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Evaluation of groundwater occurrences in the precambrian basement complex of Ilorin metropolis, southwestern Nigeria

Ocena virov podtalnice iz predkambrijske podlage območja deželne prestolnice Ilorina v jugozahodni Nigeriji

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Abstract

Surface water from the Asa and Agba dams, which hitherto supply water to Ilorin metropolis is inadequate, hence the need to supplement with water from boreholes. Forty two boreholes drilled into migmatites, granite gneiss and quartzite in Ilorin area were evaluated. Borehole data showed varied overburden thickness (1.00 m to 36.00 m). The static water level (SWL) contour map showed a radial groundwater flow pattern trending in the NE–SW and NW–SE directions, which is consistent with the structural trends in the area. Estimated yields of the boreholes ranged from 0.30 l/s to 2.75 l/s. Pumping/recovery test of four selected boreholes showed increase in productivity from granite gneiss (transmissivity, T = 11.42 m^3/d; permeability, K = 4.94 × 10^{-1} m/d) through migmatites (T = 13.4 m^3/d; K = 6.93 × 10^{-1} m/d) to quartzites (T = 17.56 m^3/d; K = 9.54 × 10^{-1} m/d). The groundwater occurrence in the area is adjudged to be moderately high. Strong correlation coefficients (+0.99) exist between Vertical Electrical Sounding (VES) and borehole log indicating that the success of borehole in the area depends strongly on production of VES report. Based on this study, minimum borehole depth of 33 m is recommended for the area.

Key words: groundwater, basement complex, borehole yield, aquifer, Ilorin

Izvleček

Površinska voda iz zajezitev Asa in Agba ne zadostuje potrebam deželne prestolnice Ilorina, zato iščejo dodatne vodne vire z vrtanjem. Na območju Ilorina so izvrtali dvainštirideset vrtin v migmatitih, granitnem gnajsu in kvarcitu. Debelina prevrtanega preperinskega pokrova je med 1 m in 36 m. Iz razporeda plastnic na karti statične gladine podtalnice je videti, da gre za radialni vzorec tečenja podtalnice v smereh NE–SW in NW–SE, kar tudi ustreza geološki zgradbi območja. Ocenjene izdatnosti vrtin so med 0,30 l/s in 2,75 l/s. Črpalni preizkusi v štirih izbranih vrtinah pričajo o naraščanju izdatnosti od granitnega gnajsa (prevodnost, T = 11,42 m^3/d; prepustnost, K = 4,94 × 10^{-1} m/d) prek migmatitov (T = 13.4 m^3/d; K = 6.93 × 10^{-1} m/d) do kvarcitov (T = 17,56 m^3/d; K = 9,54 × 10^{-1} m/d). Vire podtalnice na preiskovanem območju so ocenili za zmerno izdatne. Visoki korelacijski koeficient (+0,99) med rezultati vertikalne električne karotaže (VES) in karotažnih profilov vrtin priča o močni povezavi uspešnosti vrtin od opravljene vertikalne električne karotaže. Iz raziskave izhaja, da je na tem območju priporočljiva minimalna globina vrtanja 33 m.

Ključne besede: podtalnica, kamnine podlage, izdatnost vrtine, vodonosnik, območje Ilorina

Introduction

Rapid population growth, due to rural-urban migration resulted in increase in the number of commercial and industrial activities in Ilorin area. This population growth in turn is responsible for the rapid increase in water demand and persistent water shortage in the area. Water supply from Asa and Agba dams could no longer meet the water demand of the populace contrary to the report of Oluyide [1], which stated that Ilorin area has excess water and that boreholes are unnecessary. As a result of water inadequacy, the State Government decided to look for additional and sustainable water sources that can supplement water supply from the existing dams through the introduction of various water supply schemes. These water supply schemes include drilling of numerous boreholes. However, as laudable as this policy seems, it was not supported by adequate geological and hydrogeological baseline data, which include information on the degree of weathering and fracturing of the crystalline basement rocks and hence, the high number of low yield and outright unproductive wells reported in the area. Alao [2] investigated the occurrence of lateritic brick-clay within the weathered profiles at Okelele/Dada of Ilorin Local Government area. It is believed in this study that the occurrence of such interstitial clay in large quantity within the weathered basement could result in low yields.

Other published works on the groundwater situations of the Ilorin area include those of Oyegun [3] who identified water resources, development and management strategies in Kwara State, including Ilorin, based on a few borehole data, which is grossly inadequate to generalize the groundwater situation of the study area. Olasehinde [4] and Olasehinde and Taiwo [5] compared the geological and geophysical exploration methods for groundwater in the basement complex of the study area. They were able to establish positive relationship between the two exploration techniques. Offodile [6] studied the groundwater occurrence in basement complex of Nigeria with reference to Pampo, a village in the southern outskirts of the study area. The study was based on pumping test of a single borehole. A single borehole is considered inadequate to study the groundwater potential of such a large area.

The objectives of this study were to determine the hydrogeological characteristics of the rock units within Ilorin metropolis, to evaluate the influence of geology on the groundwater flow and development in the area, to assess the groundwater occurrence with a view to determine whether the groundwater of Ilorin metropolis could serve as additional and sustainable water supply sources.

The Study Area

Ilorin area lies between longitude 4° 30' E–4° 37' E and latitude 8° 26' N–8° 33' N (Figure 1). It covers an approximate area of 200 km^2. The sampling areas include Agbo-Oba in the west, Airport in the southwest, Sobi Hill in the northwest, Oyun in the northeast, Tanke and Fate in the east. The study area is underlain by the Precambrian basement rocks, which comprise of migmatite, granite gneiss and quartzite. The area falls between semi arid in the north and sub-humid in the south. It is characterized by two main seasons: Wet season – (March – Mid October) and Dry season – (Mid October – March). Rainfall is moderate with annual average of 1 250 mm. Humidity is relatively low. It is about 50 % between June and August. The annual mean temperature is 27 °C.

The area is well drained by various streams and their tributaries. The distributaries show dendritic drainage pattern. The main rivers are Asa and Agba Rivers, while minor rivers include Oyun and Aluko rivers. The terrain is undulating and dissected by rivers and streams. The highest altitude is about 1 200 m above sea level corresponding to the top of Sobi Hill (migmatite), while along major streams the altitude is about 250 m above sea level. The vegetation cover is basically Guinea savannah with ruminant tropical forest.

Geology and Hydrogeology of the Area

The Ilorin area is part of the Precambrian basement complex of southwestern Nigeria (Figure 1). The main rock types that characterize the geology of the area are migmatite-gneiss, granite gneiss and quartzite (Figure 2). Intrusions of pegmatite, dolerite dykes and quartz veins cut across the major rock units in the area. The migmatite-gneiss complex is presumably the oldest rock in the basement complex of Nigeria [7]. It is the most abundant and the most widespread in the study area. It is foliated and jointed. The migmatite is closely associated with quartzite in the southeastern part. Granite gneiss extends from the eastern to the southeastern part. Mineral components of the migmatite and granite gneiss are mainly microline, quartz, plagioclase, biotite and muscovite. The constituent quartz and few mica grains in the quartzite of the area are recrystallised with interlocking mosaic textures. Other rock types include pegmatite and quartz veins within the migmatite and the granite gneiss. They are of few millimeters to about a metre. They are concordant or discordant unmetamorphosed rock bodies cutting across foliation planes in the gneisses.

