Characterizing Groundwater Level and Flow Pattern in a Shallow Overburden Aquifer: a Study of Ilara-mokin and its Environs, Southwestern Nigeria

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ABSTRACT

This study characterize groundwater yield and flow pattern on a shallow overburden aquifers of a basement complex rock in Ilara-mokin and its' environs, southwestern Nigeria. A total of 40 wells were sampled by using a handheld GPS and well estimator to collect data on the wells parameters and the physiographic characteristics of the well's locations. The data collected include: elevation, longitude, latitude, well depth, depth to water and well diameter of the sampled wells. The mean yield of the well has revealed by this study is 1.21m^3, with high variability in yield depending on the nature of the underlying overburden aquifers of the sampled well. The static water level, groundwater flow direction, surface profile and 3-D elevation model of the study area were produced from the data collected using ArcGis 9.3 and surfer 8 GIS software. The groundwater flow direction in the study is towards the southwestern part of the study area with few exceptions as the case of Ikota in the eastern part of the study area. The study concluded that Ilara-mokin and it's' environs have poor groundwater yield that can sustain the increasing population. It is therefore recommended that there should be proper development, management and advance exploration of the groundwater in areas where water level is close to the surface especially within the lowland areas and isolated marginally thick overburden as confirmed by a previous hydro-geophysical studies carried out in the area.

Keywords: Groundwater Flow, Yield, Overburden, Shallow Aquifer, Characterization, Static Water Level.

1. INTRODUCTION

Groundwater is generally portable at source, available in-situ and has low temporal variability which makes it the most important source of water for rural communities (Nyagwambo, 2006). Groundwater development is somewhat complex by highly variable hydrogeological conditions making its management full of uncertainty (Taylor and Barret, 1999). According to Omorinbola (1982) about 50% of Nigeria is covered by the crystalline basement rock. This is a poor aquifer unit with low groundwater potential. That was why Nyagwambo (2006) submitted that groundwater management on a crystalline basement aquifer has the highest level of uncertainty.

In the crystalline basement complex rock, it is weathering activities that produced relatively thick overburden in which extractable groundwater resources can be found (Omorinbola, 1984). According to Azeez (1972) crystalline basement rocks do not make good aquifer because of their zero level of porosity and permeability. However, a secondary porosity can develop through a simple process of weathering, fractured fissure systems, networks of joints and cracks in the crystalline basement rocks (Wright, 1992; McFarlane, 1992) as cited by Nyagwambo (2006). The fracture zone in the crystalline basement complex rock as a result of weathering serves as a transmission conduit within the overburden aquifer (Gustafson and Krasny, 1994; Batchelor et al., 1996, Taylor and Howard, 2000) as reported by Nyagwambo (2006).

A study by Ifabiyi (1999) tried to predict the yield of boreholes on a basement complex rock aquifer and sedimentary rock in the central Nigeria. He concluded that borehole yield is low on the basement complex aquifer compared to the sedimentary rock aquifer zone. However, well yield can also differ in the same crystalline basement rock unit because of the heterogeneity and discontinuity of the aquifer. According to Gustafon and Krasny (1994) hydraulic conductivity in the fractured zone of the basement complex rock is spatially variable as the nature of the fractures and faults within the rock can make borehole yields differ by several orders of magnitude within the same rock unit and often within short distances.

As observed by Omorinbola (1984) regional differences in climate and marked spatial variation in weathering depth are reflected in the characteristics of the overburden aquifers. Studies have observed widespread and relatively thick groundwater zones in the overburden especially in the low-relief landscapes with adequate rainfall (Faniran and Omorinbola, 1980; Omorinbola, 1981) as reported by Omorinbola (1982). However, understanding the yield of wells and groundwater flow pattern in an overburden aquifer on a crystalline basement rock can therefore serve as a prerequisite to its development and management for optimal usage. Ilara-mokin and its' environ is underlain by a crystalline basement rock. According to Oladapo et al. (2009) the population depends mainly on groundwater resources for their domestic needs. This area is however faced with the challenges of inadequate water supply as the population is increasing with the establishment of polytechnic, private university, golf course and proximity to the federal university in the state capital.

This paper tries to characterize shallow groundwater yield and flow pattern in Ilara-mokin and its’ environ with a view to understand areas with high yield capability and areas where groundwater level is close to the surface and to suggest proper development, management and exploration of groundwater in the study area.

1.1. Study Area

Ilara-mokin community is in Ifedore LGA of Ondo state, south-western Nigeria. The town is located between latitude 07°21'16" and 07°22'20" N and longitude 005°05'58" and 005°07'12" E (Fig 1). Its estimated population is about 45,000 people. The local residents are mostly fish and poultry farmers. The climate of Ilara-mokin and its’ environ is of the Lowland Tropical Rain Forest type, with distinct wet and dry seasons. There is marked dry season from November to March when there is little or no rainfall. The total annual rainfall in this area is about 1800 millimeters. The mean monthly temperature ranges between 27°C to 30°C. The mean monthly relative humidity is less than 70%.

