SHALLOW AQUIFER CHARACTERISTICS, BOREHOLE YIELD AND GROUNDWATER RESOURCE SUSTAINABILITY ASSESSMENT IN THE OSUN DRAINAGE BASIN, SOUTHWESTERN NIGERIA

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ABSTRACT

This study assessed the hydrogeological characteristics of 59 boreholes from the Osun Drainage Basin, Southwestern Nigeria with a view to examining the sustainability of its groundwater resource. Data on borehole parameters (depth of hole, static water level and yield) were acquired from Osun State Rural Water and Sanitation Agency and Bayowa (2013). Likewise, hydrogeological parameters (longitudinal unit conductance, hydraulic conductivity and transmissivity) were extracted from Akinwumiju (2015). The techniques of descriptive and inferential statistics were adopted to analyze these data while the relationship between yield and other hydrogeological parameters was also modeled. Results revealed that aquifers are generally shallow, thin and less porous across the study area; indicating relatively low groundwater yield potentials. Correlation and regression analyses revealed that hydraulic conductivity, transmissivity and longitudinal unit conductance were factors influencing borehole yield in the study area. However, all the four parameters examined in this study were observed to have their individual influence on borehole yield at varying degrees. It was concluded that the basin's groundwater resource might not be able to sustain her population in the process of time as indicated by the low mean yield (0.981/s) computed for the study area but for the continuous recharge from seasonal precipitation.

Keywords: Groundwater Yield, Borehole Parameters, Basement Complex, Osun Drainage Basin, Groundwater Sustainability

INTRODUCTION

Water is a fundamental, and yet, ironically, scarce requirement imperative to human existence (Massoud *et al.,* 2010). As a universal solvent, water is central to facilitating the biological processes necessary for human life. Therefore, the degradation of our planet's water supply, and subsequently the hydrological cycle, will eliminate life faster than any nuclear arsenal (Black, 2004). Accordingly, safe, available drinking water is significant in the maintenance of humanity and our environment, within an array of contents (Massoud *et al.,* 2010). Water's priceless position within our environmental community makes it an especially critical resource to our global health. Constituting 70% of human tissue and 55% of blood, fresh, clean water sustains the ecological balance essential for planetary health and vitality across the world (Black, 2004). However, earth's potable water is less than 1% of the total water covering 71% of the earth's surface (Mahaya *et al.,* 2009). It is estimated that 96.5% of global water is contained in the Oceans and Seas; 0.93% occurs as saline groundwater; 0.07% occurs in saline lakes and the remaining 2.5% represent the global freshwater. Sixty-eight percent (68%) of the limited freshwater is locked up in form of glaciers and ice scarps; 30.1% occurs as groundwater while the remaining 1.3% represents the surface water in form of rivers (0.46%), biological water (0.22%), atmospheric water (0.22%), swamps and marshes (2.53%), soil moisture (3.52%), and ice and snow (73.1%) (Shiklomanov, 1993). In this case, groundwater constitutes the largest available freshwater reserve in the world.

Among the known sources of potable water (that is, desalination, pipe borne, rain harvesting and groundwater), groundwater has been found to be the best option particularly in Africa. Currently in Nigeria, more than 70% of the available potable water is being tapped from the ground. Except in Abuja, where over 80% of the municipal area is connected to pipe borne water network (Ali, 2012), inhabitants of Nigerian cities, towns and villages mostly rely on groundwater resources. Based on the above submissions, it can be concluded that groundwater is a major source of clean water particularly in low income countries of the world, such as Nigeria. Nevertheless, the heterogeneity of groundwater occurrence and poor understanding of groundwater resources particularly in the Basement Complex terrain constitute a barrier to efficient groundwater resource management in Nigeria. In response, research efforts are being channeled towards identifying the actual sub-surface locations of groundwater occurrence (groundwater exploration in fracture/fault zones and thick sub-surface unconsolidated regolith) for economically viable clean water supply within the Basement Complex terrain. However, only few studies have made the attempt to assess the sustainability of groundwater yield in Nigeria.

Ifabiyi (2000) attempted the comparative analyses of borehole yield potential and the predictor variables in both Basement Complex terrain and Sedimentary basin of Central-western Nigeria. The study isolated borehole depth, drawdown and screen length as the major determinant factors of borehole yield potential within the sedimentary basin, but observed that these variable could not account for borehole yield within the Basement Complex terrain. The study ascribed very high yield potential to the sedimentary basin while extremely low yield was recorded for boreholes of the Basement Complex environment. The study concluded that groundwater resource is more reliable and sustainable in the sedimentary environment compared to the uncertainty being experienced in the Basement Complex terrain due to low yield. Isaac *et al.* (2010) employed statistical techniques to evaluate the hydrogeological characteristics of 91 producing boreholes within the crystalline Basement Complex area of Northern Nigeria. The study observed that borehole yield and specific capacity of aquifer had no relationship with regolith thickness and saturated thickness at the borehole points. The Study revealed that borehole yield was generally low within the Basement Complex terrain of Northern Nigeria with an average yield of 0.76 l/s. However, isolated cases of high yields were observed where boreholes intercepted fractured aquifers. The study concluded that aquifer productivity was not significantly related to regolith and saturated thicknesses within the study area. Yaya *et al.* (2003) attempted the appraisal of groundwater resource potential of the Basement Complex rock aquifers in Zamfara State, Northern Nigeria. The study submitted that groundwater in the Basement Complex rocks of the State can mainly be tapped from fractures and joints and within the intergrannular pores of fine to coarse sand or gravel in the sedimentary areas. The study concluded by emphasizing that borehole yield is generally low across the study area.

