Scientia Africana, Vol. 13 (No.2), December 2014. Pp136-145
 ISSN 1118 - 1931

DETERMINATION OF HYDRAULIC CHARACTERISTICS OF AN AQUIFER CAPACITY FROM PUMPING TEST: A CASE STUDY OF KONSHISHA AREA, CENTRAL NIGERIA.

*** H. T. Jika and ** A. C. Tse**

**Department of Geology University of Nigeria Nsukka*
E-mail: jikahilary@yahoo.com GSM +2347033417908

*** Department of Geology, University of Port Harcourt, Nigeria.*
Email: akaha.tse"uniport.edu.ng

Received: 21-10-14
Accepted: 05-11-14

ABSTRACT

Constant rate, single well pumping tests were conducted using boreholes located in four communities in the study area with the aim of determining the aquifer hydraulic properties using the Cooper Jacob method. Fractured shales yielded groundwater into the wells whose depths ranged from 26 to 35m while the static water level varied from 5.81 to 8.76 m. During the test, the maximum drawdown observed was between 11.89 and 21.34 m. The hydraulic conductivity values fell between 6.1 x 10^{-2} and 6.45 x 10^{-1} m^3/day while transmissivity ranged from 0.49 to 4.52m^2/day and specific capacity from 18.41 to 117.92 m^2/day. The specific yield varied between 78.62 and 87.26 m^3/day. Classification based on transmissivity values shows a very low to low yield aquifer. This correlates well with the litholog which showed fractured shales as the groundwater bearing unit supplying water into the wells. Good correlation (correlation coefficient, R^2) of 0.8753 was obtained between transmissivity and specific capacity. The hydraulic coefficient and transmissivity indicate that for sustainable aquifer productivity, boreholes in the area should be installed with low horse power pump size for domestic use.

Key words: Pumping test, Aquifer, Hydraulic conductivity, Transmissivity, Specific capacity

INTRODUCTION

The study area is underlain by clayey sand and fractured shales. The fractured shales supply groundwater into drilled boreholes which often go dry shortly after they are put into use because of over-abstraction due to an increasing population and high demand for water. Investigations reveal that these boreholes, which are part of government intervention to boost rural water supply, are hardly preceded by adequate or detailed geophysical surveys to delineate the local aquifers. Also aquifer performances are not determined by standard pumping tests. Pumping test is a controlled field experiment used to characterise the hydraulic properties of an aquifer such as hydraulic conductivity, transmissivity, and storativity (Anderson and Woessner 2002) in which a well is pumped at a controlled rate and water level response (rise and fall) is measured. Transmissivity is a major hydraulic parameter of aquifers (Kruseman and De Ridder, 1970) and is generally related to productivity of a well. The higher the transmissivity, the higher the production capacity of a well (Osei 2001). The most common form of pumping test to estimate these hydraulic properties is the constant-rate test in which a control well is pumped at a constant rate and water-level response in terms of dynamic and residual drawdown is measured in one or more surrounding observation wells or in the pumping well itself which serves simultaneously as the control and observation well. Since pumping test evaluates a much larger volume of the aquifer, they are the most commonly accepted methods to determine representative aquifer hydraulic properties sites with groundwater monitoring wells (Osei, 2001, Schwartz and Zhang 2003, Tse and Amadi 2008). However, several authors, including Sriniwas and Singhal (1985), Onuoha and Mbazi (1988), Mbonu et al (1991), Kumar and Elango (2001), Okiongbo and Odubo, (2012), have shown that surface geoelectrical measurements can also be used to determine these parameters. Rural water supply in Konshisha area by groundwater abstraction from boreholes has resulted in frequent well failure and abandonment of these boreholes soon after construction, commissioning and operation due to loss of well productivity as a result of dry holes. This implies the availability of groundwater and the aquifers dynamics in the area are poorly understood. In the present study, constant rate, single well pumping tests were performed by the authors in boreholes located in communities in Konshisha area of Benue State, Central Nigeria. The data obtained from these tests were used to compute aquifer hydraulic properties of transmissivity, hydraulic conductivity and specific capacity, and also to determine the pump size for optimum and sustainable groundwater withdrawal from boreholes tapping the aquifer to forestall well failure.

