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Combined geophysical and hydrological study on climatic factors variability and their effect on aquifer productivity and recharge in Obubra, Cross River state

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Abstract

Combined techniques of geophysics, hydrology and hydrogeology were employed in the estimation of groundwater recharge. Effects of meteorological factors on groundwater recharge were critically explored. Using tritium tagging and electrical resistivity techniques groundwater recharge was estimated. VES data was obtained from 16 stations, each with a traverse length of 500 m and inter station distance of 800m. Both the wet and dry season saw the completion of Tritium tagging surveys at every site. The study also looked at how weather conditions effected the stations aquifers productivity and recharge. The study found that rising rainfall causes an increase in groundwater recharge. The episodic variations in rainfall during period match with the patterns of groundwater recharge variation (1988-2018). The study also revealed a positive association between rainfall and groundwater recharge with a correlation coefficient of 0.9 but a negative correlation between groundwater recharge, temperature and evaporation with correlation coefficients of -0.52 and -0.42. But when the three climatic variables were combined with groundwater, the regression analysis revealed a multiple coefficient of determination of 0.821 percent (R^2= 82.1 percent). Tritium tagging technique show that the recharge estimate in the study area varies between 6 and 19 percent. The study also revealed a linear relationship between electrical resistivity of the top soil and the estimated recharge.

Keywords: Groundwater; Recharge; Climatic variables; Tritium tagging; Electrical resistivity

1. Introduction

In the time past, hand dug wells as shallow as 8 m could produce water even during the dry season, in a similar vein, boreholes drills to depth of about 15m could produce water all year long. Ironically, however these same boreholes and hand dug wells dried up after a few years. This situation has persisted overtime and it is necessary to look in to its potential causes.

The majority of the boreholes were first and foremost drilled based on geophysical surveys that revealed the presence of aquifers within the depths reached during the initial drilling from which water was retrieved. As the years passes by, the aquifer recharge or productivity began to decline to a stage where an attempt to pump a 300litres of water will take more than an hour for an electrically propelled sumo-pump while it take a similar time for a manually operated borehole to pump 20 litres of water.

The decline in the recharge of the aquifer is a pointer to the fact that the available groundwater is not too sufficient, therefore since groundwater availability is a vital aspect of the hydrological cycle, it will be necessary to study the

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climatic factors that influences the hydrological cycle particularly in Obubra so as to draw inferences on their effect on aquifer recharge.

Groundwater recharge is an important component of the hydrological cycle in which surface water percolates into the subsurface adding to the existing groundwater, this process usually occurs in and around the vadose zone and is then expressed as a flux to the water table.

Groundwater can be recharged artificially or naturally, but our interest is in the natural means of groundwater recharge, which is the replenishing of the subsurface water without human technology and occurs through sources like rainfall, rivers, lakes and streams.

According to Roger and Alan (2009), variations in rainfall and evaporation have an impact on the amount of runoff and soil moisture in Africa. Rainfall plays a key role in groundwater recharge and aquifer recharge. Climate, geography, soil type and geology are examples of environmental factors that may have an impact on the rate of groundwater recharge. Aquifer or groundwater recharge is also impacted by human activities like farming, logging, pavement development, road construction and deforestation in the vadose and phreatic (water saturated) zones.

Hydro Geophysicist, hydro Climatologist and hydro Geologist must have a thorough understanding of groundwater recharge and abstraction in other to plan and develop water resources in any region of the world. Three recharge zones In Africa have been documented using rainfall data. The first zone according to Eilers, et al, 2007, includes areas with annual rainfall below 200mm, where little or no current recharge is likely to occur, The second zone, according to Edmund (2009), includes regions with rainfall in the range of 200-500m per year contribute up to five percent (25mm) ground water recharge, although much will depend on the timing and intensity of rainfall, geology of the area and human activities. The third zone, according to (Edmund, 2009) includes areas where a more accurate projection of recharge over the research region will be possible with knowledge of the dynamics of groundwater recharge and aquifer reactions (Calow and MacDonald, 2009).

The required information and knowledge shall be acquired based on the application of geophysical survey employing the vertical electrical sounding method and the analysis of climatic variables like rainfall and temperature over a period of thirty years. The common method for estimating recharge is based on monitoring water level fluctuation and specific yield of the aquifer, doing this will require the use of certain techniques like; Electrical Resistivity method, Water table Fluctuation method, Chaturvedi Empirical Method and Tritium Tagging Technique

2. Hypotheses

One hypothesis was formulated to guide the study, the hypothesis is;

Mean annual rainfall, mean annual temperature and mean annual evaporation have significant effect on aquifer recharge

2.1. Climate and geology of the study area

The study area is situated in the savannah zone of South south Nigeria between latitude $5^0 50'$N and $6^0 30'$N and longitude $8^0 01'$E and $9^0 12'$E. A variety of green plants, shrubs, grasses and trees makeup the vegetation. During the dry season, the daily temperature ranges from 32-36 ℃, and the average annual rainfall is more than 2,200mm. There are two seasons that peak twice a year, April to November (known as the rainy season) and November to April (Classify as the dry season). An average of 88 percent relative humidity prevails in the research area. The upper and lower limits of rainfall, temperature and humidity can all be seen to change

