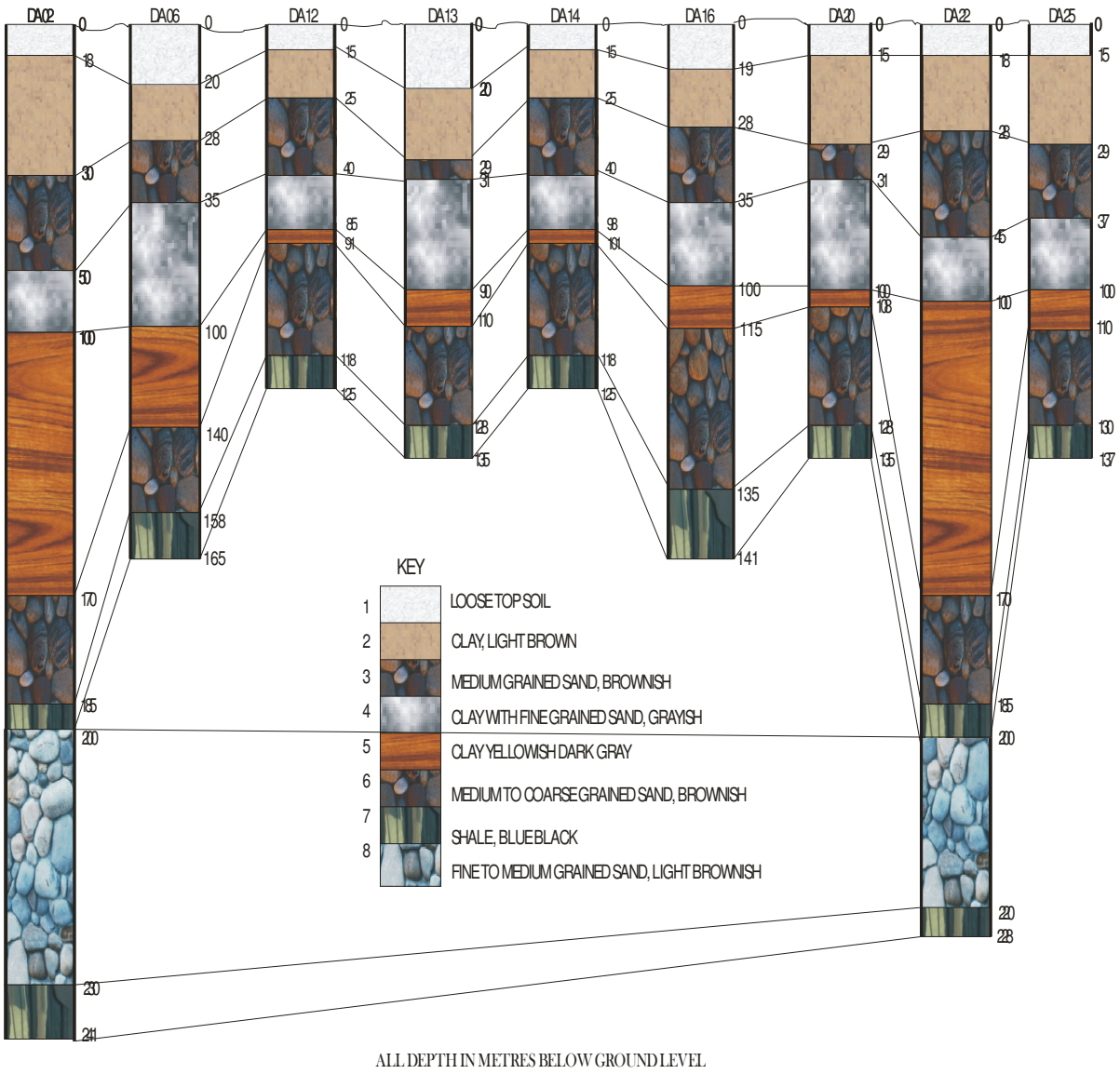


FIGURE 7: CORRELETION OF LITHOLOGS OF 9 BOREHOLES IN DAMATURU SHOWING THE WATER-TABLE AQUIFER, UPPER AND THE MIDDLE AQUIFERS IN CHAD FORMATION

4.1.5 Discharge in the study area

In aquifer, discharge can occur either naturally or artificially. Discharge through hand-dug wells and boreholes is artificial by withdrawal while discharge through stream, springs and evaporation is natural where water table is at or close to the land surface. In the rural area where the community depends mostly on groundwater extracted through hand–dug wells, the need to study the behaviour of the aquifer in terms of their discharge rate becomes imperative for proper planning and management especially in the dry season when water table recedes very rapidly. The coefficient of discharge of those aquifers which is directly related to the rate at which the water table recedes in the aquifer when properly determined could aid in establishing the probable period for the drying up of hand-dug well. Moreover, discharge in the study area is principally through withdrawal of water from hand-dug wells and boreholes by pumping.

4.1.6 Recharge in the study area

The groundwater recharge in this study area is from seasonal rainfall passing through the unsaturated zone into the saturated zone. The recharge of the water table aquifer is easily identified mostly during the rainy season, when most hand dug well's water levels were raised with a few meters higher than during the dry season. The shallow hand dug wells that are located close to the large pond within the metropolis seems to be taking the colour of water in the pond during rainy season. This is also an indication of recharge of the shallow aquifer from the pond, the negligible seasonal groundwater fluctuation less than 2 m recorded during the field work indicates low recharge. The seasonal Damaturu river that passes through the study area contributes to groundwater recharge as an influent river.

4.2 PHYSICO-CHEMICAL QUALITY OF WATER

The chemical elements of rainwater and those of groundwater have been studied to ascertain rainfall contribution to some elements in the aquifer of the study area. Parameters analysed are temperature, colour, turbidity, total dissolved solid (TDS), electrical conductivity, total hardness, total alkalinity, sodium, phosphate, calcium, magnesium, iron, chromium, chloride, sulphate, nitrates bicarbonate and fluoride were analyzed in the water quality laboratory.

The temperature of water in hand dug wells varied from 28.3^0C to 29^0C with an average of 28.44^0C, temperature of boreholes water ranges from 30.1^0C to 37^0C with average of 33.6^0C, temperature of the ponds (surface water) was constant at 27^0C, while that of rain water of June, July and August varied from 27^0 to 29.1^0C with an average of 27.9^0. The colour of groundwater in hand dug wells show a low value range between 2.0 and 25 Pt/Co, with an average of 9.3 Pt/Co while those of borehole ranges from 0.00 Pt/Co to 58 Pt/Co with an average of 14.2 Pt/Co. Rainfall however has zero value in colour. The most affected was the colour of the surface water, high value was observed in this case about 409 Pt/Co (Table 4). Turbidity of groundwater in hand dug wells varied from 1.0 FTU to 5.0 FTU with an average of 3.0 FTU and that of boreholes water ranges from 0.00 FTU to 11 FTU with average of 2.9 FTU, while this parameter in surface water was high, measuring between 35.0 FTU and 73.0 FTU. Turbidity of rainfall was between 14 FTU and 0.00 FTU with an average of 5.6 FTU.

pH of groundwater in hand dug wells varies from 7.5 to 9.0 with average of 8.4, that of borehole water was from 6.1 to 8.8 with an average value of 6.7, pH of surface water was between 7.5 and 8.5 with an average of 7.5 while for rain water between 7.0 to 7.5

was recorded with average of 7.1 respectively. The total dissolved solids of groundwater in hand dug wells range from 42.3 mg/l to 50 mg/l with an average of 180 mg/l, surface water was at 50.1 and rainfall from 20 mg/l to 667 mg/l with an average of 382 mg/l (Tables 2, 3 and 4). The electrical conductivity of groundwater in hand dug wells was between 290 µS/cm to 450 µS/cm with average of 372 µS/cm while those of borehole water ranges between 116.4 µS/cm and 610 µS/cm with an average of 210.8 µS/cm, surface water has 106.4µS/cm and rainfall 10 µS/cm to 334 µS/cm with an average of 188 µS/cm. The total hardness is between 36.0 mg/l to 47.2mg/l with an average of 42.08 mg/l for groundwater of hand dug well, 0.07 mg/l to 43.6 mg/l with an average of 19.8 mg/l for borehole water, 36.0 mg/l for surface water and 20.0 mg/l to 140 mg/l with an average of 73.3 mg/l for rainfall.

4.2.1 Cations and Anions

The chemical elements in rain water (cations and anions) analyzed includes iron, manganese, chromium, sulphate, nitrate and fluoride. These elements have high values of concentrations in June and decrease in July and August (Table 2). This is probably due to dilution brought about by continuous downpour. This should further be attributed to the fact that the first rainfall in June being in contact with a polluted atmosphere is enriched with those chemical elements in the air. There was a change in the following month of July and August.

The chemical elements values (cations and anions) in surface water compared to those in groundwater and rain water are on the high side, this could be as a result of human activities around the ponds. Elements analyzed includes manganese, calcium, magnesium, iron, chromium, chloride, sulphate, nitrates and fluoride.

Groundwater elements of hand dug wells and boreholes analyzed are; Sodium with concentration range of 22mg/l to 37mg/l with average of 32.8mg/l for hand dug wells, while for boreholes ranges from 0.00 mg/l to 43.6 mg/l with an average of 29.1 mg/l, potassium concentration in hand dug wells is between 2.5mg/l and 12mg/l with average of 5.62mg/l, while in borehole varies from 1.0 mg/l to 12 mg/l with an average of 4.8 mg/l, phosphate in hand dug wells concentration range from 0.26 mg/l to 0.85mg/l with an average of 0.6 mg/l, calcium concentration in hand dug wells ranges between 30.1mg/l and 36.9 mg/l, while in boreholes is between 0.01 mg/l to 31 mg/l with an average of 10.3 mg/l, magnesium concentration in hand dug wells ranges from 0.1 mg/l to 0.6 mg/l with average of 0.3 mg/l, and in borehole is between 0.01 mg/l and 16.5 mg/l with an average of 8.9 mg/l, iron concentration in hand dug wells ranges between 0.1 mg/l and 0.12 mg/l with an average of 0.07 mg/l.

Bicarbonate concentration in hand dug wells is from 2.0mg/l to 8.0mg/l with an average of 5.08mg/l, while in boreholes water is between 4.3 mg/l and 18.2 mg/l with an average values of 10.2 mg/l, chloride concentration in hand dug wells is between 18mg/l and 36mg/l with average of 24.8mg/l, and that of boreholes water is from 0.00 mg/l to 26 mg/l with an average of 13.3 mg/l, chromium concentration in hand dug wells ranges from 0.08 mg/l to 0.12 mg/l with an average of 0.1 mg/l, sulphate concentration in hand dug wells ranges from 2.0 mg/l to 17.0 mg/l with average value of 9.0 mg/l, while in boreholes ranges from 0.00 mg/l to 29 mg/l with average of 4.2 mg/l, nitrate concentration in hand dug wells is between 11 mg/l to 66 mg/l with average of 35.2 mg/l and fluorite concentration ranges from 0.007 mg/l to 0.05 mg/l with an average of 0.04 mg/l (tables 3 and 4)

Table 2: Physical and chemical quality of rainwater of June, July and August 2008

S/N	PARAMETERS	28 JUNE 2008	14 JULY 2008	12 AUGUST 2008
1	Colour (Pt/Co)	0.00	0.00	0.00
2	Turbidity (FTU)	14.0	3.0	0.00
3	pH	7.0	7.0	7.5
4	TDS (mg/l)	133	40	10
5	Electrical Conductivity (µS/cm)	266	82	20
6	Hardness (mg/l)	20	60	140
7	Temperature (^{0}C)	29.1	27.7	27.0
8	Iron (mg/l)	0.21	0.15	0.18
9	Manganese (mg/l)	1.2	0.2	0.9
10	Chromium^{+6} (mg/l)	0.02	0.04	0.07
11	Sulphate (mg/l)	75	11.0	9.0
12	Nitrate (mg/l)	2.0	0.00	0.00
13	Fluoride (mg/l)	2.2	1.58	0.01

Coordinates of sampling: Lat. N11^{0}44.470 Long. E011^{0}57.844 and Elevation: 370m

Located at Yobe State Water Corporation's Premises.