These crystalline basement rocks are generally older than 500 million years and contain negligible amount of groundwater when not weathered or fractured. However, significant aquifers may develop within those areas with thick weathered overburden and most importantly, fractured bedrock [8]. Annor and Olasehinde [9] noted that the basement complex of Ilorin area has varied weathered horizons as well as fractured rocks. The fractured rocks represent the deeper aquifers, which are overlain by shallow porous lateritic soil cover. Although, these rocks have low groundwater content, places abound where there are thick weathered, gritty overburden and fractures which aid groundwater accumulations. Areas with high clay contents are usually characterised by low permeability and poor aquifer conditions. Pegmatite and quartz vein filled fractures in the migmatite and quartzite of Ilorin metropolis are generally NS and NW–SE while those in the granite gneiss are NS and NE–SW (Figure 2).

Methodology

Collection of hydrogeological data from 42 boreholes within the three main rock types, namely migmatite, granite gneiss and quartzite in Ilorin metropolis were undertaken. Thirty seven (37) of the boreholes were sited within migmatite, four (4) within granite gneiss and one (1) within quartzite. The hydrogeological data were collected in November 2005 when the boreholes were completed. Location and elevation of each of the borehole above sea level was measured with Geographical Positioning System (GPS) equipment [10]. The static groundwater level in the boreholes was determined using dipper water level indicator. Computation of static water level, above sea level (SWL_{asl}) from static water level, below ground level (SWL_{bgl}) and elevation above sea level (E_{asl}) were carried out.

Depths to basement, depth to the overburden and basement aquifers, as well as, aquifer thickness were extracted from borehole log reports. Also, Vertical Electrical Sounding (VES) data on depth-to-basement were taken to facilitate comparison

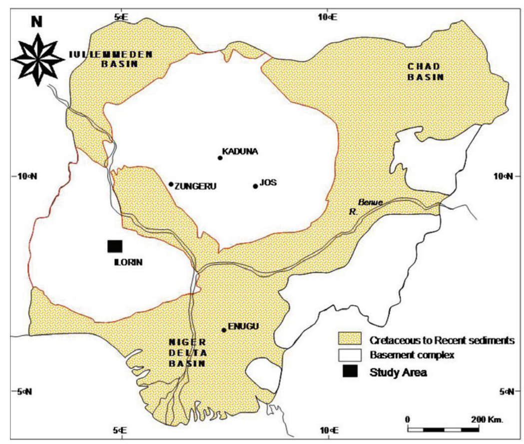
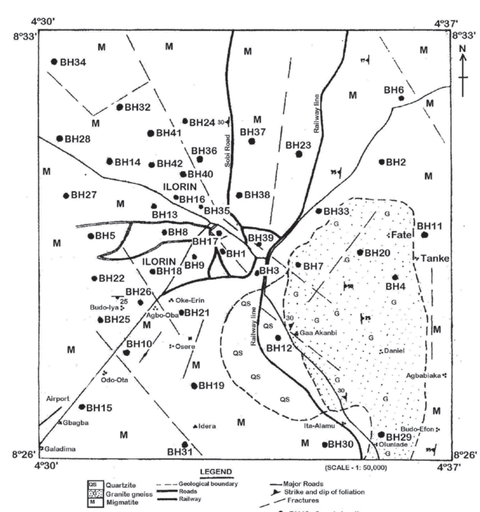


Figure 1: *Generalised geological map of Nigeria showing the location of Ilorin area.*



QS - Quartzite
G - Granite gneiss
M - Migmatite

LEGEND
Geological boundary
Roads
Railwa

Major Roads
Strike and dip of foliation
Fractures
BH 42 - Sample locations

Figure 2: *Geological and structural map of Ilorin area showing borehole locations (BH1-BH42) .*

with borehole log. Yields from selected boreholes were estimated. Correlation of the borehole parameters with estimated yields and Vertical Electrical Sounding (VES) report with borehole-logs were carried out. Computation of aquifer parameters [Transmissivity (T) and Permeability (K)] from constant pumping/recovery test was carried out, for 8 h, using 1HP submersible pump. The static water levels (above sea level) (SWL_{asl}) for the 42 boreholes were computed and used to produce SWL contour map which was used to determine the groundwater flow direction in the study area. The pumping and recovery test data are presented in supplementary Tables S1–S8 and Figures S1–S10.

Results and Discussion

The borehole data are presented in Table 1 with the summary in Table 2. The geological and structural map of the area is presented in Figure 2. Summary of the pumping and recovery tests are presented in Table 3. Results of correlations of the borehole parameters are presented in Table 4. Other details are presented as supplementary Tables and Figures.

The depth of boreholes in the study area ranged between 19.50 m and 67.60 m with mean value of 33.59 m (Table 1). Borehole productivity in the area is not strictly a function of the total depth drilled as reflected in some deep boreholes (> 30 m) with low yield (BH15, 23, 28 and 30), and some shallow boreholes (< 30 m) with high yield (BH 13, 25, and 36) (Table 1). However, it is recommended that the depth of borehole to be drilled in the area must not be less than 33.00 m so that the borehole can penetrate the fractured basement and to create sufficient space for water accumulation within the hole. The SWL contour map showed a radial groundwater flow direction in the study area (Figure 3). It is multidirectional, trending in the NE-SW and NW-SE directions. This is consistent with the structural trends in the area (Figure 2).

Depth to basement varies between 1.00 m and 36.0 m with a mean value of 12.23 m (Tables 1 and 2). Borehole log report shows that twenty four of the forty two boreholes have overburden thickness of less than 10 m (Table 1). The overburden is characterized by lateritic and clayey formations which constitute an aquitard. Aquifer thickness is between 3.00 m and 30.00 m with a mean value of 12.03 m (Table 2). Most of the aquifers occurred in the saprolite of the weathered zone and the fractured basement. However, in the northwestern part of Ilorin metropolis around Okelele and Dada area (BH 35 and BH 38), reasonable amount of groundwater occur within the thick overburden on highly fractured migmatite. Estimated yield (Tables 1 and 2) ranged between 0.30 l/s and 2.75 l/s. This determines how successful a borehole is, and showed the maximum rate a borehole can sustain reasonable drawdown in the study area. The average value of 1.60 l/s; suggested a high groundwater potential for the study area. This is in agreement with the yield of 1.5–20 l/s obtained by Offodile [6] for aquifers in some crystalline basement rocks in Nigeria.