Geologically, the region is separated into; Nkporo-Afikpo shale formation, (NASF), Awgu-Ndeaboh formation and Eze-Aku group (EAG) of cretaceous sediments. The EAG is made up of thick flaky impervious non-calcareous to calcareous shales, sandy shally limestone. The EAG is covered by the post- santonian NASF which takes up the majority of the study area western part. According to NGS 2006; Odigi & Amajor, 2009 and illustrated in fig 1, the main lithologic units in the formation are Mudstone, sandstone and shale bed. The area is drained by a few streams, creeks and Cross River tributaries including Okiphe, Ovarr, Itie, Okang, ichora, Epangha, and Okwo (Obianwu et al 2015).
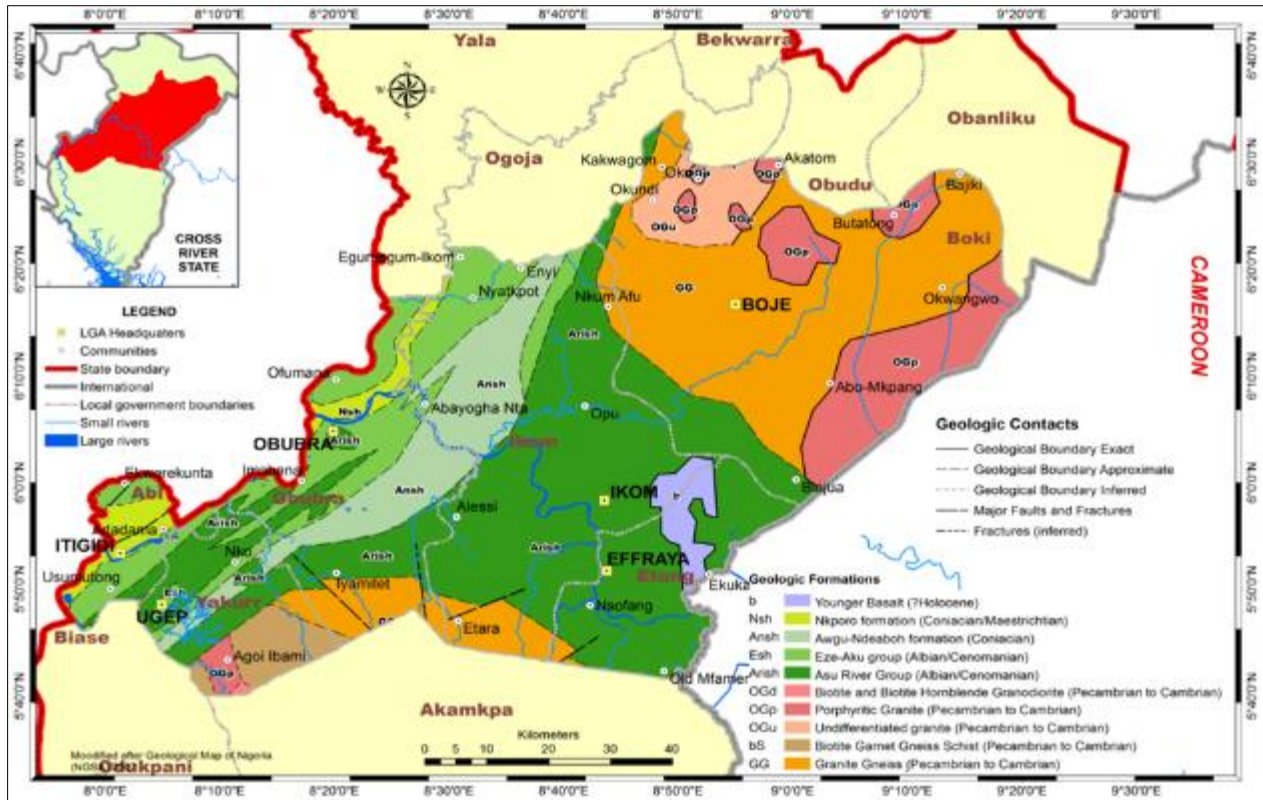
Source: Modified after Geological Map of Nigeria – NGSA, (2006).

Figure 1 Geological map of the study area

3. Material and methods

3.1. Climatic and hydrologic data

Data on Climatic variables like monthly and annual rainfall volume, temperature and evaporation for 31 years (1988-2018) for Obubra were obtained from Nigeria meteorological station Calabar office at Margaret Ekpo International Airport as shown on table 2

Static Groundwater level data was recorded base on observation made between January – December for 2016, 2017, and 2018 hydrological years by the application of graduated improvised water level recorder and corroborated with a dip meter. The groundwater recharge was deduced from the fluctuation of the water table using the water table fluctuation method which is an indirect model. In this method, the rise in water during the rainy season is used to estimate the recharge, provided that there is a distinct rainy season with the remainder of the year being relatively dry. The model is mathematically written as;

$$R(t) = Sy^x \, DH(t_1)$$

Where;

$R(t_1)$ = Recharge occurring between times t_0 and t_1,
Sy =Specific yield (dimensionless)
DH (t) = the peak water level rise attributed to the recharge period (Meinzer, 1923; Rasmussen and Andreasen, 1959; Crosole et al, 2005, Obianwu et al 2015).

The water table fluctuation model (WTFN) as pioneered by Mienzer (1923) had some key assumptions which include;

Rise and decline in level of the water table in shallow unconfined aquifer are solely due to recharge and discharge of groundwater.

The specific yield of aquifer is known and constant over a period of the water table fluctuation.

The pre-recharge water level recession can be extrapolated to determine water level rise (Healy & Cock, 2002)

These assumptions can be constrained by some factors like evapotranspiration, changes in atmospheric pressure, changes in stream stage in the case where the well is close to a stream. Because of the variation of specific yield with time for a large area it is difficult but not impossible to obtain specific yield that is representative of a large area (Loheide, Butter & Gorelick, 2005; Sopholeous & Schloss, 2000; & Obuobie, 2008) and depth to the water table as opposed to the assumption of a known and constant specific yield.

Using a pumping (drawdown) test, specific yield can be determined using the formula

$$\text{Specific yield (Sy)} \quad \frac{D1 - D2}{T}$$

Where;

D_1 = Initial depth,
D_2 = Depth after drawdown,
T = time of Drawdown

Specific yield for different soil texture have been documented (Johnson, 1967) in Obuobie et al, (2008) as shown in table 1

Table 1 Specific yield table for different soil textures

Texture	Average specific yield	Coefficient of variation (%)	Minimum specific yield	Maximum specific yield	Number of determinations
Clay	0.02	59	0.0	0.05	15
Silt	0.08	60	0.03	0.19	16
Sandy clay	0.07	44	0.03	0.12	12
Fine sand	0.21	32	0.10	0.28	17
Medium sand	0.26	18	0.15	0.32	17
Coarse sand	0.27	18	0.20	0.35	17
Gravelly sand	0.25	21	0.20	0.35	17
Fine gravel	0.25	18	0.21	0.35	17
Medium gravel	0.23	14	0.13	0.26	14
Coarse gravel	0.22	20	0.12	0.26	13

Source: (After John 1967) in Obuobie 2008

Groundwater recharge estimate data was generated using chaturvedi Empirical method (Chaturvedi, 1973) where monthly and annual rainfall amount in mm were analyzed using the mathematical relation

$$R = 1.34 (P - 1.4)^{0.5} \dots\dots\dots\dots (2)$$

Where;

