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HYDRAULIC CHARACTERISTICS OF A TYPICAL BASEMENT COMPLEX AQUIFER IN AJAOKUTA, SOUTHWESTERN NIGERIA

C.C. OSADEBE+, J.O. FATOBA and S. OBRIKE
Nigerian Building and Road Research Institute, P.M.B. 1055, Ota, Ogun State, Nigeria.

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Abstract

To establish the feasibility of water supply in a basement complex area of Ajaokuta, Southwestern Nigeria, pumping test results were used to investigate the storage properties and groundwater potential of the aquifer. The aquifer system consists of weathered and weathered/fractured zone of decomposed granitic rock with quartz veins. Kazemi *et al.* (1969) straight line method (observation well) of draw-down analysis in an unconfined aquifer ($\beta=1$) yield fracture transmissivity, fracture storativity and matrix storativity of 57.83 m^2/day, 2.91×10^{-3} and 7.49×10^{-3} respectively. These values are reasonably high. The well efficiency of the test well is 83% and discharge rate of 25m^3/hour (600m^3/day). The result is reasonably good and indicative of good groundwater potential.

Key words: hydraulic, aquifer, fracture, transmissivity, storativity.

1. Introduction

Most crystalline rocks in their fresh compact state are largely impermeable with no groundwater storage, so they generally constitute poor aquifer. However, good to very good aquifers occur in fractured and faulted zones of crystalline rocks that occur to considerable depth or weathered rocks. Wells drilled in such areas of deep weathering or intense fracture joint systems produce high yields.

Yields of boreholes in crystalline rocks are highly variable but many high yield boreholes for domestic and industrial water supply have been drilled in Nigeria and many parts of the world. Olayinka and Olorunfemi, 1992 also reported a borehole yield of 23 m^3/hr in Okene, Kogi State. Various researchers (Acworth, 1987; Olayinka and Mbachu, 1992) have reported yields varying from 1.6 to 23 m^3/hr at various basement complex areas.

Ajaokuta area is a growing town within the southwestern region of Nigeria because of the presence of steel rolling mill. Presently, the water supply in the area has been from both shallow wells from the overburden which dries out during dry season and surface water supply scheme from River Ohunene. However, River Ohunene is perennial and it remains the main source of domestic water for the community. These sources, therefore, are considered inadequate for the water supply requirement of a growing community. In addition, because of the distance of the river to the various communities and the inherent danger of pollution, there is an urgent need to identify the groundwater potential of the hard rock area. Consequently, the existing surface water supply facility is to be expanded to provide for the projected demand.

In this study, the hydraulic properties of the aquifer system are investigated as a basis for ascertaining the feasibility of water supply to the area.

Location and physiographic setting

The study area is located at about 20km Northeast of Adogo and 4 km North of Ajaokuta in Ajaokuta Local Government area of Kogi State, Nigeria. The area is located within longitudes 7° 00' and 7° 30' N and latitudes 6° 30' and 7° 00' E (Fig. 1). Generally the area is located about 150 meters above the sea level.

The drainage within the study area is dendritic in pattern with two rivers draining the area i.e. River Osara and River Uba. The rivers flow eastwards to join Rivers Niger which is a major geomorphic feature in the area (Fig. 1). The area falls within the Tropical forest-savannah mixture characterized by a mixture of trees, shrubs and grasses. The area has the peculiar climate of long dry season (October-April) and a short wet season (May-September). The mean annual rainfall is between 1000-1500 mm while the mean temperature is about 26.1 °C.

Geology

The study area is generally underlain by crystalline rocks of Basement complex rocks of southwestern Nigeria which is classified into five (5) groups (Rahaman, 1976).