Results of the Pumping/Recovery tests (Table 3) showed transmissivity (T) values between 9.11 m^3/d and 17.56 m^2/d, averaging 13.43 m^3/d, and permeability (K) values between 4.52×10^{-1} m/d and 9.54×10^{-1} m/d with mean value of 6.65×10^{-1} m/d. Generally, the pumping/recovery test of the four (4) selected boreholes showed increase in borehole productivity from granite gneiss (T = 11.42 m^3/d; $K = 4.94 \times 10^{-1}$ m/d) through migmatites (T = 13.4 m^3/d; $K = 6.93 \times 10^{-1}$ m/d) to quartzite (T = 17.56 m^3/d; $K = 9.54 \times 10^{-1}$ m/d). The highest values of T (17.56 m^3/d) and K (9.54×10^{-1}m/d) occurred in the borehole drilled through quartzite reflecting the highly fractured nature of the metasediment, while the lowest values (T = 9.11 m^3/d and $K = 5.35 \times 10^{-1}$ m/d) are obtained in boreholes within the granite gneiss (Table 3). It can therefore be said that borehole productivity increases from granite gneiss through migmatite to quartzite in the study area. However, value for storativity could not be obtained due to lack of observation wells to be used for the pumping / recovery tests.

Borehole parameters are correlated in order to obtain baseline data and relationships, which can serve as a guide to borehole site and drill depth recommendations that could be applied in related basement areas. Correlation results (Table 4) showed very high positive values for Yield/T (0.96), and moderately high positive value for Yield/Aquifer thickness (0.50). These showed very strong and strong dependence of yield on transmissivity and aquifer thickness respectively. However, for Yield/Total depth and Yield/depth to basement, the correlation values are low (0.26 and 0.28 respectively). This indicated weak dependence of yield on the two parameters. Yield/*SWL* gave an extremely low correlation value of +0.004, which suggested borehole yield does not depend on *SWL* in the area. Correlation of VES data with Borehole-logs also gave a very high positive value of 0.99. This confirmed that the VES results obtained from the area are very reliable and can be used for borehole location.

Table 1: *Borehole Data of Ilorin metropolis (Source: Field Survey, 2005)*

BH No.	Borehole location	$SWL_{(bgl)}$	$SWL_{(asl)}$	BH depth	Depth to basement (m)		Depth to aquifer	Aquifer thickness	Estimated yield
		(m)	(m)	(m)	BH Log	VES	(m)	(m)	(l/s)
BH 1	Ikokoro street	9.50	290.50	46.60	5.00	6.50	15.00	30.00	2.00
BH 2	Sango Area	8.20	301.80	34.60	19.00	22.50	22.00	9.00	1.50
BH 3	Union Bank	11.50	288.10	53.60	2.00	5.00	39.00	12.00	2.20
BH 4	Tanke	5.00	305.00	46.60	15.00	16.00	15.00	21.00	1.50
BH 5	Ilt Kewu	8.00	312.00	37.60	9.00	10.00	12.00	21.00	1.80
BH 6	Oyun	7.40	307.60	37.60	9.00	10.00	9.00	22.00	1.90
BH 7	Golf Club	16.90	295.10	67.60	3.00	6.00	42.00	5.00	2.40
BH 8	Pakata	6.30	323.70	26.00	9.00	10.00	9.00	6.00	0.30
BH 9	Ile Seriki	7.60	317.40	27.60	8.00	12.00	11.00	16.00	1.50
BH 10	Olorunshogo	5.90	304.00	21.00	15.00	16.00	15.00	8.00	1.30
BH 11	Tanke Iledu	5.90	299.10	36.00	15.00	17.00	15.00	18.00	1.75
BH 12	Gaa Akanbi	4.30	325.70	33.00	3.00	5.00	33.00	12.00	2.70
BH 13	Alore Primary School	5.30	319.70	27.00	18.90	33.00	21.00	9.00	2.00
BH 14	Ile Oloje	7.20	303.80	26.25	24.00	21.00	18.00	10.00	1.50
BH 15	Airport	5.00	357.00	34.00	24.00	28.00	25.00	4.00	1.25
BH 16	Ile Iya Balogun	7.30	316.70	32.00	6.00	9.00	6.00	15.00	1.50
BH 17	Ile Jimba	4.50	313.50	26.00	6.00	8.00	6.00	12.00	1.90
BH 18	Ode Alfa Nda	7.90	315.10	38.20	18.00	22.00	18.00	12.00	2.00
BH 19	Parliament Village	6.00	339.00	21.50	6.00	7.00	6.00	7.00	1.30
BH 20	Kitibi's residence	5.40	326.6	30.00	15.00	17.50	20.00	15.00	2.10
BH 21	C.A.C. Taiwo road	6.25	303.75	33.00	15.00	16.00	15.00	8.00	2.00
BH 22	Ojatuntun	5.00	300.25	30.75	1.00	1.50	3.00	27.00	2.75
BH 23	Railway station	11.30	239.70	38.00	3.00	4.00	3.00	15.00	1.00
BH 24	Akerebiata	5.80	300.20	29.00	12.00	14.00	12.00	12.00	1.95
BH 25	Baboko/Eruda	7.50	297.50	26.00	15.00	16.00	15.00	12.00	1.80
BH 26	Agbo-Oba	7.00	293.00	19.50	6.00	6.50	6.00	15.00	1.80
BH 27	Popo Giwa	4.00	326.00	21.00	6.00	7.50	12.00	9.00	1.50
BH 28	FGC, Ogigi	6.00	343.00	40.00	7.00	9.00	10.00	6.00	1.00
BH 29	Olunlade	3.00	337.00	38.00	10.00	12.50	20.00	17.00	1.35
BH 30	Ita Alamu	8.00	329.00	40.00	8.50	10.00	10.00	3.00	0.40
BH 31	Idera	4.00	303.00	31.00	7.00	9.00	12.00	6.50	1.25
BH 32	Oloje Housing Estate	4.00	316.00	31.00	5.00	6.00	6.00	18.00	2.00
BH 33	G.S.S. Ilorin	6.80	293.20	22.00	6.00	8.50	6.00	3.00	0.35
BH 34	Oko Olowo Garage	8.00	321.00	33.00	7.00	8.00	10.00	8.00	1.40
BH 35	Okelele	5.30	319.70	27.00	18.00	19.00	21.00	9.00	1.50
BH 36	Banni area	5.75	318.25	24.00	9.00	10.00	9.00	9.00	1.90
BH 37	Gaa Osibi	7.00	329.00	33.00	8.50	10.00	15.00	5.00	1.45
BH 38	Dada	6.00	324.00	29.00	27.00	28.00	23.00	12.00	1.60
BH 39	Ita Kudimo	6.00	298.00	32.00	7.00	8.00	22.00	6.00	1.20
BH 40	Ile Ikare Okelele	9.00	324.00	39.00	36.00	38.00	24.00	12.00	1.50
BH 41	Ile Gbongbon Okelele	7.00	328.00	33.00	33.00	34.00	18.00	15.00	1.30
BH 42	Ile Oniponmo Okelele	8.00	322.00	39.00	24.00	26.00	24.00	12.00	1.60

