EVALUATION OF HYDRAULIC PROPERTIES AND WATER TABLE FLUCTUATION OF GBAKO AQUIFER, NIGER STATE, NIGERIA

Water table fluctuation of selected hand dug wells, and hydraulic properties were determined. The methods of investigation included water level measurements, laboratory tests and analysis. The results indicated that the water level values for 16 wells under study ranged from 6.30 – 7.10 m (Minimum) and 25.40 – 26.30 m (Maximum) during rainy season, while the average during the dry season was 7.60 – 8.90 m (Minimum) and 27.10 – 28.00 m (Maximum). The depth of the wells investigated were between 11 to 30 m, and diameter of the wells ranges between 0.8 and 1.3 m. The aquifer Hydraulic properties were determined from pumping test (recovery test) method. Results showed that transmissibility magnitude ranged from 7.48 to 26.94 m^2/day. The hydraulic conductivity ranged from 1.4 to 8. 2 m/day, while specific yield average was 14.5%. The results showed that the aquifer potential of the wells in the study location is generally low which conform to the general phenomena for basement complex terrain on which Gbako drainage Basin is located. The data and results from this investigation are applicable in assessing and the management of groundwater storage, upward flux, water table configuration as well as groundwater exploration and exploitation. There was no significant differences ($P>0.05$) in the water level of the representative wells indicating they are located within the same geological formation.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Available groundwater information indicates that water level declines are occurring in key agricultural areas and that some aquifers are almost certainly experiencing high levels of over abstraction (Food and Agriculture Organization, 2007).Groundwater information plays an important role in development, and financing of agricultural projects and other politically sensitive decisions. Groundwater is commonly used in the developed world for drinking water supplies in large part because it is more economical than treating surface water for consumption. Göçmez (2009) claims that the use of groundwater is on the rise in the developing world as surface water becomes increasingly contaminated and scarce. With the increase in groundwater use, governments of developing countries rarely do invest in the researches necessary to quantify sustained yields within aquifers unless they experience water shortage. Effective management of groundwater is highly dependent on appropriate, reliable and up-to-date information. For the past 20 years rural communities in Nigeria have experienced an increase in groundwater exploitation as a result of rapidly diminishing and poor quality surface water with no rural community having less than two shallow hand dug wells. However these wells tend to go dry during dry season (Olaniyan and Olabode, 1998).

Changes in the depth of the groundwater table are determined by climatological factors (precipitation and evapotranspiration and their distributions), hydrological characteristics (drainage in and out flowing seepage), soil conditions (hydraulic conductivity), and storage capacity. Quantitative data on the depth, fluctuation and duration of the groundwater table are scarce for tropical West Africa (Ogban and Babalola, 2009).Veldkamp (1979) reported that the precipitation of groundwater regimes of soil characteristics can be inaccurate because great variation may occur during a year and between years, and because oxidation from incoming groundwater may obscure soil morphological features indicative of long term saturation. He therefore recommended the measurement of actual groundwater table depth to determine suitability for uses.

Recovery and pumping tests are normally carried out to explore how much ground water can be safely exploited from a well. It is now a well known fact that before groundwater resources can be managed, it must first be quantified through the estimation of aquifer hydraulic parameters. The success of it, however, depends much on how accurately the test data can be acquired and exhaustively analyzed. Good aquifer naturally corresponds to high porosity and high permeability characteristics (Egharevba, 2010).The result from properly conducted tests on an aquifer is the important tool in groundwater resources evaluation, monitoring and management. The knowledge of soil permeability or other aquifer constraints like transmissibility that relates to the rate of fluid movement in both soils and water bearing aquifer is needed for the design of surface and subsurface drainage facilities. Wells are either shallow or deep and may be dug, driven or bored. Dug wells are excavated by hand or by a variety of unspecialized excavation equipment. In the study area (Gbako Basin), most wells are used for domestic purposes, and water level observations reflect a rapid aquifer response to changes in conditions, presumably rainfall and abstraction (Shekwolo, 1990).

1.2 Statement of Problem

In the past 25 years, Gbako drainage basin has experienced an increase in groundwater exploitation by the rural population (Amadi *et al*., 2010). The fast growing population in the parts of the basin is connected to the high potential for agricultural production in the area which causes a serious water and population imbalance, compounding the problem of falling groundwater levels. The rapidly diminishing and poor quality surface water resource have forced the rural people of the area to install relatively inexpensive shallow hand-dug wells. However, over the years, in many areas, these wells tend to go dry during the critical dry months (January to March).

The increased exploitation of groundwater coupled with lack of information on declining water tables, extraction estimates, and aquifer properties is of great concern from a sustainability stand point. The inability to access these information, which at times is part of institutional secrecy, encourages inaction or incorrect decisions. Therefore, for a sustainable groundwater and correct decisions there is the need to study or determine water table fluctuations and aquifer properties in the study location.

1.3 Justification of the Study

Groundwater forms one of the important sources of water supplies in many areas, as it is believed to be safe and free from pathogenic bacterial and from suspended matter. The pace of groundwater withdrawal in many fertile regions is increasing due to the fast pace of population growth accompanied by agricultural and industrial development. Generous amount of money have been spent on sinking of boreholes and wells for agricultural and industrial purposes including domestic uses but not properly managed because of the fluctuating nature of groundwater New data bases need to be developed for relating the aquifer geometry vis-à-vis availability of groundwater especially in the part of Gbako drainage basin.The knowledge of groundwater fluctuation and the aquifer potential is imperative for groundwater management resources of the area.

1.4 Aim and Objectives

The study is largely on the investigation of water table fluctuation and the corresponding aquifer potential of some selected hand dug wells and boreholes around the Gbako drainage area. The objectives of the research work were to:

1. Determine the seasonal fluctuation of the depth to water level of the wells in the study area.
2. Determine the aquifer hydraulic characteristics (hydraulic conductivity, transmissibility and specific yield).

1.5 Scope of the study

The work covered the Gbako drainage basin, a catchment of the middle-Niger (Bida) Basin North of River Niger. The study location extends from Edozhigi, Zanchita through Bida/Edokota/Emizhiru, Badeggi/Essa, and Kuchiworo/Vunchi. The geology of the area, geophysical surveys and some climatic data will be considered. The aquifer hydraulic characteristics will be evaluated using hand dug wells and selected boreholes within the study area. Due to financial and time constraints, it was not possible to dig or drill new wells, so existing wells in the study area were relied upon for the required investigation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Hydro Climatic Variables

Gbako drainage area falls within the middle belt region which is characterized by wet and dry seasons. The wet season usually occur from March to October and is dominated by rainfall. The dry season occurs from November to March when the area is under the influence of North easterly winds. Spatial and temporal changes in the surface and precipitation may modify the surface hydraulic boundary conditions of, and ultimately cause a shift in the water balance of an aquifer (IGES, 2010). Changes in precipitation and evaporation translate directly to shift in soil moisture deficits, surface water runoff and groundwater recharge (Clark, 1985). Higher temperature will mean higher evaporation and plant transpiration rates and hence, more drying up soils. This will entail higher loses of soil moisture and groundwater recharge.

2.1.1 Climate

The climatic condition of the area under study is essentially the same as typical of the middle belt of Nigeria. The seasons are governed by the movement of the inter tropical discontinuity, known as the inter-tropical convergence zone (ITCZ), a zone where warm moist air from the Atlantic coverage with hot, dry and often dust-laden air from the Sahara known locally as hamatan. During the rainy season, the zone of inter-tropical discontinuity follows the sun North ward. As a result, more and more of the country comes under the influence of Moisture-Laden Tropical Marine Air. Thus, much of the country experiences a rainy season during this period. As the rainy season wanes, the zone shifts southward bringing an end to the rainy season and beginning of the dry season characterized by dust laden air from the Saharan hamatan wind. (British Geological Survey, 2009).

2.1.1.1 Rainfall

Due to the latitudinal location of the study area (9^o 00' and 9^o 15') North, it is generally classified as part of the tropical climate with alternating wet and dry season and little or no rainfall in the dry season. The wet season extends from April to October and dry season between November to March (Sehkwolo, 1990). Average annual rainfall ranges between 100 to 150mm Average annual rainfall total of 20 years indicate August and September as peak.

2.1.1.2 Temperature

Average maximum temperature of 34^oC is recorded just before the rainfall begin in April, and minimum of 25^oC at the peak of the rainfall, between august and September. Temperatures are generally high throughout the year, averaging between 25^oC and 35^oC. Higher temperature increases evaporation and therefore reduces water availability for human and ecosystems. Relative humidity averages about 75% in rainy season and 26% in the dry season. (See AppendixE)

Warm air holds more moisture and increase evaporation of surface moisture; with more moisture in the atmosphere, rainfall events tend to be more intense, increasing the potential for floods. However, if there is little or no moisture in the soil to evaporate the incident of solar radiation goes into raising the temperature which could contribute to groundwater recharge from longer and more severe droughts(Singhal *et al.*,2010).

2.2 Hydro-Chemical and Geological Regime of the Study Area

2.2.1 Hydrogeology

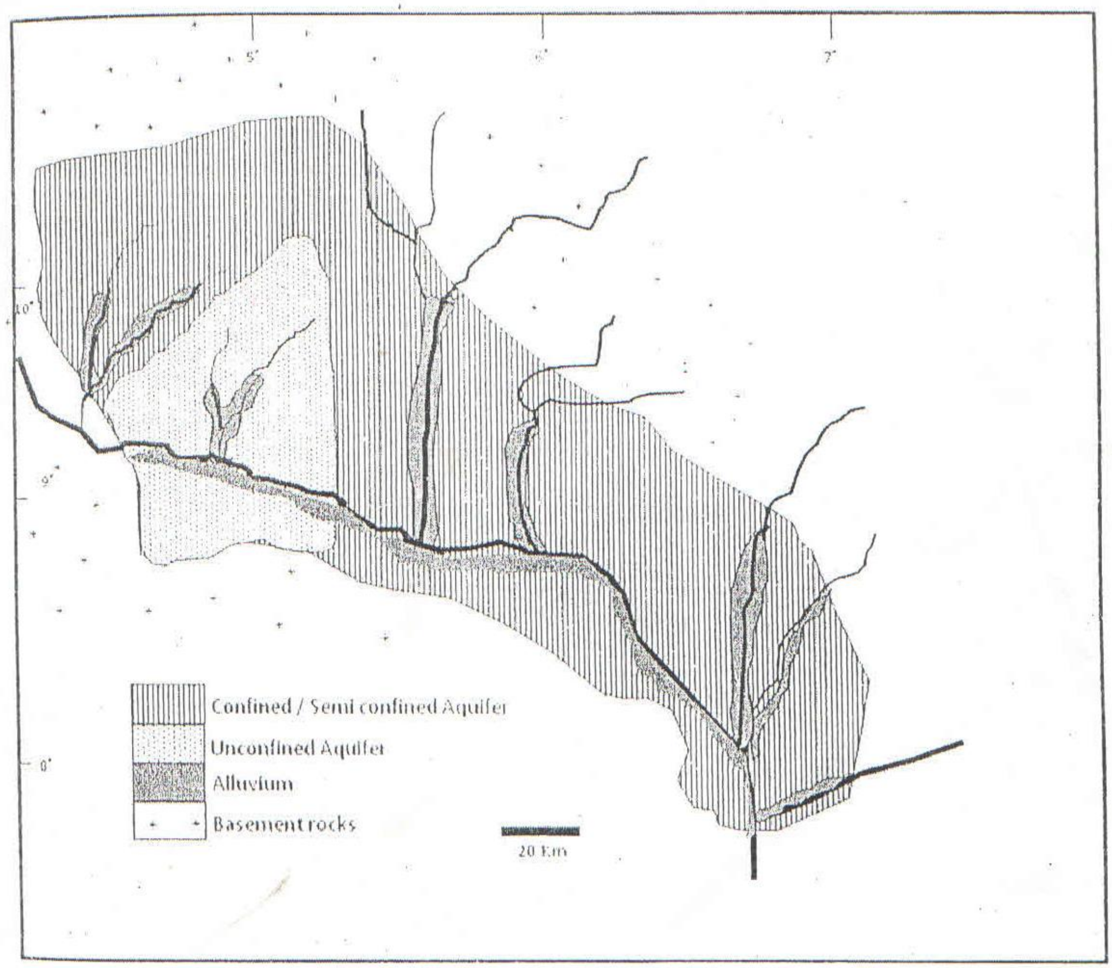
Gbako drainage area is located in the Northern part of Bida Basin which exists in the Southern district of Niger State. The occurrence and distribution of groundwater are controlled by geological factors such as the lithology texture and structure of the rocks and hydrological and meteorological factors such as streamflow and rainfall Olabode *et al*, (2001).The topography of the area is generally flat with average elevation of 120m (400ft) above sea level. The landscape is however dotted with some hills, and it is also capped by the ferruginous sandstone or laterite (Idris-Nda, 2010). The major rivers that drain the area are the River Gbako and River Lavun.

In the study area, two types of aquifer are identifiable. One is confined, while the other is unconfined. The first most widespread and occupied about 80% of the land area while the second is limited to small portions of the central and northern Bida Basin (Shekwolo, 1990). Plate I, shows aquifer types of the Bida basin. (Olabode *et al*., 2001) reported the occurrence of poor yield of groundwater eastward toward Bida, where the formation changes laterally into fine grained sand and silt.

The Bida Basin in Nigeria extends from Kontagora in the North to beyond Lokoja in the South. Its total length is estimated at 400km with a maximum width of about 160km which tapers to less than 60km at Dekina. The largest portion of the basin (the Northern part), which occurs in the Southern half of Niger State Idris Nda (2010). The origin of the basin is believed to be as a result of mega shears in the Precambrian basement which created fault patterns trending Northeast-Southwest (NE-SW) and Northwest-(NE-SE), Kogbe (1981), and Whiteman (1982) suggested the basin was formed from a simple cratonic sag.

The basin is an inter-cratonic basin that was formed during the late cretaceous as a result of reactivation of mega-shears in the pre-Cambrian basement resulting in uplifted basement blocks which form escarpments at the basin margins. The resultant marginal sedimentary fill comprises several cycles of alluvial fan deposition at the foot of the escarpment, and these grade into Lacustrine/flood basin sediments towards the axis of the basin (Braide, 1992).

The oldest rocks exposed in the Bida Basin are Maastrichtian in age but sedimentation may have started earlier. The rocks outcropping have been variously called the Nupe series, Nupe-sandstone series (Truswell and Cope, 1963). The Basin is poor in fossils and the age of the formation has been determined mainly by photo-geological correlation with the post-santonian sequence of the Anambra Basin (Dessauvagie, 1972).



Aquifer types of the Bida Basin – Nigeria (Shekwolo, 1990)

2.2.2 Stratigraphy and Sedimentation

The Bida sandstone is the basal sediment of the middle Niger Basin and it consists mainly of fine to coarse grained sandstones, conglomerates, siltstones and clay stones. (Olabode *et al*., 2001).Udensi and Osazuwa. (2004) suggested an average thickness of sedimentary pile to be 3.39km using statistical spectral analysis of the residual total magnetic field. Idris-Nda (2010) reported that two of the areas he studied showed a thickness in excess of 4.50km. Using electrical resistivity method.Dessauvagie (1972) concluded that the basal sediment consist of coarse grained colitic ironstone, dark brown to dark yellow in colour. Table 2.1 shows the stratigraphic section of the Bida Basin.

Table 2.1 Stratigraphic section of the Bida Basin

<table>
<tr><th>Age</th><th>Southern Basin</th><th colspan="3">Northern Basin</th></tr>
<tr><td>Post Cretaceous</td><td>Laterite Alluvium</td><td colspan="3">Laterite, alluvium</td></tr>
<tr><td rowspan="7">Upper Cretaceous</td><td rowspan="4">Agbaja Formaion</td><td rowspan="7">NUPE GROUP</td><td rowspan="2">Batati ironstone Formation</td><td>Edozhigi member</td></tr>
<tr><td>Kutigi member</td></tr>
<tr><td colspan="2">Enagi siltstone Formation</td></tr>
<tr><td rowspan="2">Sakpe ironstone</td><td>Wuya member</td></tr>
<tr><td>Patigi Formation</td><td>Baro member</td></tr>
<tr><td rowspan="2">Lokoja Formation</td><td rowspan="2">Bida sandstone Formation</td><td>Jima member</td></tr>
<tr><td>Doko member</td></tr>
<tr><td>Pre Cambrian</td><td colspan="4">Basement Complex</td></tr>
</table>

Source: (IdrisNda, 2010)

2.2.3 Chemical Characteristics of the Basement Complex

The major requirement for a successful irrigation is the availability of sufficient quantity and good quality water for irrigation purpose. It is obvious that the success of most irrigation schemes are halted by the unavailability of required volume and good quality water at the right time. This can be attributed to hydrological, geologic and climate variation (Mohammed and Osunde, 2001) reported that there is little variation in the quality of the groundwater within the drainage area. The difference in the quality is of little or no significance to irrigation. The groundwater in Bida Basin is fresh, free of chemical pollution and therefore suitable for many purposes especial for irrigation (Olabode *et al*., 2001).