R=Recharge (mm),
P = Precipitation (mm)
(K) Elevation data of the wells were recorded with the Global positioning System (GPS)

Table 2 Climatic variables and groundwater recharge

Year	Annual rainfall (mm)	Temperature (0c)	Evaporation (mm)	Recharge (mm)
1988	1965.7	32.6	37.9	138.0
1989	1616.5	32.7	61.3	116.4
1990	2499.9	32.2	43.8	158.1
1991	2963.9	32.0	41.3	200.5
1992	2610.5	31.2	38.9	194.2
1993	3008.6	31.0	40.8	224.5
1994	2723.2	30.3	37.5	209.5
1995	2197.6	32.6	45.0	146.4
1996	2254.5	32.8	42.5	159.8
1997	1947.9	32.5	35.2	133.6
1998	1594.6	32.4	44.7	120.0
1999	1597.2	32.7	43.3	146.5
2000	1706.5	32.9	40.3	116.8
2001	2180.5	33.1	39.8	163.6
2002	1532.5	33.2	36.3	116.0
2003	2339.8	32.8	39.7	160.4
2004	2150.4	32.9	50.1	129.1
2005	1698.6	32.8	44.7	154.8
2006	1712.7	33.1	59.2	116.4
2007	1251.4	33.4	77.6	98.9
2008	2220.7	33.4	47.1	150.7
2009	1815.8	33.7	45.3	136.8
2010	1523.9	33.6	45.5	91.3
2011	1781.6	33.6	48.4	147.3
2012	1816.3	33.8	45.8	140.7
2013	2373.1	33.4	46.6	165.1
2014	2354.7	33.5	46.3	173.1
2015	2737.9	33.7	46.4	183.7
2016	2398.7	34.2	42.9	159.6
2017	2640.2	33.4	44.0	169.7
2018	3347.5	33.3	42.1	201.4

3.2. Vertical electrical sounding (ves) data

The Schlumberger array was deployed in the resistivity survey (Keller, 1966). The instrument used for the vertical electrical sounding was the IGIS resistivity meter model SSR-MP-ATS. Four electrodes which comprises of two potential electrodes and two current electrodes were chosen at any particular time for the measurement of resistance. Current

was introduced into the ground through the two current electrodes, while the potential difference developed was measured; the resistance of the ground was recorded.

The resistivity and geometric factor (k) were calculated using the equation (3) below

$$\rho_a = \pi \frac{\frac{(AB)^2}{2} - \frac{(MN)^2}{2}}{MN} \frac{\Delta V}{I}$$

……………(3)

Where;

$$K = \pi \frac{(AB/2)^2 - (MN/2)^2}{MN}$$

………………(4)

Where;

ρ_a is apparent resistivity (Ωm),
V is Voltage (volt),
I is current in (Ampere),
K is the geometric factor,
AB is spacing between current electrodes
MN is the spacing between the potential electrodes.

The midpoint of the electrode array remained fixed while the inter electrode spacing was expanded systematically.
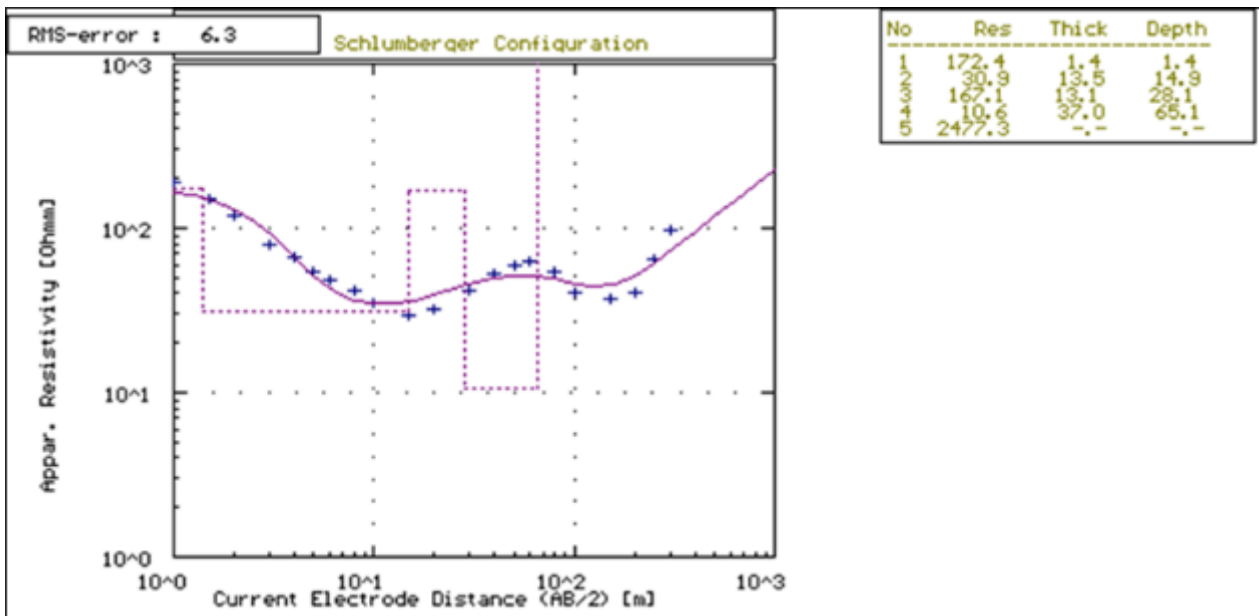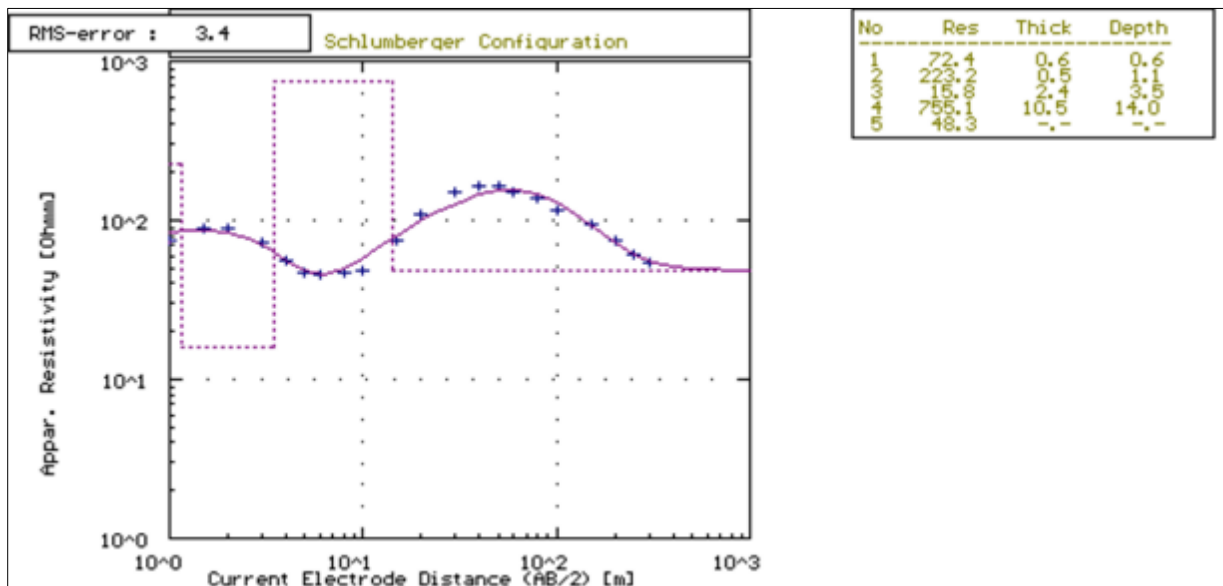