Geologic Setting

Konshisha, the study area is located in Benue State (Fig. 1) in the Middle Benue Trough of Nigeria. The trough generally consists of varied thicknesses of both continental clastic deposits and marine sediments. The origin/evolution and stratigraphy of the trough have been discussed in details by several authors including Burke et al. (1970), Grant (1971), Nwachukwu (1972), Kogbe (1976) Olade (1978), Ofoegbu (1985), Akande et al (2011), Obaje (2004). On the geological map of Nigeria (Geological Survey of Nigeria 2004) the study areas are is underlain mostly by sedimentary rocks of the Turonian Eze-Aku Formation, compsed mostly of mudstone, shale, sandstone and siltstone, except Tongu area which lies on the fringes of the sediment-basement contact (Fig. 2). The typical subsoil profile in the study area as revealed by a borehole in Mbaigbe comprise lateritic top soil underlain by clayey shales and fractured dark shales (Fig) 3).

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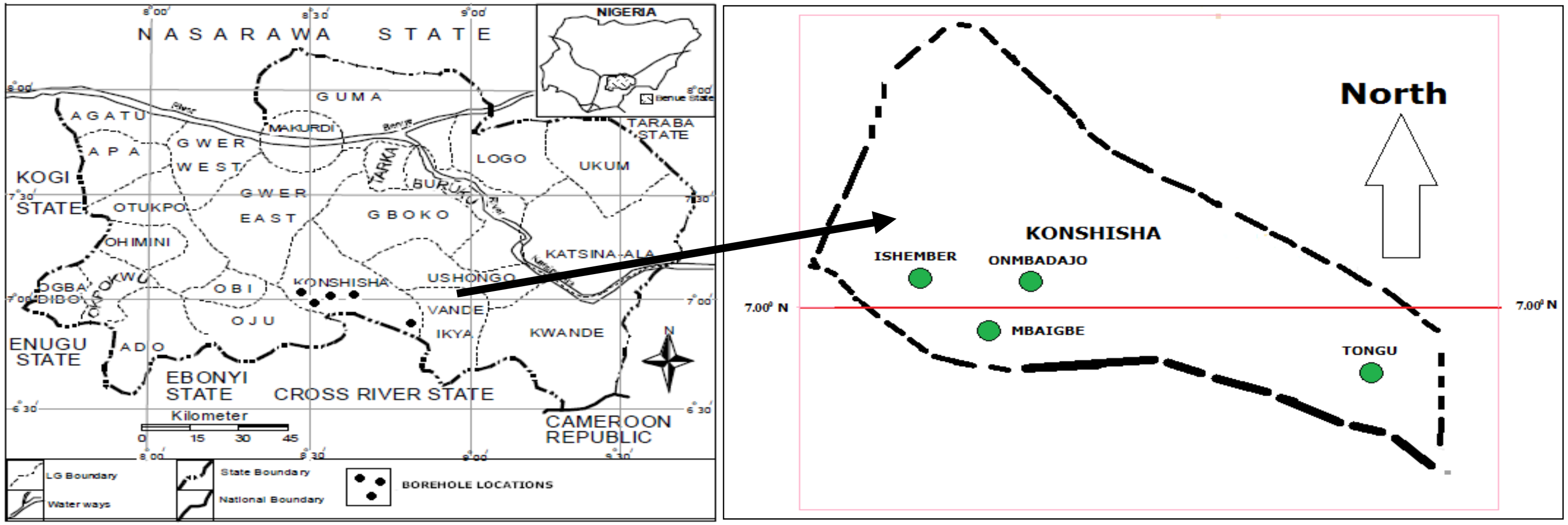

