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Aquifers Hydraulic Parameters Measurement and Analysis by Pumping Test

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Abstract Hydrogeological properties measurements through pumping or slug test is an imperative method of determining the productivity of an aquifer for effective sustainability and development. Therefore groundwater potential evaluation using pumping test was carried out on thirty six boreholes, straddling different geologic units in Southern parts of Ondo State, Nigeria. This was done in order to estimate the transmissivity and hydraulic conductivity of the overburden aquifers. The pumping test involved a 1.0-hp submersible pump with a check valve and a 19-mm diameter discharge line. The static water levels measured range between 1.2 – 30.5 m, and an average of 11.9 m. The static water level was higher in sandstone derived aquifers than shale, granite, gneiss or migmatite, with an associated low drawdowns less than 2 m. The values of hydraulic conductivity estimated in the area vary from 0.0797 (Ile Oluji) to 65.2493 m/d (Ilaje/Ese Odo/Igbekebo), and an average of 6.25 m/d. The transmissivity values range between 1.6183 – 652.4928 m^2/d. The recorded specific yield of the aquifers across the study area shows predominant range of 0 – 100 m^3/d. This range of values generally indicate a non-prolific aquifers, as the mean value obtained is less than 200 m^3/d required for domestic usage based on groundwater usage survey carried out in the study area. The findings of the study shows a fairly homogeneous hydraulic properties, except the southern part which is characterized by high yield capacity, transmissivity, hydraulic conductivity, and considerable aquifer thickness (greater than 25 m) with a steady/high drawdown. Consequently, favourable areas for future groundwater exploitation/development is the southern parts which embraced Erinje, Okitipupa, Ilaje/Ese Odo.

Keywords: *specific yield, hydraulic conductivity, piezometer, static water level, Ondo south, aquifer*

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1. Introduction

Water is a very vital natural resource that humans cannot do without. The survival of every living thing is dependent on it [1]. Water occurs on our planet in three forms as very large, medium and small standing water such as oceans, seas and numerous lakes, as bodies of flowing water in form of major rivers, streams, rivulets and springs; and as subsurface water, in films around grains, droplets in pore spaces and cavities in rocks filling them completely over variable areas and creating underground reservoirs [2]. Subsurface water is further distinguished into two main types, namely: vadose water and phreatic water. Vadose water occurs from surface downwards up to a variable depth and is in rate of downward movement under the influence of gravity. Its movement is commonly described as infiltration. The thickness of soil and rock through which vadose water infiltrates is called ‘‘zone of aeration’’. Obviously, in the zone of aeration, the soils and rocks remain unsaturated with water.

Groundwater includes all the subsurface water reaching a depth below which the pore spaces, openings and other cavities of the soil and rocks are completely filled with water. It is significant part of the hydrologic cycle containing 21% of the world’s supply of freshwater [3,4,5]. Its occurrence and movement are controlled primarily by the aquifer permeability and the lithology of the underlying strata [6,7]. The thickness, length and width of the saturated strata, the aquifer, constitute the groundwater reservoir in a given area. In this zone of saturation, movement of water is principally under the influence of hydrostatic head. It is commonly described by the term percolation, and is generally lateral in character. Water table is the name given to the upper surface of the zone of saturation and is of vital importance in the study of groundwater reservoirs [8].

With ever increasing demands on groundwater supplies, more and more thought should be given to understanding its hydraulic properties and protection [9]. The reasons for the increasing demand in groundwater investigation and supply is not far-fetch, as groundwater is the primary source of water supply abstracted through wells and boreholes for domestic, industrial, irrigation uses, especially in the Southern areas of Ondo State, Southwestern Nigeria. Therefore in order to effectively determine the hydrogeologic units' parameters or characteristics such as hydraulic conductivity, transmissivity, storability etc. was conducted. Aquifer properties is best determined from pumping test or estimated using the Dar-Zurrock parameters obtained from geophysical sounding method [8]. The estimation of aquifer hydraulic parameters using Dar-Zurrock parameters is well known and has been extensively discussed by many scholars [10,11,12]. A number of authors have determined hydraulic characteristics from surface electrical resistivity [13-20]. In this study, field pumping test was used to determine the hydrogeological parameters relevant for groundwater potential zonation of Southern parts of Ondo State, Southwestern Nigeria, for sustainable development, planning and management of the resource.

2. Physiography, Geology and Hydrogeology

The study area is located in the southwestern part of Nigeria (Figure 1) is within Universal Traverse Mercator (UTM) of 680000 – 825000mN and 645000 – 730000mE. The terrain is regionally gently undulating southward; topographic elevations vary from about 405 m above sea level in the central part (Okitipupa), with gradual slope to a near sea level swamp flat in the coastal area to the south especially in Ese Odo where the elevation less than 20 m above the sea level (Figure 1). The area is drained by many perennial streams and rivers among which are Ominla, Oluwa, Akeun, Ufara, and Oni, while the southern part is particularly characterized by lagoons, coastal creeks, canals, and several tributaries to the extensive River Oluwa [21]. The annual temperature ranges from 24 to 27 ℃ and the mean annual rainfall is over 2500 mm [22].