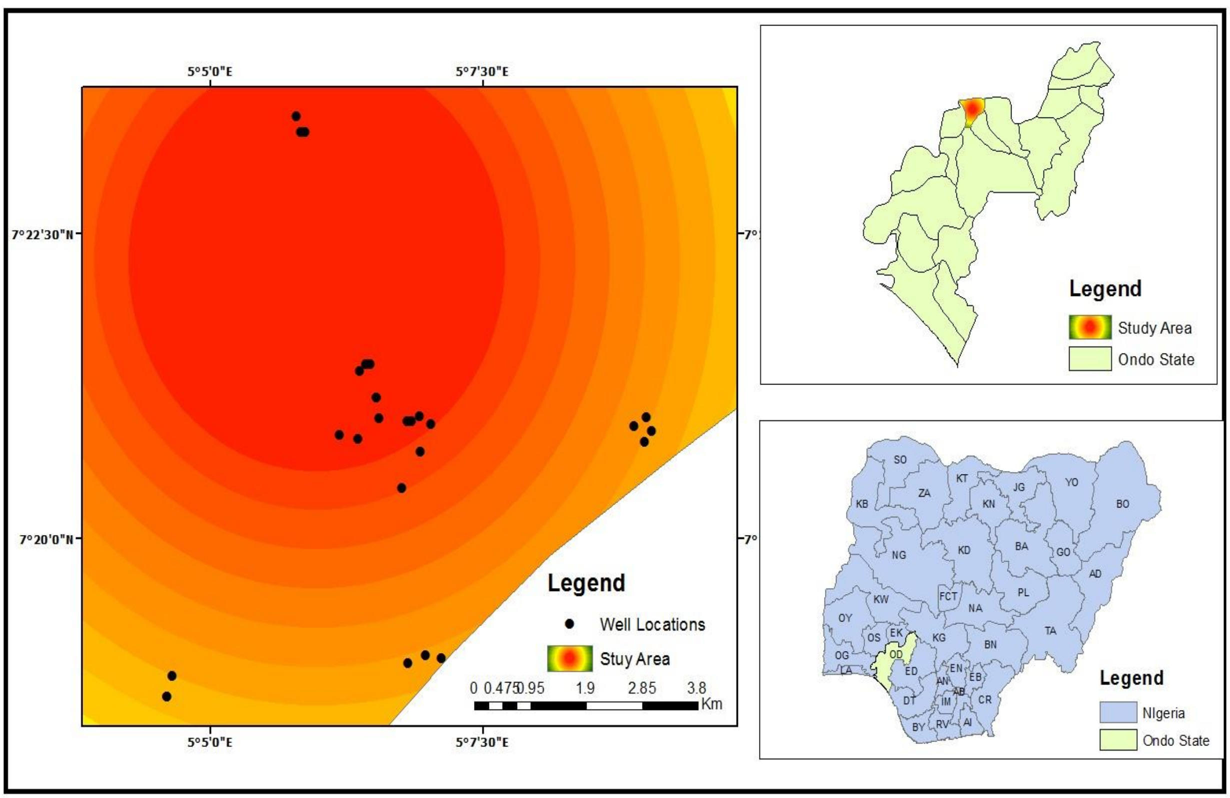

Figure 1. Map showing Nigeria, Ondo state and the study area.

The geology of Ilara-mokin is Precambrian Basement Complex rocks and is mainly of the medium grained gneisses. These are strongly foliated rocks frequently occurring as outcrops. The lithological units include variably migmatized biotite-hornblende-gneiss with intercalated amphibolite (Oladapo et al., 2009). The greater part of the study area is underlain by marginally thick overburden thus constituting shallow aquifer units (Oladapo et al., 2009). The four other communities in Ilara-mokin's environ used in this study are Ipogun, Ikota, Ero and Ibule.

2. METHODOLOGY

2.1 Data Collection

The data set for this work were collected by the authors through extensive fieldwork on hand dug well characteristics in the research area. The surface elevation and position of the sampled wells were taken before data on well characteristics were collected which include: data on depth of well, depth to groundwater, depth of groundwater, well diameter and volume of well water. The Global Positioning System (Garmin GPS Channel 76 model) was used to take the coordinates of each well in relation to the mean sea level during the day when the sky was clear. The measurement of well parameters especially depth to water were taken early in the morning around 6:00am during the wet season. The well depth, depth to water and well diameter were taken by the use of well estimator. The depths of water were calculated by getting the difference between the well depth and depth to water. The volumes of well water were calculated using the formula for calculating the volume of a cylinder since all the sampled well were wells installed with cylindrical rings. A total of 24 wells were sampled in Ilara-mokin, 4 wells were sampled in each of the four surrounding villages (Ipogun, Ikota, Ero and Ibule) giving a total of 16 wells. In all, a total of 40 wells were sampled in Ilara-mokin and its environs to have a good representation of the research area.

2.2 Data Analysis

The methods used to analyze the data generated from the field work are the following.

1) Descriptive statistics such as Mean was used to generalize characteristics of the wells collected, Standard deviation was used to determine the absolute deviation from the mean and Coefficient of variation was used to determine the relative variation from the mean.