(Source:Author's field work, 2018).

Figure 2 Apparent Resistivity model curve of OHANA (VES 10) in the study area

Maximum electrode spread of 500m was achieved during field measurement. The field measurements for AB and MN were used in calculating the geometric factor base on equation (4), Apparent resistivity values (ρ_a) were calculated by multiplying the geometric factor with the resistivity data (Arshad et al, 2007) and recorded in table 3 below, the resulting values of ρ_a were plotted on the horizontal axis while half the current electrode spacing (AB/2) is plotted on the vertical axis of a log-log graph as shown in fig 2 -4
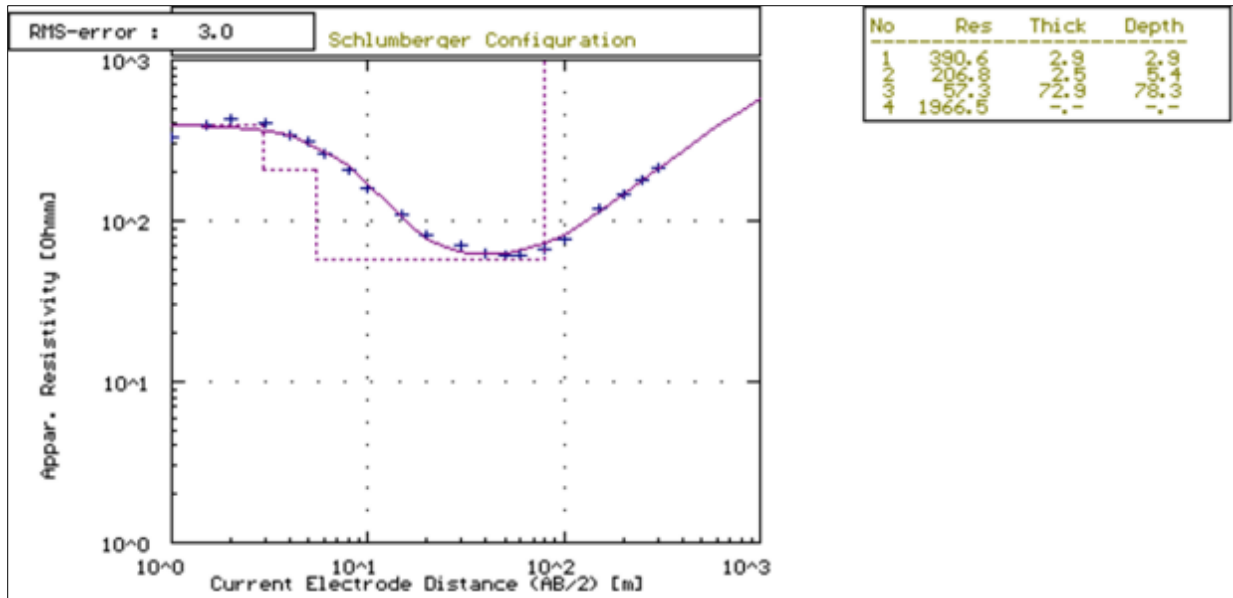
(Source:Author's field work, 2018).

Figure 3 Apparent Resistivity model curve of ONYADAMA (VES 1) in the study area

(Source: Author's field work, 2018).

