ISSN: 2639-7536

Research Article

Petroleum and Chemical Industry International

Aquifer Performance Test Analysis: An in-Depth Integration For Groundwater Potentials in Anambra Central Senatorial Zone Anambra State, Nigeria, Using Cooper-Jacob Method

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Submitted: 2025, Feb 17; **Accepted:** 2025, Mar 14; **Published:** 2025, Mar 26

Citation: Onyenweife, G. I. and Nwozor, K. K. (2025), Aquifer Performance Test Analysis: An In-Depth Integration for Groundwater Potentials in Anambra Central Senatorial Zone Anambra State, Nigeria, using Cooper-Jacob Method. *Petro Chem Indus Intern, 8*(1), 01-14.

Abstract

The study was conducted to improve the understanding of aquifer performance using Cooper-Jacob Method. This was aimed at generating results to draw the attention of the populace of the study area of ensuring sustainable and effective performance of their drilled wells to meet with the increasing population demands.Fourteen (14) existing wells were tested in the locations of seven (7) towns of Anambra central senatorial zone. The results revealed well perfomance of the study area as; Static Water Level (m) range; Anaocha 127.70-21.80, Awka North 3.05-7.62, Awka South 25.36-25.47, Dunukofia 83.84 - 21.07, Idemili North 63.62-30.27, Idemili South 178.69-135.84, Njikoka 90.93-60.85. Average Flowrate (L/S) range; Anaocha 1.61858-0.67542, Awka North 1.01016-2.064425, Awka South 1.5873-2.7277, Dunukofia 2.34328-1.04092, Idemili North 1.2134-1.288, Idemili South 1.58065-2.006696, Njikoka 0.79008- 0.94044. Range of Q. Yield of well m3/day for the locations; Anaocha 139.85-58.36, Awka North 137.14-235.67 Awka South 87.28-178.37, Dunukofia 202.46 - 89.94, Idemili North 104.84-111.35, Idemili South 136.57-173.38, Njikoka 68.26 - 81.25. Transmissivity, T (m2/day) range of the locations; Anaocha 70.351-152.525, Awka North 132.049-615.928, Awka South 30.127-5.675, Dunukofia 18.157-24.197, Idemili North 76.720-113.173, Idemili South 499.699-24.781, Njikoka 16.876-5.487. Hydraulic Conductivity (m/day) range of the locations are; Anaocha 0.4911-3.575, Awka North 8.326 - 12.101, Awka South 0.659-0.0813, Dunukofia 0.177-0.920, Idemili North 0.968-1.811, Idemili South 2.602-0.151, Njikoka 0.154-0.068. Various depth of Pump Installation was determined which ranges from 15.86-192.01 m with specific pump capacity of about 1 horse power – 7.5 horse power. Locations with high Transmissivity, T (m2/day) range revealed moderate well performance rate.

Keywords: Aquifer Performance Test, Quantity Yield, Cooper – Jacob Method, Aquifer Flowrate And Static Water Level

1. Introduction

In Anambra State, there is a growing need for sustainable groundwater resources to meet the demands of a rising population. Groundwater is a vital resource in Anambra State but the concerns about its sustainability is as a result of increasing population and development pressures. Ensuring access to clean and sustainable groundwater resources is crucial to ensure sustainable development. Groundwater is greatly used as primary source for drinking water, irrigation, and industrial activities in the region. Aquifer test and aquifer performance test (APT) are alternate designations for a pumping test which is basically employed in post drilling process to ascertain the capacity, longevity and sustainability. Pumping test is also a practical method of estimating well performance, well capacity, the zone of influence of the well and aquifer characteristics being the aquifer's ability to store and transmit water. Ensuring the well efficiency guarantee sustainability of portable water for the populace. Comprehensive knowledge on the quality of groundwater is paramount as much as ensuring its suitability for domestic, drinking, agricultural and industrial purposes, this is because groundwater is considered to be the largest reservoir of portable water and plays a vital role in complementing the water supply to meet the ever-increasing demands for clean water. Emeshili estimates that less than 5% of the population has access to public water supplies. One of the targets of the UN development goals SDGs 6 the study contributes is to reduce the proportion of people without sustainable access to safe drinking water and freshwater [1].

1.1 Study Area

This research covered 14 locations in Anambra central senatorial zone of Anambra state. These locations are as follow; Obeagu Primary School Agul, Uruoji Hall Nri, Eigbo Primary School Amansea, Street Farm Isuanaocha, Nneoma Secondary School Nibo, Millenium City Estate Awka, Nneamaka Secondary School Ifittedune, Health Center Ukpomili Ifettedune, Mother and Child PHC Ogidi, New Motor Parts Obosi, Abo-Nnokwa Idemili, Eziumuru-Nnobi Idemili, Oye Market Abba and Akama Osili Enugwuukwu. Anambra Central senatorial zone in Anambra State is one of the three Senatorial zones in the State. It has seven local government areas. They are Awka North, Awka South, Njikoka, Anaocha, Idemili North, Idemili South and Dunukofia (Figure. 1). Anambra State is situated within the latitude 05^0 32' and 06^0 45' N and longitude 06^0 43' and 07^0 22' E respectively and bordered by Delta state in the west, Imo state in the south, Enugu state in the east and Benue state to the north. Anambra state is well drained with abundant surface water. The major river systems are the Anambra drainage system to the west and the Mamu sub-basin which flow into the river Niger. It extends from the river Niger at Onitsha to the east at Oji River in Enugu State. Two climatic conditions being the dry season and the wet season exist in Nigeria which is also recognized in Anambra state. The wet season fall between seven months, from April to October with rainfall peaking generally in September. Dry season is about five months (November – March) marked by a Harmattan wind that enters in late December or in the early part of January as it leads to extreme dry heat later in February and March. Most of the locations in Anambra central senatorial zone is predominantly of late Paleocene – early Eocene Imo shale with its sandstone members (Ebenebe, Umuna and Igbaku sandstone). Imo Shale which is Paleocene to Eocene is the oldest formation in the Niger Delta Basin mainly of clayey shale with a fine texture. The Ameki Group (Eocene) overlies the Imo Shale and comprises of Nsugbe Sandstone, Nanka Sandstone and Ogwashi-Asaba Formation [2].

