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A multi-technique evaluation of the groundwater resource potentials of wuro juli well field, gombe subbasin, upper Benue basin, northeastern Nigeria

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ABSTRACT

Hydrostratigraphic mapping and results of pumping test analysis were used to investigate groundwater occurrence and the hydraulic properties of the aquifer systems in the Wuro Juli well field, near Gombe Metropolis, Gombe Sub Basin. The well field is comprised of a set of 13 deep boreholes developed to improve public water supply to Gombe Township. The delineated aquifers have several formation boundaries that inhibited lateral continuity of groundwater flow. At a discharge rate of between 43.20 m^3/day and 613.44m^3/day, the specific discharge (q) and Hydraulic Conductivity (K) values varied in the range of 1.17-2.03m^3/day and 2.75 x 10^{-2} - 2.06 x 10^{0} m^2/day, respectively. The Application of both Chow's method of Drawdown Analysis and Jacob's Residual Drawdown Method to drawdown measured during multiple pumping tests in the well field yielded very low Transmissivity (T) and Storativity (S) values. T and S varied in the range of 3.13 x 10^{-5} - 3.50 x 10^{-4} m^2/sec and 4.40 x 10^{-8} - 4.00 x 10^{-7}, respectively. The analysis of the distance-drawdown data indicated that a resultant drawdown due to simultaneous pumping of two wells for about 200 minutes ranged from about 30m near the pumping wells to 0.50m over the more distant segments of the radius of influence. The low Transmissivity (T) and Storativity (S) values of the water supply aquifers in the well field caused very low range of cone of depression, culminating in huge drawdown values within some of the pumped wells. This tight cone of depression would limit the actualization of the projected abstraction rate of 4492.80m^3/day (187.20m^3/hr) required to temporary solve water supply problems in Gombe Town. Structural discontinuities and in particular very low aquifer recharge through rainfall were other important parameters that contributed to the limitation of the groundwater potentials of Wuro Juli well field.

Introduction

Gombe Town, the state capital of Gombe State is approximately 150km east of Bauchi (Figure 1). It has an area of about 36 km^2 consisting of urban, forested and cultivated lands. It is fairly populated with a greater portion of the existing town located at the foot of the Akko Escarpment and on a shallow disk-like site. The town had witnessed a westward expansion towards the escarpment (i.e. where the NNPC depot is sited). The development has engulfed Tunfure, Shongo Idirisa and Wuro Male villages into the township.

The provision of potable water to the numerous inhabitants of Gombe metropolis and environs is of serious concern to government.

Only a few inhabitants have access to potable water, dispensed through boreholes located around Mallam Inna and Pantami areas. In areas where the Gombe Sandstone cropped out, water shortage is experienced soon after the rainy season (May – October), because the rivers are not only ephemeral but are also influent (Bala, 2009). The search for groundwater resources in the formation is difficult because of fluctuation in groundwater levels within it. Carter et al. (1963) considered the shallow aquifers of the Gombe Sandstone to be a poor aquifer, and noted that the Bima and Yolde Formations were the potential sources of water supply in Gombe Township. Accordingly, provisions of groundwater to rural communities have focused on drilling of deep boreholes, with the aim of tapping water from the Bima or Yolde. Depths of boreholes within Gombe town vary from about 180 – 250m and occasionally up to 300m in other locations such as Kumo and environs (Bala, 1981). Such projects can only be executed by government, thus culminating in the perennial water shortages in the township.

The Expansion of Gombe Township Water Supply Scheme (located in Wuro Juli near Gombe) was designed to produce about 4492.80m^3/day (187.20m^3/hr) of potable water from a set of 13 deep boreholes (WADSCO, 2000). The scheme was expected to provide an additional 30% of the projected water demand for Gombe metropolis and its environs.

Hydrostratigraphic properties of the aquifer systems were investigated to determine the feasibility of the projected water supply to the area. Hydraulic properties including Transmissivity (T) and Storativity (S) among others were evaluated from multiple pumping tests conducted in the well field. Analytical techniques were used to investigate well interference and its possible effect at different pumping rates on water level lowering in the respective 13 boreholes in the well field.