Table 3: Physical and chemical quality of groundwater in hand dug wells

S/N	Parameters	Nitel well TD 60m	DA6 borehole premises well TD 58.3m	Nayinawa Tsallake Ajari well TD 4.7m	Alhajiri well TD 44.98m	Pawari well close to the old abbatoir TD – 4.48m
1	Temperature (^{0}C)	28.5	28.7	29	28.3	27.7
2	Colour (Pt/Co)	2.0	1.0	12.1	25.0	15.7
3	Turbidity (FTU)	1.0	2.5	2.0	5.0	1.8
4	pH	9.0	8.5	7.5	8.0	9.0
5	Total Dissolved Solid (TDS) (mg/l)	220	160	160	140	220
6	Electrical Conductivity (µS/cm)	430	320	370	290	450
7	Total Hardness (mg/l)	36.0	43.1	41.0	43.1	47.2
8	Na (mg/l)	34.0	36.0	35.0	37.0	22.0
9	K (mg/l)	6.0	3.0	12.0	2.5	4.6
10	Chloride (mg/l)	24.0	26.0	20.0	36.0	18.0
11	HCO_3 (mg/l)	8.0	3.6	5.2	5.8	2.8
12	Phosphate (mg/l)	0.75	0.85	0.26	0.44	0.81
13	Calcium (mg/l)	36.9	36.3	34.1	34.3	30.1
14	Magnesium (mg/l)	0.1	0.6	0.1	0.4	0.5
15	Iron (mg/l)	0.11	0.12	0.05	0.01	0.13
16	Chromium (mg/l)	0.08	0.11	0.12	0.10	0.09
17	Sulphate (mg/l)	11.0	9.0	6.0	2.0	17.0
18	Nitrate (mg/l)	66.0	11.02	55.07	22.01	22.04
19	Flouride (mg/l)	0.07	0.05	0.04	0.05	0.007

Table 4: Borehole Water Quality Analysis in Damaturu

S/N	BH No.	Temp. (^{0}C)	Colour (Pt/Co)	Turbidity (FTU)	pH	EC (µS/cm)	Total Hardness	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	SO_4 (mg/l)	Cl (mg/l)	HCO_3 (mg/l)
1	**DA 02**	36.1	0	0.8	8.8	420	0.07	34	5	0.01	0.01	29	0	13.2
2	**DA 06**	30.2	0	0.3	6.1	150	32	43.6	4.6	11	21	1	20	11
3	**DA 08**	34.6	0	0.7	6.7	210	24	30.21	5.12	13	11	2.1	21.8	8.7
4	**DA 10**	36	0	0.06	7	157	28	32	3.5	17	11	1.1	10	15
5	**DA 12**	33.7	0	1.4	6.3	170	20	0	1	11	9.3	0.5	13.9	6.5
6	**DA 13**	30.1	0	0.6	6.1	160	34	22	3	18	16.5	0	18	7.2
7	**DA 14**	35.2	0	7	7	147	38	34	6	22	16	1	24	10.5
8	**DA 15**	35.1	14	6	7.6	144.9	6.38	24	4.2	1.6	0.65	0	4.4	18.2
9	**DA 16**	35.5	0	0	6.5	116.4	3.29	30	5	0.12	0.87	9	0	17.3
10	**DA 17**	30.1	11	5	6.2	146	21	30.01	6.01	10	9.3	0	2.1	8.3
11	**DA 20**	31.1	58	4.8	6.4	150	43.6	42	2.7	31	12.6	8	18	5.6
12	**DA 22**	30.2	49	0.3	6.4	230	15	35	12	9	6	4	20	7.2
13	**DA 25**	34.6	13	1	6.2	610	21	36	3	10	11	0	26	6.1
14	**DA 30**	34.2	17.5	11	7.2	200	9.06	20	6	1.76	7.3	0	18.7	4.3
15	**DA 36**	37	51	5	6.5	151	1.79	23	4.2	0	0.52	7	1.9	13.4

All analysis of water samples were conducted in the Yobe State Water Quality Laboratory by M. M. Zanna

Table 5: Physical and Chemical Quality of Surface Water of large pond in Damaturu

S/N	PARAMETERS	CONCENTRATION	COORDINATES OF POND	
1	Temperature (^{0}C)	27	**LAT (N)**	**LONG (E)**
2	Colour (Pt/Co)	409	11.75086	11.95765
3	Turbidity (FTU)	73.0	11.75113	11.95713
4	pH	7.5	11.75053	11.95564
5	TDS (mg/l)	50.1	11.74975	11.95423
6	Electrical Conductivity (µS/cm)	106.4	11.75077	11.95403
7	Total Hardness (mg/l)	36.0	11.75136	11.95526
8	Total Alkalinity	303	11.75256	11.95708
9	Manganese (mg/l)	0.0	11.75250	11.95831
10	Calcium (mg/l)	28.0	11.75171	11.95852
11	Magnesium (mg/l)	8.0	11.75057	11.95913
12	Iron (mg/l)	1.11	11.74857	11.96087
13	Chromium (mg/l)	0.08	11.74797	11.96014
14	Chloride (mg/l)	12.0	11.74418	11.95370
15	Sulphate (mg/l)	2.0	11.74800	11.95013
16	Nitrates (mg/l)	5.0	11.75060	11.95036
17	Fluoride (mg/l)	1.08		

4.3 PIPER TRILINEAR DIAGRAM (WATER FACIES)

Chemical parameters of water samples in the 15 boreholes and 5 selected hand dug wells as plotted on Piper (1944) trilinear diagram indicates that there are not less than ten water types identified in the 20 water samples .

1. Ca – Na – Cl is the water type in 4 hand dug wells comprising of primary salinity (carbonate hardness) exceeding 70 per cent that is, chemical properties are dominated by alkalies and strong acids. While Ca – Na – Cl – SO_4 is for one hand dug well (Pawari HDW 5) primary salinity (carbonate hardness) exceeding 50 per cent that is, chemical properties are also dominated by alkalies and strong acids.

2. Na – Mg – Ca - Cl water type is for boreholes DA/06, DA/08, DA/14, DA/22 and DA/25

3. Na – HCO_3 water type is for boreholes DA/16 and DA/35

4. Na – Mg – Ca is water type for DA/10 and DA/17

5. Mg – Na – Ca - Cl is water type for DA/13

6. Na – HCO_3 – SO_4 is water type for DA/15

7. Na – Cl – Mg is water type for DA/20

8. Na – Mg – Cl is water type for DA/30

9. Mg – Ca – Cl is water type for DA/12

10. Na – SO_4 is water type for DA/2

The most likely dissolved minerals that may constitute the above water types includes sylvite (KCl), halite (NaCl), anhydrite ($CaSo_4$) carbonates ($CaCo_3$) and bicarbonates (HCO_3) (Fig 8).

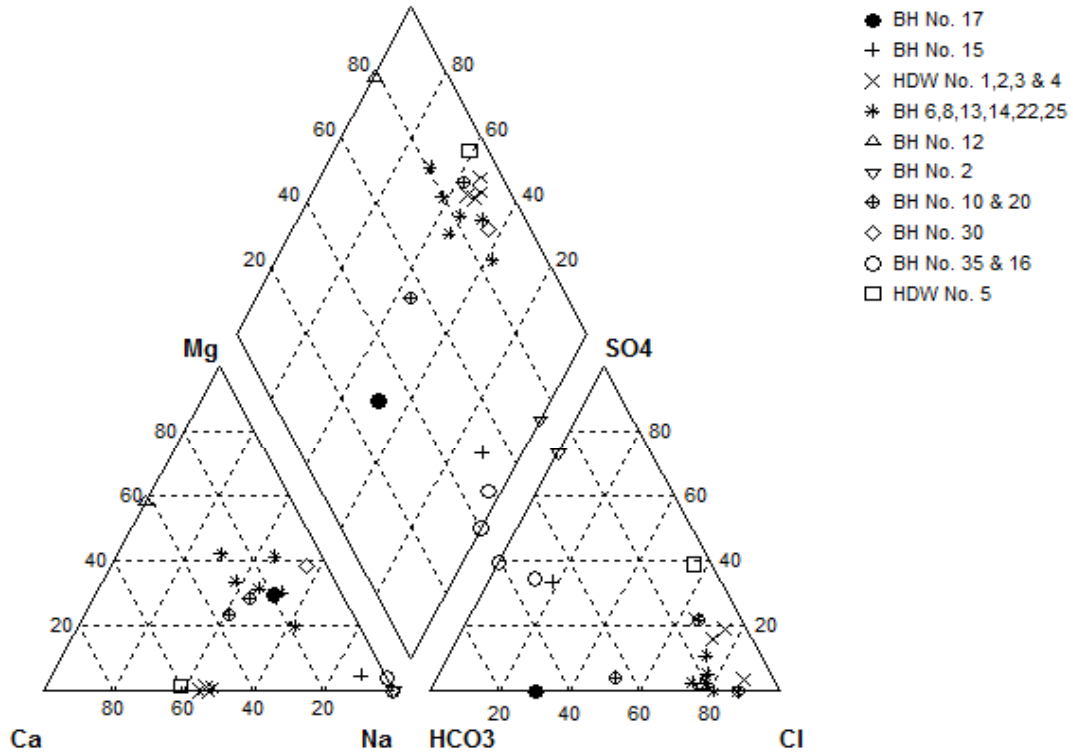


Fig 8: Piper Trilinear Diagram depicting water facies in the study area.

4.4 CHEMISTRY AND USAGE OF WATER

The chemical and biological characteristics of water determine its usefulness for domestic, industrial and agricultural purposes. Water chemistry study could also give important clues of the geological history of an area, the direction of water movement and a probable presence of hidden ore deposits (Eduvie,1991).

The amount of dissolved minerals in groundwater depends on a large number of factors, which include the type of soil or rock through which it passes, the time taken for the water to pass through various geological terrain, temperature, pressure, and materials already in solution. The purpose of determining the water chemistry in the area of study is mainly to evaluate the water for domestic use especially for drinking and for other uses such as in agriculture and industries.

4.4.1 Water Quality

4.4.1.1 Hydrogen ion Exponent (pH)

The pH of water is a measure of its acid-base equilibrium and is usually controlled by the carbon dioxide picked up from atmosphere as rain falls, presence of acids of peaty origin, decaying vegetation, and presence of sulphates. These factors cause low pH of water. Low pH may be also caused by precipitation of ions in a stored water sample before testing, especially if several days elapsed between sampling and testing. On the other hand, high pH results from the presence of magnesium, potassium and sodium in high concentration.

Temperature slightly affects pH also, especially low mineralized water. In pure water, a decrease in pH of about 0.4 occurs temperature rises by 25^{o}C (Schoeneich, 2001).

On the basis of pH, water is described as neutral if 6.8 < pH < 7.2, weakly alkaline if 7.2 < pH < 7.8. The water is weakly acidic if 6.8 > pH > 6.0 and acidic if 6.0 > pH > 4.5.

pH of groundwater in the study area is however neutral going by the above water pH categorization. Average pH of groundwater in hand dug well was 8.4 and those of boreholes water was 7.2 and those of surface water and rain water was 7.5 and 7.1 respectively.