Fig 1: Map of Benue State showing the study area

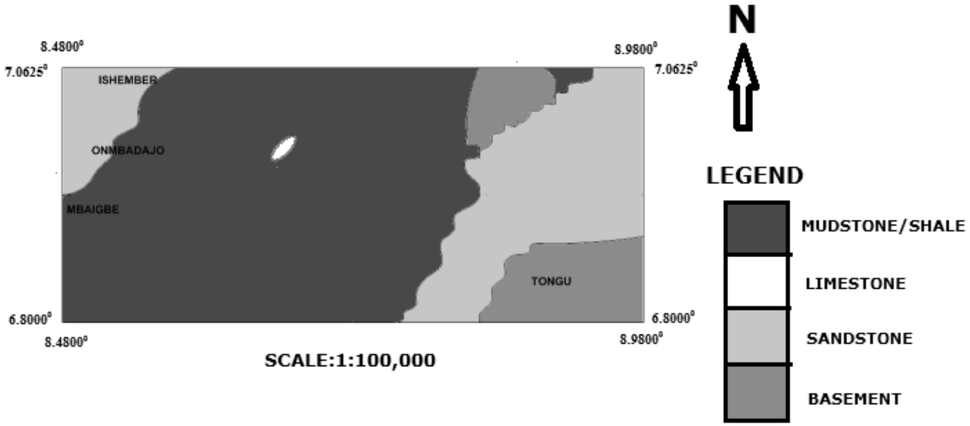

Fig 2 Geology map of the study area (from Geology map of Nigeria, GSN 2004)

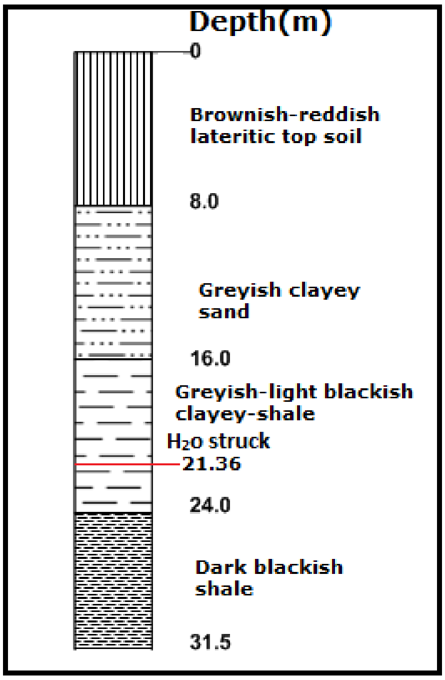

Fig 2. Mbaigbe litholog typical of area

MATERIALS AND METHOD

Data for this study were obtained during a UNICEF sponsored, Millennium Development Goal (MDG) government project for rural water supply through boreholes. Boreholes in the study communities were drilled using a manually operated rig mounted on a tripod. The boreholes were completed, cased, screened and developed according to standard procedures. Lithologic logs constructed from the recovered soil samples during drilling enabled the establishment of the subsurface stratification (consisting of lateritic soil, clayey sand and fractured shales from top to bottom), casing and screen positions, static water levels and aquifer textural properties. Pumping test involving a constant rate, single well test was conducted as described by U.S. EPA (1995) in each location using one horsepower Grundfos submersible pump. During the test, water-level response in terms of dynamic drawdown was measured in the pumping well itself which served simultaneously as the control and observation well. This test was chosen because of its ease of field operations, logistics and economic considerations because it allows a rapid and economical calculation of aquifer properties, including K and T of the zone of interest at a single location. Estimation of aquifer properties was achieved by using the Cooper and Jacob (1946) straight-line solution to time-drawdown data collected in the observation well which is a modification to the Theis (1935) non-equilibrium well equation. Accordingly,

Q = flow rat = volume/time ……(1)

$$T = \frac{2.3Q}{4\pi \Delta S} \text{ ………………………(2)}$$

$$Cs = \frac{Q}{s} \quad (m^2/day) \text{…………….(3)}$$

Hydraulic conductivity, K, = $\frac{T}{B}$ …..(4)

Scientia Africana, Vol. 13 (No.2), December 2014. Pp136-145
 ISSN 1118 - 1931

where
Q = specific yield (m^3/day)
Cs = Specific capacity
T = Transmissivity (m^2/day)
S = average draw-down
ΔS = Change in draw-down over one log cycle
B = aquifer thickness (equivalent to screened length)

RESULTS AND DISCUSSION

Results of aquifer hydraulic properties are shown in Table 1.