Figure 4 Apparent Resistivity model curve of OVOKWA (VES 4) in the study area

Table 3 Summary of results of Geoelectric parameters

VES No.	Elevation Above sealevel (m)	Location	Number of Layer	Geo-electric layers Resistivity (Ohm-m)						Geo-electric Layers Thickness (m)						Depth to bottom of Geoelectric layers (m)				
				ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	d_1	d_2	d_3	d_4	d_5	d_6	h_1	h_2	h_3	h_4	h_5
1	53	Onyadama 1	4	360.6.	206.8	57.3	194.5	_	–	2.9	2.5	72.9	-	–	–	2.9	5.4	78.5	-	–
2	54	Onyadama 2	5	400	700	250	27	60	–	1.0	1.50	4.5	36	–	–	1.0	1.5	6.0	42.0	–
3	50	Onyadama 3	5	230	260	70	17	65-	-	1.0	0.5	3.5	15-	-	-	1.0	1.5	34.0	-	-
4	45	Ovokwa 1	5	72.4	228.3	15.8	755.1	48.3	-	0.6	0.5	2.4	10.5	-	-	0.6	1.1	3.5	14.0	-
5	47	Ovokwa 2	6	50	20	50	65	70	35-	1.0	0.7	2.1	6.4	8.8	-	1.0	1.7	3.8	10.2	19
6	89	Okumuruktet	3	160	170	120	_	_	–	3.0	47				–	3.0	50			-
7	61	Okumuruktet 2	5	50	49	40	80	150	–	1.00	0.5	3.5	13	–	–	1.0	1.5	5.0	18.0	–
8	63	Okorokpana 1	6	130	150	125	18	34	–	1.0	1.0	6.0	22	–	–	1.0	2.0	8.0	30	–
9	64	Okorokpana 2	6	60	25	35	70	25	150	1.0	1.3	2.5	8.5	37	–	1.0	2.3	4.8	13	50
10	51	Okorokpana 3	6	50	55	50	30	65	30	1.0	0.8	4.2	14.0	30	–	1.0	1.8	6.0	20	50
11	57	Owakande 1	4	200	500	1200	500		–	1.2	13.8	135		–	–	1.2	15	150		–
12	76	Edondon 1	5	218	254	291	265	38	–	1.5	5.3	24.8	53.6	–	–	1.5	6.8	31.3	84.9	–
13	78	Edondon 2	6	143	106	236	88	132	99	1.3	4.06	12.8	40.6	59.6	–	1.3	5.3	18,2	58.8	118.3
14	104	Iyamoyoung 1	5	95.5	216.8	1063	116	129		.0.7	5.0	33.8	49.6		–	0.7	5.7	39.5	89.2	_
15	107	Iyamoyoung 2	5	491	1540	522	–	–	–	3.07	14.3	45.2	66	–	–	3.07	17.37	62.49	128.7	–
16	48	OHANA	5	172.4	30.9	167.1	10.6	2477.3	–	1.4	13.5	13.1	37	-	–	1.4	14.9	28.1	65.1	-

Table 4 Hydrologic data from hydrogeophysical activities

VES Station No.	Location	Pumping rate (L/S)	Discharge	Draw down (m)	Transmissibility	SWL (m)	Specific capacity m3/day/m
1	Onyadama 1	10.4m2/day 0.9	0.25	4452	11.80 m2/day 1.02x10-3	6.50	5.61x10-3
2	Onyadama 2	3.47m2/day 0.3	8.3x10-2	39.88	3.8x104	13.11	2.08x10-3
3	Onyadama 3	23.1m2/day 2.0	5.5x10-1	32.68	3.11x10-3	10.70	1.68x10-2
4	Ovokwa 1	57.6m2/day	0.05	2.7m	24.52m2/day	40.3	1.85x10-2
5	Ovokwa 2	86.4m2/day	6.11 x 10-2	14.0	14.0m2/day	53	4.3x10-3
6	Okwurumetete 1	23.m2/day 2.0	5.5 x 10-1	22.97	4.48 x 10-3	21.6	2.3x10-2
7	Okumurutete 2	23.1m2/day 2.0	5.5 x 10-1	14.65	6.9x10-3	13.46	3.75x10-2
8	Okorokpama 1	9.25m2/day 0.8	2.22x10-1	39.38	1.03x10-3	4.19	5.63x10-3
9	Okorokpama 2	76.3m3/day	1.99x10-2	14.5	17.4m2/day	54.5	1.37x10-3
10	Okorokpama 3	57.6m3/day	3.01x10-1	5.0	18.8m2/day	8.0	6.0x10-2
11	Owakande 1	32.98m2/day 2.85	7.93x10-1	1.8	8.06x10-2	3.49	4.4x10-1
12	Edondon 1	37.03m2/day 3.2	8.8x10-1	2.1	7.74x10-2	3.5	4.19x10-1
13	Edondon 2	113.7m3/day	4.18x10-1	1.6	35.8m2/day	6.4	2.6x10-1
14	Iyamoyong	34.2m2/day 2.96	8.22x10-1	0.9	1.67x10-1	3.0	9.1x10-1
15		113.7m3/day	3.41x10-1	2.5	4.98m2/day	5.4	1.3x10-1
16	Ohanna	67.12m2/day 5.8	1.6x10-1	2.4	1.22x10-1	4.0	6.6x10-1, 18.12

Both forward and inverse modeling methods were used in computer programme software RESIST to generate layer parameter (layer resistivity and layer thickness).

The data acquired from the resistivity survey was used to establish the existence of aquifers and their respective depths. In another consideration soundings were conducted near existing boreholes and pumping test data were collected from the Cross River State water Board Limited (CRSWL) Calabar for boreholes within the study area. The pumping test was repeated on the boreholes after one year on the same months during the dry seasons and the rainy season when the previous measurement was made and the results were compared with the VES results.

The pumping test was carried out in motorized boreholes drilled by CRSWBL & Rural Water Sanitation and Agency (RUWASAN). The test was conducted in two stages namely; the constant rate test and the recovery test. During and after the pumping test, data were collected, analyzed and interpreted so as to determine the following hydrologic parameters; (i) specific capacity, transmissivity, drawdown, specific yield and storativity as recorded in table 4. The equipment used in carrying out the pumping test include;

1.5Hp submersible pump and cable, a calibrated 20 litre container, a Dip meter, a Generator, a Stopwatch, Riser pipes and Clamps. The Jacob's no formula was used to determine the transmissivity and storativity of borehole.
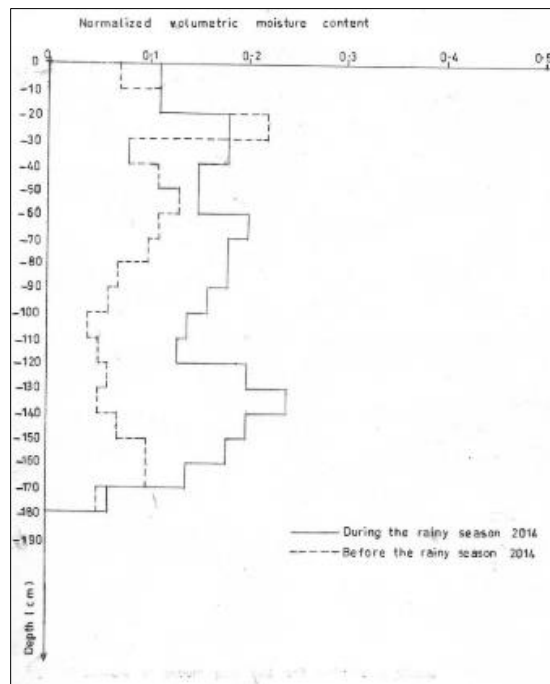

Figure 5 Movement of tritium peak and soil moisture at Ohana

Sixteen sites participated in tritium tagging research as elucidated by Bhishm and Nachiappan (1995). The sites were chosen based on the resistivity values and degree of saturation of the soil layers in the specific study area. In the chosen sites various soil types were recorded.