The present study area is the Osun Drainage Basin that cut across Ekiti and Osun States in the forested region of Southwestern Nigeria. All the inhabitants of the basin rely either completely or in part on groundwater resource for their daily water supply (Akinwumiju, 2015). However, attempt to meet potable water demand within the basin has not yielded positive result due to very many failed boreholes with extremely low yield, which has been attributed to the hydrogeological characteristics of its aquifers (Akinwumiju, 2015). Generally, many studies have affirmed that borehole/well failure in the Basement Complex terrain has been ascribed to institutional problems and lack of basic planning data such as hydrogeological information (Eduvie, 2006, 2008; Eduvie and Olabode, 2012; Olabode and Bamgboye, 2013).

Therefore, there is need to further investigate the determinant factors of borehole yield in the crystalline rock environment. To this end, this study attempts to harness hydrogeological (borehole and VES-based parameters) data and subject them to statistical analyses with the aim of isolating the variables that determine borehole yield within the Basement Complex environment. The specific objectives are to model the relationship among the available hydrogeological parameters; establish a relationship between borehole yield and the other hydrogeological parameters; carefully consider the implication of the outcome of this study on groundwater development and management vis-à-vis the attempt to sustainably meet water demand of the inhabitants of Osun Drainage Basin in Southwestern Nigeria.

The Study Area

Osun Drainage Basin lies within Latitudes 7°35'N and 8° 00'N and Longitudes 4°30'E and 5°10'E (Figure 1). Osun Catchment (2,194.59 km^2)

extends from the upland area of Ekiti State to the low lying area of Osun State, covering 21 Local Government Areas. The basin is underlain by metamorphic rocks, comprising Schist Complex including amphibolites; migmatite-gneiss complex; quartzo-feldspathic granite with gneiss; quartzite; silicified sheared rock and quartz veins and migmatite. Also, part of the basin is underlain by granitic rocks comprising porphyritic granite; charnockitic rocks; coarse porphyritic biotite and biotite hornblende granite; pegmatite undifferentiated granite, migmatite and migmatite gneiss, older granite, migmatite porphyroblastic, biotite granite and metadiorite (Figure 2). From the above description, it can be deduced that the rocks of the basin is dominated by unstable ferromagnesian mineral rocks (schist and amphibolite), which usually weather into clay especially under tropical climatic condition with tendency for low groundwater yielding capacity. However, the capacity of the crystalline basement rocks to store, transmit and yield reasonable quantity of groundwater depends on the degree of interconnection of the voids/pore spaces within the weathered regolith, the extent, thickness and continuity of the fractures/faults and on the degree to which the fractures are hydraulically connected (Offodile, 2002; Akinluyi, 2013).

