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DETERMINATION OF HYDRAULIC CONDUCTIVITY USING EMPIRICAL FORMULAE FROM GRAIN SIZE ANALYSIS OF LOKOJA AND PATTI FORMATIONS, NORTH CENTRAL NIGERIA.

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Abstract: Boreholes within Lokoja and Patti formation, both unconformably overlying the Basement Complex, generally experience low water yeild and failure. Hydraulic conductivity, porosity and coefficient of uniformity of both Formations were determined using Hazen empirical formula and grain size distribution analysis then correlated to determine reasons for failure and low yields of boreholes in the area. Coefficient of uniformity (U) for Lokoja Formation ranged from 2.2 to 5.2 with a mean value of 3.65 while that of Patti Formation ranged from 2.7 to 4.4 with a mean value of 3.62. Soil porosity (n) for Lokoja Formation ranged from 35% to 42% with a mean value of 38.6% while that of Patti Formation ranged from 37% to 41% and mean value of 38.6%. Effective grain size (D_{10}) ranged from 0.12mm – 0.25mm for Lokoja Formation and 0.14mm - 0.3mm for Patti Formation. Hydraulic conductivity (K) for Lokoja Formation ranged from 1.44 x 10-4m/s to 6.25 x 10-4m/s with a mean value of 3.17 x 10-4 m/s while that of Patti Formation ranged from 2.56 x10-4 m/s to 9 x10-4 m/s with a mean value of 4.63 x 10-4 m/s. Based on the results of the analysis, soils within the study area are well sorted, highly porous and made up of fine sands and fine to medium-grained sandstones. Comparison of hydraulic conductivity of both formations ip ndicated the fine to medium-grained sandstones of Patti Formation have higher hydraulic conductivity compared to those of Lokoja Formation. It also revealed that sandstones within the Patti Formation are highly porous, fairly permeable, and more aquiferous than those of the Lokoja Formation. Sandstone of Patti Formation have higher potential for groundwater exploration and exploitation compared to that of Lokoja Formation.

Keywords: Hydraulic Conductivity, Hazen Empirical Formula, Lokoja Formation, Patti Formation, Bida Basin, North Central Nigeria.

Introduction

Hydraulic conductivity is a physical characteristic of soil that is very important in groundwater and hydrological studies, for example in groundwater movement, infiltration, leaching, and design of drainage systems (Boadu 2000). In a study of groundwater flow, the knowledge of saturated hydraulic conductivity of soil is necessary for modeling flow in soils, both in the saturated and unsaturated zone, and transportation of water-soluble pollutants in soils (Odong, 2008). It is also an important parameter for designing the drainage of an area and in the construction of earth dams and levees. Furthermore, it is of paramount importance to some geotechnical problems, including the determination of seepage losses, settlement computations, and stability analyses (Boadu 2000).

It has long been established that hydraulic conductivity is related to the grain-size distribution of granular porous media (Freeze and Cherry 1979). The inter-relationships are very useful for the estimation of conductivity values where direct permeability data are sparse such as in the early stages of aquifer exploration. Due to the difficulties and the high cost of carrying out direct field and laboratory measurements of hydraulic conductivity, the indirect method was used to partially solve the problem., Accurate estimation of hydraulic conductivity in the field using field methods is limited by the lack of precise knowledge of aquifer geometry and hydraulic boundaries (Ume et al. 1989). The cost of field operations and associated well construction can also be prohibitive. Laboratory tests on the standards, present formidable problems in the sense of obtaining representative samples and very often, long testing times. Alternative methods of estimating hydraulic conductivity from empirical formulae based on grain-size distribution characteristics were developed and used to overcome these problems (Ume et al. 1989, Carrier 2003). Consequently, Groundwater professionals have tried for decades to relate hydraulic conductivity to grain size. While the tasks appear straight forward, the correlation is not easily achieved (Pinder and Celia 2006). Numerous investigators have studied this relationship and several formulae have been established based on experimental work. Among the several attempts made are those of Hazen (1892) and Alyamani and Sen (1993)..

Though series of investigations on determination of hydraulic conductivity using grain size analysis have been carried out in Nigeria, only few researchers have carried out research in Lokoja, the study area. Vrbka et al (1999) determined the hydraulic characteristics of the Maastrichtian sedimentary rocks of the Southeastern Bida Basin, Central Nigeria, and reported a geometric mean hydraulic conductivity of 3.3m/day. Idris-Nda (2013) used Hazens empirical method to report hydraulic conductivity of 18.5m/day, 37m/day, and 32m/day for three aquifers at different depths within the Bida Basin, North central Nigeria. Olusegun et al (2018), investigated the hydraulic characteristics of aquifers in Lokoja and Patti Formations using a combination of vertical electrical sounding (VES), pumping test, and laboratory test. Their result gave hydraulic conductivity (K) values between 1.92-91.7 m/day and 2.15-31.8 m/day for aquifers of Lokoja and Patti Formations respectively. The aim of this study is to determine and correlate the hydraulic conductivity, coefficient of uniformity, and porosity of Lokoja and Patti Formation using grain size distribution analysis.