$SWL_{(bgl)}$ - Static Water Level $_{(below\ ground\ level)}$, BH – Borehole,
$SWL_{(asl)}$ - Static Water Level $_{(above\ sea\ level)}$, VES – Vertical Electrical Sounding

Table 2: *Summary of Borehole data of Ilorin metropolis*

	$SWL_{(bgl)}$	$SWL_{(asl)}$	BH depth	Depth to basement (m)		Depth to aquifer	Aquifer thickness	Estimated yield
	(m)	(m)	(m)	BH Log	VES	(m)	(m)	(l/s)
Minimum	3.00	288.50	19.50	1.00	1.50	3.00	3.00	0.30
Maximum	16.90	357.00	67.60	36.00	38.00	42.00	30.00	2.75
Mean	6.80	313.84	33.59	12.23	14.15	15.86	12.03	1.60
Standard deviation	2.66	15.63	9.99	8.06	8.30	11.39	6.43	0.52

$SWL_{(bgl)}$ - Static Water Level (below ground level), BH – Borehole,
$SWL_{(asl)}$ - Static Water Level $_{\text{(above sea level)}}$, VES – Vertical Electrical Sounding

Table 3: *Summary of the results of constant-rate pumping and recovery tests*

Pumping recovery test No.	BH No.	Rock type	*T*-value from PT (m^3/d)	*T*-value from RT (m^3/d)	Average *T* (m^3/d)	*K*-value from PT (× 10^{-1} m/d)	*K*-value from RT (× 10^{-1} m/d)	Average *K* (× 10^{-1} m/d)
1	BH 29	Granite gneiss	8.99	9.24	9.11	5.28	5.43	5.35
2	BH 4	Granite gneiss	13.07	14.38	13.72	4.35	4.7	4.5
3	BH 10	Migmatite	11.48	16.21	13.84	6.37	9.00	7.68
4	BH 24	Migmatite	11.39	14.54	12.96	5.42	6.92	6.17
5	BH 12	Quartzite	16.37	18.75	17.56	9.09	10.00	9.54
		Minimum	8.99	9.24	9.11	4.35	4.70	4.52
		Maximum	16.37	18.75	17.56	9.09	10.00	9.50
		Mean	12.26	14.62	13.43	6.10	7.21	6.65

BH = Borehole, PT = Pumping test, RT = Recovery test, *T* = Transmissivity, *K* = Permeability

Table 4: *Table of correlation of borehole data from Ilorin metropolis*

S/No	Parameter Correlated	Coefficient of correlation	Implications
1	Yield/Total depth	0.26	Yield weakly depends on the total depth.
2	Yield/Aquifer Thickness	0.50	Yield moderately depends on aquifer thickness.
3	Yield/Depth to basement (Overburden thickness)	0.28	Yield weakly depends on overburden thickness.
4	Yield/SWL	0.004	Yield is almost independent of static water level.
5	Yield/Transmissivity	0.96	Yield depends strongly on transmissivity of aquifer.
6	Borehole log/VES	0.99	Detection of subsurface structures strongly depends on VES.

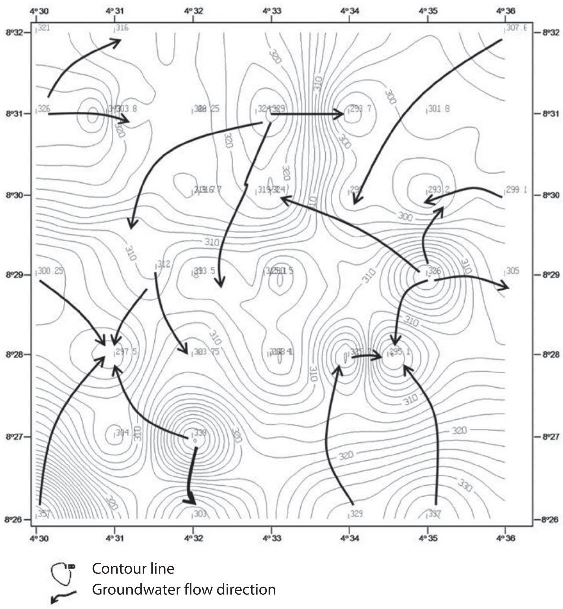


Figure 3: *Static Water Level (SWL) above sea level Contour map of the Study Area showing the groundwater flow direction.*

Conclusions

Groundwater occurred in the weathered and fractured zones of the basement rocks underlying Ilorin metropolis. The groundwater flow direction is generally radial and multidimentional, trending mainly in the NE–SW and NW–SE directions, which is consistent with the fracture pattern in the area. Borehole productivity increases from granite gneiss through migmatite to quartzite. It can be concluded that the groundwater potential of Ilorin metropolis is moderately high, judging from the values of the aquifer parameters, transmissivity (*T*), permeability (*K*) and yield, which are consistent with data of good aquifers in the crystalline basement complex of Nigeria.

Observation wells should be used during pumping test in order to determine average storativity of the aquifers. Further studies should involve pumping of borehole water for several days to reach equilibrium. This would permit assessment of the groundwater using specific capacity rather than aquifer parameters. The groundwater of Ilorin area can be harnessed through boreholes to support the existing dams however, computation of safe yield is necessary for proper groundwater planning, development and management.

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Supplementary Material

Tables S1–S8 and Figures S1–S10.

Table S1: *Pumping Test of Borehole (BH 29) and (BH 4) in granite gneiss of Ilorin metropolis*

Borehole (BH 29) in granite gneiss				Borehole (BH 4) in granite gneiss			
Time (min)	Water level (Draw- down, S) (m)	Time (min)	Water level (Draw- down, S) (m)	Time (min)	Water level (Draw- down, S) (m)	Time (min)	Water level (Draw- down, S) (m)
1	3.105	85	6.040	1	5.205	85	8.099
2	3.230	90	6.115	2	5.352	90	8.199
3	3.271	100	6.175	3	5.484	100	8.225
4	3.271	110	6.263	4	5.610	110	8.360
5	3.472	120	6.324	5	5.785	120	8.451
6	3.575	130	6.410	6	5.812	130	8.525
7	3.652	140	6.505	7	5.903	140	8.580
8	3.794	150	6.613	8	5.981	150	8.642
9	3.839	160	6.721	9	6.091	160	8.795
10	4.030	170	6.800	10	6.180	170	8.805
12	4.030	180	6.901	12	6.297	180	8.875
14	4.176	190	6.984	14	6.365	190	8.993
16	4.275	200	7.072	16	6.444	200	9.192
18	4.340	210	7.183	18	6.540	210	9.275
20	4.455	230	7.254	20	6.641	230	9.388
22	4.596	250	7.331	22	6.721	250	9.465
24	4.663	270	7.430	24	6.782	270	9.530
26	4.701	290	7.531	26	6.884	290	9.622
28	4.877	310	7.610	28	6.992	310	9.720
30	4.945	330	7.699	30	7.100	330	9.801
35	5.076	350	7.792	35	7.203	350	9.890
40	5.170	370	7.881	40	7.298	370	9.967
45	5.293	390	7.979	45	7.406	390	10.065
50	5.384	410	8.067	50	7.492	410	10.184
55	5.455	430	8.157	55	7.585	430	10.275
60	5.531	450	8.247	60	7.665	450	10.351
65	5.620	470	8.325	65	7.763	470	10.415
70	5.735	490	8.413	70	7.822	490	10.487
75	5.845			75	7.901		
80	5.957			80	7.985		

