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GEOLOGY AND HYDROGEOLOGY OF GROUNDWATER SYSTEMS OF YOLA AREA, NORTHEAST, NIGERIA

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ABSTRACT

The study Area which is underlain by the Bima Sandstone Formation occupies an area of about 431Km^2 in northeastern Nigeria. Groundwater in the area occurs in two aquifer systems namely the upper alluvial aquifer and the lower-semi-confined to confined aquifer systems. The upper alluvial aquifer system occur at a depth range of 20m to 80m with an average thickness of about 39m and have undergone lower diagenetic alteration, and thus behave like recent or quaternary sands. The mean hydraulic conductivity is 2.54m/d with a corresponding mean transmissivity value of 237m^2/d determined from both the pumping test method and the Statistical Grain-size method with an average yield of about 9.63m^3/hr which indicate poor to moderate aquifer. The lower semi-confined to confined aquifer system occur at a depth range 80m to 250m with an average thickness of about 14.52m and have undergone inherent compaction/cementation(diagenetic effect), probably arising from the longer burial history. These gave a mean hydraulic conductivity value of 3.81m/d and a mean transmissivity value of 103.51m^2/d with an average yield of about 47.25m^3/hr and thus a moderate to good aquifer. The average linear groundwater velocity estimated from Darcy's Law range from 27.48m/yr to 79.33/yr for the upper unconfined aquifer system and from 48m/yr to 149m/yr for the lower semi-confined aquifer system respectively. Linear-regression analysis of the transmissivity and specific capacity indicate a good correlation between log transmissivity and log specific capacity for the underlying aquifers. Finally with a total groundwater reserve of about 5,826,904,500m^3 estimated for the study area as well as the relatively high recovery rate of the boreholes indicates very high groundwater potentials of the underlying aquifers.
The above information will also give insight into the hydrogeology and assist in the overall groundwater resources management of the area.
Keywords: Groundwater, aquifer systems, transmissivity, Yola, Nigeria

INTRODUCTION

The evaluation of groundwater resources for development requires an understanding of the geologic and hydrogeologic properties of the aquifers. In Yola area, the aquifers of the Bima Sandstones Formation are of particular importance because they are in most cases the only alternative source for water supply that is readily available for the growing urban and rural population. The high variability of well yields in the aquifers in the area show the need for greater understanding of the geologic and hydrogeologic processes involved. Increased understanding of these processes affecting groundwater flow system in the area would give an insight into the hydrogeology of the area. This paper is aimed at understanding the local relations among geology and the groundwater flow system and also at helping to define the hydraulic characteristics and distribution of the aquifers in the area for effective management and future development. The data on which this paper is based were collected as part of groundwater developments between 1981 and 2007 and are described elsewhere (Obiefuna in preparation), but are incorporated here to support the interpretation. Location map of the study area is shown in Figure 1

Geology of the Study Area

The study area is underlain by Bima Sandstone which marks the base of the sedimentary succession in the Upper Benue Trough. It varies in thickness from 100m to 300m and has a maximum thickness at the Lamurde anticline where it exceeds 3000m. The differing degree of sediment accumulation in the trough and the irregular relief of the underlying crystalline basement on which the sediments accumulated are probably responsible for the variation in thickness. The Bima Sandstone rocks in the Upper Benue Basin have been sub-divided from base to top into three sandstone members. These include the lower Aptian/Albian Bima, the Middle Albian Bima Sandstone and the late Albian/Cenomanian Upper Bima Sandstone (Carter et al., 1963).

The study area is underlain by the upper member of the Bima Sandstone (B3) which is a Cretaceous sedimentary unit of the Yola Arm of the Upper Benue Trough. The Upper Bima Sandstone (B3) was marked by the deposition, during the Cenomanian? of fluvio-deltaic sandstones and arkoses which commenced in the south and extended progressively northwards. Several episodes of transgression and regression (often linked with sedimentary disturbances) are registered in the Bima Sandstone. The surface geologic units of the study area are the fine-medium grained sandstone to the north and south and the coarse grained sandstone to the northeast (Figure 2).

The depth to the bedrock varies from 30 meters to more than 45meters. Stratigraphically, the Bima Sandstone consist of alternating layers of poorly to moderately consolidated fine to coarse grained sandstone, clay-shales; siltstone and mudstone with an average thickness of more than 250 meters as seen from their outcrops in the field. This geologic Formation which reaches several hundred meters in thickness is of significant hydrogeologic interest. From field observations, exposures of Bima Sandstone in the study area is light brown to reddish brown in colour, feldspathic and fine to coarse grained in texture. It is highly crystalline and cemented in places especially north of Jimeta and Yola as well as Girei areas.

The grain-sizes range from 0.43mm to 2.20mm indicating a fine to coarse grained sandstone that is poorly to moderately sorted. The mineralogical composition of the Bima Sandstone consist essentially of 50-60% quartz, 26-28% plagioclase feldspar, 4% microcline feldspar 8% clay matrix 8% iron oxide and 3% calcite and are thus classified as arkosic sandstone.

In thin section, the quartz is sub-angular to sub-rounded and rimed by reddish brown colouration indicating iron-oxide. The feldspars are largely plagioclase and microcline parts of which have been altered to clay matrix. It is thus both texturally and mineralogically immature and hence competent. The predominance of quartz grains could be due to diagenetic effect of compaction and pressure solution at greater depths. Hence the quartz grains responded by shifting into more dense packing arrangements during the middle to later stages of diagenesis leading to reduction in porosity of the sandstone. The sandstone is thus highly indurated and has reduced porosity probably due to increased siliceous cementation especially adjacent to lineaments. The Bima Sandstone has abundant soft-sediment deformation structures that include cusps, droplets, convolute bedding, deformed cross-bedding and sand volcanoes (Abubakar et al., 2006).

The structures in most outcrops are sandwiched between undeformed cross-bedded strata that have no major textural differences with the sediments hosting them. The cusps are both simple internal cusps and interpenetrative cusps and are formed by post-depositional fluidization triggered by seismic shocks, where the interpenetrative cusps serve as conduits through which sands rose to the surface to form volcanoes(Abubakar et al.,2006) The droplets are the discrete type associated mostly with complex deformed cross-bedding while the convolute bedding forms concentric antiforms and synforms without any evidence of faulting and gradually wore out vertically upward. The deformed cross-bedding is represented by both simple and complex recumbent folds of flood and seismically induced origin respectively. The source of the seimic shocks may be episodic syndepositional mesozoic volcanism of Jurasssic to Albian times within the Upper Benue Trough (Abubakar et al., 2006). Overlying the Bima Sandstone in the study area is the river course alluvium which is composed of sands, silts, shales and clays and is confined mainly along the course of the River Benue and its tributaries. Field studies have shown that there is hydraulic connection between the river course alluvium and the underlying Bima Sandstone Formation as indicated by the similar depth to static water level.

Hydrogeology of the Study Area

The hydrogeology of the study area is described in reports by Obiefuna et al (1999) Bassey and Obiefuna (2005) and Obiefuna (in preparation). Results of a twenty-six year (1981-2007) hydrogeologic investigation (Obiefuna in preparation) indicate that two aquifer systems namely; an upper unconfined alluvial aquifer and the lower semi-confined to confined aquifer capable of yielding water in sufficient quantites for both rural and urban water supplies exist in the area.

The hydrogeology of the area is primarily controlled by secondary porosity in the form of fractures developed in sedimentary units in which the primary porosity has been destroyed through compaction (Obiefuna in preparation). Analysis of the available lithologic data from wells drilled in the area indicates that the two aquifer systems provide most of the well water. The accurate definition of the limits and types of aquifers in the area is not simple because of the heterogeneity of the Bima Sedimentary Sequence and the different criteria used in the lithological description of the well records. However, based on available borehole lithologic logs an unconfined to confined aquifer system exist in areas underlain by the recent quaternary river coarse alluvial stratigraphic unit which laterally changes to upper unconfined aquifer system in areas underlain by the Cretaceous sandstone. This is subsequently underlain by the lower semi-confined to confined aquifer system. Thus while the recent quaternary sediments constitute the shallow upper alluvial aquifer, the older Cretaceous sediments constitute the lower semi-confined aquifer system.

In the study area the alluvial deposits, composed of recent sediments such as sands, silts, shales and clays that reaches more than 80 meters in thickness are fully saturated. This aquifer is probably recharged by direct exfiltration of the River Benue. The fine to coarse grained sand units form the aquifers which are separated by aquitards and aquicludes of poorly permeable silts and clays. They occur at depths of 20-40m and 45-80m respectively and were penetrated at shallow depths ranging from 5m to more than 80m below the surface and are thus subjected to little diagenetic alteration than the underlying older Cretaceous sands. Diagonally along the southeast-northwest part, the alluvial aquifer decreases in thickness as it moves away from the River Benue interfingering with some saturated sand lenses in the blanketing clay-shales and siltstone of the Bima Sandstone Formation at a depth of more than 30m and within the deeper aquifers. The lateral extent of this aquifer system extend although the study area displaying semi-confining to confining conditions in places. It varies in thickness from 6m in Bagalchi, Damare and Gokra in the Northern part to 48m in Sanda Primary School in Yola Town in the South with an overall average thickness of about 14.52m.