Location and Accessibility of the Study Area

The study area is located within the southern Bida Basin, a part of Mount Patti and Felele-Nataco area. It is bounded by latitude 07^{0}46'45.6'' to 07^{0}53'21" and longitude 006^{0}40'00" to 006^{0}46'00", a covering area of approximately 112km^2 (Figure1). The study area is mostly accessible by road, and footpaths.

The study area lies within the Sedimentary Basin of Nigeria. Lokoja is located at the confluence of Niger and Benue Rivers and the contacts between Precambrian Basement Complex, Campanian-Maastrichtian sedimentary Bida Basin (Omada *et al*., 2009), and Lower Benue sedimentary inland basin (Benue Trough) of Nigeria. The study area in Lokoja covers the Lokoja and Patti Formation which unconformably overlies the basement complex. It consists of sandstones, which outcrop around the Lokoja area between Felele and Koton-Karfi. Around this location, conglomerates, coarse false-bedded sandstones, fine to medium-grained sandstone, siltstone and claystone are known to occur (Obaje 2009) (Figure 1).

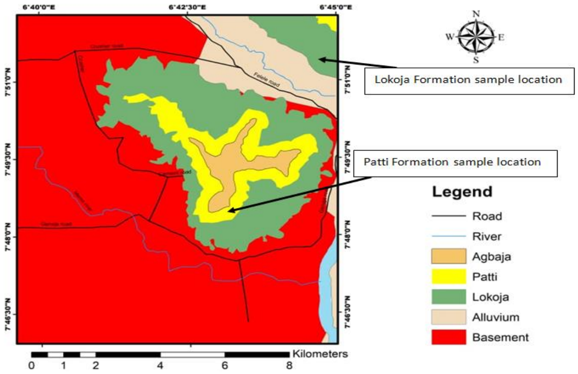

Figure 1: Geology map of the study area (modified after Musa and Schoneich, 2011)

Lokoja sub-basin of the Bida Basin is a NW – SE shallow, down warped trough, which resulted from the wrench fault movement associated with the tectonic framework of the Nigerian sedimentary basins (Jones, 1953 and Braide, 1992) which was filled with Campanian – Maastrichtian sediments as confirmed paleontological and sedimentological studies (Ojo, 1992, Abimbola 1997). Lokoja sandstone is the oldest formation in the southern Bida basin being 90 – 280m thick, overlain by 70 – 100m thick Maastrichtian Patti formation and about 5 – 20m thick of Agbaja Ironstones overlying the middle Patti formation (Braide, 1992, Ladipo 1994). Stratigraphically, in the Southern Bida Basin, the Campanian – Maastrichtian Lokoja Formation unconformably overlies the Pre-Cambrian to Lower Paleozoic Basement gneisses and schists. This is overlain by the Maastrichtian Patti Formation and succeeded by the Maastrichtian Agbaja Ironstone Formation.

Materials and Methods

Sample Collection

Ten soil samples were collected from two different locations at Lokoja Formation at distances of five metres (5m) apart. Another set of five soil samples were collected from one location at Patti Formation. In each formation, the samples were collected across the same sandstone unit. Shovel and geological hammer were used to clear vegetative cover and remove weathered rocks to obtain fresh in-situ rock samples. The samples were collected in a white polythene bag to avoid contamination and carefully labeled before taking them to the laboratory for analysis.

Laboratory or Grain-size Distribution Analysis

The Grain size analysis (sieve analysis) was carried out in the Sedimentology Laboratory of the Department of Geology, Federal University Lokoja, Kogi State. The primary aim of the sieve analysis was to determine particle size distribution from which the hydraulic conductivity was obtained. The sample was first oven-dried in an oven machine at a temperature of 108^0C. Lumped or conglomerated soil samples were crushed using a rubber mortar and pestle. 100g of the crushed weighed soil sample was taken. A stack of sieves was prepared according to mesh sizes in the following decreasing order >4.0mm, 2.0mm, 1.00mm, 0.90mm, 0.45mm, 0.154mm, 0.125mm, 0.09mm, <0.076mm.

A pan was placed under the last sieve to collect the portion of soil passing the sieves. The weighed sample of soil was poured into the stack of sieves from the top and the cover was put in place. The stack was placed in the sieve shaker and clamped. The sieve shaker was switched on and adjusted to run for ten minutes. After ten (10) minutes, the machine automatically stopped and the various sizes retained in each sieve was recovered and weighed. The retained samples in each screen were collected with the aid of a brush and then weighed using a weighing balance. This gave a relative measure of different size populations in each of the samples. The procedure was repeated for all the other samples.