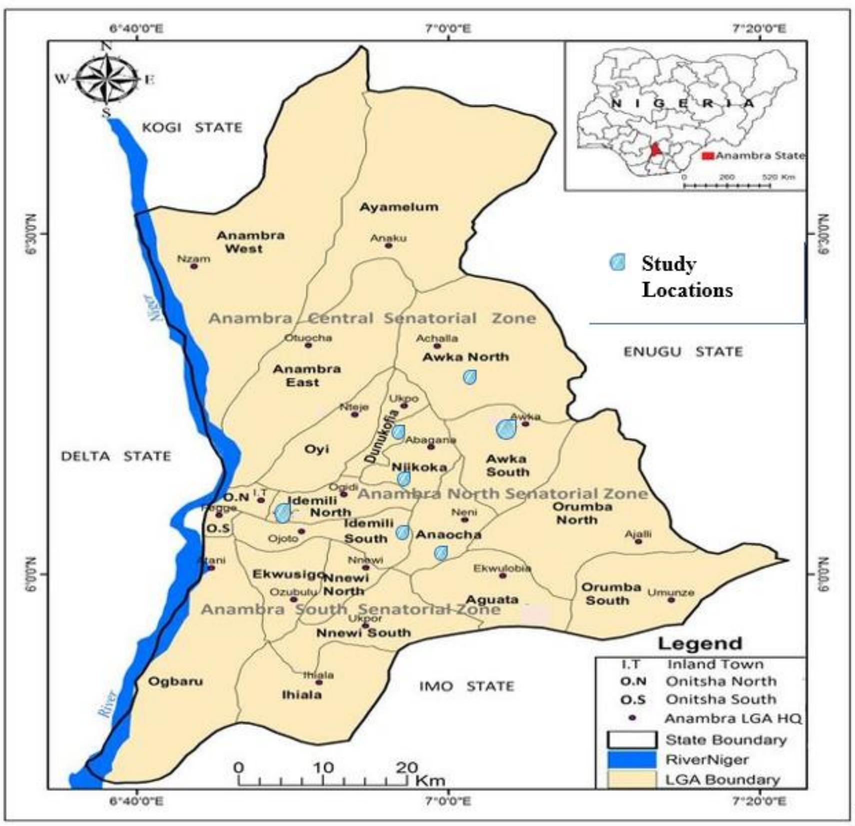


Figure 1: Map of Anambra State Highlighting the Study Locations

2. Methodology

Aquifer performance test or pumping testing is carried in an existing well for the purpose of determining relevant from aquifer parameters, for optimum use of the borehole. Pumping test involved constant discharge test and recovery test. The need for this pumping test in an existing well is to know the capacity of the pump to be installed into the borehole and the safety level. It helps to know the top of water table using Cooper – Jacob's analysis modified by David, K. T. [3]. Pumping tests are essential for evaluating aquifer characteristics, determining well productivity, and estimating the hydraulic parameters of groundwater systems. A pumping test is a field experiment in which a well is pumped at a controlled rate and water-level response (drawdown) is measured in one or more surrounding observation wells and optionally in the pumped well (control well) itself. Response data from pumping test are used to estimate the hydraulic properties of aquifers, evaluate well performance and identify aquifer boundaries. Aquifer test and aquifer performance test (APT) are alternate designations for a pumping test. Thus, pumping tests are indispensable tools for characterizing aquifers and evaluating well performance, with the Cooper-Jacob method serving as a cornerstone for data analysis. The Cooper-Jacob method (H.H. Cooper and C.E. Jacob 1946) is a widely adopted semi-logarithmic approximation technique for analyzing pumping test data. Note that, The Cooper-Jacob method is specifically designed for confined aquifers.

The integrated analysis of aquifer transmissivity, hydraulic conductivity and flowrate was calculated respectively from the pumping test data according to Cooper – Jacob's method modified by David Keith Todd [3].

$$\text{Transmissivity , } T = \frac{2.3XQ(m3\ /day)}{4\pi\Delta S} \qquad 1$$

Where 2.3 is constant, Q = yield of borehole for a known average flow rate inm^3/day, 4 is constant, ΔS= difference in line of best fit before the equilibrium from the plot of drawdown vs logarithm of time after pumping test.

Also, hydraulic conductivity, $K = \frac{T}{h}$ 2

where T= Transmissivity and h = Saturated aquifer thickness
Flowrate = volume of bucket/Time 3

Cooper-Jacob method employed in this study is detailed on the knowledge of aquifer characteristics to interpret drawdown data and estimate hydraulic parameters such as transmissivity and storage coefficient of aquifer (Keith, D., 1965). This method utilizes the drawdown data collected during a pumping test to determine the aquifer's hydraulic properties, such as Water level at equilibrium during discharge and recovery test, transmissivity (T), Average Flowrate (L/S), Q. Yield of well m^3/day, Drawdown at Equilibrium and Specific Capacity m^2/day.

2.1 Results & Interpretation

In this study fourteen (14) locations were covered. The field data collected during the pumping test using a water level tape and indicator with stop watch, the initial level in the tape include time and water level measured from the top of pipe down to the water level in the well which is constant discharge test. During discharge and recovery test water level were measured. In discharge test readings were taken from top to the subsurface as the water level was noted when pumping started while in recovery test readings were taken from the subsurface to the top having the water level from the level of water when pumping stopped.

The data from constant discharge and recovering test were interpreted by creating the third column which is the drawdown having the symbol of 'S' in meter (Table 1 and 2). Drawdown is the difference between the static water level and the level in the well after pumping revealed. The drawdown was calculated by subtracting the static water level from the water level measured at each time. The static water level (SWL) was measured prior to the drawdown in the well from reference point which is measured at the time pumping started in constant discharge test.

Well Location: Obeagu Primary School Agulu **Latitude: N06^0 5' 47.328"**
Senatorial zone: Anambra Central **Longitude: E007^0 1' 37.811"**
L.G.A Anaocha **Elevation: 189 m**
Type of Test Conducted: Constant Discharge & Recovery Test

Constant Discharge Test						**Recovery Test**				
Time since Pumping Started (min)	**Water level (m)**	**Static Water Level (m)**	**Drawdown S'(m)**	**Volume of container used (L)**	**Flowrate L/s**	**Time since pumping stopped (min)**	**Water level (m)**	**Static Water Level (m)**	**Drawdown S' (m)**	**Remarks**
0	127.70		0	Water clear and silt free		0	130.74		3.04	
1	131.10		3.40			1	125.30		2.40	
2	130.45		2.75			2	126.20		1.00	
3	130.55		2.85			3	127.70		0	
4	130.59		2.89			4	127.70		0	
5	130.65		2.95			5	127.70		0	
6	130.75		3.05			6	127.70		0	
7	130.85		3.15			7	127.70		0	
8	130.92		3.22			8	127.70		0	
9	130.74		3.04			9	127.70		0	

15	130.74		3.04	24.567L	**Flowrate= 1.6378 L/S**	15	127.70		0	
20	130.74		3.04			20	127.70		0	
25	130.74		3.04			25	127.70		0	
30	130.74		3.04			30	127.70		0	
35	130.74		3.04			35	127.70		0	
40	130.74		3.04			40	127.70		0	
45	130.74		3.04			45	127.70		0	
50	130.74		3.04			50	127.70		0	
55	130.74		3.04			55	127.70		0	
60	130.74		3.04	98.646	**Flowrate= 1.6441 L/S**	60	127.70		0	
80	130.74		3.04			80	127.70		0	
90	130.74		3.04							
100	130.74		3.04			-				
110	130.74		3.04	175.582	**Flowrate= 1.5962 L/S**	-				
120	130.74		3.04			-				
140	130.74		3.04			-				
160	130.74		3.04			-				
180	130.74		3.04	Water clear and silt free		-				
210	130.74		3.04	335.202	**Flowrate= 1.5962 L/S**	-				
240	130.74		3.04			-				
Average Flow rate: 1.61858 L/S **Average Volume of bucket used: 158.4993 L**										

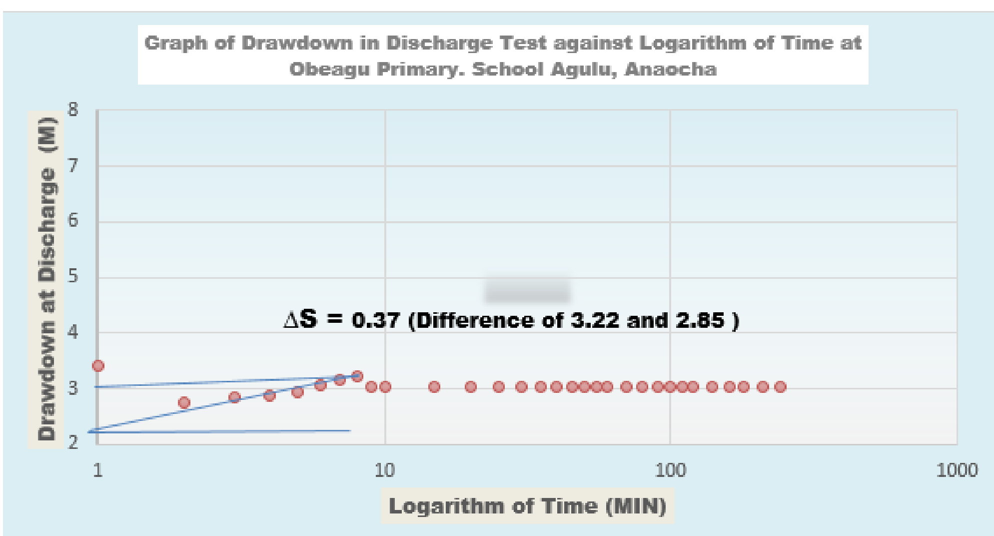
Table 1: Interpreted Pumping Test Result of Obeagu Primary School Agulu