(i) Migmatite gneiss complex which comprises of biotite and biotite hornblende gneisses, quartzite and quartz schist and small lenses of calcilicate rocks

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+ *corresponding author*

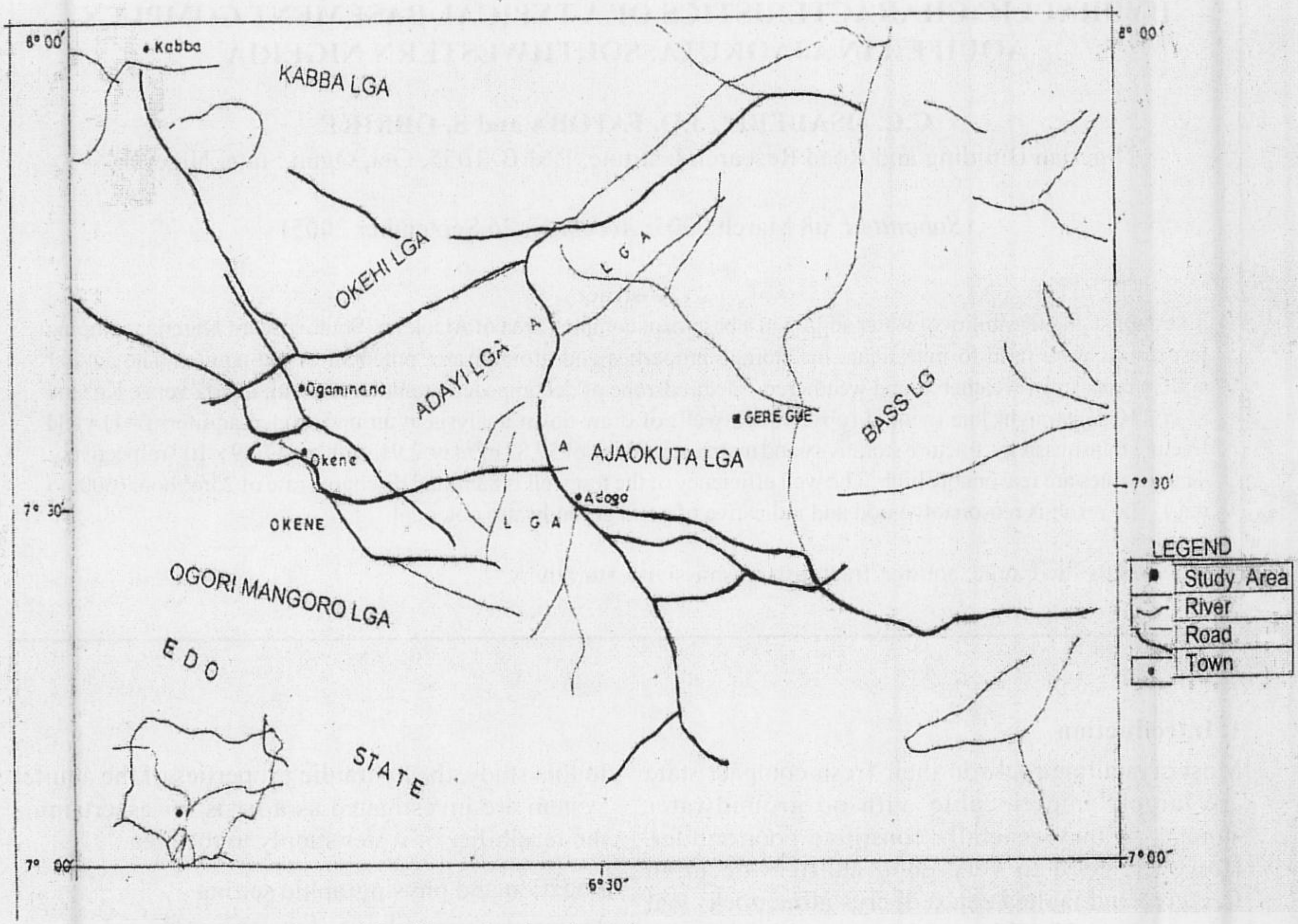


Fig. 1: Map of part of Kogi State showing the study area.