A confining condition was observed in Gorka and Jambutu areas whereas an unconfined situation was observed towards Yola town in the Southern part of the study area. The blanketing clay-shales and siltstones is an aquiclude-aquitard system of local significance that acts as the natural relatively impermeable to semi-permeable barrier that limits the vertical infiltration of rainfall into the deeper aquifers within the study area. Field studies have shown that there is hydraulic connection between the upper unconfined (alluvial) aquifer and the underlying Bima Sandstone Formation. This aquifer at a depth of 18 to 39 meters in the distal southern part of the alluvial deposits is under unconfined condition. The depth to static water levels in wells tapping these aquifers is generally relatively low whereas well yields are relatively high. The depth to static water level ranging from 1m at Vinikilang to 56m in Girei to the North and from 3m at Jimeta to 51m at Sebore to the South has been observed with yields ranging from 2 to 15litres/sec (with drawdown ranging from 6m to 43m) in several hours of pumping from shallow boreholes tapping this aquifer. Borehole Lithological logs reveal that the depth to the base of this aquifer varies from 21m at Bagalchi and Gokra to 75m at Girei to the north and from 21m at Limawa and Rumde to 75m in Yola town to the South with an average depth of about 48m. The base is made up of clay-shales, sandy-clays and clayey- sands respectively.

The water table is usually high ranging from 1m at discharge areas to51m maximum at recharge areas. Recharge is also sustained mostly by seepage from the Benue River. The shallow water is thus susceptible to the vagaries of the relatively sensitive climatic regime in the study area. Downward leakage into the underlying lower semi-confined to confined aquifer system is promoted by heterogeneity within the Bima Sandstone Formation. It also contributes to the groundwater development and are largely exploited in rural areas by means of shallow wells for domestic, agricultural and livestock needs. The lower semi-confined to confined aquifer system is located within a complex sequence of clastic sediments of Albian age called the Bima Sandstone, the thickness and lithology of which show significant lateral variation. It is a multilayer aquifer system which extends over a surface area of 430km^2. The aquifer consist of medium to coarse grained sands and silts alternating with thick layers of clay-shales and sandy-clays and clayey-sands with hydraulic gradients varying from 0.0006 to0.0173 to the north and from 0.0064 to 0.0493 to the south. Its depth of occurrence reaches locally up to 80 to 200m while its penetrated thickness ranged between 9m and 129m with an average thickness of about 36m. The depth to static water levels in wells tapping these aquifers is generally relatively higher than in alluvial aquifer and ranges from 0.436m/hr to 54m/hr. They are confined above by clay-shales, sandy- clays and clayey-sands respectively (see Figures 3 and 4). About 68 wells are exploited from this aquifer in the region of interest. Most of the groundwater abstraction is from this aquifer. Pumping is mostly through privately owned boreholes used to supply hotels, Schools and industries which are largely concentrated within the city centre.

Groundwater Flow System

Figure 5 is a Potentiometric map of the study area that is based on data from domestic well logs (Tables 1 and 2). Well Locations and well-head elevation were determined in the field using the Global Positioning System (GPS) and existing topographic maps of the area. Well locations are accurate to within ±10m, and well-head elevations are accurate to within ±7.5m. Potentiometric heads used in the construction of the map were derived from drilling programs undertaken during 1981-2007.

Two groundwater flow systems are recognized in the study area and these are the shallow upper largely unconfined alluvial flow system and the deeper lower semi-confined to confined flow system of the Bima Sandstone Formation. The flow directions in the two flow systems are assumed to be in the same direction due to similar depth to static water levels. The upper unconfined groundwater flow system perhaps receives direct recharge from rainfall over its permeable soil cover and flow is from areas of higher elevation such as hills or undulating ridges (Bagale hills) to areas of lower elevation such as river or stream valleys (River Benue Valley). It is therefore mainly structurally controlled and occurs at a depth of less than 80meters and at average hydraulic gradients of 0.008 and 0.0231 to the northeast and southwest respectively. Figure 5 indicates that to the northeast a localized recharge area of the aquifer occurred to the west whereas to the southwest it is northeastwards towards the River Benue. It discharges naturally at points or areas where the aquifer with its underlying relatively impermeable alluvial units such as clay-Shales and mudstone intercepts the ground surface in river or stream valleys. Two groundwater mounds occur within the study area. A snake-like shaped groundwater mound exist to the northeast around Girei where groundwater flows radially away from it discharging naturally into the Benue River and as seasonal streams and rivers to the south. Another one occurred to the south around Yola town and Karewa area and again flowing radially from the mound discharges naturally into the Benue River as well as into some seasonal streams and rivers to the north.

The regional groundwater flow system in the area occurs at a depth of about 80m below the ground surface. To the northeast of the study area the regional groundwater flow direction is to the southwest while to the southwest it is northeastwards. The recharge area of this flow system probably occurred to the northeast and to the southwest and discharges naturally towards the Benue River. The two groundwater flow systems thus converges and discharges as baseflow into the Benue River which flow diagonally along the southeastern-northwestern directions dividing the study area into two equal halves. Hence the relationship between the two flow systems depends largely on the relative depth to static water level in the two flow systems and the gauge height of the Benue River. The Benue River will thus be influent or effluent depending on the depth to static water level and the gauge height of the Benue River which is largely dependent on the vagaries of seasonal climatic variations. The water table in the bedrock is typically 0-6m below the ground surface in low-lying areas and 10-50m below the ground surface at hill slopes and the hills. The amplitude of the annual variation of the water table is about 3-5m. Thus depending on the local topography and the soil cover thickness, there is groundwater in the soil, with a water table that differs from that in the bedrock.

According to Meyboom(1966) and Brassington(1988), recharge and discharge areas can be delineated on the basis of topography; piezometric patterns, hydrogeochemical trends, the use of environmental isotopes and soil and land surface features.

The soil type in the study area is variable. Along the Benue River Valley which coincide with the local and regional discharge area they consist of alluvial deposits made up of fine sands, silts, clay-shales and mudrock. To the northeast and southwest which probably constitute the recharge area the soil type ranges from deep porous brown soils to weathered red earth and coarse acid sands. They are thus relatively porous and permeable which encourages infiltration.

The depth to static water level in areas close to discharge areas are less than 10m whereas towards the recharge area it may be up to 50m. The Benue River Valley conforms to a topographic low where groundwater flow is directed downward away from the water table and displays depressed groundwater troughs. The water level fluctuations are thus comparatively small with groundwater head increasing with depth. The groundwater quality is hence expected to be comparatively older and more mineralized and thus relatively more saline (with larger TDS values).

However, the above characteristics of discharge area changes as we move towards the recharge area to the northeast and to the southwest across the Benue River. The recharge area in the study area is nevertheless characterized by generally influent or losing stream, relatively deep water and generally coarse textured residual soils as observed earlier.

Aquifer parameters

Reliable values of the hydraulic parameters of aquifers in the study area are largely encouraging. Available data are based on short-duration and long-duration aquifer tests conducted by the Adamawa State Water Board, Yola and the Upper Benue River Basin Develpoment Authority Yola between 1981 to 2007 on 27 boreholes for community water supplies. Successful wells range from 21-240 meters in depth and are completed with PolyVinyl-chloride (PVC) pipes that are screened across production zones. A successful well is defined as a well with an estimated yield of at least 10l/min (Acheampong and Hess, 1998); well were initially developed by air-lifting and later stressed with submissible pumps at constant to variable pump rates for at least 2 to 72 hours. Drawdown and discharge data were recorded; data from the aquifer tests were collected from the pumped wells without any water-level measurements from observation wells. In general, some data are imprecise and the test length is too short to obtain reliable aquifer parameters on a regional scale. The aquifer data obtained from the above agencies were plotted on semi-log scale and were analyzed using the classical pumping test methods such as Theis (1935), Logans (1964) and Cooper and Jacob (1946) methods. These methods were originally derived for isotopic porous media; however, Todd (1995) observes that rock aquifers with secondary permeabilities exhibit homogeneous characteristics when sufficiently large volume of water is considered. A two hour aquifer test probably does not fit this restriction on a regional scale but a seventy-two hours aquifer test will. Thus pumping test data were analyzed with these methods to estimate the characteristics of fractured aquifers on both local to regional scale.

However, some of the data sets were affected by borehole storage, partial penetration, extreme anisotropy, and the possible presence of no flow boundaries and unaccounted for fluctuations in barometric pressures. These effects were not measured in the analysis. The latter portions of the drawdown data of most of the wells appeared to satisfy the requirements of classical Theis (1935) methods and these segments were used for the analysis.

The results of the study indicate that the available groundwater recharge is about 149.988 million cubic meters per annum out of which 63.072 million cubic meters is the estimated present net annual draft leaving a huge balance of about 86.916 million cubic meters still available.

Figures 6,7 and 8 are simple semi-log plot of time-drawdown data for wells where the aquifer appears to satisfy classical assumptions, as represented by both the drawdown and recovery plots. Specific-Capacity values were calculated for the wells as the ratio of discharge to drawdown after 2 to 72 hours of pumping. A list of wells with calculated transmissivities, hydraulic conductivities and specific capacities is shown in Tables 4 and 5. The subsurface geology at some well site is given in figures 9. Thus, results from wells that penetrate a particular geologic unit can be compared directly. The hydraulic conductivity, K, values for the upper alluvial (largely unconfined) aquifer was determined employing both the pumping test and the granulometric methods (Tables 3 and 4).