Empirical Formula and Determination of Parameters

From the sieve analysis, the cumulative percentage weight passing was obtained as shown in Tables 1 and 2 and the results were then plotted on a semi-logarithmic graph to obtain the grain-size distribution curves for each sample as shown in figure 2 to figure 6 below. From the grain-size distribution curves, the values of D_{60} and D_{10} were determined and these values were substituted into Hazen's (1892) formula. Hazen's (1892) formula was employed in this study for the determination of the hydraulic conductivity of the soil samples since he stated in his work that his rule was applicable over the range of D_{10} particle size 0.1 mm to 3.0 mm and for soils having uniformity coefficient (D_{60}/D_{10}) less than five (5) and this is applicable since the grain size and uniformity coefficient obtained in this work falls between this ranges. He determined that the D_{10} particle size (called the 'effective grain size') and D_{60}/D_{10} ('the uniformity coefficient') were both important factors. Hazen's rule for estimating hydraulic conductivity K is commonly expressed as:

$$K = C\,(D_{10})^2 \qquad (1)$$

Where C is a correlation factor and D_{10} is the 10 percent particle size taken from the particle size distribution curves. Hazen (1892) also stated that (when K is in m/s and D_{10} is in millimeters) the correlation factor C could vary between about 0.007 and 0.014. In geotechnical practice, presumably for reasons of simplicity, C is commonly taken to be 0.01.

1m/s=86400m/day

Other parameters that can be calculated include

Porosity (n) may be derived from the empirical relationship with the coefficient of grain uniformity (U) as given by Hazen (1892):

$$n = 0.255(1 + 0.83^U) \qquad (2)$$

Where U is the coefficient of grain uniformity and is given by:

$$U = \{D_{60}/D_{10}\} \qquad (3)$$

D_{60} and D_{10} in the formula represent the grain diameter in (mm), which are 60% and 10% of the sample, respectively.

Results and Discussion

Results of the particle size distribution analyses of the twenty soil samples (ten for each formation) studied are shown in Tables 1 (Lokoja formation) and 2 (Patti formation). The grain-size distribution curves for the sample are presented in figures 2 to 6. Results of the calculated hydraulic conductivity and other parameters for the Lokoja and Patti formation are shown in tables 3 and 4.

Table 1: Results of sieve analysis on samples of the Lokoja Sandstone Formation

	Sample No.11	Sample No.12	Sample No.13	Sample No.14	Sample No.15	Sample No.16	Sample No.17	Sample No.18	Sample No.19	Sample No.20
Mesh Size	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
4	99.07	89.89	97.76	95.61	93.86	97.4	99.89	99.18	99.06	94.4
2	97.84	80.72	88.42	93.94	88.73	88.4	99.79	94.20	95.42	85.3
1	93.84	63.75	75.8	88.41	71.23	73.0	89.78	76.12	90.32	76.5
0.9	93.64	62.75	71.37	88.40	70.73	72.0	89.58	76.01	90.21	76.2
0.45	38.66	34.59	26.80	68.37	22.94	37.0	30.93	26.32	75.33	49.3
0.154	3.59	2.0	11.98	12.94	3.11	11.5	6.10	6.09	10.0	7.6
0.125	1.33	7.60	5.38	12.52	1.71	3.5	3.40	4.36	5.6	4.0
0.09	0.7	1.14	2.13	0.20	0.91	0.7	1.40	1.22	5.6	1.6
0.076	0	0	0	0.10	0	0	0	0	0	0

Table 2: Results of sieve analysis on samples of the Patti Formation

	Sample No.1	Sample No.2	Sample No.3	Sample No.4	Sample No.5	Sample No.6	Sample No.7	Sample No.8	Sample No.9	Sample No.10
Mesh Size	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
4	97.90	96.50	98.33	89.85	94.39	99.48	97.24	97.60	99.20	93.90
2	90.00	88.60	90.71	85.89	86.79	96.16	87.70	95.80	93.30	84.80
1	73.70	72.30	76.83	72.28	68.77	78.30	71.37	75.08	70.80	65.80
0.9	73.20	71.80	76.51	71.68	68.47	78.09	69.57	74.77	70.40	65.40
0.45	29.70	28.30	30.27	21.02	22.82	31.67	33.19	30.83	25.30	19.50
0.154	7.10	5.70	6.89	1.12	3.40	3.74	5.83	9.71	2.90	4.70
0.125	3.50	3.60	3.44	0.71	0.90	1.45	3.72	6.91	1.10	3.00
0.09	0.90	0.90	0.94	0.61	0.70	1.25	0.74	4.00	0.80	0.80
0.076	0	0	0	0	0	0	0	0	0	0