The area is underlain by the Coastal Plain Sands or the Benin Formation (Figure 2). The sediments of the Coastal Plain, deposited during the Late Tertiary – Early Quaternary period [23], consist of unconsolidated, coarse to medium- fine grained sands and clayey shale in places [24]. The sands are generally moderately sorted and poorly cemented. The Benin Formation is overlain by lateritic overburden or recent alluvial deposits and underlain by the Paleocene Akinbo Formation. This formation is predominantly shally. Outcrops of shales were mapped around a spring at Ode Aye [21]. The Akinbo shale is underlain by the continental Cretaceous sediments of the Abeokuta Group [25]. The Coastal Plain sands constitute the major shallow hydro-geologic units in the area. Aquifers are characteristically continental sands, gravels, or marine sands. The lateritic earth overlying the sands, as well as the underlying impervious clay/shale member of the Akinbo Formation, constitute protective configuration for the aquifer unit.

Also, the high annual rainfall and other favourable climatic and geologic factors guarantee adequate groundwater recharge in the area. However, Odigbo falls within the geologic terrain underlain by the Precambrian basement complex rocks of southwestern Nigeria (Figure 3), characterized by the Migmatite-gneiss complex, older granites, charnockites, quartzite and minor intrusive lithologies. The local geology consists of quartzite and biotite granites. Field observation shows that biotite granites in the area occur as large igneous bodies, or as boulders, with grey to pink in colours, and largely coarse-grained. Fractures and minor faults were noticed in both the quartzite and biotite granites outcrops across the area.