2.2.4 Surface Water and Groundwater Interaction

The understanding and description of surface water groundwater interaction is necessary in order to identify and show the principal processes involved in the interaction and needed for effective water resources management. The independence of surface water and groundwater, as well as the other components of the hydrological budget, are represented in the hydrological cycle. The nature of the interdependence however, especially as usually depicted in diagrams, has tended to be taken simplistically (Black, 1996). The hydrological processes concerned in surface water – groundwater interaction are not limited to a particular landscape or specific systems, neither are they restricted by regulations nor policy controls. They sustain the interaction in all the landscapes. Hydrological processes involved in surface water and groundwater interaction are evaporation, transpiration,

precipitation, run off, infiltration, percolation and deep seepage (Kelbe and Germishyse, 2000). However all these processes can be conveniently presented in terms of groundwater recharge and discharge (figure2.1)

Groundwater recharge can be described as the water which percolates into the groundwater body, while groundwater discharge can be described as the emergence of groundwater to the surface as springs, water feeding rivers, swamps and Lakes, water pumped from wells and water evaptranspiredby deep rooted plants taping water from the vadose and groundwater zones (Idowu, 2007). The generalized flow path from precipitation to recharge is through infiltration from precipitation, or seepages from surface water bodies, into vadose tone, followed by percolation to the water table into the groundwater system. The magnitude of the infiltration depends upon avariety of factors, such as the amount and intensity of rainfall, vadose-zone hydraulic properties, available storage volume in the vadose zone, channel geometry and wetted perimeter, flow duration and depth, antecedent soil moisture, clogging layers on the channel bottom and water temperature (Sophocheous, 2002). The variability and distribution of the hydraulic conductivities of streambed deposits and aquifer materials, act as the key factors determining the volume of large scale and small scale exchange processes, as well as the residence time of water within the riverine aquifer (Brunke and Gonser, 1997).

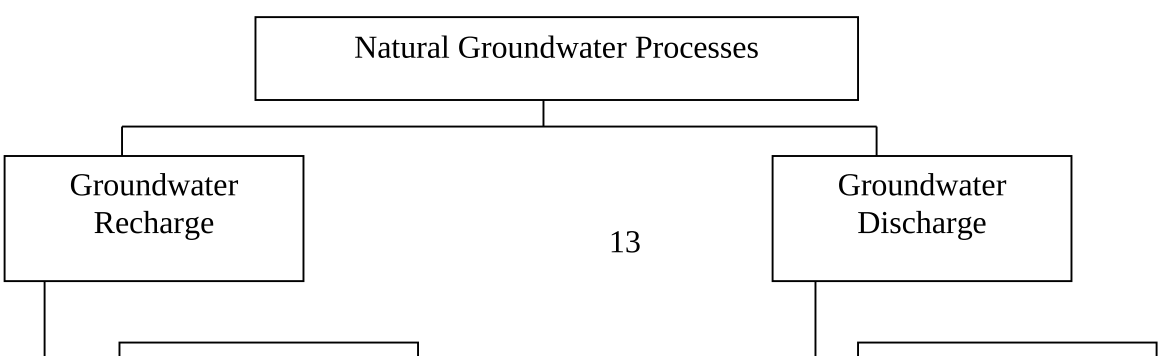


Figure 2.1The principal hydrological processes involved in surface water and groundwater interaction (Kelbe and Germishuye, 2000) and (Idowu, 2007)

2.2.5 Nature of the Flow System

Groundwater flow is generally from the uplands to the plains. The directions of groundwater flow depends on the contrasts in the hydraulic conductivity of soils and rocks at different parts of the systems, as well as the connectivity of the referential-flow-network (Clark, 1985). The basement aquifer, even where continuous, has low permeability and the main groundwater flow system are localized between recharge on watersheds to discharge by runoff or evaporation in valley bottomlands. All methods of estimating recharge are subject to considerable uncertainty (Simmers, 1988). This is generally more for basement aquifer as a result of their heterogeneity and the complex nature of the flow system (Simmers, 1988). Basement aquifers are distinctive in that their occurrence and characteristic are largely a consequence of the interaction of weathering processes related to recharge and groundwater through flow (Wright, 1992).

2.3 Groundwater Regime

Groundwater is subsurface water that fills voids and permeable geological formations. Groundwater can also be referred to as water under positive pressure (i.e. greater than atmospheric pressure in the saturated zone of earth material).

2.3.1 Well and its Classification: - A well is a hole usually vertical, excavated in the earth for bringing groundwater to the surface. Open wells mostly called dug wells are generally open masonry wells, having comparatively, bigger diameters and are suitable for low discharges of the order of 1 to 5 litres per second. The diameters of open wells generally vary from 1 to 9m, and they are generally less than 30m, in depth; Open wells may be classified into the following two types:

Shallow Well: - This is the one which rest in a pervious stratum and draws its supply from the surrounding material.

Deep Well: - Is the one which rests on an impervious 'mota' layer and draw its supply from the pervious formation lying below the mota layer, through a borehole made into the 'mota' layer.

Hand Dug wells may mainly fall under shallow well types. The main advantage of dug wells is its low cost of construction and maintenance. Some disadvantages of hand dug wells are that not much consideration is given to the engineering design; they are shallow and lack continuous casing making them subject to contamination from nearby surface water sources.

In addition, they may go dry during periods of drought if the water table drops below the dug well bottom (Jimoh and Wojuola, 2008).

2.4 Hydraulic Properties

2.4.1 Transmissibility

Transmissibility is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed in square meters per day. Transmissibility also know as transmissivity is a measure of the amount of water that can be transmitted by the full saturated thickness of the aquifer under hydraulic gradient of 1. The transmissivity, T, is the product of the hydraulic conductivity and saturated thickness of the aquifer b: The dimensions of transmissibility are (L^2/T). Common units are square meters per day or square feet per day. Aquifer transmissivity is a concept that assumes flow through the aquifer to be horizontal. In some cases, this is a valid assumption; in orders, it is not (Felter, 2001).

2.4.2 Hydraulic Conductivity

Hydraulic conductivity, symbolically represented as K, is a property of soil or rock, that describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the materials and on the degree of saturation. There are two broad categories of determining hydraulic conductivity: Empirical approach by which the hydraulic conductivity is correlated to soil properties like pore size and particle size (grain size) distributions, and soil texture. Experimental approach by which the hydraulic conductivity is determined from hydraulic experimental approach which is broadly classified into: Laboratory tests using soil samples subjected to hydraulic experiments. Field tests (onsite, insitu) that are different into: small scale field tests, using observations of the water level in cavities in the soil. Large scale field tests, like pump tests in wells or by observing the functioning of existing horizontal drainage system (Felter, 2001).

2.4.3 Specific Yield

This is the quantity of water which a unit volume of aquifer, after being saturated, will yield by gravity; it is expressed either as ratio or as a percentage of the volume of the aquifer. The yield of an aquifer can be estimated in two different ways; on the basis of flow velocity of the groundwater and by performing pumping tests in the field. On the basis of flow velocity of the groundwater, if a well is penetrated through an aquifer, the water will rush into it with a velocity(V); and if A is the area of the aquifer opening into the well then Q will be given as –

$$Q = V.A. \tag{2.1}$$

By pumping tests yield can be estimated by conducting two direct practical tests in the field. Pumping test and Recuperating test (Felter, 2001).

Pumping Test: - Huge amount of water is drawn from the well, so as to cause heavy drawdown in its water level. The rate of pumping is changed and so adjusted that the water level in the well becomes constant. In this condition of equilibrium, the rate of pumping will be equal to the rate of yield, and hence, the rate of pumping will directly give us the yield of the well at a particular drawdown.

Recuperating Test: - In this method, water is first of all drained from the well at a fast rate, so as to cause sufficient drawdown. The pumping is then stopped. The water level in the well will start rising. The rise is noted at regular intervals of time, till the initial level is reached.

Knowing the area of the well and the rise of the water level, the volume of the water yield in that given time interval, can be worked out at different drawdown (Felter, 2001).

2.5 Test Types and Protocols

2.5.1General Principle of Conducting Pumping Test

A pumping test is a means of investigating how easily water flows through the ground into a well. It basically consists of pumping in a controlled way at predetermined rates with the resulting effects on water levels being measured in both the pumping well and observation boreholes, if any. Pumping water levels are often thought of in terms of the drawdown that is the difference between any instance water-level reading and the water level in the borehole prior to the start of pumping. There are four types of pumping test and are classified according to the purpose for which information is needed (Rushton and Rafhod, 1980).

2.5.2 Test Types

2.5.2.1 Proving Test: - These are used to establish the yield at a well either just after its construction or if there is any doubt as to the maximum sustainable rate at which it can be pumped.

2.5.2.2 Aquifer Test: - These tests are designed to provide information on aquifers hydraulic properties involving measurements on a number of observation wells. They may last a few days or several weeks.

2.5.2.3 Steps Test: - These consist of pumping a borehole at several different rates for periods of the same duration to establish the relation between pumping rates and drawdown.

This information defines the hydraulic characteristics of the wells under consideration rather than the aquifer, and is used for selecting the appropriate pump and for monitoring pump efficiency.

2.5.2.4 Licensing Test: - In countries where an abstraction licensing system is in force, pumping tests are used to establish the impact of a new abstraction on other water users and the water environment in general. Monitoring spring and stream flow usually is part of these tests, in addition to measurements of water levels in other wells. The pumping rate and the changes in the water levels in the pumping well are to be measured.

Idris-Nda (2010) conducted aquifer tests on boreholes in some parts of Bida basin using the Cooper-Jacobs single well aquifer tests method.Table2.2shows some of the results obtained.

Table 2.2: Summary of pumping test analysis using the Cooper-Jacob method

Location	Static Water Level (m)	Flow Rate (It/m)	Aquifer Thickness (m)	Hydraulic Conductivity K (m/d)	Transmissivity (m^2/d

Enagi	8.41	38	18	0.55	30.48
Danchitagi	24.0	40	30	0.36	36.58
Vunchi	12.2	40	20	0.58	36.58
Doko	22.2	38	20	0.52	33.53
Kutigi	14.3	48	17	0.76	42.57
Somajiko	24.0	40	16	0.67	36.58
Gbangba	27.0	40	15	0.73	36.58
Busu	9.6	42	17	0.67	36.58
Mokwa	6.9	50	20	0.67	45.72
Bida	10.8	36	17	0.58	30.48
Bokani	24.4	32	17	0.58	28.35
Gulu	24.4	38	17	0.61	33.53
MEAN	**17.3**	**40**	**18.6**	**0.61**	**35.63**

2.6 Steps for Conducting Pumping Test

Measure the static water Level: - Water must not be collected from the well for a minimum of four hours (for these wells, because their recovery was fast (< 3 - hour); shallow wells and wells in low- transmissibility aquifers may have to rest longer, typically 24-48 hrs before the pumping test is conducted. Agreement on the part of the well users is necessary to ensure accurate static water level measurements.

1. **Lower the water level indicator**: - (Programmed to take measurements at least every ten seconds) into the well several minutes before pumping starts to establish the static water level. Note the static water level indicated.
2. Pumping the well until an apparent equipment pump level is established; record pumping time starts. Take water level measurements with the indicator approximately every minute during pumping or at a predetermined time interval during pumping.
3. Record the time pumping ceases.
4. Measure the depth to water level with indicator, lift the tape approximately 0.3ft (0.09/44) from where water was when pumping was stopped. Record water level and time when

the water level reaches the sounder probe of the indicator, then lift another 0.3ft (0.09/44), again record the water level and time, repeat until static water level is reached. In this study, normally between 10 and 20 data points from the sounder were recorded for each test.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The following materials were used in conducting the investigations and analysis of the research work; Global Positioning System (GPS) Garmin Emese Legend, it was used for establishment of samples points and wells locations. Water level indicator was used for the determination of groundwater levels from wells, C100 multi-parameter ion specific meter was used for determination of pH and a water pump of 0.5 horse power rating powered by a 2.0 KV generator was used for pumping water from the wells.

3.2 Methods

3.2.1 Location and Accessibility of the Study Area

The study area (Gbako Basin) lies between latitude $9^0 00'$N and 6^0 30'E in the northern sector of the middle-Niger (Bida) basin of Nigeria. It extends from Vunchi area in the East to Edozhigi in the west, all forming parts of Bida, Gbako, Katcha, and Lavun Local government areas of Niger State. The area is easily accessible through Federal trunks A and B roads, and minor untarred roads.

Essa, Baddegi, Bida, Zauchita lies on Abuja-Bida-Lagos road, Kuchiworo and Vunchi are along Bida-Jima-Nupeko road, while Emi-Zhiru is by the Federal Girl's College along Lemu-Wushishi road. All the roads are accessible throughout the year; Figure 3.1 shows the study location.

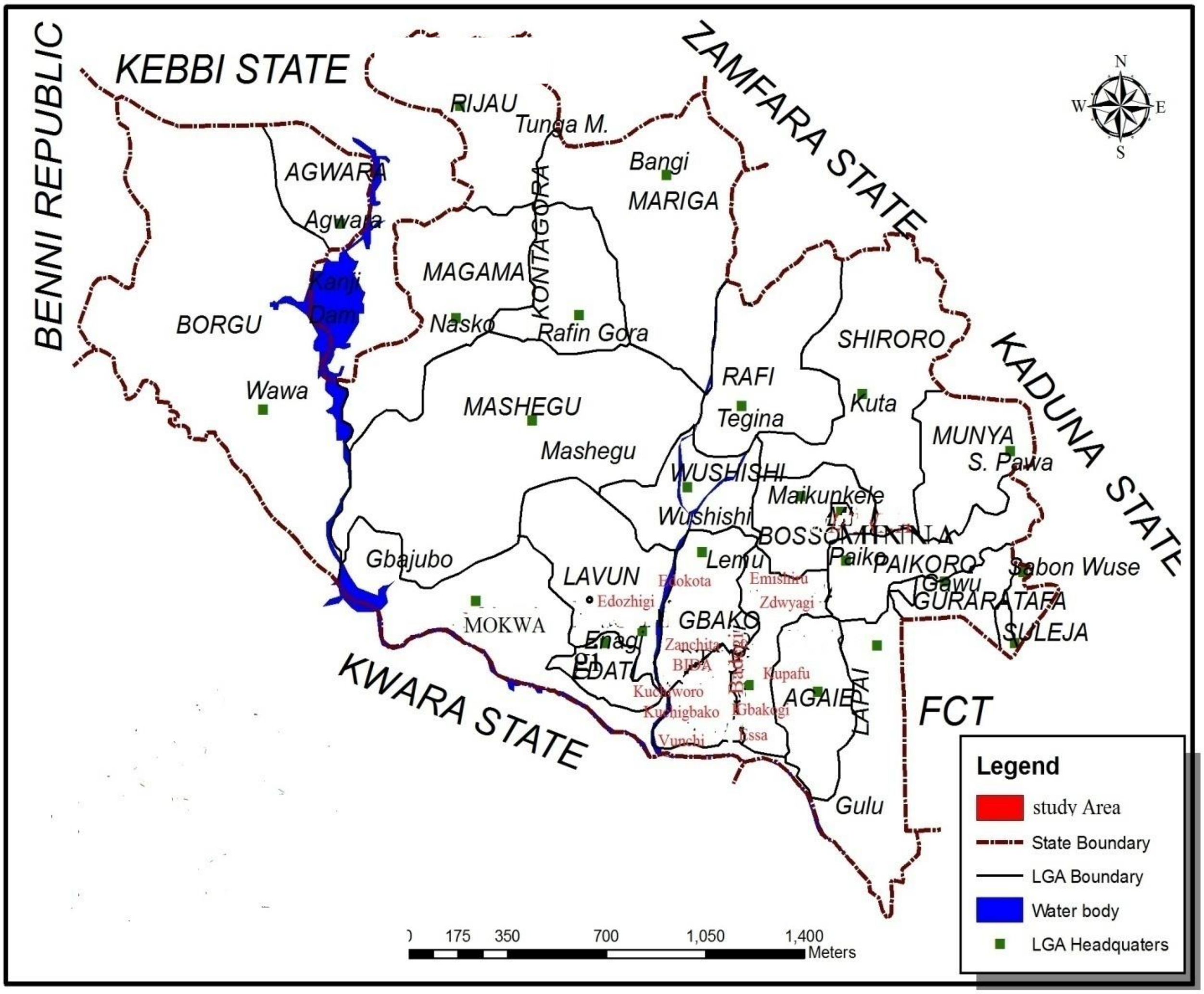


Figure 3.1: Map of Niger State Showing Study Area

3.2.2 Preliminary Investigation

This method involves the review of all available data on the study area and the entire basin, survey of all the catchment and documenting of all information that were considered relevant to the research. The investigation includes collecting data from literature, interview, and field or wells location identification. Data collected from relevant literature include topographic map and dug well age from Niger State Ministry of water Resources and Agricultural Development Project.

