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Hydraulic properties determination from pumping test in Northern areas of Ondo state, South-western Nigeria for groundwater development

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Abstract. Groundwater potential evaluation of the Northern area of Ondo State using information obtained from hydrogeological measurements of hydraulic conductivity, transmissivity, and yield aquifer characteristics from 37 drilled boreholes. These data were analyzed alongside the information gathered during the pumping test at each site which includes drawdown values, static water level, and pumping rate. The average depth of the borehole and installation depth are 30.76 m and 28.9 m respectively. The static water level ranges from 2.7 m to 14.0 m with an average of 6.0 m. The drawdown recorded from the observation wells varies from 1.9 m and 15.1 m. The yield capacity of the boreholes ranges between 0.40 – 2.98 L/s, and an average of 25.5654 m³/d. The values of hydraulic conductivity conducted in the area vary from 0.37 to 23.29 m/d, and an average of 3.67 m/d. The calculated transmissivity for the study area ranges from 4.79 (gneiss) to 165.32m²/d (migmatite) and an average of 30.08m²/d. The values of specific capacity vary from 4.07 – 140.53, while storativity within the range of 0.0002 – 0.001 are the most dominant showing a corresponding low specific capacity values generally less than 10 m²/d. Consequently, specific yield, hydraulic conductivity, and transmissivity values were integrated to generate a groundwater potential map for Ondo Northern area.

1. Introduction

Groundwater is a natural treasure and most important natural resource [1]. Groundwater is one of the most important natural resources on earth, derived from surface precipitation (rain), surface water and melted snow which percolate into the subsurface earth through pore spaces, jointed and fracture planes, filtered by the earth medium and store in the pore spaces of the sediments and weathered zone [2]. Groundwater is abstracted through hand-dug wells, hand-pump operated shallow wells and submersible pump operated deep wells [3]. Therefore because of the ever increasing population growth, the requirement for water supply for various purposes have increased the demand for groundwater since large number of communities depend majorly on groundwater through hand dug wells and boreholes as a supplement to supply from surface sources.

The crystalline basement rocks in their undeformed occurrence possess little or no primary inter-granular porosity or permeability and the hydrogeological properties they possess are thus mainly

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determined by secondary transmissivity. The high rate of failure of boreholes in the basement rocks can be largely attributed to the fact that very little is usually known about the hydraulic properties of the aquifer units such as hydraulic conductivity (K), transmissivity (T), and storability. The understanding of aquifer characteristics will invariably assist the sustainability of the groundwater resources in a particular geologic environment [4]. Pumping test have proved to be one of the most effective ways of obtaining hydraulic characteristics of geological formations through which the groundwater is moving. The principle of a pumping test is that water is pumped from a well and the discharge of and drawdown in the well are measured in piezometers at known distances from the well. The hydraulic characteristics of the aquifer can be calculated by substituting these measurements into an appropriate well-flow equation [1, 2]. Pumping tests and other hydraulic tests can greatly improve our understanding of the hydraulics of aquifers and their potential for groundwater supplies [5 ,6, 7]. Therefore on this basis, determination and evaluation of aquifer(s) hydraulic properties were undertaken in the Northern areas of Ondo State, South-western Nigeria, with the purpose of classifying the aquifer units into different hydrogeological zone or potential; and to enhance the success rate of groundwater abstraction through wells/boreholes. In addition this will serve as a useful guide to an elaborate groundwater development programme for the area.

2. Materials and methods

2.1The Study area

The study area is located at the northern area of Ondo State, South-western Nigeria (figure. 1). Represented in Universal Traverse Mercator (UTM), it lies within Latitudes 795000 and 855000mN and Longitudes 785000 and 825000mE. The study area is accessible through Akure –Owo, Benin – Ifon, and Lokoja - Ajowa highways. The area varies from 300 m (in Owo) to 560 m (Oke-Agbe) above the sea level. The prominent topographic features in the area are the residual hills which form recognizable inselberg with elevation ranging from about 430 to 518 m above sea level (figure 2). The study area is drained by River Ose and Ogbese and their numerous tributaries (figure 3). The climate of the area of tropical rain forest; with precipitation varying from 1000 mm to 1800 mm with an average of 1500 mm. The temperature varies from 21°C to 33°C with mean temperature of 24°C and relative humidity of 80% [8]. The vegetation is the rain forest type with tall crowned trees mixed with thick undergrowth.