4.4.1.2 Bicarbonate Hazard {meq/l = HCO_3– (Ca +Mg)}

Bicarbonate Hazard means excess of bicarbonate over calcium, all expressed in milliequivalents per litre (meq/l). Values of Bicarbonate Hazard from 0.00 to 1.25 meq/l are considered safe for irrigation purposes, from 1.25 meq/l to 2.50 marginal and above 2.50 meq/l unsuitable. Negative values are not recorded but are shown as zero (Schoeneich, 2001). Water with bicarbonate hazard greater than 1.25 meq/l should not be applied for irrigation except possibly on a very sandy highly permeable soils, or in conjunction with chemical soil amendments, like gypsum. To calculate for the bicarbonate hazard, all elements must be converted from mg/l or ppm to meq/l (table 8).

Bicarbonate Hazard calculated for the groundwater in this study area ranges between 0.00 and 0.01 meq/l. These values falls within the 0.00 meq/l and 1.25 meq/l which indicates that the water is safe for irrigation purposes.

Table 6: Conversion factors from mg/l to meq/l values of mg/l are to be multiplied by conversion factors

S/N	CATIONS (in mg/l or PPM)	Conversion Factors	ANIONS (in mg/l or PPM)	Conversion Factors
1	Calcium, Ca	0.04990	Bicarbonate, HCO_3	0.01639
2	Sodium, Na	0.04350	Carbonate, CO_3	0.03333
3	Potasium, K	0.02557	Chloride, Cl	0.02821
4	Magnesium, Mg	0.08228	Nitrate, NO_3	0.01613
5	Ammonium, NH_4	0.05544	Nitrite, NO_2	0.02174
6	Iron, F^{++}	0.03364	Phosphate, PO_4	0.03159
7	Iron, F^{+++}	0.08371	Sulphate, SO_4	0.02083

Table 7: Suitability of Water for irrigation purposes in respect of Bicarbonate Hazard (meq/l)

Bicarbonate, meq/l		
0.00 meq/l	**1.25 meq/l**	**2.50 meq/l**
Water safe for irrigation	Water marginal for irrigation	Water un-suitable for irrigation

Source : Schoeneick, 2001.

4.4.1.3 Sodium Hazard.

Low sodium hazard shows that the water is suitable for irrigation purposes. But if the water has medium or higher sodium hazard, it then means that it is not suitable for irrigation activities especially on clayey impermeable soil types, unless if gypsum or other chemical amendments are applied to the soil to neutralise the hazard.

Sodium Hazard is calculated according to the following formula:

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

Interaction of mineral components of sub-surface rock units with groundwater under confining pressure and temperature leads to hydrolysis; it results in the breaking up of feldspars into their component metals and consequently the formation of clay minerals with the released metals becoming soluble cat ions. This process is responsible for the presence of Ca, Mg, Na, and K in water samples especially groundwater. High sodium content in some groundwater can be attributed to the weathering of sodium dominated feldspars found in the rock units which are in direct contact with the groundwater (Olatunji*et al.,* 2001).

Table 8: Water classification for irrigation purposes based on Sodium Adsorption Ration (SAR) After Hem (1959)

SAR	WATER CLASS	QUALITY
0-10	Excellent	**Low sodium**
10-18	Good	**Medium sodium**
18-26	Fair	**High sodium**
26-100	**Poor**	**Very high sodium**

The calculated values of sodium hazard of the groundwater in the study area falls within the excellent category for irrigation activities, based on the classification by Hem (1959) (table 10).

4.5 WATER USAGE

On the whole, the groundwater in this study area is good for both drinking and domestic use, this is evident from the TDS values of groundwater analyzed. The physical qualities for usage such as colour, odour and taste are completely absent, the anions and cations fall within the permissible limit of World Health Organization's (WHO) standard for drinking water (2004) and the Nigerian Standard for Drinking Water (NIS, 2007).

Going by the agrarian nature of the populace in the study area, groundwater of this shallow aquifer could be recommended for irrigation purposes because it has low bicarbonate hazard, low sodium hazard and very low salinity hazard (Fig. 9).

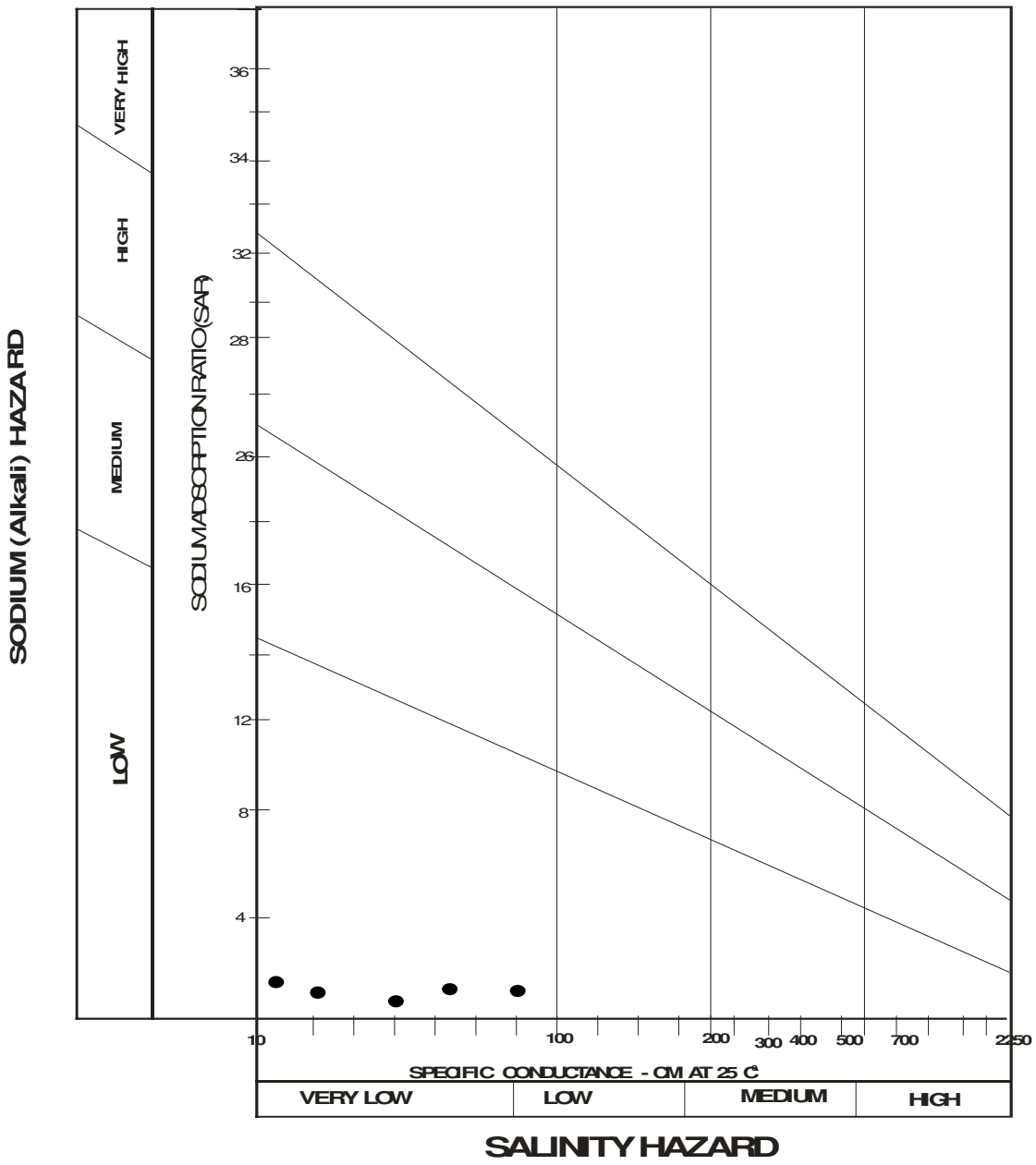


Fig. 9: U.S Salinity laboratory diagram applied to classification of groundwater for irrigation in Damaturu and environs

4.6 AQUIFER

Water table aquifers were tapped by hand dug wells in the study area, while deep aquifers were tapped by boreholes. The water bearing zones of the upper aquifer are made up of loose medium to fine grained brownish sand, impervious layers occur in the upper part of the formation. The top most sand horizon could be patchy in nature ,this had already focused attention on the presence of patchy aquifer in the Upper zone in the Chad Basin (Kogbe, 1992).

Table 9: Upper Aquifer Sub-Zone Classification by Barber and Jones (1960)

S/No.	Sub-zone	From - To	Thickness (m)
1	A	Sometimes (0) ground surface – 37m	10- 40 m
2	B	38 – 72m	1.5 to 10m
3	C	73 -120m	3m average, locally 47m.

Barber and Jones (1960) sub-divided the Upper Aquifer into three, namely A, B, and C (Table 9). Hand dug wells with different depths to water levels in the study area might be tapping different sub-zones within the Upper Aquifer. Upper Aquifer thickness ranges between 10 and 40m, however, it could be thicker in some localized cases. This is probably as a result of merger with other sub-zones (Barber and Jones, 1960)

4.6.1 Hydraulic Properties of Aquifer

Aquifer characteristics i.e. its hydraulic conductivity, transmissivity, storage coefficients and discharge generally describes the ability of an aquifer to transmit water into wells in economic quantity.

4.6.1.1 Aquifer characteristics of the study area

4.6.1.2 Hydraulic conductivity

Hydraulic conductivity is the ease with which an aquifer transmits water under the influence of hydraulic gradient, a dynamic parameter that controls the flow of groundwater. Pumping test (flow test) of a borehole is the most reliable and accurate method of determining this parameter. The Cooper Jacob's non-equilibrium method was used by the author to evaluate the aquifer properties for confined aquifer within the study area.

Table 10: Pump-test data for 10 boreholes in the study area

S/N	BH NO	STATIC WATER LEVEL (m)	PUMP CAPACITY (l/s)	PUMPING RATE (l/s)	DURATION BEFORE STABILIZATION (min)	DYNAMIC WATER LEVEL (m)	TOTAL DEPTH DRILL (m)	AQUIFER THICKNESS (m)
1	DA 02	51.71	4	1.58	140	58.11	241	20
2	DA 05	48.96	4	3.18	210	52.18	205	20
3	DA 06	59.65	2	1.4	180	61.22	165	20
4	DA 12	60.51	2	1.2	190	62.98	125	16
5	DA 13	68.01	2	0.54	210	69.34	135	17
6	DA 14	65.32	2	0.54	90	65.56	125	16
7	DA 16	55.94	3	1.57	210	58.02	141	15
8	DA 20	57.23	3	1.34	180	59.25	135	17
9	DA 22	47.52	3	1.77	90	51.15	228	20
10	DA 25	56.33	3	1.45	140	59.69	137	17.5

Table 11: Calculated Values of Transmissivity, Hydraulic conductivity and storage coefficient obtained from the ten boreholes.