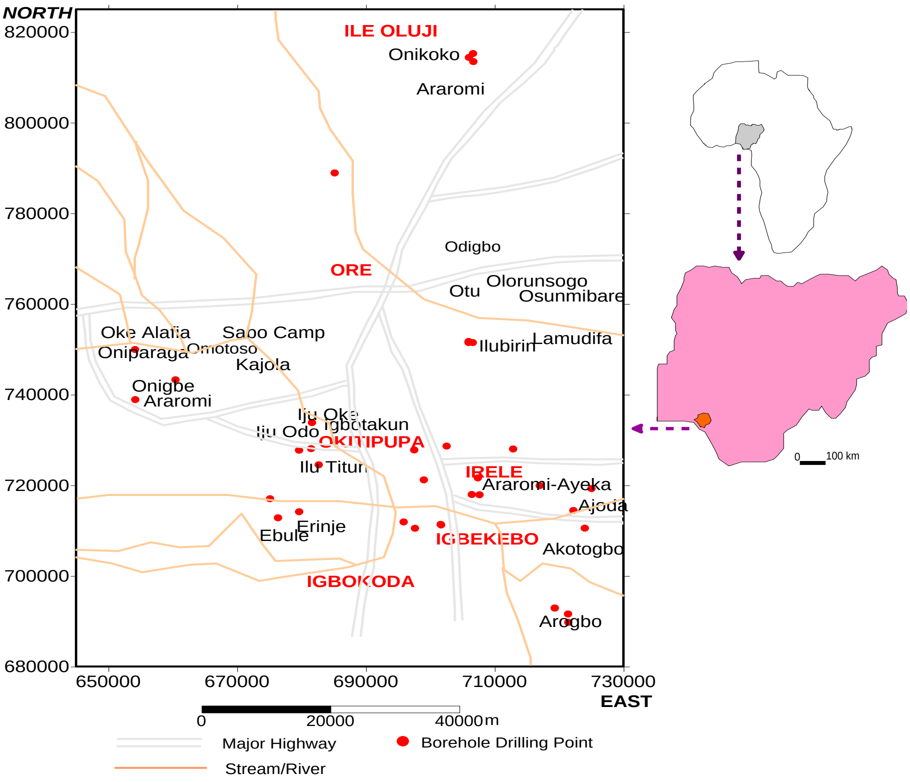

Figure 1. Location map of the study area showing the sampling points

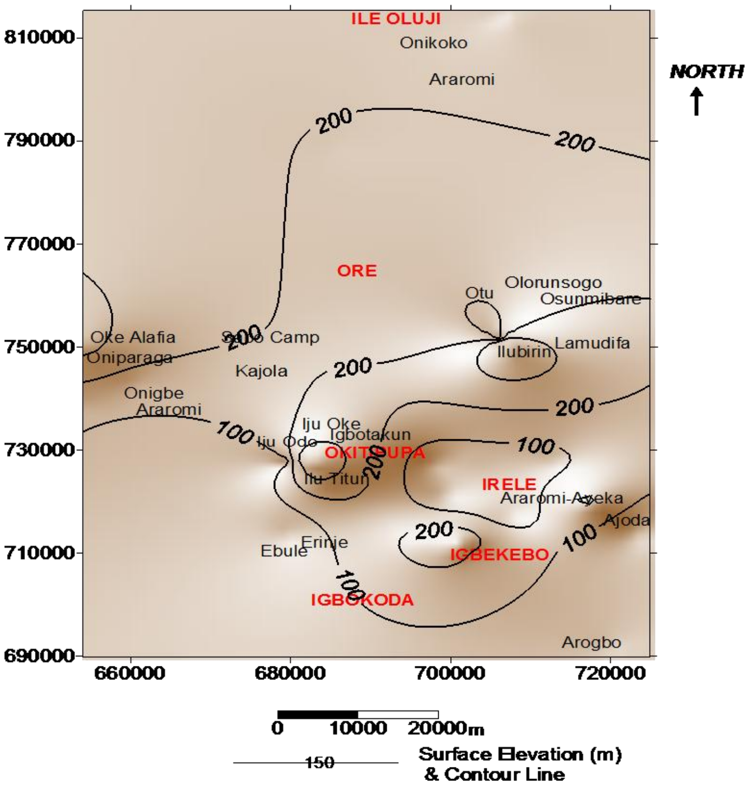

Figure 2. Shaded relief map of the study area

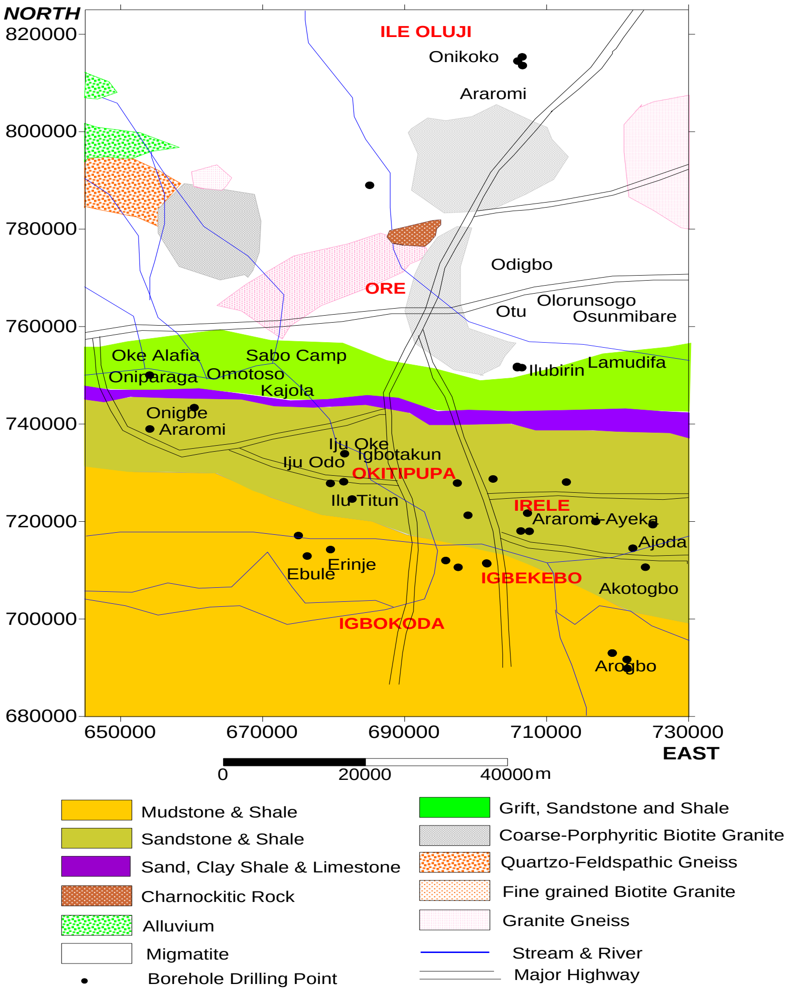

Figure 3. Geological map of the study area (modified after [26]) showing the geologic units and borehole drilling points

3. Material and Method

Pumping tests were performed Thirty six boreholes, straddling different geologic units as shown in Figure 3. This was done in order to estimate the transmissivity, hydraulic conductivity and storability of the overburden aquifers. Prior to initiating the test, the following data were gathered: the geologic characteristics of the subsurface that may influence ground water flow, the type of water-bearing zone and its lateral and vertical extent; the depth, thickness, and lateral extent of any confining beds; location of recharge and discharge boundaries, horizontal and vertical flow components (e.g., direction, gradient); location, construction, and zone of completion of any existing wells in the area; location and effects of any pumping wells; approximate values and spatial variation of formation T and S; and determination of seasonal ground water fluctuations and any regional water level trends.

All these were information were studied or acquired so as to have a successful test and reliable data. A single well pumping test involves pumping at a constant or variable rate and measuring changes in water levels during pumping and recovery. Such tests are used to determine T and K when water level recovery is too rapid for slug tests and no observation wells or piezometers are available. A simplistic single well test consists of pumping at a constant rate and measuring drawdown.