2.2 Geology and Hydrogeology of the Area

Aquifer test or pumping test was conducted to estimate the hydraulic properties of aquifers such as transmissivity, hydraulic conductivity, aquifer yield, and storativity; to evaluate the well performance and to identify the aquifer boundaries, which is for the evaluation of an aquifer by stimulating the aquifer through constant pumping, and observing the aquifer's response (drawdown) in the observation wells [2]. However aquifer's hydraulic properties depend on its hydrogeologic characteristics. The area falls within the South-western Basement Complex, which is part of the Basement Complex of Nigeria. The lithologic units include Schist, Quartzite, gneiss and Migmatite (figure 2). These types of rock units are usually characterized by poor hydraulic properties due low porosity and hydraulic conductivity. However these properties can be improved by fracturing, faulting, jointing etc. Porosity of a rock is its property of containing pores or voids, while hydraulic conductivity is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The Schist is characterized by parallel arrangement of its constituent minerals. The flaky minerals give rise to its schistocity which include muscovite and biotite. In the study area, the schist is observed as a low-lying outcrop of quartz-mica-schist which occurs prominently at Owo and environ.

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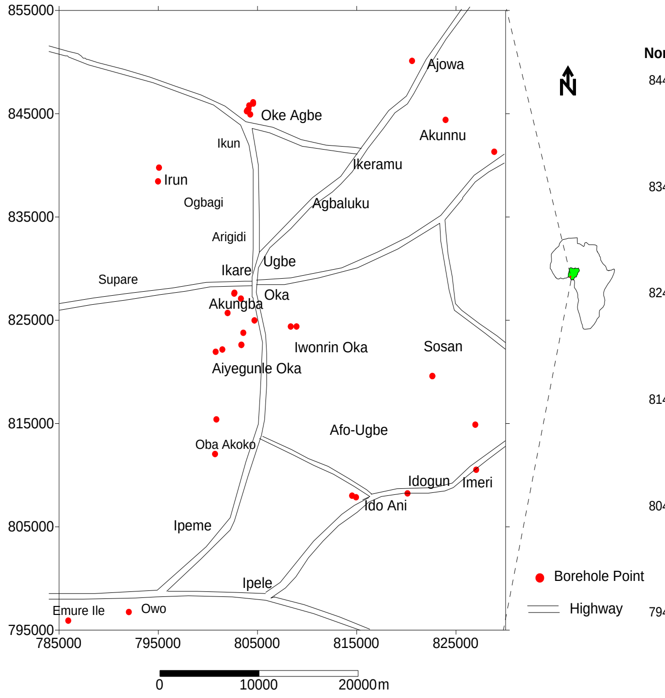

Figure 1. Location Map of the study area showing the drilled borehole locations

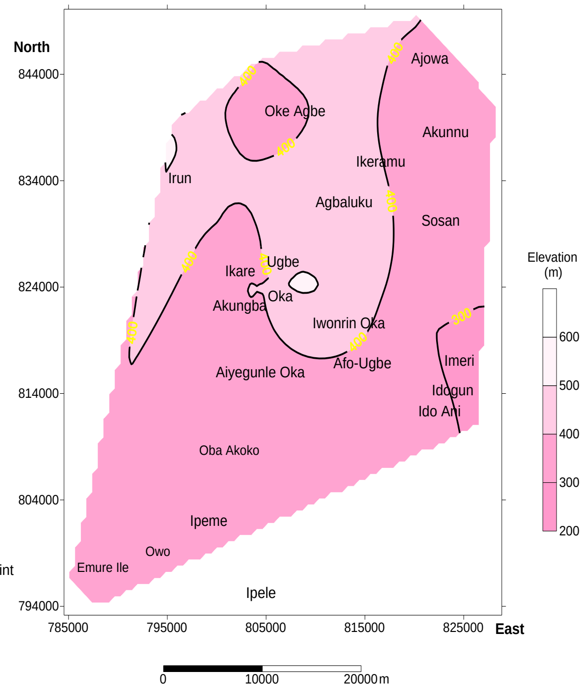

Figure 2. Topographical Map of the study area showing a variation between 200 and 600 m