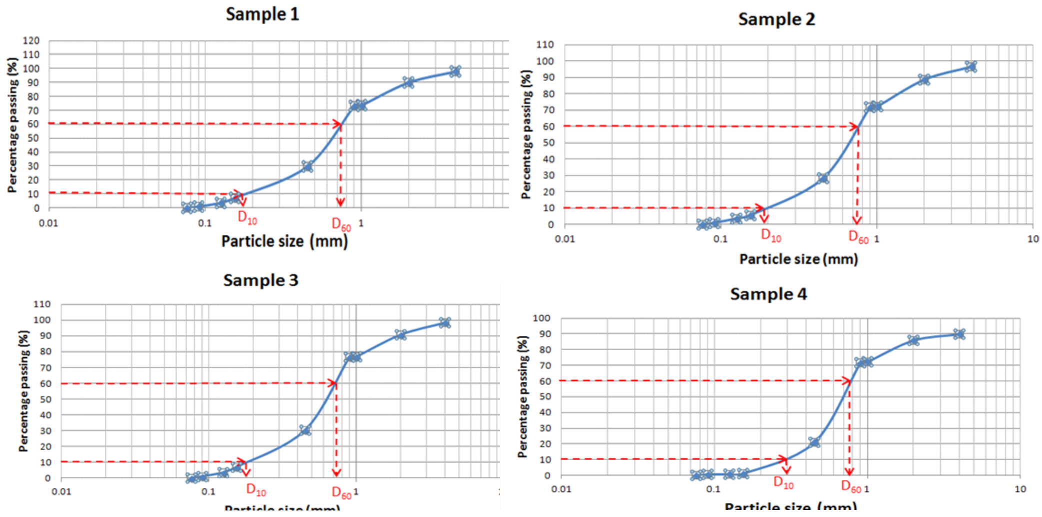

Figure 2: Grain-size distribution curve for samples 1-4

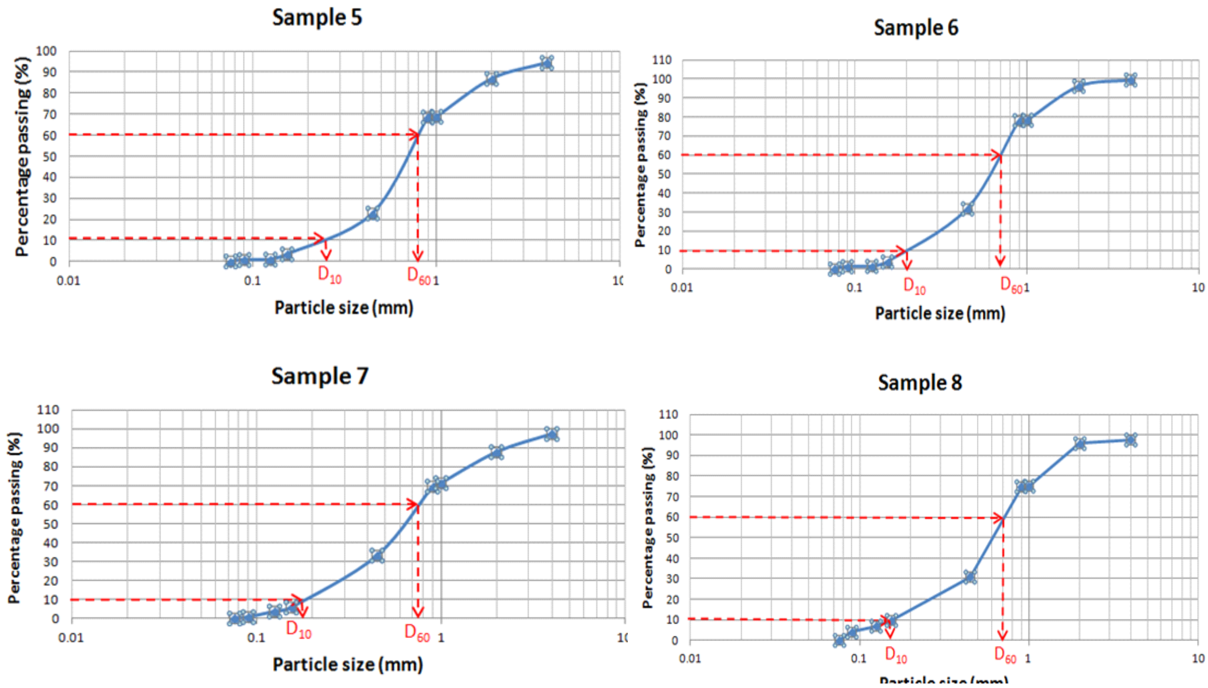

Figure 3: Grain-size distribution curve for samples 5-8

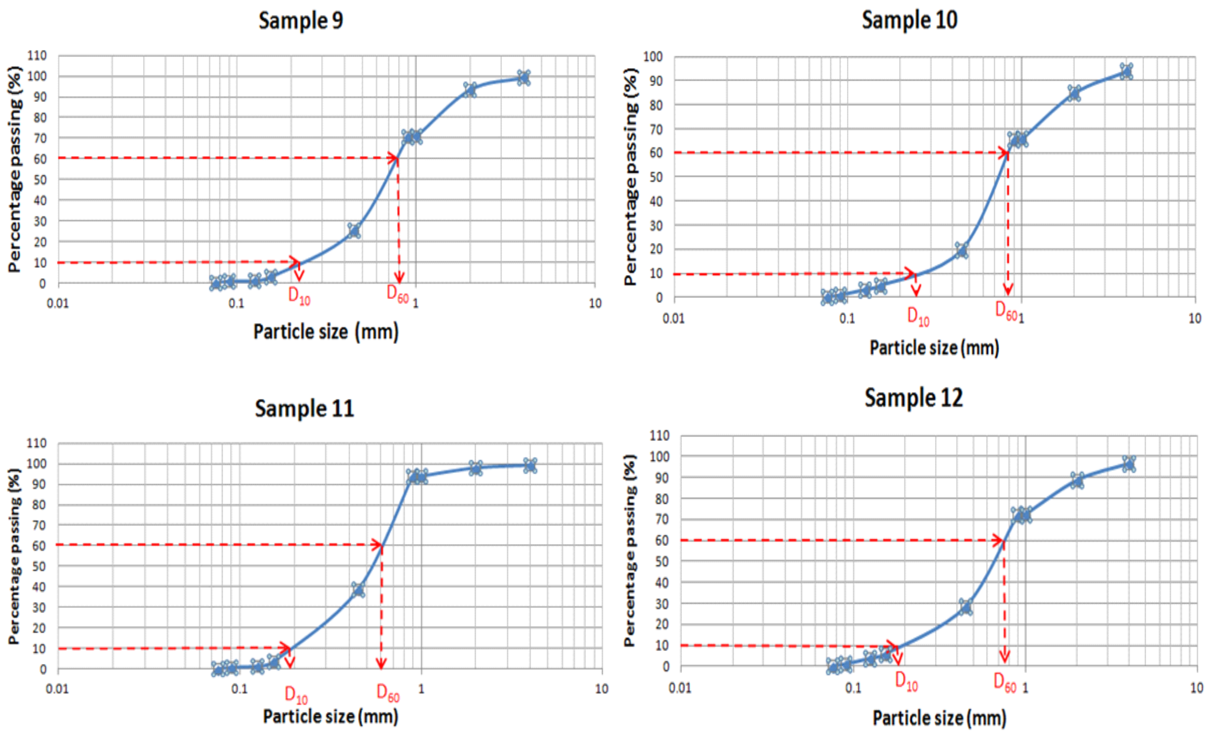

Figure 4: Grain-size distribution curve for samples 9-1

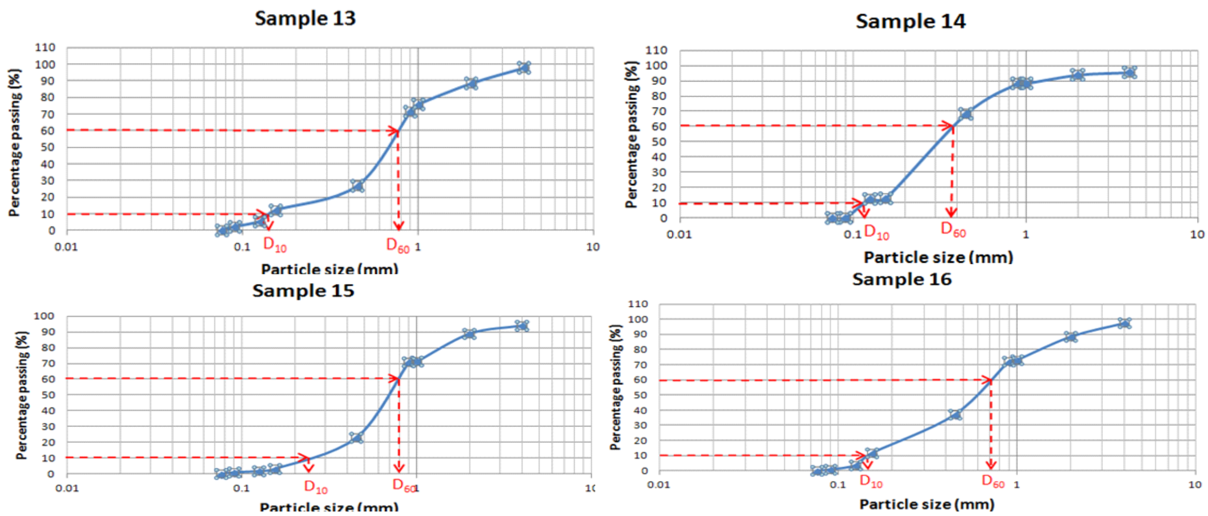

Figure 5: Grain-size distribution curve for samples 13-16

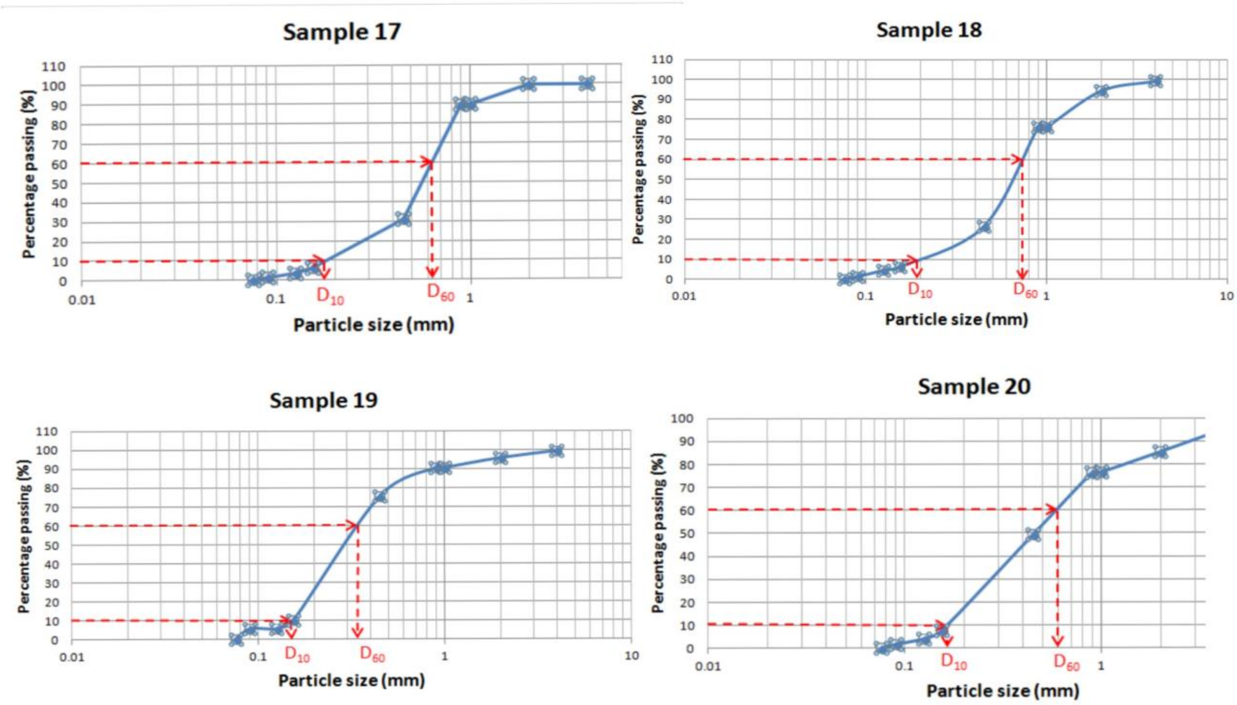

Figure 6: Grain-size distribution curve for samples 17-2

From the value of the data obtained, as shown in Table 3 and 4, the values of coefficient of uniformity (U) for Lokoja Formation ranges from 2.2 to 5.2 with a mean value