(ii) Slightly migmatised to unmigmatised para-schists and meta-igneous rocks.
(iii) Charnockitic rocks
(iv) Older granites which comprise of rock varying in composition from granodiorite to granite and potassic syenite
(v) Unmetamorphosed dolerite dykes

The quartzite, migmatite gneiss, grey gneisses and phyllite/schist are very exposed in most part of the area. The phyllite/schist is the meta conglomerates which occur at the bank of River Niger. The rocks strike in the north-south direction from the outcrops at the study area. The relics of quartzite comprise of many joints through which water could penetrate. The geological map of the area is shown in Fig. 2.

2. Materials and Method

A test well and two observation wells (SP 1and SP 2) were drilled. The pumping test was conducted on the test well with two observation wells (SP1 and SP2) to determine the potential for groundwater resources of the study area. The pumping test was carried out at a constant discharge rate of 25 m^3/hr (600 m^3/day) and the pumping water levels were measured using dip-meter at the test well and observation wells (SP 1 and SP2) at a distance of 15 m and 30 m respectively.

Initially, the readings in the production well and observation wells were at every one minute for the first 10 minutes followed by every 2 minutes for the next 10 minutes. Thereafter, readings were taken at every 5 minutes, 10 minutes and 30 minutes. Uninterrupted readings were achieved for 10 hours of pumping. At the termination of pumping test, measurement of well recovery or recharging commenced immediately.

The well efficiency was estimated as the percentage of pumping level inside casing to draw down outside casing i.e.

$$Efficiency = \frac{\text{pumping level inside casing}}{\text{drawdown outside casing}} \times 100$$

3. Interpretation of Data

The pumping test data were analyzed using data obtained from the observation well (sp1). Kazemi *et al.,* 1969 straight line method was adopted for the study. On a sheet of semi-log paper, plot of drawdown (m) versus time (mins) was drawn with time on the logarithm scale as shown in Fig.3. This

