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Estimating Aquifer Hydraulic Properties in Bida Basin, Central Nigeria Using Empirical Methods

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Abstract

An evaluation of the aquifer properties of the inland sedimentary Bida basin, central Nigeria, was conducted using empirical methods derived from particle size distribution curves. The main aquifer properties determined were hydraulic conductivity, porosity, effective porosity and coefficient of uniformity. Samples for analysis were obtained from test water wells drilled to 100m in selected parts of the Basin. The empirical method used was the Hazens method, while porosity was determined in the laboratory. The results show that three levels of aquifers generally exist in the Basin. The aquifer material consist of well sorted medium sand to fine gravel. The upper aquifer occurs at a depth of between 10 – 18m and has a hydraulic conductivity of 18.5m/d and effective porosity of 9.0. The second, or middle, aquifer occurs at a depth of between 45 – 65m and has a hydraulic conductivity of 37m/d and effective porosity of 20. The third, or lower, aquifer occurs between 80 – 100m and has a hydraulic conductivity of 32m/d and effective porosity of 24. Effective porosity generally increases with depth in the basin indicating coarsening up of the sandstone with fewer fine grained cementing material. Mean hydraulic conductivity value is 29.16m/d, porosity 63%, effective porosity of 6.7 and coefficient of uniformity of 2.8. The results have therefore shown that it is possible to obtain quantitative results from particle size distribution curves that are useful for the determination of hydraulic properties of aquifers.

Keywords: aquifer, hydraulic conductivity, porosity, Bida basin

1. Introduction

An aquifer is defined as a geological material that is capable of storing and transmitting water to wells placed in them in sufficient quantities to be considered economical. Geological materials that make up aquifers include sandstone, gravel and siltstone. In hard rock areas the term can also be used loosely for fractured and weathered rock. The properties these materials must possess to be considered as aquifers include but not restricted to porosity, permeability, hydraulic conductivity and specific yield. These properties may vary spatially because of geologic heterogeneity. Estimation of these properties allows quantitative prediction of the hydraulic response of the aquifer to recharge and pumping. Aquifer properties can be estimated on a local scale by analysis of data from aquifer tests, or on a regional scale by numerical simulation of groundwater flow by use of a computer based model (Justine, 2007). Many different techniques have been proposed to determine aquifer properties including field methods (pumping test of wells, tracer tests), laboratory methods and calculation from empirical formulae (Todd & Mays, 2005). Properties like permeability can be determined in the laboratory using permeameters, while other parameters like porosity and hydraulic conductivity can be determined using empirical formulae based on grain-size analysis. It has long been recognized that hydraulic conductivity is related to the grain-size distribution of granular porous media (Freeze & Cherry, 1979). This interrelationship is useful for the estimation of conductivity values where direct permeability data are not available. Accurate estimation of aquifer properties using field methods is costly and prone to errors as a result of poor knowledge of aquifer geometry and hydraulic boundaries. Laboratory tests are also limited by non-availability of equipment in this part of the world, obtaining representative samples and long time required for testing. Estimating these properties from empirical formulae based on grain-size distribution characteristics have been developed and used to overcome these problems (Uma et al., 1989).

The present work was aimed at determining the aquifer properties of the northern sector of the Bida basin using established empirical formulae. The specific objectives include a determination of the porosity, effective porosity, hydraulic conductivity and uniformity coefficient of the aquifer material at various depths in the basin.

2. Established Empirical Formulae

Hydraulic conductivity (K) can be estimated by analysis of the particle size distribution of the sediment of interest, using empirical equations relating Hydraulic Conductivity (K) to some size property of the sediment. Several empirical methods have been summarized from former studies by Vukovic and Soro (1992) and presented a general formula:

$$K = \frac{g}{v} \cdot C \cdot f(n) \cdot d_e^2 \quad (1)$$

where K = hydraulic conductivity; g = acceleration due to gravity; v = kinematic viscosity; C = sorting coefficient; $f(n)$ = porosity function, and d_e = effective grain diameter. The kinematic viscosity (v) is related to dynamic viscosity (μ) and the fluid (water) density (ρ) as follows:

$$v = \frac{\mu}{\rho}$$

The values of C, $f(n)$ and de are dependent on the methods used in the particle size distribution analysis. According to Vukovic and Soro (1992), porosity (n) may be derived from the empirical relationship with the Coefficient of Uniformity (CU) as follows:

$$n = 0.255\left(1 + 0.83^{CU}\right)$$

where CU is the coefficient of grain uniformity and is given by:

$$CU = \left(\frac{d_{60}}{d_{10}}\right)$$

$\boldsymbol{d_{60}}$ and $\boldsymbol{d_{10}}$ in the formula represent the grain diameter in (mm) for which, 60% and 10% of the sample respectively, are finer than, which are readily obtained from the particle size distribution curve.

The following formulae have been presented from former studies with varying conditions of application. They take the general form presented in Equation (1) above but with varying ***C, f(n)*** and ***de*** values.