2) Inferential statistics such as Multiple Correlation was used to determine the degree of association between the physiographic and well characteristics in the study area. While multiple regression analysis (Enter and Stepwise) were used to determine the relationship between depth to water, physiographic parameters and well variables as well as the relationship between volume of water and well parameters.
3) Static water level of the research area was computed by deducting depth to water from the surface elevation. This can be written as:

$$S_{wl} = E - D_{wt} \quad \text{(i)}$$

Where, S_{wl} = Static water level; E = Surface elevation; D_{wt} = Depth to water table

The output of this computation and the measured parameters (elevation, northing and easting) were used to produce the static water level contour map and Digital Elevation Model (DEM) of the research area in ArcGis 9.3 and Surfer 8 software. Also the groundwater flow map of the research area was prepared based on the observations of Adeoye (2012, unpubl. Data), Buddermeier and Schloss (2000) that groundwater would flow from the highest values of contour lines to the lowest values in a direction perpendicular to the contour lines.

3. RESULTS

3.1. General Characteristics of the Shallow Groundwater

The study area is Precambrian Basement Complex rocks and is mainly of the medium grained gneisses. According to Oladapo et al. (2009), the greater part of Ilara-Mokin town is underlain by marginally thick overburden thus constituting shallow aquifer units with poor to marginal groundwater potential. Table 1 provides the information on the wells sampled in Ilara-mokin and its environs.

Table 1 shows that the wells diameter in the study area ranges between 0.60m and 1.50m with a mean value of 0.80m. The wells diameter standard deviation and coefficient of variation obtained are 0.17m and 21.25%, respectively. The depth to water ranges between 1.85m and 8.07m with a standard deviation of 1.70m and coefficient of variation of 35.71%. The total well depth in Ilara-mokin and its' environ ranges between 2.78m and 11.56m with a mean depth of 6.91m. The standard deviation and coefficient of variation obtained for total well depth are

1.79m and 25.90%, respectively. The depth of water in the research area ranges between 0.50m 4.93m and the mean depth of water obtained was 2.43m. The depth of water standard deviation was 1.22m and the coefficient of variation was 50.21%. The highest volume of water recorded was in Oke Ode area in Ilara-mokin community which has a yield of 3.12m^3. The lowest yield was 0.19m^3 and was also recorded in Ilara-mokin community in Aiyetoro area. The standard deviation and coefficient of variation of well yield in the area were 0.71m and 58.68%, respectively.

Table 1. Well Characteristics and Water Yield in Ilara-mokin and the Environs (Source: Fieldwork, 2013).

S. No.	***Well Location***	***Elevation (m)***	***Latitude***	***Longitude***	***Total well depth (m)***	***Depth to water (m)***	***Depth of water (m)***	***Well diameter (m)***	***Volume of well water (m^3)***
1	Better life area-i	348	7°21'25.7"	5°06'25.7"	6.80	4.90	1.90	0.78	0.91
2	Better life area-ii	335	7°21'22.3"	5°06'22.3"	7.20	5.00	2.20	1.30	1.78
3	Better life area-iii	331	7°20'56.4"	5°06'18.4"	5.22	4.21	1.01	0.90	0.64
4	Ifelodun area-i	344	7°21'00.5"	5°06'27.8"	7.80	5.60	2.20	0.80	1.11
5	Ifelodun area-ii	346	7°21'02.7"	5°06'31.3"	6.50	3.50	3.00	0.76	1.36
6	Ayetoro Area-i	350	7°20'59.1"	5°06'33.0"	9.59	8.07	1.52	0.64	0.49
7	Ayetoro Area-ii	344	7°21'59.7"	5°06'34.6"	8.38	6.84	1.54	0.70	0.59
8	Ayetoro Area-iii	349	7°21'06.5"	5°06'32.7"	2.78	2.30	0.50	0.70	0.19
9	Ayetoro Area-iv	344	7°21'09.2"	5°06'31.4"	3.44	2.38	1.10	0.80	0.55
10	Hospital Rd-i	341	7°20'50.8"	5°06'11.3"	5.00	3.60	1.40	0.85	0.79
11	Hospital Rd-ii	338	7°20'41.1"	5°06'14.4"	5.00	3.90	1.10	0.60	0.31
12	Hospital Rd-iii	353	7°20'47.6"	5°06'14.3"	8.20	4.20	4.00	0.84	2.22
13	Hospital Rd-iv	334	7°20'49.1"	5°06'21.1"	6.10	1.85	4.25	0.65	1.41
14	Odo Igbeyin-i	358	7°20'57.8"	5°06'48.5"	8.70	6.60	2.10	0.75	0.93
15	Odo Igbeyin-ii	360	7°20'59.8"	5°06'50.8"	6.90	5.60	1.30	0.85	0.74
16	Oke Ode-i	348	7°21'00.1"	5°06'55.3"	9.13	7.78	1.40	0.66	0.48
17	Oke Ode-ii	362	7°20'56.5"	5°06'59.5"	7.78	2.85	4.93	0.63	1.54
18	Oke Ode-iii	370	7°20'56.3"	5°07'01.6"	7.77	3.38	4.40	0.95	3.12
19	Ajiluyi/Oke	350	7°20'24.7"	5°06'45.3"	7.35	5.30	2.10	0.85	1.19