of 3.65 while that of Patti Formation ranges from 2.7- 4.4 with a mean value of 3.62 which indicates that all the samples within the study area are well sorted. This is in agreement with Fetter (2014) that classified sandstone with a coefficient of uniformity (U) between 0.1 to 5.0/5.4 as well sorted. Also, these values are in the same ranges as that obtained by Idris-Nda (2013) elsewhere within the same basin.

	0.002mm	0.075	0.425	2	4.75	20	80	300
Clay (Size)	Silt (Size)	Fine	Medium	Coarse	Fine	Coarse	Cobble	Boulder
		Sand			Gravel			

Figure 7: International Standard (I.S) Classification (IS: 1498-1970)

Soil porosity (n) for Lokoja Formation ranges from 35% to 42% with a mean value of 38.6% while that of Patti Formation ranges from 37% to 41% with a mean value of 38.6% (Table 4). Freeze and Cheery (1979), indicated that any unconsolidated sands with a porosity value ranging from 25 - 50% is a good geological material and can serve as water-bearing sandstone strata. All the samples collected fall within this range as such will serve as good aquifers. . Also, Todd and Mays (2005) gave porosity values of 33% and 37% for fine and medium-grained sandstone, this also describes the sandstone of both formations as made up of fine to medium-grained. These porosities values are less than what was obtained by Idris (2013).