Well Location: Uruoji Hall Nri **Senatorial zone: Anambra Central** **L.G.A Anaocha** **Type of Test Conducted: Constant Discharge & Recovery Test**						**Latitude: N06^{0} 0' 9.684''** **Longitude: E007^{0} 58' 40.979''** **Elevation: 214 m**				
Constant Discharge Test						**Recovery Test**				
Time since Pumping Started (min)	**Water level (m)**	**Static Water Level (m)**	**Drawdown S'(m)**	**Volume of container used (L)**	**Flowrate L/s**	**Time since pumping stopped (min)**	**Water level (m)**	**Static Water Level (m)**	**Drawdown S' (m)**	**Remarks**
0	21.80		0	Water clear and silt free		0	23.25		1.45	
1	23.02		1.22			1	22.02		0.22	
2	23.07		1.27			2	21.87		0.07	
3	23.11		1.31			3	21.82		0.02	
4	23.12		1.32			4	21.81		0.01	
5	23.13		1.33			5	21.80		0	
6	23.17		1.37			6	21.80		0	
7	23.15		1.35			7	21.80		0	
8	23.19		1.39			8	21.80		0	
9	23.21		1.41			9	21.80		0	
15	23.24		1.44	10.926	**Flowrate= 0.7284 L/S**	15	21.80		0	
20	23.25		1.45			20	21.80		0	
25	23.25		1.45			25	21.80		0	
30	23.25		1.45			30	21.80		0	

35	23.25		1.45			35	21.80		0	
40	23.25		1.45			40	21.80		0	
45	23.25		1.45			45	21.80		0	
50	23.25		1.45			50	21.80		0	
55	23.25		1.45			55	21.80		0	
60	23.25		1.45	43.02	**Flowrate= 0.7170 L/S**	60	21.80		0	
80	23.25		1.45	53.08	**Flowrate= 0.6635 L/S**					
90	23.25		1.45							
100	23.25		1.45			-				
110	23.25		1.45	69.938	**Flowrate= 0.6358 L/S**	-				
120	23.25		1.45			-				
140	23.25		1.45			-				
160	23.25		1.45			-				
180	23.25		1.45	Water clear and silt free		-				
210	23.25		1.45	132.806	**Flowrate= 0.63241 L/S**	-				
240	23.25	**21.80**	1.45			-		**21.80**		
Average Flowrate: 0.67542 L/S **Average Volume of bucket used: 61.954 L**										

Table 2: Interpreted Pumping Test Result of Uruoji Hall Nri, Anaocha

From the constant-rate pumping test performed in the well, ensuring a stable discharge rate (Q). Record the drawdown (s) in at least one observation well or the pumping well itself at several time intervals (t). Plot the drawdown data on semi-logarithmic paper, with drawdown (s) on the logarithmic axis and time (t) on the linear axis. Figure. 2 below presents the plot of drawdown in discharge test against logarithm of time for well (WL) 1 and 2 Obeledu Primary School Agulu and Uruoji Hall Nri Anocha respectively. The difference in the match point on the straight-line portion of the plot, corresponding to a time value of t' and a drawdown value were determined which known as change in s' ΔS . The drawdown is the difference in static water level and water level at each time pumping progresses. The plots of drawdown against logarithm of time show the difference in the drawdown intercept (ΔS). Table 3 summarized parameters from discharge and recovery test from field data, Anambra Central.



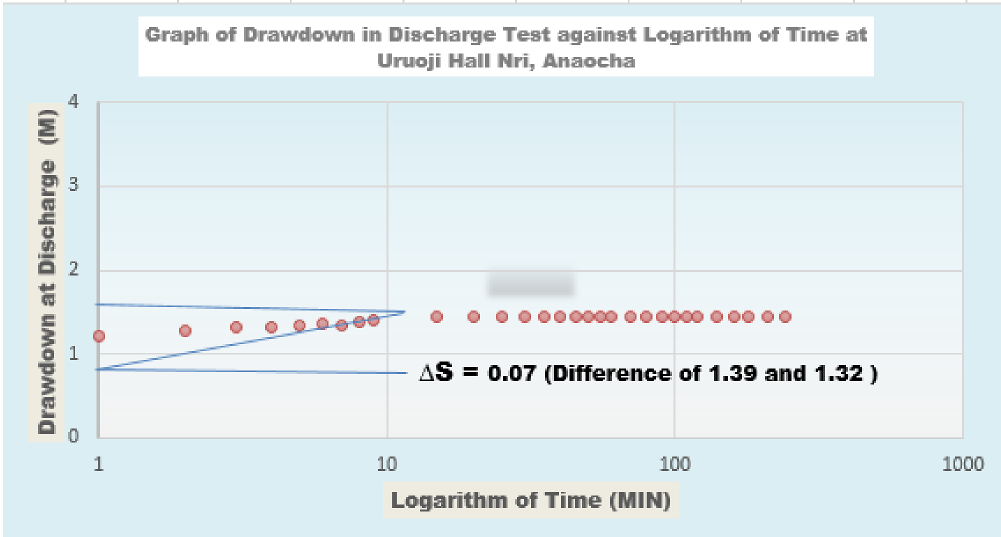


Figure 2: Plots of drawdown against logarithm of time showing the difference in the drawdown intercept (ΔS) of tested well locations at Obegu Primary School Agulu and Uruoji Hall Nri, Anaocha

Well No.	Well Location	LGA	Static Water Level (m)	Water Level at Equilibrium during Discharge Test (m)	Water Level at Equilibrium during Recovery Test (m)
WL 1	Obeagu Primary School Agulu	Anaocha	127.70	130.74	127.70
WL 2	Uruoji Hall Nri		21.80	23.25	21.80
WL 3	Eigbo Primary School Amansea	Awka North	3.05	3.94	3.05
WL 4	Street Farm Isuanaocha		7.62	10.65	7.62
WL 5	Nneoma Secondary School Nibo	Awka South	25.36	28.86	25.36
WL 6	Millenium City Estate Awka		25.47	33.05	25.47
WL 7	Nneamaka Secondary School Ifittedune	Dunukofia	83.84	90.1	83.84
WL 8	Health Center Ukpomili Ifettedune		21.07	23.64	21.07
WL 9	Mother and Child PHC Ogidi	Idemili North	63.62	63.87	63.62
WL 10	New Motor Parts Obosi		30.27	30.72	30.27
WL 11	Abo-Nnokwa Idemili	Idemili South	178.69	180.28	178.69
WL 12	Eziumuru-Nnobi Idemili		135.84	137.12	135.84
WL 13	Oye Market Abba	Njikoka	90.93	93.88	90.93
WL 14	Akama Osili Enugwuukwu		60.85	68.01	60.85

Table 3: Summarized Parameters from Discharge and Recovery Test from field Data, Anambra Central