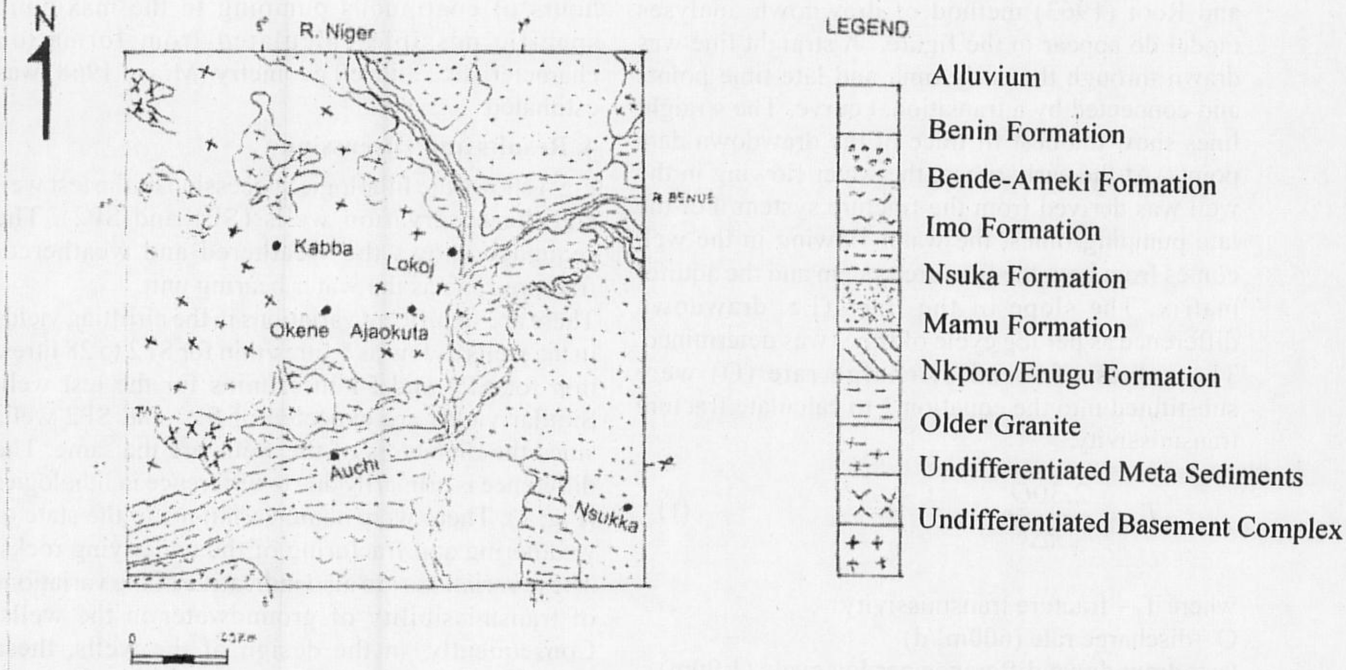


Fig. 2: Geological Map of Ajaokuta and Environs

Fig. 3: PLOT OF DRAWDOWN AGAINST TIME OF THE OBSERVATION WELL (SP 1)

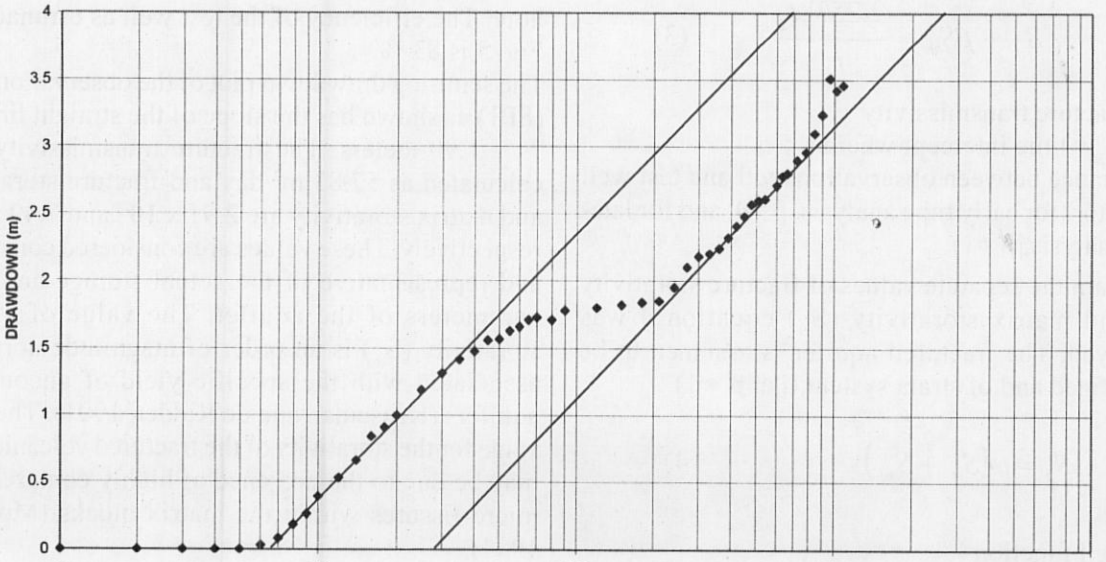


figure clearly reveals the double porosity of the aquifer because it shows the early time, intermediate time and late time segments characteristics of double porosity. The two parallel straight lines of the Warren and Root (1963) method of drawdown analyses model do appear in the figure. A straight line was drawn through the early time and late time points and connected by a transitional curve. The straight lines show the best fit trace of the drawdown data points. At the early times, the water flowing in the well was derived from the fracture system. For the late pumping times, the water flowing in the well comes from both the fracture system and the aquifer matrix. The slope of the lines (i.e. drawdown difference as per log cycle of time) was determined. The values of s and discharge rate (Q) were substituted into the equation 1 to calculate fracture transmissivity,

$$T_f = \frac{2.30Q}{4\pi\Delta s} \qquad (1)$$

where T_f = fracture transmissivity
Q =discharge rate ($600 m^3/d$)
“s = draw-down difference per log cycle (1.90m)
π = constant (3.14)