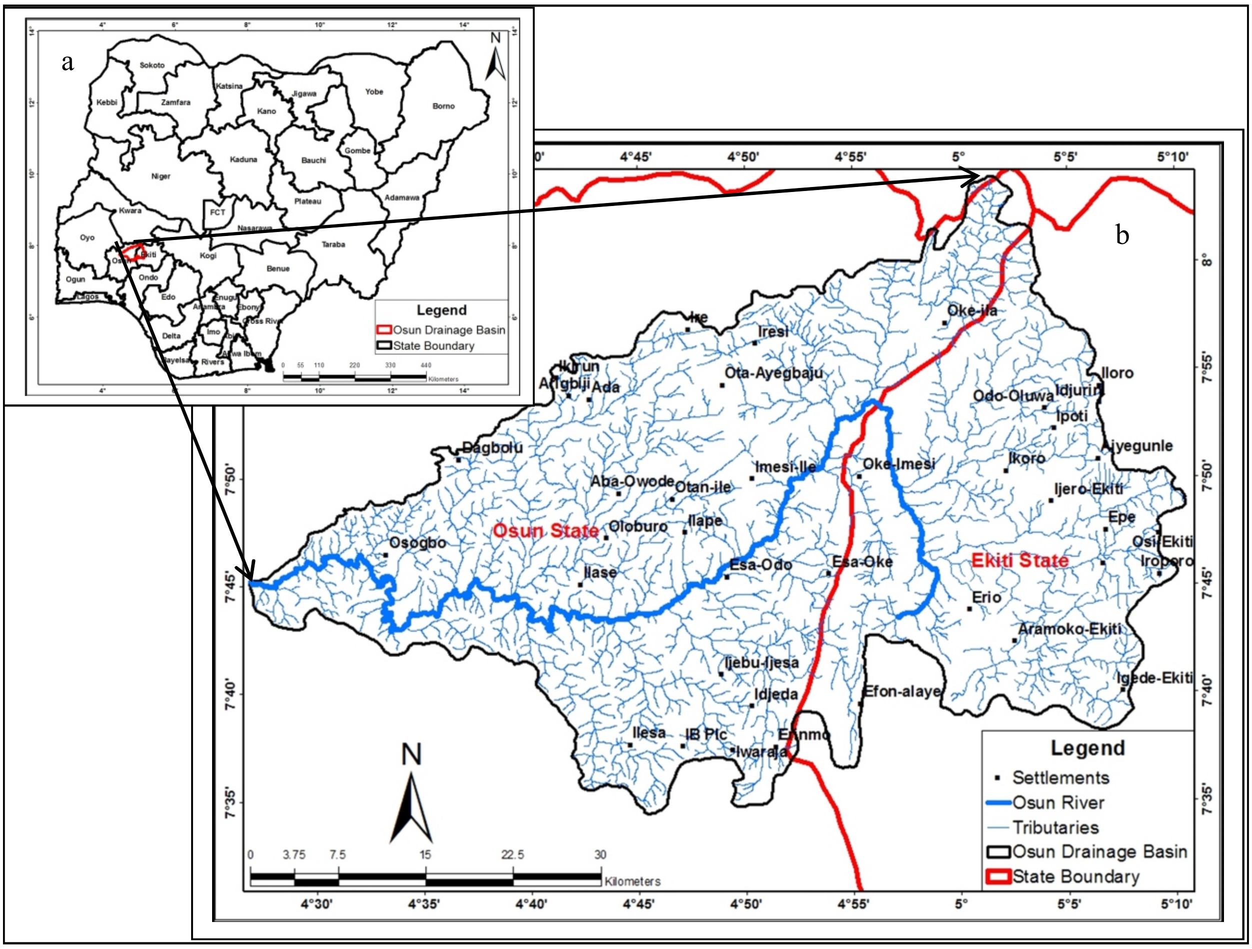

Figure 1: Map of the Study Area showing a): Nigeria's State Boundaries; b): Osun Drainage Basin

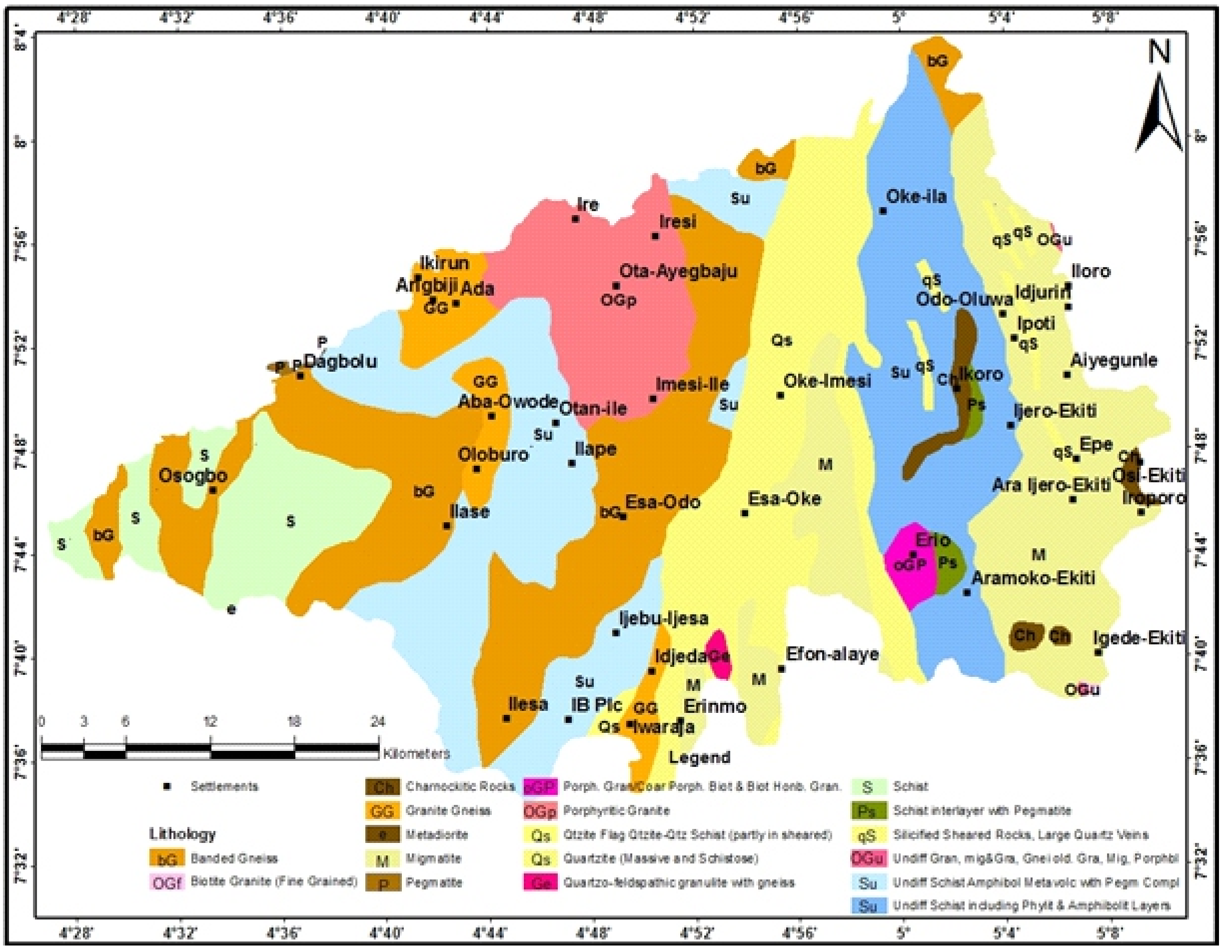

Figure 2: The Geological Map of Osun Drainage Basin (Extracted from NGSA, 2006)