Location: Borehole (BH 29) Olunlade
SWL: = 3.00 m
Average pumping rate (Q) = 1.28 l/s
Type of Pump: 1 HP

Borehole (BH 4) location: Tanke
SWL (Static Water Level) = 5.00 m
Average Pumping Rare (Q) = 1.82 l/s
Pumping Duration = 490 mins
Type of Pump = 1 HP Submersible

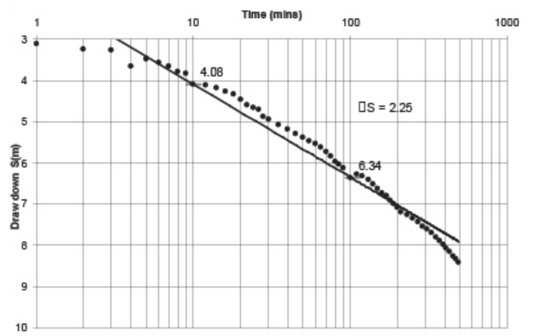

Figure S1: *Pumping Test curve of borehole (BH 29) in granite gneiss of Ilorin metropolis.*

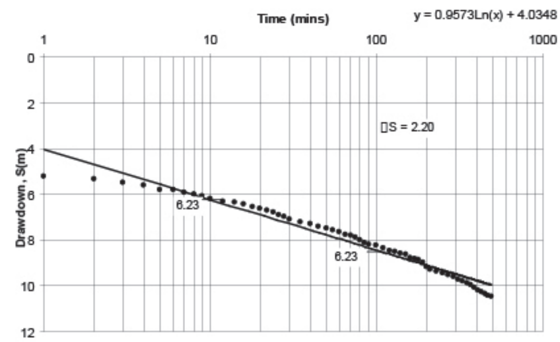

Figure S2: *Pumping Test Curve of Borehole (BH 4) in granite gneiss of Ilorin metropolis.*

Table S2: *Recovery Tests of Borehole (BH 29) in granite gneiss of Ilorin metropolis.*

t' (min)	R.W.L (m)	S' (RWL-SWL) (m)	t (490 + t') (min)	t/t'	t' (min)	RWL (m)	S' (RWL-SWL) (m)	t (490 + t') (min)	t/t'
1	8.263	5.263	491	491.00	85	4.677	1.635	575	6.76
2	8.111	5.111	492	246.00	90	4.635	1.635	580	6.44
3	7.966	4.966	493	164.33	100	4.594	1.594	590	5.90
4	7.810	4.810	494	123.50	110	4.559	1.559	600	5.45
5	7.656	4.656	495	99.00	120	4.519	1.519	610	5.08
6	7.506	4.506	496	82.66	130	4.439	1.439	620	4.76
7	7.357	4.357	497	71.00	140	4.404	1.404	630	4.50
8	7.207	4.207	498	62.25	150	4.372	1.372	640	4.26
9	7.058	4.058	499	55.44	160	4.379	1.379	650	4.06
10	6.907	3.907	500	50.00	170	4.307	1.307	660	3.88
12	6.761	3.761	502	41.83	180	4.277	1.277	670	3.72
14	6.746	3.746	504	36.00	190	4.245	1.245	680	3.57
16	6.601	3.601	506	31.62	200	4.214	1.214	690	3.45
18	6.455	3.455	508	28.22	210	4.181	1.281	700	3.33
20	6.303	4.303	510	25.50	230	4.146	1.246	720	3.13
22	6.163	3.163	512	23.27	250	4.114	1.114	740	2.96
24	6.017	3.017	514	21.41	270	4.083	1.083	760	2.81
26	5.872	2.872	516	19.84	290	4.053	1.053	780	2.68
28	5.352	2.742	518	18.50	310	4.018	1.018	800	2.58
30	5.607	2.607	520	17.33	330	3.984	0.984	820	2.48
35	5.472	2.472	525	15.00	350	3.950	0.950	840	2.40
40	5.352	2.352	530	13.25	370	3.911	0.911	860	2.32
45	5.242	2.242	535	11.88	390	3.871	0.871	880	2.25
50	5.143	2.143	540	10.80	410	3.876	0.876	900	2.19
55	5.053	2.053	545	9.90	430	3.875	0.874	920	2.13
60	4.968	1.968	550	9.16	450	3.874	0.874	940	2.08
65	4.898	1.898	555	8.53	470	3.874	0.874	960	2.04
70	4.836	1.836	560	8.00	490	3.874	0.874	980	2.00
75	4.773	1.773	565	7.53					
80	4.7231	1.723	570	7.13					

SWL = 3.00 m
Time of pumping = 490 min
Borehole location: Olunlade
Average pumping rate (*Q*) = 1.28 l/s

t′ = time since start of recovery
t = time since start of pumping
R.W.L. = Recovery water level
S = Residual drawdown
SWL = Static Water Level

Table S3: *Recovery Tests of Borehole (BH 4) in granite gneiss of Ilorin metropolis*

t/ (min)	*R.W.L* (m)	*S*/ (*RWL-SWL*) (m)	*t* (490 + *t*/) (min)	*t*/*t*/	*t*/ (min)	*RWL* (m)	*S*/ (*RWL-SWL*) (m)	*t* (490 + *t*/) (min)	*t*/*t*/
1	10.265	5.265	491	491.00	85	7.865	2.865	575	6.76
2	10.124	5.124	492	246.00	90	7.767	2.767	580	6.44
3	9.989	4.989	493	164.33	100	7.713	2.713	590	5.90
4	9.864	4.864	494	123.50	110	7.664	2.664	600	5.45
5	9.741	4.741	495	99.00	120	7.608	2.608	610	5.08
6	9.627	4.627	496	82.66	130	7.552	2.552	620	4.76
7	9.524	4.524	497	71.00	140	7.499	2.499	630	4.50
8	9.423	4.423	498	62.25	150	7.445	2.445	640	4.26
9	9.324	4.324	499	55.44	160	7.387	2.387	650	4.06
10	9.225	4.225	500	50.00	170	7.331	2.331	660	3.88
12	9.138	4.138	502	41.83	180	7.272	2.272	670	3.72
14	9.053	4.053	504	36.00	190	7.218	2.218	680	3.57
16	8.971	3.971	506	31.62	200	7.160	2.160	690	3.45
18	8.895	3.895	508	28.22	210	7.101	2.101	700	3.33
20	8.819	3.819	510	25.50	230	6.501	1.501	720	3.13
22	8.749	3.749	512	25.27	250	6.438	1.438	740	2.96
24	8.680	3.680	514	21.41	270	6.376	1.376	760	2.81
26	8.612	3.612	516	19.84	290	6.317	1.317	780	2.68
28	8.545	3.545	518	18.50	310	6.259	1.259	800	2.58
30	8.450	3.450	520	17.33	330	6.201	1.201	820	2.48
35	8.416	3.416	525	15.00	350	6.144	1.144	840	2.40
40	8.451	3.451	530	13.25	370	6.088	1.088	860	2.32
45	8.288	3.288	535	11.88	390	6.032	1.032	880	2.25
50	8.228	3.228	540	10.80	410	5.906	0.906	900	2.19
55	8.170	3.170	545	9.90	430	5.905	0.905	920	2.13
60	8.113	3.113	550	9.16	450	5.904	0.904	940	2.08
65	8.057	3.057	555	8.53	470	5.904	0.904	960	2.04
70	8.022	3.022	560	8.00	490	5.904	0.904	980	2.00
75	7.969	2.969	565	7.53					
80	7.919	2.919	570	7.13					