The early time and late time straight lines were extended until they intercept the time axis where s = o and t_1 and t_2 were determined. The values of T_f, t_1, and r were substituted into equation 2 to calculate fracture storativity (S_f). The values of T_f, t_2, r and β were substituted into equation 3 to calculate fracture storativity (S_f) and matrix storativity(S_m).

$$S_f = \frac{2.25T_f t_1}{r^2} \qquad (2)$$

$$S_f + \beta S_m = \frac{2.25T_f t_2}{r^2} \qquad (3)$$

T_f = fracture transmissivity
t_1 and t_2 = time intercept where s = o
r = distance between observation well and test well
β = factor (for early time analysis, β =0; and for late-time analysis, β =1)

To obtain the separate values of fracture storativity (S_f) and matrix storativity (S_m) equation 4 was employed. The fractured aquifer is assumed to be unconfined and of strata system (i.e. β = 1)

$$S_f = \omega(S_f + S_m) \qquad (4)$$

where
ω = well function

The semi-log plot of time versus drawdown (Fig. 3) shows that the centre of transition period is at 110 mins. At t = 110 mins, s_v = 1.05 meters and “s = 1.90 meters. Substituting the values of s_v and “s into equation 5

$$\omega = 10^{-\Delta s_v / \Delta s} \qquad (5)$$

The well efficiency which is the ratio of the actual specific capacity at the designed well yield after 24 hours of continuous pumping to the maximum specific possible calculated from formation characteristic and well geometry (Mogg, 1968) was estimated.

4. Results and Discussion

Fig.4 shows the lithologic succession of the test well and the observation wells (SP1 and SP2). The sequence shows the weathered and weathered/ fracture zone as the water bearing unit.

There are significant variations in the airlifting yields in the wells as low as 5 litres/min for SP2 to 28 litres/ min for SP1 and 54 litres/mins for the test well. Similar yields are expected of SP1 and SP2 wells since the diameters of the wells are the same. The difference is primarily due to difference in lithologies (Fig. 4). There were some variations in the state of weathering and fracturing of the underlying rocks. These variations are also indicative of the variations of transmissibility of groundwater in the wells. Consequently, in the design of the wells, these variations informed the placement of the screens in various wells.

Tables 1 and 2 show the drawdown data of the test well and observation well (SP1). With constant pumping rate of 25 m^3/hr, the maximum observed drawdown in the pumped well after 16 hours of pumping is 13.23 meters. After 18 hours of pumping, readings in the observation well (Table 2) appear to be stabilizing as expected of aquifer in a basement complex region stabilization or state of equilibrium of drawdown. The recovery rate as shown in Table 3 indicates that the well recovery data is good with over 75 % recovery achieved within the first one hour. The efficiency of the test well as estimated in Fig. 5 is 83 %.

The semi-log drawdown plot of the observation well (SP1) as shown has the slope of the straight lines as “s = 1.90 meters. The fracture transmissivity was calculated as 57.83 m^2/day and fracture storativity and matrix storativity are 2.91×10^{-3} and 7.49×10^{-3} respectively. These values are considered consistent and representative of the actual storage and flow parameters of the aquifer. The value of matrix storativity (S_m) is an order of magnitude normally associated with the specific yield of unconfined aquifers (Kruseman and de Ridder, 1991). The high value for the storativity of the fractured volcanic rock may be due to the presence of highly compressible micro-fissures within the matrix blocks (Moench, 1984).