1) **Hazen:** $K = \frac{g}{v} \times 6 \times 10^{-4}\left[1 + 10(n - 0.26)\right]d_{10}^2$

Hazen formula is used for uniformly graded sand however it could also be used for fine sand to gravel range, provided the sediment has a uniformity coefficient less than 5 and effective grain size between 0.1 and 3mm.

In its simplified form, the Hazen equation could also be given as:

$$K = C\,(d_{10})^2$$

Where; C is a coefficient based on the following table;

Very fine sand, poorly sorted	400-800
Fine sand with appreciable fines	400-800
Medium sand, well sorted	800-1200
Coarse sand, poorly sorted	800-1200
Coarse sand, well sorted, clean	1200-1500

2) **Kozeny-Carman:** $K = \frac{g}{v} \times 8.3 \times 10^{-3}\left[\frac{n^3}{(1-n)^2}\right]d_{10}^2$

The Kozeny-Carman formula is not appropriate for either soil with effective size above 3mm or for clayey soils (Carrier, 2003).

3) **Breyer:** $K = \frac{g}{v} \times 6 \times 10^{-4} \log \frac{500}{U} d_{10}^2$

Breyer's formula is considered most useful for materials with heterogeneous distributions and poorly sorted grains with uniformity coefficient between 1 and 20, and effective grain size between 0.06mm and 0.6mm.

4) **Slitcher:** $K = \frac{g}{v} \times 1 \times 10^{-2} n^{3.287} d_{10}^2$

This formula is most applicable for grain-size between 0.01mm and 5mm.

5) **Terzaghi:** $K = \frac{g}{v} \cdot C_t \cdot \left(\frac{n - 0.13}{\sqrt[3]{1-n}} \right)^2 d_{10}^2$

Where Ct = sorting coefficient and $6.1\times10^{-3} < C_t < 10.7\times10^{-3}$. Terzaghi's formula is most applicable for large-grain sand (Cheng & Chen, 2007).

6) **USBR:** $K = \frac{g}{v} \times 4.8 \times 10^{-4} d_{20}^{0.3} \times d_{20}^2$

The United States Bureau of Reclamation (USBR) formula calculates hydraulic conductivity from the effective grain size (d_{20}), and does not depend on porosity; hence porosity takes on value 1. The formula is most suitable for medium-grain sand with uniformity coefficient less than 5 (Cheng & Chen 2007).

7) **Alyamani & Sen:** $K = 1300\left[I_o + 0.025(d_{50} - d_{10})\right]^2$

Where I_o is the intercept (in mm) of the line formed by d_{50} and d_{10} with the grain-size axis, d_{10} is the effective grain diameter (mm), and d_{50} is the median grain diameter (mm). The method considers both sediment grain sizes $\mathbf{d_{10}}$ and $\mathbf{d_{50}}$ as well as the sorting characteristics.

3. Geology and Hydrogeology of Study Area

The area of study is the northern sector of the Bida (Middle-Niger) Basin of Nigeria. It extends from Gulu area in the south to Kontagora / Wara in the north (both in Niger state, Nigeria) where it contacts the crystalline rocks of the Basement Complex system. It lies between latitude $8^0 50'$N and $10^0 50'$N and longitude $4^0 50'$E and $7^0 00'$E covering an area of about 45000km^2 north of River Niger (Figure 1).