Hazen (1893) method indicates K values ranging from 9.03×10^{-3} m/s to 3.36×10^{-1} with a mean value of about 7.53×10^{-2} m/s.

Harleman et al (1963) method gave K values that range between 1.60×10^{-3} m/s to 2.16×10^{-1}m/s with a mean value of about 4.83×10^{-2} m/s

Masch and Denny (1966) gave K values that vary from 3.77×10^{-5} m/s to 2.83×10^{-4} with a mean value of about 1.20×10^{-4} m/s.

Uma et al., (1989) indicate K values that range from 9.50×10^{-5} m/s to 1.28×10^{-2} m/s with a mean value of about 2.86×10^{-3} m/s. Finally Uma and Leohnert(1994) gave K values ranging from 6.8×10^{-7} m/s to 1.13×10^{-5} with a mean value of about 3.46×10^{-6} m/s. It was observed that only Masch and Denny (1966) and Uma et al (1989) methods gave the results that matched the aquifer samples of the study area when compared with other statistical grain-size methods and were therefore adopted. The values of hydraulic conductivity, K, obtained from the various pumping test methods for the upper unconfined aquifer are shown in Table 4. The values obtained from the Cooper-Jacob (1946) vary from 0.021m/day to 152.17m/day whereas those obtained from the Theis (1935) Recovery method varies from 0.052m/day to 19.28m/day.

The logan (1964) method gave K values that varies from 0.081m/day to 23.28m/day as against values of 0.072m/day to 3.50 m/day obtained from the Step-drawdown method. The K values generally fall within the range (10^{-2} m/day to 10^{2}m/day) which indicate moderate to good aquifers. The values obtained from the statistical grain-size (granulometric) methods are essentially uniform and compare favourably with values got from the pumping test methods. This is expected in view of the fact that upper alluvial aquifer occurs at a relatively shallow depth (less than 80m) and are composed of recent sediments. It has been observed by Uma and Leohnert (1994) that both methods generally give similar values in recent sediments that have not been subjected to significant diagenetic alteration.

A summary of the hydraulic conductivity, K, values obtained from both the pumping test and the statistical grain-size methods for the upper unconfined alluvial aquifer indicate values ranging from 0.051m/day to 56.98m/day with a mean value of 2.54m/day.

The hydraulic conductivity, K, values for the lower semi-confined aquifer was determined employing the pumping test methods. The values obtained from the Cooper-Jacob (1946) method varies from 0.59m/day to 27.98m/day whereas those obtained from the Theis(1935) Recovery Technique varies from 0.99m/day to 12.81m/day.

The Logans(1964) however gave values that vary from 1.11m/day to 15.47m/day with an average value of 8.29m/day. A summary of hydraulic conductivity values obtained for the lower semi-confined to confined aquifer employing the pumping test and the statistical grain-size methods indicate values ranging from 0.22m/day to 10.48m/day with a mean value of 3.81m/day.

Thus the K values obtained for this aquifer falls within the range of 10^{-2} m/day to 10^{2} m/day which indicate an aquifer system of moderate to good performance (Todd,1995). The K values obtained from pumping test method for the lower semi-confined to confined aquifer which is composed of older and diagenetically altered sediments is much lower than those of statistical grain-size methods. This is perhaps due to increased compaction and cementation undergone by the sediments of this aquifer system (Uma and Leohnert, 1994).

Transmissivity T is defined as the ease with which a saturated aquifer transmits water through its entire thickness.

It is represented mathematically as;

$$T = Kb \ (m^2/s)$$

Where

K =hydraulic conductivity

b = saturated thickness of the confined aquifer or the height of the water table above the top of the underlying aquitard that bounds the aquifer from the unconfined aquifer (Freeze and Cherry, 1979).

The saturated thickness of the upper unconfined alluvial aquifer was estimated from borehole lithological analyses and surface exposures of the aquifer whereas those of the lower semi-confined to confined aquifer was estimated from the screen length and borehole logs. The transmissivity values of the upper unconfined alluvial aquifer ranges from 1.52m^2/day to 349.86m^2/day with a mean value of 37.99m^2/day whereas those obtained from granulometric methods vary from 9.97×10^{-3} m2/s to 1.52 m^2/s (Table 3).

The transmissivity values for the lower semi-confined to confined aquifer varies from 9.18m^2/day to 349.93m^2/day with a mean value of about 103.51m^2/day. The variation in transmissivity values in the two aquifer systems are because of variation in the thickness of the aquifer rather than in hydraulic conductivity.

Furthermore the pumping test result indicates that the phreatic aquifer has an average hydraulic conductivity of 2.54m/day, a transmissivity value of 37.99m^2/day and a specific yield of 27%. The recharge area on either side of the study area is about 337.5km^2 and the expected average net abstraction rate is 172800m^3/day by the year 2020. This would yield an average rate of 0.000512m/day. The average coefficient of storage values of 0.13 for upper unconfined aquifer and1.64 for the lower Semi-confined to confined aquifer(Table 4) indicate that confining condition exists in the two aquifer systems.

Relation between transmissivity and specific capacity

The specific capacity which is a measure of the productivity and efficiency of a pumping well is defined as discharge per unit drawdown and is related by the following relation,

Sc = Q/S

Sc =Specific Capacity (m^3/hr/m)

Q =Discharge (m^3/hr)

S =Drawdown (m)

Driscoll (1986) presents empirical equations that were used to predict the specific capacity, Sc of pumping wells in the study area (Table 5). The equation were derived using Cooper and Jacob (1946) Approximation to the Theis solution

Q/s=T/Q183log2.25Tt/rwS

Where

Q = the Pumping rate.

S = the drawdown in the pumping well.

T = the aquifer transmissivity,

t = the time since pumping began.

rw= the radius of the pumping well

S = the aquifer storativity.

Specific capacity is commonly used to estimate transmissivity of aquifers because of the availability of specific capacity data from drillers logs and the relative expense of obtaining transmissivity through aquifer testing (Clifton 1981; Huntley et al 1992). The relationship between transmissivity and specific capacity was examined to determine the possibility of using specific capacities of wells in other parts of the study area to predict the transmissivity in those areas. Then relation between tranmissivity and specific capacity shown in figure 10 indicates a moderate correlation; the correlation coefficient r is 0.62 (r^2 =0.39).

Outliers, some with low transmissivity and high specific capacities and others with high transmissivties and specific capacities, have a very great influence on the position of the least square regression line. Thus because the distributions of transmissivity and Specific Capacity for the data-set are log-normal, a log-log transformation of the data was made to produce the normally regression theory. A linear regression analysis of log transmissivities and log specific capacities shown in figure 11 gives the following linear function relationship.

$$\text{Log } T = 0.993483 \log Sc + 1.389348$$

Where;

T = transmissivity in m^2/day
Sc = Specific capacity in m^3/hr/m

Log transmissivity and log specific capacity of the aquifers are well correlated; r is 0.90. The Coefficient of determination r^2 is 0.81 which implies that 81% of the variation in transmissivity is due to the specific capacity. Values of the regression coefficients are quite specific for the units of transmissivity and specific capacity used for the analysis. Considering the small sample size, the applicability of the relation determined between transmissivity and specific capacity to the rest of study area is unclear; it may be limited to the population considered. The scattered nature of the data (figure 12) and the relatively large error in log transmissivity (0.9), is probably due to the anisotropic nature of the fracture Bima Sandstone rocks which would modify the response of the wells to aquifer testing.

Well Yields, Transmissivity and Total Well Depth

Estimated well yields in the study area range from 0.72m^3/hr to about 54m^3/hr. Although the initial estimated yields are relatively high, in most cases they decline substantially after the wells have been pumped for a lengthy period of time, a couple of years in some cases, and even less than a year in other cases. When abstraction rates are small or moderate (1.44m^3/hr to 7.2m^3/hr), which is the case for most of the wells in the study area, lateral flow dominates over vertical flow.

Transmissivity thus becomes the most important aquifer parameter. The relation between well yield and transmissivity, shown in figure 13 indicates a poor correlation; r is 0.51 and r^2 is 0.26. The Coefficient of determination value, r^2 value 0f 0.26 implies that 26% variation in well yields is due to transmissivity. A comparison of well yields and depths of wells in the study area however, does not show any positive correlation since r is 0.54 and r^2 is 0.29 implies that 29% variation in total depth is due to well yields. The poor correlation between well yield and depth shown in Figure 14 suggests that water bearing structures in the area are discrete entities with variable production rates, even over depths of a few meters. The wells generally have low specific capacities and deepening them beyond these depths has little or no effect on their ultimate specific capacities and yields as observed in the relative deep wells (BH84,BH85 and BH86).

The discrete nature of the water bearing structures indicates that the likelihood of a regional scale shallow groundwater flow system is very low.

A comparison of well yields among wells is not appropriate because of the considerable overlap of the aquifers within the study area. The production units of most of the wells drilled in the study area are logged as either alluvium or cretaceous sandstone. The success rate of wells (wells with yields at least 1.44m^3/hr) penetrating alluvial aquifer in the study area is more than 90% whereas that of wells drilled through cretaceous sandstone is up to 80%. Wells drilled in the Upper alluvial aquifer especially along the banks of the Benue River generally have better yields than wells drilled or completed in the deeper cretaceous aquifer. Thus the alluvium is considered to be more prolific aquifer in the study area.