When the water level has stabilized, steady flow conditions can be assumed and the variation of the Theim equation can be used for estimating T, modified from Boonstra and de Ridder [27].

3.1. Pumping Well Design

The design of the pumping test was dependent on the hydrogeological environment and the purpose of the test. Therefore the test was designed and taking into cognizance, the determination of pumping well location and design, pumping rate, pump selection, location and depth of observation wells, test duration, discharge rate measurements and devices, interval and method of water level measurements, and method of analyzing the data collected.

During the pumping test in the study area, a 1.0-hp submersible pump with a check valve and a 19-mm diameter discharge line. The flow rate was measured using a flow meter. The pumped water was discharged 30-m from the test well. Data loggers were used to monitor water levels in pumping and observation wells. Periodic water level measurements were also recorded with a depth-to-water level meter. The pumping test lasted for a period of between 5 to 12 hours depending on the time at which the individual borehole been pumped achieved equilibrium, with the pumping rate which depends on the yield of the pumping well (aquifer unit) and on the borehole response to water abstraction. It drilled boreholes accommodated the pump, assure hydraulic efficiency, and allow measurement of depth to water before, during and after pumping.

Transmissivity measurements from aquifer tests were divided by a thickness value to obtain hydraulic conductivity. The length of the open interval of the well or borehole was used to calculate hydraulic conductivity from this transmissivity.

$$K = \frac{1.18Q}{hs}. \tag{1}$$

The transmissivity is obtained from;

$$T = Kh \tag{2}$$

where;
K = Hydraulic Conductivity (m/s)
Q = Yield of borehole or well discharge (l/s)
h = Thickness of aquifer or screen length used (m)
s = Recorded maximum Drawdown in the pumping well (m)
T = Transmissivity (m^2/s).

4. Results and Discussion

The results of the pumping test are presented in Table 1 and Table 2 showing the calculated hydraulic properties of different hydrogeological/aquifer units. After the well site has been chosen, drilling operations begun. The well consist of an open-ended pipe, perforated or fitted with a screen in the aquifer to allow water to enter the pipe, and equipped with a pump to lift the water to the surface in accordance to Driscoll [28], Groundwater Manual [29], and Genetier [30]. The depth of the well varies from 18 m (in Ilaje and Ese Odo due to shallow depth to the aquifers) to 100 m (in Okitipupa) with an average of 33.9 m. The boreholes were drilled to the bottom of the aquifers and this allows longer well screen to be placed, which will enhances a higher well yield. The installation depths of the boreholes vary from 12.4 m to 98 m. The length of the borehole screen which is the thickness of the aquifer is between 8.2 – 28.3 m with an average of 28.3 m. The thickness of the aquiferous units is thicker in the southern part than any other area in the study area. The depth at which the screen is placed, is depth at which the coarsest materials are found. To prevent the blocking of well screen openings by spherical grains, long narrow slits were preferable. The water delivered by the wells was prevented from returning to the aquifer by conveying the water through a large-diameter pipe, to a distance of 100 m. Figure 4 shows that the aquifer thickness increases towards the south, in order of magnitude of 25 m with a corresponding static water level of 15m.

The static water levels measured in piezometers represent the average head at the screen of the piezometers and range between 1.2 – 30.5 m, and an average of 11.9 m. The static water level was higher in sandstone derived aquifers than shale, granite or migmatite, with an associated low drawdowns less than 2 m. In unconfined aquifers, which is the case in the study area, the loss of head propagates slowly, and the release of water from storage is mostly due to the dewatering of the zone through which the water is moving, and only partially due to the compressibility of the water and aquifer material. Hydraulic conductivity (K) which its physical meaning is stated as “the volume of liquid flowing perpendicular to a unit area of porous medium per unit time under the influence of a hydraulic gradient of unity.”

The hydraulic conductivity of fractured rocks depends largely on the density of the fractures and the width of their apertures. The values of hydraulic conductivity estimated in the area vary from 0.0797 (Ile Oluji) to 65.2493 m/d (Ilaje/Ese Odo/Igbekebo), and an average of 6.25 m/d. Figure 5 shows a nearly homogeneous and isotropic medium because of little variation observed in K-values, except small area around Arogbo, Erinje, and part of Okitipupa which depict high K-values (greater than 20 m/d). However K-values in the range of 0 – 20 m/d is the most preponderant. Figure 6 shows the variation of transmissivity values across the study area, and it varies between 1.6183 – 652.4928 m^2/d. Transmissivity describes the ease with which water moves through a large porous medium body such as a horizontal; or layered aquifer. It is simply the product of hydraulic conductivity and saturated thickness of the aquifer. High transmissivity values greater than 50 m^2/d characterized the southern area, while low (less than 10 m^2/d) in Ore and Ile Oluji areas. However, this finding is typical of the basement complex of Nigeria.