3.2.3 Field Work

The field work included collection of samples for analysis coupled with data collection; i.e., rainfall, temperature and relative humidity and water level measurements in wells. The location of samples points or wells location was established using hand held Global Positioning System (GPS). The physical parameters measured include the location, depth and diameter of each well. Other parameters obtained from the field were inventory of the well lining, well covering and static water level. The depth of each well was also measured.

Plate II: Global Positioning System (GPS) Garmin Emese Legend.

3.2.4Water Level Measurements

In the determination of ground water levels from the ground surface of the wells and boreholes around the drainage area, battery operated water level indicator was used in determining the levels of water from the ground surface. Water level indicator consists of a portable 9 volt battery and metallic electrode head attached to an insulated terminal calibrated as a tape. The metallic head of the terminal was allowed into the observation well; and as soon as it is in contact with the water surface a sound is produced outside by an indicator.

At this point, the depth of water table was recorded. Permission was obtained from the owner of each well so as to take readings, Water depth readings was taken in the evening (between 6:30 and 8:30 hours) and in the morning (between 6:00 and 8:00 hours)the next day. Water was not lifted from the wells during the study period. Sixteen hand dug wells were randomly chosen as representative wells for the study area.

Plate III: Electronic water level indicator.

The diameter of the wells were recorded using measuring tape. Where well diameter was not uniform, average diameter was taken with the help of individuals who assisted in recording inner diameters of the wells. Total depth of most of the wells were observed and recorded during peak of dry season when most of the wells in the area are completely dry or as a result of continuous withdrawal of water.

Water level monitoring was performed five times for each wells per month between November 2010 and January 2012. In March 2011 and September 2011 each set of pumping and recovery tests were performed, it allowed observation of potential changes in well productivity over the course of the dry season. Static water levels for all wells were measured once a month between December 2010 and September 2011.

3.2.5 Laboratory Analysis and Statistical Analysis

pH of the samples were analyzed in the Civil Engineering laboratory of Federal University of Technology Minna.Plate IV shows the C100 multi-parameter ion specific meter used for the determination of pH. Data were analyzed using the tools available in Microsoft Excel 2010. One way ANOVA with alpha value of 0.05 was adopted for analysis.

Plate IV: C100 multi-parameter ion specific meter.

3.2.6 Specific Yield

The specific yield (for unconfined aquifer) or storage coefficient (for confined aquifer) is the volume of water yield (v) per unit horizontal area (A_h) and per unit drop of water table (for unconfined aquifer) or piezometric surface DHs (for confined aquifer).

$$S_y (\text{or } S_c) = {}^{V}/_{A_h} \cdot DH \quad (3.1)$$

Alternatively, specific the yield (S_y) of an open well (dug well) can be expressed as (Modi, 1995)

$$S_y = \frac{2.30}{t} \log_{10} (h_1/h_2) \qquad (3.2)$$

where,

S_y = specific yield

t = time after Pumping had stopped

h_1= initial water level during recovery test

h_2 = final water level during recovery test

Thus, in time (t) after the pumping had stopped the water level in the well recuperates from h_1 to h_2(measured during the well recovery test).Time (t) was recorded when pumping from the individual well was stopped while $h_1$is the depth to water level when pumping had stopped and h_2 is the recovery depth at the static water level. If the well recuperates by dh in a time dt, the volume of water (dv) entering the well can therefore be expressed as;

$$dv = A\,dh \qquad (3.3)$$

where, A = cross sectional area of the well at its botton.

Using the value of S_y, the value of well discharge or well yield under a constant depressed head (h) may be determined.

3.2.7 Transmissibility

The coefficient of transmissibility or transmissivity (T) is the ability of the aquifer to transmit water. It is equal to the discharge rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Thus,

$$T = Kb \qquad (3.4)$$

where, b is the saturated (average) thickness of the aquifer and K is the hydraulic conductivity or coefficient of permeability. Recovery test method (Theis, 1935) was used for the determination of the transmissibility of the wells investigated. In this method the analysis of recovery data was used since no observation well was available for pumping well. Data analysis is similar to that of pumping curve analysis, with one difference. The recovery curve were plotted as residual (i.e., remaining) drawdown as a functions of the ratio of the time since pumping started (t) to the time since pumping stopped (t). The ΔS value over one log cycle was measured after drawing a straight line through the data as showing figure 3.2. Jacob's equation was used to estimate the transmissibility values of the dug wells under study because it relates the rate of residual drawdown to the bulk of other aquifer parameters (Eqn 3.5a). In the recovery test method, the pumping or observation well was not involved but during recovery period, the rate of recharge Q to the well was assumed constant and equaled the mean pumping rate during the pumping operation.

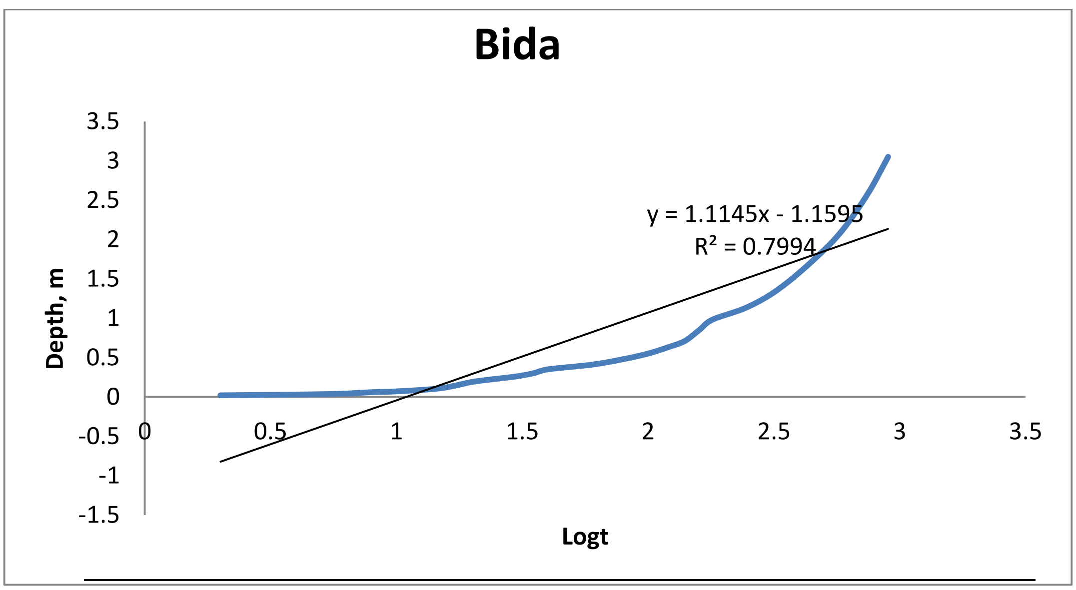


Figure 3.2:Exampleof Jacob's Straight-line for recovery curve analysis, from well 1 (Bida), trial 1,

Pumping was done at constant rate using a water pump of 0.5 hp rating and powered by a 2.0 kV generator. A storage water tank of 600 litres capacity was used during well pumping for water collection. The constant pumping discharge rate (Q) was 4.0 L/min.

When pumping was stopped, the water level in the pumping well rose. The residual drawdown (recovery depth) was then measured in the test well at different time intervals by means of calibrated water level indicator. The measured values of the rise of water level (recovery level within the aquifer were plotted against time). Equation 3.5a was used to determine the transmissibility (T) value from the plotted data (Arora, 2006, Nwankwoala *et al.*, 2008;Egharevba, 2010).

$$\Delta S = \frac{2.3Q}{4\pi T} \qquad (3.5)$$

Hence

$$T = \frac{2.3Q}{4\pi \Delta S} \qquad (3.5a)$$

where, Q is the constant well water pumping rate, and ΔS is the slope of the recovery depth vs time graph over one log cycle. Having computed T, the coefficient of permeability value (k) of the aquifer may be estimated from Equation 3.4.

Georghe and Krawny standards for transmissibility were used to interpret transmissibility of the dug wells. Table 3.1 showed the two standards with the expected soil materials according to their classification. Georghe classified transmissibility value of <0.5 to be negligible while in Krawny it is classified to be very low. Transmissibility values of 10-100 is considered intermediate using Krawny Standard, but 5-50 is classified low using Gheorghe standard.

Table 3.1Gheorghe and Krawny standards for transmissibility (T) Classification

Gheorghe (1978)		Krawny (1993)			
T (m^2/day)	Potential	T (m^2/day)	Potential	k/m/day	Material
> 500	High	>1000	very high	$10^{-8} – 10^{-12}$	clay
50 – 500	Moderate	100 – 1000	High	0.1 – 1.0	surface loam
5 – 50	Low	10 – 100	intermediate	1-5	fine sand
0.5- 5	Very low	1 – 10	Low	5 – 20	medium sand
< 0.5	Negligible	0.1 – 1	very low	20 – 100	coarse sand

Source: Nwankwola *et al.* (2008), Amadi *et al.* (2010) and Egharevba (2010)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Inventory of some hand dug wells

Results obtained in this study showed that water level measurements across the study area indicated that all the wells are shallow, since they fall between the depth of 11 to 30 m (Table 4.1).The water level data indicated that there was a seasonal response of water level to groundwater recharge. The depth to water level of the aquifer showed a gradual increasing trend (rising water level), during rainy season, while lowering water level was observed during dry season. The monthly water level data are presented in Appendix A. The data showed that, from April to October of 2011 there is continuous water level increment compared to other months of the year.

The yield of an open well is limited because such wells can be excavated only to a limited depth where the groundwater storage is also limited. From the depth of all wells in Table 4.1 the wells can be classified as shallow wells which rest in a pervious stratum and draw its supply from the surrounding materials. Moreover, in such wells, the water can be withdrawn only at the critical velocity for the soil. The limit place on the velocity. therefore, also limits the maximum possible safe discharge of an open shallow well. Since a shallow well draws water from the topmost water bearing stratum, its water is liable to be contaminated by the rain water percolating in the vicinity, which may take with it minerals or organic matter from decomposing animals and plants (Kogbe, 1981).The water in a deep well, on the other hand, is not liable to get such impurities and infections. Secondly, the pervious formations below the mota layer generally contain greater quantities of groundwater, yielding high specific yield. Hence, greater discharge and greater supplies can be obtained from a deep well as compared to those from a shallow well. Table 4.1shows the well age, well depth, well diameter and nature of well. The depth and diameter of hand dug well contributes largely to its yield, the deeper a well the greater the quantity of specific yield. Large diameter also provides bigger storage for a well. Four of the sixteen wells under consideration were lined with concrete casing. The purpose of the lining is to ensure that the well retain its excavated shape, allowing access to the water in the aquifer, while at the same time helping to prevent contamination of the aquifer.

Table 4.1: Inventory of some hand dug wells in the Gbako drainage basin

Well No	Well Age (yrs)	Well Depth (m)	Well Diameter (m)	Nature of wells
W1	91	12	1.2.	Unlined
W2	32	15	1.1	Unlined
W3	22	13	1.0	Concrete casing
W4	42	30	0.8	Unlined
W5	23	15	1.1	Unlined
W6	39	30	1.7	Unlined
W7	35	16	1.0	Concrete casing
W8	35	16	1.0	Concrete casing
W9	35	18	1.0	Concrete casing
W10	20	11	1.3	Unlined
W11	12	17	1.1	Unlined
W12	32	15	1.0	Unlined
W13	27	20	0.9	Unlined
W14	11	13	1.0	Unlined
W15	41	11	0.8	Unlined
W16	51	14	1.2	Unlined

4.2 Physical Parameters

4.2.1 Temperature

Temperature and pH were determined on the basis that they affect the solubility of most compounds. Example increase (high) temperature condition increases solubility of ions while pH also control precipitation of certain ions

Changes in regional temperature and precipitation have important implications for all aspects of the hydrologic cycle. Variation in these parameters determine the amount of water that reaches the surface, evaporates or transpires back to the atmosphere, infiltrate into the groundwater system, runs off the land, and ultimately becomes base flow to streams and river. (Singh and Kumar, 2008). Table 4.2 shows average temperature for dry season and rainy season with the depth at which the water sample were taken, temperature ranges between (30.7 – 32.1)^{o}C with mean of 31.4^{o}C in rainy season (October). While that of dry season (February) are 30.0-32.8^{o}C with means of 26.5^{o}C.Depth to water level affect water temperature because farther away the sun is from the water, it gets colder because it cannot be heated as much. From Table 4.2 wells with deeper water level has lower temperature level, and when the temperature increases the water particles move faster and when they move too fast the water evaporates, but when the temperature decreases, the particles move slower, creating no heat. This principle has effect on ground water fluctuation as it decreases water level on wells.

Table 4.2: Temperatures of selected dug wells across the basin with corresponding water levels.

Location	Temperature ^{o}C (Feb. 2011)	Water Level (M)	Temperature ^{o}C (Oct. 2011)	Water Level (M)

Bida	32.5	11.10	31.1	8.00
Edokota	30.1	27.40	31.5	25.80
Esungi	32.8	14.00	32.0	11.41
Edozhigi	30.8	8.70	32.0	3.30
Badeggi	31.0	8.90	31.5	7.10
Zdwyagi	32.4	14.20	31.6	9.30
Gbanchitako	30.0	28.00	31.3	26.30
Kupafu	31.2	14.62	31.4	9.00
Gbakogi	31.1	15.10	30.8	9.20
Essa	31.2	15.32	31.6	11.64
Vunchi	31.0	16.10	32.1	10.31
Emi-Shiru	32.4	13.10	30.7	9.10
Kuchi-woro	31.0	17.00	31.1	13.10

4.2.2 pH

Good pH levels of drinking water from well should be between pH level of 7 and 8.5, if the pH level is lower than 7, the water is acidic and can lead to several problems for an individual’s health. It may be from a natural geological condition in the well or ground. If water ionizes further as temperature rises, so hydrogen ion concentration rises, this means that pH decreases. But water remains neutral, as the number of hydrogen irons increases. This is why a pH meter always has a temperature compensating probe. Table 4.3 shows pH ranged between 7.00 - 8.20 during dry season (February, 2011) and 6.96 - 7.80 during rainy season. It is concluded that the water from the wells is suitable for irrigation and adequate for nutrient availability.

Table 4.3: pH of selected dug wells with corresponding water level across the basin.

Location	pH (Feb. 2011)	Water Level (M)	pH (Oct. 2011)	Water Level (M)
Bida	7.61	11.10	7.41	8.00
Edokota	8.11	27.40	7.74	25.80
Esungi	7.41	14.00	7.24	11.41
Edozhigi	7.30	8.70	7.31	7.30
Badeggi	7.56	8.90	7.56	7.10

Zdwyagi	7.00	14.20	6.96	9.30
Gbanchitako	8.20	28.00	7.80	26.30
Kupafu	7.70	14.62	7.71	9.00
Gbakogi	7.43	15.10	7.45	9.20
Essa	7.60	15.32	7.43	11.64
Vunchi	7.24	16.10	7.23	10.31
Emi-Shiru	7.16	13.10	7.16	9.10
Kuchi-woro	7.61	17.00	7.60	13.10

4.3 Water Level Measurement

The result of water level measurements conducted across the study area shows that the average depth of water levels in the wells is between 6.30-26.30m. Table 4.4 shows the summary of water levels during wet and dry seasons. The highest depth of water level from the bottom was obtained during the peak of wet season (in September). The lowest depth of water level from the well bottom was recorded during the peak of dry season (February to March). This confirms that the source of recharge to the aquifer is rainfall between April and October. During the dry season, water is either abstracted from the aquifer through wells, lost through evaporation, or both. These processes lower the water table in the unconfined aquifer; this observation is in agreement with the report of Jimoh and Wojuda (2008).