CONCLUSION

Existing data from shallow and deep drilled wells in Yola area were analyzed to gain insights into the hydrogeology of the area. Aquifer-test and grain-size data on more than 28 wells were used to determine hydraulic parameters of the underlying aquifers. Hydraulic conductivity ranges from 0.051m/day to 56.98m/day for the upper unconfined aquifer and from 0.22m/day to 10.48m/day for the lower semi-confined to confined aquifer. The transmissivity values ranges from 1.52m^2/day to 349.86m^2/day for the Upper unconfined aquifer and from 9.18m$^{2/}$day to 349.93m^2/day for the lower semi-confined aquifer.

A linear regression model was used to establish an empirical relationship between transmissivity and specific capacity of the aquifer. The application of linear regression analysis to the logs of transmissivity and specific capacity is more appropriate than the original transmissivity and specific capacity values.
The hydraulic parameters indicate aquifer systems of poor to good performance.

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TABLE 1: HYDRAULIC HEAD VALUES CALCULATED FOR THE HAND-DUG WELLS IN THE STUDY AREA (After Obiefuna in Preparation)

S/N	LOCATION	HAND-DUG WELL PROJECT NUMBER	COORDINATE IN DEGREE	ELEVATION ABOVE MEAN SEA LEVEL	SWL	HYDRAULIC HEAD (m)
1	LAINDE	HW1	N09°21'6.3" E012°30'8.22"	179m	24.2	154.8
2	DAMARA	HW2	N09°10'4.62" E012°26'41.82"	174.545m	9.09	165.46
3	NJOBBORE	HW3	N09°17'1.02" E012°29'22.92"	150.91m	1.21	149.7
4	MODIRE	HW4	N09°17'24. 6" E012°30'35.16"	192.72m	23.33	169.39
5	VINIKILANG	HW5	N09°17'24.6" E012°30'35.22"	191.82m	1.52	190.3
6	BAJABURE	HW6	N09°20'54.66" E012°29'3.54"	207.58m	2.12	205.37
7	WURO ALHAJI	HW7	N09°19'44.4" E012°28'37.62"	218.79m	7.88	210.91
8	KOFARE BAGALCHI (JAURO HAMIDU)	HW8	N09°20'54.66" E012°29'3.42"	205.15m	23.33	181.82
9	BAGALCHI	HW9	N09°21'25.38" E012°28'52.98"	203m	6.06m	196.94
10	SABON GARI	HW10	N09°20'24.28" E012°30'25.8"	237.88m	2.42m	235.46
11	SANGEREI	HW11	N09°20'56.84" E012°30'50.58"	233.94m	3.64	230.3
12	GIREI	HW12	N09°21'28.38" E012°32'20.7"	233.03m	7.27m	225.76
13	TASHA MAITARARE	HW13	N09°22'22.26" E012°33'11.04"	255.76m	27.27m	228.49
14	SABERE	HW14	N09°23'17.22" E012°33'17.52"	238.18m	36.36m	201.82
15	DIGINO	HW15	N09°23'17.82" E012°33'16.62"	238.18m	21.21m	216.97
16	NYIBANGO	HW16	N09°16'35.7" E012°30'37.26"	183.33	2.12m	181.21
17	DIDANGO	HW17	N09°15'47.52" E012°30'37.26"	172.73	2.12	170.61
18	TAKWANDE	HW18	N09°16'22.14" E012°29'53.22"	165.76m	3.94m	161.82
19	YOLDE PATE	HW19	N09°16'50.88" E012°27'3.24"	163.64m	4.3m	159.34
20	RUMDE	HW20	N09°10'36.3" E012°32'46.44"	190.3M	17.8M	172.5
21	MBAMBA R WAZIRI	HW21	N09°10'36.24" E012°32'46.26"	186.97m	7.6m	179.37
22	WUROCHEKKE	HW22	N09°12'32.22" E012°30'34.38"	167.27m	8m	159.27
23	YOLA TOWN	HW23	N09°12'35.58" E012°29'42.12"	167.27m	2.7m	164.57
24	JIMETA	HW24	N09°12'43.38" E012°28'53.34"	178.48m	1.40m	177.08
25	BACHURE	HW25	N09°14'46.86" E012°25'33.12"	192.12m	5.2m	186.92
26	KAREWA	HW26	N09°15'16.5" E012°26'36.42"	189.39m		
27	DEMSAWO	HW27	N09°16'50.46" E012°25'50.94"	167.88m	1m	166.88

S/N	LOCATION	HAND-DUG WELL PROJECT NUMBER	COORDINATE IN DEGREE	ELEVATION ABOVE MEAN SEA LEVEL	SWL	HYDRAULIC HEAD (m)
28	JEKPEDEDE	HW28	N09◦17'43.02" E012◦24'41.64"	166.97m	9.09m	157.88
29	HULERE	HW29	N09◦17'53.7" E012◦24'13.86"	175.45m	8.48m	166.97
30	DAMILU	HW30	N09◦16'14.76" E012◦25'17.64"	183.33m		
31	KOFARE BAGALCHI (JAURO HAMIDU)	HW31	N09◦16'43.5" E012◦24'41.58"	165.76m	6.36m	159.4
32	KOFARE BAGALCHI (JAURO HAMIDU)	HW32	N09◦16'5.64" E012◦24'19.32"	179.09m	6.06m	173.03
33	BAJABURE	HW33	N09◦19'1.86" E012◦28'34.56"	221.82m	9.09m	212.73
34	GIREI	HW34	N09◦22'22.38" E012◦33'10.68"	260m	8.48m	251.52
35	GIREI	HW35	N09◦21'23.28" E012◦32'10.68"	262.72m	3.64m	259.08
36	TAFARE BUHU	HW36	33P0220165 UTM1030847	173m	2.12m	170.88
37	LABONDO	HW37	N09◦22'50.94" E012◦23'57.0"	165.15m	10.9	154.25
38	KABAWA	HW38	N09◦21'12.48" E012◦25'14.82"	163.64m	6.7m	156.94
39	FASARE	HW39	N09◦19'41.1" E012◦26'40.2"	166.67m	7.1m	159.57
40	GOKRA	HW40	N09◦23'35.52" E012◦26'18.60"	175.76m	12.6m	163.16
41	BATARE	HW41	N09◦23'56.46" E012◦29'7.32"	193.94m	4.2m	189.74
42	SEBORE	HW42	33P0233679 UTM1009347	164.55	12	152.55
43	RUGANGE	HW43	33P0226421 UTM1021166	164.55	12	152.55
44	MANDARARE	HW44	33P0230594 UTM1019157	164.55	13	151.55
45	YOLDE PATE11	HW45	33P0210050 UTM1018823	179.09	7.88	171.21
46	KAREWA	HW46	N09◦15'24" E012◦26'57.18"	172	62	110
47	KAREWA	HW47	N09◦15'25.26" E012◦26'56.7"	203	58	145
48	JAMBUTU	HW48	N09◦17'24.42" E012◦25'38.16"	154	6.06	147.94

Table 2: Hydraulic head values calculated for the boreholes in the study area (After Obiefuna in Preparation)

S/N	LOCATION	BOREHOLE LOCAL NUMBER	BOREHOLE PROJECT NUMBER	COORDINATES	ELEVATION ABOVE SEA LEVEL(M)	DEPTH TO STATIC WATER LEVEL(M)	HYDRAULIC HEAD(M)
1	YOLDE PATE		BH133	N09^{0}12' E012^{0}26'	170.91m	10.64	160.27
2	MBAMBA		BH98	N09^{0}11'33.96" E012^{0}30'11.76"	187.9	12	175.90
3	MBAMBA CORNER		BH99	N09^{0}1'10.24" E012^{0}31'43.26"	182.4	9.8	172.60
4	WURO-DOLE		BH92	N09^{0}12'15.24" E012^{0}30'23.46"	173.3	8.12	165.18
5	BAKO PRIMARY SCHOOL YOLA TOWN		BH93	N09^{0}12'10.68" E012^{0}28'21.84"	176.7	18.27	158.43
6	RABEH		BH94	N09^{0}12' E012^{0}28'	175.5	12.35	163.15
7	ARMY BARRACKS ROAD JIMETA		BH75	N09^{0}1'44.62" E012^{0}26'30.6"	167.27	8.00	159.27
8	ARMY BARRACKS ROAD JIMETA		BH88	N09^{0}14' E012^{0}26'	170	9.60	160.4
9	KAREWA EXTENTION		BH48	N09^{0}15' E012^{0}26'	187.88	45	142.88
10	JIMETA		BH84	N09^{0}16' E012^{0}26'	175.8	4.04	171.76
11	DEMSAWO		BH87	N09^{0}17' E012^{0}25'	163.64m	5.07	158.57
12	STATE POLY JAMBUTU		BH36	N09^{0}17' E012^{0}25'	156.36	4.5	151.86
13	DAMILU		BH81	N09^{0}16' E012^{0}25'	177.58	6.10	171.58
14	MODIRE		BH120	N09^{0}17' E012^{0}30'	178.79m	25	153.79
15	NJOBBORE		BH124	N09^{0}17' E012^{0}29'	172.73	5.25	167.48
16	BAJABURE PHASE1		BH20	N09^{0}19' E012^{0}28'	228.48	10.25	218.23
17	KOFARE		BH136	N09^{0}15'57.5" E012^{0}27'13.14"	196.7	6.5	190.2
18	FUTY		BH10	N09^{0}20 ' E012^{0}30'	241.21m	25	216.21
19	SABERE		BH121	N09^{0}23' E012^{0}33'	234.55m	38	196.55
20	GIREI		BH7	N09^{0}21'54" E012^{0}33'10.4"	261.21m	51.28	209.93
21	GIREI		BH6	N09^{0}21' E012^{0}3245"	258.48	18.5	239.98
22	WURO ALHAJI		BH122	33P0220616 UTM1032699	199m	5.15m	193.85
23	BAJABURE PHASE11		BH21	33P0219118 UTM1025141	196m	6.42	189.58
24	LAINDE		BH123	33P0221223 UTM1030050	188m	25.50	162.50
25	DAMARE		BH24	33P0210200 UTM1030724	173m	9.4	163.6
26	DABARE		BH125	33P0210005 UTM1030860	178m	8.60	169.40
27	BADARISA		BH18	33P0221014 UTM1029845	207m	28	179
28	LABONDO		BH126	N09^{0}22'5" E012^{0}2'45.52"	170.91m	12	158.91
29	KABAWA		BH127	N09^{0}21'11.34" E012^{0}25'16.14"	169.7m	7.10	162.60