S/N	B/H NO	TRANSMISSIVITY (T) m^2/sec	HYDRAULIC CONDUCTIVITY (K) m^2/sec	STORAGE COEFFICIENT
1	DA 02	45×10^{-3}	2.3×10^{-2}	2.0×10^{-1}
2	DA 05	18×10^{-2}	9.0×10^{-2}	2.8×10^{-1}
3	DA 06	28×10^{-1}	1.4×10^{-1}	1.1×10^{-1}
4	DA 12	8.9×10^{-2}	5.6×10^{-3}	2.7×10^{-1}
5	DA 13	7.4×10^{-2}	4.4×10^{-3}	2.4×10^{-1}
6	DA 14	4.1×10^{-1}	2.6×10^{-2}	2.2×10^{-2}
7	DA 16	14×10^{-2}	9.3×10^{-3}	6.0×10^{-1}
8	DA 20	12×10^{-2}	7.1×10^{-3}	6.4×10^{-1}
9	DA 22	8.9×10^{-2}	4.5×10^{-3}	2.7×10^{-1}
10	DA 25	7.9×10^{-2}	4.5×10^{-3}	3.0×10^{-1}

Hydraulic conductivity (K) = T/b

Where T = Transmissivity

b = Aquifer thickness

The hydraulic conductivity of ten boreholes as calculated (table 11) ranges between 1.4 x 10^{-1} m^2/day to 9.3 x 10^{-3} m^2/day with a mean value of 5.07 x 10^{-3} m^2/day, this values show that the aquifer's hydraulic conductivity in the study area is good going by bouwers standards (table 12).

Table 12: Bouwers standards for hydraulic conductivity (K)

Materials	K Ranges (m/day)
Clay Soils (surface)	0.01- 0.2
Deep clay beds	$10^{-8}$to 10^{-2}
Loam soils (surface)	0.1 to 1
Fine Sand	1 to 5
Medium sand	5 to 20
Coarse Sand	20 to 100
Gravel	100 to1000
Sand and gravel mixes	5 to 100
Clay, sand, and gravel mixes (till)	0.01 to 0.1

4.6.1.3 Transmissivity (T)

The transmissivity of an aquifer is the rate at which water flows through a vertical strip of the aquifer of a unit width and extending through the full saturated thickness under unit hydraulic gradient.

Therefore, transmissivity (T) = 2.30Q/4x3.142x $\triangle s$

Where Q= Pumping rate (well discharge m^3/day)

$\triangle s$ = Change in drawdown

The calculated transmissivity values (table 11) of the aquifer from the ten boreholes ranges from 4.1 x 10^{-1} m^2/day to 45.0 x 10^{-3} m^2/day with a mean value of 15.45 x 10^{-2} m^2/day. This values falls under moderate potentials as classified by Gheorghe standards (table 13).

Table 13: Gheorghe standards for transmissivity (T)

Transmissivity Range (m^2/day)	Transmissivity potentials
> 500	High potential
50 - 500	Moderate potential
5 - 50	Low potential
0.5 – 5	Very low potential
< 0.5	Negligible potential

4.6.1.4 Storativity (Storage Coefficient)

Storage coefficient (Storativity) is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

With the transmissivity known,

Storativity (S) = $2.25Tto/r^2$

Where T= Transmissivity

to = Zero drawdown intercept

r^2 = Radius of the pumping well

Storage coefficient as calculated for the 10 boreholes (table 11) ranges from 1.1 x 10^{-1} to 6.4 x 10^{-1} with an average of 3.13 x 10^{-1}.

4.6.1.5 Aquifer Recharge and Discharge

To evaluate groundwater recharge in northern part of Nigeria many studies has been carried out (Adegoke, 1985; Bako *et al.,*1998; Edmunds *et al.,*2002). The main source for groundwater recharge in this study area is from infiltration of rainfall during the rainy period, which is about four months starting from June to October. Similarly, ground water recharge are also from perennial rivers which are influent, while the discharge of aquifer in the area of study is mainly by artificial abstraction from wells and boreholes by pumping.

CHAPTER 5

5 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSION

The distribution of hand dug wells as well as boreholes in the study area is shown on the map produced, large pond as well as rivers and streams were also clearly shown with blue colour, this gives an idea of the spread of hand dug wells as well as boreholes in the area. The water-table contour map of the study area was constructed using the difference between the elevation and the water level in hand dug wells and static water level of boreholes respectively. The contour map was used in establishing the groundwater flow direction of the aquifers of the area, discovery of two large groundwater depressions created by over pumping of the aquifers in the study area and establishment of a groundwater ridge created by the River Damaturu changing its regime from effluent to an influent river.

The physical and chemical quality of groundwater in hand dug wells and boreholes, surface water and rain water were assessed. The chemical element in the rainfall does not have much effect on the groundwater. The surface water has high values of chemical parameter and tend to be polluted, this is obviously due to human activities. The quality of groundwater in general in the study area with reference to analysis made for their physico-chemical parameters compared with the Nigerian drinking water standards of 2007 and that of the World Health Organization (WHO) drinking water standards of 2004 show that most of the major ions falls within the standard limit of drinking water and domestic use. The water quality for irrigation based on Sodium

Adsorption Ratio (SAR) calculated and the bicarbonate hazard determined, indicates that groundwater in the study area is suitable for irrigation purposes.

This study has however revealed that the phreatic aquifer of the study area varies in depth and thickness, this could be a case of tapping from different zones of the upper aquifer of the Chad Formation classified into A, B and C. The aquifer is very shallow in the *fadama* parts of the study area, about 3m to 5m deep, while it is deeper in the rest of the study area. Surface water from the large pond at the centre of Damaturu contaminates the groundwater of that area, this was evident from the elements analyzed from the water samples of both the wells and pond.

Correlation of borehole lithologs revealed the sub-surface geology/lithology of the study area, it indicates the different depths at which the Upper and Middle aquifers are encountered in boreholes.

Water-types of the area were also established using the AQUACHEM software. Not less than 10 water types were obtained from the 5 hand dug wells and 15 boreholes plotted on the piper diagram.

Characteristics of confined aquifer in the study area using borehole pumping test data was evaluated, its transmissivity (T), Hydraulic conductivity (K) and Storage coefficient (S) were confirmed to be good in performance.

5.2 RECOMMENDATIONS

Groundwater resources have played and will continue to play an important role in meeting the water needs of the inhabitants of the study area, especially for domestic and livestock consumption. The scientific management of groundwater resources of the area

is absolutely essential for sustainable groundwater development and economic advancement of the people.

It is therefore necessary to understand the aquifer behaviour and interactions with infiltrating and deeply percolating water.

There is a need to investigate further and establish areas of possible recharge to the aquifers and recharge capacity. The two groundwater depressions created by over pumping within the study area is alarming, there is a need to establish an artificial recharge reservoirs at the upper course of the River Damaturu so that water in the reservoirs would recharge the ground water during the dry season to make up the lost part due to over exploitation.

The large pond at the centre of Damaturu poses danger to the phreatic aquifer and as well environmental hazard to the inhabitants of that area because it is obviously recharging the wells around it. The Government should design a modality in which water abstracted in such wells close to those ponds are not consumed by the populace rather be put to other safer domestic use.

Boreholes distribution in the area should be controlled in other to avoid interference of wells and over abstraction. The proliferation of tube wells (wash boreholes) in the study area should also be looked into especially the mode of construction. There should be proper check by the Government on how these wells are drilled by involving trained hydrogeologists and geologist to site the locations of drilling, supervise the drilling and design the wells then the water be subjected to laboratory test before is put to public use.

Chemical quality of groundwater is one of the most important aspects in hydrogeology in general and in this study in particular. Groundwater of the phreatic aquifer in the study area is vulnerable to contamination because of its shallow nature. Proper chemical and bacteriological analyses of the water from such aquifers should be a standing order by the government. People need to be constantly sensitized on the dangers of poor hygiene, especially open defecation close to their water source.

Due to the scarcity of rainfall in the study area and also the impending danger of groundwater insecurity the over exploitation of the Chad Formation aquifers might cause in that area, a further study on the aquifer recharge and discharge, the expansion or otherwise of those depressions and a remedy to arrest the situation are recommended, also water management plan of both surface and groundwater of Damaturu and its environs, interaction of groundwater with the river and the large pond situated at the centre of Damaturu town be made. It is further recommended that the Yobe State Government should establish 'Green Zones' in which people should be exempted from cultivating crops, grazing animals, building or any other purpose in those area, this would greatly improve groundwater recharge and control desertification.

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APPENDIX I

BOREHOLES TAPPING FROM DEEP AQUIFER OF CHAD FORMATION IN THE STUDY AREA

S/N	BOREHOLE NO/ NAME	STATIC WATER LEVEL (m)	PUMP CAPACITY (l/s)	MAP ELEV (m)	GROUND WATER ELEVATION	PUMPING RATE (l/s)	DURATION BEFORE STABILIZATION (min)	DYNAMIC WATER LEVEL (m)	TOTAL DEPTH DRILL (m)	AQUIFER THICKNESS (m)	SCREEN LENGTH (m)	COODINATES	
												LAT	LONG
1	DA 02	51.71	4	366	314	1.58	140	58.11	241	20	15	11°45′24.0″	11°57′31.0′
2	DA 05	48.96	4	365	316	3.18			205			11°45′12.7″	11°58′10.5′
3	DA 06	59.65	2	375	315	1.4	180	61.22	165	20	15	11°44′19.7″	11°57′42.8′
4	DA 08	58		374	316				180	30	15	11°44′55.9″	11°58′17.3′
5	DA 10	54.6		376	321				157	25	15	11°44′15.6″	11°57′50.0′
6	DA 12	60.51	2	376	315	1.2	190	62.98	125	16	12	11°44′19.3″	11°57′59.7′
7	DA 13	68.01	2	387	319	0.54	210	69.34	135	17	12	11°46′30.9″	11°57′03.1′
8	DA 14	65.32	2	392	327	0.54	90	65.56	125	16	12	11°41′28.3″	11°56′47.7′
9	DA 15	56.7		381					144	20	15	11°43′13.2″	11°57′25.2′
10	DA 16	55.94	3	379	323	1.57	210	58.02	141	15	12	11°43′56.7″	11°57′39.3′
11	DA 17	50.91		364	313				150	25	15	11°44′26.6″	11°56′51.2′
12	DA 20	57.23	3	377	320	1.34	180	59.25	135	17	12	11°44′36.6″	11°59′12.3′
13	DA 22	47.52	3	371	323	1.77	90	51.15	228	20	15	11°45′29.1″	11°59′44.4′
14	DA 23	57.2		367	310				192			11°45′17.3″	11°56′47.4′
15	DA 25	56.33	3	378	322	1.45	140	59.69	137	17.5	15	11°43′37.2″	11°57′12.7′
16	DA 27	51.5		364	313				135			11°44′51.3″	11°57′26.3′
17	DA 28	46.6		374	327				149			11°44′49.1″	11°58′27.7′
18	DA 30	58.9		380	321				147	20	15	11°46′00.1″	11°56′51.5′
19	DA 31	48		377	329				135			11°44′25.3″	11°58′08.8′