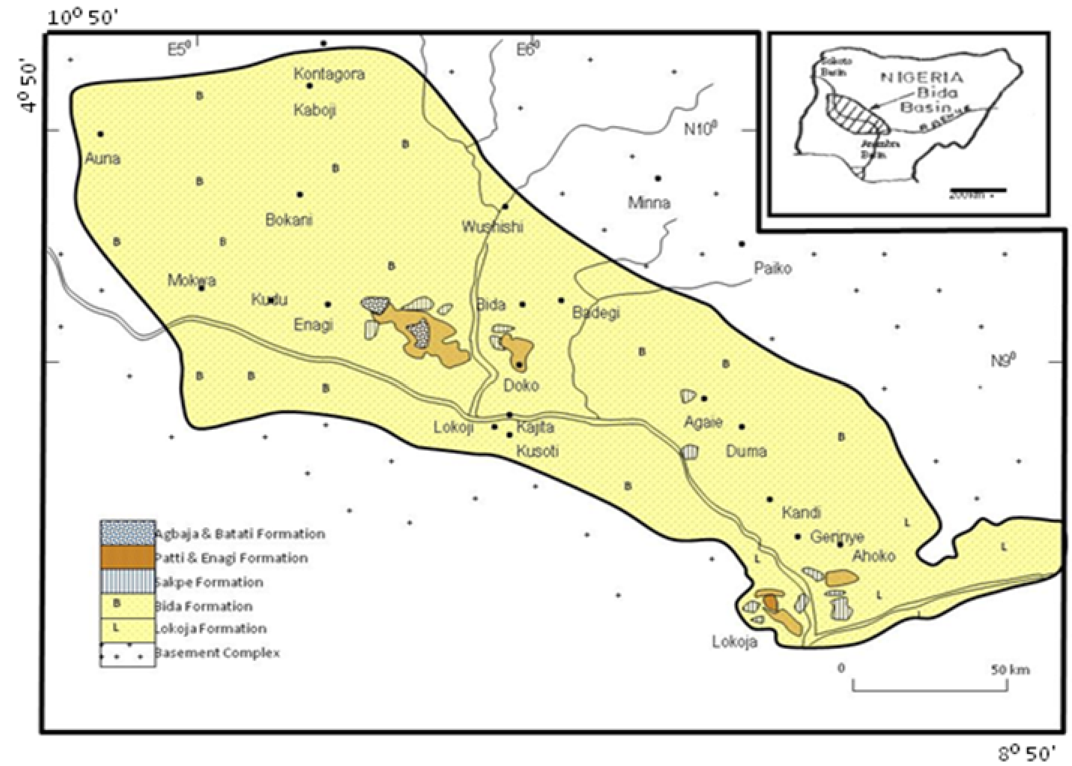

Figure 1. Map of Nigeria showing the Bida basin

The basin is located between Sokoto (Iullemeden) and Dahomey basins. The basin is described as a "down warped basin" because it hasn't been subjected to much orogenic activities; but in actual sense it has under gone a lot of faulting. Its origin is related to the Santonian orogeny – an episode of tectonic activities in the south eastern Nigeria. It contains mainly upper Cretaceous (Maastrichtian) rocks near the surface. Sedimentary fill has been put at 915m-2000m (300-6500ft) thick using gravity data (Ojo & Ajakaiye, 1976; Udensi & Osazuwa, 2005). Stratigraphically it is divided into Southern and Northern parts. The Southern sector consists mainly Lokoja, Agbaja and Patti Formations and the Northern sector consists of Batati, Enagi, Sakpe and Bida Formations (Adeleye, 1976; Obaje, 2009).

The aquifer in the Basin is represented mainly by the Bida sandstone Formation which is the oldest unit in the Basin and occurs at variable depths. Four aquifer types were identified in the basin (Idris-Nda, 2010); an unconfined aquifer occurring at a shallow depth of between 40 to 80m, a semi-confined aquifer occurring between 80 and 100m, a confined aquifer occurring at depths greater than 150m, and a perched aquifer which occurs at a shallow depth of 30 to 60m.

The basin is located about 600 Km away from the Atlantic Ocean (Lagos) and is separated by a wide belt of impermeable rocks of the Basement Complex system of Nigeria. As such the saline waters of the Atlantic ocean has very little or no effect on the basin.

4. Data Acquisition and Interpretaion

The aquifer properties that were determined are porosity, effective porosity, coefficient of uniformity and hydraulic conductivity of the geological material that make up the Basin. The determinations were generally carried out on representative samples with depth (up to 120m) using sieve analysis and empirical methods. Two samples each were obtained from wells drilled in the northern, central and southern parts of the Basin. In-situ samples that were not disaggregated were also obtained from exposures, road cuts and cliff faces.

4.1 Porosity and Effective Porosity

The porosity of earth materials is the percentage of the rock or soil that is void of material. It is defined mathematically by the equation

$$\eta = \frac{100Vv}{V} \quad \text{(Fetter, 2001)}$$

Where η is the porosity (percentage);

Vv is the volume of void space in a unit volume of the earth material;

V is the unit volume of earth material including both Voids and solids.

Porosity was determined in the laboratory by taking a sample of known volume, oven drying at 105°C until a consistent weight was reached, and the sample was then submerged in a known volume of water until it was saturated. The volume of the voids (Vv) is equal to the original water volume less the volume left after the sample was removed.

Effective porosity, ηe, is the porosity available for fluid flow. The amount of water held in a rock depends on the porosity of the material.

4.2 Coefficient of Uniformity and Hydraulic Conductivity

The Coefficient of Uniformity (Cu) of sediment is a measure of how well or poorly sorted it is. The coefficient of uniformity is the ratio of the grain size that is 60% finer by weight, d_{60}, to the grain size that is 10% finer by weight, d_{10}

$$Cu = d_{60}/d_{10} \quad \text{(Fetter, 2001)}$$

A sample with a Cu less than 4 is well sorted, while a Cu that is more than 6 is poorly sorted.

The coefficient of uniformity and Hydraulic conductivity were determined from grain-size distribution curves plotted for samples in the Basin with depth.

The hydraulic conductivity of soil or rock is related to Darcy's flow theory (1856) whose experiment demonstrate positively that the volume of water which passes through a bed of sand of a given nature is proportional to the pressure and inversely proportional to the thickness of the bed traversed. This may be expressed in more general terms as

$$Q = - KA (dh/dl) \text{ or } Q = KVi$$

Where dh/dl is known as hydraulic gradient, K is the hydraulic conductivity and Q is the discharge. The negative sign indicate that flow is in the direction of decreasing hydraulic head.