By keeping an eye on the tritium injection's downward vertical trajectory, groundwater recharge was estimated. A peak in the tritium activity versus depth plot indicates the tracer's position. Six holes with circular geometries were simultaneously injected with a 40μcurie/Cm³ tritium from the University of Calabar's nuclear laboratory at a depth of 70cm below the surface. At time the tritium was injected before the wet season and after 5 months later during the wet season, soil samples were taken (July 2017). The samples were taken with a hand auger at depths ranging from 10cm to 2m. In the laboratory of Cross River Water Board Limited standard gravimetric techniques were used to calculate the volumetric moisture content of each soil sample. According to fig 5 the volumetric moisture content was plotted against depth and ranged from 0.05 to 0.24. The amount of soil moisture extracted from each soil sample was measured using a liquid scintillation counter (L.SC) from the nuclear laboratory of physics department of the University of Calabar was used to measure the tritium activity of soil moisture extracted from respective soil sample. To calculate the shift in the injected tritium the centre of gravity (C.G) of the tritium activity peak was identified. Because of the effect of diffusion, hydraulic pressure, osmotic pressure and dispersion processes the tritium activity peak could not spike. For each site,

Plots of count rates versus depth were created. Fig 6 illustrate a plot of count rate, centre of gravity of tritium and volumetric moisture content for one of the selected locations in the Eze Aku group. The depth of tritium injection and the peak's centre of gravity, were taken into account to determine the shift in the tritium peak, the shift position varied between19.5 to 138. 6cm for all sixteen sites.

By taking into account the product of tritium peak shift and effective mean volumetric moisture content in the tritium peak shift, the size of the recharge throughout the time interval of tritium injection (before the rainy season) and sampling (during the rainy season) was calculated (Zimmerman et al, 1967a, 1967b)
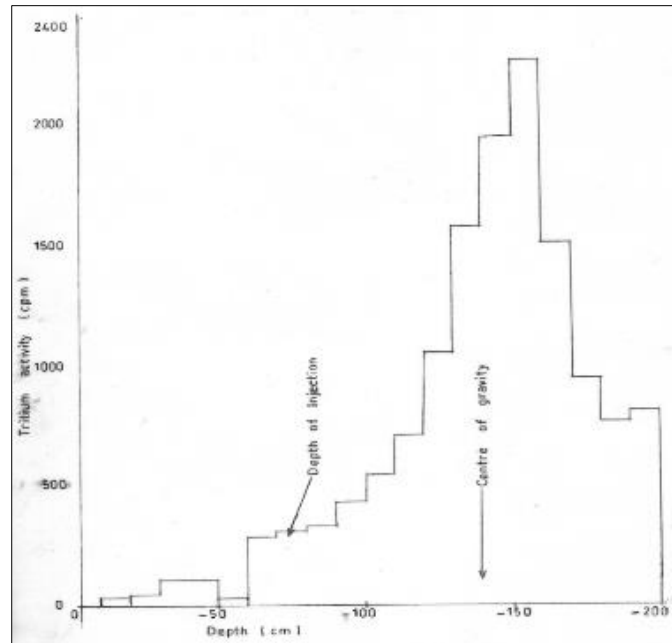

Figure 6 Tritium Peak Shift measured at one Station in the study area

Table 5 Tritium activity and depth

Tritium activity (cpm)	Depth (cm)
20	0
45	-10
50	-20
48	-30
100	-40
50	-50
250	-60
255	-70
350	-80
500	-90
850	-100
12,500	-110
1,700	-120
2,150	-130
1,200	-140
400	-150
200	-160
100	-170
300	-180

Equation (1) below can be used to mathematically determine the proportion of groundwater recharge

$$R = \tilde{v} \, {}^* \Delta S \, (100/p)$$

Where;

R is the percentage recharge to groundwater,
$\tilde{V}$ is the effective mean volumetric moisture content in the tritium peak shift region,
ΔS is the shift in tritium peak in cm
P is rainfall in cm.

Rainfall data was collected from NIMET Calabar. water table depths and elevation values were determined for the chosen sixteen sites and nearby VES sounding stations during the time of tritium injection (before the rainy season) and at three months after the rainy season the depth of water table was plotted alongside surface elevation (relief) in fig 7. There were also plots of water table fluctuation versus recharge percent.
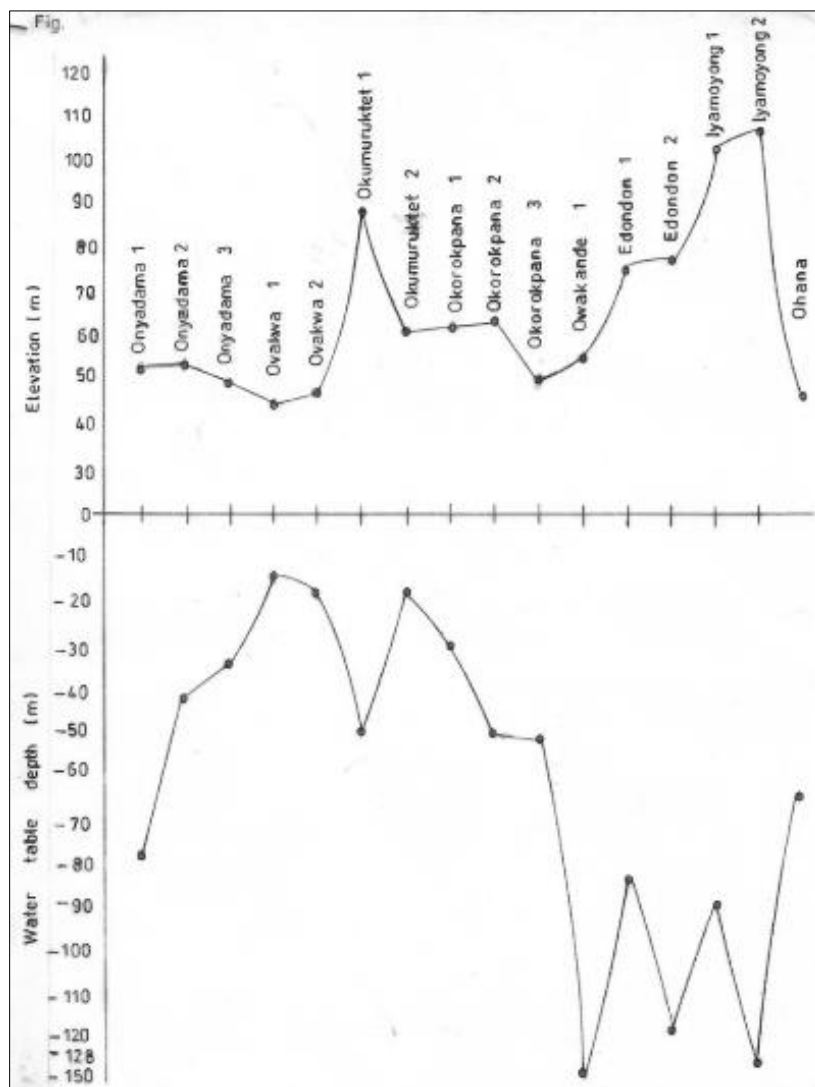