20	DA 35	59.81	381	321	145.2			$11^{0}44'02.4''$	$11^{0}58'14.1'$
21	DA 36	52.1	382	330	138	18	12	$11^{0}43'05.6''$	$11^{0}57'30.0'$
22	DA 38	49	371	322	148			$11^{0}44'48.4''$	$11^{0}58'03.9'$
23	DA 39	50.1	361	311	150			$11^{0}44'46.8''$	$11^{0}57'00.6'$
24	DA 41	50.3	365	315	153			$11^{0}45'08.4''$	$11^{0}57'49.9'$
25	DA 44	55	367	312	138			$11^{0}44'43.6''$	$11^{0}57'28.2'$
26	DA 49	50	362	312	133			$11^{0}44'57.9''$	$11^{0}57'39.8'$
27	DA 51	56	365	310	150			$11^{0}45'33.4''$	$11^{0}57'07.3'$
28	DA 55	47.9	373	325	145			$11^{0}44'08.4''$	$11^{0}57'10.8'$
29	FEDPOLY	49.5	376	327	115			$11^{0}44'48.5''$	$11^{0}58'47.9'$
30	SABON PEGI (SP1)	45.1	372	327	102			$11^{0}45'08.41'$	$11^{0}58'32.2'$
31	SABON PEGI (SP2)	48.8	365	316	101			$11^{0}45'27.1''$	$11^{0}58'22.0'$
32	GASHUA ROAD (GR)	47.1	370	323	107			$11^{0}45'50.7''$	$11^{0}57'31.7'$
33	BUHARI QUARTER (BQ)	50.2	368	318	137			$11^{0}45'42.2''$	$11^{0}57'54.6'$
34	SINDIRI	59.8	390	330	187			$11^{0}49'05.8''$	$11^{0}54'30.9'$
35	NYANYA (NY)	51.2	386	335	145			$11^{0}42'43.1''$	$11^{0}57'51.9'$
36	3 STAR HOTEL (3SH)	54.4	377	323	198			$11^{0}44'12.9''$	$11^{0}55'07.1'$
37	INDUSTRIAL LAYOUT (IL)	56.1	378	322	134			$11^{0}44'12.9''$	$11^{0}55'07.1'$
38	ZANNA ZAKARIA ESTATE (ZZ)	57.8	395	337	253			$11^{0}46'59.8''$	$11^{0}56'40.0'$

APPENDIX II

Depths to water levels (mbgl) in hand dug wells during peak of dry season (April) and end of rainy season (October) in Damaturu

Well No	Location	COORDINATES		Map Elevation (m)	Dry Season Ground water Elevation	Dry Season Water Level (mbgl) Date of Measurement: 15 April, 2009	End of rainy Season Water Level (mbgl) Date of Measurement: 20 October, 2008	End of rainy Season Groundwater Elevation (m)	Water Table Fluctuation (m)	Total depth of well (m)	Remarks
		Lat (N)	Long (E)								
1	Digmari	$11^0$43′35.2″	$11^0$55′12.1″	369	366	3.0	1.7		1.3	3.5	Well in the Fadama area
2	Malmattari	$11^0$42′07.8″	$11^0$57′32.1″	381	375	6.2	4.87		1.33	7.5	Well located southeastern end of the village.
3	Malmattari 2	$11^0$42′14.9″	$11^0$57′48.0″	384	379	5.0	2.63		2.37	7.5	A few meters away from the first well
4	Sindiri	$11^0$49′05.2″	$11^0$54′34.2″	398	>273	Dried	122			124.6	Well not in use close to a borehole
5	Nayinawa Tsallake	$11^0$44′09.9″	$11^0$56′53.8″	368	362	5.12	0.36		1.2	6.5	Well covered with iron sheet closed to a foot ball field
6	Nayinawa Kandahar	$11^0$44′51.4″	$11^0$56′29.4″	368	362	5.76	5.6		0.16	7.5	Well with two tiers closed to a residence
7	Nayinawa Kandahar 2	$11^0$44′32.4″	$11^0$56′05.6″	368	362	5.77	5.41		0.36	7.5	Well with one tier
8	Nayinawa Ajari	$11^0$44′34.3″	$11^0$56′46.1″	368	363	5.1	4.23		0.87	7.5	Well closed to a GSM mast
9	Pawari	$11^0$45′11.8″	$11^0$57′25.6″	367	362	5.2	3.85	363	1.35	7	Well close to the Damaturu old abattoir
10	Pawari 2	$11^0$45′10.7″	$11^0$57′15.3″	367	363	4.4	3.67	363	0.73	7	Well located on ‘T’ junction close to a red mud mosque.

11	Pawari 3	$11^0$45′11.6″	$11^0$57′25.0″	367	363	4.27	3.54	363	0.73	5.5	Well located in front of a house (private)
12	Pawari 4	$11^0$45′05.0″	$11^0$57′24.1″	367	364	3.2	1.7	365	1.5	7	Well very close to the large pond
13	Pawari 5	$11^0$45′08.5″	$11^0$57′19.9″	366	362	4.3	2.79	363	1.51	7	Well in front of a residential house
14	Pawari Layout	$11^0$45′22.0″	$11^0$57′10.5″	367	361	6.2	6.18	361	0.02	7	Well located close to an electric pole in front of a residential house
15	Alhajiri	$11^0$44′48.3″	$11^0$57′36.2″	368	323	45	44.68	323	0.32	50	Well located close to the Alhajiri borehole near a welder.
16	One million Road	$11^0$45′00.4″	$11^0$57′10.5″	367	363	3.68	2.18	365	1.5	7	Well located in front of a residential house close to the pond.
17	Nayinawa	$11^0$44′59.8″	$11^0$57′19.3″	367	363	3.55	3.35	364	0.2	7	Well located close to the large pond and a tube well
18	NITEL office	$11^0$44′38.2″	$11^0$57′45.1″	371	315	56.32	55.46	316	0.86	60	Well located in the center of NITEL office premises Damaturu.
19	Fulatari	$11^0$45′23.1″	$11^0$57′46.5″	367	363	4.03	3.81	363	0.22	6.5	Well located close to a mud mosque and a baobab tree.
20	Gujba Raod	$11^0$44′19.3″	$11^0$57′43.3″	374	316	58	57.1	317	0.9	60	Well in BH premises, DA 6

APPENDIX III

Rainfall depth for Six Years for Damaturu and its Environs

SN	YEAR	MONTH	RAINFALL (mm)
1	2002	JANUARY	0.00
2	2002	FEBRUARY	0.00
3	2002	MARCH	0.00
4	2002	APRIL	0.00
5	2002	MAY	50.90
6	2002	JUNE	80.60
7	2002	JULY	117.90
8	2002	AUGUST	129.60
9	2002	SEPTEMBER	231.70
10	2002	OCTOBER	0.00
11	2002	NOVEMBER	0.00
12	2002	DECEMBER	0.00
		TOTAL = 610.7	
1	2003	JANUARY	0.00
2	2003	FEBRUARY	0.00
3	2003	MARCH	0.00
4	2003	APRIL	0.00
5	2003	MAY	5.30
6	2003	JUNE	42.70
7	2003	JULY	112.80
8	2003	AUGUST	169.60
9	2003	SEPTEMBER	130.10
10	2003	OCTOBER	147.50
11	2003	NOVEMBER	0.00
12	2003	DECEMBER	0.00
		TOTAL = 608.0	
1	2004	JANUARY	0.00
2	2004	FEBRUARY	0.00
3	2004	MARCH	0.00
4	2004	APRIL	0.00
5	2004	MAY	17.20
6	2004	JUNE	89.30
7	2004	JULY	97.40
8	2004	AUGUST	255.80
9	2004	SEPTEMBER	35.20
10	2004	OCTOBER	10.50
11	2004	NOVEMBER	0.00
12	2004	DECEMBER	0.00
		TOTAL = 505.4	
1	2005	JANUARY	0.00

2	2005	FEBRUARY	0.00
3	2005	MARCH	0.00
4	2005	APRIL	30.00
5	2005	MAY	63.50
6	2005	JUNE	114.00
7	2005	JULY	153.30
8	2005	AUGUST	346.80
9	2005	SEPTEMBER	95.30
10	2005	OCTOBER	51.60
11	2005	NOVEMBER	0.00
12	2005	DECEMBER	0.00
		TOTAL = 854.5	
1	2006	JANUARY	0.00
2	2006	FEBRUARY	0.00
3	2006	MARCH	0.00
4	2006	APRIL	0.00
5	2006	MAY	NOT RECORDED
6	2006	JUNE	NOT RECORDED
7	2006	JULY	99.30
8	2006	AUGUST	187.00
9	2006	SEPTEMBER	197.60
10	2006	OCTOBER	0.00
11	2006	NOVEMBER	0.00
12	2006	DECEMBER	0.00
		TOTAL= 161.3	
1	2007	DATA NOT AVAILABLE AT THE TIME OF THIS WORK	
1	2008	JANUARY	0.00
2	2008	FEBRUARY	0.00
3	2008	MARCH	0.00
4	2008	APRIL	0.00
5	2008	MAY	13.90
6	2008	JUNE	51.00
7	2008	JULY	68.00
8	2008	AUGUST	268.00
9	2008	SEPTEMBER	80.00
10	2008	OCTOBER	21.40
11	2008	NOVEMBER	0.00
12	2008	DECEMBER	0.00
		TOTAL = 502.3	

APPENDIX IV

Nigerian Standards for Drinking Water (After SON 2007)

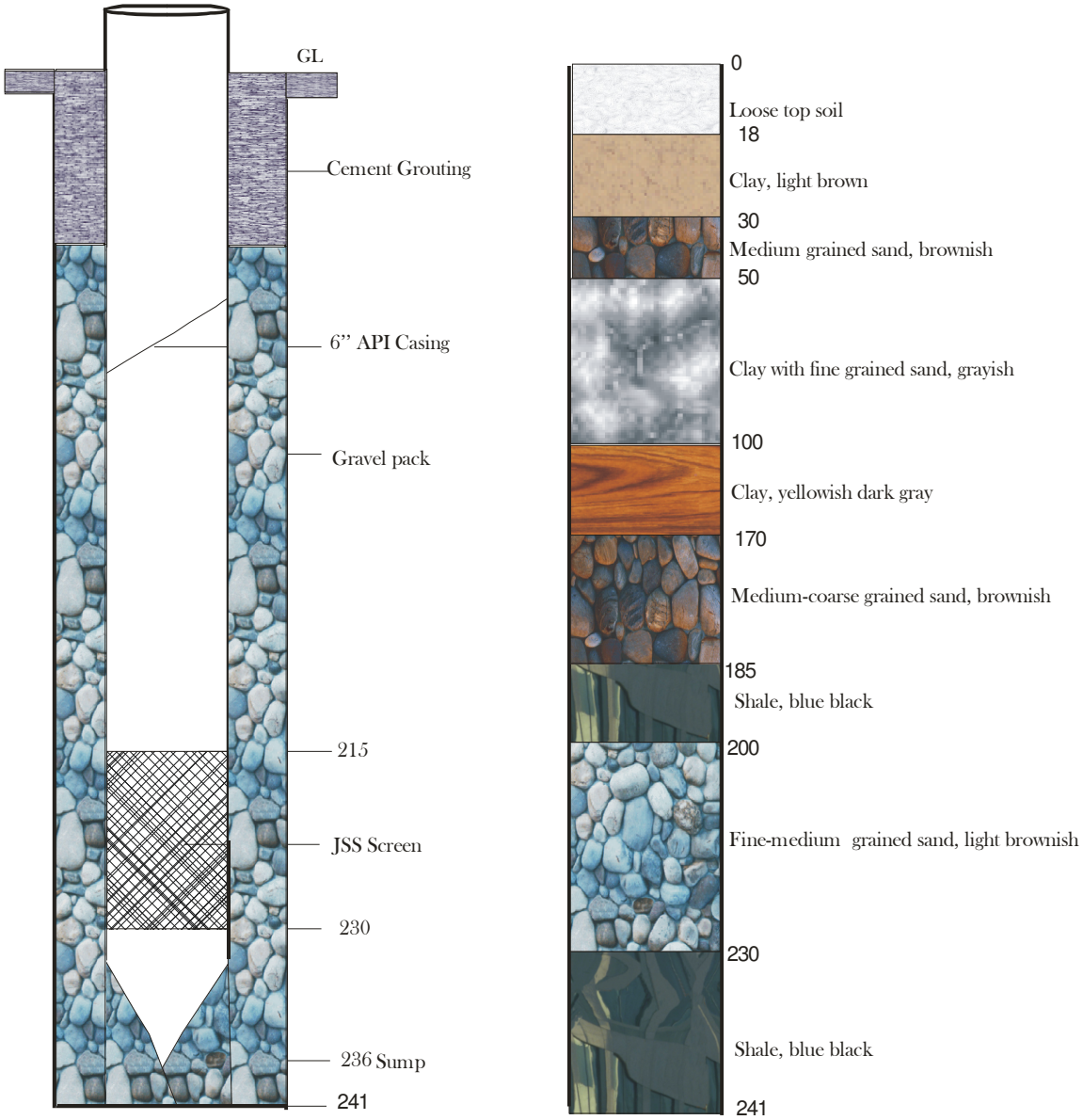
S/No	Substance Characteristic / Elements	Recommended Limit (mg/l)	Maximum Permissible Limite (mg/l)
1	Ph	6.5	8.5
2	Total Dissolved Solid (TDS)	500	1500
3	Electrical Conductivity (EC)	-	1000
4	Sodium (Na^{+})	150	200
5	Potassium (K^{+})	-	-
6	Magnesium (Mg^{2+})	0.20	150
7	Calcium (Ca^{2+})	75	200
8	Sulphate (So_4^{2-})	100	400
9	Chloride (Cl^{-})	250	600
10	Bicarbonate (Hco_3^{-})	-	-
11	Iron (Fe^{+2})	0.3	1.0
12	Nitrate ($N0_3$)	-	50