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Physiographic Features, Geology and Hydrogeology of the Study Area

The Wuro Juli area near Gombe metropolis is within the Gombe sub-basin in the upper Benue Basin and lies in the sub-Sudan climatic zone (Benkhelil, et al., 1989; Figure 1). The area under investigation is bounded by latitudes $11^{o}05^{1}$ and $11^{o}25^{1}$N and longitudes$10^{o}05^{1}$ and $10^{o}25^{1}$E.

The area is well-linked by roads to other regional centers like Biu/Maiduguri, Potiskum/Damaturu, Bauchi/Jos, Kari/Kano and Kumo/Yola.

Many streams truncate some parts of Gombe town with an eastward flow direction from their sources at the Akko Escarpment. Available rainfall records showed an average annual rainfall of about 1600mm (Figure 2), most of which fell between June and September. The area is virtually dry with very high temperatures and low humidity from the months of October to April.

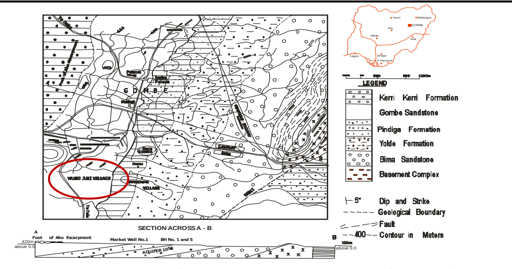

Figure 1. Geological Map of Study Area, showing Location of Gombe (adapted after Thompson, 1958)

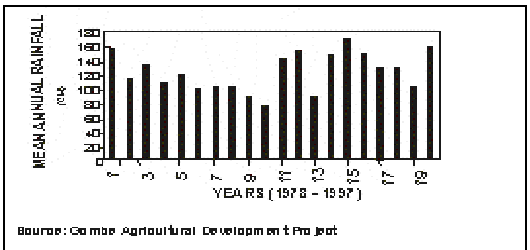

Figure 2. Mean Annual Rainfall Data of Gombe

The stratigraphy in the area began in the Cretaceous with the deposition of continental Bima Sandstone, which lies unconformably on the Basement Complex (Table 1). The Bima Sandstone is light brown, feldspathic and medium-coarse grained. It is succeeded by the transitional Yolde Formation which shows rapid alternation of siltstones, silty clay and clayey shale and well bedded, flaggy fine-grained sandstones (Reyment, 1965). The Turonian Pindiga Formation made up of blue-greenish shales and limestone interbeds overlie the Yolde Formation. The Cretaceous deposits were terminated with the deposition of the regressive Gombe Sandstone, typified by a variable succession of well bedded, fine to medium-grained sandstones, and sandy to silty shales with occasional mudstones (Carter et al., 1963).

The Cretaceous sediments in the area generally dip northwest and underlie the western limb of the Liji Anticline, whose axis trends NE-SW. The Basement Complex rocks of Liji Hill occupy the core of the anticline (Offodile, 1991; Figure 1).

The Tertiary deposits consist of continental sequences of flat-lying grits, sandstones and clays of the Keri- Keri Formation (Adegoke, et al., 1986).

The sediments of the Yolde Formation form the most reliable aquifer despite rapid changes in facies while the Bima Sandstone is low yielding. Water from the Gombe Sandstone is laden with iron, while the Pindiga Formation is even less reliable than the Bima Sandstone, because its aquifers occur within predominantly clayey shale/limestone beds and are often too thin and lenticular to give appreciable yields (Offodile, 1991).