SWL = 5.00 m
Time of pumping = 490 min
Borehole location: Tanke
Average pumping rate (*Q*) = 2.23 l/s
SWL = Static Water Level

t/ = time since start of recovery
t = time since start of pumping
R.W.L. = Recovery water level
S = Residual drawdown

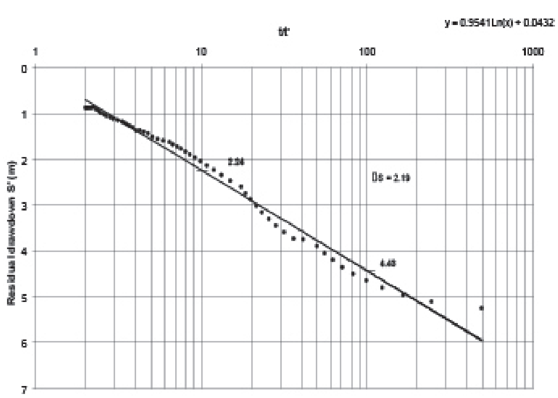

Figure S3: *Recovery Test curve of Borehole (BH 29) in granite gneiss of Ilorin metropolis.*

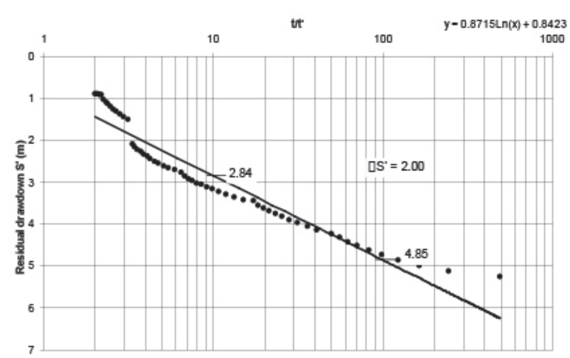

Figure S4: *Recovery Test Curve of Borehole (BH 4) in granite gneiss of Ilorin metropolis.*

Table S4: *Pumping Test of Borehole (BH 10) and (BH 24) in migmatite of Ilorin metropolis*

Time (min)	Water level (Draw- down, S) (m)	Time (min)	Water level (Draw- down, S) (m)	Time (min)	Water level (Draw- down, S) (m)	Time (min)	Water level (Draw- down, S) (m)
1	5.105	85	7.621	1	5.095	85	7.950
2	5.165	90	7.690	2	5.145	90	8.020
3	5.210	100	7.790	3	5.185	100	8.167
4	5.273	110	7.910	4	5.295	110	8.284
5	5.381	120	8001	5	5.390	120	8.385
6	5.422	130	8.118	6	5.484	130	8.740
7	5.480	140	8.201	7	5.567	140	8.594
8	5.595	150	8.299	8	5.561	150	8.692
9	5.677	160	8.430	9	5.725	160	8.790
10	5.725	170	8.510	10	5.789	170	8.881
12	5.790	180	8.624	12	5.894	180	8.950
14	5.881	190	8.711	14	5.993	190	9.015
16	5.964	200	8.815	16	6.110	200	9.115
18	6.125	210	8.920	18	6.215	210	9.192
20	6.190	230	9.014	20	6.321	230	9.324
22	6.273	250	9.105	22	6.435	250	9.444
24	6.344	270	9.210	24	6.522	270	9.524
26	6.405	290	9.333	26	6.616	290	9.651
28	6.499	310	9.416	28	6.701	310	9.765
30	6.536	330	9.504	30	6.775	330	9.850
35	6.666	350	9.619	35	6.872	350	9.949
40	6.774	370	9.705	40	6.984	370	10.023
45	6.872	390	9.800	45	7.101	390	10.101
50	6.980	410	9.910	50	7.233	410	10.210
55	7.025	430	10.002	55	7.334	430	10.314
60	7.192	450	10.092	60	7.448	450	10.420
65	7.283	470	10.172	65	7.535	470	10.500
70	7.394	490	10.255	70	7.621	490	10.587
75	7.430			75	7.704		
80	7.515			80	7.892		

Location: Borehole (BH 10) Olohunsogo
SWL (Static Water Level) = 5 900 m
Average Pumping rate (Q) = 1.62 1/s
Time of pumping = 490 min
Type of Pump: 1 HP Submersible

Location: Borehole (BH 24) Akerebiata
SWL (Static Water Level) = 5 800 m
Average Pumping rate (Q) = 1.731/s
Time of pumping = 490 min
Type of Pump: 1 HP Submersible

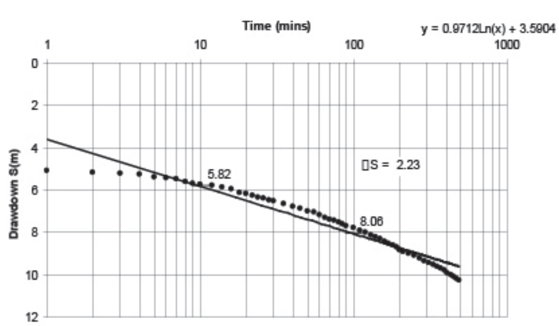

Figure S5: *Pumping Test Curve of Borehole (BH 10) in migmatite of Ilorin metropolis.*

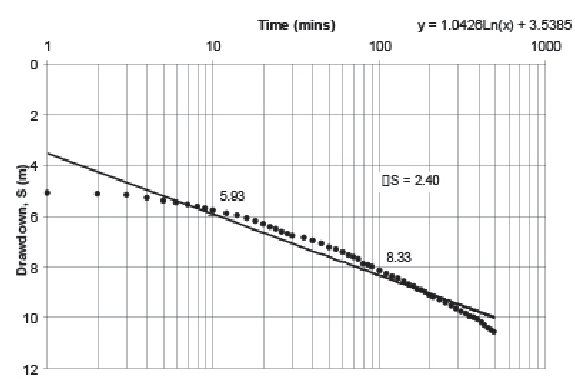

Figure S6: *Pumping Test Curve of Borehole (BH 24) in migmatite with overburden aquifer in Ilorin metropolis.*