International Drinking Water Standards, World Health Organization (WHO) 2004

S/No	Substance Characteristic / Elements	Recommended Limit (mg/l)	Maximum Permissible Limite (mg/l)
1	pH	6.5	8.5
2	Total Dissolved Solid (TDS)	500	1500
3	Electrical Conductivity (EC)	-	1480
4	Sodium (Na^{+})	150	200
5	Potassium (K^{+})	10	15
6	Magnesium (Mg^{2+})	39	150
7	Calcium (Ca^{2+})	75	200
8	Sulphate (So_4^{2-})	150	250
9	Chloride (Cl^{-})	200	500
10	Bicarbonate (HCO_3^{-})	500	1000
11	Iron (Fe^{+2})	0.3	1.0
12	Nitrate ($N0_3$)	20	45

APPENDIX V

DAMATURU DA/02 LITHOLOGS AND BOREHOLE DESIGN

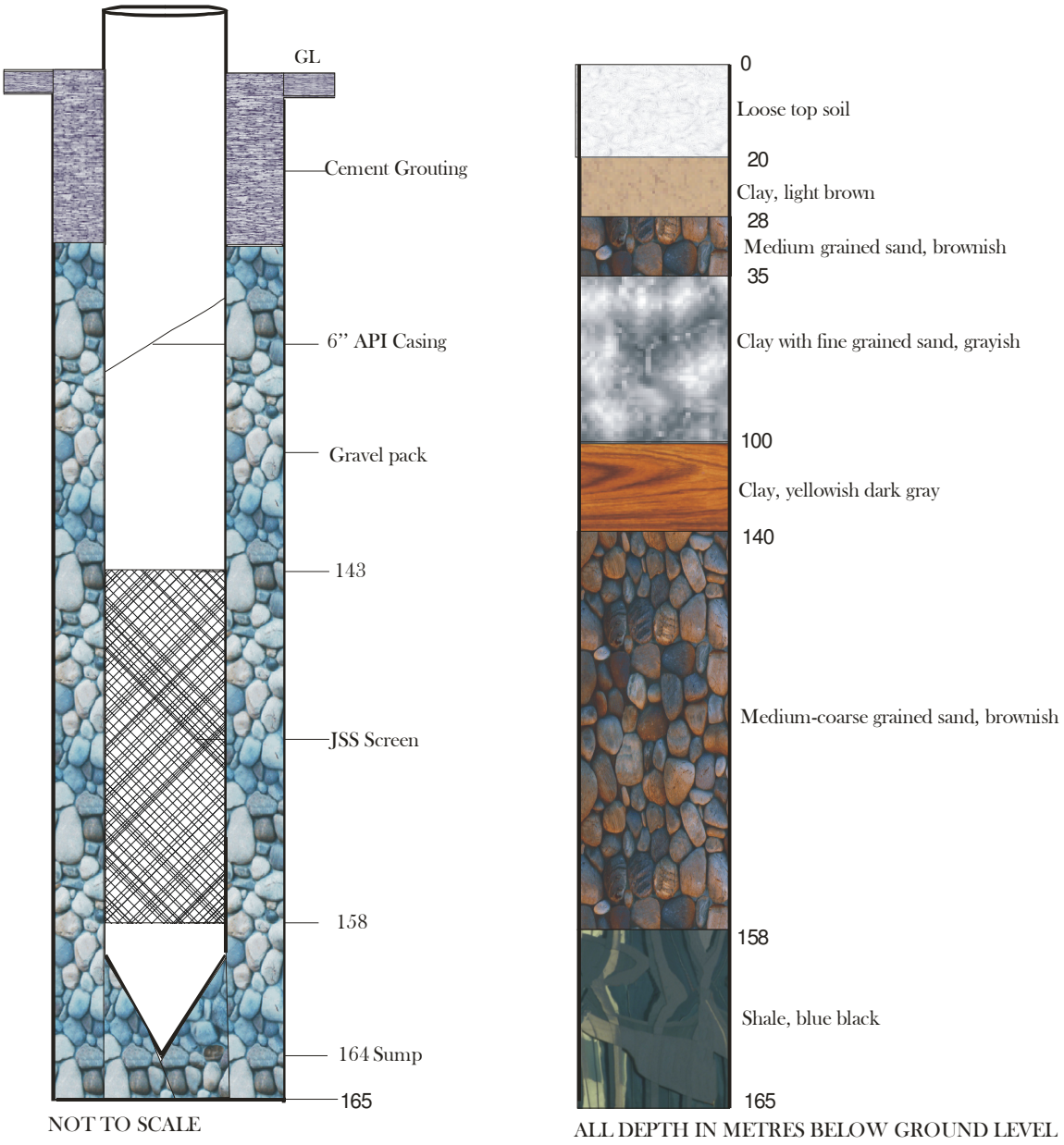


NOT TO SCALE

ALL DEPTH IN METRES BELOW GROUND LEVEL

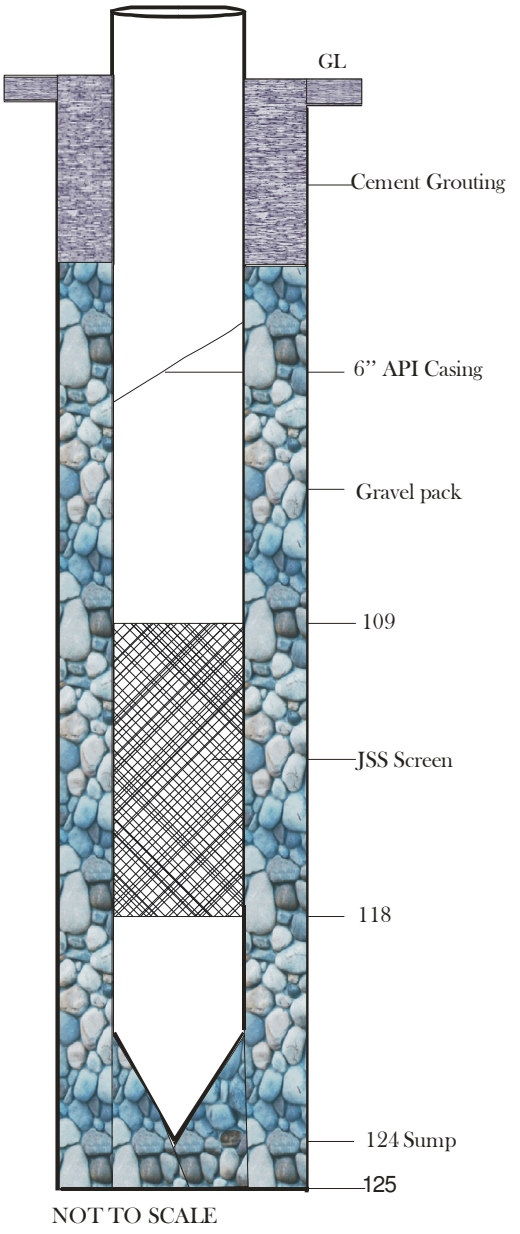
BOREHOLE COORDINATE: LAT. $11^0 45' 24'' N$ LONG. $11^0 57' 31'' E$

DAMATURU DA/06 LITHOLOGS AND BOREHOLE DESIGN

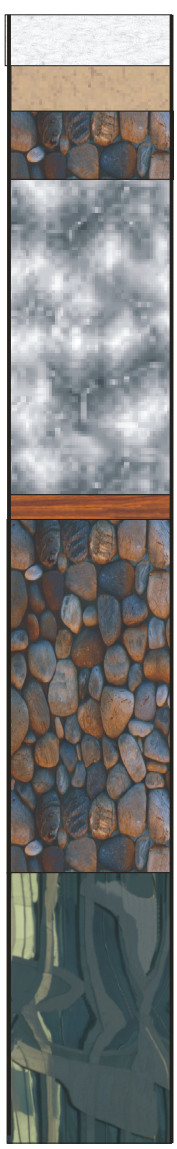


BOREHOLE COORDINATE: LAT. $11^{0}44'19.7''N$ LONG. $11^{0}57'42.8''E$

DAMATURU DA/12 LITHOLOGS AND BOREHOLE DESIGN



NOT TO SCALE

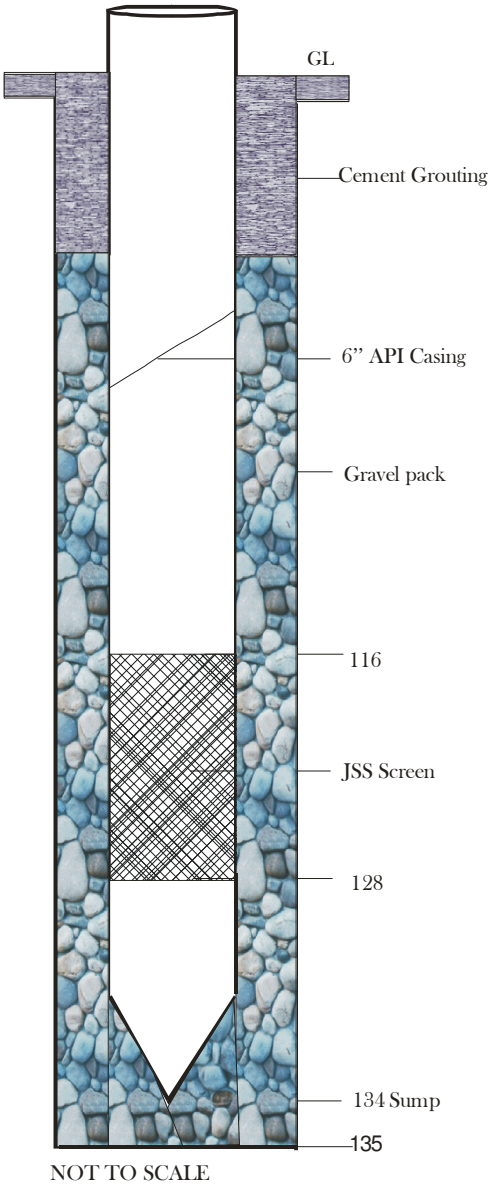


0
Loose top soil
15
Clay, light brown
25
Medium grained sand, brownish
40
Clay with fine grained sand, grayish
85
91 Clay, yellowish dark gray
Medium-coarse grained sand, brownish
118
Shale, blue black
125