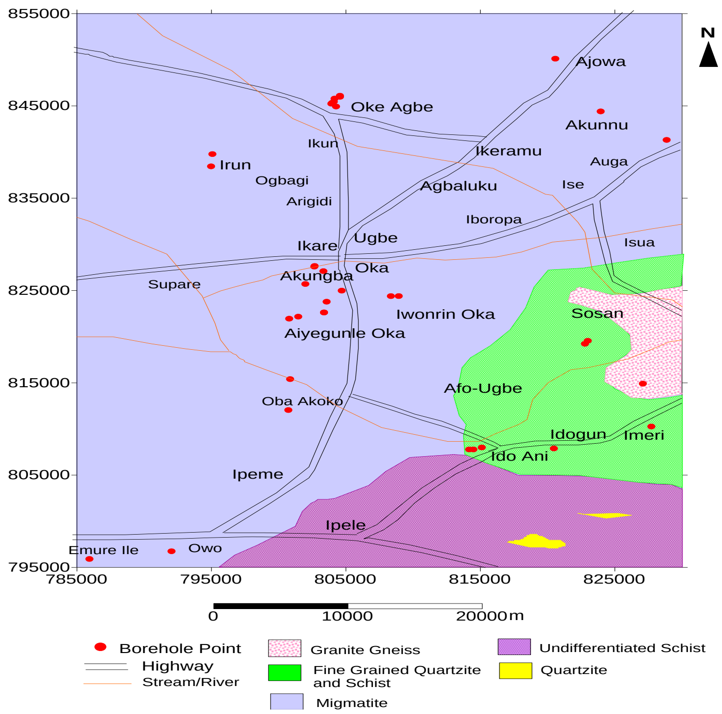

Figure 3. Geological map of Northern area of Ondo State (modified after Geological Survey [9]

The schists have been highly weathered to low-lying terrains and covered by vegetation. However, the schist is exposed along Owo - Akungba highway. At some places in Isuada and Ipele, the schists are pegmatised as a result of intrusion. The pegmatites occur in two varieties: those found in association with migmatites, and those commonly found intruding mainly into the schist. The variety found in association with the schist is simply massive and form widespread undulating topography. It forms elongated hill around Ipele area. Some of the pegmatites have been weathered and disintegrated into rubbles and boulders, while the feldspar has been converted into clay. The Quartzite is a metamorphosed arenaceous rock and appear as massive and schistose in places. Some of the quartzites are coarsely crystalline while others are medium grained. The schistose variety forms two prominent and sub-parallel ridges which extend for several kilometers at Owo, the South-western flank of the study area. Migmatite is a mixed rock which is made up of two different sources. The two materials are pre-existing host rock which is a metamorphic rock and invading granitic material which may take the form of magma and hydrothermal solution.

The migmatite observed in the study area occurs as a low-lying and extensive outcrop which is foliated especially in Akoko and IdoAni. It contains minerals such as biotite, quartz and feldspars. It is medium to coarse grained in size. The migmatite is intruded by pegmatite in Akoko area, which is either cross-cutting the host rock or are found aligned parallel in the N-S structural trend of the host rock in association with the quartz veins and aplites. The groundwater within the study area occurs under water table conditions and at depths where it may be confined by interstitial clays. The primary permeability in this unit is low due to clay which results from the weathering of schist and migmatite that contain ferromagnesian minerals. Although areas underlain by schist are usually characterised by thick weathering depths, the ability of this thick overburden to transmit groundwater could be hindered by the low permeability of the clayey aquifer. Groundwater yield of such an area can be attributed to the secondary porosity and permeability of basement bedrock created by fractures, joints, faults and sheared basement bedrock. Presence of pegmatitic and quartzo-feldspathic veins can also enhance groundwater yield. The depth to groundwater is shallow (i.e. less than 20 m).

2.3 *Determination of Transmissivity and Specific Capacity*

Adequate design and execution of a pumping test involves considerable planning and attention to detail. An understanding of fundamental well hydraulics is necessary not only for the interpretation of data, but also for the experimental design by which valid and usable data are obtained. The borehole data used for this study were obtained from the completion report of the drilled boreholes prepared by Ondo State Water Corporation, Ondo State, South-western, Nigeria.

The information covers the different geologic units such as schist, migmatite, granite, gneiss, granite gneiss, and quartzite (Fig. 2). Data such as the borehole depth, aquifer thickness, and material composition of the aquifer units. All these were information were deduced from the lithological logs of 37 boreholes drilled in th e study area. These data were analyzed alongside the information gathered during the pumping test at each site which include borehole yield, drawdown values, static water level, and pumping rate.

$$K = \frac{1.22Q}{hs} \quad (1)$$

The transmissivity is obtained from;

$$T = Kh \quad (2)$$

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)

[10] gave the following equations for determination of storability of wells:

$$h_o - h = \frac{15.3\ QW_u}{T} \quad (3)$$

and

$$S = \frac{Ttu}{360r^2} \quad (4)$$

u = argument in the solution of the differential equation of the confined flow of water in the aquifer
s = Drawdown
r =Radial distance of the pumping well
W_u = Well function
S = Storability
t = Time of pumping