	Adura-i								
20	Ajiluyi/Oke Adura-ii	350	7°20'22.3"	5°06'44.7"	7.11	5.42	1.87	0.83	1.01
21	Ajiluyi/Oke Adura-iii	363	7°20'31.0"	5°06'46.2"	9.41	4.60	4.81	0.86	2.79
22	Ajiluyi/Oke Adura-iv	361	7°20'36.5"	5°06'43.2"	6.49	2.75	3.74	0.84	2.07
23	Ajiluyi/Oke Adura-v	372	7°20'42.9"	5°06'55.7"	9.08	5.55	4.25	0.82	2.24
24	Elizade Rd	324	7°21'09.9"	5°06'31.4"	5.58	3.86	1.72	1.00	1.35
25	Ipogun-i	314	7°18'52.3"	5°04'38.8"	6.81	5.60	1.21	0.65	0.40
26	Ipogun-ii	309	7°18'49.9"	5°04'33.5"	8.29	5.70	2.59	0.75	1.14
27	Ipogun-iii	299	7°18'46.7"	5°04'35.8"	4.39	2.62	1.77	0.72	0.72
28	Ipogun-iv	298	7°18'41.9"	5°04'35.9"	6.65	3.60	3.05	0.80	1.53
29	Ikota-i	375	7°20'59.6"	5°09'00.4"	6.64	5.41	1.23	0.70	0.47
30	Ikota-ii	357	7°20'52.6"	5°09'03.3"	11.56	7.20	4.36	0.80	2.19
31	Ikota-iii	378	7°20'47.4"	5°08'59.1"	7.60	4.88	2.72	0.70	1.05
32	Ikota-iv	348	7°20'55.3"	5°08'53.3"	6.50	3.10	3.40	0.85	1.93
33	Ero-i	360	7°23'28.1"	5°05'47.4"	4.70	3.21	1.49	0.78	0.71
34	Ero-ii	361	7°23'20.2"	5°05'52.3"	9.24	7.84	1.40	0.65	0.46
35	Ero-iii	362	7°23'20.2"	5°05'51.3"	6.06	4.50	1.56	0.83	0.84
36	Ero-iv	352	7°23'20.3"	5°05'49.8"	6.24	4.59	1.65	0.83	0.89
37	Ibule-i	366	7°19'01.1"	5°07'07.5"	4.70	2.40	2.30	0.93	1.56
38	Ibule-ii	395	7°19'02.6"	5°06'58.8"	5.63	5.63	3.13	0.68	1.14
39	Ibule-iii	360	7°18'56.2"	5°06'50.0"	6.31	6.31	2.90	1.50	2.28
40	Ibule-iv	390	7°18'58.5"	5°06'48.8"	7.85	7.85	4.24	0.65	1.19
Mean					6.91	4.76	2.43	0.80	1.21
SD					1.79	1.70	1.22	0.17	0.71
Mi					2.78	1.85	0.50	0.60	0.19
Ma					11.56	8.07	4.93	1.50	3.12
CV					25.90%	35.71%	50.21%	21.25%	58.68%

Note: *SD: Standard Deviation; Mi: Minimum; Ma: Maximum; CV: Coefficient of Variation.*

3.2 Relationship between Well and Physiographic Characteristics

The relationship between elevation, latitudes, longitudes, well depth, depth to water and well diameter is presented in table 2.

Table 2. Correlation Matrix of Well and Physiographic Characteristics.

	Elevation	***Latitude***	***Longitude***	***Well depth***	***Depth to water***
Latitude	0.22				
Longitude	0.62**	0.10			
Well depth	0.21	0.02	0.24		
Depth to water	0.25	0.01	0.10	0.72**	
Well diameter	-0.03	-0.08	0.06	-0.10	-0.07

Note: ***Correlation is significant at the 0.01 level (2-tailed).*

Table 2 shows that elevation and longitude have a strong positive correlation (r=0.62) at 99% significance level which is an indication that the elevation in the eastern part is high compared to all other areas in Ilara-mokin and its environ. Also, well depth and depth to water have a strong positive correlation (r=0.72) at 99% significance level. However, elevation and well depth have a weak positive correlation (r=0.21) which was not significant at 99% confidence level. The relationship between depths to water (dependent variable), physiographic and well parameters are presented in Tables 3.3 and 3.4, respectively.

Table 3. Model Summary of Depth to Water, Physiographic and Well Parameters.

Model	***R***	***R Square***	***Adjusted R Square***	***Std. Error of the Estimate***
1	.746[a]	.556	.491	1.21169

Note: *a. Predictors: (Constant), Well diameter, Elevation, Well depth, Latitude, Longitude.*

The result of multiple linear regression model presented in table 3, with five explanatory variables, has an R squared value of 0.556. This signifies that 56% of the total variation in well depth in the study area can be explained by well depth, well diameter, elevation, longitude and latitude.