Table 4.4 Water Level Measurement Across the Gbako Drainage Basin

Increased variability in rainfall may decrease groundwater recharge in humid areas because

Well No	Location	Well Coordinates		Alt(m)	Well depth (m)	WaterLevelRange (m)		Diameter of well (m)
		Nº	Eº			Rainy Season April-Oct.	Dry Season Feb-March	
W1	Bida	9º.04'	6º.00'	143	12	6.40-8.00	9.80-11.10	1.2
W2	Zdwyagi	9º.07'	6º.01'	156	15	8.00-9.30	11.40-14.20	1.1
W3	Baddegi	9º.03'	6º.08'	87	13	6.30-7.10	7.60-8.90	1.0
W4	Edokota	9º.07'	5º.57'	188	30	25.00-25.80	25.91-27.40	0.8
W5	Emi-Shiru	9º.08'	6º.01'	133	15	8.60-9.10	10.00-13.10	1.1
W6	Gbanchitako	9º.01'	5º.09'	203	30	25.40-26.30	27.10-28.00	1.1
W7	Kupafu	9º.03'	6º.12'	131	16	8.10-9.00	9.40-14.62	1.0
W8	Gbakogi	9º.02'	6º.11'	132	16	8.60-9.20	9.82-15.10	1.0
W9	Essa	9º.03'	6º.13'	132	18	10.00-11.64	12.0015.32	1.0
W10	Kuchigbako	9º.00'	5º.58'	143	11	6.20-7.34	8.00-10.00	1.3
W11	Vunchi	8º.57'	5º.57'	146	17	9.40-10.31	11.12-16.10	1.1
W12	Esungi	9º.00'	5º.59'	163	15	10.80-11.41	11.83-14.00	1.0
W13	Kuchiworo	9º.00'	5º.58'	170	20	12.60-13.10	13.64-17.00	0.9
W14	Edozhigi (1)	9º.05'	5º.51'	101	13	8.60-9.40	10.00-11.10	1.0
W15	Edozhigi (2)	9º.06'	5º.51'	86	11	6.90-7.30	7.48.8.70	0.8
W16	Zanchita	9º.07'	5º.95'	163	14	8.70-9.10	10.41-11.34	1.2

more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff. In semi-arid and arid areas, however, increased rainfall variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations during floods(Friedrich *et al*; 2008).

The Table 4.4 shows groundwater level within the study location, it indicate that Edokota and Gbanchitako have the deepest well with lower groundwater levels while Badeggi, Edozhigi and Kuchigbako seemed to have a higher water level. This is in agreement with Idris-Nda (2010) that predicted alluvial deposits around the basin. Olabode *et al.*, (2001) specifically reported alluvial deposits in the main rivers valley of Niger particularly Edozhigi and Badeggi.

Tables 4.5 - 4.7 show monthly water level range in the part of the basin and monthly mean,all in meters, all wells depth are indicated in Table 4.4.Generally at Gbako drainage basin, water levels at the fringes of the basin are deeper, shallow levels are encountered at the middle parts of the basin. It could be seen from Tables 4.5. to 4.7 that Edokota have a deeper water level while Badeggi have shallow water levels. The highest groundwater recharge took place between August and October with highest recorded depth to water level of 6.10 - 7.00. Appendix A shows the depth to water level in the part of the basin with date which they are recorded during the two seasons (Dry and Rainy Seasons).

Table 4.5: Monthly water level range in the parts of the basin(Dug well)

	W_1 (Bida)		W_2 (Badeggi)		W_4 (Edokota)	
Month	MonthlyRange (m)	Monthly Mean (m)	MonthlyRange (m)	Monthly Mean (m)	MonthlyRange (m)	Monthly Mean (m)
Jan. 2011	8.10-9.30	8.80	7.60-8.10	8.10	20.20-20.80	20.80
Feb. 2011	9.50-9.90	9.70	8.20-8.80	8.40	20.30-21.80	21.30
Mar. 2011	9.50-10.40	9.90	7.90-8.60	8.20	21.80-22.80	22.30
Apr. 2011	9.30-10.90	10.30	7.90-9.10	8.60	22.60-23.80	23.10
May 2011	9.40-10.60	9.90	8.60-9.30	9.00	23.00-23.50	23.20
Jun. 2011	8.40-9.60	8.90	8.40-9.20	8.80	21.30-23.00	22.40
July 2011	7.00-8.20	7.60	7.50-8.10	8.00	20.00-20.90	20.50
Aug. 2011	6.40-7.60	6.80	6.60-7.30	7.00	19.80-20.40	20.00
Sept. 2011	6.60-7.70	6.70	6.00-6.80	6.40	19.60-20.00	19.70
Oct. 2011	6.10-6.30	6.10	5.80-6.90	6.60	19.70-20.60	20.40
Nov. 2011	6.10-7.10	6.80	6.40-7.10	6.70	19.90-20.80	20.60
Dec. 2011	7.30-8.00	7.70	7.40-8.10	7.60	20.10-20.90	20.60

Table 4.6: Monthly water level range in the parts of the basin (Dug Well)

	W_9 (Essa)		W_{11} (Vunchi)		W_{13} (Kuchi-Woro)	
Month	MonthlyRange (m)	Monthly Mean (m)	MonthlyRange (m)	Monthly Mean (m)	MonthlyRange (m)	Monthly Mean (m)
Jan. 2011	9.80-10.60	10.60	12.30-30.40	13.40	14.80-16.40	16.40
Feb. 2011	10.80-12.40	11.40	14.00-15.30	14.70	16.50-17.50	17.00
Mar. 2011	10.60-12.10	11.10	13.70-14.50	13.90	17.30-17.90	18.10
Apr. 2011	9.80-12.00	11.30	13.70-15.10	14.50	17.60-18.80	18.10
May 2011	10.00-10.90	10.60	13.60-15.20	14.70	18.30-19.40	18.90
Jun. 2011	9.80-10.20	10.00	13.10-13.70	13.50	16.90-17.70	17.30
July 2011	9.60-10.10	9.80	12.70-13.50	12.90	14.60-16.80	16.10
Aug. 2011	9.00-9.80	9.20	11.20-11.80	11.50	14.00-15.30	14.60
Sept. 2011	8.90-10.00	9.40	11.00-11.30	11.10	13.00-14.20	13.60
Oct. 2011	8.50-9.40	8.90	11.40-12.00	11.30	13.70-14.70	13.50
Nov. 2011	9.20-10.10	9.80	11.80-12.50	12.00	14.10-14.60	14.20
Dec. 2011	10.30-10.90	10.60	12.00-12.80	12.40	14.20-15.60	14.40

Table 4.7: Monthly water level range in the parts of the basin (Dug Well)

Month	W_{14} (Edozhigi)		W_{16} (Zanchita)	
	MonthlyRange (m)	Monthly Mean (m)	MonthlyRange (m)	Monthly Mean (m)
Jan. 2011	11.80-30.00	12.40	9.40-10.80	10.00
Feb. 2011	12.90-13.20	13.00	9.30-10.40	9.90
Mar. 2011	13.00-14.20	13.30	10.50-11.30	10.80
Apr. 2011	12.90-14.00	13.70	10.30-11.60	10.70
May 2011	11.70-13.80	13.10	11.60-12.50	12.00
Jun. 2011	11.10-12.00	11.50	8.60-10.10	9.40
July 2011	10.50-11.20	10.80	8.50-9.00	8.70
Aug. 2011	9.80-10.50	10.30	8.00-9.00	8.50
Sept. 2011	8.80-10.30	9.50	8.50-.900	8.80
Oct. 2011	8.80-10.60	9.80	8.90-10.20	9.10
Nov. 2011	9.30-10.90	10.20	9.20-10.70	9.60
Dec. 2011	10.90-13.30	10.90	9.50-10.80	10.10

There were no significant difference ($P>0.05$) in the groundwater level of the representative dug wells in Table 4.5, 4.6 and 4.7. The result shows no significant difference based on their recharge (rainfall) within the same geological formation. Table 4.8 shows the annual sum, average and variance for all the representative wells, while Table 4.9 shows sum of square, mean and significance between groups and within groups.

Table 4.8: ANOVA: Single Factor

Groups	*Months*	*Sum*	*Average*	*Variance*
W1 Bida	12	98.93	8.244167	2.126863
W3 Badeggi	12	93.4	7.783333	0.819697
W4 Edokota	12	254.9	21.24167	1.449924
W9 Essa	12	122.7	10.225	0.692955
W11 Vunchi	12	155.9	12.99167	1.760833
W13 Kuchi-Woro	12	192.4	16.03333	3.629697
W14 Edozhigi	12	140.5	11.70833	2.549924
W16 Zanchita	12	117.6	9.8	1.034545

Table 4.9 Sum of Square, Mean and Significant Difference

Source of variation	Sum of Square	df	Mean	F	Sig.
Between groups	1705.296	7	243.6137	138.57	1.04E-01
Within groups	154.7088	88	1.758055		
Total	1860.005	95			

4.4 Hydraulic Properties

4.4.1 Transmissibility

Recovery depth/cycle (ΔS) values were determined from the measured values of the rise of water level (recovery level) within the aquifer plotted against time on log cycle (Appendix B).Using equation (3.5a), the transmissibility of the dug wells under study were computed, in classifying the hydraulic properties of the aquifer (transmissibility and hydraulic conductivity) obtained from the study was compared to the standard given by Gheorghe (1978) and Krawny (1993).

Gheorghe and Krawny international standard are relevant here because it confirm that the dug wells under study were indeed of low aquifer potential which confirms to existing experience and geological terrain (basement complex).Table 4.10shows the range of transmissibility magnitude (7.48 to 26.94 m^2/day) of the wells. Wells under this study are of low potential under Gheorghe's standard, similarly except for well W8 and W16 which are low, others can be classified as intermediate under Krawny Standard.

The maximum transmissibility value (26.94 m^2/day) was obtained from well W_{15} (located at Edozhigi) while the lowest magnitude (7.48 m^2/day) occurred in well W8 (located in Gbakogi). The average transmissibility value for the wells was 17.54 m^2/day, which of course correspond to low and intermediate aquifer potential under the Gheorghe and Krawny criteria, respectively. Thus, the status of the groundwater availability of these dug wells can best be adequate for small withdrawals for low water supply for private consumption usage most specially during dry season. However, if need be these dug wells can be further developed by way of increasing the depth and casing of the wells so as to improve upon the potential of the aquifer. The geological formation of the study area (basement complex) supports this assertion. To secure high productivity to meet the increasing stress on groundwater due to human development, population growth and increased reliance on groundwater, the intake of each hand dug well can thus be designed to fit the nature of the aquifer.

Table 4.10 Transmissibility characterization of dug well in Gbako drainage basin

Well No	Recovery Depth/Cycle (ΔS)	Transmissibility (m^2/Day)	aquifer potential Gheorghe/Krawny Standard
W1	1.11	24.51	Low/Intermediate
W2	1.06	24.45	Low/Intermediate
W3	1.46	17.78	Low/Intermediate
W4	1.28	18.77	Low/Intermediate
W5	1.73	13.88	Low/Intermediate
W6	1.21	19.35	Low/Intermediate
W8	1.56	7.48	Low/Low
W13	1.77	13.58	Low/intermediate
W15	1.08	26.94	Low/Intermediate
W16	1.42	8.66	Low/Low

4.4.2 Coefficient of Permeability

The permeability of a particular material is defined by its permeability coefficient (k). The coefficient of permeability of each of the wells was estimated from equation 3.4.Table 4.11 gives the estimated values of the aquifer permeability. The permeability values ranged from 1.4 to 8.2 m/day. Wells W1 and W2 with values of 8.2 and 8.1 respectively, which falls within the same axis perform better than all other wells. The low aquifer hydraulic characteristic (k values of 1.4 to 8.2 m/day and T value of 7.48 to 26.94 m^2/day) of Gbako drainage basin is within basement complex terrain and not exceptional. Similarly Idris-Nda (2010) obtained a value of K=8.0 m/day and T=33.7 m^2/day for certain aquifer at middle Niger basin of Bida.

4.4.3 Specific Yield

The specific yields for the wells were computed using equation 3.2. The values of the specific yield are as shown in Table 4.11. The range of specific yield was between 7 and 22 %. The average specific yield was 14.5 % corresponding to average hydraulic conductivity and transmissibility values 3.56 m/day and 13.24 m^2/day respectively.

Table 4.11: Aquifer thickness, static water level (SWL), coefficient of permeability (k) and well specific yield.

Well No	Aquifer Thickness (m)	SWL(m)	K(m/d)	Specific Yield (%)
W1	3.0	8.8	8.2	17
W2	3.0	10.7	8.1	16
W3	4.3	7.5	4.1	22
W4	3.6	26.3	5.2	7
W5	4.3	10.2	3.2	18
W6	3.2	26.7	6.0	7
W8	5.2	10.7	1.4	14
W13	5.2	14.8	2.6	11
W15	3.5	7.5	7.8	18
W16	4.1	9.9	2.1	15

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the study, the following conclusions were made:

1. Groundwater level ranged between 6.30 – 7.10 m (Minimum) and 25.40 – 26.20m (Maximum) during rainy season, and 7.60 – 8.90 m (Minimum) and 27.10 – 28.00m (Maximum) in the dry season, respectively.
2. The transmissibility ranges between 7.48 to 26.94 m^2/day while hydraulic conductivity was between 1.4 to 8.2 m/day. The average specific yield was 14.7 %.
3. The hydraulic status of the dug wells indicated that the groundwater supply potential is only adequate for smaller withdrawals of the order of 1-5 litres per second. The low aquifer potential could be attributed to geological formation (basement complex) and length of dry season in the region.
4. In addition, the well depths ranged between 11 to 30 m indicating a perched aquifer.
5. There was no significance difference ($P > 0.05$) in the groundwater level within the study location (basement).

5.2 Recommendations

1. It is recommended that institutional adaptation should be promoted including enhancement of groundwater governance and straightened local groundwater management. Groundwater management policies can be made more effective by raising local awareness.

2. The existing hand dug wells can further be developed by depth increment to deeper horizon of 1-2m with casing for adequate yield.
3. Additional viable boreholes be provided by the government or authority concerned to permit adequate withdrawal all year round.
4. Rainwater harvesting structures for groundwater recharge is a feasible structural adaptation option to augment groundwater supply potentials of Gbako drainage basin.
5. To fill the knowledge gaps and reduce uncertainty regarding the evaluation of hydraulic properties and water table fluctuation of selected aquifer, more research is needed. Priority research topics include groundwater flow pattern in aquifer of Gbako drainage area and effect of climate change on groundwater level of Gbako drainage area.

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APPENDIX A

Depth of groundwater levels at Bida location (W_1) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
28/1/11	9.1	14/5/11	10.3	26/9/11	6.6
29/1/11	8.1	15/5/11	9.4	7/10/11	6.1
30/1/11	9.3	24/5/11	9.6	8/10/11	6.1
1/2/11	9.6	25/5/11	9.5	9/10/11	6.2
2/2/11	9.8	4/6/11	9.6	22/10/11	6.3
9/2/11	9.7	5/6/11	9.5	23/10/11	6.2
10/2/11	9.7	6/6/11	8.8	24/10/11	6.2
11/2/11	9.5	19/6/11	8.8	6/11/11	6.2
13/2/11	9.8	20/6/11	8.4	7/11/11	6.2
14/2/11	9.9	21/6/11	8.6	8/11/11	6.1
22/2/11	9.8	4/7/11	8.2	21/11/11	6.5
23/2/11	9.7	5/7/11	7.9	22/11/11	6.9
1/3/11	9.8	6/7/11	7.6	23/11/11	7.1
2/3/11	9.7	17/7/11	7.6	6/12/11	7.3
3/3/11	9.5	18/7/11	7.4	7/12/11	7.7
4/3/11	9.5	19/7/11	7.2	8/12/11	7.8
14/3/11	9.7	30/7/11	7.5	21/12/11	7.7
15/3/11	10.2	31/7/11	7.0	22/12/11	7.6
25/3/11	10.1	1/8/11	6.9	23/12/11	7.8
26/3/11	10.3	2/8/11	6.4	30/12/11	8.0
29/3/11	10.4	13/8/11	7.4		
8/4/11	10.5	14/8/11	7.0		
9/4/11	10.6	15/8/11	7.6		
19/4/11	10.7	25/8/11	6.8		
20/4/11	10.7	26/8/11	6.5		
21/4/11	10.9	31/8/11	6.4		
28/4/11	10.8	10/9/11	6.8		
29/4/11	9.3	11/9/11	7.1		
4/5/11	10.6	12/9/11	6.7		
5/5/11	10.5	25/9/11	6.7		