Figure 7 Plots of water table fluctuation versus recharge percent

4. Results and Discussion

Using the tritium tagging tracing technique the groundwater recharge in the study area was estimated to range from 6 to 19 percent. Correspondingly, the downward vertical recharge depends on the infiltration characteristics of the

unsaturated topsoil layer. As it is common knowledge in ground resistivity studies, resistivity of a soil depends on the type of soil, the degree of saturation, the age of the rock types, degree of cementation, and infiltration characteristics, low permeability soils produce low resistivity values and high permeability soils produce high resistivity values (Israil M et al 2006).
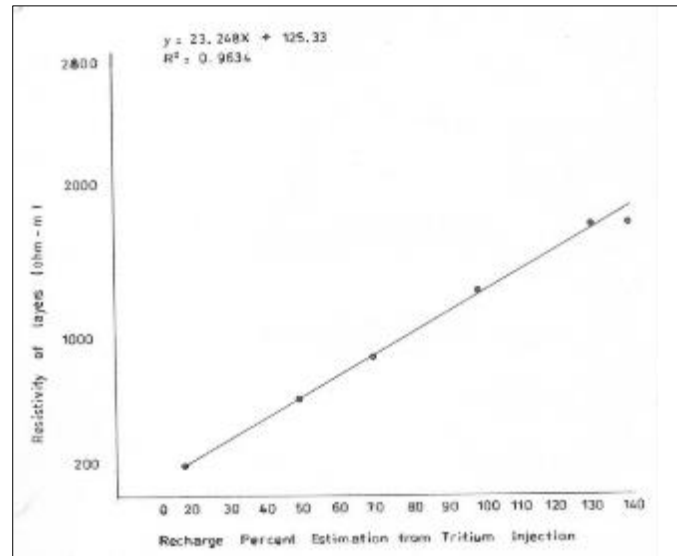

Figure 8 Correlation of Recharge Percent Estimated from Tritium Tagging Technique and resistivity of the layers of the soil

Table 6 Correlation results between recharge, rainfall, temperature and evaporation

	Recharge	Rainfall	EVAPO	
Recharge	1.000	0.905	-0.522	-0.429
Rainfall	0.905	1.000	-.325	-0.380
TEMPMAX	-0.522	-0.325	1.00	-0.53
EVAPO	0.429	-0.380	0.353	1.00
Sig. (1-tailed) Recharge	0.000	0.001	0.008	
Rainfall	000	-	0.327	0.017
TEMPMAX	0.001	0.0327	0	0.26
EVAPO	0.008	0.017	0.026	-
NRecharge	31	31	31	31
Rainfall	31	31	31	31
TEMPMAX	31	31	31	31
EVAPO	31	31	31	31

From the interpreted resistivity gathered from the study region at and around the chosen sites, the resistivities of the non-aquiferous upper layers was determine. The resistivity of non-aquiferous top layers and the predicated recharge per cent were shown to be linearly related (Fig 8). For the study area, this empirical relationship is known as the as the recharge model for the study area. Other empirical relationship between resistivity and hydraulic characteristics have also been studied and are referred to as model relationships in the hydrogeology field (Mazac eta al 1985). On the other hand evaporation, mean annual temperature and annual rainfall totals all have a major impact n groundwater recharge. Data from table 2 were used to assess the study's sole hypothesis. Multiple regression and correlation were used. According to table 6's multiple correlation matrix, the correlation coefficients for mean annual rainfall, mean annual

temperature and evaporation are 0.90, -0.52 and -0,42 respectively. This demonstrates that while temperature and evaporation have negative high correlations with recharge (-0.52 and -0.42) respectively, rainfall has a high positive correlation with recharge (0.90). This supported earlier research done by Idowu and Martin (2007), groundwater recharge was measured as being between 3 percent and 20 percent of total annual precipitation in the phreatic basement aquifer of okpeki Drainage basin, South-Western Nigeria. According to their research, precipitation has a beneficial impact on groundwater recharge. High correlation coefficient of 0.7 was obtained the correlation analysis technique.

Prior to applying the multiple regression analysis, a linear regression analysis was conducted to determine the extent to which each climatic component affected groundwater recharge in the research area. The coefficient of Determination (R^2) for the simple linear regression model of rainfall 0.821 or 82.1 per cent. This suggests that annual rainfall amounts in Obubra as shown in table 7, account for about 82.1 percent of groundwater recharge.

Based on table 8, the regression model can be expressed mathematically as written based on table 8 as

$$Y = 23.021 + 0.07x_1 + e$$

Where;

Y   =   Groundwater recharge

X_1 =   Amount of annual rainfall in millimeter (mm)

e   =   Stochastic error term which suggests that groundwater recharge will rise by 0.070mm for every unit increase in yearly precipitation.