Notable geological structures within the study area include Efon Ridge Mountains and the Zungeru-Ifewara Fault Zone that dissect the study area (De Swardt, 1953; Elueze, 1977; Boesse and Ocan, 1988; Oluyide, 1988; Odeyemi *et al.,* 1999; Awoyemi *et al.,* 2005).

MATERIALS AND METHODS

Borehole parameters (depth, yield, groundwater elevation, borehole point elevation) for 59 locations were obtained from Osun State Rural Water and Sanitation Agency and Bayowa (2013). Vertical Electrical Sounding-derived geoelectrical parameters were extracted from Akinwumiju (2015) (See Table 1). The selected locations are presented in Figure 3 and the corresponding hydrogeological parameters are presented in Table 1. Multiple Correlation and Regression Methods were employed to evaluate the relationship among the hydrogeological parameters and predict borehole yield (dependent variable) based on its relationship with static water level, longitudinal unit conductance, hydraulic conductivity and transmissivity (predictor variables X_1, X_2, X_3……X_n). Furthermore, Stepwise Regression Analysis was adopted to isolate a set of hydrogeological parameters that constitute the major yield predictor variables within the study area. This is defined in equation below:

$$Y = a + b_1X_1 + b_2X_2 \ldots\ldots + b_iX_i \pm e \ldots\ldots\ldots\ldots (1)$$

Where a = intercept; b_1, b_2 ……...b_i = partial regression coefficients; e = error term

The Regression Models were computed with the aid of electronic computing using SPSS statistical package.