Depth of groundwater levels at Zdawayag location (W_2) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
28/1/11	12.4	8/6/11	9.7	26/1011	10.4
29/1/11	12.6	9/6/11	9.6	27/1011	10.6
30/1/11	12.5	22/6/11	9.5	9/11/11	10.9
9/2/11	12.8	23/6/11	9.5	10/11/11	11.3
10/2/11	12.8	24/6/11	9.6	11/11/11	11.3
11/2/11	13.4	5/7/11	9.3	24/11/11	11.6
13/2/11	13.6	6/7/11	9.2	25/11/11	11.7
22/2/11	13.8	7/7/11	9.2	26/11/11	11.7
23/2/11	13.4	18/7/11	9.3	9/12/11	11.6
1/3/11	13.6	19/7/11	9.0	10/12/11	11.7
2/3/11	13.7	20/7/11	7.2	11/12/11	11.9
3/3/11	13.8	31/7/11	8.8	24/12/11	12.0
5/3/11	13.7	1/8/11	8.9	25/12/11	12.1
14/3/11	13.7	2/8/11	8.9	26/12/11	12.0
15/3/11	13.8	3/8/11	9.0		
25/3/11	13.7	16/8/11	9.3		
26/3/11	13.9	17/8/11	9.3		
4/4/11	11.8	18/8/11	8.9		
5/4/11	11.2	27/8/11	9.4		
6/4/11	11.3	28/8/11	9.5		
25/4/11	11.6	7/9/11	9.3		
26/4/11	12.1	8/9/11	9.4		
27/4/11	12.4	9/9/11	9.3		
4/5/11	12.7	22/9/11	9.5		
5/5/11	12.6	23/9/11	9.7		
16/5/11	9.3	24/9/11	9.8		
17/5/11	9.4	10/1011	9.8		
26/5/11	9.6	11/1011	10.1		
27/5/11	9.5	12/1011	10.0		
7/6/11	9.8	25/1011	10.3		

Depth of groundwater levels at Badeggi location (W_3) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
3/2/11	8.4	14/6/11	9.2	31/10/11	6.3
4/2/11	8.3	15/6/11	8.8	1/11/11	6.4
5/2/11	8.2	28/6/11	8.8	2/11/11	6.7
15/2/11	8.5	29/6/11	8.6	15/11/11	6.7
16/2/11	8.2	30/6/11	8.4	16/11/11	6.7
24/2/11	8.8	11/7/11	8.5	17/11/11	6.7
25/2/11	8.5	12/7/11	8.1	30/11/11	7.1
26/2/11	8.6	13/7/11	8.0	1/12/11	7.4
9/3/11	8.5	24/7/11	7.9	2/12/11	7.6
10/3/11	7.9	25/7/11	7.5	15/12/11	8.1
11/3/11	8.4	26/7/11	8.0	16/12/11	7.7
19/3/11	8.0	7/8/11	7.2	17/12/11	7.6
20/3/11	8.6	8/8/11	7.0	15/1/12	7.6
21/3/11	8.5	9/8/11	7.3	16/1/12	7.8
30/3/11	8.2	21/8/11	7.2	17/1/12	7.8
31/3/11	7.9	22/8/11	6.6		
13/4/11	7.9	1/9/11	6.8		
14/4/11	8.5	2/9/11	6.3		
15/4/11	8.7	3/9/11	6.5		
28/4/11	9.0	16/9/11	6.7		
29/4/11	9.1	17/9/11	6.6		
30/4/11	8.8	18/9/11	6.5		
9/5/11	9.1	29/9/11	6.0		
10/5/11	9.3	30/9/11	6.5		
11/5/11	9.1	1/10/11	6.6		
20/5/11	9.1	2/10/11	6.9		
21/5/11	9.1	3/10/11	5.8		
30/5/11	9.3	16/10/11	5.9		
31/5/11	8.6	17/10/11	5.8		
13/6/11	9.1	18/10/11	6.1		

Depth of groundwater levels at Edokota location (W_4) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
1/2/11	20.8	24/6/11	21.3	11/11/11	19.3
2/2/11	20.3	5/7/11	20.9	24/11/11	19.3
12/2/11	21.7	6/7/11	20.4	24/11/11	19.4
13/2/11	21.8	7/7/11	20.7	26/11/11	19.6
14/2/11	21.5	18/7/11	20.6	9/12/11	19.7
22/2/11	21.6	9/7/11	20.8	10/12/11	20.4
23/2/11	21.4	20/7/11	20.1	11/12/11	20.2
4/3/11	22.4	31/7/11	20.0	24/12/11	20.1
5/3/11	21.8	1/8/11	20.4	25/12/11	20.4
14/3/11	22.1	2/8/11	20.0	26/12/11	20.5
15/3/11	22.8	3/8/11	19.8	20/1/12	20.7
25/3/11	22.4	16/8/11	20.4	21/1/12	20.7
26/3/11	22.7	17/8/11	19.9	22/1/12	20.8
7/4/11	22.6	18/8/11	19.7	23/1/12	20.7
8/4/11	22.7	27/8/11	20.0		
9/4/11	22.6	28/8/11	19.9		
19/4/11	23.5	7/9/11	19.6		
20/4/11	23.8	8/9/11	19.6		
21/4/11	23.5	9/9/11	20.0		
4/5/11	23.4	22/9/11	20.0		
5/5/11	23.2	23/9/11	19.9		
16/5/11	23.5	24/9/11	19.6		
17/5/11	23.3	10/10/11	19.4		
26/5/11	23.0	11/10/11	19.6		
27/5/11	23.3	12/10/11	19.2		
7/6/11	23.0	25/10/11	19.7		
8/6/11	23.0	26/10/11	19.4		
9/6/11	22.8	27/10/11	19.6		
22/6/11	22.3	9/11/11	18.8		
23/6/11	22.2	10/11/11	19.5		

Depth of groundwater levels at Emi-Shiru location (W_5) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
28/1/11	11.4	8/6/11	8.6	26/10/11	8.9
29/1/11	11.0	9/6/11	8.4	27/10/11	9.1
30/1/11	11.8	22/6/11	8.9	9/11/11	9.0
9/2/11	10.7	23/6/11	8.7	10/11/11	8.9
10/2/11	10.8	24/6/11	8.9	11/11/11	9.0
11/2/11	11.1	5/7/11	9.0	24/11/11	9.3
13/2/11	11.2	6/7/11	8.7	25/11/11	9.3
22/2/11	10.8	7/7/11	8.6	26/11/11	9.4
23/2/11	11.0	18/7/11	8.8	9/12/11	9.3
1/3/11	11.8	19/7/11	8.1	10/12/11	9.6
2/3/11	10.8	20/7/11	8.0	11/12/11	9.7
3/3/11	11.2	31/7/11	8.4	24/12/11	9.5
5/3/11	10.6	1/8/11	8.4	25/12/11	9.3
14/3/11	10.8	2/8/11	7.9	26/12/11	9.4
15/3/11	11.7	3/8/11	8.3		
25/3/11	11.3	16/8/11	8.5		
25/3/11	10.7	17/8/11	8.6		
4/4/11	10.9	18/8/11	8.1		
5/4/11	11.6	27/8/11	8.3		
6/4/11	11.4	28/8/11	8.7		
25/4/11	11.3	7/9/11	8.6		
26/4/11	10.8	8/9/11	8.7		
27/4/11	11.0	9/9/11	8.9		
4/5/11	10.3	22/9/11	8.8		
5/5/11	9.0	23/9/11	8.6		
16/5/11	9.5	24/9/11	8.8		
17/5/11	10.0	10/10/11	8.8		
26/5/11	11.6	11/10/11	8.5		
27/5/11	12.0	12/10/11	8.9		
7/6/11	9.5	25/10/11	9.0		

Depth of groundwater levels at Gbanchitako location (W_6) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
6/2/11	22.4	11/6/11	21.5	4/11/11	21.2
7/2/11	23.1	12/6/11	21.5	5/11/11	21.4
8/2/11	23.1	25/6/11	21.6	8/11/11	21.3
17/2/11	22.8	26/6/11	21.3	19/11/11	21.4
18/2/11	22.9	27/6/11	21.2	20/11/11	21.8
19/2/11	23.0	8/7/11	21.2	3/12/11	21.8
6/3/11	23.4	9/7/11	21.3	4/12/11	21.0
7/3/11	23.2	10/7/11	21.2	5/12/11	22.2
8/3/11	23.6	21/7/11	21.0	18/12/11	22.2
16/3/11	24.1	22/7/11	21.2	19/12/11	22.3
17/3/11	23.8	23/7/11	21.6	20/12/11	22.0
18/3/11	24.2	4/8/11	20.8	11/1/12	22.1
27/3/11	24.1	5/8/11	20.9	12/1/12	22.3
28/3/11	24.4	6/8/11	20.3	13/1/12	22.1
29/3/11	24.7	19/8/11	20.2		
29/3/11	24.5	20/8/11	20.1		
20/4/11	24.7	20/8/11	20.1		
11/4/11	24.4	29/8/11	20.2		
12/4/11	24.3	30/8/11	20.4		
22/4/11	24.4	13/9/11	20.2		
23/4/11	24.4	14/9/11	20.2		
24/4/11	24.3	15/9/11	20.1		
6/5/11	24.5	27/9/11	20.0		
7/5/11	24.6	28/9/11	20.0		
8/5/11	24.5	4/10/11	20.0		
18/5/11	23.8	5/10/11	20.4		
19/5/11	23.6	19/10/11	20.1		
28/5/11	23.6	20/10/11	20.4		
29/5/11	23.3	21/10/11	20.6		
10/6/11	23.0	3/11/11	20.8		

Depth of groundwater levels at Gbakog location (W_8) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
3/2/11	13.6	15/6/11	12.0	2/11/11	12.0
4/2/11	13.6	28/6/11	1203	15/11/11	12.1
5/2/11	13.5	29/6/11	12.3	16/11/11	12.3
15/2/11	13.6	30/6/11	12.1	17/11/11	12.6
16/2/11	13.6	11/7/11	11.7	30/11/11	12.7
24/2/11	13.4	12/7/11	11.6	1/12/11	12.8
25/2/11	13.7	13/7/11	11.4	2/12/11	12.8
26/2/11	13.9	24/7/11	11.3	15/12/11	12.8
9/3/11	14.4	25/7/11	11.4	16/12/11	13.0
10/3/11	14.6	26/7/11	11.3	17/12/11	13.2
11/3/11	14.5	7/8/11	11.0	15/1/12	13.4
19/3/11	14.7	8/8/11	11.5	16/1/12	13.1
20/3/11	14.8	9/8/11	10.9	17/1/12	13.0
21/3/11	14.6	21/8/11	11.1		
30/3/11	14.7	22/8/11	11.0		
31/3/11	14.8	1/9/11	11.1		
13/4/11	14.9	2/9/11	10.9		
14/4/11	14.7	3/9/11	10.0		
15/4/11	14.4	16/9/11	10.1		
28/4/11	14.4	17/9/11	10.1		
29/4/11	13.6	18/9/11	9.7		
30/4/11	12.8	29/9/11	10.1		
9/5/11	12.5	30/9/11	10.4		
10/5/11	12.6	1/10/11	10.6		
11/5/11	12.4	2/10/11	10.8		
20/5/11	12.4	3/10/11	10.8		
21/5/11	12.5	16/10/11	11.2		
30/5/11	12.6	17/10/11	11.0		
31/5/11	12.4	18/10/11	11.4		
13/6/11	12.3	31/10/11	11.7		
14/6/11	12.2	1/11/11	11.9		

Depth of groundwater levels at Essa location (W_9) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
3/2/11	12.4	15/6/11	9.8	2/11/11	10.1
4/2/11	12.2	28/6/11	10.0	15/11/11	10.1
5/2/11	11.0	29/6/11	10.2	16/11/11	9.8
15/2/11	11.0	30/6/11	10.1	17/11/11	9.8
16/2/11	11.8	11/7/11	10.0	30/11/11	10.1
24/2/11	11.5	12/7/11	10.0	1/12/11	10.3
25/2/11	10.9	13/7/11	10.0	2/12/11	10.6
26/2/11	10.8	24/7/11	9.7	15/12/11	10.8
9/3/11	10.6	25/7/11	10.1	16/12/11	10.9
10/3/11	10.9	26/7/11	9.6	17/12/11	10.6
11/3/11	11.9	7/8/11	9.8	6/1/12	11.0
19/3/11	10.9	8/8/11	9.0	7/1/12	11.3
20/3/11	11.0	9/8/11	9.1	8/1/12	11.6
21/3/11	10.8	21/8/11	9.0		
30/3/11	12.1	22/8/11	9.1		
31/3/11	11.0	1/9/11	9.0		
13/4/11	11.8	2/9/11	9.6		
14/4/11	12.0	3/9/11	9.5		
15/4/11	12.0	16/9/11	10.0		
28/4/11	12.0	17/9/11	9.8		
29/4/11	9.8	18/9/11	9.5		
30/4/11	10.7	29/9/11	9.6		
9/5/11	10.8	30/9/11	8.9		
10/5/11	10.9	1/10/11	8.5		
11/5/11	10.7	2/10/11	8.9		
20/5/11	10.8	3/10/11	8.6		
21/5/11	10.9	16/10/11	8.9		
30/5/11	10.0	17/10/11	9.4		
31/5/11	10.4	18/10/11	9.3		
13/6/11	10.1	31/10/11	9.1		
14/6/11	10.2	1/11/11	9.2		

Depth of groundwater levels at Vunchi location (W_{11}) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
6/2/11	15.3	25/6/11	13.7	19/11/11	11.5
7/2/11	15.2	26/6/11	13.6	20/11/11	11.8
8/2/11	14.9	27/6/11	13.1	3/12/11	11.9
17/2/11	14.0	8/7/11	13.2	4/12/11	12.4
18/2/11	14.7	9/7/11	13.5	5/12/11	12.6
19/2/11	14.4	10/7/11	12.9	18/12/11	12.8
6/3/11	13.7	21/7/11	12.7	19/12/11	13.5
7/3/11	13.7	22/7/11	12.9	20/12/11	13.7
8/3/11	14.0	23/7/11	12.7	2/1/12	14.0
16/3/11	13.8	4/8/11	11.7	3/1/12	14.2
17/3/11	14.8	5/8/11	11.5	4/1/12	14.1
18/3/11	13.8	6/8/11	11.8		
27/3/11	13.9	19/8/11	11.5		
28/3/11	13.7	20/8/11	11.4		
29/3/11	14.0	29/8/11	11.2		
10/4/11	13.9	30/8/11	11.5		
11/4/11	13.7	13/9/11	11.3		
12/4/11	14.9	14/9/11	11.0		
22/4/11	14.9	15/9/11	11.3		
23/4/11	14.9	27/9/11	11.0		
24/4/11	15.1	28/9/11	11.3		
6/5/11	15.2	4/10/11	10.9		
7/5/11	15.1	5/10/11	11.1		
8/5/11	15.2	6/10/11	11.0		
18/5/11	15.1	19/10/11	11.1		
19/5/11	15.2	20/10/11	11.3		
28/5/11	13.8	21/10/11	11.4		
29/5/11	13.6	3/11/11	11.6		
10/6/11	13.5	4/11/11	11.5		
11/6/11	13.6	5/11/11	11.6		
12/6/11	13.6	18/11/11	11.5		

Depth of groundwater levels at Kuchiworo location (W_{13}) January to May

Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
6/2/11	16.5	12/6/11	17.5	5/11/11	13.4
7/2/11	16.8	25/6/11	17.4	18/11/11	13.4
8/2/11	17.0	26/6/11	17.4	19/11/11	13.6
17/2/11	17.2	27/6/11	16.9	20/11/11	13.5
18/2/11	17.4	8/7/11	16.7	3/12/11	13.6
19/2/11	17.5	9/7/11	16.8	4/12/11	14.0
6/3/11	17.5	10/7/11	16.5	5/12/11	14.2
7/3/11	17.9	21/7/11	16.2	18/12/11	14.5
8/3/11	17.6	22/7/11	16.2	19/12/11	14.6
16/3/11	17.5	23/7/11	14.6	20/12/11	14.8
17/3/11	17.5	4/8/11	15.3	11/1/12	15.0
18/3/11	17.3	5/8/11	15.3	12/1/12	15.1
27/3/11	17.8	6/8/11	15.2	13/1/12	15.3
28/3/11	17.8	19/8/11	14.2		
29/3/11	17.7	20/8/11	14.0		
10/4/11	17.7	29/8/11	14.2		
11/4/11	18.5	30/8/11	14.4		
12/4/11	18.8	13/9/11	14.2		
22/4/11	17.9	14/9/11	14.0		
23/4/11	17.6	15/9/11	13.6		
24/4/11	18.2	27/9/11	13.3		
6/5/11	18.6	28/9/11	13.0		
7/5/11	19.1	4/10/11	12.7		
8/5/11	18.9	5/10/11	12.6		
18/5/11	19.0	6/10/11	12.8		
19/5/11	19.4	19/10/11	12.8		
28/5/11	19.4	20/10/11	12.9		
29/5/11	18.3	21/10/11	13.3		
10/6/11	17.7	3/11/11	13.1		
11/6/11	17.3	4/11/11	13.4		