The value of the well function W_u was obtained and the equivalent value u, obtained from the table and this enabled the computation of S. The specific storage S_s is obtained from the equation:

$$S = S_s h \quad (5)$$

The specific capacity of the wells S_c was determined using [11] formula:

$$S_c = 2.73\text{Kh}\,\frac{1}{log_{10}^{2/r}} \quad (6)$$

The formula can be modified by correct substitutions to give:

$$S_c = 0.85\text{Kh} \quad (7)$$

3. Results and Discussion

3.1 Pumping Tests Records

The results of the pumping test are presented in Tables 1 and 2 showing the calculated hydraulic properties of different hydrogeological/aquifer units. The total depth of the drilled boreholes varies from 12 m on granite gneiss to 50 m in Migmatite/Granite rock, with an average of 30.76 m. This implies that the overburden is relatively thicker than what is obtained in gneiss environment. However the installation depth is between 11.8 m and 49.6 m, and an average of 28.9 m. The static water level ranges from 2.7 m to 14.0 m with an average of 6.0 m. Based on the thickness of the aquiferous units, the screen length adopted during the construction of the boreholes is between 4.0 m (granite) and 22.1 (migmatite). The drawdown recorded from the observation wells varies from 1.9 m and 15.1 m. The highest drawdown value was observed in well 34 which corresponds to a Schist environment. The specific yield which is the ratio of the volume of water drained to the total volume of aquifer mass. It is sometimes also termed as effective porosity. It is the amount of groundwater that can be withdrawn from the aquifer without resorting to mining of water [12]. However, the water holding capacity of a soil mass depends on the grain size, shape and distribution of pores. The soils with small pore spaces retain more water. The retention varies inversely as the size of the pores. The yield capacity of the boreholes ranges between 4.0726 – 140.5255 m^3/d, and an average of 25.5654 m^3/d. This range of values signify a non-prolific aquifers, as the mean value obtained is less than 100 m^3/d required for domestic usage based on groundwater usage survey carried out in the study area. The groundwater yield of boreholes (figure 4) can be used as an index for the assessment of groundwater potential of the district. Figure 4 shows a near homogeneous yield capacity of the aquiferous units, as they are generally less than 1.0 L/s except Oke-Agbe environment, which are characterized by yield values greater than 2.6 L/s. In OkeAgbe area, the geology is migmatite with quartzite and pegmatite intrusions, therefore the weathered material is a little bit sandy in contrast to clayey overburden in other places. The specific yield capacity in Owo and Ose are fair (between 1.6 – 2.6 L/s), while low yield values are sporadically recorded in Oka, Akungba, Imeri, Irun and Akunnu.