Table 1: Summary of results obtained from pumping test data

Borehole Location	Co-ordinates	Borehol depth (m)	Screen (m)	Lithology	SWL (m)	S	T (m^2/day)	K (m^2/day)	Cs (m^2/day)	Q (m^3/day)
Tongu Township	N06.84072 E008.95795	35.00	5	Fractured shales	8.10	20.42	0.79	1.58×10^{-1}	25.41	86.40
Onmbadajo	N07.03245 E008.50096	26.00	6	Fractured shales	8.76	11.89	3.19	5.32×10^{-1}	117.92	87.26
Mbaigbe	N07.03958 E008.47044	31.50	8	Fractured shales	7.78	21.34	0.49	6.10×10^{-2}	18.41	78.62
Ishember	N07.06207 E008.55255	26.00	7	Fractured shales	5.81	12.81	4.52	6.46×10^{-1}	108.00	86.40

S = Drawdown, T = Transmissivity K = Hydraulic conductivity, Cs = Specific Capacity. Q =Specific Yield

Table 2. Transmissivity magnitude classification (after Krasny 1970)

Coefficient of Transmissivity (m^2/day)	Magnitude Classification	Magnitude Designation
Above 1000	I	Very high
100-1000	II	High
10-100	III	Intermediate
1-10	IV	Low
0.1-1	V	Very low
0-0.1	VI	Imperceptible

Fractured shales yielded groundwater into the test wells whose depths ranged from 26 to 35m while the static water level varied from 5.81 to 8.76 m. During the test, the maximum drawdown observed was between 11.89 and 21.34 m. Graphs of drawdown plotted against time since pumping started are shown in Figs. 3, 4, 5 and 6. Data analysis showed that the hydraulic conductivity values fell between 6.1×10^{-2} and 6.45×10^{-1} m^3/day. Transmissivity ranges from 0.49 to 4.52m^2/day while specific capacity ranges from 78.62 to 86.40 m^2/day. According to the Krasny (1970) transmissivity classification scheme, the aquifer in the area may be classified as very low to low in the designation of transmissivity magnitude (Table 2). There is a good correlation (correlation coefficient, R^2=0.8753) between transmissivity and specific capacity when their values were plotted on a graph (Fig. 7). This result reveals that the higher the value of specific capacity of an aquifer and its transmissivity, the better the production of the well. The transmissivity distribution of the area (Fig. 8) shows increasing transmissivity in north western part of the study area. Hydraulic conductivity, K, which measures the ease with which an earth material transmits fluids fell between 6.1 x 10^{-2} and 6.45 x 10^{-1} m^3/day. This is rated as very poor and the values correlate very well with transmissivity. The hydraulic properties of the aquifers in the area are affected by the presence of shale. Shale is a fissile sedimentary rock that is highly porous but its transmission of water is poor. Shale tansmits water only when it is fractured. This is evident in boreholes at Onmbadajo and Ishember areas where the transmissivity have relatively significant values of 3.19 and 4.52 m^2/day respectively. According to Driscoll (1986), an aquifer with a transmissivity value of less than 12.4m^2/day (0.5m^2/h or 1.44 x 10-4m^2/sec) can supply enough water only for domestic purposes, but with higher values can supply adequate water for industrial, domestic and irrigation uses. Hence from the results, aquifers in the area can provide water only for domestic use. The low to very low yield of these aquifers imply that well productivity can only be sustained if they are installed with low horse power pumps preferably hand pumps.