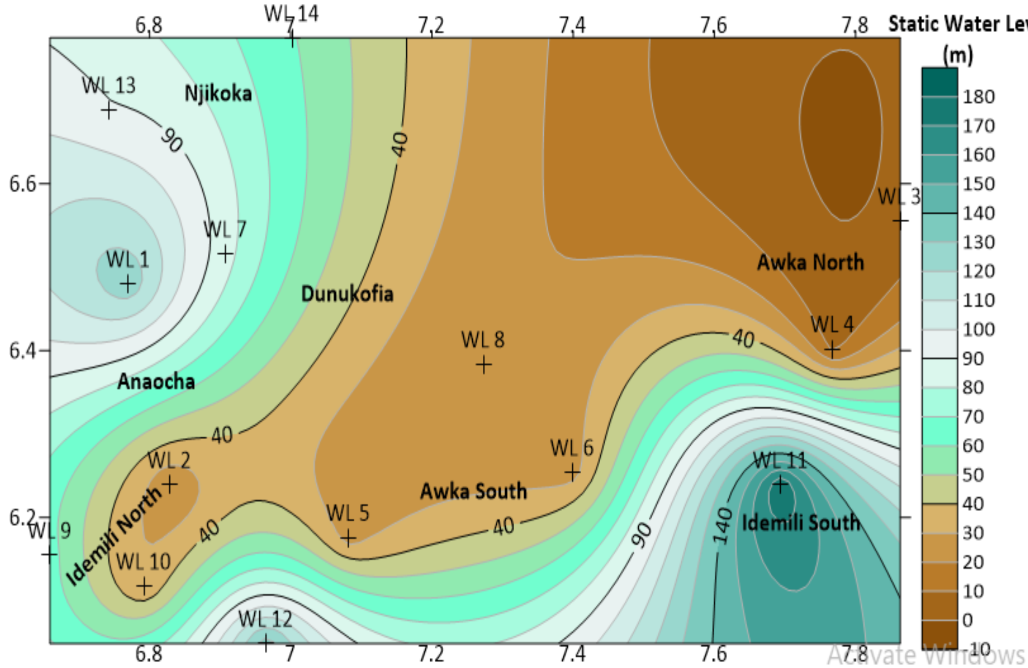


Figure 3: Map Showing the Static Water Level of Well Locations in Anambra Central

Figure 3, the static water level map reveals distinct patterns of groundwater availability across the region, which can be categorized into shallow, moderate, and deep zones based on the depth to the water table:

Shallow Zones (Well 2,3.4,5,6,8,10,): These zones (Partly Anaocha, Awka North, Awka South, partly dunukofia and Idemili North are situated in low-lying areas on the topographic map ranging from -10 t0 50m, characterized by flat terrain and proximity to surface water bodies. Wells in this zone have an average static water level of 25 meters below ground surface. The shallow water table suggests a high potential for groundwater extraction, making these locations suitable for shallow hand-dug wells or small-scale irrigation projects or suggesting a higher groundwater table and potentially more accessible water resources. This could be indicative of high aquifer recharge rates, favorable geological formations, or the presence of surface water bodies that contribute to groundwater replenishment. This zone is recognized by their brown colour on the legend Moderate Zones (Wells 1,7,9,13 and 14)): Located in transitional topographic regions (Partly Anaocha, Dunukofia, Idemili North) and Njikoka these zones exhibit a moderate elevation gradient between the shallow and deep zones. Wells in this zone display an average static water level of 95 meters below ground surface. The groundwater resources in these areas may be suitable for domestic and agricultural purposes, but the increased depth may necessitate more advanced drilling techniques and moderate pumping costs. This could be attributed to a combination of factors, including a reduction in recharge rates, less permeable geological formations, or increased groundwater extraction. Consequently, these areas may require more advanced drilling techniques and efficient water management practices to ensure sustainable use.It ranges from from 50 to120m.

Deep Zones (Wells 11 and 12): Positioned in elevated areas of the topographic map, these zones (Idemili south) experience a substantial increase in the depth to the water table, with an average static water level of 150 meters below ground surface. Drilling and pump installation in these areas may be more challenging and require specialized equipment. While the groundwater resources in these zones may be limited, they can still be considered for large-scale water supply projects or as a supplementary source during periods of water scarcity. This region may face challenges in terms of water supply, necessitating the exploration of alternative sources, implementation of water-saving measures, or the adoption of recharge initiatives to restore groundwater levels. The zone ranges from from 120 to 180m on the topography map.

2.2 Integrated Interpretation from Pumping Test Concept Showing Parameters for Well Performance Rate

The field data was further interpreted with the adaptation of Cooper-Jacob approach of analyzing borehole parameters. By analyzing these parameters collectively, relevant professionals can assess the performance of a well and make informed decisions about its performance, maintenance, and potential for sustainable water extraction. In this step of integrated interpretation of field data, another essential parameter was evaluated in this research in the selected 41 existing borehole/drilled well in the three senatorial zones of the 21 local governments of the study area. These parameters are; Av. Vol. of Bucket used (L), Average Flowrate. (L/S), Q. Yield of well m^3/day, Drawdown at Equilibrium and Specific Capacity m^2/day.Specific capacity is the rate of discharge of the well per unit drawdown. It is calculated by dividing the Yield of well which is pumping rate (Q) by the drawdown (S). Specific capacity provides a measure of the efficiency of the well in producing water from the aquifer (Table 4.). Higher specific capacity values indicate better performance, as the well can produce more water with less drawdown.

Well No.	Well Location	LGA	Av. Vol. of Bucket used (L)	Average Flowrate. (L/S)	Q. Yield of well m^3/day	Drawdown at Equilibrium	Specific Capacity m^2/day
WL 1	Obeagu Primary School Agulu	Anaocha	158.4993	1.61858	139.85	3.04	46.00
WL 2	Uruoji Hall Nri		61.954	0.67542	58.36	1.45	40.25
WL 3	Eigbo Primary School Amansea	Awka North	150.666	1.5873	137.14	0.89	154.09
WL 4	Street Farm Isuanaocha		283.7456	2.7277	235.67	3.03	77.78
WL 5	Nneoma Secondary School Nibo	Awka South	97.1876	1.01016	87.28	3.50	24.94
WL 6	Millenium City Estate Awka		204.65	2.064425	178.37	7.58	23.53
WL 7	Nneamaka Secondary School Ifittedune	Dunukofia	411.3069	2.34328	202.46	6.26	32.34
WL 8	Health Center Ukpomili Ifettedune		98.8929	1.04092	89.94	2.57	35.00
WL 9	Mother and Child PHC Ogidi	Idemili North	118.1378	1.2134	104.84	0.28	374.43
WL 10	New Motor Parts Obosi		117.4314	1.2888	111.35	0.45	247.44
WL 11	Abo-Nnokwa Idemili	Idemili South	151.8877	1.58065	136.57	1.57	86.99
WL 12	Eziumuru-Nnobi Idemili		190.6748	2.006696	173.38	1.28	135.45
WL 13	Oye Market Abba	Njikoka	74.8572	0.79008	68.26	2.95	23.14
WL 14	Akama Osili Enugwuukwu		83.1061	0.94044	81.25	7.16	11.35

Table 4: Integrated Interpretation From Pumping Test Concept Showing 1stSet Parameters For Well Performance Rate, Anambra Central

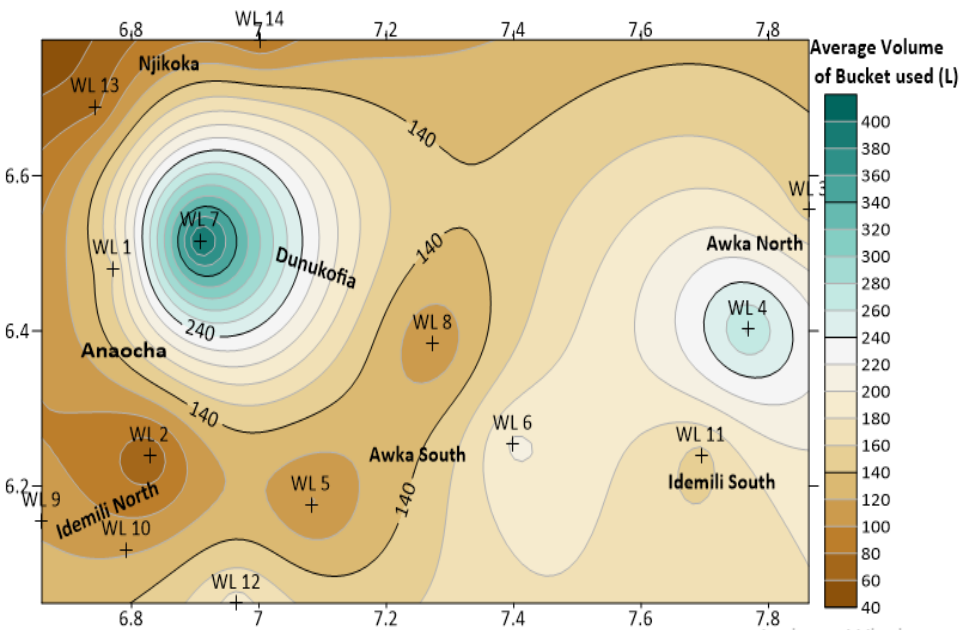


Figure 4: Map Showing Average Volume of Bucket used in Well Locations at Anambra Central