S/N	LOCATION	BOREHOLE LOCAL NUMBER	BOREHOLE PROJECT NUMBER	COORDINATES	ELEVATION ABOVE SEA LEVEL(M)	DEPTH TO STATIC WATER LEVEL(M)	HYDRAULIC HEAD(M)
30	DEGRIBATA		BH128	N09^{0}20'44.28" E012^{0}25'44.76"	168.79	8.75	160.04
31	GORKA		BH25	N09^{0}23'35.64" E012^{0}26'18.18"	176.36m	13.36	163
32	BATARE		BH129	N09^{0}23'56.46" E012^{0}29'7.32"	195.45m	16.40	179.04
33	RUMNDE ALKALI		BH134	33P0231173 UTM1016312	186.67m	6.87	179.80
34	SEBORE		BH100	33P0233729 UTM1009394	215.76	45.76	170
35	RUGANGE		BH135	33P0226769 UTM1021045	169.09	15.60	153.49
36	NJOBOLI KAREWA GADA	ADA/TH10/987/98	BH117	33P0234938 UTM1018369	197.88m	32.50	165.38
37	WURO-HAUSA YOLA TOWN		BH110	33P0226106 UTM1018942	167.88	15.30	152.58
38	TOUNGO-A YOLA TOWN		BH106	33P0220000 UTM1018886	187.27	13.00	174.27
39	GERIYO		BH57	33P0210747 UTM1029146	137.27	6.27	131
40	ABATTOIR ALONG YOLA ROAD		BH134	33P0220105 UTM1020937	138.18	8.20	129.98
41	YOLDE PATE 11		BH137	33P0210417 UTM1018917	176.06	8.96	167.10
42	(RUMDE WARD) CHINKO JIMETA		BH60	N09^{0}17'1.86" E012^{0}27'46.32"	162.42	7.52	154.90
43	DOUGIREI		BH66	33P0222380 UTM1023387	200.3	20.30	180
44	WATER TREATMENT PLANT ALONG RIVER BENUE JIMETA		BH130	33P0221809 UTM1026712	172.73	9.31	163.42
45	MAKURDI STREET, JIMETA ALHERI JIMETA		BH131	33P0219953 UTM1026474	171.82	7.65	164.17
46	JAMBUTU		BH37	N09^{0}17'20.04" E012^{0}25'35.46"	168	5.10	162.9
47	BAGALCHI		BH17	N09^{0}20'0.3" E012^{0}29'23.4'	221	8.20	212.8
48	KAREWA GRA		BH51	N09^{0}15'24.72" E012^{0}26'57.36"	203	15.00	188

Table 3: Hydraulic properties of some samples of the bima sandstone (upper unconfined alluvial aquifer) from the study area determined from granulometric methods (after obiefuna in preparation)

Location	Hydraulic conductivity values (m/s)						Transmissivity values (m^2/S)					
	Hazen (1893)	Harlemanet al (1963)	Masch and Denny (1966)	Uma et al (1989)	Uma and Leohnert (1992)	Average	Hazen (1893)	Harleman et al (1963)	Masch and Denny (1966)	Uma et al (1989)	Uma and Leohnert (1994)	Average
HW9 Bagalchi thickness= 6m	2.25×10^{-2}	1.46×10^{-1}	2.13×10^{-4}	9.55×10^{-5}	1.33×10^{-5}	3.38×10^{-2}	13.5×10^{-2}	8.76×10^{-1}	12.78×10^{-4}	5.73×10^{-4}	7.95×10^{-5}	2.03×10^{-1}
HW1 Lainde thickness= 15m	3.55×10^{-2}	2.42×10^{-3}	1.80×10^{-5}	1.46×10^{-5}	3.04×10^{-7}	7.98×10^{-3}	5.63×10^{-1}	3.63×10^{-2}	2.70×10^{-4}	2.19×10^{-4}	4.56×10^{-6}	1.20×10^{-1}
HW7 Wuro Alhaji thickness= 7.9m	4.0×10^{-3}	2.56×10^{-3}	1.78×10^{-1}	3.42×10^{-2}	1.14×10^{-5}	4.38×10^{-2}	3.16×10^{-2}	2.02×10^{-2}	1.41	2.70×10^{-1}	9.01×10^{-4}	3.47×10^{-1}
HW 19 Yolde pate thickness= 4.3m	4.9×10^{-3}	2.25×10^{-3}	2.46×10^{-5}	1.36×10^{-2}	3.13×10^{-5}	4.14×10^{-3}	2.11×10^{-2}	9.68×10^{-3}	1.06×10^{-4}	5.85×10^{-2}	1.35×10^{-4}	1.79×10^{-2}
HW34 Girei thickness= 9m	3.36×10^{-1}	2.16×10^{-1}	2.83×10^{-1}	1.28×10^{-2}	1.13×10^{-5}	1.70×10^{-1}	3.20	1.94	2.55	1.15×10^{-1}	1.12×10^{-4}	1.53
HW 40 Gokra thickness= 12.6m	2.03×10^{-3}	3.30×10^{-3}	2.56×10^{-5}	1.96×10^{-5}	6.05×10^{-7}	1.08×10^{-3}	2.56×10^{-2}	3.96×10^{-2}	3.23×10^{-4}	2.47×10^{-4}	7.62×10^{-6}	1.32×10^{-2}
HW 33 Bajabure thickness= 9.1m	3.52×10^{-3}	1.30×10^{-1}	2.69×10^{-2}	8.65×10^{-2}	2.45×10^{-5}	4.94×10^{-2}	3.18×10^{-2}	1.18	2.45×10^{-1}	7.87×10^{-1}	2.23×10^{-4}	4.49×10^{-1}
HW 24 Jimeta thickness= 1.4m	8.64×10^{-3}	2.60×10^{-3}	1.96×10^{-5}	1.82×10^{-5}	1.40×10^{-7}	2.26×10^{-3}	12.10×10^{-3}	3.63×10^{-3}	2.74×10^{-5}	2.55×10^{-5}	1.96×10^{-7}	2.49×10^{-2}
HW27 Demsawo thickness= 5m	6.72×10^{-3}	3.18×10^{-3}	5.08×10^{-5}	2.05×10^{-5}	4.21×10^{-7}	1.99×10^{-3}	3.36×10^{-2}	1.59×10^{-2}	2.54×10^{-4}	10.25×10^{-5}	2.11×10^{-6}	9.97×10^{-3}
HW48 Jambutu thickness= 6.1m	9.03×10^{-3}	1.60×10^{-3}	3.77×10^{-5}	9.50×10^{-5}	6.80×10^{-7}	2.15×10^{-3}	5.51×10^{-2}	9.76×10^{-3}	2.30×10^{-4}	5.80×10^{-4}	4.15×10^{-6}	1.31×10^{-2}

TABLE 4: ESTIMATED HYDRAULIC CONDUCTIVITY, K AND SPECIFIC STORAGE Ss VALUES IN MULTI-AQUIFER TEST(After Obiefuna in Preparation)