Table 1. Lithostratigraphic Subdivisions for the Gongola Basin (Zaborsky et al., 1997; Haque et al., 1988)

GONGOLA BASIN		AGE		Time Scale (Ma) (Haq et al., 1988)
		PLEISTOCENE		
Kerri Kerri Formation		PALEOCENE (at least in part)		
Gombe Sandstones		MAASTRICHTIAN		65, 70
Pindiga Formation	Fika Member ? Unconformity ?	CAMPANIAN		75
		SANTONIAN		80
		CONIACIAN		85, 90
	Dumbulwa Gulani/ Deba Fulani Member	UPPER	TURONIAN	95
		MIDDLE		100
	Kanawa Member	LOWER		105, 110
Yolde Formation		CENOMANIAN		115, 120
BIMA GROUP	"Upper Bima Formation"	ALBIAN		125
	"Middle Bima Formation"	APTIAN		130
	"Lower Bima Formation"	PRE-APTIAN		135, 140, 145
Crystalline Basement		PRECAMBRIAN		

Methodology

The hydrostratigraphical study of the area was done by extensive investigations involving geological mapping and good follow-up close-paced traverses to delineate lithofacies and their boundaries and the identification of major and minor structural trends. The data were augmented with borehole lithologic logs to determine the potentials of the different aquifer units in the Wuro Juli area.

Further insights were provided through a series of pumping test activities conducted in the boreholes. The field layout was designed in such a way that each borehole has intervening distances of 200-350m from nearby boreholes (Figure 3).

Pumping test experiments involved Step Drawdown tests and Constant Rate Pumping tests in each of the 13 boreholes. Static water and dynamic water levels were measured in nearby wells (standard observation wells) and also in the respective pumping wells with well sounders installed in tremie pipes.

Simultaneous pumping (Multiple pumping) test programme of BH.3 and BH.11 used adjoining boreholes as observation wells. Well recovery was also monitored for all the pumped wells.

Chow's Method of Drawdown analysis and Jacob's Residual Drawdown method were utilized to investigate Transmissivity (T), Storativity, (S) and Yield potentials of the aquifer systems, while the Babuszkin and Sichardt formulae were used to calculate Hydraulic Conductivity (K) and extent of cone of depression (r), respectively.

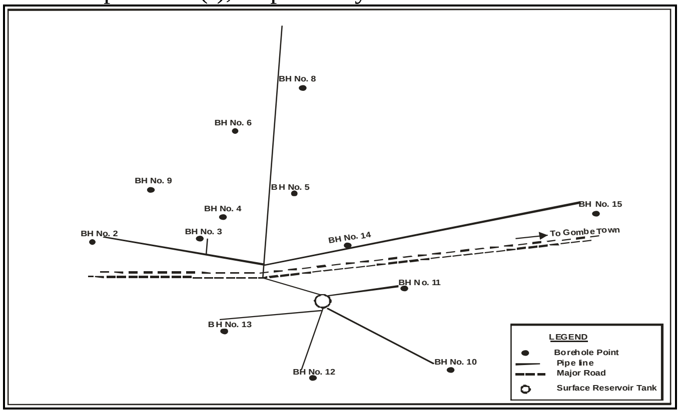

Figure 3. Wuro Juli Borehole Gathering and Wells Layout

Data analysis and results

Hydrostratigraphy and Aquifer Units

Figure 4 shows the lithologic succession deduced from borehole lithologic logs of BHS. 3, 4, 5, 6, 10 and 11 spaced between 200 and 350m in the Wuro Juli well field. The boreholes in the well field exhibited similar lithologic characteristics except boreholes 1 and 7 that were drilled into shale lithofacies down to 310m without encountering any major aquifers and subsequently abandoned. Both boreholes were located west of the well field where the Yolde Formation dips greatly beneath the Pindiga, Gombe and Keri-Keri Formations. Table 2 shows the summary of parameters of the completed productive boreholes drilled in the well field, which adhered strictly to standard practice (Johnson Inc., 1975). The total depth of the boreholes ranged from 271.95 to 320.57m (Figure 5) and the average installed screen length was between 27 to 51m.

Figure 4 revealed only 2 aquifer units of the Yolde Formation (upper and lower aquifers) with borehole 11 tapping both aquifers. Records of water level data (Figure 6) show a gradual increase in the piezometric surface toward the northwest direction towards Akko Hill (Figure 7). These differentials highlight syndepositional activities especially folding/faulting that may have demarcated the well field into several incongruous aquifer units with limited lateral extent.