Hydraulic conductivity can be defined as the volume of water that will flow through a unit cross-sectional area of aquifer in unit time, under a unit hydraulic gradient and at a specified temperature. It depends on a variety of physical factors including porosity, particle size and distribution, shape of particles, arrangement of particles and other factors (Legrand, 1971; Rasmusen, 1964). The usual unit used by hydrogeologists is meters per day (m/d).

The hydraulic conductivity of materials in the Basin was estimated from the grain size distribution curve using the Hazen method.

5. Results and Discussion

Table 1. Sieve analysis result for a part of the basin from 0-40m depth

Sieve	Percentage Passing									
No	0-4	4-8	8-12	12-16	16-20	20-24	24-28	28-32	32-36	36-40
10	100	100	100	98.99	98.89	20.57	100	98.7	98.97	98.67
22	69.6	95.1	98.4	26.61	67.87	1.66	80.34	28.01	78.25	67.50
30	48.9	73.5	77.0	15.26	37.14	1.09	52.68	16.34	50.12	45.29
44	30.3	40.8	38.6	7.10	16.45	1.02	31.16	8.91	35.26	22.08
60	16.8	18.9	17.5	3.28	6.79	0.80	18.64	4.58	28.64	14.87
85	5.08	9.5	9.12	9.12	2.13	0.60	8.88	2.56	9.55	6.26
100	3.8	5.7	4.93	1.44	1.56	0.30	3.26	1.61	3.89	2.71

Table 1 shows the results of sieve analysis of geological materials with depth in the basin from 0-40m depth, results of the remaining analysis is presented at the end of this paper. A plot of the result shown in Figure 1 shows that a major part of the geological materials fall within the sand range with grain sizes ranging from 0.1 to 10mm diameter, generally coinciding with a range of fine to medium gravel. While Figure 2 is the graph of effective diameter of materials with depth.

The first 8m of the Basin consist of sediments that are gap graded, which means a particular grain size is missing, and becomes well graded till 20m, uniformly graded at 32m and repeated the cycle again, this reflects the cyclic nature of deposition in the Basin indicating different periods of deposition which may characterize a continental environment of deposition when water level will rise at a particular period (which may coincide with rainy season for example) and has a high energy flux, then drop at other periods with low energy flux.