Based on International Standard (I.S.) (1498-1970) classification scheme for grain size analysis shown in figure 7, both Lokoja and Patti Formation are made up of fine sands as their effective grain size (D_{10}) presented in table 3 and 4 ranges from 0.12mm – 0.25mm (Lokoja Formation) and 0.14mm - 0.3mm (Patti Formation).

Table 3: Summary of Calculated Hydraulic Conductivity (K) values based on D_{10} for Lokoja Formation

S/N	*Sample ID*	*Coordinates*	*Grain size at Lokoja Formation* D_{10} *(mm)*	D_{60} *(mm)*	*u*	*n (%)*	$K= C(d_{10})^2$ *(m/s)*
1	Sample 11	N 7⁰50’59.3” E 6⁰45’21.7”	0.19	0.60	3.2	40.0	3.61×10^{-4}
2	Sample 12	N 7⁰50’59.5” E 6⁰45’22.5”	0.19	0.88	4.1	37.0	3.61×10^{-4}
3	Sample 13	N 7⁰50’59.7” E 6⁰45’22.8”	0.15	0.78	5.2	35.0	2.25×10^{-4}
4	Sample 14	N 7⁰50’59.5” E 6⁰45’22.7”	0.12	0.38	3.2	40.0	1.44×10^{-4}
5	Sample 15	N 7⁰50’59.2” E 6⁰45’21.6”	0.25	0.80	3.2	40.0	6.25×10^{-4}
6	Sample 16	N 7⁰50’59.3” E 6⁰45’21.7”	0.15	0.70	4.7	36.0	2.56×10^{-4}
7	Sample 17	N 7⁰50’59.4” E 6⁰45’21.8”	0.18	0.62	3.4	39.0	3.24×10^{-4}
8	Sample 18	N 7⁰50’59.5” E 6⁰45’21.9”	0.19	0.72	3.8	38.0	3.61×10^{-4}
9	Sample 19	N 7⁰50’59.4” E 6⁰45’21.7”	0.16	0.35	2.2	42.0	2.56×10^{-4}
10	Sample 20	N 7⁰51’14.7” E 6⁰43’03.0”	0.17	0.60	3.5	39.0	2.89×10^{-4}
	Minimum				2.2	35.0	1.44×10^{-4}
	Maximum				5.2	42.0	6.25×10^{-4}
	Mean				3.65	38.6	3.17×10^{-4}

Table 4: Summary of Calculated Hydraulic Conductivity (K) values based on D_{10} for Patti Formation

S/N	*Sample ID*	*Coordinates*	*Grain size at Patti Formation* D_{10} *(mm)*	D_{60} *(mm)*	*u*	*n (%)*	$K= C(d_{10})^2$ *(m/s)*
1	Sample 1	N 7⁰49’8.1” E 6⁰44’0.7”	0.18	0.62	3.4	39.0	3.24×10^{-4}
2	Sample 2	N 7⁰49’8.3” E 6⁰44’0.9”	0.14	0.75	3.9	38.0	3.61×10^{-4}
3	Sample 3	N 7⁰49’8.5” E 6⁰44’1.2”	0.18	0.72	4.0	38.0	3.27×10^{-4}
4	Sample 4	N 7⁰49’8.8” E 6⁰44’1.5”	0.30	0.80	2.7	41.0	9.0×10^{-4}
5	Sample 5	N 7⁰49’9.0” E 6⁰44’1.8”	0.25	0.80	3.2	40.0	6.25×10^{-4}
6	Sample 6	N 7⁰49’9.2” E 6⁰44’1.9”	0.20	0.70	3.5	38.0	4.0×10^{-4}
7	Sample 7	N 7⁰49’10.0” E 6⁰44’2.3”	0.18	0.75	4.2	37.0	3.24×10^{-4}
8	Sample 8	N 7⁰49’10.5” E 6⁰44’2.4”	0.16	0.70	4.4	37.0	2.56×10^{-4}
9	Sample 9	N 7⁰49’10.6” E 6⁰44’2.5”	0.22	0.80	3.6	39.0	4.84×10^{-4}
10	Sample 10	N 7⁰49’10.7” E 6⁰44’2.6”	0.25	0.82	3.3	39.0	6.25×10^{-4}
	Minimum				2.7	37.0	2.56×10^{-4}
	Maximum				4.4	41.0	9.0×10^{-4}
	Mean				3.62	38.6	4.63×10^{-4}

The results of hydraulic conductivity (K) for twenty (20) extracted samples from surface outcrops belonging to Lokoja and Patti Formations are presented in Tables 3 and 4 respectively.