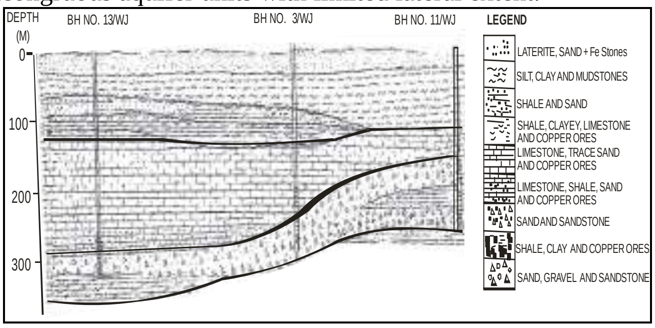

Figure 4. Lithologic Cross Section deduced from borehole

Chow's (1975) method of drawdown analysis was applied to drawdown data obtained from observation wells (BHs, 10, 12, 13 and 14) located near reference wells (3 and 11) that were simultaneously pumped at Q = 216m^3/day and 587.52m^3/day, respectively. The sequence was recognized as a multi-aquifer system and therefore could be potentially leaky. However, in the context of the overall storage and yield of the system, the application of a leaky aquifer model may at best be desirable but not crucial (Freeze and Cherry, 1979).

Figures 8 and 9 show the plots of simultaneous constant rate pumping test results for the pumped wells and observation wells, respectively used for the computation of some of the aquifer hydraulic parameters (Table 3).

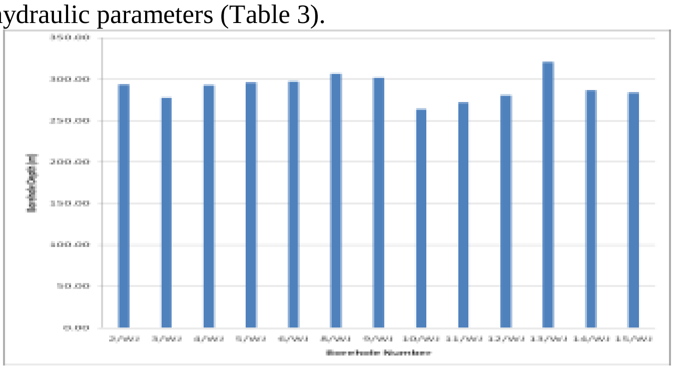

Figure 5. Respective Depth of Boreholes in the Wuro Juli Well Field

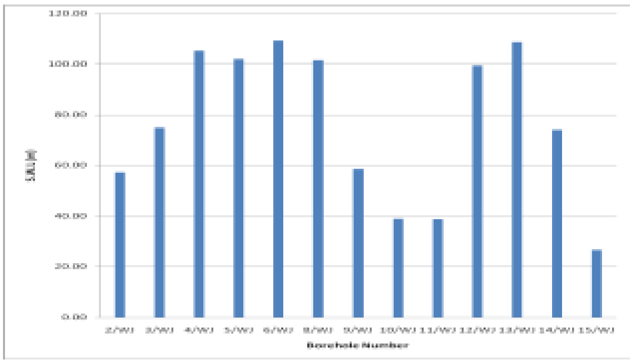

Figure 6. Static Water Level Record of Boreholes in the Wuro Juli Well Field

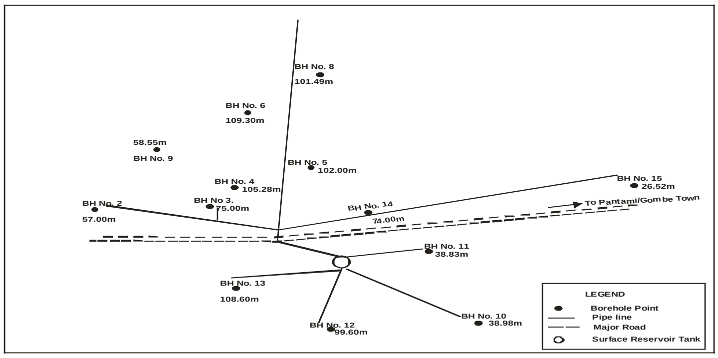

Figure 7. Piezometric Surface Distribution in the Wuro Juli Well Field

The Coefficient of Transmissivity in m^2/sec. was computed from the relation (Freeze and Cherry, 1976):