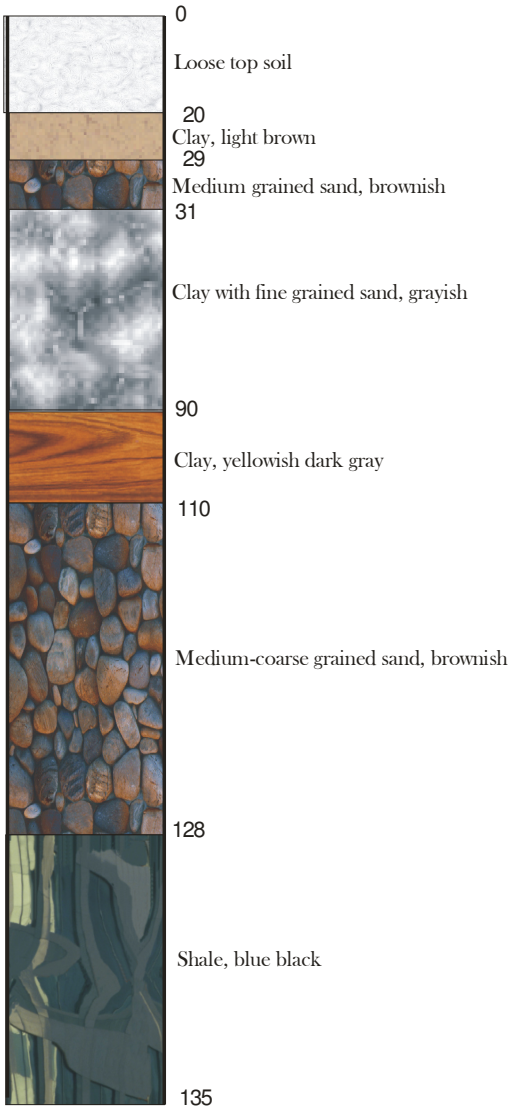
ALL DEPTH IN METRES BELOW GROUND LEVEL

BOREHOLE COORDINATE: LAT. $11^0 44' 19.3'' N$ LONG. $11^0 57' 59.7'' E$

DAMATURU DA/13 LITHOLOGS AND BOREHOLE DESIGN



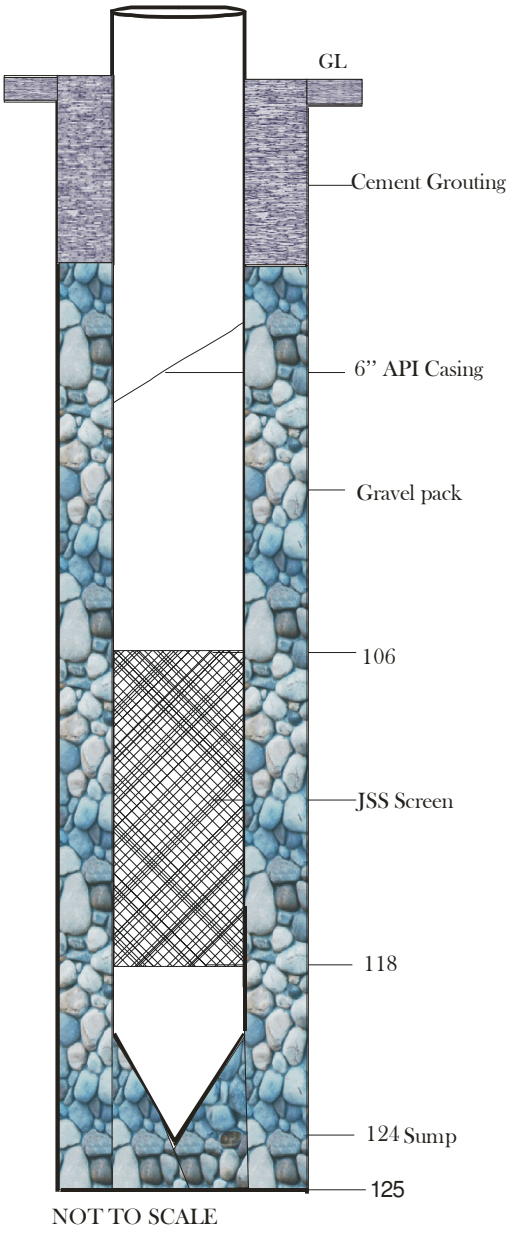
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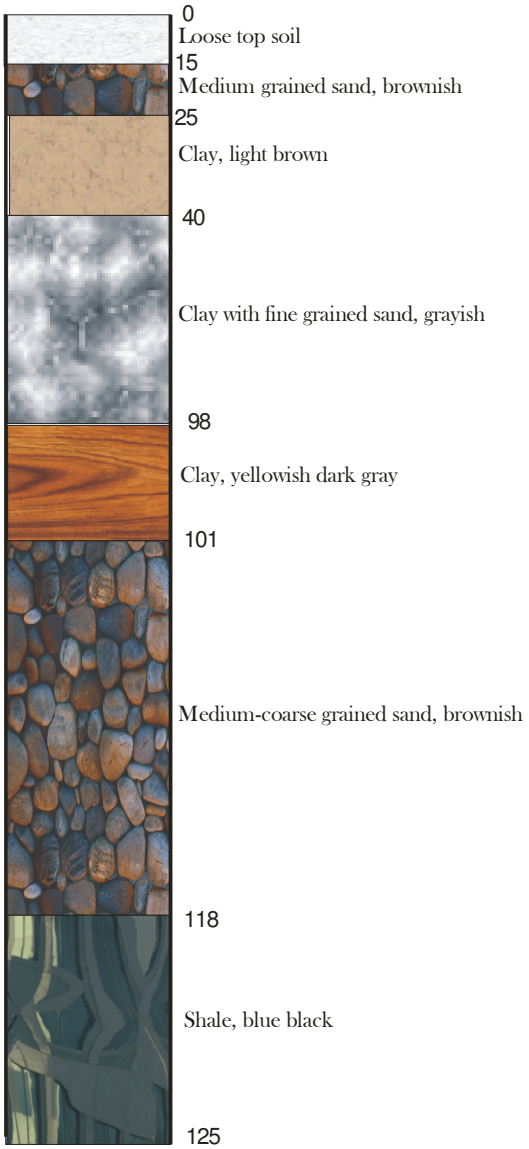
ALL DEPTH IN METRES BELOW GROUND LEVEL