Depth of groundwater levels at Edozhigi location (W_{15}) January to May

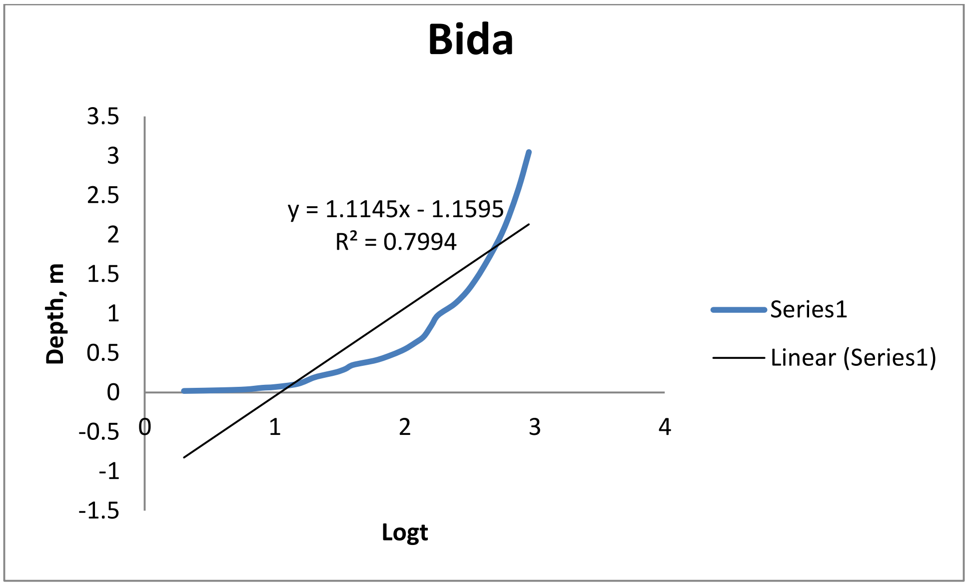
Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
31/1/11	13.0	17/6/11	11.3	14/11/11	10.3
1/2/11	13.0	18/6/11	11.1	27/11/11	10.7
2/2/11	13.1	1/7/11	11.1	28/11/11	11.6
20/2/11	12.9	2/7/11	11.2	29/11/11	11.9
21/2/11	13.0	3/7/11	11.0	12/12/11	11.7
27/2/11	13.0	14/7/11	10.9	13/12/11	12.0
28/2/11	13.2	15/7/11	10.6	14/12/11	12.1
12/3/11	12.6	16/7/11	10.7	27/12/11	12.0
13/3/11	13.2	27/7/11	10.6	28/12/11	12.2
22/3/11	12.8	28/7/11	10.8	29/12/11	12.3
23/3/11	14.2	29/7/11	10.5	27/1/12	12.6
24/3/11	13.7	10/8/11	10.9	28/1/12	12.6
1/4/11	13.9	11/8/11	9.8	29/1/12	12.6
2/4/11	14.0	12/8/11	9.8		
3/4/11	14.0	23/8/11	10.8		
16/4/11	12.9	24/8/11	10.5		
17/4/11	13.8	4/9/11	10.3		
18/4/11	14.1	5/9/11	9.4		
19/4/11	13.8	6/9/11	9.6		
1/5/11	13.4	19/9/11	9.5		
2/5/11	13.7	20/9/11	9.5		
3/5/11	13.7	21/9/11	8.8		
12/5/11	13.8	13/10/11	8.8		
13/5/11	13.0	14/10/11	9.2		
22/5/11	12.4	15/10/11	9.8		
23/5/11	11.7	28/10/11	10.2		
1/6/11	12.0	29/10/11	10.1		
2/6/11	12.0	30/10/11	9.8		
3/6/11	11.5	12/11/11	10.2		
16/6/11	11.4	13/11/11	10.4		

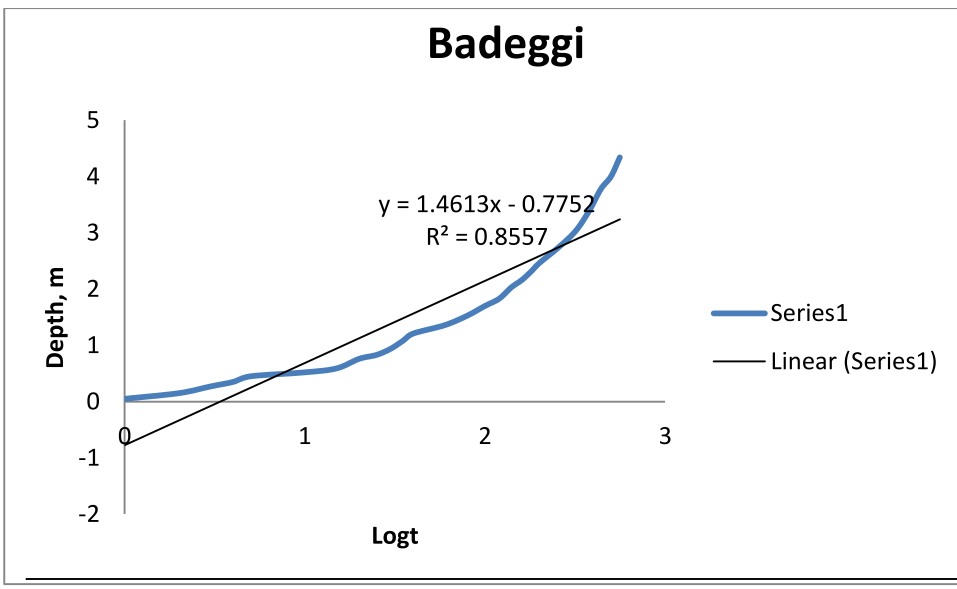
Depth of groundwater levels at Zanchita location (W_{16}) January to May

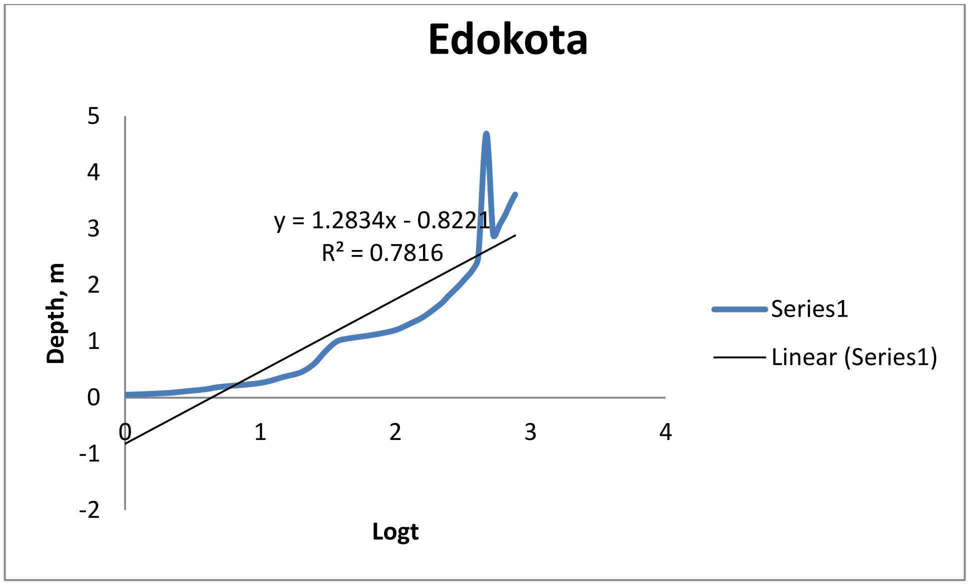
Date	Depth (m)	Date	Depth (m)	Date	Depth (m)
31/1/11	10.0	18/6/11	8.7	27/11/11	9.1
1/2/11	10.0	1/7/11	8.7	28/11/11	9.2
2/2/11	9.3	2/7/11	8.9	29/11/11	9.3
20/2/11	10.4	3/7/11	8.5	12/12/11	9.5
21/2/11	10.2	14/7/11	8.8	13/12/11	9.6
27/2/11	9.8	15/7/11	8.9	14/12/11	9.6
28/2/11	9.9	16/7/11	9.0	27/12/11	9.7
12/3/11	11.3	27/7/11	8.7	28/12/11	9.8
13/3/11	10.9	28/7/11	8.9	29/12/11	9.8
23/3/11	10.7	29/7/11	8.7	24/1/12	10.1
24/3/11	10.5	10/8/11	9.0	25/1/12	9.9
1/4/11	10.5	11/8/11	8.3	26/1/12	10.3
2/4/11	10.5	12/8/11	8.8		
3/4/11	10.6	23/8/11	8.4		
16/4/11	10.3	24/8/11	8.0		
17/4/11	10.7	4/9/11	8.9		
18/4/11	11.2	5/9/11	9.0		
19/4/11	11.6	6/9/11	8.9		
1/5/11	11.9	19/9/11	8.7		
2/5/11	12.4	20/9/11	8.8		
3/5/11	12.0	21/9/11	8.5		
12/5/11	12.5	13/10/11	8.6		
13/5/11	11.9	14/10/11	8.5		
22/5/11	11.6	15/10/11	8.7		
23/5/11	11.8	28/10/11	8.8		
1/6/11	10.1	29/10/11	8.8		
2/6/11	9.2	30/10/11	8.9		
3/6/11	9.0	12/11/11	8.8		
16/6/11	9.0	13/11/11	8.9		
17/6/11	8.6	14/11/11	9.0		

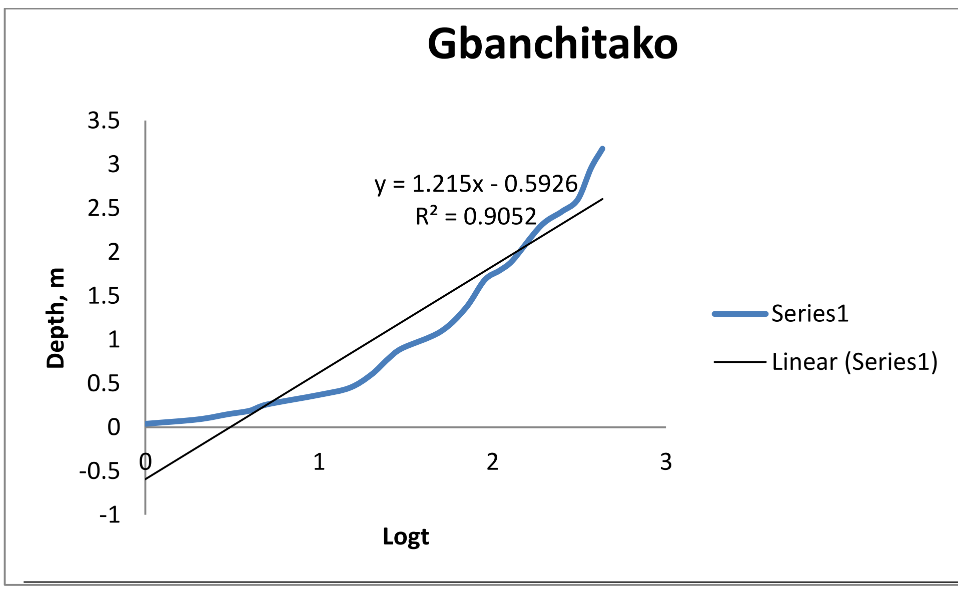
APPENDIX B

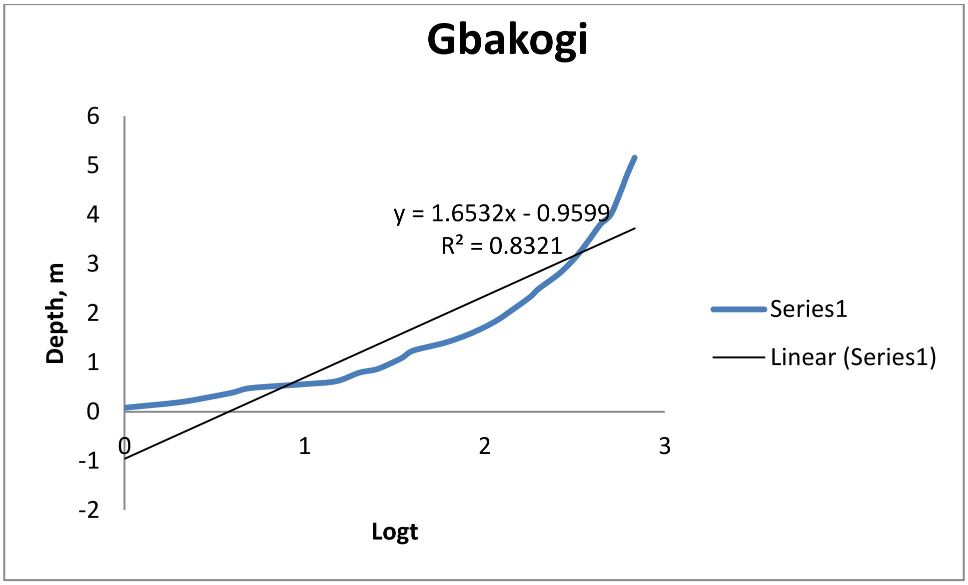
The slope of the recovery depth Vs time graph over one log cycle.

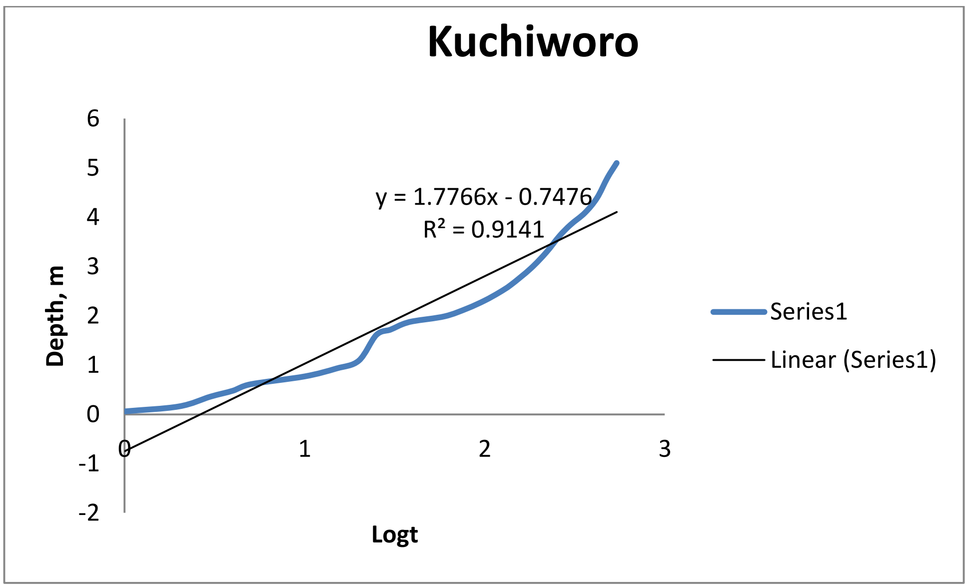


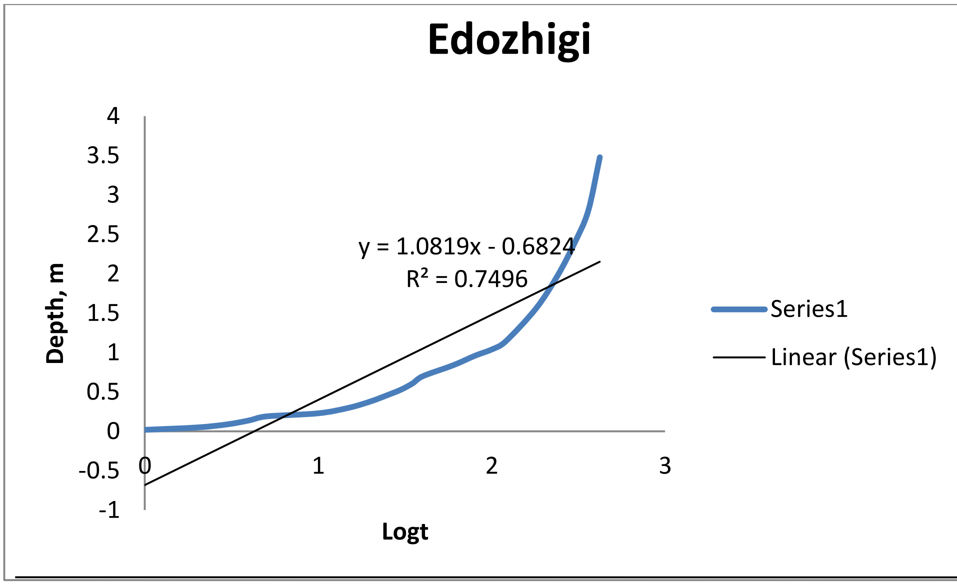


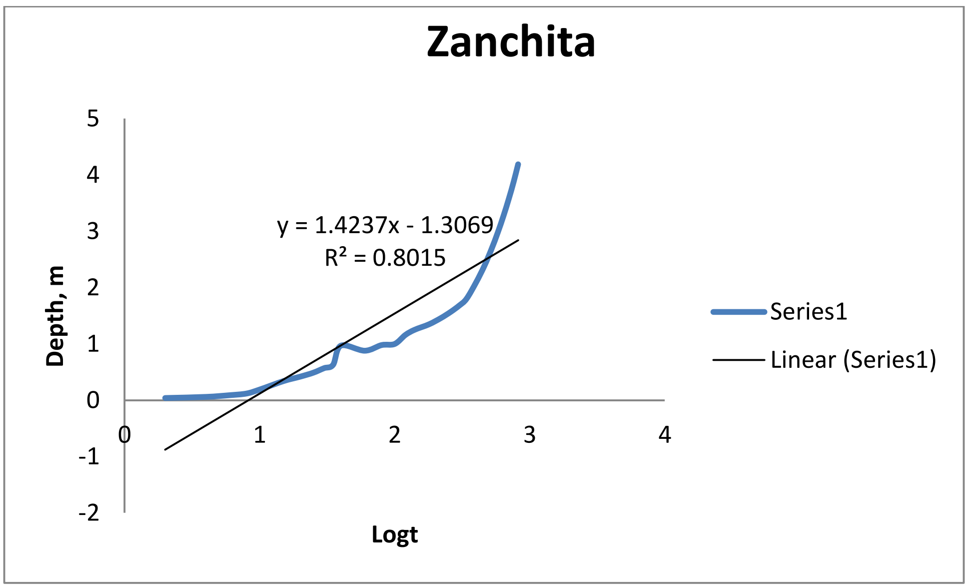

Edokota
5
4
3
2
1
0
-1
-2
Depth, m
0
1
2
3
4
Logt
y = 1.2834x - 0.8221
R² = 0.7816
Series1
Linear (Series1)