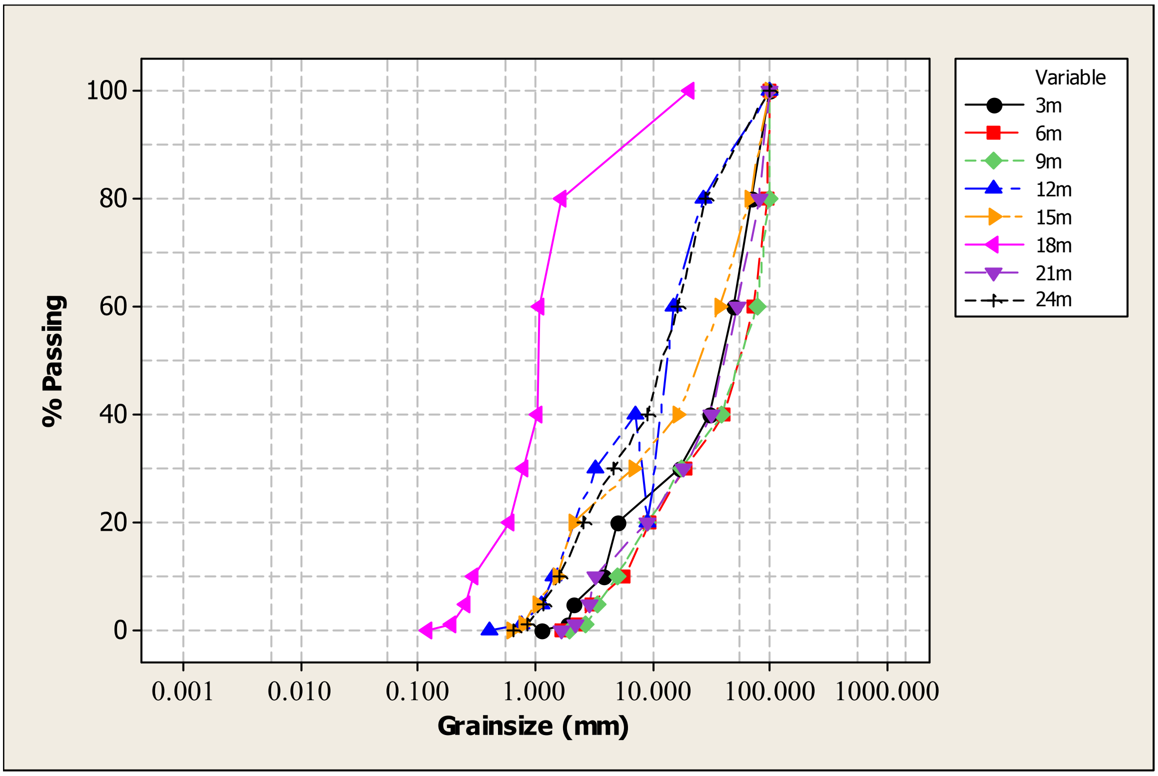

Figure 1. Sieve analysis of geological materials with depth in the Bida basin

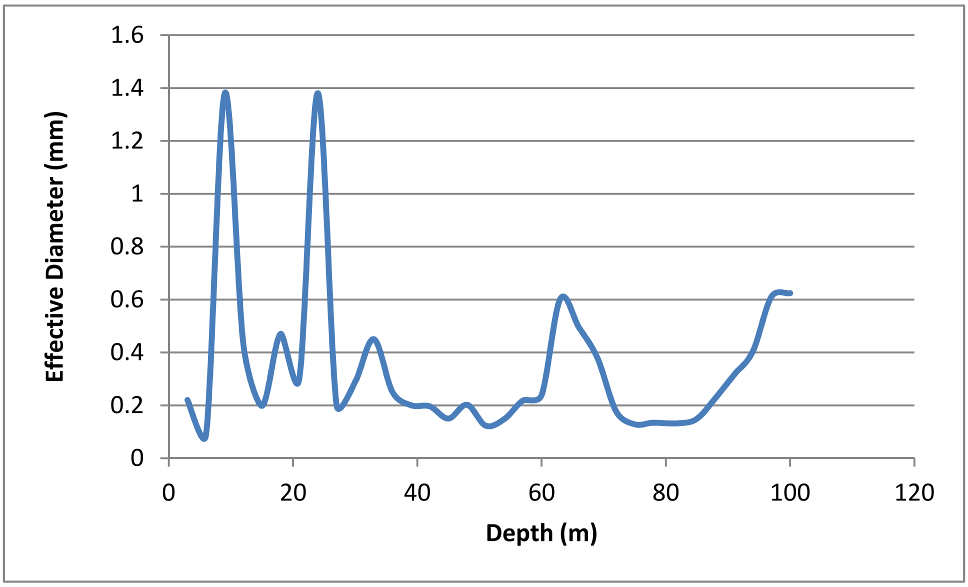

Figure 2. Effective diameter of materials with depth in a part of the basin

Results of the hydraulic conductivity of materials in the basin determined from the particle size distribution curve (Figure 1) and calculated using the Hazen formula is presented in Table 2.

Table 2. Hydraulic conductivity of geologic materials with depth in the Bida basin

Depth (m)	Description	Hydraulic Conductivity K (m/d)
3	Reddish brown sandy topsoil	3.87
6	Reddish brown clayey sandstone	1.28
9	Reddish brown sandy clay	1.14
12	sandy clay - fine grained	1.4
15	Clay	0.78
18	Sandstone medium grained	17.6
21	Brownish – grayish fine grained sandstone	4.5
24	Brownish – medium grained Sandstone	11.52
27	Greyish medium grained	3.2
30	Fine to medium grained Sandstone	6.68
33	Fine grained grayish Sandstone	12.15
36	Fine to medium grained grayish Sandstone	3.75
39	Greyish medium to fine grained Sandstone	2.4
42	Medium to fine grained clayey Sandstone	1.18
45	Brownish medium grained Sandstone	1.35
48	Medium to fine grained clayey Sandstone	1.22
51	Clay	0.3
54	Clayey Sandstone	0.44
57	Fine grained brownish clayed sand	1.43
60	Brownish medium to fine grained Sandstone	4.57
63	Gravel – coarse Sandstone	36.2
66	Clayey Gravel	19.6
69	Gravelly Clay with coarse grained Sandstone	11.4
72	Clay - greyish	0.63
75	Clay	0.33
78	Clay	0.2
81	Sandy clay - fine grained	0.35
84	Clayey Sandstone	0.44
87	Yellowish Sandstone- fine grained	1.56
90	Sandstone - coarse grained	4
93	Sandstone - coarse grained	6.53
96	Gravelly Sandstone	29.86
99	Gravel	31.15
100	Gravel	33.5

From the scatter plot of hydraulic conductivity with depth in the basin (Figure 3) it could be seen that highest hydraulic conductivity occurs in gravel and gravelly sandstone that occurs at two levels; 60 – 70m and 96 – 100m in most parts of the Basin, least hydraulic conductivity occurs in the clays while sandstone with different contents of clay occupies an intermediate position.