$$T = \frac{Q}{4\Pi} W(u)$$

Where, Q = discharge in m^3/day and s = drawdown. Values of W(u) and u corresponding to drawdown(s), measured at time(t), estimated from the Chow's function:

$$F(u) = \frac{W(u)\, e^u}{2.30}$$

Storativity was also estimated using the formula

$$S = \frac{4U_{A1}T_{tA1}}{r^2}$$

Where U_{A1}, is read off the Chow's nomogram (Figure 10), t_{A1} is an arbitrary point A, that corresponds to the value of time read off the time-axis of the observed pumping well (Figure 8).

The estimated values of Transmissivity (T) and Storativity (S) using the Chow's method and the Jacob's residual drawdown method ranged from 3.13 x 10^{-5} to 3.5 x 10^{-4} m^2/sec and 4.4 x 10^{-8} to 4.0 x10^{-7}respectively (Table 4).

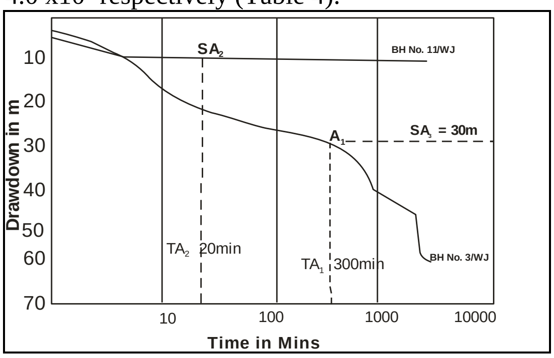

Figure 8. Simultaneous Constant Rate Pumping Test Result Plots of Bh. 3 and Bh. 11 (Pumping Wells)

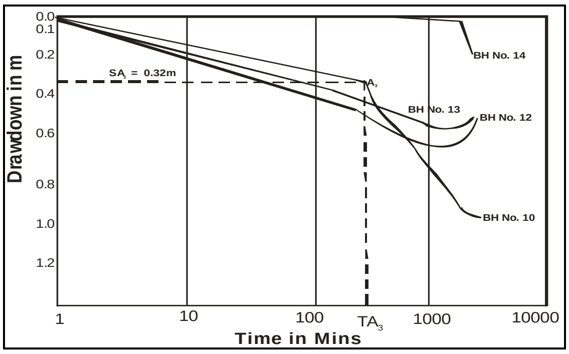

Figure 9. Simultaneous Constant Rate Pumping Test Result Plots of Bhs. 10, 12, 13 and 14 (Observation Wells)

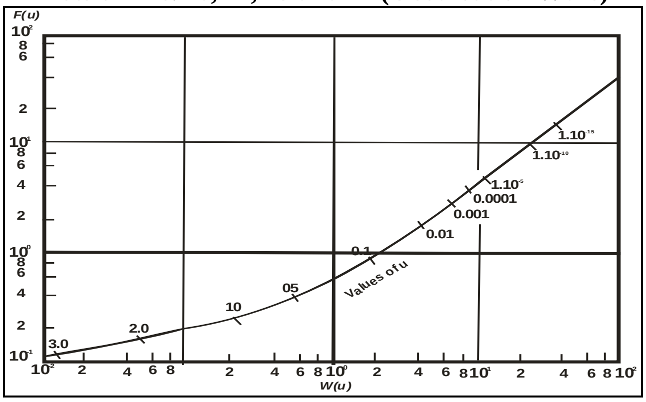

Figure 10. Chow's Nomogram used for Pumping Test Analysis

Discussion

Groundwater Occurrence and Discharge in the Wuro Juli Well Field

The Wuro Juli well field, in the Gombe sub-basin, is underlain by the Gombe Sandstone, Yolde and Pindiga Formations. The interbedding of sandstone, shale and limestone members of the respective formations presents multi-aquifer systems (Figure 4).