The fractured aquifer system has relatively high transmissivity and storativity values indicating suitability for water well exploitation. Field and analytical studies of pumping test results show that substantial drawdown magnitude would be expected

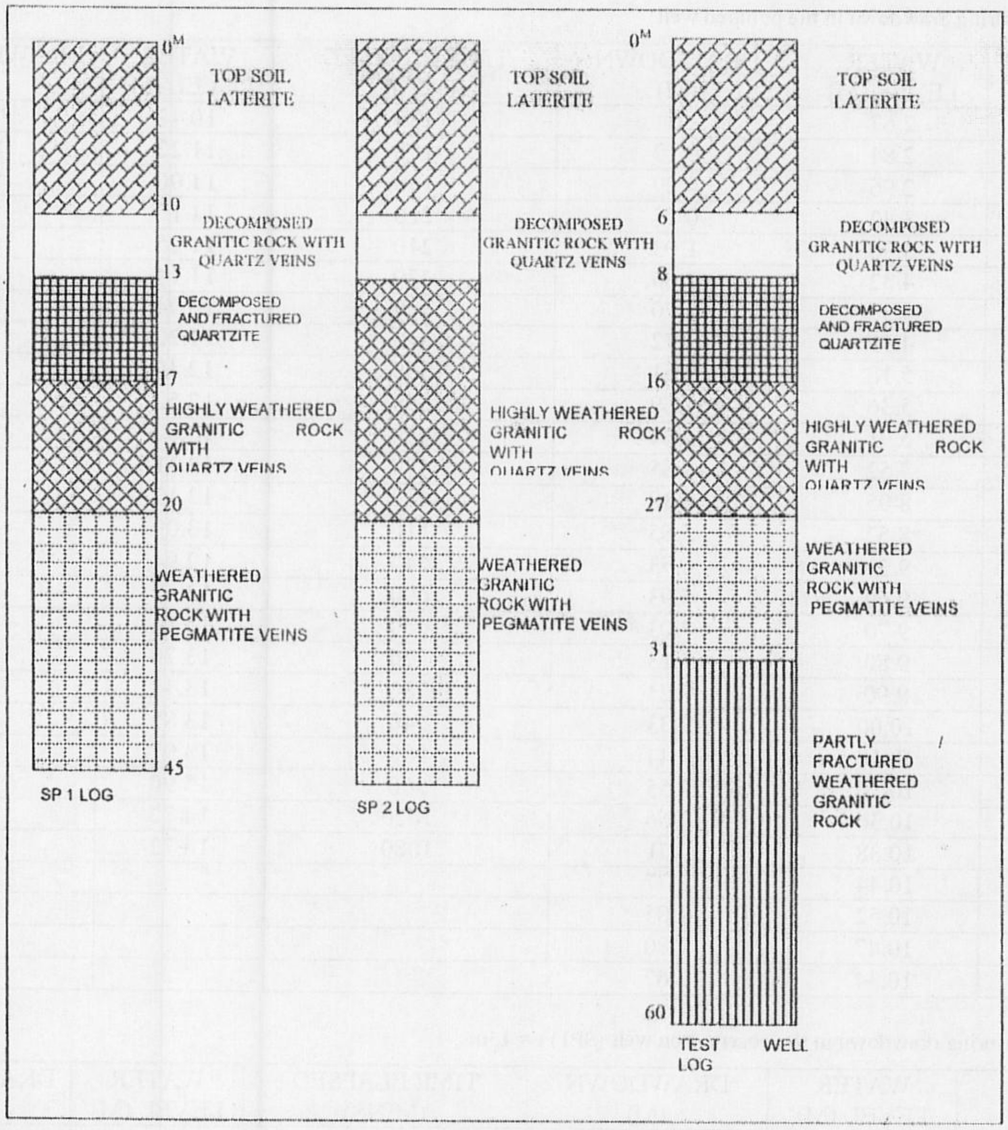


Fig. 4: Borehole logs for test well and observation wells (SP 1 and SP 2)

particularly where several wells are pumped simultaneously. In consideration of the low potential to aquifer recharge by rainfall, the rate of abstract would be checked such that the wells would reasonably be sustained by the aquifer system without lowering the water table appreciably. However, with adequate spacing out of the pumping wells, excessive drawdown and considerable lowering of the water table could not occur in the borehole.