The recorded specific yield of the aquifers across the study area is shown in Figure 7. The map shows predominant range of 0 – 100 m^3/d. This range of values generally indicate a non-prolific aquifers, as the mean value obtained is less than 200 m^3/d required for domestic usage based on groundwater usage survey carried out in the study area. However high yield aquifers are observed around Igbokoda/Igbekebo area. The groundwater yield of boreholes can be used as an index for the assessment of groundwater potential of the area.

Table 1. Pumping Test Data obtained from the Boreholes

S/No.	Easting (mE)	Northing (mN)	Elev. (m)	T.D (m)	I.D (m)	SWL (m)	SL (m)	D (m)	Yield (m^3/d)	P.C (Hp)	Geology
1	697422	727882	26	18.0	17.5	2.6	10	7.4	103.68	1.0	SH
2	679554	714245	12	20.0	12.4	3.0	8.2	0.5	108.86	1.0	SH
3	675029	717118	20	30.0	25.0	11.0	18.5	3	103.68	1.0	SH
4	676271	712913	9	21.0	20.0	4.7	17	4.3	107.14	1.0	ST
5	719248	693002	3	18.1	17.5	3.0	10	0.2	110.59	1.0	ST
6	721351	689846	8	29.6	28.0	2.0	21.2	4	106.27	1.0	ST
7	721313	691689	9	22.0	16.0	1.5	9.6	2.5	111.46	1.0	ST
8	698919	721283	9	20.0	19.0	3.5	10.5	0.4	108.86	1.0	ST
9	701598	711339	222	25.0	24.6	2.4	8.8	2.1	106.27	1.0	MG
10	685073	788998	187	20.0	19.6	3.6	16.9	9.7	86.40	1.0	MG
11	705927	814485	221	45.0	44.6	6.9	8.9	8.1	104.54	1.0	MG
12	706606	813566	260	30.0	29.0	14.5	24.5	6.5	103.68	1.0	MG
13	706558	815341	261	40.0	26.0	6.3	19.2	1.7	107.14	1.0	MG
14	707566	717996	43	42.0	40.0	23.0	17.1	0.8	110.59	1.0	ST
15	723914	710625	43	42.0	35.0	12.2	26.8	5.3	110.59	1.0	ST
16	724955	719354	78	35.0	34.0	29.2	24.2	2.8	103.68	1.0	ST
17	719248	693002	63	36.0	29.0	18.0	26.1	1	110.59	1.0	ST
18	712783	728093	65	31.0	30.0	17.9	20.4	2.1	110.59	1.0	ST
19	706368	718054	45	42.0	40.0	30.5	22.6	1.6	106.27	1.0	ST
20	702457	728730	62	20.0	15.5	8.0	9.9	1.8	106.27	1.0	ST
21	707307	721713	50	42.0	41.8	28.0	23.8	13	65.66	1.0	ST
22	722146	714519	26	45.0	32.0	28.0	20.5	4.2	106.27	1.0	SH
23	705872	751814	35	30.0	29.5	5.2	18.8	8.5	69.12	1.0	MG
24	654106	738986	133	28.0	27.6	7.3	18	8	107.14	1.0	GE
25	660358	743364	153	32.0	31.6	6.8	19.8	18.4	105.41	1.0	GE
26	705872	751570	353	30.0	29.5	5.2	18.8	22.9	69.12	1.0	GE
27	706518	751570	357	30.2	30.0	6.6	17.9	15.4	86.40	1.0	GE
28	654075	750042	333	28.0	27.6	7.3	17.2	8	107.14	1.0	GE
29	679542	727821	59	31.0	30.9	12.0	20.3	18.9	25.92	1.0	ST
30	695787	711995	231	100.0	98.0	14.0	28.3	61.9	553.82	1.0	ST
31	697540	710602	234	45.0	35.5	23.0	15.5	0.4	108.00	1.0	ST
32	682599	724608	311	45.5	42.7	25.6	18.1	3	107.14	1.0	ST
33	681417	728164	405	45.5	42.7	26.8	16.2	3.2	106.27	1.0	ST
34	681547	733909	226	46.0	45.6	1.2	14.4	18.2	107.14	1.0	ST
35	701536	711462	323	27.0	26.6	13.0	10.3	2	106.27	1.0	SH
36	716918	720005	223	27.0	26.4	13.5	10.2	3.5	107.14	1.0	ST

Note: ST-Sandstone; GE-Granite; MG-Migmatite; SH-Shale; T.D – Total Depth; I.D-Installation Depth; SWL-Static Water Level; SL-Screen Length; D-Drawdown; P.C-Pump Capacity.