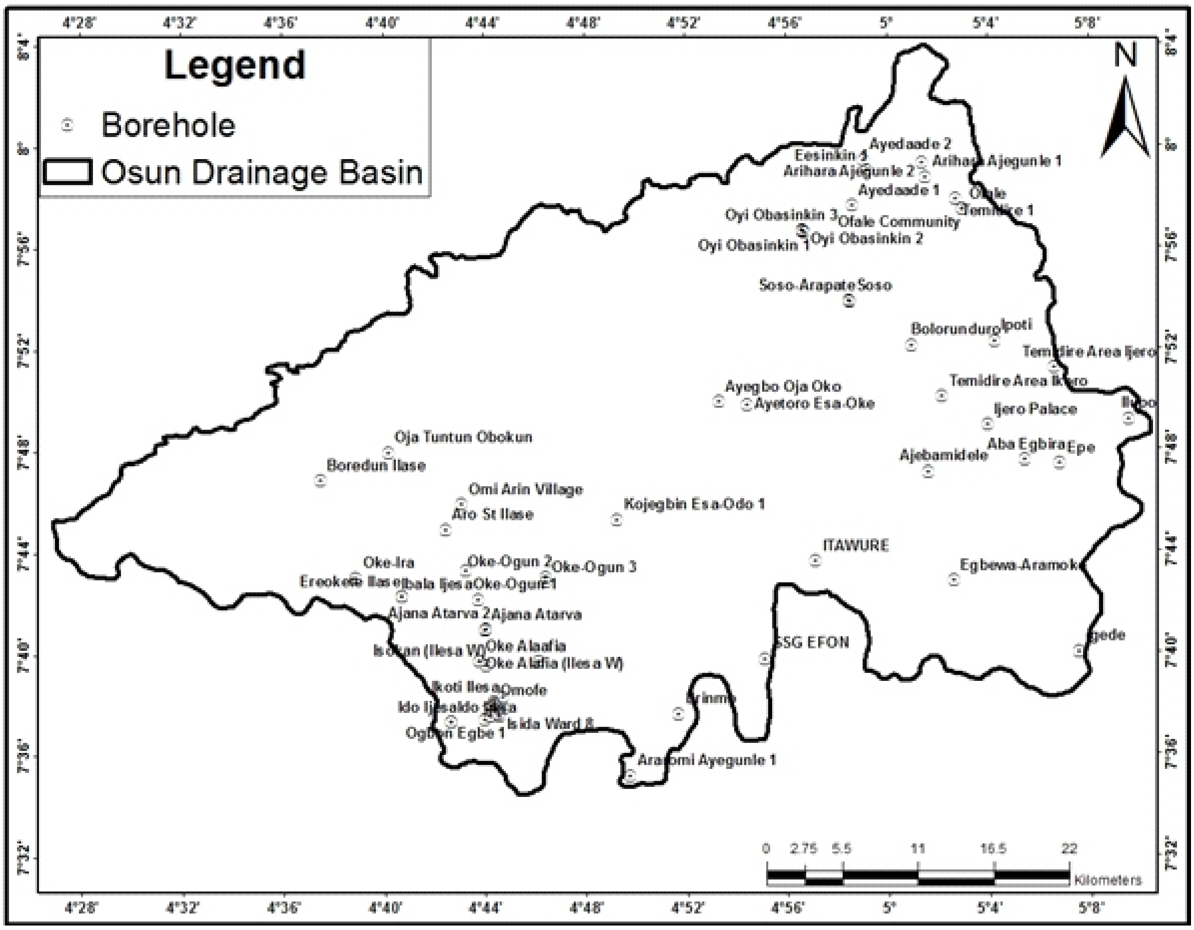

Figure 3: Map of the Study area showing the Locations of Sampled Boreholes

Table 1: Hydrogeological Parameters of the Selected Boreholes

S/No.	BOREHOLE DEPTH (m)	YIELD (l/s)	SWL (m)	LUC (s)	TMS (m^3/s)	HC (m/s)
1	37.8	0.2	13.9	0.08191	0.001574	0.000069
2	45	0.531	2	0.19935	0.003858	0.000082
3	32	0.086	3.4	0.170966	0.001476	0.000033
4	25	0.6687	5	0.289364	0.011146	0.000157
5	30.5	0.1935	4.1	0.285822	0.011645	0.000157
6	41.5	0.2	3	0.158449	0.000463	0.000023
7	56	2.5	9	0.059973	0.0014	0.000116
8	55	2.35	9	0.173362	0.001237	0.00005
9	53	1.9	5	0.043949	0.007358	0.000243
10	45	0.06527	10	0.351949	0.004157	0.000106
11	70	2.5	6.8	0.048969	0.0151	0.000493
12	60	2	7	0.708219	0.006375	0.000081
13	26.84	0.473	8	0.036165	0.007068	0.000107
14	26.84	0.5421	7.6	0.030025	0.00203	0.000094
15	45	0.1832	8.9	0.073348	0.003869	0.00027
16	31.3	0.35	3.2	0.212088	0.001715	0.000057
17	45	0.1371	7.5	0.244534	0.006173	0.000003
18	50	2.25	4.5	0.157691	0.001987	0.000113
19	50	1.2	21	0.527053	0.000739	0.000009
20	31	0.8	12	0.089727	0.001164	0.000072
21	29.3	0.2286	6.3	0.252065	0.008427	0.000139
22	45	0.16	12.21	0.170554	0.001214	0.000052
23	26.4	0.5807	10	0.361564	0.00683	0.000128
24	45	0.2414	6.7	0.362351	0.00839	0.000001
25	45	0.1437	4.3	0.465076	0.006189	0.000054
26	30.5	0.1437	4.3	0.465076	0.006189	0.000054
27	72	1.33	1.3	0.154485	0.005532	0.000143
28	50	0.8	6	0.132936	0.002762	0.000086
29	35	0.1714	10	0.422382	0.002171	0.000002
30	26	1.2	4	0.027022	0.001206	0.000117
31	50	3.57	1.7	0.22967	0.001685	0.00007
32	45	0.4706	10	0.251479	0.005405	0.000096
33	30.5	0.4706	10	0.171415	0.003689	0.000082
34	45	0.4364	5.8	0.203462	0.013099	0.000157
35	45	0.45	7	0.255625	0.000507	0.000011
36	21.3	1.1	5.7	0.089579	0.00173	0.000107
37	28.1	0.5911	14	0.27032	0.002257	0.000008
38	50	0.13	11	0.285849	0.00669	0.00017
39	50	0.13	11	0.234201	0.00553	0.000168
40	45	0.1482	7.63	0.24682	0.008032	0.00009
41	29.89	0.2344	15	0.372359	0.004967	0.00001
42	45	0.3288	8.24	0.219193	0.015868	0.000162
43	36.6	0.9143	4.1	0.291048	0.015032	0.000169
44	65	2	3.75	0.153313	0.005461	0.000245
45	58	2	5.5	0.804463	0.000146	0.000006
46	63	2.5	4.5	0.106135	0.003156	0.000196
47	31.7	0.6667	5.5	0.354326	0.003193	0.000046
48	35	0.136	14.6	0.382216	0.003581	0.000009
49	35	0.1112	18	0.368296	0.002386	0.00001
50	45	0.2286	6.3	0.252065	0.008427	0.000139
51	52	2.5	3	0.316786	0.003028	0.000089
52	52	2.5	4	0.25068	0.002176	0.000078
53	60	2.5	3	0.148078	0.002826	0.000215
54	31.4	1.14	8.7	0.366094	0.00032	0.000026
55	31.4	1.14	8.7	0.459944	0.000754	0.000021
56	47	2.98	2.6	0.55634	0.000254	0.00001
57	50	2.5	5	0.047598	0.0135	0.00033
58	38	1.1	9.1	0.107428	0.001012	0.000155
59	38	1.1	9.1	0.202747	0.001665	0.00008

SWL = Static Water Level, LUC = Longitudinal Unit Conductance, TMS = Transmissivity, HC = Hydraulic Conductivity

RESULTS AND DISCUSSION

The spatial characteristics of hydrogeological parameters are presented in Table 2. The values of borehole yield ranged from 0.65 to 3.57 l/s, reflecting a wide margin between the highest and the lowest yield value. The computed mean yield of borehole is 0.98 l/s, which indicates that borehole yield is generally low across the study area. This situation is expected due to the observed low values of hydraulic conductivity and transmissivity across the study area, resulting from high clay contents of the aquifers of the study area (Akinwumiju, 2015). The values of standard deviation and coefficient of variation (SD = 0.94; CV = 95.85%) indicate that yield varies both relatively and absolutely across the study area.