Table 4. Relationship between Depth to Water, Physiographic Parameters and Well Variables

Model		***Unstandardized Coefficients***		***Standardized Coefficients***	***t***	***Sig.***
		B	***Std. Error***	***Beta***		
1	(Constant)	215.441	165.547		1.301	.202
	Elevation	0.020	0.012	0.251	1.686	.101
	Latitude	-5.512	15.825	-0.041	-0.348	.730
	Longitude	-36.114	23.517	-0.227	-1.536	.134
	Well depth	0.685	0.113	0.721	6.060	.000
	Well diameter	0.156	1.161	0.016	0.135	.894

Note: *a. Dependent Variable: Depth to Water.*

From table 4, for every 1% increase in elevation, well depth and well diameter, there is 0.02%, 0.69% and 0.16% increase in depth to water, respectively. Also, for every 1% decrease in latitude and longitude, that’s movement towards the center of the study area, there is -5.51% and

-36.11% decrease in depth to water, respectively, in the study area. Based on table 4, the relationship between depths to water, physiographic and well parameters can be given as:

I. The theoretical model is:

$$depthtowater = a + b_1 elevation + b_2 latitude + b_3 longitude + b_4 welldepth + b_5 welldiameter + e$$

II. The estimated model is:

$$depthtowater = 215.441 + 0.020_{elev} - 5.512_{lat} - 36.114_{\log} + 0.685_{welldepth} + 0.156_{welldiameter} \text{ .... (ii)}$$

The parameters were further subjected to stepwise regression to be able to ascertain what variable contributed highest to depth to water out of the five explanatory parameters. The result is presented in tables 5 and 6, respectively.

Table 5. Model Summary of Stepwise Regression of Depth to Water, physiographic and Well Parameters.

Model	***R***	***R Square***	***Adjusted R Square***	***Std. Error of the Estimate***
1	.716[a]	.513	.500	1.20038

Note: *a. Predictors: (Constant), Well depth.*

The result of the stepwise regression analysis indicates that out of the five explanatory variables, total well depth explained 51.3% of the variation in depth to water while the four remaining variables (elevation, latitude, longitude and well diameter) accounted for just 48.7% of the variation in depth to water.

Table 6. Stepwise Regression of Depth to Water, Physiographic and Well Parameters.

Model		***Unstandardized Coefficients***		***Standardized Coefficients***		
		B	***Std. Error***	***Beta***	***t***	***Sig.***
1	(Constant)	0.060	.767		.078	.938
	Well depth	0.680	.108	.716	6.328	.000

Note: *a. Dependent Variable: Depth to water.*

From table 6, the estimated model of the stepwise regression analysis is written thus:

$$depthtowater = 0.06 + 0.68_{welldepth} \text{ .... (iii)}$$

3.3 Relationship between Volume of Well Water (yield) and Well Parameters

Relationship between volume of well water (yield) and well parameters is presented in table 7.

Table 7. Model Summary of Volume of Water and Well Parameters.

Model	***R***	***R Square***	***Adjusted R Square***	***Std. Error of the Estimate***
1	.965[a]	.931	.923	.19624

Note: *a. Predictors: (Constant), Well diameter, Depth to water, Depth of water, Well depth.*

The result of multiple linear regression model presented in table 7, with four explanatory variables, has an R squared value of 0.931. This signifies that 93.1% of the variation in well yield in the study area can be explained by well depth, depth to water, depth of water and well diameter.

Table 8. Relationship between Volume of Water and Well Parameters.

Model		***Unstandardized Coefficients***		***Standardized Coefficients***	***t***	***Sig.***
		B	***Std. Error***	***Beta***		
1	(Constant)	-1.552	.206		-7.549	.000
	Well depth	0.138	.039	.348	3.548	.001
	Depth to water	-0.133	.036	-.319	-3.691	.001
	Depth of water	0.357	.040	.617	8.985	.000
	Well diameter	1.955	.190	.468	10.313	.000

Note: *a. Dependent Variable: Volume of well water; Source: Authors Computation, 2013.*

From table 8, for every 1% increase in well depth, depth of water and well diameter, there is 0.138%, 0.357% and 1.955% increase in well yield, respectively. Also, for every 1% decrease in depth to water, there is -0.133% decrease in well yield in the study area. Based on table 8, the relationship between volume of water (well yield), depth to water, depth of well, depth of water and well diameter can be given as:

I. The theoretical model is:

$$Volumeofwater = a + b_1 welldepth + b_2 depthtowater + b_3 depthofwater + b_4 welldiameter + e$$

II. The estimated model is:

$$volumeofwater = -1.552 + 0.138_{welldepth} - 0.133_{depthtowater} + 0.357_{depthofwater} + 1.955_{welldiameter} \ldots \text{(iv)}$$

3.4. Groundwater Flow Direction in Ilara-mokin and its Environ

The static water level values calculated were converted to a Digital Elevation Model (DEM) using 3D analyst tools. This was used to generate the static water level contours and 3D model of Ilara-mokin and its environ using ArcGis 9.3 and Surfa 8 softwares. The values of the static water levels and groundwater flow direction were contoured on the map of the study area as shown in figure 2. Static Water Level Contour Interpolation, Surface Profile of Ilara-mokin and its environs; and Overlay of Surface Contour and Static Water level were shown in figure 3. While the 3-D elevation of Ilara-mokin and its environs are shown in figure 4.