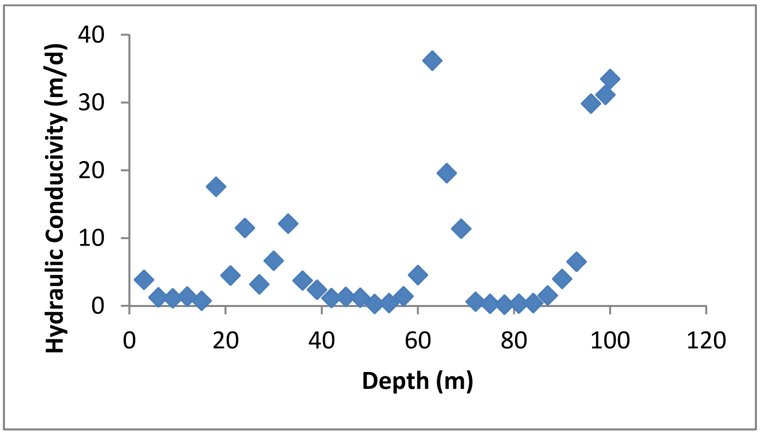

Figure 3. Scatter plot of Hydraulic conductivity of materials in the basin with depth

Table 3 is the result of the effective porosity, total porosity and coefficient of uniformity, while effective porosity and total porosity were determined in the laboratory, coefficient of uniformity was determined from the particle size distribution curve. Computation used for determination of the porosity can be found at the end of this paper.

Table 3. Effective porosity, Porosity and Coefficient of Uniformity of materials with depth

Depth (m)	Effective Porosity	Total porosity %	Cu
3	5.68	74.9	3.41
6	4.73	35.3	0.44
9	5	35.3	3.05
12	3.32	72.3	3.49
15	2.54	69.1	5.00
18	8.37	67.9	2.72
21	5.17	64.8	2.32
24	4.9	67	3.30
27	4.5	66.2	2.83
30	6.92	66.7	3.45
33	5.65	66.6	3.33
36	5.88	64.4	2.88
39	7.26	64.7	2.67
42	5.55	65.2	1.92
45	5.03	63.2	3.02
48	8.4	63.8	2.62
51	1.6	63.3	0.68
54	4.19	63.2	1.10
57	20.08	63.1	2.03
60	4.31	63.7	3.26
63	4.55	67	4.02
66	3.01	66.6	2.15
69	3.06	65.4	2.20
72	3.45	64.2	2.18
75	4.02	66.2	3.21
78	3.85	63.2	2.52
81	4.02	63.3	2.20
84	5.67	63.9	3.50
87	10.32	64.1	3.67
90	15.45	65	3.98
93	22.58	67	4.10
96	14.67	66.85	3.84
99	8.25	64	3.23

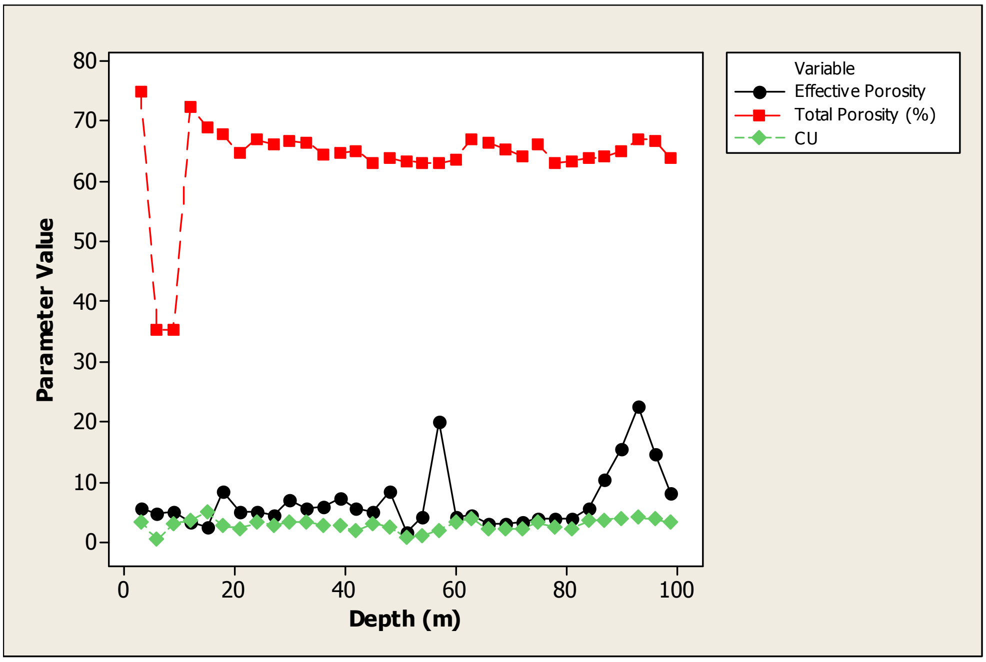

Figure 4. Graph of effective Porosity, total Porosity and Uniformity Coefficient

From the graph of Effective Porosity, Porosity and Uniformity Coefficient shown in Figure 4 above, it shows that porosity of the materials is almost uniform with depth, except just below the surface where porosity values are lower. However effective porosity is only higher at deeper levels, (40-60m and also between 87-96m) which means that even though the materials are porous, the pore spaces are only interconnected at deeper levels. This means that at shallow depths water can only be transmitted to wells placed in them in small quantities. The graph of the coefficient of uniformity shows that the materials fall within the well sorted range, at shallower levels it trends towards being poorly sorted and becomes well sorted at between 40 and 60m.