The spatial distribution and orientation of these contours on the average volume bucket topography map which can be categorized into high, medium, and low-volume zones based on the calculated average volume of buckets from the available well data allow for the identification of potential hydrocarbon traps, where the juxtaposition of reservoir and seal units has created favorable conditions for hydrocarbon accumulation. Moreover, the correlation of these features with underlying structural trends, such as faults or folds, can further refine the understanding of hydrocarbon migration pathways, entrapment mechanisms, and exploration prospects. The three-layer stratigraphic sequence, with its distinct colors and inferred shifts in depositional conditions, provides a glimpse into the region's sedimentary history. The bluish, whitish-brown, and brown layers may represent a progression from deeper marine settings to shallower marine or transitional environments and finally to terrestrial or fluvial conditions. This interpretation, when integrated with additional data, such as sedimentary structures or fossil assemblages, can help refine the understanding of the area's paleogeography and paleoenvironments, informing geological research and resource exploration efforts (Figure. 4).

High-Volume Zones (Well 7): Characterized by an average bucket volume exceeding 320 Litres, these zones demonstrate a high potential for groundwater storage. Wells within these area (Partly Dunukofia) may be ideal for large-scale irrigation projects, municipal water supplies, or industrial use. However, proper management and conservation practices should still be employed to ensure the long-term availability and quality of the groundwater resources. The bluish coloration of this layer suggests a fine-grained, clay-rich composition, likely indicating a depositional setting characterized by low-energy conditions and a significant supply of fine-grained sediment. Such conditions are typically found in deeper marine environments or offshore settings. As such, this layer may represent deposition under relatively deep, low-energy marine conditions, where clay and silt particles settled out of suspension. Medium-Volume Zones (Wells 1,3,4,6,11 and 12): These zones exhibit an average bucket volume ranging from 180-320 Litres, indicating a moderate capacity for groundwater storage. The wells located in these areas (Partly Anaocha), Awka North, (Partly Awka South,) and Idemili South may be suitable for various purposes, such as small-scale irrigation, domestic use, or small community water supplies. However, the medium volume of buckets suggests that water resources may still need to be managed and monitored to ensure long-term sustainability. The transition from the bluish layer to a whitish-brown layer may indicate a shift in depositional conditions. The lighter color could suggest a decrease in the proportion of clay minerals, potentially reflecting an increase in the influence of higher-energy processes or a change in sediment source. The whitish-brown hue might indicate the presence of biogenic materials, such as carbonate shells or siliceous organisms, or a greater proportion of quartz-rich sand and silt. This layer could represent deposition in a shallower marine environment or a transitional setting, such as a shoreface or deltaic environment, where waves and currents have a more substantial impact on sediment transport and deposition.

Low-Volume Zones (Wells 2,5,8,9,10,13, and 14): These zones (Partly Anaocha, Awka South, Duukofia), Idemili North and Njikoka are characterized by an average bucket volume of less 160 liters, suggesting a limited capacity for groundwater storage in the subsurface. The wells within these zones may not yield substantial amounts of water, potentially requiring additional wells or alternative water sources for large-scale or continuous use. The brown layer suggests a further change in the depositional setting, potentially indicating a shift towards more terrestrial or fluvial conditions. The brown color could be due to the presence of iron oxides or organic matter, which are commonly associated with deposition in fluvial, floodplain, or swamp environments. This layer may represent deposition under terrestrial conditions, where sediment transport and deposition are primarily controlled by river systems, overbank flooding, and localized sediment reworking by wind or shallow water currents.

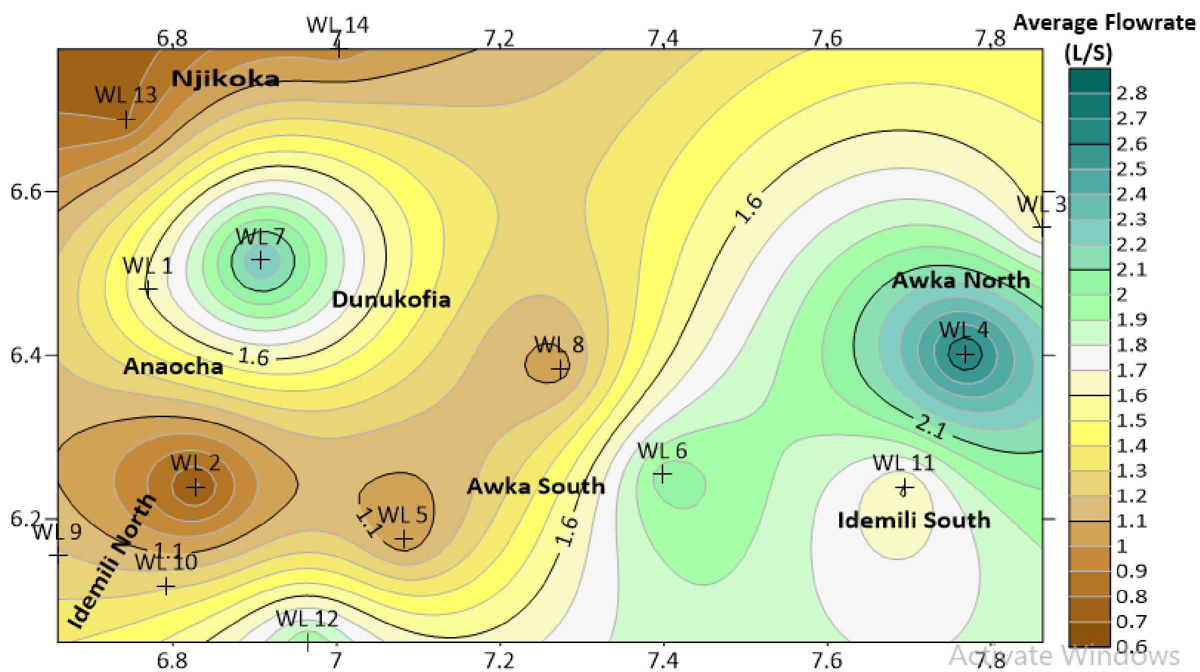


Figure 5: Map showing Average Flowrate in Well Locations at Anambra Central

The map illustrates the spatial distribution of average flow rate across the region, which can be categorized into low, medium, and high-flow zones based on the calculated average flow rate data from the available 14 wells (Figure 5): Low-Flow Zones (Wells 2,5,8,9.13 and 14): These zones (Partly Anaocha, Awka South, Dunukofia, Idemili North) and Njikoka are characterized by an average flow rate of less than 1.3liters per second, indicating relatively low groundwater yield. Wells within these zones may not provide sufficient water supply for large-scale or continuous use, necessitating additional wells or alternative water sources for such purposes. This zone is recognized by brown colour. Medium-Flow Zones (Wells 1,3,6,10,11 and 12): These zones (Partly Anaocha, Awka North, Awka South, Idemili North) and Idemili south exhibit an average flow rate ranging from 1.3 to 2.1 liters per second, suggesting a moderate capacity for groundwater supply. Wells located in these areas may be suitable for various applications, such as small-scale irrigation, domestic use, or small community water supplies. However, the medium flow rate indicates that water resources may still need to be managed and monitored to ensure their long-term sustainability. The zone is ranged from yellow to light green High-Flow Zones (Wells 4 and 7): Characterized by an average flow rate exceeding 2.1liters per second, these zones demonstrate a high potential for groundwater supply. Wells within these areas may be ideal for large-scale irrigation projects, municipal water supplies, or industrial use. While these high-flow zones offer promising water resources, proper management and conservation practices should still be employed to ensure the long-term availability and quality of the groundwater. This zones are situated are the following regions (partly Awka North and Dunukofia). This zone is recognized by colour brown.