Table S5: *Recovery Tests of Borehole (BH 10) in migmatite of Ilorin metropolis*

t′ (min)	*R.W.L* (m)	*S′* (*RWL-SWL*) (m)	*t* (490 + *t′*) (min)	*t/t′*	*t′* (min)	*RWL* (m)	*S′* (*RWL-SWL*) (m)	*t* (490 + *t′*) (min)	*t/t′*
1	10.102	4.202	491	491.00	85	7.555	1.655	575	6.76
2	9.949	4.049	492	246.00	90	7.513	1.613	580	6.44
3	9.799	3.899	493	164.33	100	7.468	1.568	590	5.90
4	9.648	3.748	494	123.50	110	7.422	1.522	600	5.45
5	9.496	3.596	495	99.00	120	7.378	1.478	610	5.08
6	9.346	3.446	496	82.66	130	7.333	1.433	620	4.76
7	9.196	3.296	497	71.00	140	7.291	1.391	630	4.50
8	9.047	3.147	498	62.25	150	7.246	1.346	640	4.26
9	8.898	2.998	499	55.44	160	7.200	1.300	650	4.06
10	8.750	2.850	500	50.00	170	7.155	1.255	660	3.88
12	8.644	2.744	502	41.83	180	7.109	1.209	670	3.72
14	8.540	2.640	504	36.00	190	7.066	1.166	680	3.57
16	8.450	2.550	506	31.62	200	7.002	1.122	690	3.45
18	8.370	2.470	508	28.22	210	6.917	1.077	700	3.33
20	8.300	2.400	510	25.50	230	6.927	1.027	720	3.13
22	8.250	2.350	512	25.27	250	6.874	0.974	740	2.96
24	8.199	2.299	514	21.41	270	6.770	0.870	760	2.81
26	8.150	2.250	516	19.84	290	6.720	0.820	780	2.68
28	8.102	2.202	518	18.50	310	6.663	0.763	800	2.58
30	8.053	2.153	520	17.33	330	6.662	0.762	820	2.48
35	8.010	2.110	525	15.00	350	6.662	0.762	840	2.40
40	7.964	2.064	530	13.25	370	6.661	0.761	860	2.32
45	7.918	2.018	535	11.88	390	6.661	0.761	880	2.25
50	7.814	1.914	540	10.80	410	6.660	0.760	900	2.19
55	7.829	1.929	545	9.90	430	6.660	0.760	920	2.13
60	7.779	1.879	550	9.16	450	6.660	0.760	940	2.08
65	7.734	1.834	555	8.53	470	6.660	0.760	960	2.04
70	7.686	1.786	560	8.00	490	6.660	0.760	980	2.00
75	7.642	1.742	565	7.53					
80	7.598	1.698	570	7.13					

SWL = 5.00 m
Time of pumping = 490 min
Borehole location: Olohunsogo
Average pumping rate (Q) = 1.62 l/s

t′ = time since start of recovery
t = time since start of pumping
R.W.L. = Recovery water level
SWL= Static Water Level
S′ = Residual drawdown

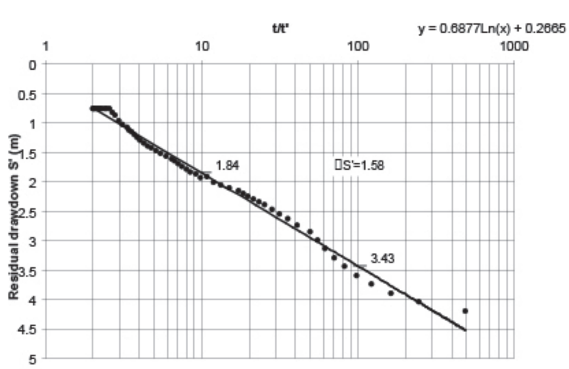

Figure S7: *Recovery Test curve of Borehole (BH 10) in migmatite of Ilorin metropolis.*

Table S6: *Recovery Tests of Borehole (BH 24) in migmatite of Ilorin metropolis*

$t^{/}$ (min)	R.W.L (m)	$S^{/}$ (RWL-SWL) (m)	t (490 + $t^{/}$) (min)	$t/t^{/}$	$t^{/}$ (min)	RWL (m)	$S^{/}$ (RWL-SWL) (m)	t (490 + $t^{/}$) (min)	$t/t^{/}$
1	10.442	4.642	491	491.00	85	7.401	1.601	575	6.76
2	10.297	4.498	492	246.00	90	7.361	1.651	580	6.44
3	10.154	4.354	493	164.33	100	7.316	1.516	590	5.90
4	10.009	4.209	494	123.50	110	7.269	1.469	600	5.45
5	9.866	4.966	495	99.00	120	7.224	1.424	610	5.08
6	9.726	3.926	496	82.66	130	7.180	1.380	620	4.76
7	9.583	3.783	497	71.00	140	7.140	1.340	630	4.50
8	9.439	3.639	498	62.25	150	7.100	1.300	640	4.26
9	9.299	3.499	499	55.44	160	7.060	1.260	650	4.06
10	9.158	3.358	500	50.00	170	7.019	1.219	660	3.88
12	9.123	3.323	502	41.83	180	6.978	1.178	670	3.72
14	8.987	3.187	504	36.00	190	6.938	1.138	680	3.57
16	8.855	3.055	506	31.62	200	6.893	1.093	690	3.45
18	8.725	2.925	508	28.22	210	6.858	1.058	700	3.33
20	8.594	2.794	510	25.50	230	6.822	1.022	720	3.13
22	8.461	2.661	512	25.27	250	6.790	0.990	740	2.96
24	8.338	2.538	514	21.41	270	6.757	0.957	760	2.81
26	8.228	2.428	516	19.84	290	6.718	0.918	780	2.68
28	8.128	2.328	518	18.50	310	6.683	0.883	800	2.58
30	8.038	2.238	520	17.33	330	6.651	0.851	820	2.48
35	7.958	2.158	525	15.00	350	6.615	0.815	840	2.40
40	7.881	2.081	530	13.25	370	6.580	0.780	860	2.32
45	7.826	2.026	535	11.88	390	6.550	0.750	880	2.25
50	7.766	1.966	540	10.80	410	6.549	0.749	900	2.19
55	7.711	1.911	545	9.90	430	6.548	0.749	920	2.13
60	7.668	1.868	550	9.16	450	6.548	0.748	940	2.08
65	7.601	1.801	555	8.53	470	6.548	0.748	960	2.04
70	7.560	1.760	560	8.00	490	6.548	0.748	980	2.00
75	7.507	1.707	565	7.53					
80	7.453	1.653	570	7.13					

SWL = 5 800 m
Time of pumping = 490 min
Borehole location: Akerebiata
Average pumping rate (*Q*) = 1.73 l/s
SWL= Static Water Level