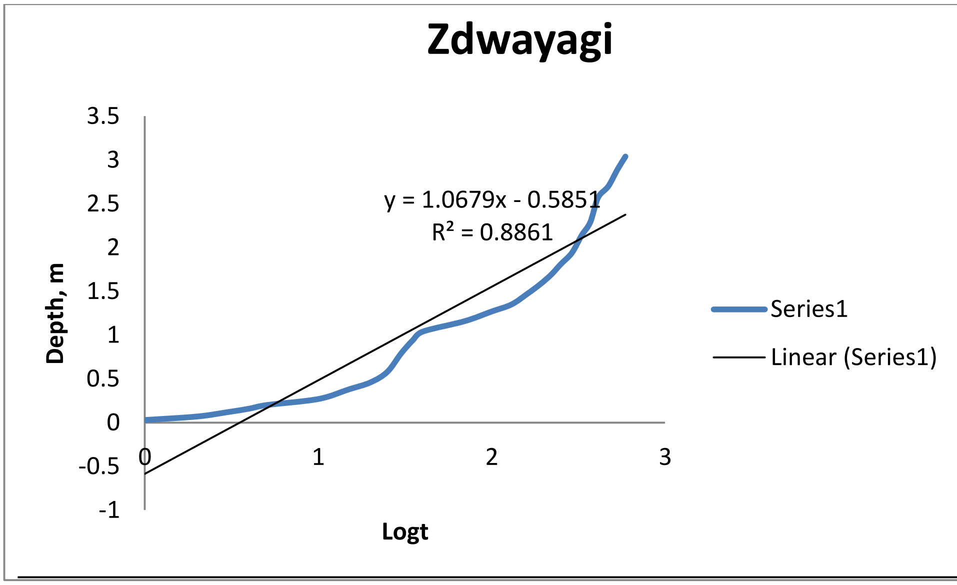

Gbanchitako
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
Depth, m
0
1
2
3
Logt
y = 1.215x - 0.5926
R² = 0.9052
Series1
Linear (Series1)


Gbakogi
Depth, m
6
5
4
3
2
1
0
-1
-2
0
1
2
3
Logt
y = 1.6532x - 0.9599
R² = 0.8321
Series1
Linear (Series1)


Kuchiworo
Depth, m
6
5
4
3
2
1
0
-1
-2
0
1
2
3
Logt
y = 1.7766x - 0.7476
R² = 0.9141
Series1
Linear (Series1)


Edozhigi
y = 1.0819x - 0.6824
R² = 0.7496
Depth, m
Logt
Series1
Linear (Series1)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
1
2
3


Zanchita
y = 1.4237x - 1.3069
R² = 0.8015
Depth, m
Logt
Series1
Linear (Series1)
5
4
3
2
1
0
-1
-2
0
1
2
3
4


Zdwayagi
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
Depth, m
0
1
2
3
Logt
y = 1.0679x - 0.5851
R² = 0.8861
Series1
Linear (Series1)

APPENDIX C

COMPUTATION OF TRANSMISSIBILITY (T) OF THE DUG WELLS

W_1

$Q=6.19m^3/hr$

$\Delta S=1.11$

Therefore $T=\frac{2.3Q}{4\pi\Delta S} = \frac{2.3x6.19x24}{4x\pi 1.11} = \frac{341.688}{13.94} = 24.51m^2/day$

W_2

$Q=5.90m^3/hr$

$\Delta S=1.06$

Therefore $T=\frac{2.3Q}{4\pi\Delta S} = \frac{2.3x5.90x24}{4x\pi 1.06} = \frac{325.68}{13.32} = 24.45m^2/day$

W_3

$Q=5.91m^3/hr$

$\Delta S=1.46$

Therefore $T=\frac{2.3Q}{4\pi x\Delta S} = \frac{2.3x5.91x24}{4\pi x1.46} = \frac{326.2}{18.34} = 17.78m^2/day$

W_4

$Q=5.47m^3/hr$

$\Delta S=1.28$

Therefore $T = \frac{2.3Q}{4\pi\Delta S} = \frac{2.3x5.41x24}{4\pi x1.28} = \frac{301.944}{16.08} = 18.77m^2/day$

W_5

$Q = 6.19m^3/hr$

$\Delta S = 1.73$

Therefore $T = \frac{2.3Q}{4\pi\Delta S} = \frac{2.3x6.19x24}{4\pi 1.73} = \frac{341.688}{21.74}$

$= 15.71m^2/day$

W_6

$Q = 5.33m^3/hr$

$\Delta S = 1.21$

Therefore $T = \frac{2.3Q}{4\pi\Delta S} = \frac{2.3x5.33x24}{4\pi 1.21} = \frac{294.216}{15.20} = 19.35m^2/day$

W_8

$Q = 2.81m^3/hr$

$\Delta S = 1.65$

Therefore $T = \frac{2.3Q}{4\pi\Delta S} = \frac{2.3x2.81x24}{4\pi 1.65} = \underline{155.112} = 7.48m^2/day$

W_{13}

$Q = 5.47m^3/hr$

$\Delta S = 1.77$

Therefore $T = \frac{2.3Q}{4\pi\Delta S} = \frac{2.3x5.47x24}{4\pi 1.77} = \frac{301.944}{22.24}$

$= 13.57 m^2/day$

W_{15}

Q=6.62

$\Delta S=1.08$

$$\text{Therefore } T=\frac{2.3Q}{4\pi\Delta S} = \frac{2.3x6.62x24}{4\pi 1.08} = \frac{365.424}{13.57} = 25.97 m^2/day$$

W_{16}

$Q=2.80m^3/hr$

$\Delta S=1.42$

$$\text{Therefore } T=\frac{2.3Q}{4\pi\Delta S} = \frac{2.3x2.80x24}{4\pi 1.42} = \frac{154.56}{17.84} = 8.66 m^2/day$$

APPENDIX D

COMPUTATION OF COEFFICIENT OF PERMEABILITY (K) OF THE DUG WELLS

$T = kb$: - $K = {}^{T}/_{b}$

Where T is the ability of the aquifer to transmit water (transmissibility).

Where b is the saturated (average) thickness of the aquifer

And K is the hydraulic conductivity or coefficient of permeability

For: W1 $T = 24.51m^2/day$ b = 3.0m

$$K = \frac{24.51}{3.0}$$
$$= 8.17$$
$$= 8.2m/day$$

W2 $T = 24.45m^2/day$ b = 3.0m

$$K = \frac{24.45}{3.0}$$
$$= 8.15$$
$$= 8.2m/day$$

W3 $T = 17.78m^2/day$ b = 4.3m

$$K = \frac{17.78}{4.3}$$
$$= 4.1m/day$$

W4 $T = 18.77m^2/day$ $b = 3.6m$

$$K = \frac{18.77}{3.6} = 5.2m/day$$

W5 $T = 15.71m^2/day$ $b = 4.3m$

$$K = \frac{15.71}{4.3} = 3.6m/day$$

W6 $T = 19.3m^2/day$ $b = 3.2m$

$$K = \frac{19.3}{3.2} = 6.0m/day$$

W8 $T = 7.48m^2/day$ $b = 5.2m$

$$K = \frac{7.48}{5.2} = 1.4m/day$$

W13 $T = 13.58m^2/day$ $b = 5.2m$

$$K = \frac{13.58}{5.2} = 2.6m/day$$

W15 $T = 26.94m^2/day$ $b = 3.5m$

K = <u>26.94</u>

$$= \frac{3.5}{7.69}$$

= 7.7m/day

W16 T = 8.66m^2/day b = 4.1m

$$K = \frac{8.66}{4.1}$$

= 2.1m/day

APPENDIX E

Table 1.0: Mean monthly Rainfall (mm) from 1992-2011

Year/ Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Means
1992	0.0	0.0	0.0	141.7	163.6	133.9	128.6	148.4	216.0	31.5	0.0	0.0	78.06
1993	0.0	0.0	61.6	8.9	154.7	241.8	206.9	308.4	240.4	152.8	0.0	0.0	114.63
1994	0.0	0.0	0.0	38.0	171.9	151.4	75.8	425.7	194.0	102.1	0.0	0.0	96.58
1995	0.0	0.0	22.9	43.8	92.3	128.7	236.7	307.5	152.2	105.6	12.3	0.0	91.83
1996	0.0	0.0	0.0	12.6	199.9	190.7	201.8	326.1	170.5	41.3	0.0	0.0	96.82
1997	0.0	0.0	64.9	53.9	129.3	279.2	219.0	227.2	147.5	135.4	7.2	0.0	105.30
1998	0.0	0.0	0.0	67.1	213.2	75.5	239.7	145.5	153.7	103.0	0.0	0.0	83.14
1999	0.0	0.0	9.8	112.1	135.4	196.8	264.1	194.5	153.7	98.0	0.0	0.0	97.27
2000	0.0	0.0	9.5	13.3	118.5	280.5	191.9	284.3	262.8	42.0	0.0	0.0	100.24
2001	0.0	0.0	0.0	62.4	115.9	119.3	245.9	345.5	301.6	66.0	0.0	0.0	104.72
2002	0.0	0.0	0.5	44.9	78.0	135.9	199.2	199.9	252.0	107.7	21.7	0.0	86.48
2003	0.0	0.0	0.0	20.2	210.2	169.4	238.4	151.7	162.8	72.9	36.0	0.0	88.47
2004	0.0	0.0	0.0	57.7	177.0	162,6	143.8	355.9	146.8	135.6	0.0	0.0	98.45
2005	0.0	0.0	3.6	80.6	238.4	233.2	172.4	192.7	203.3	115.0	6.1	0.0	106.47
2006	0.0	0.0	0.0	92.2	121.2	221.0	155.1	243.0	201.9	140.1	6.1	0.0	98.38
2007	0.0	0.0	0.0	48.6	164.7	225.0	259.7	257.0	191.1	127.9	0.0	0.0	106.16
2008	0.0	0.0	3.6	80.6	192.7	233.0	172.4	238.4	203.3	115.0	6.1	0.0	103.45
2009	0.0	0.0	0.0	92.2	121.2	221.0	155.1	243.0	201.9	202.6	0.0	0.0	103.08
2010	0.0	0.0	3.5	102.8	164.2	243.9	245.7	237.1	202.2	206.4	0.0	0.0	117.15
2011	0.0	0.0	0.0	63.3	164.4	119.1	263.4	309.2	210.0	145.8	0.0	0.0	106.26

Source: (NCRI Badeggi 2011)

Table 1.1: Mean monthly temperature in ^{o}C from 1992-2011

Year/ Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Means**
1992	23.5	25.5	29.5	29.0	28.5	27.5	26.5	27.0	26.0	27.0	26.0	24.0	26.67
1993	24.0	27.0	29.0	31.0	30.0	27.0	26.5	27.0	27.0	28.0	27.5	26.5	27.54
1994	24.0	27.5	32.0	31.0	29.0	27.5	27.5	27.0	28.0	28.0	26.5	24.5	27.63
1995	24.5	26.5	31.5	32.0	29.5	28.5	27.5	27.0	27.5	28.0	27.0	26.0	27.96
1996	25.0	29.0	31.0	32.0	28.5	27.0	27.0	26.0	26.0	27.0	25.5	26.0	27.50
1997	29.0	28.5	30.5	30.0	28.5	27.0	27.5	27.5	27.5	28.0	28.5	26.0	28.21
1998	26.0	30.0	31.5	33.0	29.5	28.5	28.0	27.0	27.0	28.5	28.0	26.0	28.58
1999	26.0	28.5	31.0	31.0	29.0	27.5	27.0	26.5	27.0	28.0	28.0	25.5	27.92
2000	26.5	26.5	30.0	31.5	30.0	27.5	26.5	26.5	27.0	28.0	27.5	24.5	27.67
2001	24.0	26.5	30.0	31.0	29.5	28.0	27.0	26.5	26.5	28.0	27,0	25.5	27.50
2002	25.0	77.5	31.5	30.5	31.0	28.0	27.0	26.0	26.5	27.0	26.5	25.5	27.67
2003	26.0	29.0	31.0	31.5	30.0	27.5	27.0	26.5	26,0	28.0	27.5	24.5	27.88
2004	25.5	28.0	31.0	31.5	28.5	27.5	27.5	26.5	27.0	28.0	27.5	25.5	27.83
2005	26.0	28.0	30.0	30.5	28.5	27.5	27.0	27.0	27.0	28.0	28.0	24.5	27.67
2006	26.5	28.5	30.5	31.5	28.5	28.0	26.5	26.5	27.0	27.0	28.0	25.5	27.83
2007	24.0	27.0	30.0	31.5	29.0	27.5	26.5	27.0	27.0	28.0	26.5	25.0	27.42
2008	25.0	27.5	29.0	30.5	27.5	27.0	26.5	27.0	28.5	28.5	27.5	26.0	27.54
2009	26.3	29.1	29.0	31.5	30.5	28.0	27.0	26.5	26,5	28.0	27.0	25.0	27.87
2010	27.0	27.0	30.5	30.0	29.0	26.5	26.5	27.0	26.5	28.0	27.5	24.5	27.50
2011	26.0	20.5	31.0	30.5	29.5	28.0	27.9	28.6	27.1	28.9	27.7	26.0	28.34

Source: (NCRI Badeggi 2011)

Table 1.2: Mean monthly Percentage Relative Humidity from 1992-2011

Year/ Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Means**
1992	65.0	63.0	66.0	82.0	84.0	86.0	88.0	87.0	87.0	87.0	82.0	68.0	73.28
1993	51.0	52.0	62.0	67.0	75.0	83.0	87.0	87.0	87.0	87.0	83.0	80.0	73.42
1994	66.0	48.0	68.0	69.0	80.0	81.0	84.0	85.0	85.0	85.0	81.0	69.0	72.42
1995	50.0	40.0	69.0	69.0	75.0	81.0	84.0	89.0	85.0	85.0	81.0	67.0	71.58
1996	67.0	65.0	65.0	65.0	78.0	83.0	86.0	88.0	87.0	87.0	77.0	65.0	74.00
1997	57.0	30.0	54.0	70.0	77.0	82.0	84.0	82.0	82.0	82.0	82.0	72.0	69.08
1998	52.0	43.0	33.0	68.0	83.0	82.0	85.0	84.0	85.0	85.0	82.0	74.0	69.08
1999	54.0	57.0	68.0	70.0	79.0	85.0	87.0	86.0	86.0	86.0	85.0	72.0	74.33
2000	65.0	36.0	45.0	66.0	73.0	86.0	87.0	87.0	86.0	86.0	82.0	72.0	70.50
2001	57.0	37.0	57.0	65.0	77.0	80.0	85.0	84.0	86.0	81.0	86.0	61.0	69.83
2002	41.0	42.0	60.0	69.0	67.0	81.0	86.0	88.0	86.0	84.0	76.0	57.0	69.75
2003	61.0	58.0	50.0	69.0	73.0	84.0	86.0	89.0	87.0	82.0	75.0	57.0	72.58
2004	56.0	40.0	41.0	67.0	80.0	84.0	89.0	88.0	86.0	84.0	73.0	67.0	71.25
2005	33.0	42.0	57.0	63.0	73.0	81.0	87.0	88.0	84.0	74.0	32.0	31.0	62.101
2006	30.0	18.0	46.0	64.0	78.0	82.0	85.0	85.0	82.0	78.0	45.0	28.0	60.19
2007	40.0	25.0	55.0	63.0	72.0	77.0	81.0	86.0	80.0	84.0	64.0	46.0	64.41
2008	44.0	37.0	58.0	72.0	82.0	87.0	89.0	86.0	80.0	78.0	49.0	44.0	67.16
2009	56.0	48.0	58.0	69.0	80.0	81.0	84.0	89.0	85.0	81.0	68.0	58.0	71.41
2010	54.0	47.0	64.0	67.0	77.0	84.0	87.0	87.0	84.0	82.0	72.0	53.0	71.50
2011	55.0	65.0	60.0	70.0	77.0	79.0	87.0	82.3	85.0	82.0	78.0	59.0	73.28