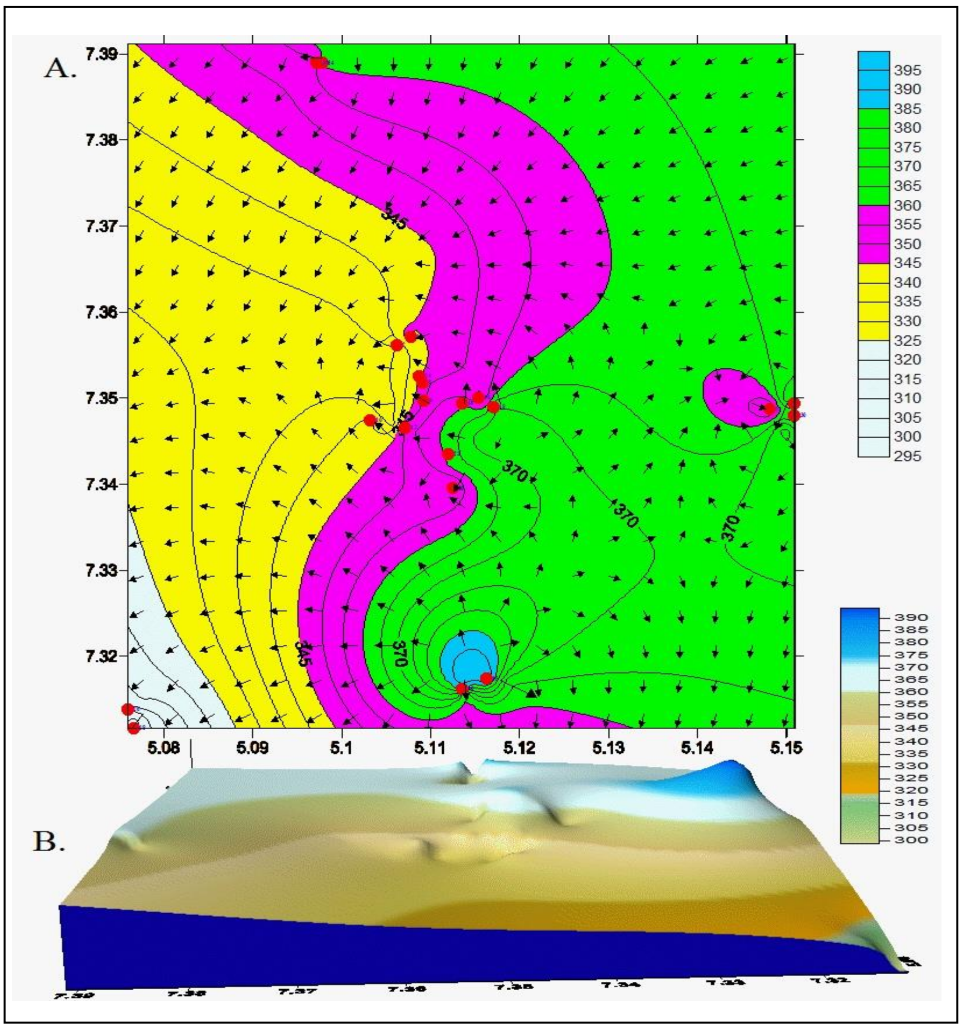

Figure 2. Static water level and Groundwater Flow Direction (A) in Ilara-mokin and its Environ. The elevation is indicated by the bar (right) in meters (Source: Generated by the Authors from the Field data, 2013).