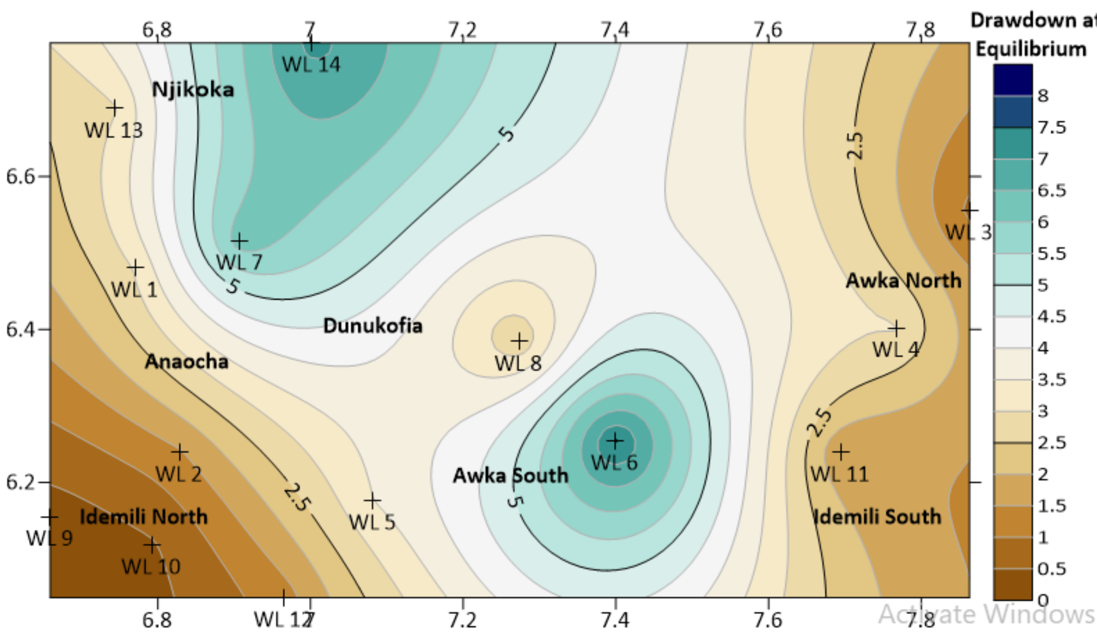


Figure 6: Map showing Drawdown at Equilibrium in Well Locations at Anambra Central

The map provides an overview of drawdown at equilibrium across the region, showcasing the spatial distribution of groundwater level decreases upon long-term pumping. The data obtained from 14 wells can be used to classify the area into low, moderate, and high drawdown zones, offering views into the aquifer's hydraulic properties and its response to pumping activities (Figure. 6). Low Drawdown Zones (Wells 2,3,4,9,10,11 and 12): These zones (partly Anaocha, Awka North, Idemili North and Idemilim South) exhibit a drawdown of less than 3 s at equilibrium, implying a minor decrease in groundwater levels during long-term pumping. This limited drawdown suggests a robust hydraulic connection between the wells and the aquifer, indicating high transmissivity and storage characteristics. Consequently, these areas may be suitable for groundwater extraction with minimal adverse effects on the aquifer's long-term performance. Low Drawdown Zone is Identified by brown colour. Moderate Drawdown Zones (Wells 1,5,8 and 13) Characterized by a drawdown of 3 to 6, these zones suggest a moderate decline in groundwater levels due to pumping activities. The moderate drawdown may signify a reasonably efficient hydraulic connection with the aquifer, yet long-term pumping could lead to reduced well efficiency or increased pumping costs. Proper monitoring and management strategies are crucial to ensure the sustainable use of groundwater resources in these regions (partly Anaocha, Awka south, Dunukofia, Idemili South). Identified as whitish brown on the map legend. High Drawdown Zones (Wells 6,7 and 14): With a drawdown exceeding 6, these zones (partly Awka South, Dunukofia and Njikoka demonstrate a significant decrease in groundwater levels upon pumping. This high drawdown could be attributed to a combination of factors, including lower aquifer transmissivity, reduced storage capacity, or a higher local demand for groundwater extraction. Long-term pumping in these areas may require advanced pumping technologies, alternative water sources, or recharge initiatives to counteract the substantial decline in groundwater levels.

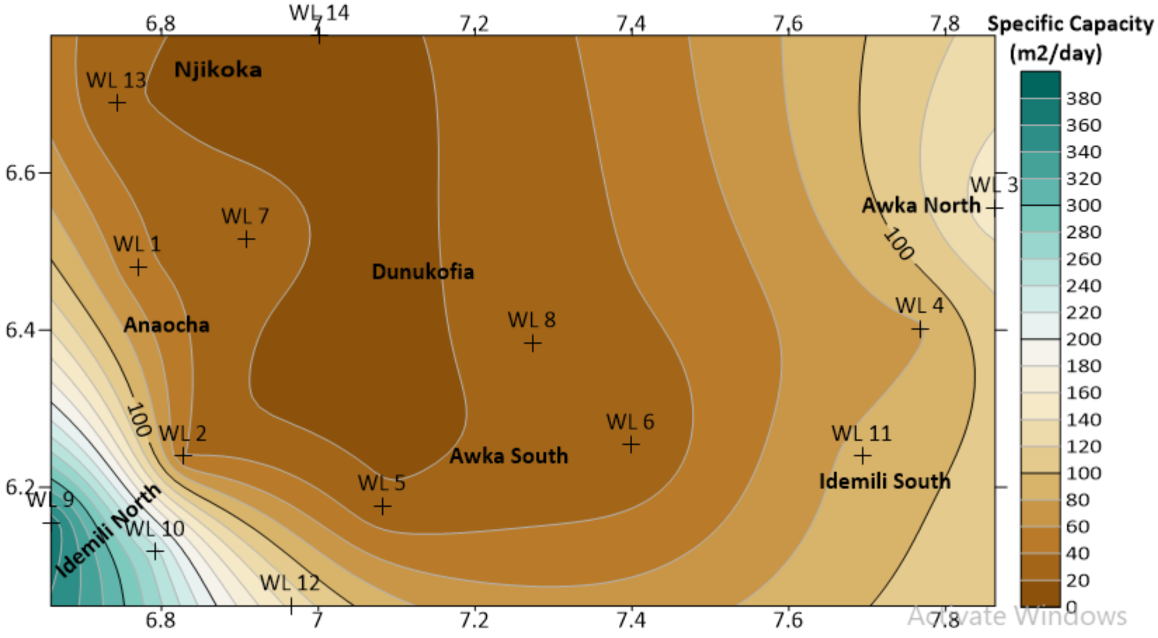


Figure 7: Map showing Specific Capacity of Well Locations in Anambra Central

This study focused on evaluating the specific capacity of 14 well points within a designated study area, with the goal of characterizing the productivity and efficiency of these wells. Specific capacity was calculated as the ratio of pumping rate to drawdown and serves as a crucial indicator of a well's performance. The 14 well points were classified into three distinct categories based on their specific capacity values: high, moderate, and low (Figure 7). High Specific Capacity (well 9 and 10) exhibited high specific capacity values, ranging from 280 to 380 m2/day of drawdown. These wells demonstrated exceptional efficiency and productivity, suggesting a robust connection to the underlying aquifer and favorable hydrogeological conditions. The zones (Idemili North) are signified by Bluish colour. Moderate Specific Capacity (well 3,11 and 12) were classified as having moderate specific capacity, with values ranging from140 to 280 m^2/day of drawdown. These wells showed satisfactory performance and indicated moderately favorable aquifer characteristics, such as permeability and storage capacity. This zone (Partly Awka North and Idemili South) is designated to be identified with whitish brown coloration. Low Specific Capacity (1,2,4,5,6,7,8,13 and 14) exhibited lower specific capacity values, ranging from0 t0 140 m^2/day of drawdown. These wells may be influenced by less favorable hydrogeological conditions or localized factors, such as well screen clogging, reduced aquifer thickness, or low hydraulic conductivity. The zone (Anaocha, partly Awka North, Awka South, partly Dunukofia and Njikoka) can be identified based on the colour brown that showcase the position range of low specific capacity range. The table 5 below presents other parameters from the pumping test analysis of Anambra Central senatorial zone.