Table 1. Pumping Test Data obtained from the Boreholes

S/No.	Easting (mE)	Northing (mN)	Elev.	T.D (m)	I.D (m)	SWL (m)	SL (m)	D (m)	Yield (L/s)	P.C (Hp)	Geology
1	802674	827662	365.0	20.0	19.0	4.3	9.0	6.7	1.10	1.0	GN
2	823949	844405	374.0	40.0	39.9	3.0	6.9	3.9	0.55	1.0	MG
3	804267	844936	355.0	30.0	20.0	5.0	8.7	3.7	1.24	1.0	GN
4	803374	822628	401.0	43.0	40.0	6.4	10.1	5.7	1.24	1.0	GN
5	803370	822617	322.0	12.0	11.8	7.0	9.5	2.5	1.23	1.0	GG
6	803567	823788	427.0	40.0	32.0	5.2	6.5	4.5	1.23	1.0	GN
7	828855	841317	363.0	27.0	23.0	6.0	6.0	7.2	1.20	1.0	MG
8	822618	819599	295.0	24.2	23.5	7.8	4.0	6.2	1.23	1.0	GE
9	803978	845333	512.0	50.0	37.0	2.8	6.3	3.5	2.79	1.0	GE
10	795071	839781	344.0	33.0	32.8	10.6	6.4	6.1	0.80	1.0	MG
11	820573	850116	403.0	32.0	31.2	6.5	8.2	2.2	0.80	1.0	MG
12	804556	846106	515.0	50.0	39.4	5.2	7.1	1.9	2.98	1.0	MG
13	803918	845241	506.0	18.0	17.8	4.0	9.0	5	2.89	1.0	GN
14	804558	845983	513.0	40.0	39.6	7.0	8.8	6.8	2.98	1.0	MG
15	804160	845796	520.0	40.0	39.5	8.4	12.3	3.9	2.90	1.0	MG
16	804101	845457	510.0	35.0	34.5	5.3	11.1	6.8	2.87	1.0	GE
17	794973	838452	530.0	30.0	29.6	10.3	9.8	4.2	1.15	1.0	MG
18	822618	819599	295.0	30.0	29.0	7.8	10.0	6.2	1.28	1.0	GN
19	801984	825707	331.0	22.0	21.9	8.0	7.4	9.4	0.90	1.0	GG
20	804690	824987	362.0	29.0	28.8	8.0	8.5	8.8	0.40	1.0	GN
21	800852	815403	299.0	31.0	30.0	3.5	9.0	8.5	1.23	1.0	GE
22	800782	821950	306.0	30.0	29.6	2.7	7.0	4.3	1.20	1.0	GE
23	801455	822170	301.0	19.0	18.7	3.0	8.6	5.6	0.69	1.0	GE
24	803327	827099	350.0	30.0	29.6	3.2	9.1	5.9	1.24	1.0	MG
25	800719	812051	334.0	50.0	49.6	14.0	8.1	7.1	1.23	1.0	MG
26	808346	824395	550.0	18.5	18.0	3.0	6.0	3.1	1.26	1.0	MG
27	808929	824398	523.0	26.0	25.6	3.0	7.0	4.4	1.01	1.0	MG
28	802649	827587	365.0	22.0	21.0	3.6	22.1	7.7	0.59	1.0	MG
29	814927	807866	346.0	33.0	32.0	6.4	15.0	3.6	1.20	1.0	SC
30	814527	808018	346.0	32.0	31.5	8.8	10.3	3.3	1.23	1.0	SC
31	827036	810527	280.0	33.0	32.0	12.7	12.9	7.6	0.50	1.0	SC
32	826946	814893	275.0	21.0	20.0	6.0	13.0	9.9	0.90	1.0	SC
33	820113	808238	340.0	26.0	25.6	6.0	13.5	11.5	1.20	1.0	SC
34	784540	796711	320.0	34.0	33.6	5.6	14.7	15.1	1.23	1.0	SC
35	785926	795919	326.0	23.5	20.2	3.0	6.0	13	1.10	1.0	QS
36	792031	796754	334.0	34.0	33.6	6.1	12.9	10.5	0.60	1.0	QS
37	787531	793171	346.0	30.0	29.5	2.7	11.9	10.2	0.76	1.0	QS

SC-Schist; QS-Quart Schist; MG-Migmatite; GE-Granite; GN-Gneiss; GG-Granite Gneiss; T.D – Total Depth; I.D-Installation Depth; SWL-Static Water Level; SL-Screen Length; D-Drawdown; P.C-Pump Capacity. Source: Water Corporation of Ondo State, Nigeria

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

S/No.	Easting (mE)	Northing (mN)	Hydraulic Conductivity (m/d)	Transmissivity (m^2/d)	Specific Capacity (m^3/d)	Storativity	Geology
1	802674	827662	1.9229	17.3058	14.7099	0.000404	GN
2	823949	844405	2.1544	14.8652	12.6355	0.000413	MG

3	804267	844936	4.0605	35.3259	30.0270	0.001138	GN
4	803374	822628	2.2704	22.9308	19.4912	0.000841	GN
5	803370	822617	5.4590	51.8607	44.0816	0.002363	GG
6	803567	823788	4.4325	28.8115	24.4898	0.001601	GN
7	828855	841317	2.9280	17.5680	14.9328	0.000566	MG
8	822618	819599	5.2278	20.9116	17.7749	0.000674	GE
9	803978	845333	13.3373	84.0252	71.4214	0.002708	GE
10	795071	839781	2.1600	13.8240	11.7504	0.000323	MG
11	820573	850116	4.6744	38.3302	32.5806	0.000894	MG
12	804556	846106	23.2851	165.3241	140.5255	0.004592	MG
13	803918	845241	6.7695	60.9258	51.7869	0.001692	GN
14	804558	845983	5.2493	46.1935	39.2645	0.001283	MG
15	804160	845796	6.3724	78.3803	66.6233	0.001829	MG
16	804101	845457	4.0080	44.4884	37.8151	0.001038	GE
17	794973	838452	2.9451	28.8617	24.5325	0.000673	MG
18	822618	819599	2.1762	21.7617	18.4974	0.000508	GN
19	801984	825707	1.3638	10.0923	8.5784	0.000236	GG
20	804690	824987	0.5637	4.7913	4.0726	0.000112	GN
21	800852	815403	1.6948	15.2531	12.9651	0.000424	GE
22	800782	821950	4.2023	29.4162	25.0037	0.000817	GE
23	801455	822170	1.5102	12.9877	11.0396	0.000722	GE
24	803327	827099	2.4345	22.1536	18.8305	0.000714	MG
25	800719	812051	2.2544	18.2608	15.5217	0.000669	MG
26	808346	824395	7.1405	42.8433	36.4167	0.001571	MG
27	808929	824398	3.4223	23.9564	20.3629	0.000878	MG
28	802649	827587	0.3655	8.0767	6.8652	0.000224	MG
29	814927	807866	2.3424	35.1360	29.8656	0.000819	SC
30	814527	808018	3.8144	39.2884	33.3951	0.000916	SC
31	827036	810527	0.5376	6.9347	5.8945	0.000193	SC
32	826946	814893	0.7371	9.5825	8.1452	0.000266	SC
33	820113	808238	0.8148	10.9991	9.3492	0.000611	SC
34	784540	796711	0.5841	8.5862	7.2983	0.000477	SC
35	785926	795919	1.4865	8.9191	7.5812	0.000495	QS
36	792031	796754	0.4669	6.0233	5.1198	0.000334	QS
37	787531	793171	0.6599	7.8539	6.6758	0.000436	QS