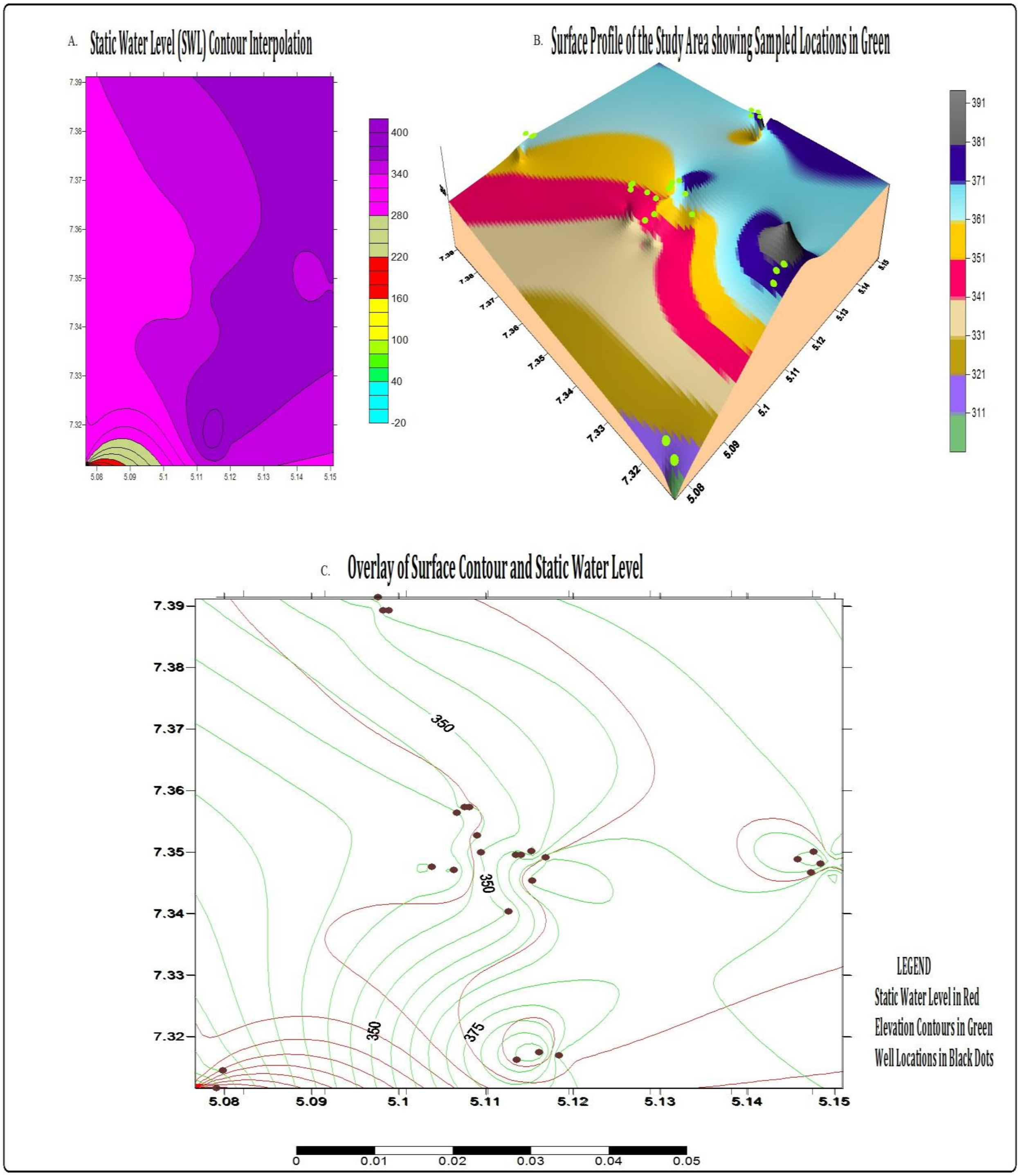

Figure 3. (A) Static Water Level Contour Interpolation, (B) Surface Profile of Ilara-mokin and its environs; and (C) Overlay of Surface Contour and Static Water level (Source: Generated by the Authors from the Field data, 2013).

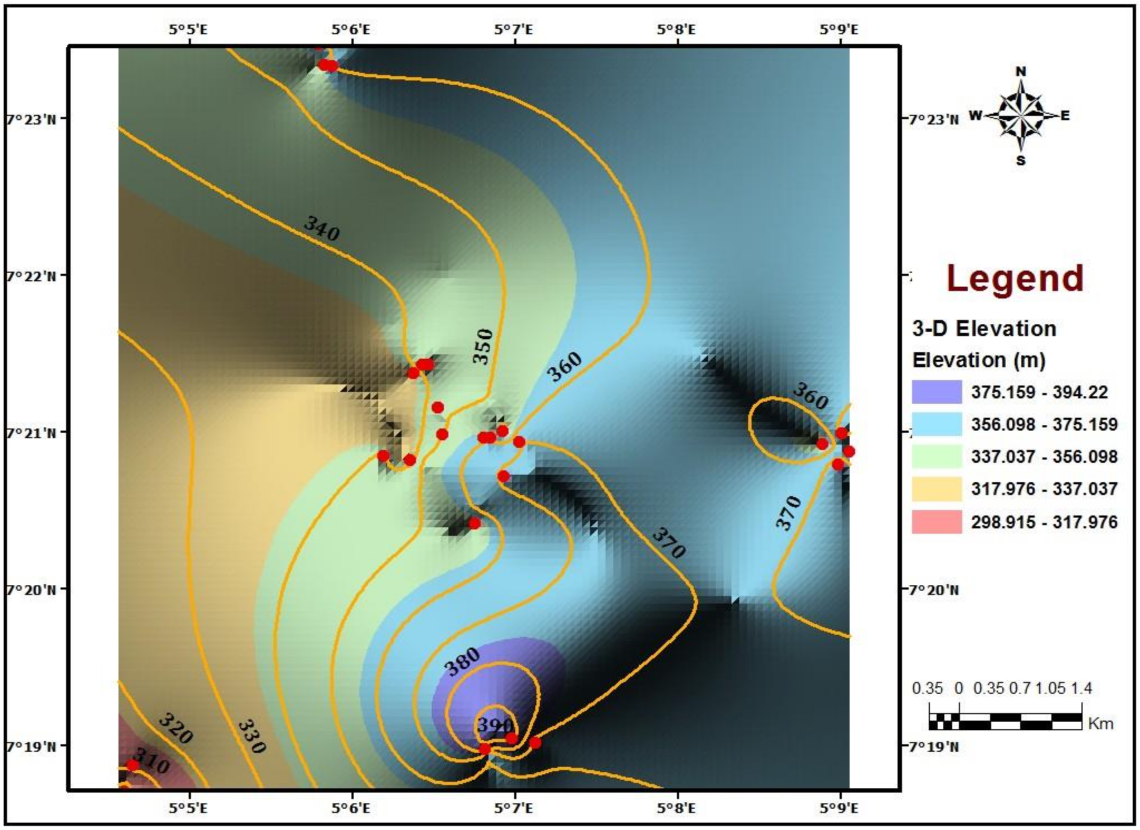

Figure 4. 3-D elevation of Ilara-mokin and its environs (Source: Generated by the Authors from the Field data, 2013).