5. Conclusion

The aquifer for the groundwater in the study area is weathered/fractured basement complex. The extent of its continuity and homogeneity could not be ascertained. However, the yields of the boreholes within the area like any other basement complex area depend on the nature of the weathered layer which is variable depending on the lithology, the thickness of the weathered layer, the interconnectivity of the fractured zone and the available water recharge of the area.

The result of the data interpretation revealed the double porosity of the aquifer because it shows the early time; intermediate time and late time segments characteristics of double porosity media. The sustainable yield of 25 m^3/hr and the efficiency of the test well are reasonably good and indicate that the area has good groundwater potential that can be exploited for adequate provision of water supply. The aquifer also has moderate transmissivity and storativity values indicating suitability for water well exploitation especially in a hard rock area.

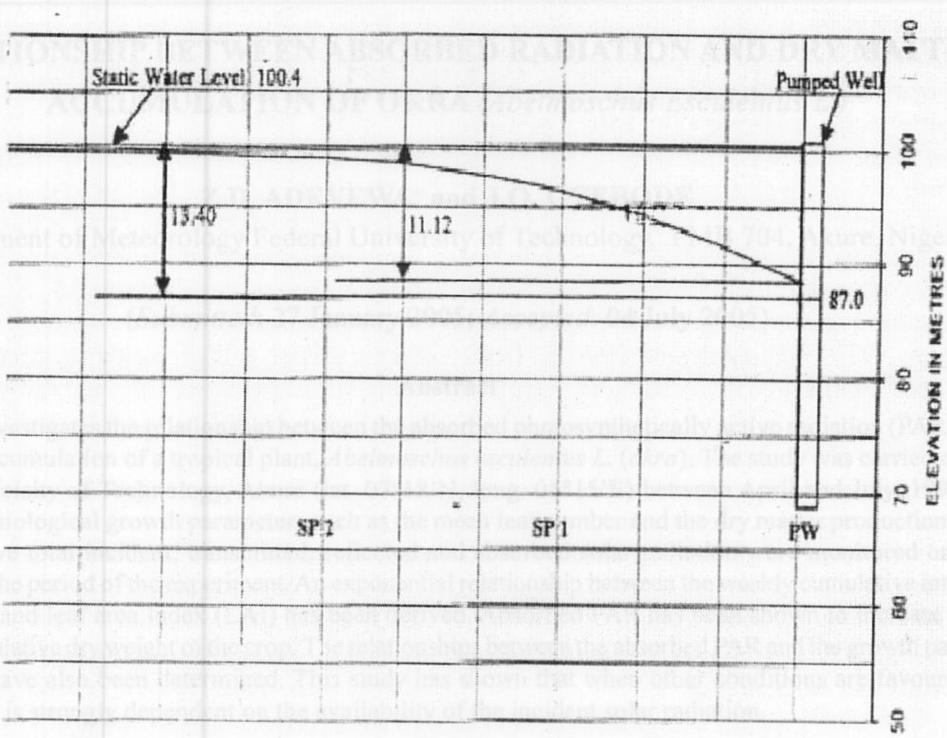
With additional boreholes in the area and adequate storage facility, Ajaokuta area of Southwestern Nigeria will benefit immensely from the urban and rural water supply embarked by the Federal Government of Nigeria.