$t^{/}$ = time since start of recovery
t = time since start of pumping
R.W.L. = Recovery water level
S = Residual drawdown

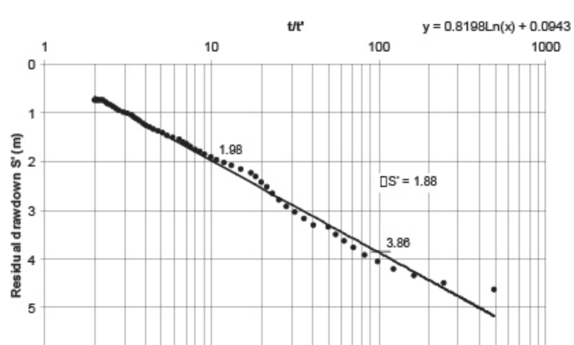

Figure S8: *Recovery Test Curve of Borehole (BH 24) in migmatite of Ilorin metropolis.*

Table S7: *Pumping Test of Borehole (BH 12) in quartzite of Ilorin metropolis*

Time (min)	Water level (Draw- down, S) (m)	Time (min)	Water level (Draw- down, S) (m)
1	4.396	85	7.105
2	4.455	90	7.185
3	4.536	100	7.295
4	4.625	110	7.395
5	4.741	120	7.523
6	4.850	130	7.595
7	5.018	140	7.747
8	5.057	150	7.762
9	5.125	160	7.815
10	5.295	170	7.892
12	5.360	180	7.978
14	5.450	190	8.058
16	5.550	200	8.128
18	5.601	210	8.237
20	5.715	230	8.304
22	5.830	250	8.423
24	5.924	270	8.507
26	5.997	290	8.589
28	6.095	310	8.684
30	6.185	330	8.790
35	6.290	350	8.890
40	6.375	370	8.995
45	6.447	390	9.081
50	6.455	410	9.163
55	6.570	430	9.230
60	6.690	450	9.302
65	6.763	470	9.385
70	6.814	490	9.471
75	6.950		
80	7.015		

Location: Borehole (BH 12) Gaa-Akanbi
SWL (Static Water Level) = 4.30 m
Average Pumping Rate (Q) = 2.23 1/s
Pumping Duration: 490 min
Type of Pump = 1 HP Submersible (Grundfos)

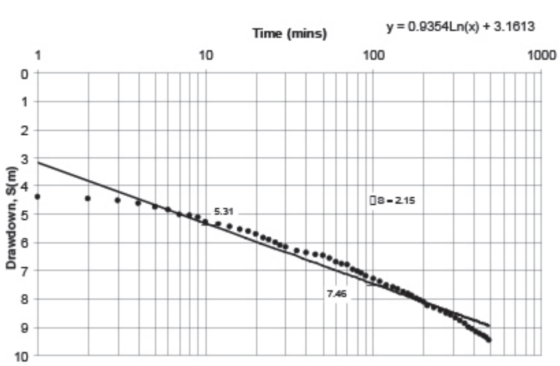

Figure S9: *Pumping Test Curve of Borehole (BH 12) in quartzites of Ilorin metropolis*

Table S8: *Recovery Tests of Borehole (BH 12) in quartzites of Ilorin metropol*

$t^{/}$ (min)	R.W.L (m)	$S^{/}$ (RWL-SWL) (m)	t (490 + $t^{/}$) (min)	$t/t^{/}$	$t^{/}$ (min)	RWL (m)	$S^{/}$ (RWL-SWL) (m)	t (490 + $t^{/}$) (min)	$t/t^{/}$
1	9.321	5.021	491	491.00	85	6.353	2.053	575	6.76
2	9.170	4.870	492	246.00	90	6.294	1.994	580	6.44
3	9.022	4.722	493	164.33	100	6.241	1.941	590	5.90
4	8.873	4.573	494	123.50	110	6.157	1.857	600	5.45
5	8.728	4.428	495	99.00	120	6.137	1.837	610	5.08
6	8.582	4.282	496	82.66	130	6.092	1.792	620	4.76
7	8.297	4.137	497	71.00	140	6.048	1.748	630	4.50
8	8.162	3.997	498	62.25	150	6.003	1.703	640	4.26
9	8.027	3.862	499	55.44	160	5.961	1.661	650	4.06
10	7.897	3.727	500	50.00	170	5.918	1.618	660	3.88
12	7.897	3.597	502	41.83	180	5.873	1.573	670	3.72
14	7.768	3.468	504	36.00	190	5.829	1.529	680	3.57
16	7.648	3.348	506	31.62	200	5.786	1.486	690	3.45
18	7.527	3.227	508	28.22	210	5.745	1.445	700	3.33
20	7.427	3.127	510	25.50	230	5.705	1.405	720	3.13
22	7.332	3.032	512	25.27	250	5.664	1.364	740	2.96
24	7.239	2.939	514	21.41	270	5.621	1.321	760	2.81
26	7.149	2.849	516	19.84	290	5.577	1.277	780	2.68
28	7.064	2.764	518	18.50	310	5.532	1.232	800	2.58
30	6.981	2.681	520	17.33	330	5.482	1.182	820	2.48
35	6.911	2.611	525	15.00	350	5.432	1.132	840	2.40
40	6.851	2.551	530	13.25	370	5.376	1.076	860	2.32
45	6.786	2.486	535	11.88	390	5.326	1.026	880	2.25
50	6.724	2.424	540	10.80	410	5.277	0.977	900	2.19
55	6.673	2.373	545	9.90	430	5.246	0.946	920	2.13
60	6.623	2.323	550	9.16	450	5.245	0.945	940	2.08
65	6.571	2.271	555	8.53	470	5.245	0.945	960	2.04
70	6.517	2.217	560	8.00	490	5.245	0.945	980	2.00
75	6.465	2.165	565	7.53					
80	6.405	2.109	570	7.13					

SWL = 4 300 m
Time of pumping = 490 min
Borehole location: Akerebiata
Average pumping rate (*Q*) = 2.23 l/s
SWL = Static Water Level

t/ = time since start of recovery
t = time since start of pumping
R.W.L. = Recovery water level
S/= Residual drawdown

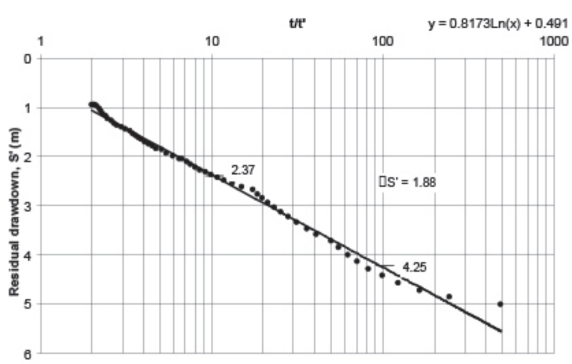

Figure S10: *Recovery Test Curve of Borehole (BH 12) in quartzites of Ilorin metropolis.*