Table 2. Calculated Hydraulic properties/characteristics of the Aquifers in the Study Area

S/No.	Easting (mE)	Northing (mN)	**Yield (m^3/d)**	**Hydraulic Conductivity (m/d)**	**Transmissivity (m^2/d)**	**Geology**
1	697422	727882	103.68	1.6533	16.5328	SH
2	679554	714245	108.86	31.3316	256.9190	ST
3	675029	717118	103.68	2.2044	40.7808	SH
4	676271	712913	107.14	1.7294	29.4001	ST
5	719248	693002	110.59	65.2493	652.4928	ST
6	721351	689846	106.27	1.4788	31.3502	ST
7	721313	691689	111.46	5.4799	52.6072	ST
8	698919	721283	108.86	30.5856	321.1488	ST
9	701598	711339	106.27	6.7858	59.7147	MG
10	685073	788998	86.40	0.6219	10.5105	MG
11	705927	814485	104.54	1.7112	15.2299	MG
12	706606	813566	103.68	0.7682	18.8219	MG
13	706558	815341	107.14	3.8732	74.3650	MG
14	707566	717996	110.59	9.5394	163.1232	ST
15	723914	710625	110.59	0.9188	24.6224	ST
16	724955	719354	103.68	1.8055	43.6937	ST
17	719248	693002	110.59	4.9999	130.4986	ST
18	712783	728093	110.59	3.0462	62.1422	ST
19	706368	718054	106.27	3.4679	78.3756	ST
20	702457	728730	106.27	7.0371	69.6672	ST
21	707307	721713	65.66	0.2504	5.9603	SH
22	722146	714519	106.27	1.4565	29.8574	SH
23	705872	751814	69.12	0.5104	9.5955	MG
24	654106	738986	107.14	0.8779	15.8026	GE
25	660358	743364	105.41	0.3414	6.7599	GE
26	705872	751570	69.12	0.1895	3.5616	GE
27	706518	751570	86.40	0.3698	6.6203	GE
28	654075	750042	107.14	0.9188	15.8026	GE
29	679542	727821	25.92	0.0797	1.6183	SH
30	695787	711995	553.82	0.3731	10.5576	ST
31	697540	710602	108.00	20.5548	318.60	ST
32	682599	724608	107.14	2.3282	42.1402	ST
33	681417	728164	106.27	2.4190	39.1878	ST
34	681547	733909	107.14	0.4823	6.9462	SH
35	701536	711462	106.27	6.0874	62.7005	SH
36	716918	720005	107.14	3.5412	36.1201	SH

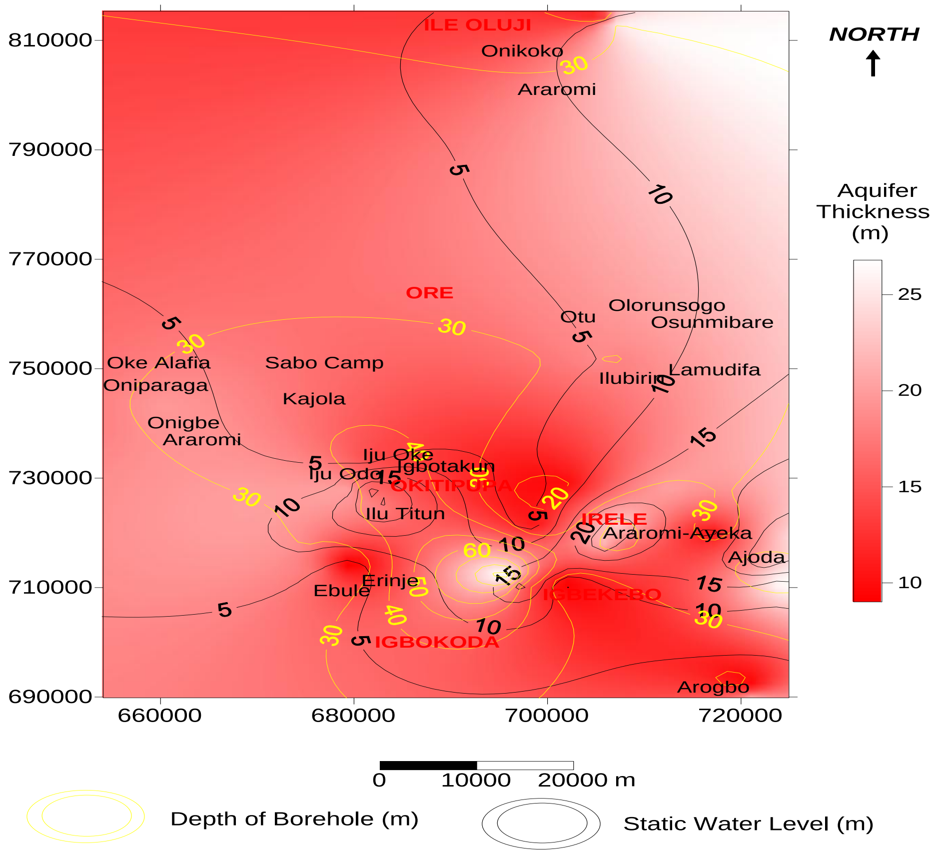

Figure 4. Spatial variation of Aquifer thickness, Static water level, and depth of borehole across the study area