Table 1: Measuring drawdown in the pumped well

ELAPSED MINS)	WATER LEVEL (M)	DRAWDOWN (M)	TIME ELAPSED (MINS)	WATER LEVEL (M)	DRAWDOWN (M)
0.0	2.67	0	120	10.47	7.80
1.0	2.84	0.17	150	11.22	8.55
2.0	2.96	0.29	180	11.00	8.33
3.0	3.42	0.75	210	11.17	8.50
4.0	3.70	1.03	240	11.25	8.50
5.0	4.32	1.65	270	11.14	8.58
6.0	4.37	1.70	300	10.94	8.47
7.0	4.39	1.72	330	11.22	8.27
8.0	5.18	2.51	360	12.30	8.55
9.0	5.36	2.69	390	12.52	9.63
10.0	5.91	3.24	420	12.62	9.85
12.0	7.52	4.85	450	13.11	9.95
14.0	8.05	5.38	480	13.12	10.44
16.0	8.52	5.85	510	13.09	10.45
18.0	9.20	6.53	540	12.94	10.42
20.0	9.60	6.93	600	13.90	10.27
25.0	9.70	7.03	660	15.14	11.23
30.0	9.80	7.13	720	13.70	12.47
35.0	9.90	7.23	780	13.42	11.03
40.0	10.00	7.33	540	13.85	10.75
45.0	10.10	7.44	900	13.97	11.18
50.0	10.20	7.55	960	15.90	11.30
55.0	10.30	7.66	1020	14.72	13.23
60.0	10.38	7.71	1080	14.72	12.05
65.0	10.44	7.77			
70.0	10.52	7.85			
80.0	10.47	7.80			
90.0	10.34	7.67			

Table 2: Measuring drawdown in the observation well (SP1) r = 15m

E ELAPSED (MINS)	WATER LEVEL (M)	DRAWDOWN (M)	TIME ELAPSED (MINS)	WATER LEVEL (M)	DRAWDOWN (M)
0	2.54	0.0	150	4.36	1.82
1	2.54	0.0	180	4.38	1.84
2	2.54	0.0	210	4.39	1.85
3	2.54	0.0	240	4.49	1.95
4	2.54	0.0	270	4.64	2.10
5	2.54	0.0	300	4.72	2.18
6	2.57	0.03	330	4.74	2.20
7	2.62	0.08	360	4.78	2.24
8	2.72	0.18	390	4.86	2.32
9	2.80	0.26	420	4.95	2.41
10	2.93	0.39	450	5.02	2.48
12	3.07	0.53	480	5.19	2.57
14	3.20	0.66	510	5.14	2.60
16	3.38	0.84	540	5.15	2.61
18	3.45	0.91	600	5.33	2.71
20	3.54	1.00	630	5.32	2.78
25	3.73	1.19	660	5.34	2.80
30	3.86	1.32	720	5.44	2.90
35	3.96	1.42	780	5.50	2.96
40	4.02	1.48	840	5.64	3.10
45	4.10	1.52	900	5.78	3.24
50	4.13	1.59	960	6.05	3.51
55	4.17	1.63	1020	5.96	3.42
60	4.20	1.66	1080	6.00	3.46
70	4.27	1.73			
80	4.25	1.71			
90	4.32	1.78			
120	4.34	1.80			



$$Efficiency=\left(\frac{Pumping\ level\ inside\ ca\sin g}{Draw-down\ outside\ ca\sin g}\right)x100$$

Fig. 5: Estimating well efficiency for the test well

Table 3: The recovery rates in the test well

Elapsed time (Minutes.)	% Recovery
10	54
20	68
30	79
40	81
50	83
60	84

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decreased gradually with crop maturity. LAI decreased as k* increased. An exponential relationship between the two variables has been derived.

Although the fraction of total solar radiation transmitted by the crop decreased as LAI increased, no apparent relationship was found between the two variables. An exponential relationship between the weekly cumulative intercepted PAR (CIPAR) and LAI has been obtained. The derived relationship between the former and the extinction coefficient (k*) is linear. Absorbed PAR has been shown to increase strongly with the cumulative dry weight of the crop. A strong exponential relationship also exists between them. Moreover, the weekly cumulative dry weight production of the crop has been shown to be better correlated with cumulative IPAR than with the weekly dry weight production. The study has also showed that when other conditions are favourable, the intercepted PAR increases exponentially with the cumulative weekly rainfall. The exponential relationship could be due to the fact that fertiliser was applied six weeks after planting. Generally, the weekly values of the parameters are poorly correlated while the cumulative amounts are strongly correlated.

The results from this experiment have demonstrated the fact that the growth and yield of *okra* are very sensitive to the quality as well as the quantity of the prevalent radiation microclimate.

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