S/N	BOREHOLE PROJECT NUMBER	LAYER(AQUIFER)	THICKNESS (m)	HYDRAULIC CONDUCTIVITY K(m/d)	SPECIFIC STORAGE(Ss1/m)	TOTAL DEPTH (m)
1	BH13	UNCONFINED (UPPER)	SL =15	0.67	0.1417535181	55
2	BH24	UNCONFINED (UPPER)	6	2.35	0.324441427	41
3	BH37	UPPER UNCONFINED	12	0.27	0.018379445	47
4	BH40	UPPER UNCONFINED	12	0.62	0.14646106	37.5
5	BH79	UPPER UNCONFINED	15	3.13	0.54830150	55
6	BH81	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	24 112	6.05 1.3	0.045732025	240
7	BH82	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	12 18.06	13.16 8.75	0.4807757086	148
8	BH83	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	9.3 24.3	9.17 3.51	0.4065118244 2.061098340	140
9	BH84	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	12.3 15.56	8.53 6.75	2.075301130	148
10	BH85	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	21.64 27.76	4.28 3.33	2.448773013	164
11	BH86	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	6.12 12.24	1.5 0.75	0.004059515917	165
12	BH87	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	15.48 27.72	7.05 3.94	2.792598592	140
13	BH88	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	6.14 33.39	56.98 10.48	0.00972855	187
14	BH89	UPPER UNCONFINED	41	0.096	0.00972855	48
15	BH91	UPPER UNCONFINED	10.2	1.047	0.00972855	75
16	BH92	UPPER UNCONFINED	15	0.34	0.00972855	56
17	BH93	UPPER UNCONFINED	15	0.17	0.00972855	55
18	BH94	UPPER UNCONFINED	15	0.1	0.00972855	57
19	BH95	UPPER UNCONFINED	15	0.6	0.00972855	57
S/N	BOREHOLE PROJECT NUMBER	LAYER(AQUIFER)	THICKNESS (m)	HYDRAULIC CONDUCTIVITY K(m/d)	SPECIFIC STORAGE(Ss1/m)	TOTAL DEPTH (m)
20	BH104	UPPER UNCONFINED	33	0.051	0.00972855	45
21	BH105	UPPER UNCONFINED	27	0.152	0.00972855	36
22	BH106	UPPER UNCONFINED	6	0.27	0.00972855	39

23	BH107	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	15	0.29	0.00972855	56
24	BH118	UPPER UNCONFINED LOWER SEMI CONF-CONFINED	34 82.7	0.47 0.22	0.00972855	245
25	BH119	UNCONFINED (UPPER)	15	0.56	0.00972855	56
26	CHIKITO FUFORE	UPPER UNCONFINED	15	3.49	0.00972855	

TABLE 5 : HYDRAULIC PROPERTIES OF BOREHOLES IN THE STUDY AREA(After Obiefuna in Preparation)

S/N	**LOCATION**	**BOREHOLE PROJECT NUMBER**	**TRANSMISSIVITY m^2/day**	**SPECIFIC CAPACITY m^3/hr/m**	**DISCHARGE m^3/hr**	**TOTAL DEPH (m)**
1	SANGERE FUTY	BH13	23.258	0.59	10.8	55
2	DAMARE	BH24	14.07	0.92	3.6	41
3	JAMBUTU	BH37	3.19	0.196	3.6	47
4	DAMILU	BH40	7.43	0.449	7.2	37.5
5	BA'ATTA	BH79	46.88	2.746	79.2	55
6	DAMILU	BH81	441.678	5.947	54	240
7	JIMETA	BH82	157.96	8.96	54	148
8	BRISCOE COMPANY JIMETA	BH83	85.27	3.469	46.8	140
9	JIMETA	BH84	104.95	4.83	50.4	148
10	NASSARAWO	BH85	92.46	3.89	54	164
11	DOUBELLI	BH86	9.16	0.436	18	165
12	DEMSAWO	BH87	109.03	4.106	54	140
13	ARMY BARRACKS ROAD	BH88	349.84	2.123	46.8	48
14	ALKALAWA	BH89	3.91	0.221	1.8	48
15	DISTANCE LEARNING YOLA	BH91	10.68	0.12	5.148	75
16	WURO-DOLE YOLA	BH92	5.079	0.34	10.8	56
17	BAKO PRIMARY SCHOOL YOLA	BH93	2.608	0.15	3.6	55
18	RABE YOLA	BH94	1.515	0.096	3.6	57
19	MBAMBA	BH95	9.036	0.18	3.6	57
20	MAKAMA-A YOLA	BH104	1.689	0.0857	1.44	45
21	MAKAMA-B YOLA	BH105	4.1075	0.176	3.24	36
22	TOUNGO WARD YOLA	BH106	1.6213	0.09	1.8	39
23	BAKO BYE PASS YOLA	BH107	4.355	0.259	7.2	56
24	NJOBOLI/NJOBOLIYO	BH118	18.3	1.096	15.84	245
25	JABI-LAMBA GIREI	BH119	8.423	0.56	10.8	56
26	CHIKITO FUFORE		52.39	0.26	7.2	

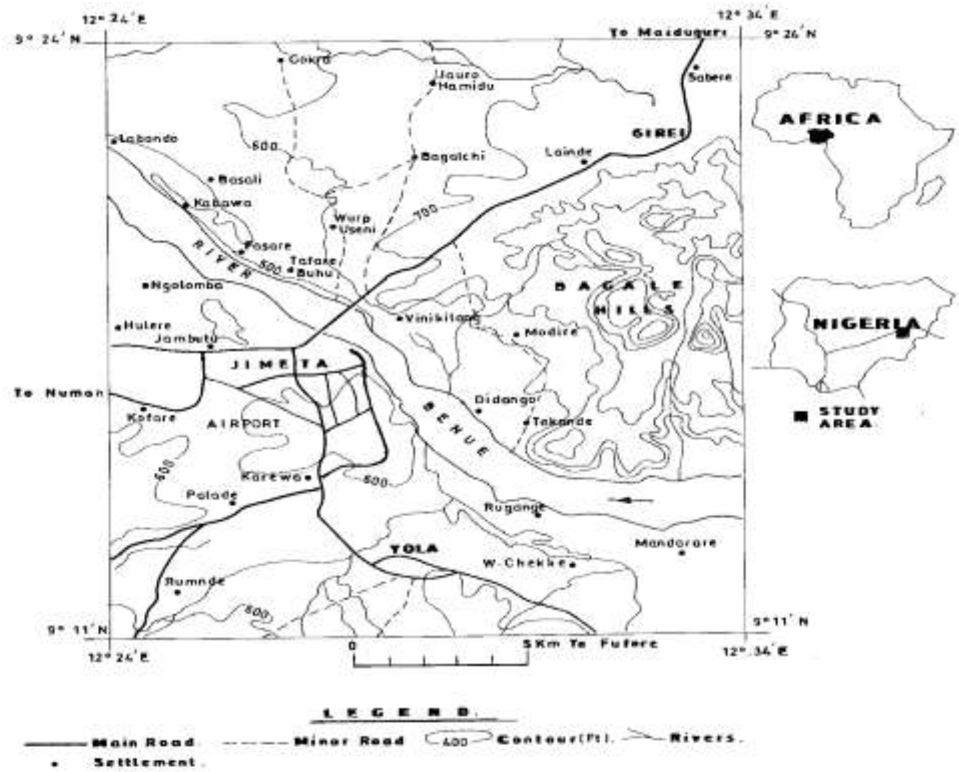

Fig. 1: Map of the study area showing access routes.

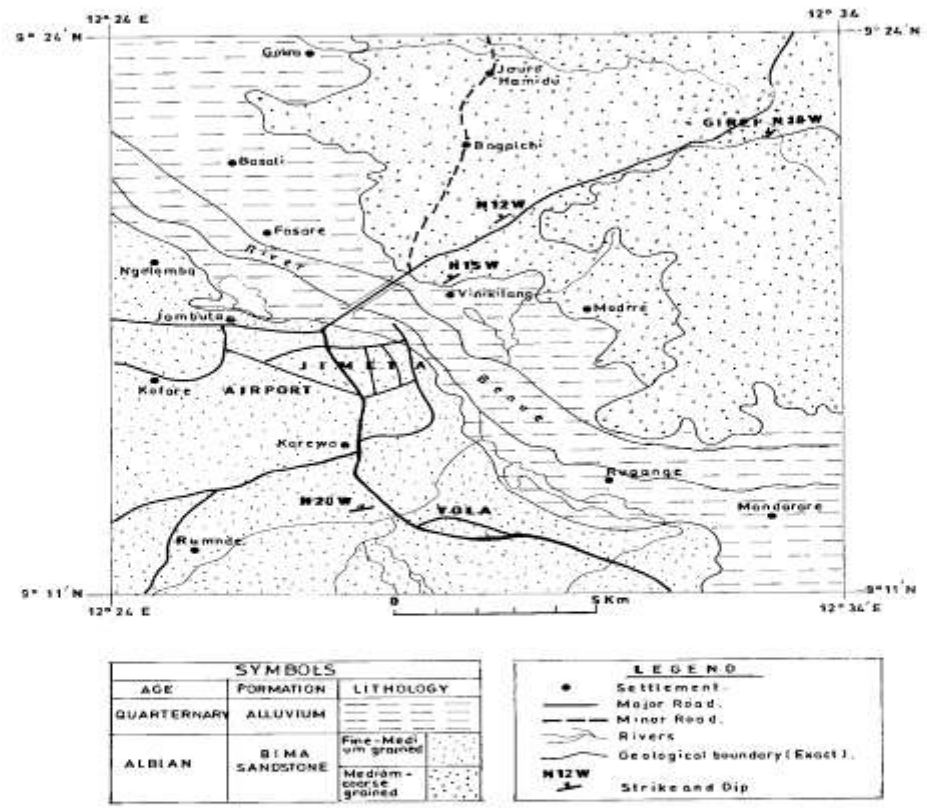

Fig. 2: Geological map of the study area.