Following mathematical calculation was done to test for significance

t   = $0.82 [\sqrt{31-^2}/_1 – (0.82)^2]$

t   = $0.82 \sqrt{29/0.3276}$ =   0.82 x 9.4

t   =   calculated = 7.70

df   =   N-2, 31 – 2 = 29 at 0.05 confidence level

t   =   tabulated = 2.04

Since the t-calculated value of 7.70 is greater than the t-tabulated of 2.04, the null hypothesis is rejected in favor of the research hypothesis. The groundwater recharge in the research area is strongly influenced by rainfall, according to table 8'

From table 8 it is further deduced that the t-value is 11.46 at 0.05 significant level, this implies that rainfall is significant and

Table 7 Model Summary of Rainfall and Recharge

Change Statistics						
Adjusted R		Std. Error of the R Square	R Square			
Model	R		Square	Estimate	Change	Sig. F Change
1	0.905a	0.821	0.810	13.9246	0.821	0.000

a.   Predictors: (Constant), Rainfall

Table 8 Results of correlation coefficients[a]

standardized		Unstandardized Coefficients		coefficients	
Model	B	Std. Error	Beta	t	Sig.
1	Constant	23.021	12.121	2.170	0.046
Rainfall	0. 070	0.005	0.905	12.010	0.000

a. Dependent Variable: Recharge

A basic linear model with the following formula takes temperature and groundwater recharge into account.

$$Y = 780.56 - 21.56 \, x_1 + e$$

Where;
Y   =   groundwater recharge
X_1 =   annual temperature (°C)
e   =   stochastic error term

According to the model, groundwater depletes by 21.56 units whenever the temperature rises and the opposite is equally true. This shows that groundwater recharge and temperature are inversely related; hence, a low temperature will lead to a high groundwater recharge or the reverse. Using the Coefficient of multiple determination (R^2) = 26.4 percent it can be concluded that temperature influences groundwater recharge by roughly 26.4 (table 9); the remaining 73.6 percent influence of groundwater recharge's influence comes from the other elements. Additionally a test of significant was run on the outcome, demonstrating that the t-value of -3.349 is below 0.05 significance threshold set for this investigation (table 10). Therefore, the null hypothesis is accepted that there is no significant effect of temperature on groundwater recharge

$$t = 0.26 \left[\sqrt{31 - 2} / 1 - (0.26)^2 \right]$$

$$t = 0.26 \sqrt{29/0.970}$$

$$t = 0.26 \times 5.46 = 1.47$$

t- calculated = 1.47

df   =   N-2, 31 – 2 = 29 at 0.05 confidence level

t   =   tabulated = 2.04

since the t-calculated value of 1.47 is less than the t-tabulated value of 2.04, the null hypothesis is accepted.

Table 9 Model Summary of Temperature and Recharge

			Change Statistics			
Adjusted R		Std. Error of the R Square	R Square			
Model	R		Square	Estimate	Change	Sig. F Change
1	0.522	0. 264	0.253	28.7590	0.264	0.003

a. Predictors: (Constant), TEMP

Table 10 coefficients[a]

standardized		Unstandardized Coefficients		coefficients	
Model	B	Std. Error	Beta	t	Sig.
1	Constant	780.567	200.456	4.148	0.000
	TEMP	-21.561	5.972	-3.349	0.003

a. Dependent Variable: Recharge

A simple linear regression model between evaporation and groundwater recharge is expressed below as:

$$Y = 247.142 - 1.94\ x_1 + e$$

Where:

Y = groundwater recharge

X_1 = annual evaporation amount (mm) e = stochastic error term

From the model, a given rise in evaporation, groundwater recharge will decrease by

1.94 units. In contrast, groundwater recharge will rise by 1.94 units for every unit decrease in evaporation, this suggests that evaporation and groundwater recharge have a negative relationship.

Additionally, the Coefficient of Multiple Determination of (R^2) = 19.6 percent indicates that evaporation is responsible for around 19.6 percent of the influence on groundwater recharge in the region (Table 11). The remaining 90.4 percent is the consequence of additional factors. The t- value of -2.56 (Table 12) was found to be less than 0.05 significance level chosen for this study when the significance of this study was tested. As a result it is considered that evaporation has no discernible impact on groundwater recharge. Similarly, the following mathematical computations revealed thus:

$t = 0.19[\sqrt{31 - ^2/_1 - (.019)^2}]$

$t = 0.19\ \sqrt{29/0.963})$

$t = 0.19 \times 5.49$

t= calculated = 1.04

df = N-2, 31-2 =29 at *0.05* confidence *level*

t-tabulated value =2.04.

Since the t-calculated value of 1.04 is less than the t-tabulated value of 2.04, the null hypothesis is accepted and the alternative hypothesis rejected that there is no significant effect of evaporation on groundwater recharge.

Table 11 Model Summary of Evaporation and Recharge

Model Summary of Temperature and Recharge						
Change Statistics						
Adjusted R		Std. Error of the R Square	R Square			
Model	R		Square	Estimate	Change	Sig. F Change
1	.429a	.196	0. 156	31.43571	0. 196	0.016

a. Predictors: (Constant), EVAPO

Table 12 Coefficients [a]

standardized		Unstandardized Coefficients		coefficients	
Model	B	Std. Error	Beta	t	Sig.
1	Constant	247.142	247.142	7.072	0.000
EVAPO	-1.946	0.741	-0.4297	-2.560	0. 16

a. Dependent Variable: Recharge

4.1. Recommended aquifer management practices

The following aquifer management practices have been recommended to sustain groundwater recharge all year round in the area. 1. There should be adequate legislation to protect watersheds around the low-lying northern zones. There should be standard measure in abating groundwater excessive abstraction in such shallow aquifer areas Chemicals should not be dumped on drains or on the ground. Environmentally friendly methods of waste management, such as waste recycling, should be adopted to reduce the impact of industrial wastes on the environment.

5. Conclusion

This study entailed the deployment of Geophysical, hydrological and geological techniques in the estimation of groundwater potentials, recharge, and productivity in a known geological formation. The results present here are based on extensive studies using surface electrical resistivity method, tritium tagging technique, groundwater monitoring and analysis of climatic factors. The result obtained shows a relationship which is extremely useful for groundwater resources evaluation and recharges estimation in a particular area of interest and is valid for an area of similar geology. When this kind of relationship or model is developed for a given area, the determination of groundwater recharge will be easier, economical and less time-consuming when using electrical resistivity measurement. It is deduced from the study that there were variations in the aquifer recharge, this was on account of various hydro, metrological, geophysical and geological factors in addition to experimental uncertainty. This variation is reflective of the inherent variability phenomenon of groundwater recharge in the study area.

Compliance with ethical standards

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