It can therefore be deduced from these that the zones with higher conditions of porosity and hydraulic conductivity are at 40-60m and 90-100m.

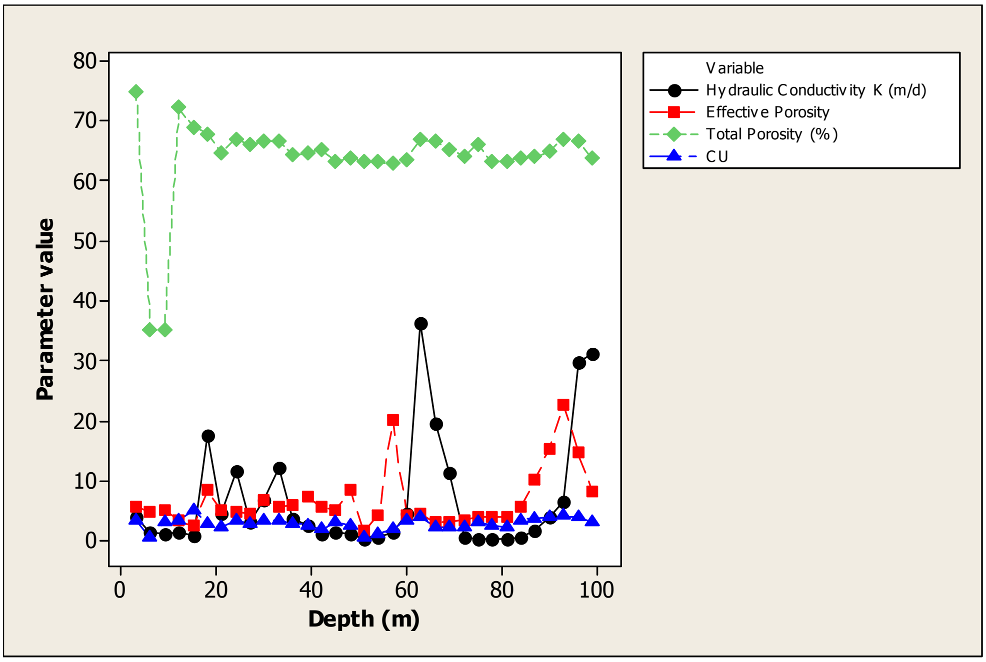

Figure 5. A comparison of the effective porosity, coefficient of uniformity and hydraulic conductivity in the Bida basin

A comparison of the four (Figure 4) curves show that the properties that define the characteristics of an aquifer, effective porosity and hydraulic conductivity, as determined using empirical methods compare very well. Three levels of aquifer can clearly be identified based on these two parameters; Table 4 summarises the three levels of aquifers in the area and their properties.

Table 4. Summary of aquifer properties and depth in the basin

Aquifer Number	Effective Porosity, ηe	Hydraulic Conductivity, K, m/d	Depth, m
1	9.0	18.5	18
2	20	37	65
3	24	32	100

Hydraulic conductivity, which is a measure of the ease with which a fluid (usually water) can move through the pore spaces shows that it is highest at deeper levels (70 and 100m) and lower at shallower levels. This trend is also shown by the porosity, effective porosity and coefficient of uniformity. A plot of the "effective diameter" (D_{10}), which empirically has been strongly correlated with the permeability of fine-grained sandy soils, with depth shows high grain sizes at shallower levels (mostly gravel) while at deeper levels, corresponding to the level with high hydraulic conductivity, the grain sizes have intermediate sizes and represent the aquifer in the basin.

6. Conclusion

The aquifer properties of the Bida Basin as determined using empirical methods from particle size distribution curves has shown that three levels of aquifers generally occurs in the basin. The first aquifer has a hydraulic conductivity value of 18.5m/d and occurs at a shallow depth of 18m. Most hand dug wells and very shallow water wells derive their water from this aquifer. The aquifer material is mostly made up of an admixture of clay and sandstone. The second aquifer level occurs at a depth of 65m with the hydraulic conductivity been 37m/d, while the third aquifer occurs at a depth of 100m with a hydraulic conductivity of 32m/d. The aquifer materials in both aquifers are made up of coarse sandstone to fine gravel respectively. These aquifers are capable of yielding large volumes of water to boreholes drilled in them. Effective porosity in the basin increases with depth, this may be attributed to the virtual absence of clay and other cementing materials in the sandstone that make up the aquifer at depth.

The various hydraulic parameters estimated using empirical formulae and presented here will no doubt aid in borehole programs and provide additional database for groundwater development and utilization in the study area. The results have therefore shown that it is possible to obtain quantitative results from particle size distribution curves that are useful for the determination of hydraulic properties of aquifers.