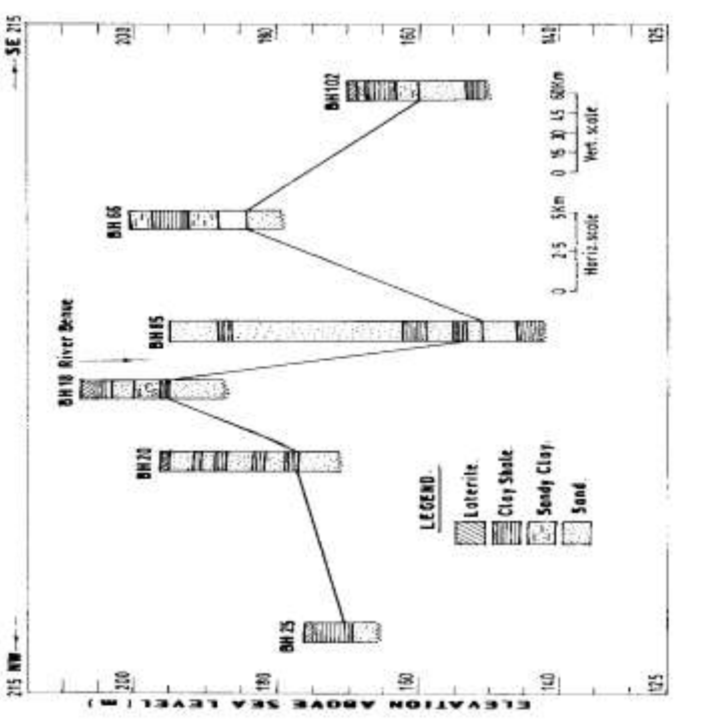

Fig.3 Correlation of some boreholes logs showing the nature of the aquifer systems in the study area.

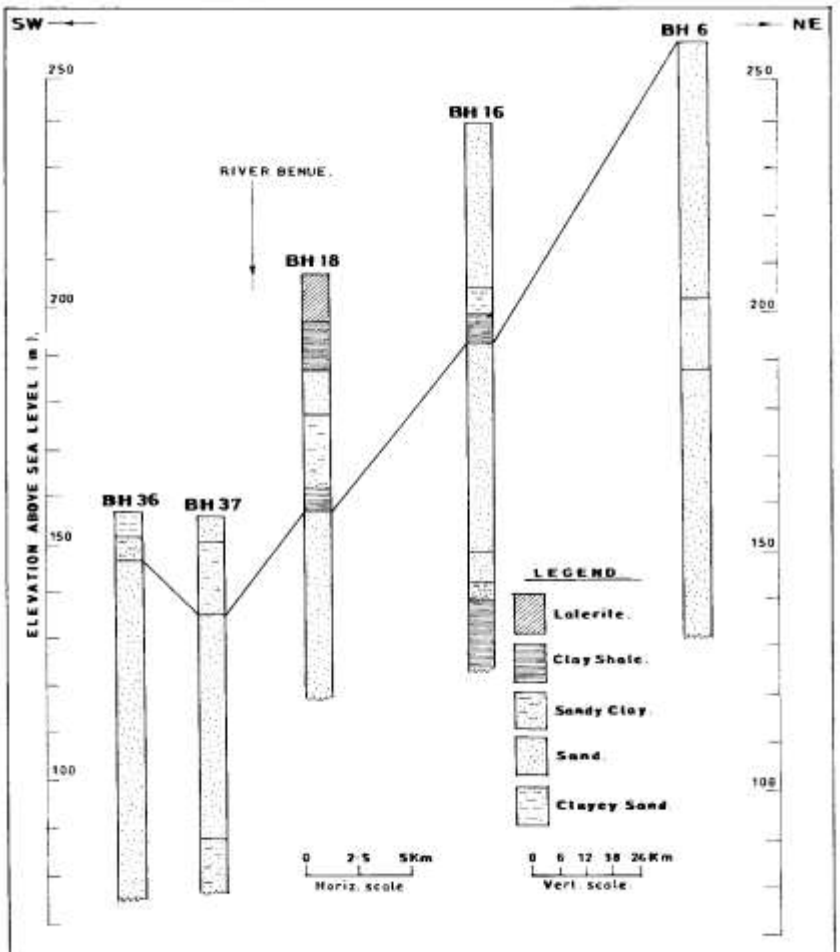

Fig. 4: Correlation of some borehole logs showing the nature of the aquifer system in the study area.

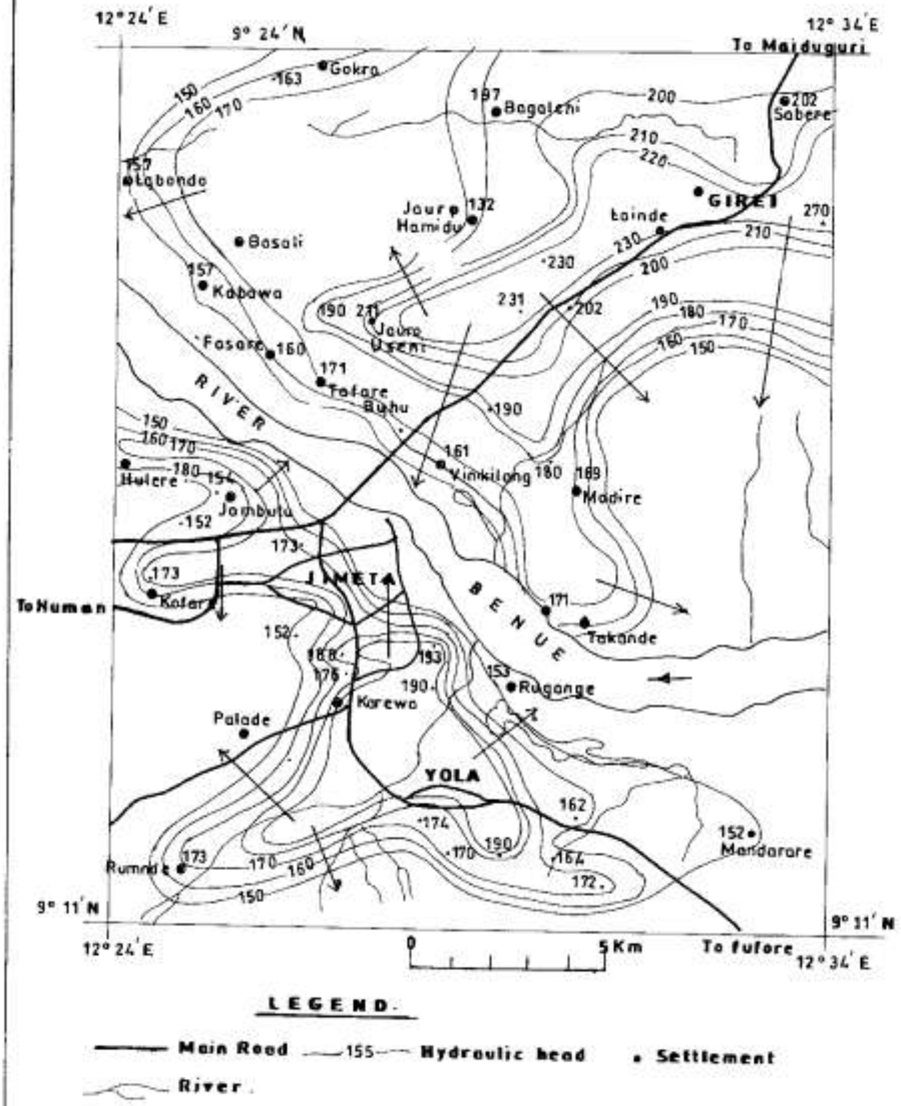

Fig: 5: Hydraulic head distribuition and groundwater flow direction in the upper unconfined (Alluvial) aquifer systems.

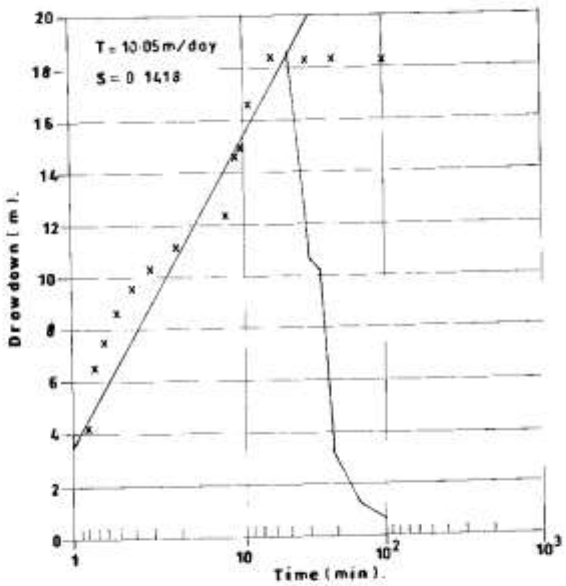

Fig. 6: Relation between time and drawdown for aquifer test of well BH 13.