Well No.	**Well Location**	**LGA**	**(ΔS) Difference in Drawdown intercept.**	**Transmissivity, T (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Depth of Pump Installation (m)**	**Pump Capacity Installed**
WL 1	Obeagu Primary School Agulu	Anaocha	0.37	70.351	0.4911	143.25	5.5 Horse Power
WL 2	Uruoji Hall Nri		0.07	152.525	3.575	42.67	1.5 Horse Power
WL 3	Eigbo Primary School Amansea	Awka North	0.19	132.049	8.326	15.86	1 Horse Power
WL 4	Street Farm Isuanaocha		0.07	615.928	12.101	50.9	3 Horse Power
WL 5	Nneoma Secondary School Nibo	Awka South	0.53	30.127	0.659	45.72	1.5 Horse Power
WL 6	Millenium City Estate Awka		5.75	5.675	0.0813	69.80	7.5 Horse Power
WL 7	Nneamaka Secondary School Ifittedune	Dunukofia	2.04	18.157	0.177	102.7	5.5 Horse Power
WL 8	Health Center Ukpomili Ifettedune		0.68	24.197	0.920	26.3	1 Horse Power

WL 9	Mother and Child PHC Ogidi	Idemili North	0.25	76.720	0.968	79.24	1.5 Horse Power
WL 10	New Motor Parts Obosi		0.18	113.173	1.811	62.48	2 Horse Power
WL 11	Abo-Nnokwa Idemili	Idemili South	0.05	499.699	2.602	192.01	7.5 Horse Power
WL 12	Eziumuru-Nnobi Idemili		1.28	24.781	0.151	164.58	7.5 Horse Power
WL 13	Oye Market Abba	Njikoka	0.74	16.876	0.154	109.45	2 Horse Power
WL 14	Akama Osili Enugwuukwu		2.71	5.487	0.068	80.77	2 Horse Power

Table 5: Integrated Interpretation from Pumping Test Concept Showing 2nd Set Parameters for Well Performance Rate, Anambra Central

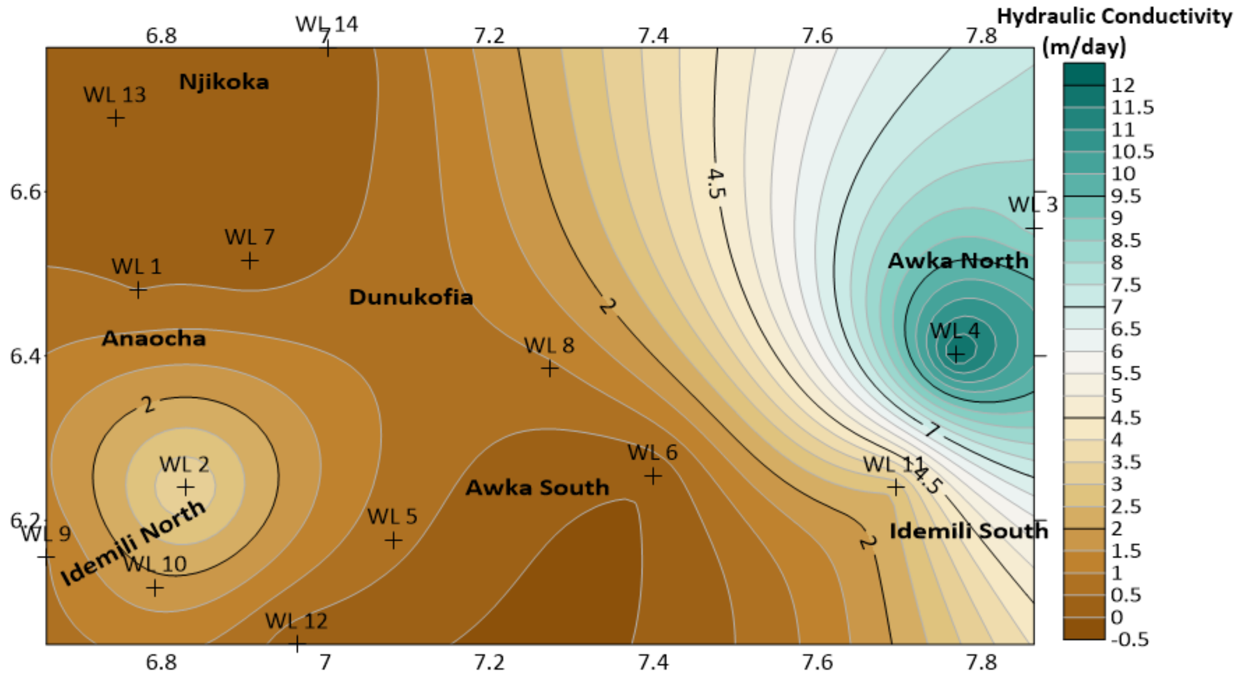


Figure 8: Map showing Hydraulic Conductivity of Well Locations in Anambra Central

High Hydraulic conductivity (Wells 4): The high hydraulic conductivity values in this zone (Partly Awka North), allowing for efficient water transmission and quick replenishment of groundwater after pumping. This can be attributed to favorable aquifer properties, such as high porosity, permeability, and well-connected fracture networks. This zone ranges from 8.5 metres and above and denoted by a bluish colour Moderate Hydraulic conductivity (Wells 2,3 and 11): The moderate pace of hydraulic conductivity values in these zones (partly Anaocha, Awka North and Idemili South). While the aquifer still responds relatively well to pumping, the hydraulic conductivity is slower compared to High Hydraulic conductivity zones. This could be due to a combination of factors, such as lower porosity, less permeability, or reduced connectivity between fractures. It ranges from 4 to 8.5metres and it can be recognized on the topographic map by whitish brown colouration. Low Hydraulic conductivity (Wells 1,5,6,7,8,9,10,12,13 and 14): The low hydraulic conductivity values in these zones (partly Anaocha), Awka South, Dunukofia, Idemili North, partly Idemili South and Njikoka limiting the aquifer's capacity to transmit water. Factors contributing to low hydraulic conductivity may include reduced porosity, low permeability, or the presence of less permeable geological formations. It ranges from -0.5 to 4m and it can be identified on the above topographic by colour brown.