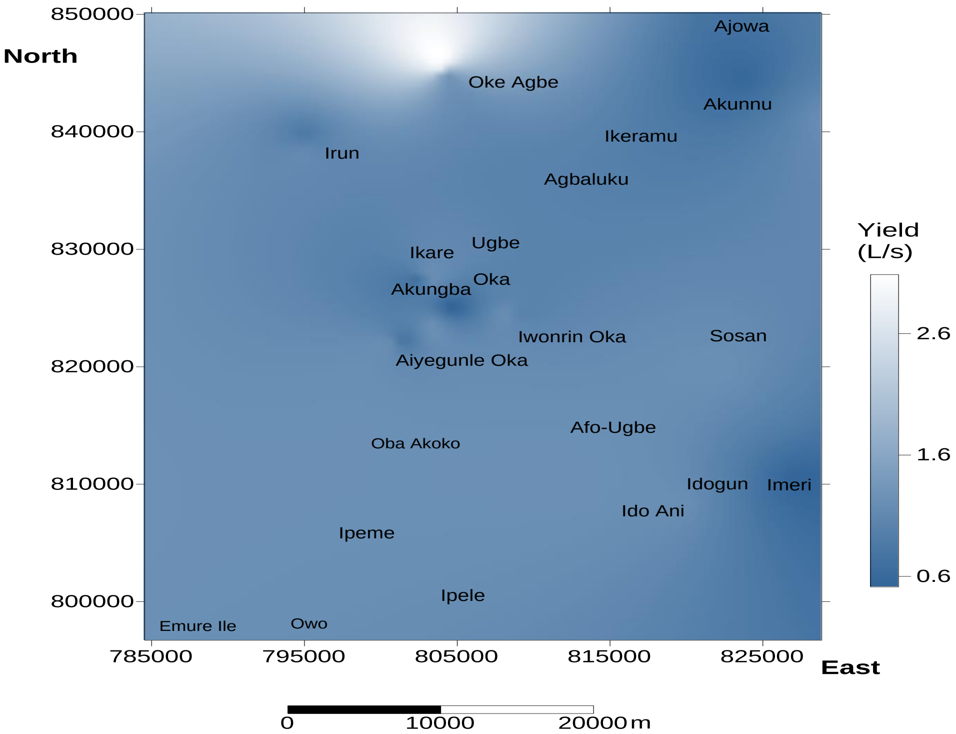

Figure 4. Map of the Study area showing variation of specific yield, with a predominantly near-homogeneous yield capacity

Hydraulic conductivity in 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 values of hydraulic conductivity conducted in the area vary from 0.37 to 23.29 m/d, and an average of 3.67 m/d as shown in figure 5. 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. The areas with high yield are characterized with high transmissivity values above 80 m^2/d and high hydraulic conductivity above 15 m/d. Transmissivity as one of hydrogeological parameters gives the capacity of an aquifer to transmit water through its entire thickness. The calculated transmissivity for the study area ranges from 4.79 (gneiss) to 165.32 m^2/d (migmatite) and an average of 30.08 m^2/d. The values of specific capacity vary from 4.07 – 140.53, while storativity within the range of 0.0002 – 0.001 are the most dominant showing a corresponding low specific capacity values generally less than 10 m^2/d. These clearly indicate that the northern part of the area is the most prolific in terms of groundwater exploitation and thus the most promising in siting productive boreholes. This zone corresponds to the area of high aquifer transmissivity and thickness and thus are good prospects for drilling boreholes. This area also recorded the highest value of storativity of 0.004592. The storativity is as shown in Figure 6