Table 2: Spatial Characteristics of Hydrogeological Parameters

N	Parameter	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation (%)
59	Yield (ltr/s)	0.65	3.57	0.98	0.94	95.85
59	Borehole Depth (m)	21.30	72.00	42.37	12.01	28.33
59	SWL (m)	1.30	21.00	7.45	4.03	54.09
59	LUC (S)	0.03	0.84	0.25	0.16	64.24
59	TMS (m^3/s)	0.00015	0.016	0.0050	0.0043	86.00
59	HC (m/s)	0.000001	0.00049	0.00010	0.00009	86.71

The values of borehole depth ranged from 21.30 to 72.00 m with a mean of 42.37 m, which suggest that boreholes are mostly shallow in the study area. The mean depth of hole recorded for the study area showed that majority of the sampled boreholes tap water from shallow aquifers, which can be attributed to the occurrence of relatively low overburden thicknesses across the study area (Akinwumiju, 2015). Consequently, boreholes in Osun Drainage Basin are generally shallow and less variable both relatively and absolutely as indicated by the computed values of standard deviation and coefficient of variation (SD = 12.01 m; CV = 28%). However, average borehole yield is very low in the crystalline rock environment (Olorunfemi, 1990). The values of static water level ranged from 1.30 to 21.00 m with a mean of 7.45 m. The mean static water level is low; emphasizing that groundwater elevation is generally high across the study area. This attribute can be ascribed to thin overburden as well as favorable tropical climate of the study area. The values of standard deviation (4.03 m) and coefficient of variation (54%) emphasized that static water level is less variable both absolutely and relatively across the study area. This attribute has enabled low income earners to assess groundwater through shallow hand dug wells across Osun Drainage Basin.

The values of longitudinal unit conductance (LUC) ranged from 0.03 to 0.84 Siemen (S) with a mean of 0.25 S. The mean LUC is very high, indicating high aquifer clay content vis-à-vis high porosity. The interpretation of this attribute is that aquifers have high water storage and retention capacity across the basin. The computed standard deviation and coefficient of variation (SD = 0.16; CV = 64.24%) indicate that LUC vary both relatively and absolutely across the study area. Values of hydraulic conductivity (HC) ranged from 1.0×10^{-6} to 4.9×10^{-4} m/s with mean of 1.03×10^{-4} m/s, which indicate very low aquifer's pore connectivity across the study area. The computed standard deviation and coefficient of variation (9×10^{-5} m/s; CV = 86.71%) showed that hydraulic conductivity is generally low and highly heterogeneous across the study area. The interpretation of this is that aquifer's capacity to release water into boreholes and wells is generally low across the study area. The values of transmissivity ranged from 1.5×10^{-4} to 1.6×10^{-2} m^3/s with a mean of $10^{-3} \times 5$ m^3/s. The mean value of transmissivity computed for the study area is low, indicating restricted groundwater movement within aquifers of the study area. The calculated standard deviation and coefficient of variation (SD = 4.3×10^{-3} m^3/s; CV = 86%) showed that transmissivity vary significantly across the study area.

The correlation matrix of the hydrogeological parameters is presented in Table 3. Results revealed that hydraulic conductivity is the only parameter that has positive association with borehole yield with correlation values of 0.302. The interpretation of this is that borehole yield increases as hydraulic conductivity.

Table 3: Correlation Matrix of Hydrogeological

	Yield	SWL	LUC	TMS	HC
Yield	1.000				
SWL	-0.378	1.000			
LUC	-0.041	0.148	1.000		
TMS	-0.132	-0.167	-0.093	1.000	
HC	0.302	-0.261	-0.507	0.596	1.000

The correlation between yield and hydraulic conductivity (0.302) is relatively weak but it is quite significant at $\alpha = 0.01$. The interpretation of this association is that hydraulic conductivity is a significant indicator of aquifer productivity both in Basement Complex and sedimentary environment. Analyses revealed that yield exhibits negative but weak association with static water level with correlation values of -0.38. It was observed that the correlation between yield and static water level is quite significant at $\alpha = 0.002$. Analyses showed that static water level also exhibit negative but weak association (-0.26) with hydraulic conductivity at 0.05 significant level. The interpretation of this association is that when hydraulic conductivity is high, static water level will be low and consequently, groundwater head will be high.

An inverse but strong relationship (-0.51) was observed between longitudinal unit conductance and hydraulic conductivity at $\alpha = 0.000$. This association means that when the former is high, the latter will be low and this relationship significantly influences aquifer productivity particularly within the crystalline rock environment. In this case, when longitudinal unit conductance is high, aquifer productivity will be low and aquifer productivity will be high when its hydraulic conductivity is high. Results showed that transmissivity exhibits positive and significant relationship with hydraulic conductivity with correlation values of 0.60 at $\alpha = 0.000$. The interpretation of this is that transmissivity increases with increasing hydraulic conductivity. However, it is pertinent to state that transmissivity is a function of both hydraulic conductivity and aquifer thickness. Thus, the higher the hydraulic conductivity and the aquifer thickness, the higher the productivity of such an aquifer.