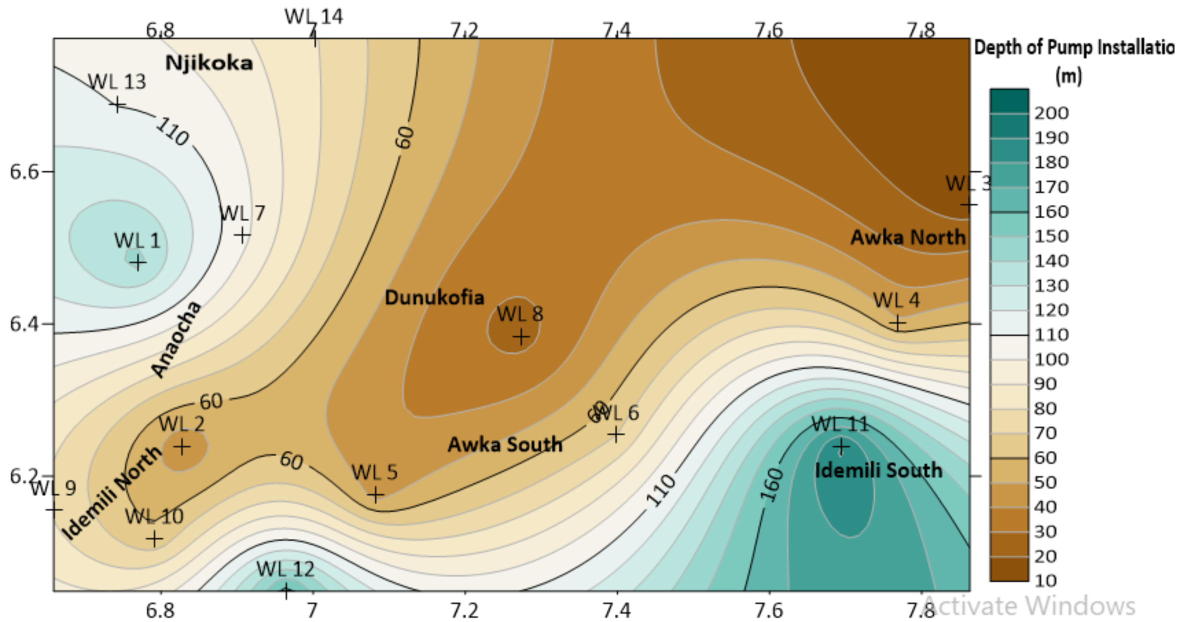


Figure 9: Map showing Depth of Pump Installation of Well Locations in Anambra Central

The interpretation of the depth of pump installation on a topographic map with several well points shows spatial distribution of groundwater resources and potential areas for drilling and pump installation. Each well point represents a location where vertical electrical sounding (VES) measurements were taken to estimate the depth of the water table and underlying geologic layers. The map reveals distinct patterns of groundwater availability, which can be categorized as shallow, moderate, and deep zones based on the depth of pump installation (Figure. 9). Shallow Zones (Wells 2, 3, 4,5,8 and 10): These zones are located in low-lying areas (partly Anaocha), Awka North (partly Awka south, Dunukofia and Idemili North) on the topographic map, characterized by flat terrain and proximity to surface water bodies. The wells in this zone have an average depth of 35m. The shallow groundwater table suggests a high potential for groundwater extraction, and these locations may be suitable for shallow hand-dug wells or small-scale irrigation projects. This zone ranges from 10 to 70 (brown). Moderate Zones (Wells 1,6,7,9,13and 14): These zones (partly Anaocha, Awka South, Idemili North) and Njikoka are found in transitional topographic regions, with a moderate elevation gradient between the shallow and deep zones. Wells in this zone exhibit an average depth of 105m. The groundwater resources in these areas may be suitable for domestic and agricultural purposes, but the increased depth may require more advanced drilling techniques and higher pumping costs. The zone ranges from 70 to 140 m (whitish Brown). Deep Zones (Wells, 11, and 12): Located in elevated areas (Idemili South) partly of the topographic map, these zones exhibit a substantial increase in the depth of pump installation, with an average depth of 170meters. Drilling and pump installation in these areas may be more challenging and expensive, requiring powerful pumps and specialized equipment. The groundwater resources in these zones may be limited, but they can still be considered for large-scale water supply, projects or as a supplementary source during periods of water scarcity) this zones ranges from 140 to 200 m.(Bluish).

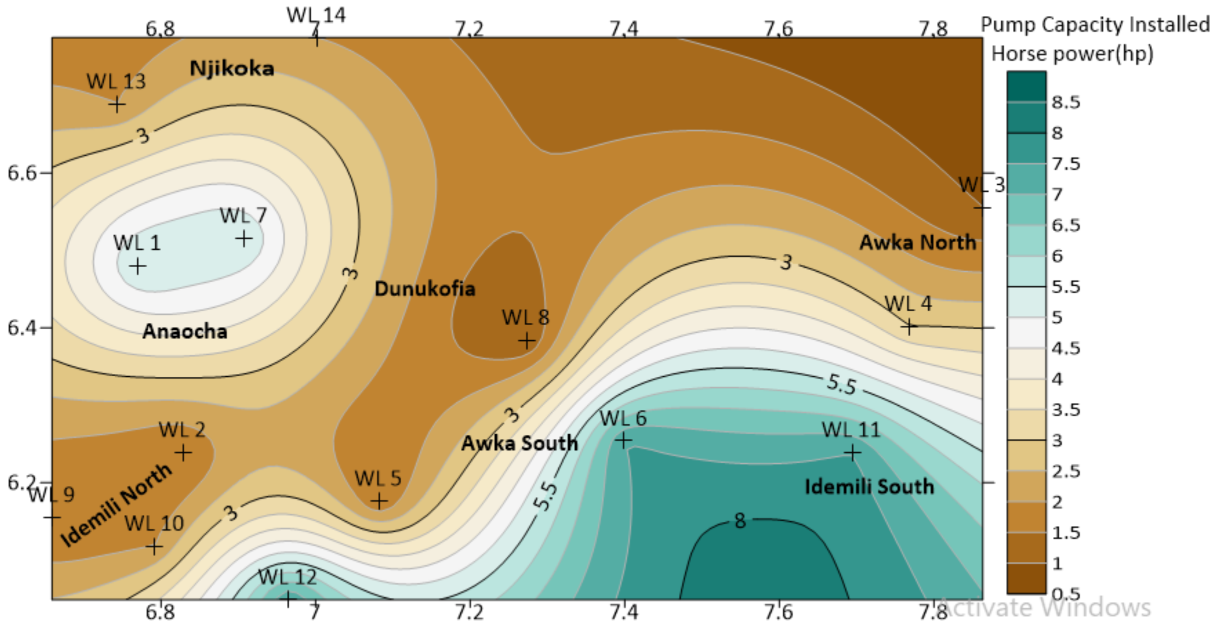


Figure 10: Map showing Depth of Pump Capacity Installed in Well Locations at Anambra Central

The map reveals distinct patterns of pump capacity installed, which can be categorized as high, moderate, and low zones based on the yield of the wells (Figure. 10). The interpretation of pump capacity installed on a topographic map with 14 well points shows spatial distribution of groundwater resources and the potential yield of wells within the study area. Each well point represents a location where a pumping test has been conducted to determine the capacity of the well to provide water. High Capacity Zones (Wells 6, 11, and 12) These zones are located in areas (partly Awka South) and Idemili South on the topographic map, characterized with favorable hydrogeological conditions, such as thick aquifers and high permeability. The wells in this zone exhibit an average capacity of over 7.5hp making them suitable for large-scale water supply projects, such as municipal water systems or industrial applications.This zone ranges from 5.5 to 8.5 hp. (bluish). Moderate Capacity Zones (Wells 1,4 and7). These zones (partly Anaocha, Idemili North and Duukofia) are found in regions with moderate hydrogeological conditions, characterized by adequate aquifer thickness and moderate permeability. Wells in this zone have an average capacity ranging from 4 hp, making them suitable for domestic use, small-scale agriculture, or commercial purposes. The zone ranges from 3 to 5.5 hp (whitish Brown). Low Capacity Zones (Wells2, 3, 5,8,9,10,13 and 14): Located in areas (partly Anaocha, Awka North, Awka south, Dunukofia, Idemili and Njikoka) with challenging hydrogeological conditions, such as low permeability or limited recharge, these zones exhibit an average well capacity of less than 2hp. Wells in these areas may be suitable for individual households, small-scale irrigation, or livestock watering, but they may require careful planning and management to ensure a continuous supply of water. This zone ranges from 0.5 to 3.0 hp (Brown).

3. Conclusions

Based on the Aquifer performance test carried out on the fourteen (14) locations of drilled wells in the study area, this study concludes the following; Aquifer performance test or pumping testing is considered very important to know the depth of pump installation and the capacity of pump to be installed in a drilled well. Aquifer performance is relevant determined from aquifer parameters, for optimum use of the borehole. Ensuring the capacity of the well performance from carrying out pumping test will help to know the sustainability and whether to serve for commercial or domestic purposes.The efficiency of the wells generally in Anambra central senatorial zone proved moderate in flowrate and quantity yield.

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