In this study, specific yield, hydraulic conductivity, and transmissivity values were integrated to generate a groundwater potential map for Ondo Northern area. The data sets were imported into Surfer 13 software for storage followed by the allocation of weights to each parameter (see Table 3) and different scores to each attributes within the parameters. Figure 7 shows the generated groundwater potential map for the study area. The map classifies the study area into different groundwater potential zones as Low (0 – 25%), Fair (25 – 50%), Good (50 – 75%), and Excellent competence (75 - 100%). Most parts (75%) of the study area are characterized by Fair potential water bearing units and is widespread in Akoko area. The good and excellent groundwater potential areas are located at the extreme northern part of the study area especially around Oke-Agbe, and accounted for combined 10% of

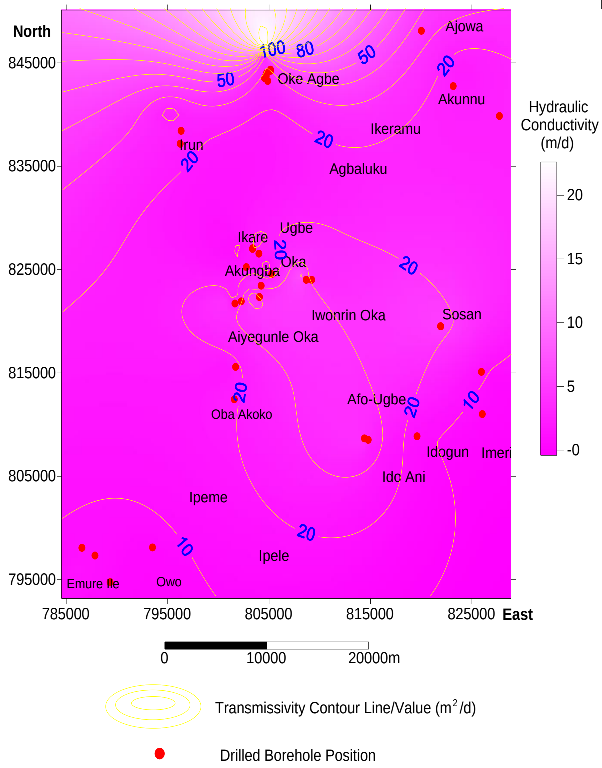

Figure 5: Map of the Study area showing variation of Hydraulic Conductivity and Transmissivity across the area

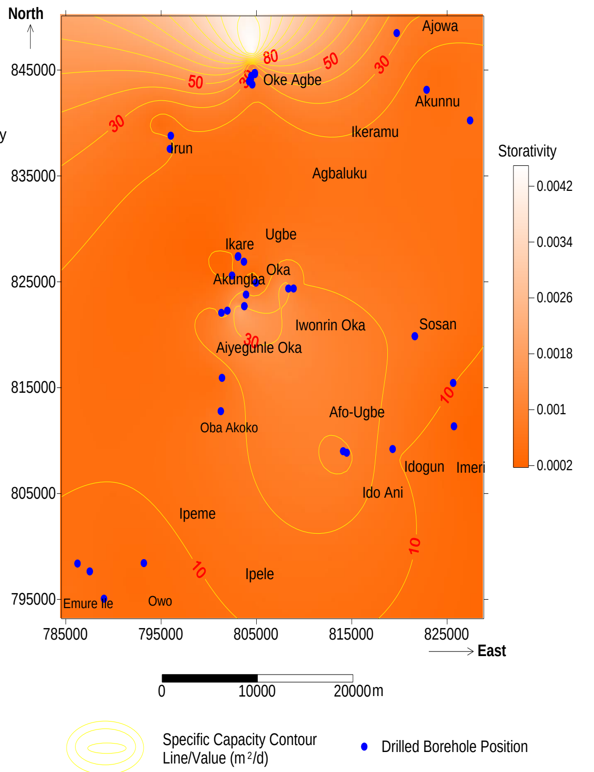

Figure 6: Map of the Study area showing distribution of aquifer storativity and specific capacity values across the study area