The relationship between hydrogeological parameters and yield is explained by the equation below:

$$Y = 0.940 - 0.077X_1 + 1.886X_2 - 136.222X_3 + 7636.492X_4 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$(R = 0.643, R^2 = 41.3\%, SE = 0.746)$$

Where, Y = Borehole Yield, X_1 = Static Water Level, X_2 = Longitudinal Unit Conductance, X_3 = Transmissivity, X_4 = Hydraulic Conductivity

This relationship explains 41.3 percent of the regression plain, which is not strong but quite significant ($\alpha = 0.000$). The results of the regression analysis revealed that all the examined predictor variables (hydraulic conductivity, tranmissivity, longitudinal unit conductance and static water level) can give meaningful explanation of borehole yield in the study area. However, the observed weak but significant relationship suggest that there would be other variable(s), which predominantly influence the yield of borehole in the study area. Thus, prediction of borehole yield is very complex within the Basement Complex environment.

The outcome of the statistical analyses undertaken in this study agrees with existing studies on groundwater resources within the Basement Complex environment. This study revealed that borehole yield is generally low across Osun Drainage Basin, which is peculiar to typical crystalline rock environment in Nigeria (Olorunfemi, 1990, 2009; Olorunfemi and Fasuyi, 1993; Yaya *et al.,* 2003; Isaac *et al.,* 2010; Akinluyi, 2013; Bayowa, 2013; Ojo *et al.,* 2015; Akinwumiju, 2015). Result showed that borehole depths are generally shallow across Osun Drainage Basin, emphasizing that aquifers are mostly shallow and usually occur within overburden regolith.

Analysis revealed that groundwater head is generally shallow, which indicate that groundwater resource can easily be assessed at low cost within the study area. This study showed that aquifer's hydraulic conductivity and thickness are significant determinant factors of aquifer productivity within the Basement Complex terrain (Ifabiyi, 2000; Isaac *et al.,* 2010). Also, it was revealed that the aquifers of Osun Drainage Basin have the capacity to store and retain water but with low tendency to release the water into boreholes.

CONCLUSION

This study adopted statistical method to assess the relationship between borehole yield and hydrogeological parameters across Osun Drainage Basin in the forested region of the Basement Complex terrain of Southwestern Nigeria. The study revealed that borehole yield is generally low across the basin. Likewise, it was discovered that aquifers of the study area are generally shallow and less prosperous. It was observed that aquifer characteristics vary significantly across the study area. The study also affirmed that hydraulic conductivity, transmissivity, longitudinal unit conductance and static water level variously influence the yield of borehole and that, these variables are strong enough to give meaningful explanation and determine the yield of borehole across the study area. The study concluded that the basin's groundwater resource might not be able to sustain her population in the process of time as indicated by the low mean yield recorded for the study area but for the continuous recharge from seasonal precipitation.

REFERENCES

Akinluyi, F. O. 2013. Integration of Remotely Sensed and Geophysical Data in Groundwater Potential Evaluation of the Basement Complex Terrain of Ondo State, Southwestern Nigeria. *An Unpublished Ph.D Thesis*, Dept. of Geology, OAU, Ile-Ife, Nigeria

Akinwumiju, A. S. 2015. GIS-Based Integrated Approach to Groundwater Potential Assessment of Osun Drainage Basin, Southwestern Nigeria. *An Unpublished Ph.D. Thesis* Submitted to the Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Ile-Ife, Nigeria. 316pp

Ali, K. A. 2012. Development of Water Supply Infrastructure in Nigeria: Challenges and Prospects. *Nigeria Society of Engineers*. 38 p.

Ashaolu E. D. and Omotosho O. 2015. Assessment of static water level and overburden pattern for sustainable groundwater development and management in Ilorin City, Nigeria. *Malaysian Journal of Society and Space* Vol.11 (9) Pp. 1 – 11

Awoyemi, M. O.; Onyedim, G. C.; Arubayi, J. B. and Ariyibi, E. A. 2005. Influence of Lithology and Geological Structures on Drainage Patterns in Part of the Basement Complex Terrain of Southwestern Nigeria. *Ife Journal of Science,* 7(2), 291-296

Bayowa, O. G. 2013. Hydrogeophysical Investigation of the Basement Complex Terrain of Ekiti State, Southwestern Nigeria. *An Unpublished Ph.D Thesis*, Dept. of Geology, OAU, Ile-Ife, Nigeria.

Black, M. 2004. The No-Nonsense Guide to Water. New Internationalist Publications Ltd.