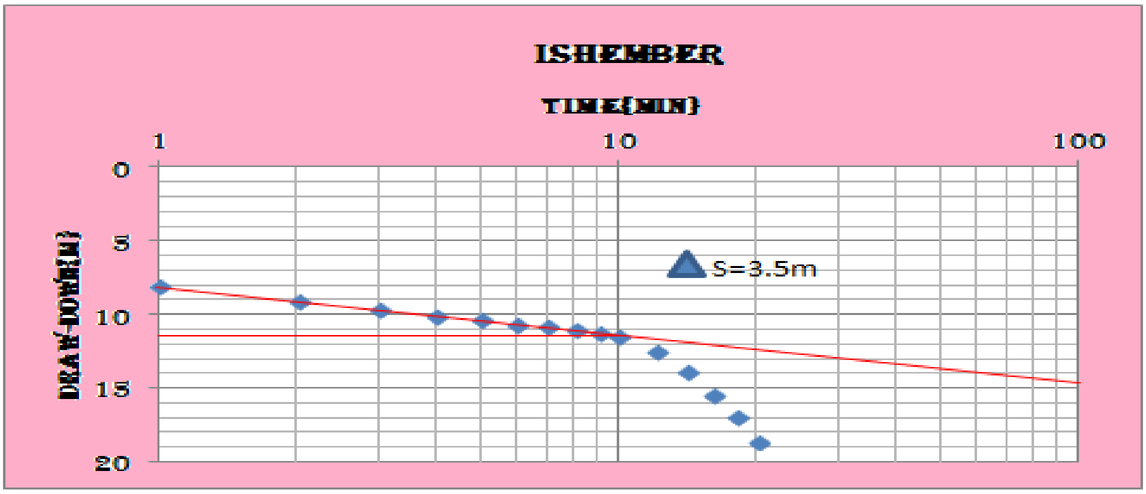

Figure 4: Drawdown against time in Ishember Community

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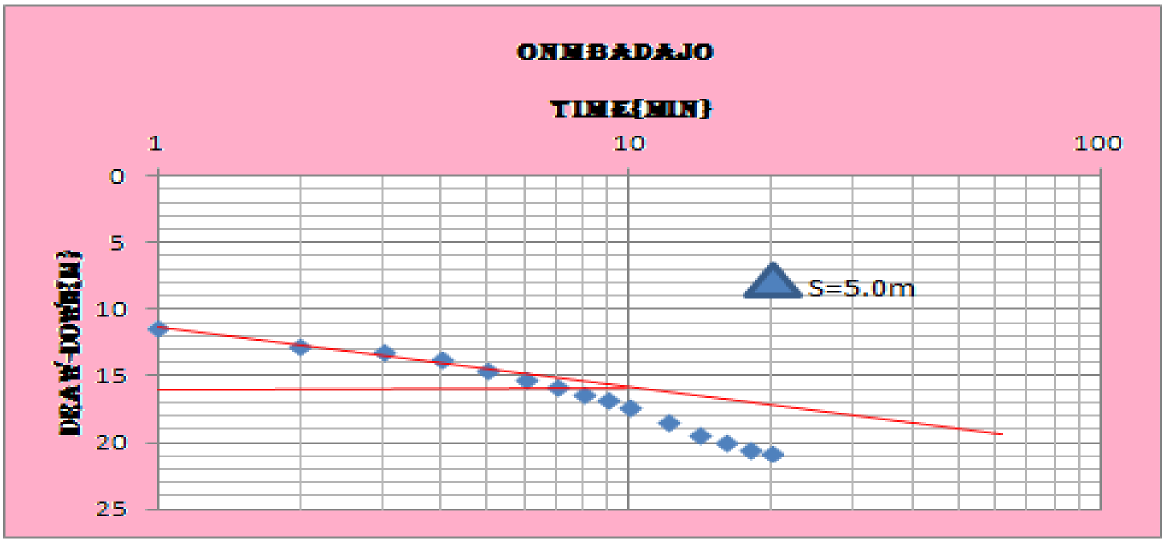