BOREHOLE COORDINATE: LAT. $11^0$46′30.9″N LONG. $11^0$57′03.1″E

DAMATURU DA/14 LITHOLOGS AND BOREHOLE DESIGN



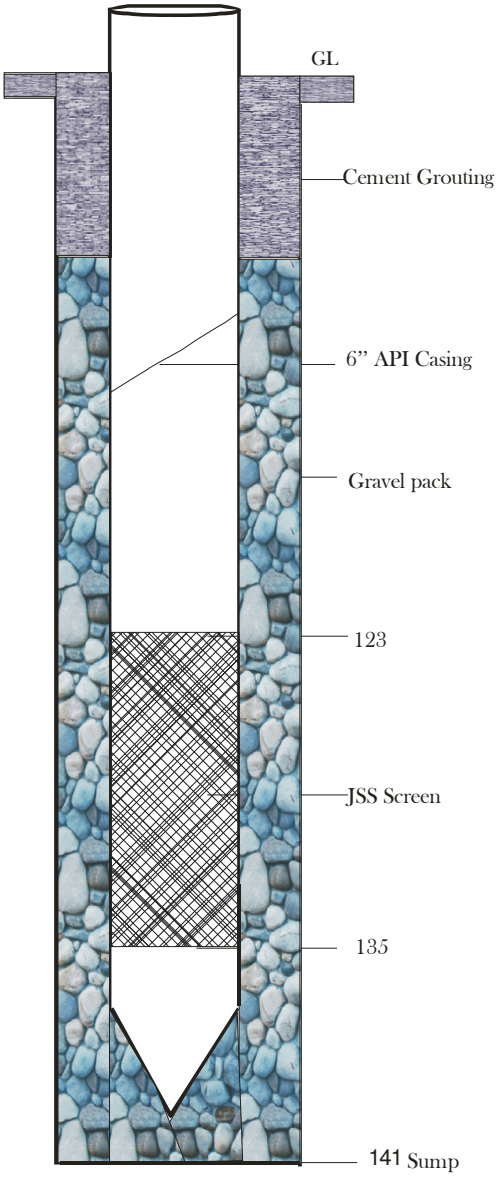
NOT TO SCALE



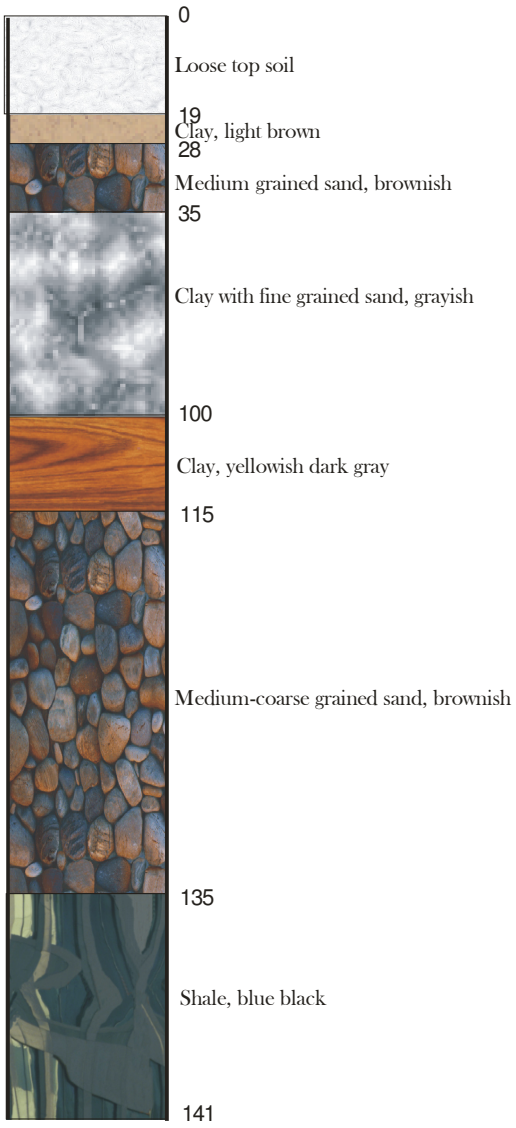
ALL DEPTH IN METRES BELOW GROUND LEVEL

BOREHOLE COORDINATE: LAT. $11^0 41' 28.3'' N$ LONG. $11^0 56' 47.7'' E$

DAMATURU DA/16 LITHOLOGS AND BOREHOLE DESIGN



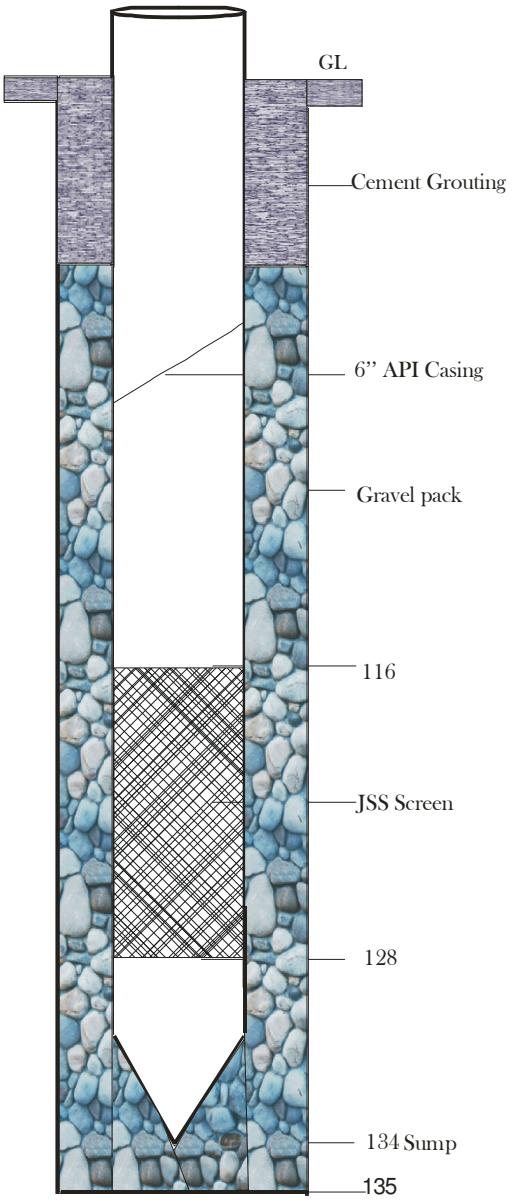
NOT TO SCALE



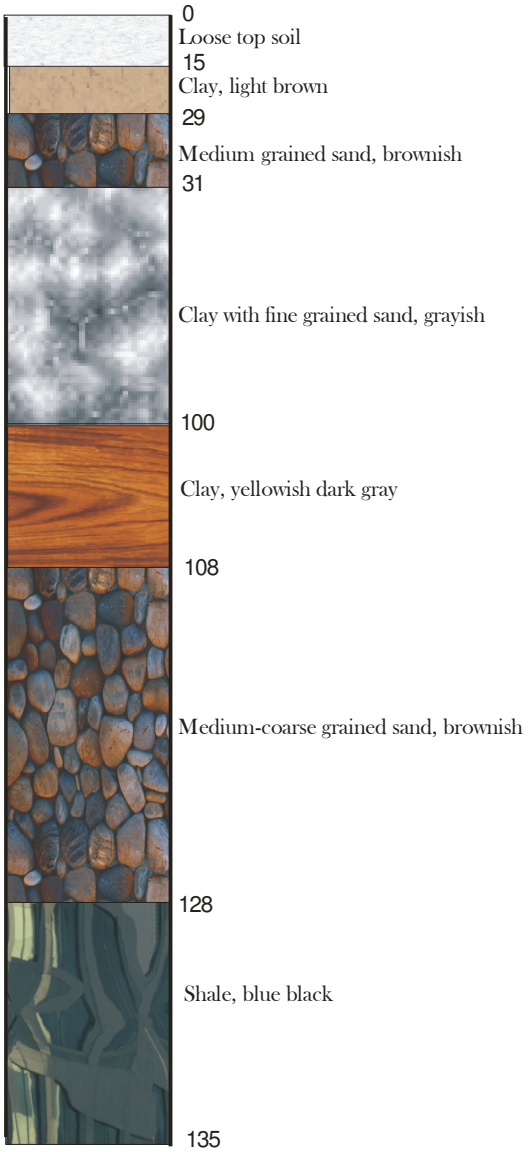
ALL DEPTH IN METRES BELOW GROUND LEVEL

BOREHOLE COORDINATE: LAT. $11^{0}43'56.7''N$ LONG. $11^{0}57'39.3''E$

DAMATURU DA/20 LITHOLOGS AND BOREHOLE DESIGN



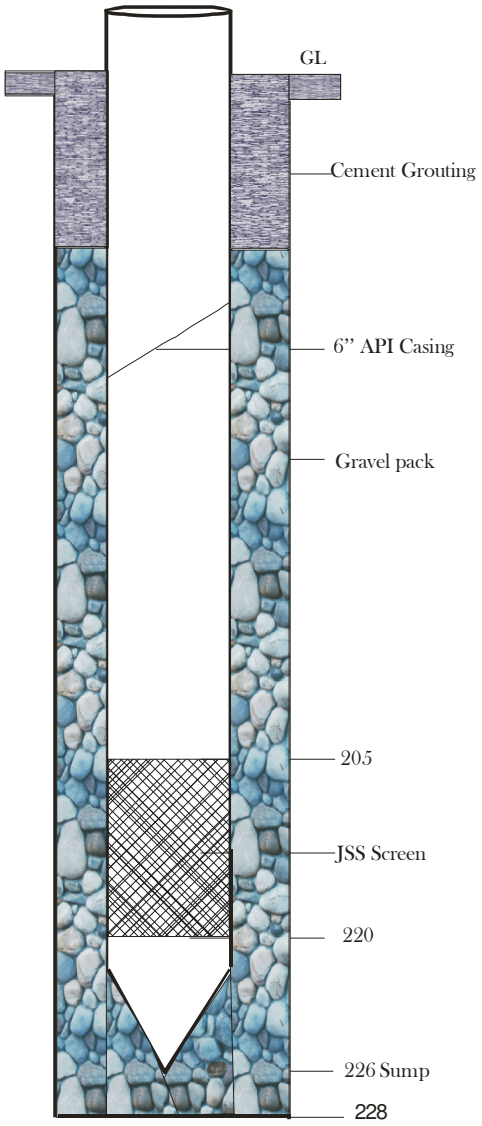
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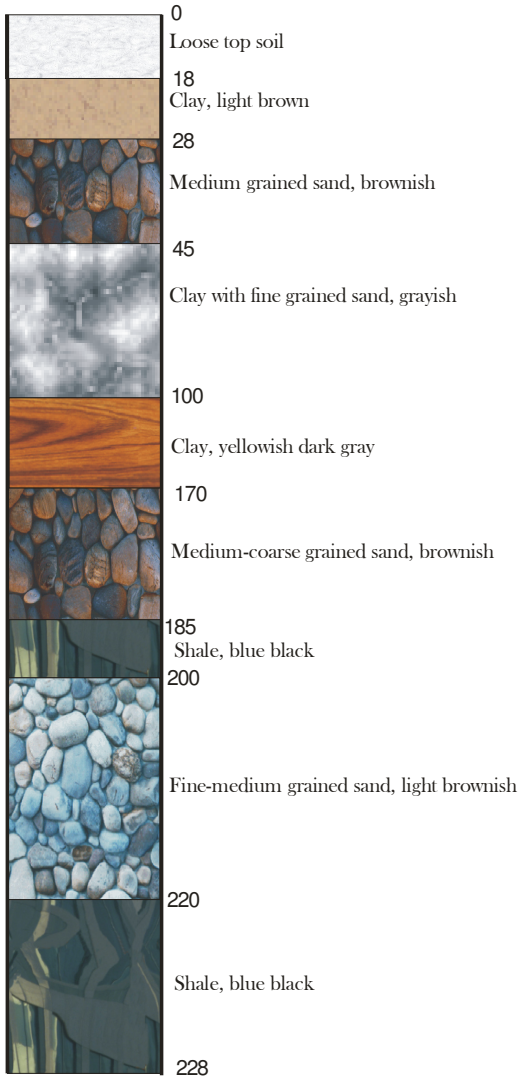
ALL DEPTH IN METRES BELOW GROUND LEVEL

BOREHOLE COORDINATE: LAT. $11^{0}44'36.6''N$ LONG. $11^{0}59'12.3''E$

DAMATURU DA/22 LITHOLOGS AND BOREHOLE DESIGN



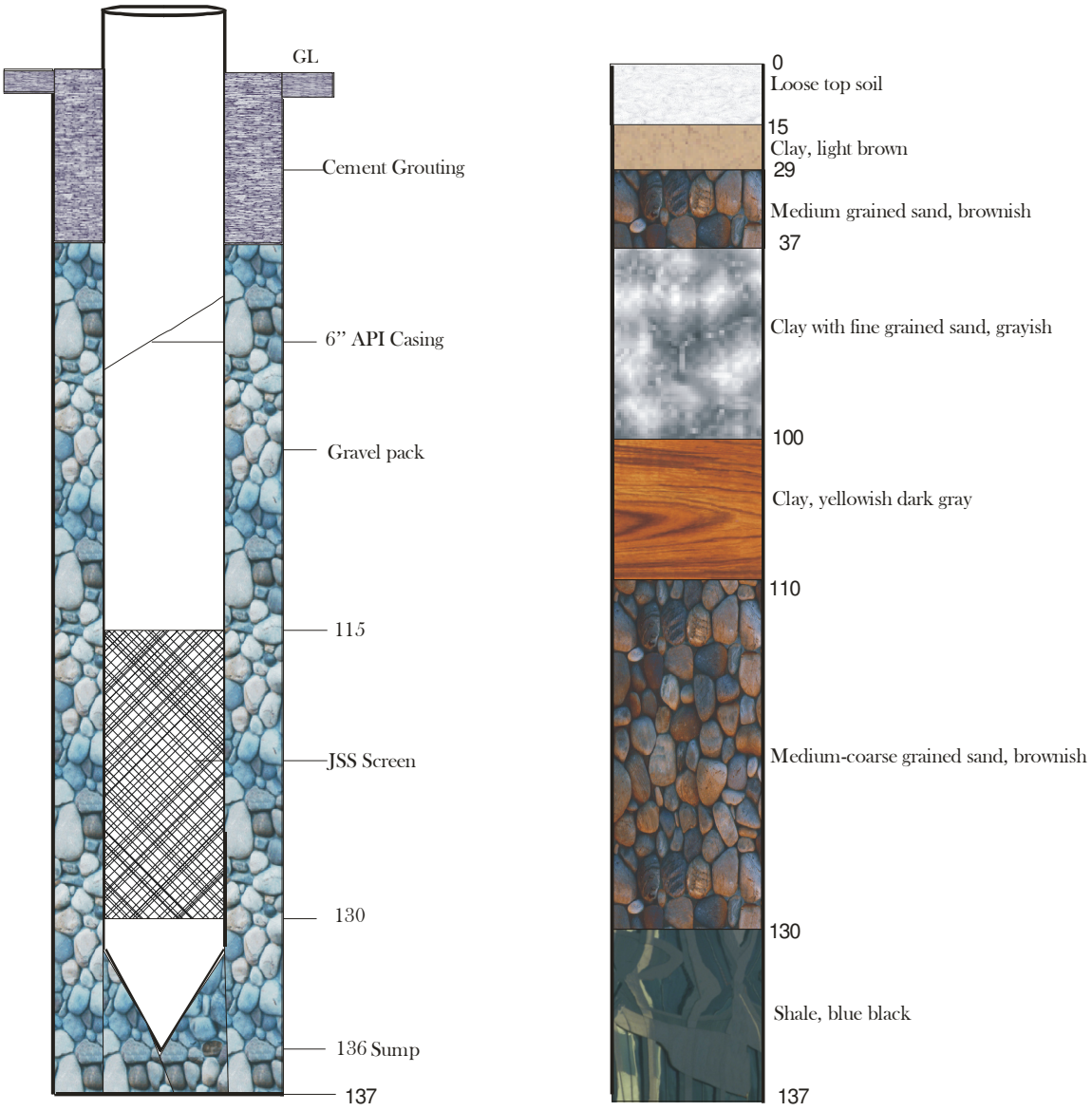
NOT TO SCALE



ALL DEPTH IN METRES BELOW GROUND LEVEL

BOREHOLE COORDINATE: LAT. $11^0 45' 29.1'' N$ LONG. $11^0 59' 44.4'' E$

DAMATURU DA/25 LITHOLOGS AND BOREHOLE DESIGN



BOREHOLE COORDINATE: LAT. $11^0 43' 37.2'' N$ LONG. $11^0 57' 12.7'' E$