The Gombe Sandstone aquifers that occupy the upper sections of the groundwater systems in the Wuro Juli well field occur in unconfined conditions while the aquifers of the Pindiga and Yolde Formations at the lower sections occur under confined conditions (Figure 4).

The boreholes drilled in the well field were designed to tap water from the Pindiga and Yolde Formation aquifer units as predrilling baseline survey precluded the abstraction of water from the aquifer units of Gombe Sandstone due to its excessive iron content (WADSCO, 2000; Bala, 2009).

Values of the piezometric surfaces measured in boreholes drilled into target formations, ranged from 38.83 to 109.30m (Figure 8). The distribution showed a gradual increase in the piezometric surface towards the northwest (i.e. towards Akko Hill; Figure 1) and shallowing to the east, towards Pantami village. This trend corresponds to the progressive shallowing of depths to which the Yolde Formation aquifers were encountered in the drilled wells to the east (towards Pantami).

The uneven distribution of the piezometric surface and aquifer horizons in the well field were most probably caused by dislocations (faults) arising from tectonic activities. The faults may have delimited the well field into several discontinuous aquifer compartments with distinct hydraulic properties, culminating in low aquifer capacity in some of the wells with limited areal extent.

Tectonic activities and in particular folding/faulting have overriding effects on aquifer lateral continuity and pressure relief. Boreholes sited towards Akko Hill (to the west) have deep water levels (piezometric surfaces), thin aquifer thickness and restricted areal extent (Figure 4), unlike the boreholes in the eastern section (towards Pantami). Tokarski (1972) studied the 170m lithostratigraphical sequences of shale-mudstone-sandstone interbeds occurring in cyclotherms in the study area and typified them as flysch-like sedimentation. Zaborski (2003) later attributed the rapid changes in facies to synsedimentary movements along the Gombe Fault which, at Pantami, brings near vertical lower Gombe Sandstone into contact with the Yolde Formation and Bima Group, and just to the north, shales of the Pindiga Formation in contact with the Bima Formation.

Wuro Juli area is located just at the foot of Akko Hill with elevation in excess of 2500 feet (about 762m) above mean sea level. The hydraulic gradient around Akko Hill areas is high, hence groundwater discharge is directed eastwards, towards lower gradients around Pantami and Tolba areas (Figure 1). Future drilling programs should be sited towards these areas to reduce depths and costs.

Groundwater Yield Potential

The yield potential in the area was evaluated using the relationship between drawdown, (s), Storativity (S) and Transmissivity: The drawdown (s) at any given discharge (Q), at any point on the cone of depression is inversely proportional to Storativity (S) and Transmissivity (T)(Freeze and Cherry, 1979).

The T and S values computed for the boreholes (well field) are very low (Table 3). The shape and size of the cone of depression around the boreholes would therefore be tight and deep drawdown cones. Borehole interference is therefore expected to be minimal if the boreholes are widely spaced.

Low Transmissivity of the groundwater systems in the well field would also imply that the average annual groundwater discharge from the well field would be low.

Furthermore, most of the streams that originated from the Akko Hill and traversing the area are ephemeral, groundwater recharge in the area is through rainfall. Available rainfall records for the area showed an average annual rainfall of about 1600mm. This very low recharge potential in the area, due to low precipitation and high evapotranspiration finally culminates in low aquifer capacity.

The projected abstraction rate of 4492.80m^3/day (187.20m^3/hr) is considered significant and would cause substantial lowering of the piezometric surface in the respective boreholes, (in the short term), especially as aquifer recharge through rainfall is very low and low Transmissivity caused by confining boundary conditions that limit lateral groundwater flow.

Well Interference

Low Transmissivity and Storativity values are indicative of tight and deep drawdown cones (Freeze and Cherry, 1979). However, high well interference and excessive cumulative drawdown with a considerable lowering of water table in the well field could occur in the long run if pumping wells were not adequately spaced.