The hydraulic conductivity (K) value for Lokoja Formation ranges from 1.44 x 10^{-4}m/s to 6.25 x 10^{-4}m/s with a mean value of 3.17 x 10^{-4} m/s and that of Patti Formation ranges from 2.56 x10^{-4} to 9 x10^{-4} m/s with a mean value of 4.63 x 10^{-4} m/s. Based on the classification ranges of values for hydraulic conductivity of geological materials by Singhal and Gupta (1999) shown in figure 8, a fractured sandstone has a hydraulic conductivity between 10^{-3}m/s to 10^{-6}m/s. All the samples collected have value within the range, indicating that the Lokoja and Patti sandstone will serve as an aquiferous zone having moderate hydraulic conductivity value.

Table 5: Summary of Calculated Hydraulic Conductivity (K) and Effective Grain-Size (D_{10}) analysis values for Lokoja and Patti Formation.

S/N	*Sample ID*	*D_{10} (mm)*	*Sand Classification*	*$K= C(d_{10})^2$ (m/s)*	*Aquifer Potential*
1.	Sample 1	0.18	fine	3.24 x 10^{-4}	Moderate
2.	Sample 2	0.14	fine	3.61 x 10^{-4}	Moderate
3.	Sample 3	0.18	fine	3.27 x 10^{-4}	Moderate
4.	Sample 4	0.30	fine	9.0 x 10^{-4}	Moderate
5.	Sample 5	0.25	fine	6.25 x 10^{-4}	Moderate
6.	Sample 6	0.20	fine	4.0 x 10^{-4}	Moderate
7.	Sample 7	0.18	fine	3.24 x 10^{-4}	Moderate
8.	Sample 8	0.16	fine	2.56 x 10^{-4}	Moderate
9.	Sample 9	0.22	fine	4.84 x 10^{-4}	Moderate
10.	Sample 10	0.25	fine	6.25 x 10^{-4}	Moderate
11.	Sample 11	0.19	fine	3.61 x10^{-4}	Moderate
12.	Sample 12	0.19	fine	3.61 x10^{-4}	Moderate
13.	Sample 13	0.15	fine	2.25 x10^{-4}	Moderate
14.	Sample 14	0.12	fine	1.44 x10^{-4}	Moderate
15.	Sample 15	0.25	fine	6.25 x10^{-4}	Moderate
16.	Sample 16	0.15	fine	2.56 x10^{-4}	Moderate
17.	Sample 17	0.18	fine	3.24 x10^{-4}	Moderate
18.	Sample 18	0.19	fine	3.61 x10^{-4}	Moderate
19.	Sample 19	0.16	fine	2.56 x10^{-4}	Moderate
20.	Sample 20	0.17	fine	2.89 x 10^{-4}	Moderate

Though both formations fall within moderate hydraulic conductivity, the value of hydraulic conductivity for Patti sandstone is greater than that of Lokoja sandstone and this is not in agreement with what was concluded by Idris-Nda (2013) and Olusegun *et al* (2018) that described the Lokoja sandstone as having hydraulic conductivity greater than that of Patti sandstone. The observed disagreement may be as a result of the variation in depth of sample collection.

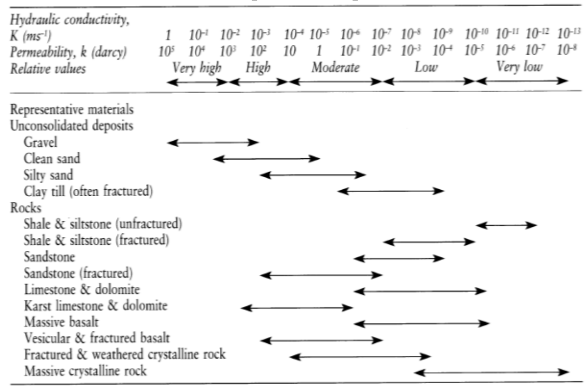

Figure 8: Range of values of hydraulic conductivity and permeability for various types of geological materials (Singhal and Gupta, 1999).

Conclusion

Based on the results of porosity values of the well sorted fine to medium grained sandstones of Lokoja and Patti Formations, it can be concluded that the formations will serve as water-bearing strata or are aquiferous. Though, I.S. (1498-1970) classification scheme for grain size analysis, indicates that both Patti and Lokoja Formation are made up of fine sands, both formations have moderate hydraulic conductivity with Patti Formation having relatively higher hydraulic conductivity values than the Lokoja Formation. That also implies that Patti Formation is more aquiferous due to its greater hydraulic conductivity and should be more targeted for appreciable groundwater quantity. From the results, the generally experienced low water yeild and failure of boreholes in the area can be attributed to the Lokoja Formation which has a lower hydraulic conductivity.

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