Fig. 5: Drawdown against time in Onmbadajo Community

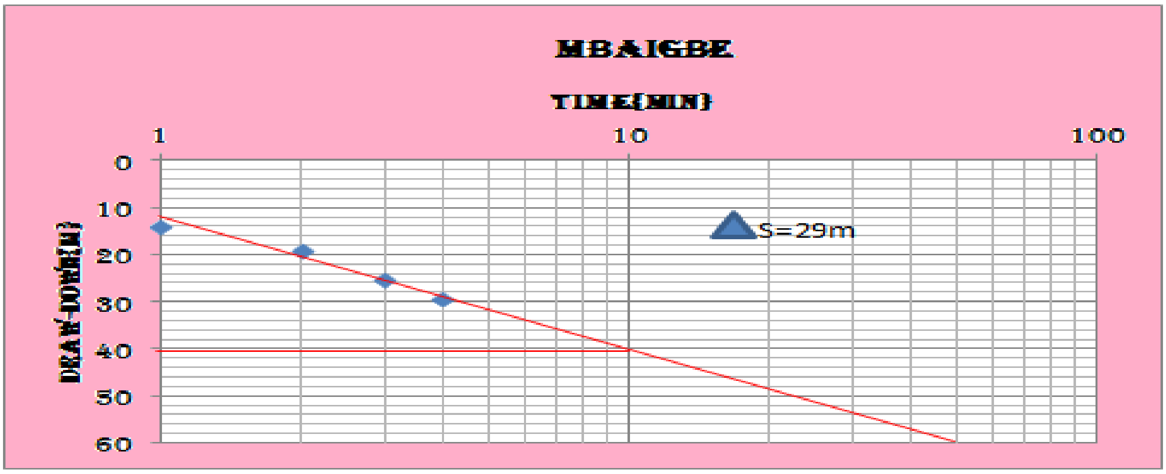

Fig. 6: Drawdown against time in Mbaigbe Community

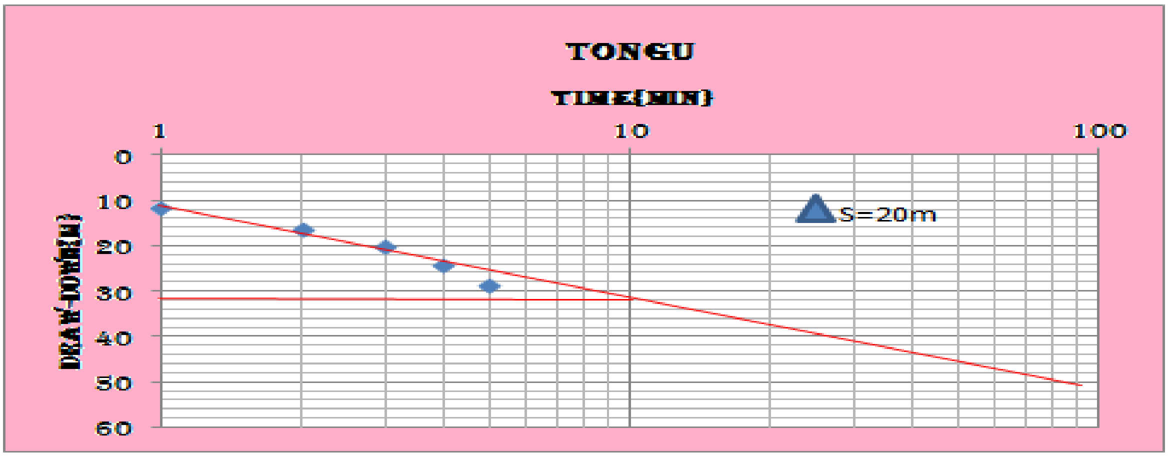

Fig. 7: Drawdown against time in Tongu Township

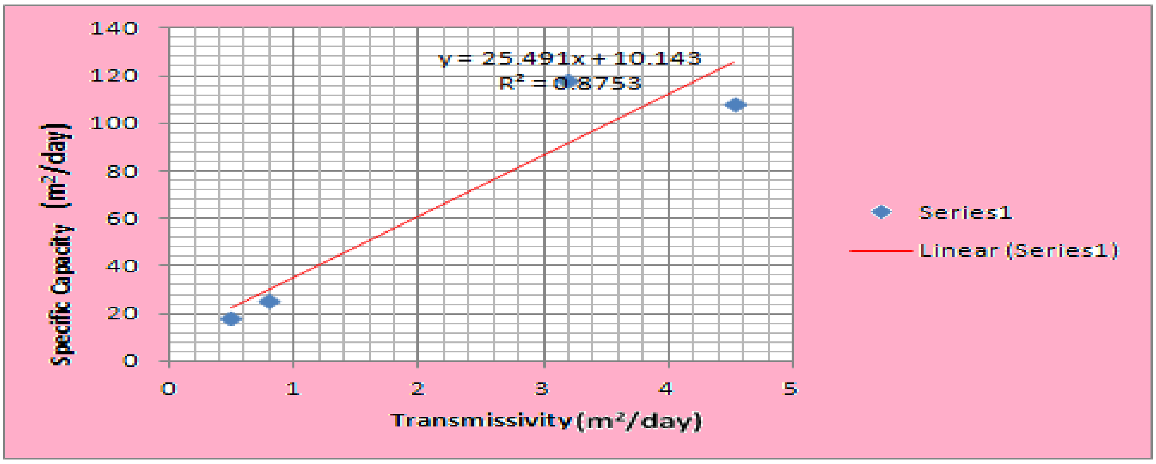

Fig. 8. Correlation coefficient between transmissivity and specific capacity

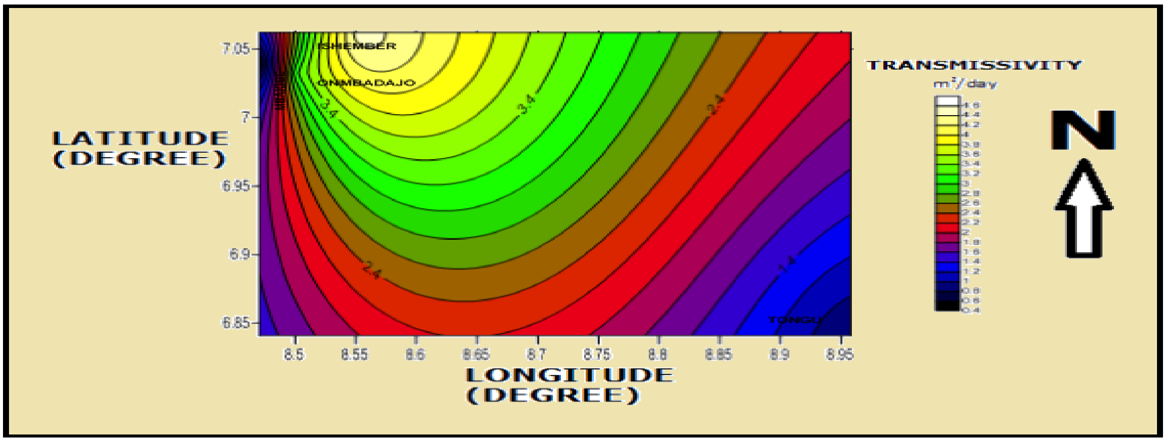

Fig. 9 Transmissivity distribution in the study area

The hydraulic properties in the area show that the aquifer which consists of fractured shales is of very low yield. These results may be as a result of the aquifer materials not being sufficiently fractured. In view of the low yields from the boreholes due to low transmissivity, low horse power pump are recommended for installation preferably low pressure hand pumps to ensure sustainable groundwater withdrawal and continuous availability.

The authors are grateful UNICEF and Benue State Government for permission to use the data for non academic purposes. The management of Global Geo-consult is acknowledged for their assistance with the field logistics

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