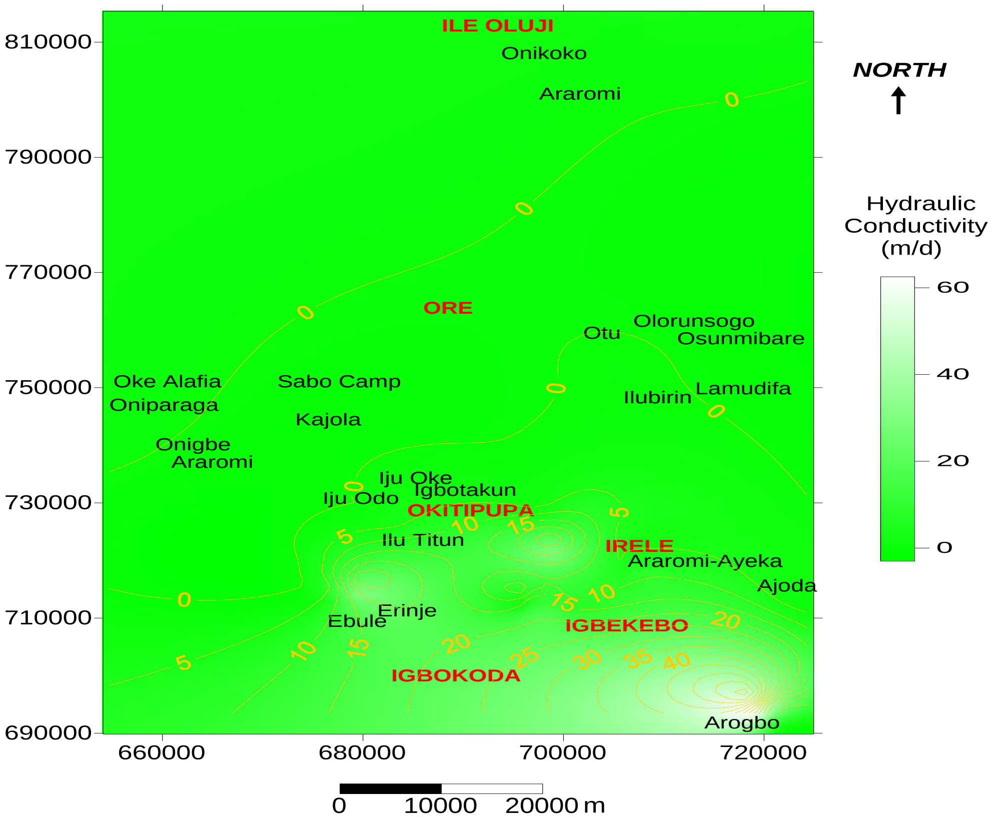

Figure 5. Distribution of the hydraulic conductivity across the study area

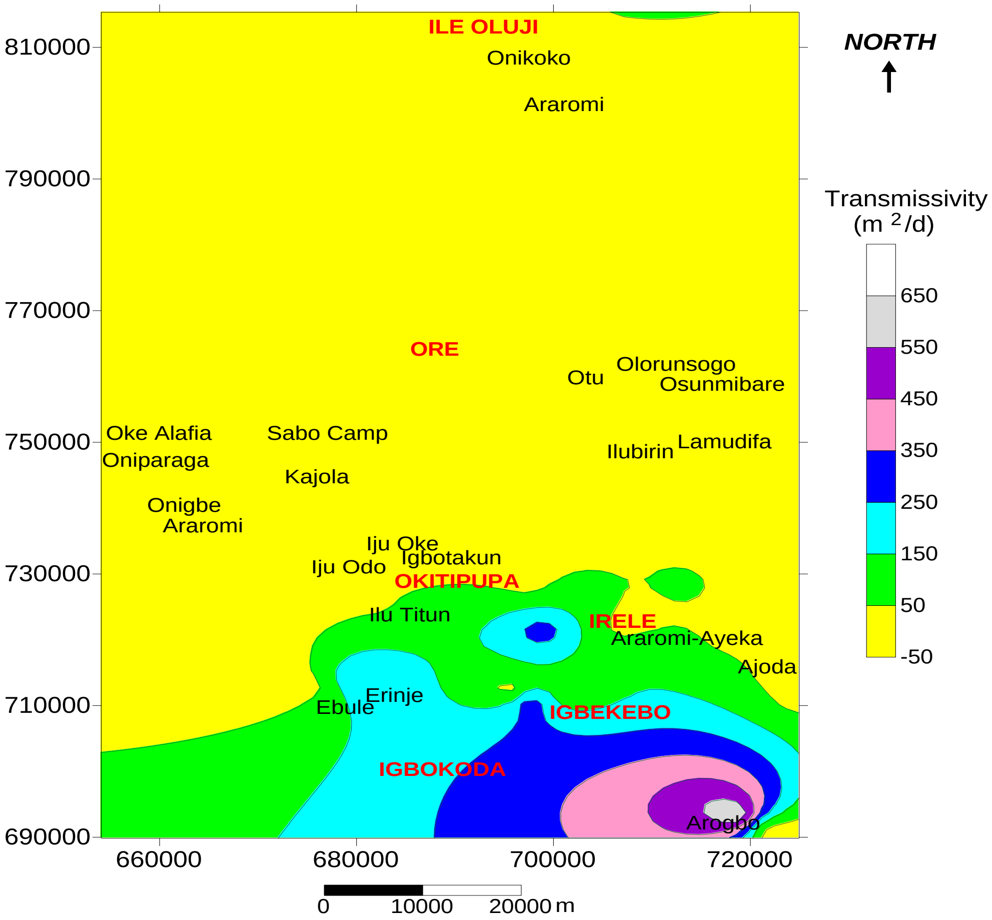

Figure 6. Spatial variation of transmissivity values across the Study area

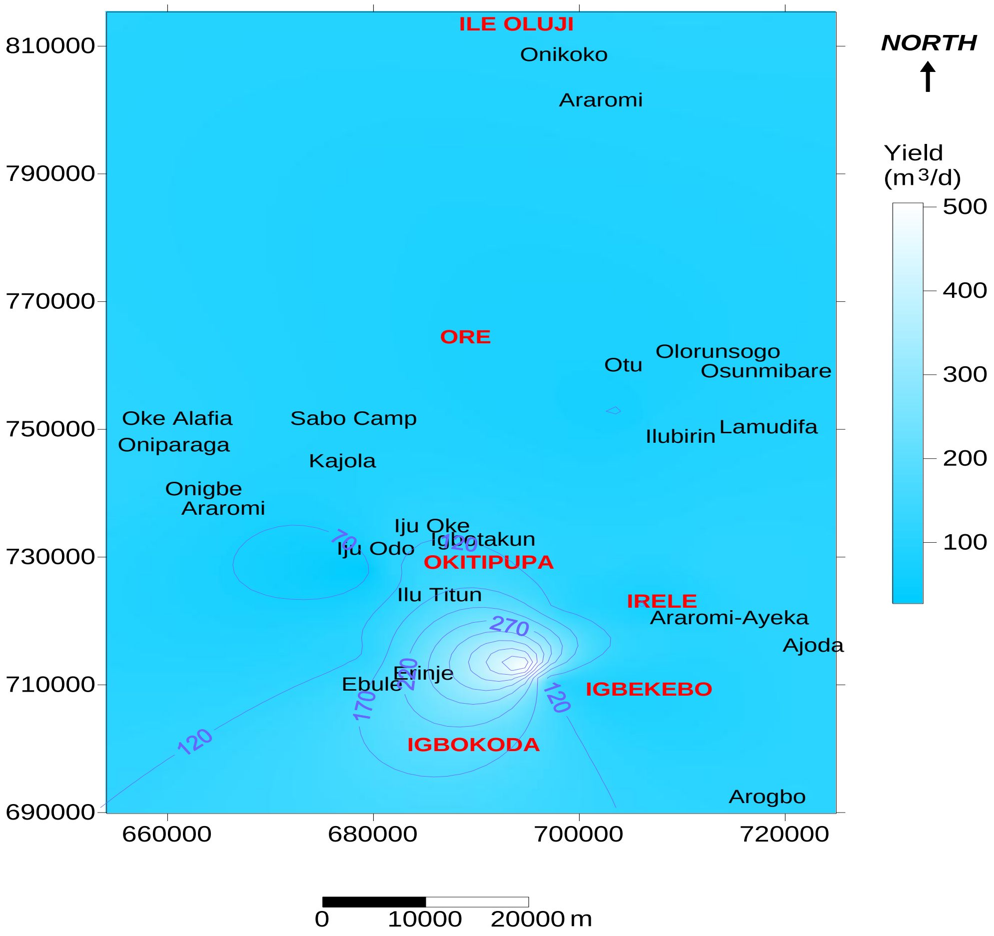

Figure 7. Distribution of yield values of the aquifer units across the study area

5. Conclusion

Pumping tests are used to determine in-situ properties of water-bearing formations and define the overall hydrogeologic regime. Such tests can determine transmissivity (T), hydraulic conductivity (K), storativity (S), connection between saturated zones, identification of boundary conditions, and the cone of influence of a pumping well in a ground water extraction system. The findings of the study shows a fair homogeneous hydraulic properties, except the southern part which shows distinct good hydraulic properties, characterized by high yield capacity, transmissivity, hydraulic conductivity, and considerable aquifer thickness (greater than 25 m) with a steady/high drawdown. Consequently, favourable areas for future groundwater exploitation / development is the southern parts which embrace Erinje, Okitipupa and Ilaje/Ese Odo.

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Conflict of Interests

The authors have not declared any conflict of interests.

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