4. DISCUSSION

As revealed by the study in Ilara-mokin and its' environs, the actual groundwater table is around 4.76m deep on average. Though the result of the coefficient of variation shows that the depth to water (upper level of groundwater) in the study area is not uniform, displaying a very high variability. The wells on the high elevations in places like Aiyetoro area, Better life area, Odo Igbeyin, Oke ode, Ikota, Ero and Ibule recorded the higher depth to water compared to well on low elevations in places like Hospital road, Ipogun among others. This distribution in groundwater level can be attributed to the elevation as observed by Plummer and Carlson (2008) and Adeoye (2012). However, there are exceptional cases in places like Oke ode with elevation of 348m having a 7.78m depth to water compared to a place in Ibule on an elevation of 366m having a depth to water of 2.40m. This may be attributed to the thickness of the overburden underlying the two areas and the level of porosity/permeability of the aquifer. Another factor may be the level of abstraction of groundwater in Oke ode in Ilara-mokin compared to that of Ibule, one of the village in its' environ. All these points raised may affect the rate of recovery of the static water level in these two locations and hence the observation recorded.

The mean well depth in the study area is 6.91m, with the highest well depth (11.56m) recorded in Ikota on an elevation of 357m while the lowest well depth (2.78m) was recorded in Aiyetoro area on an elevation of 349m. The result of the coefficient of variation (25.90%) shows that the well depths in the study area are relatively homogeneous. Wells located on high elevations are deeper than those on lower elevations; this was also observed by Adeoye (2012. The well depths however varied across the study area which may further be attributed to the cost and crude technology of sinking the wells as well as the level of expertise of the local diggers. The well diameter which is largely homogeneous also revealed that the technology employed in sinking these shallow wells in the study area is similar. Such crude technology includes hoe, shovel, and diggers among others which are common instruments in digging shallow wells in Nigeria. This was also observed by Iroye (1994); and Adeoye (2012).

The well with highest yield (3.12m^3) was recorded in Oke ode area in Ilara-mokin community. Though this area is on a high elevation, the reason for this high yield recorded is that it is located on a marginally thick overburden aquifer. This is evident in the hydrogeological evaluation carried out by Oladapo et al. (2009), which classified Oke ode as one of the few areas with marginal groundwater potential in Ilara-mokin. The lowest well yield (0.17m^3) was also recorded in Aiyetoro area of Ilara-mokin community. This observation may be due to the shallow depth (2.78m) of the well and Aiyetoro area may fall on the part of Ilara-mokin underlain by thin overburden (Oladapo et al., 2009) which is a poor aquifer unit in a crystalline basement hydrogeological setting. This was in contrast to Adeoye (2012) observation which recorded lowest yield in wells that are deeper than the mean well depth in the study area. Oladapo et al. (2009) further stressed that no area in Ilara-mokin can be classified as areas with medium or high groundwater potential zone. This assertion is evident in the low level of yields recorded in the study area.

In table 3, the result of the multiple linear regression model of the depth to water with five explanatory variables show that 56% of the total variation in depth to water in the study area can be explained by well depth, well diameter, elevation, longitude and latitude. However, the remaining 44% can be ascribed to the nature and type of the overburden aquifer in the study. See Oladapo et al. (2009) for the overburden thickness delineation map of the study area. The variables were further subjected to stepwise regression which shows that well depth accounted for more than half (51.3%) of the variation in depth to water out of the 56% accounted for by the five explanatory variables. From table 7, the result of the multiple regression analysis of the volume (yield) of well water with four explanatory variables show that 93% of the variation in well yield can be explained by well depth, depth to water, depth of water and well diameter. It is important to note that that it was only well parameters that were considered in this analysis. Which means the nature and type of the underlying aquifer of the sampled wells were not considered in determining variation in well yield of the study area.

As shown in figure 2, the highest elevation in the study area is 395m above sea level. This is in Ibule and the lowest elevation is 298m above sea level which is in Ipogun. According to Buddermeier and Schloss (2000), and also confirmed by Adeoye (2012), groundwater flow from the highest values of contour line to the lowest values in a direction perpendicular to the contour lines. On this basis, groundwater flow from Ibule towards Ipogun, Ilara-mokin and Ikota. Also, all groundwater in the study area flow towards Ipogun which have the lowest elevation with the exception of some part of Ikota which is on the eastern part of the study area, with a lowland compared to its surroundings. The implication of the flow pattern observed in the study area is that places on the lowland or elevation will have high volume of water. This is however subjected to the nature and type of the aquifer in the lowland area.

5. CONCLUSION

This study attempted to characterize shallow well yield and groundwater flow pattern in Ilara-mokin and its' environs using both well parameters and physiographic characteristics of the study area. The study revealed that the well yield in the study area is very low and as observed by Oladapo et al. (2009) that the greater part of the study area is underlain by a marginally thick overburden. Thus, the area has poor groundwater potential. It is therefore concluded that the study area have poor water yield and potential that can sustain its increasing population. On this basis, there is a need for proper development, management and advance exploration of groundwater in the study area. Particularly, in those areas where static water level is close to the surface and in the lowland areas as it is revealed by the groundwater flow direction of this study. Also, there should be an alternative source of water such as water transfer from areas of water surplus in the region to meet the domestic water needs of the populace.

6. ACKNOWLEDGEMENTS

Special thanks to Dr. Ifabiyi I.P of the department of Geography and Environmental Management, University of Ilorin, Ilorin, Nigeria, who gave us the insight on this study and provided us with the field instruments. We also appreciate Prof. and Mrs. I.A Adebayo who provided the transportation and also introduced us to the people of the community where this research was carried out.

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