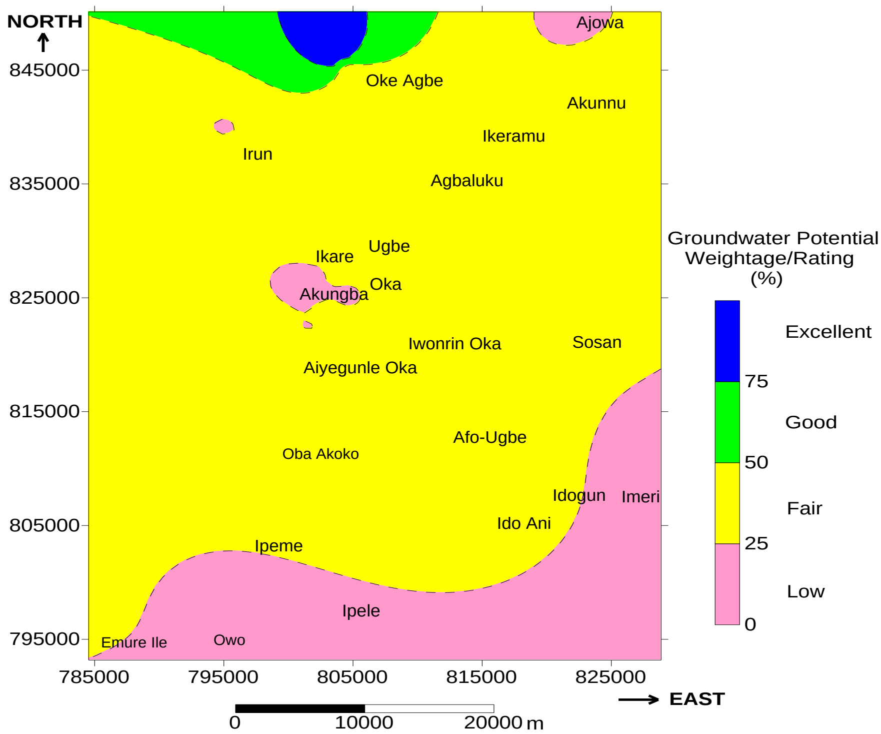

Figure 7: Groundwater Potential Map generated for the Study area by combining the Transmissivity, Hydraulic Conductivity, and Yield values

Table 3:Multi-criteria Evaluation Parameters for Groundwater Potential of the Study Area

S/N	Parameter	Attribute	Rating	Weightage (%)
1	Yield (L/s)	0 – 1	5	40
		1 – 2	20	
		>2	40	
2	Hydraulic Conductivity (m/d)	0 – 50	10	30
		50 – 100	20	
		100 – 200	30	
3	Transmissivity (m²/d)	<1	1	30
		1 – 5	5	
		5 – 100	15	
		100 – 1000	30	

4. Conclusion

The Groundwater potential assessment of the Northern area of Ondo State using hydrogeological measurement was studied. The total depth of the drilled boreholes varied from 12 m on granite gneiss to 50 m in Migmatite/Granite rock, with an average of 30.76 m, with an average installation depth of 28.90 m. The static water level ranges from 2.7 to 14.0 m with an average of 6.0 m. Based on the thickness of the aquiferous units, the screen length adopted during the construction of the boreholes is between 4.0 (granite) and 22.1 m (migmatite). The drawdown recorded from the observation wells varies from 1.9 and 15.1 m. The highest drawdown value was observed in well 34 which corresponds to a Schist environment. The yield capacity of the boreholes ranged between 4.07 – 140.53 m^3/d, and an average of 25.57 m^3/d. This range of values signify a non-prolific aquifers, as the mean value obtained is less than 100 m^3/d required for domestic usage based on groundwater usage survey carried out in the study area. The values of hydraulic conductivity conducted in the area vary from 0.37 to 23.29 m/d, and an average of 3.67 m/d. The calculated transmissivity for the study area ranges from 4.79 (gneiss) to 165.32 m^2/d (migmatite) and an average of 30.08 m^2/d. The values of specific capacity vary from 4.07 – 140.53, while storativity within the range of 0.0002 – 0.001 are the most dominant showing a corresponding low specific capacity values generally less than 10 m^2/d. The generated groundwater potential map for the study area classified the study area into different groundwater potential zones as low (0 – 25%), fair (25 – 50%), good (50 – 75%), and excellent competence (75 - 100%). Most parts (75%) of the study area are characterized by fair potential water bearing units and is widespread in Akoko area. The good and excellent groundwater potential areas are located at the extreme northern part of the study area especially around Oke-Agbe, and accounted for combined 10% of the study area. The Low groundwater potential zone (15%) is observed in Owo, Akungba, and Ajowa.

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