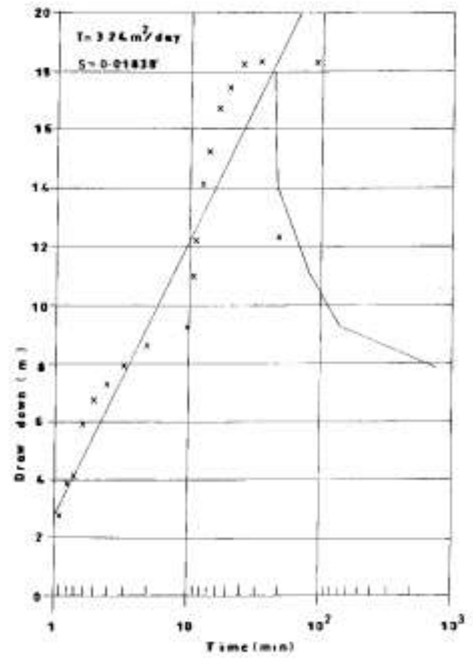

Fig 7 Relation between time and draw down for aquifer test of well BH 37

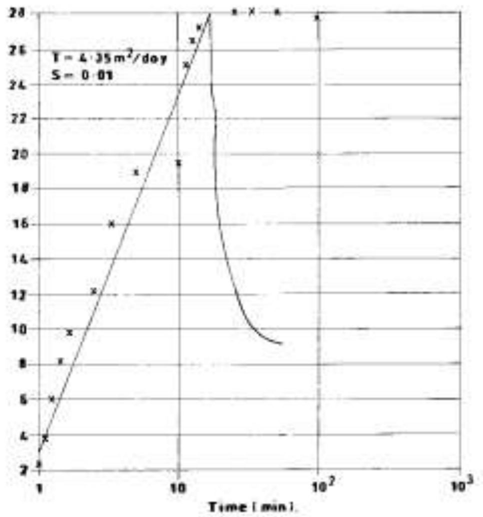

Fig.8 Relation between time and drawdown for aquifer test of well BH 107.

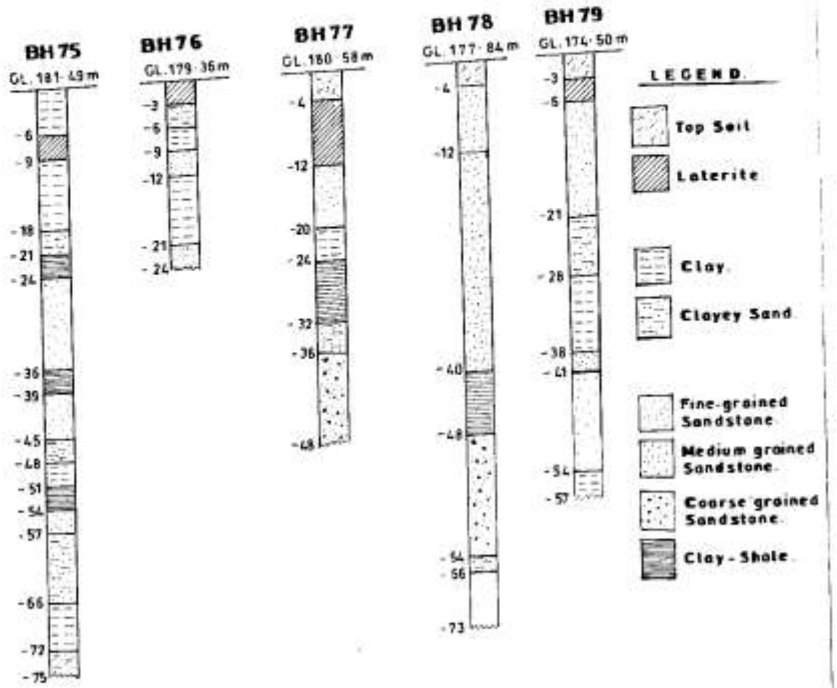

Fig. 9: Lithological logs of some boreholes in the study area.

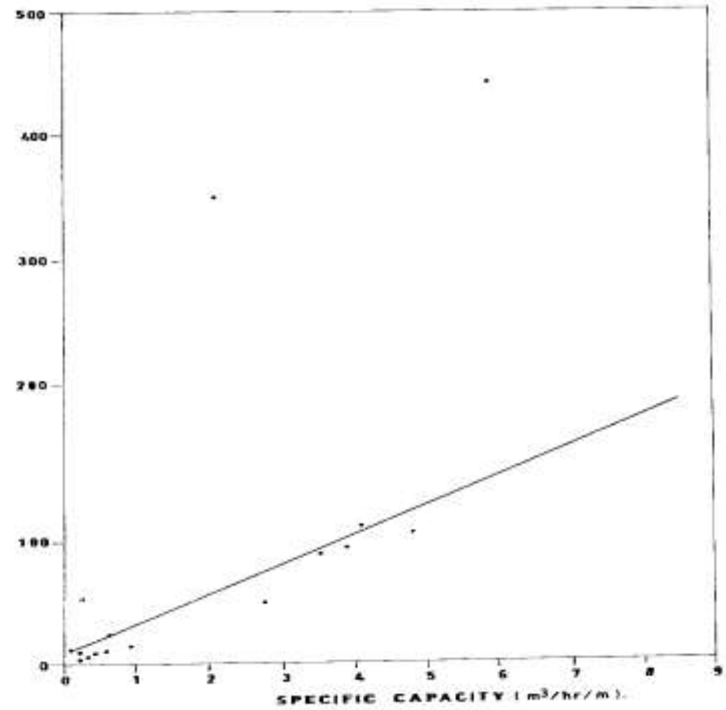

Fig. 10: Relation between transmissivity and specific capacity.

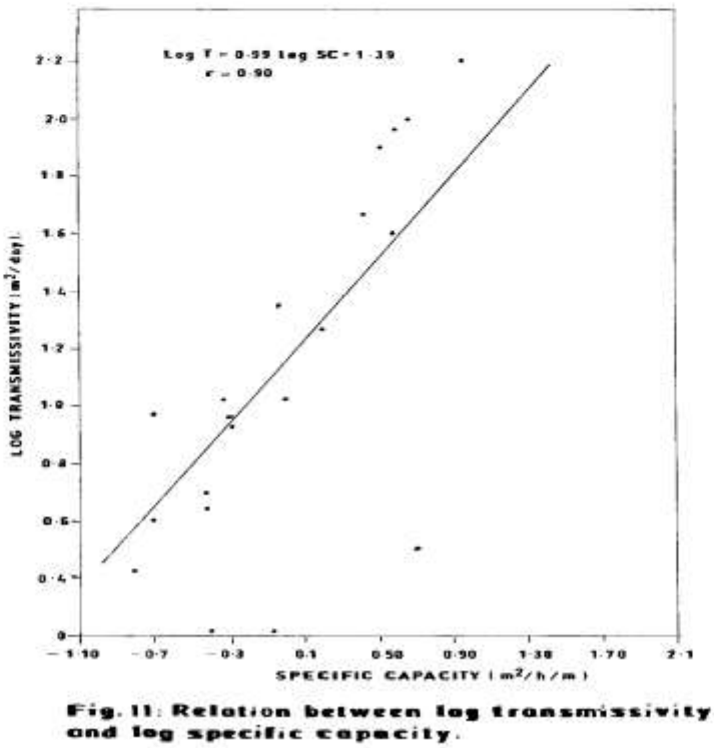

Fig. 11: Relation between log transmissivity and log specific capacity.

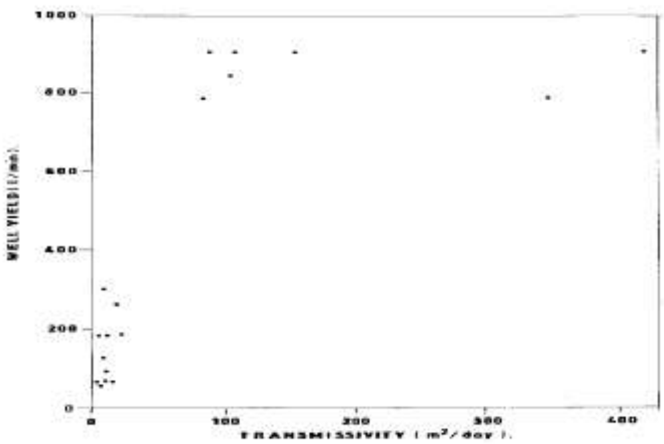

Fig. 12 : Relation between well yield and Transmissivity

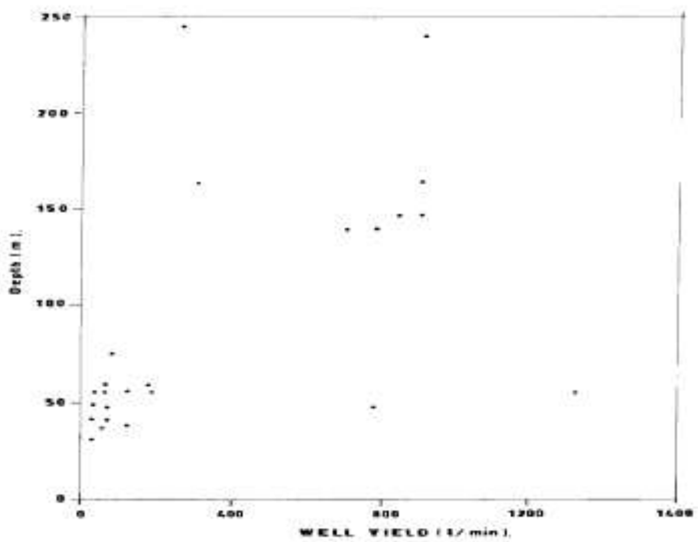

Fig. 13 . Relation between total depth in metres and well yield in l/min.