Source: (NCRI Badeggi 2011)

Table 1.3: Monthly Radiation (mm) from 1992-2011

Year/ Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Means**
1992	15.1	17.6	16.6	17.3	12.0	14.1	13.5	11.5	15.0	18.4	16.0	15.5	15.22
1993	15.2	17.9	17.1	17.4	16.0	15.0	13.7	14.8	16.6	18.3	17.2	14.4	16.13
1994	13.7	15.6	19.3	16.1	16.0	15.3	14.2	13.0	15.5	18.1	18.2	15.9	15.91
1995	14.5	18.0	18.9	16.9	16.3	15.0	13.8	13.2	16.3	18.0	18.5	15.6	16.25
1996	15.0	17.3	18.2	18.0	16.7	15.1	13.2	12.8	15.2	17.9	18.1	12.8	15.86
1997	15.8	18.3	17.5	18.4	17.7	15.7	13.3	14.9	14.9	17.3	18.0	15.4	16.43
1998	14.3	17.6	11.9	18.4	16.8	16.2	13.4	12.6	14.3	18.3	18.1	15.1	15.58
1999	14.8	17.5	19.8	18.4	16.3	14.0	14.0	11.8	13.6	16.8	17.6	15.6	15.85
2000	15.5	17.5	19.7	17.6	16.0	15.1	13.1	13.7	16.0	18.1	17.7	16.0	16.33
2001	16,0	18.0	19.9	17.4	17.0	16.1	13.2	13.0	16.0	19.4	19.3	17.0	16.86
2002	15.0	18.4	19.0	17.4	17.3	16.5	14.0	13.5	16.0	17.0	18.0	17.0	16.59
2003	15.3	17.3	18.0	16.4	16.0	15.0	14.0	13.2	14.5	18.0	18.2	16.0	15.99
2004	15.0	17.4	18.0	17.0	16.0	14.0	12.0	12.4	16.0	16.0	18.0	15.0	15.57
2005	17.1	14.6	15.8	16.8	15.3	14.3	10.9	9.2	11.9	15.6	13.6	14.3	14.17
2006	14.8	16.2	17.5	16.5	15.3	14.4	11.8	11.8	15.0	14.8	16.7	13.5	14.85
2007	15.6	18.1	17.7	17.5	16.0	15.0	12.5	12.3	16.8	17.1	17.0	13.5	15.75
2008	15.3	17.6	15.5	17.3	12.0	15.1	14.5	11.5	15.0	18.4	16.0	15.5	15.39
2009	14.6	17.1	16.7	17.5	15.0	14.9	12.5	12.3	16.8	17.1	17.0	13.5	15.41
2010	15.6	218.1	17.3	18.2	17.4	15.4	13.0	14.6	14.6	17.0	18.0	15.4	16.21
2011	14.4	16.3	17.8	16.8	15.5	14.1	12.1	12.5	14.6	16.8	16.6	14.4	13.75

APPENDIX G

Plate. Pumping Test (Recovery Test) Method

RTICLE SIZE DISTRIBUTION

	Sieve Size (mm or N)	Mass Retained	Mass Passing	% Passing
0-4m 1	10	0.11	106.03	100
	22	5.08	100.94	95.1
	30	22.9	78.04	73.58
	45	34.71	43.33	40.8
	60	23.31	20.02	18.9
	85	9.91	10.11	9.5
	100	4.09	6.02	5.7
	Pan	5.92	0.1	
		106.14		
	Sieve Size (mm or N)	**Mass Retained**	**Mass Passing**	**% Passing**
4-8m 2	10	0.04	120.13	100
	22	1.82	118.3	98.4
	30	25.74	92.57	77
	45	46.41	46.43	38.6
	60	25.35	21.08	17.5
	85	10.12	10.96	9.12
	100	5.04	5.92	4.93

	Pan	5.92		
		120.17		
	Sieve Size (mm or N)	**Mass Retained**	**Mass Passing**	**% Passing**
8-12m	10	1.72	168.79	98.99
3	22	123.41	45.38	26.61
	30	19.36	26.02	15.26
	45	13.92	12.1	7.1
	60	6.51	5.59	3.27
	85	2.31	3.28	1.92
	100	0.81	2.47	1.44
	Pan	2.47		
		170.51		

PARTICLE SIZE DISTRIBUTION

	Sieve Size (mm or N)	**Mass Retained**	**Mass Passing**	**% Passing**
12-16m	10	2.26	202.61	98.89
4	20	63.41	139.06	67.87
	30	62.97	76.09	37.14
	45	42.38	33.71	16.45
	60	19.8	13.91	6.79
	80	9.55	4.36	2.13
	100	1.16	3.21	1.56

		204.87		
	Sieve Size (mm or N)	**Mass Retained**	**Mass Passing**	**% Passing**
16-20m 5	10	78.92	31.57	28.57
	20	29.73	1.84	1.66
	30	0.64	1.2	1.09
	45	0.39	0.81	
	60	0.25	0.56	
	80	0.16	0.4	
	100	0.07	0.33	
	Pan	0.33		
		110.49		
	Sieve Size (mm or N)	**Mass Retained**	**Mass Passing**	**% Passing**
20-24m 6	10	0.65	146.05	100
	20	28.19	117.86	80.34
	30	40.57	77.29	52.68
	45	31.58	45.71	31.16
	60	18.37	27.34	18.64
	80	14.3	13.04	8.88
	100	8.25	4.79	3.26
		146.7		

PARTICLE SIZE DISTRIBUTION

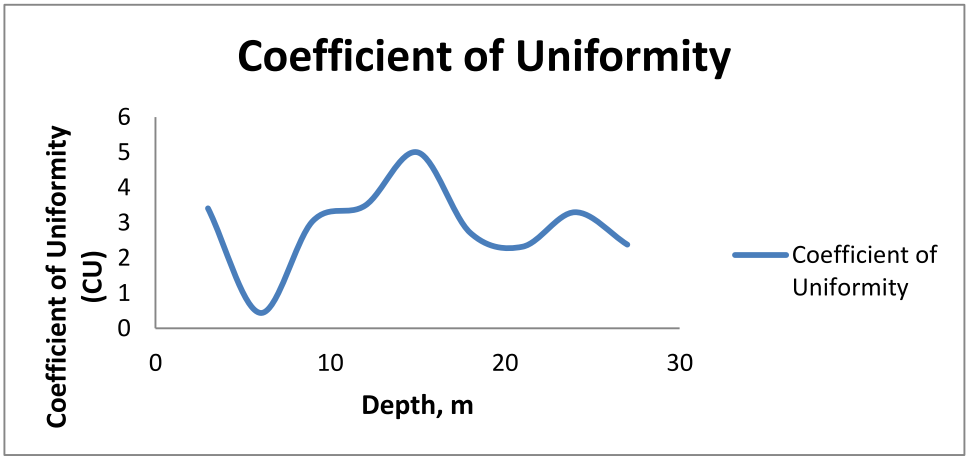
	Sieve Size (mm or N)	Mass Retained	Mass Passing	% Passing
24-28m	10	2.96	225.4	98.7
7	20	161.43	63.97	28.01
	30	26.66	37.31	16.34
	45	16.97	20.34	8.91
	60	9.87	10.47	4.58
	80	4.63	5.84	2.56
	100	2.16	3.68	1.61
		228.36		

INVENTORIES OF SOME BOREHOLES IN THE STUDY AREA

Locality Altitude total Aquifer S.W.L Dynamic Draw Yield Specific

Located	M(ASL)	Depth (M)	Thickness		Level	Down	Capacity	
Bida	140	60.0	33.4	8.4	24.0	11.6	4.8	0.76
Bida	150	50.0	33.5	16.4	24.4	11.6	4.5	0.78
Zdwagi	150	50.0	28.4	12.4	33.5	11.1	2.7	0.24
Gbakogi	150	40.0	15.0	4.8	26.4	21.6	40.8	0.48
Vunchi	170	57.9	3.0	6.7	35.4	24.7	19.7	0.80

Source: - Ruwatsan (2011).



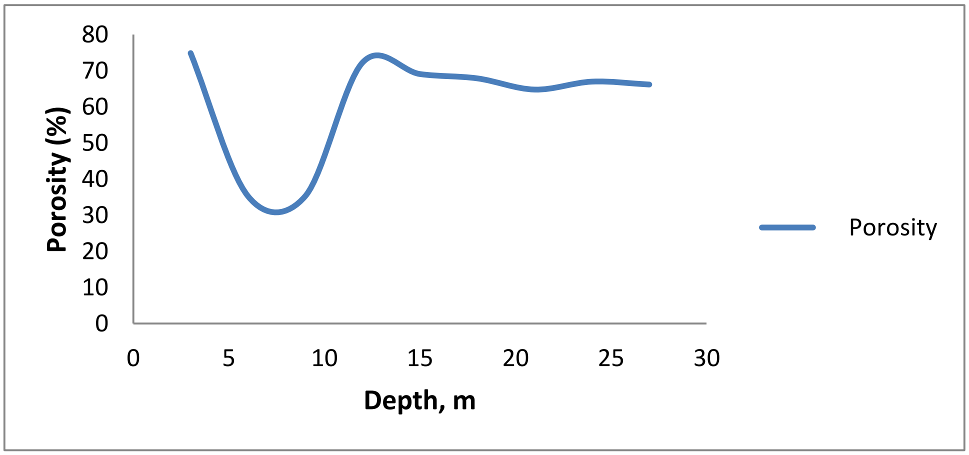


Fig 2.2 shows the classification of the earth crust and occurrence of subsurface water.

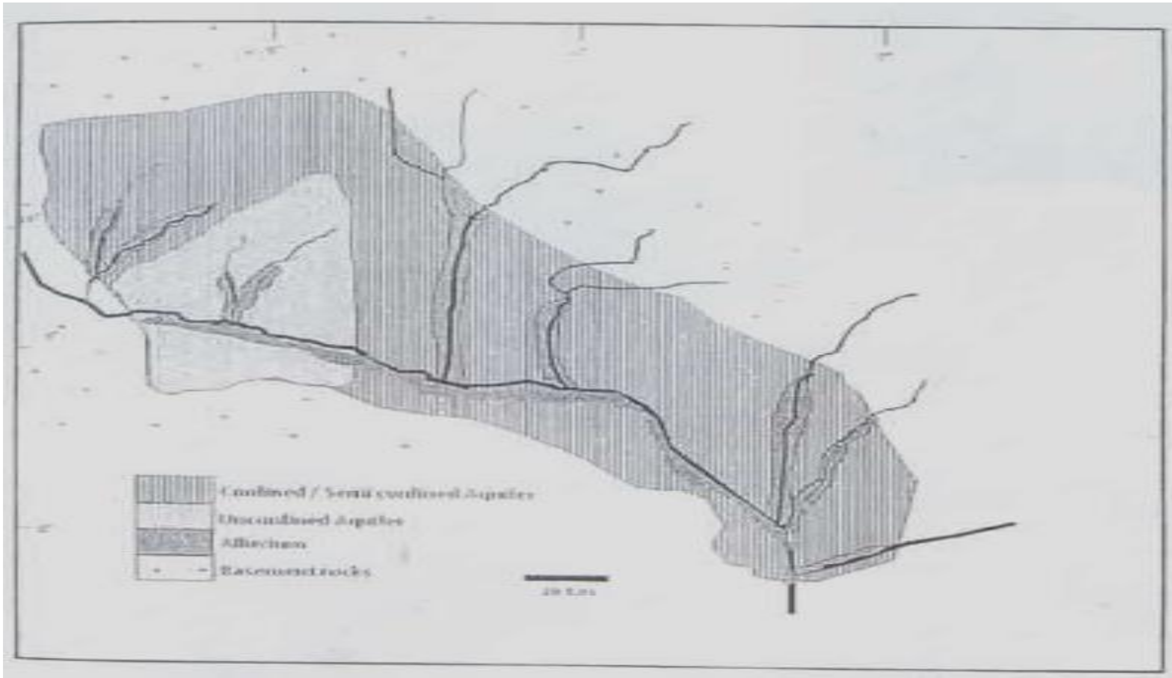


Figure 2.1: Aquifer types of Bida basin (shekwolo, 1990)

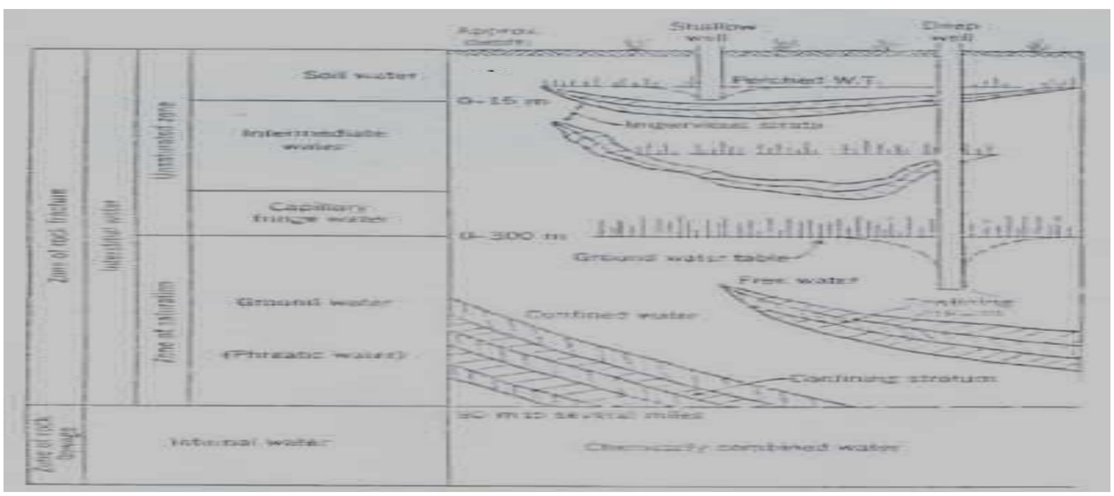


Figure 2.2: Classification of the earth crust and occurance of subsurface water (kogbe, 1981)

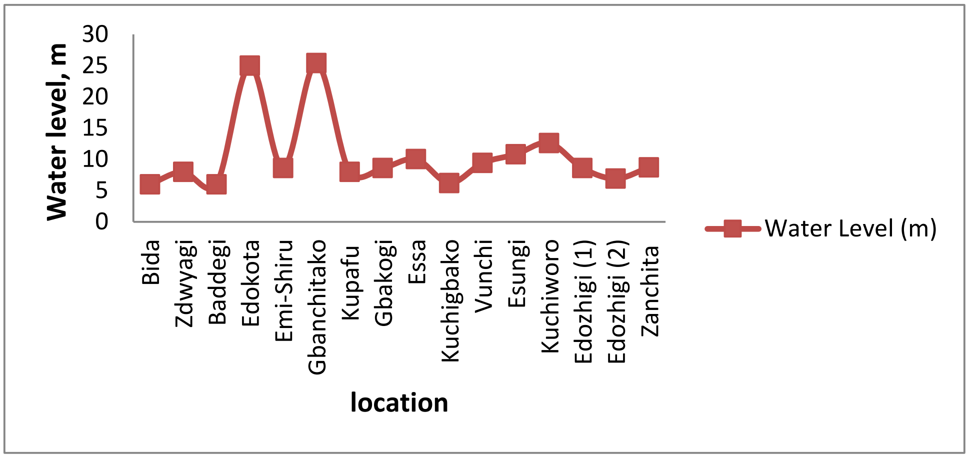


Figure 4.2 Groundwater level measurements

During the field study a survey carried out revealed that the people living in the study area depends on hand-dug wells, streams and few available boreholes. More people depend on hand-dug well, because it is economical way of accessing potable water. The cost of well construction with cover and concrete casing is about ₦150,000.00 Economic factors made people prefer hand-dug wells as against boreholes which cost about ₦280.000.00 Hand-dug wells in the region are usually 0.8-1.7m in diameter and rarely more than 15m deep. The intake of each hand-dug well is designed to fit the nature of the aquifer. It is either porous concrete, standard concrete or dug well below the intake discharge level incase of unlined. All the dug wells measured and studied are not covered.