Table 5. Determination of porosity of geological materials with depth

Sample No.	Description	Depth (m)	Dry weight	Ww (g)	Wv (g)	Ww-Wv (g)
1.	Reddish brown sand	3	16	271.00	265.32	5.68
2.	Reddish brown sand	6	15	265.27	265.27	4.73
3.	Reddish brown	9	17	276	271	5.0
4.	Reddish clay sand	12	18	260.49	257.17	3.32
5.	Reddish clay	15	17	257.12	254.58	2.54
6.	Reddish brown sst	18	16.50	278.82	270.45	8.37
7.	Brownish – grayish	21	16	270.40	265.23	5.17
8.	Brownish – medium grained	24	17.05	265.17	260.27	4.9
9.	Brownish – medium grained	27	18	260.19	255.69	4.5
10.	Fine to medium brownish	30	17.30	255.57	248.65	6.92
11.	Fine grained grayish	33	12	248.51	242.86	5.65
12.	Fine to medium grained grayish sst	36	16	287.94	282.06	5.88

Sample No.	Description	Depth (m)	Dry weight	Ww (g)	Wv (g)	Ww-Wv (g)
13.	Fine to medium grained grayish sst	39	16	281.98	274.72	7.26
14.	Medium to fine grained clay	42	15	274.01	268.54	5.55
15.	Brownish medium grained sst	45	15.50	268.49	263.46	5.03
16.	Medium to fine grayish	48	15	260.09	258.49	1.6
17.	Clay	51	20.35	258.40	250.002	8.398
18.	Clay sst	54	11.36	249.97	245.78	4.19
19.	Fine grained brownish clay sand	57	5.77	245.72	243.64	2.08
20.	Medium – fine grained brownish sst	60	20.66	243.57	239.35	4.31
21.	Gravel – coarse sst	63	17.02	239.26	234.71	4.55
22.	Clay	66	17.02	234.67	228.96	5.71

Table 6. Laboratory determination of porosity

P1 Sample weight	P2 Dry weight	P3 Vw	P4 Vw-Sample	Total porosity	Effective porosity
16	10.66	0.666	0.251	74.9	5.68
15	8.57	1.714	0.647	35.3	4.73
17	12.46	0.733	0.647	35.3	5.0
18	14.73	0.818	0.277	72.3	3.32
17	14.45	0.85	0.309	69.1	2.54
16.50	15.40	0.933	0.321	67.9	8.37
16	14.39	0.85	0.330	64.9	5.17
17.05	15.28	0.896	0.338	64.8	4.90
18	15.88	0.882	0.333	6.2	4.5
17.30	15.31	0.885	0.334	66.7	6.92
12	11.32	0.943	0.356	66.6	5.65
16	14.99	0.937	0.353	64.4	5.88
16	14.75	0.922	0.348	64.7	7.26
15	14.62	0.975	0.368	65.2	5.55
15.50	15.08	0.973	0.367	63.2	5.03
15	14.39	0.959	0.362	63.3	1.60
20.35	19.83	0.975	0.368	63.8	8.40
11.36	11.12	0.979	0.369	63.2	4.19
5.77	5.55	0.962	0.363	63.1	2.08
20.66	18.07	0.875	0.330	67.0	4.31
17.02	15.79	0.928	0.350	65.0	4.55
17.02	15.07	0.885	0.334	66.6	5.71

P1 = weight of sample.

P2 = weight of sample after oven drying.

P3 = volume of water sample was submerged in.

P4 = volume of water after sample was removed.

Table 7. Sieve Analysis data from 45m to 100m depth (a-d)

a) 45-55m

Sieve	Mass retained	Mass passing	% passing
10	0.65	146.05	100
22	28.19	117.86	80.34
30	40.57	77.29	52.68
44	31.58	45.71	31.16
60	18.37	27.34	18.64
85	14.3	13.04	8.88
100	8.25	4.79	3.26
pan	4.79		

b) 55-65m

Sieve	Mass retained	Mass passing	% passing
10	2.96	225.4	98.7
22	161.43	63.97	28.01
30	26.66	37.31	16.34
44	16.97	20.34	8.91
60	9.87	10.47	4.58
85	4.63	5.84	2.56
100	2.16	3.68	1.61
pan	3.68		

c) 65-76m

Sieve	Mass retained	Mass passing	% passing
10	2.26	202.61	98.89
22	63.55	139.06	67.87
30	62.97	76.09	37.14
44	42.38	33.71	16.45
60	19.80	13.91	6.79
85	9.55	4.36	2.13
100	1.16	3.20	1.56
pan	3.20		

d) 75-85m

Sieve	Mass retained	Mass passing	% passing
10	78.92	31.57	28.57
22	29.7	1.84	1.66
30	0.64	1.20	1.09
44	0.39	0.81	-
60	0.25	0.56	-
85	0.16	0.40	-
100	0.07	0.33	0.30
pan	0.33		

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