The range of cone of depression that determines the extent of borehole interference was estimated for the different aquifer blocks using the formula developed by Sicharadt:

$$R = 10 \times s(K)^{1/2}$$

(Where R = Range of Cone of Depression, s = Drawdown and K = Hydraulic Conductivity)

The cone ranged between 126.16 and 379.87m. The radial distance between the 13 boreholes ranged from 200 to 350m.

Based on the present pumping well spacing, pumping rate and observed drawdown magnitudes, it is apparent that undesirable environmental hazards of excessive water level lowering would occur unless the aquifer system is appropriately recharged or abstraction of water regulated to the capacity of the wells.

Data on the recharge pattern for the area is not available. It is reasonable to expect a rather low recharge based on available rainfall data. If we, however, assume a rather high recharge rate of 30% (Nwankwor, 1995), this would provide an annual recharge of only 0.48m based on the known average rainfall of 1600mm in the area. For a porosity of about 0.3 considered reasonable for the aquifer material, this amounts to a water rise of about 1.44m in a year. When this value was compared with the drawdown observed from the analysis of pumping test data, it was observed that a resultant drawdown cone of about 30m would occur near the pumping wells and a cone of about 0.5m over the more distant segments of the radius of influence.

It is evident, therefore, that the recharge rate is substantially less than the projected abstraction rate, indicating a potential for drastic water table lowering and its attendant problems including incessant burning of borehole submersible pumps and its accessories in the short run and associated environmental hazards of land subsidence in the long run.

Conclusions

The Expansion of Gombe Township water supply project located in Wuro Juli (near Gombe) was designed to contribute about 4492.80m^3/day (187.2m^3/hr) of potable water through a set of 13 deep boreholes variously sited between 200-350m apart.

The aquifer systems have low Transmissivity and Storativity values. Several formation boundary conditions compartmentalize the well field into several incongruous aquifer units with limited lateral extents. High drawdown values within pumping wells are expected in the short term and an extensive groundwater lowering in the long run due essentially to small well spacing of some of the wells and very low aquifer recharge.

Field and analytical studies of pumping test and Hydrostratigraphic data show that the projected abstraction rate is significantly greater than can be reasonably sustained by the aquifer systems without causing appreciable lowering of the piezometric surfaces in well field.

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Table 2. Summary of Borehole Completion Data

Bh. No	Drilled Depth (m)	Casing Length (m)	Screen Length (m)	Sump Length (m)	Borehole Depth (m)	Gravel (m^3)	Backfills (m^3)
2/WJ	302.42	254.70	36.00	3.00	293.70	8.34	13.35
3/WJ	279.72	238.32	36.00	3.45	277.77	11.34	9.24
4/WJ	299.37	263.00	27.00	3.00	293.00	7.89	13.49
5/WJ	298.02	244.70	48.00	3.30	296.00	16.32	4.91
6/WJ	300.39	245.10	51.00	1.10	297.20	16.70	4.96
8/WJ	311.37	271.00	33.00	3.00	307.00	10.99	11.26
9/WJ	306.93	263.00	36.00	3.00	302.00	9.16	12.77
10/WJ	264.00	227.67	36.00	3.00	263.67	8.66	10.17
11/WJ	272.59	232.27	36.00	3.68	271.95	8.85	10.61
12/WJ	280.68	238.08	36.00	6.40	280.48	9.79	10.25
13/WJ	321.00	279.74	36.00	5.26	320.57	5.80	17.10
14/WJ	286.67	245.87	36.00	4.70	286.57	15.08	10.61
15/WJ	284.38	244.38	36.00	3.30	283.68	14.86	5.20

Table 4. Aquifer T and S values determined from Drawdown Data Analysis.

	VALUES	METHOD USED	
PARAMETER	BH.3	BH.11	
Transmissivity m^2/sec.	2.65×10^{-5} 3.13×10^{-5}	2.85×10^{-4} 3.55×10^{-4}	CHOW'S METHOD JACOB'S METHOD
Storativity	2.05×10^{-9} 4.40×10^{-5}	9.3×10^{-7} 4.0×10^{-7}	CHOW'S METHOD JACOB'S METHOD