Boesse, T. N. and Ocan, O. O. 1988. Geology and Evolution of the Ife-Ilesa Schist Belt, Southwestern Nigeria. *Symposium on Benin-Nigeria Go-traverse of Proterozoic Geology and Tectonics of High Grade Terrains.*, 87-107

Carter, R. 2012. Rural Water Supply Network. Newletter. RWSN. Switzerland

De Swardt, A. M. J. 1953. The Geology of the Area around Ilesa. *Geol. Surv. Nig. Bulletin* 23

Eduvie, M. O. 2006. Borehole Failure and Groundwater Development in Nigeria. A Paper Presented at the National Seminar held on the Occasion of Water Africa Exhibition. Lagos, Nigeria

Eduvie, M. O. 2008. Difficult Groundwater Terrains of Nigeria in relation to Drilling Cost. A Paper Presented at the *Stakeholders Workshop for Developing Term of Reference for the Study of Public and Private Borehole Drilling in Nigeria*. Lagos, Nigeria

Eduvie, M. O. and Olabode, O. 2012. A Critical Review of Hand Pump Utilization for

Rural Water Supply: Case Studies. Nigeria

Elueze, A. A. 1977. Geological and Geochemical Studies in the Ilesa Schist Belt in relation to the Gold Mineralization. *An Unpublished M. Phil. Thesis*. University of Ibadan.

Ifabiyi, I. P. 2000. Predicting Borehole Yield in Precambrian Basement Complex and Sedimentary Rocks in Central Western Nigeria. Review of Growth and Change

Isaac, O. O., Agunwamba J. C. and Ademiluyi J. O. 2010. Assessment of Aquifer Characteristics in Relation to Rural Water Supply in part of Northern Nigeria. *Researcher* 2: 22-27.

JMP 2012. Joint Monitoring Programme for Water Supply and Sanitation. Progress on Sanitation and Drinking-Water, 2012 Update.

Mahaya, E.; Tippins, D. J.; Mueller, M. P. and Thomson, N. 2009. Infections Disinfection: Exploring Global Water Quality. *Science Activities,* 46, 25-31

Massoud, M. A.; Abdolmonim, A. A.; Jurdi, M. and Nuwayhid, I. 2010. The Challenges of Sustainable Access to Safe Drinking Water in Rural Areas of Developing Countries: Case of Zawtar El-charkieh, Southern Lebanon. *J. Envtal. Health,* 72, 24-30

Mogaji K. A., Olayanju G. M. and Oladapo M. I. 2011. Geophysical evaluation of rock type impact on aquifer characterization in the Basement Complex Areas of Ondo State, Southwestern Nigeria: Geo-electric Assessment and Geographic Information Systems (GIS) Approach. *Int. J. Wat. Res. Envt. Eng.* Vol. 3(4), pp. 77-86

Odeyemi, I .B.; Anifowose, Y. B. and Asiwaju-Bello, Y. A. 1999. Multi-Technique Graphical Analyses of Fractures from Remote Sensing Images of Basement Regions of Nigeria. *J. Min. Geol.,* 35(1), 9-21

Offodile, M. E. 2002. *Groundwater Study and Development in Nigeria.* Mecon Geology and Engineering Services Ltd., Jos, Nigeria. 2nd Edition, 453 Pp.

Ojo, J. S., Olorunfemi, M. O., Akintorinwa, O. J., Bayode, S., Omosuyi, G. O. and Akinluyi, F.O. 2015. GIS Integrated Geomorphological, Geological and Geoelectrical Assessment of the Groundwater Potential of Akure Metropolis, Southwest Nigeria. *J. Earth Sci. Geotecn. Eng.* 5(14): 85-101

Olabode, O. T. and Bamgboye, O. A. 2013. Why Borehole Drilling and Construction Projects fail. A Paper Presented at a *Seminar Organized by the Association of Water Well drilling Rig Owners and Practitioners* (AWDROP), Ibadan, Nigeria

Olorunfemi, M. O. (2009). Groundwater Exploration, Borehole Site Selection and Optimum Drilling Depth in Basement Compex Terrain. Special Publication Series 1 (ISSN 0795-6495). Nigerian Association of Hydrogeologists. 20p

Olorunfemi, M. O. 1990. The Hydrogeological Implication of Topographic Variation with Overburden Thickness in Basement Complex Area of Southwestern Nigeria. *J. Min. Geol,* 26(1).

Olorunfemi, M. O. and Fasuyi, S. A. 1993. Aquifer Types and the Geoelectric/Hydrogeologic Characteristics of Part of the Central Basement Terrain on Nigeria (Niger State). *J. Afri. Earth,* 16(3), 309-317

Oluyide, P. O. 1988. Structural Trends in the Nigerian Basement Complex. In Oluyide, P. O., Mbonu, W. C., Ogezi, A. E., Egbuniwe, I. G., Ajibade, A. C., and Umeji, A. C. (Eds.): Precambrian Geology of Nigeria. *Geol. Surv. Nigeria* 99 – 102

Oyedele E. E. A and Olayinka E. I. 2012. Statistical Evaluation of Groundwater Potential of Ado-Ekiti, Southwest, Nigeria. *Transnational Journal of Science and Technology* 2(6), 110-127.

Shiklomanov, I. 1993. World Freshwater Resources. In: Peter, H (Ed.). *Water in Crisis: A Guide to the World's Freshwater Resources*

Yaya O. O., Dossah B. and Chukwurah M. A. 2003. An Appraisal of Hand-pump Boreholes in Zamfara State-Nigeria. *29th WEDC International conference.*