Standard Scientific Research and Essays Vol 11(1): 01-013, January, 2023 (ISSN: 2310-7502)
http://www.standresjournal.org/journals/SSRE

Research Article

Estimation of Aquifer Hydraulic Conductivity and Evaluation of Empirical Formulae Based on Grain Size Analysis (GSA) in Imo State, southeastern Nigeria

***[1]Terhemba Theophilus Emberga, [2]Alexander Opera, [2]Samuel Onyekuru, [1]Alexander Omenikoro, [3]Ali Bilar, [1]Chika Abara Josiah, [1]Uhiara Chukwemeka**

[1]Department of Physics/Electronics, Federal Polytechnic Nekede, Owerri
[2]Department of Geology, Federal University of Technology, PMB 1526 Owerri
[3]Department of Chemistry, Federal University of Technology, PMB 1526 Owerri
[4]Department of Chemistry/Biochemistry, Federal Polytechnic, Nekede, Owerri

*Corresponding author: terhemba4sure@yahoo.com

Accepted 25 January, 2023

Abstract

Grain size distribution of forty (40) aquiferious samples from boreholes drilled within the study area were determined by means of mechanical sieve analysis. From the distribution curves, grading characteristics: d_{10}, d_{20}, d_{30}, and d_{60} , their derivatives such as the effective size, uniformity coefficient, coefficient of sorting, coefficient of gradation and porosity were calculated. The hydraulic conductivity of the unconsolidated aquifer materials was first evaluated using empirical formulae on the basis of the grain size. Analysis of the results obtained using the various empirical formulae show that only Slitchter, and Hazen formulae reliably estimated the hydraulic conductivities of the various soil samples .The Beyer, and USBR empirical formulae, significantly underestimated the hydraulic conductivities of the samples and are probably not within the domain of applicability for the soils analyzed in the study area. Result of the study showed that the Hazen model estimated hydraulic conductivity values which varied from 0.09334- 5.10745 m/day with a mean value of 1.662 m/day while estimated from the Kozeny- Carman equation gave values which ranged between 3.782 – 1458.38 m/day with a mean value of 366.04 m/day. Also estimates made using the Brayer empirical equation revealed hydraulic conductivity values ranging between 0.0347 – 3.388m/day with a mean value of 0.676 m/day while the Slitcher's equations gave values ranging between 0.529 – 15.999m/day with a mean value of 3.92 m/day. The USBR equation gave hydraulic conductivity values which ranged between 0.00234 - 0.254 m/day with a value of 0.46 m/day

Keywords: Grain size distribution; Sieve analysis; hydraulic conductivity

INTRODUCTION

Physical characteristics of aquifers such as hydraulic conductivity, transmissivity and storativity that control groundwater flow and transport are very important properties and are usually estimated for groundwater flow model calibration. These parameters are also important properties for the assessment of contaminated land, and for safe construction of civil engineering structures. The hydraulic conductivity (K) is a hydro geologic property of the medium which refers to the ease with which a fluid can flow through the medium, it depends upon the porous medium and flowing fluid.

The aim of this study is to estimate the value of hydraulic conductivity across sections of the shallow aquifer and assess its variability within the Study area. Secondly, the study attempts to evaluate the applicability and reliability of some of the commonly used empirical formulae for the determination of hydraulic conductivity of unconsolidated soil materials. Accurate groundwater resource assessment and a quantitative description of aquifers have become imperative to address several hydrological and hydrogeological problems associated with groundwater exploration and exploitation. Hydraulic conductivity appears to be the most problematic to obtain because of either the great range of observed values or the unsatisfactory laboratory measurements (Mendosa et al., 2003).

Geology of the Study area

Imo State is made up of the bedrock of a sequence of sedimentary rocks about 5480 m thick and with ages ranging from Upper Cretaceous to Recent as seen in figure 1. The deposition of these sedimentary rocks is related to the opening of the South Atlantic Ocean and the formation of the rift-like Benue Trough of Nigeria in the Mesozoic (Uma, 1989). Generally, there are two different classes of formations underlying the Imo State: about 80% of the basin consists of Coastal Plain Sands, which are composed of non-integrated sediments represented by the Benin and Ogwashi-Asaba Formations, and the alluvial deposits at the estuary at the Southern end of the Imo River Basin. The remaining 20% is underlain by a series of sedimentary rock units that get younger southwestward, a direction that is parallel to the regional dip of the formations.

In Southeastern Nigeria, the Imo Formation shows lateral variation in sandstones in places. The Imo Formation is of Paleocene age and is characterized by Eponides Elevatus (Plummer), Frondicularia Phosphatica, Russo, etc (Reyment, 1965). Lithologically, the Imo Shale is composed mainly of shales and clay. However, in some places, sandstones and limestones may be present. The formation is not good for groundwater exploitation except in places with sandstone intercalations

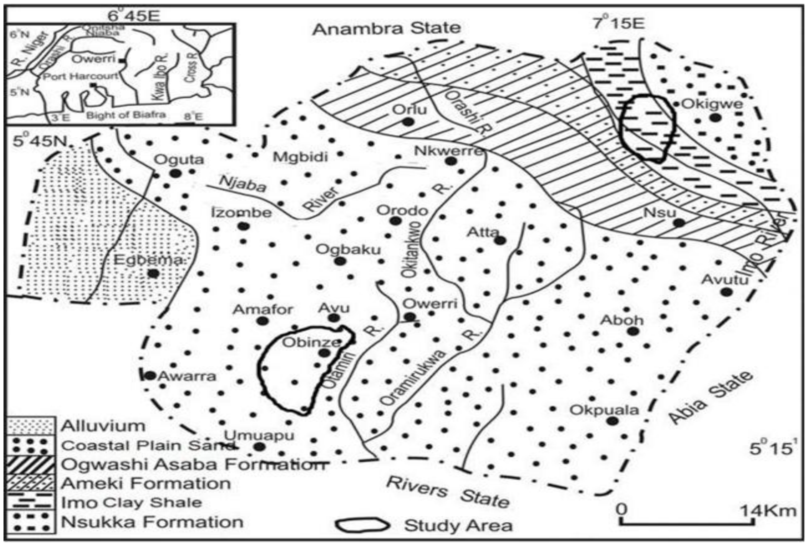


Figure 1. Geological map of Imo State

MATERIALS AND METHODS

Many researchers have developed empirical equations for obtaining hydraulic conductivity from grain size distributions of saturated sandstone formations worldwide (Vukovic and Soro, 1992; Fetter, 2001; Kasenow, 2002; Carrier, 2003; Odong, 2007; Riera et al., 2010). Previously, geoscientists have estimated local aquifer hydraulic parameters in intermediate to high permeability sandstone formations with the aid of devices like the flow meter (Molz et al., 1989). However, besides the use of pumping test, other scientists have estimated aquifer hydraulic parameters like storage coefficient and hydraulic conductivity on a local scale with the aid of grain size distribution (GSD) curves (Molz et al., 1989; Wolf, et al., 1991; Hess et al., 1992; Stauffer and Manoranjan, 1994; Boman et al., 1997; Carrier, 2003; Odong, 2007). Also further studies to analyze the predictive accuracies of the GSD technique have been done by some researchers. For example, qualitative comparative analyses between the various techniques of aquifer hydraulic conductivity estimation can be found in several literatures (Wolf et al., 1991; Stauffer and Manoranjan, 1994; Boman et al., 1997; Ejiogu et al., 2019; Urom et al., 2020).

It is well known and sufficiently understood that a relationship exists between aquifer hydraulic conductivity and the physical properties of saturated granular porous media which can be established using the grain size distribution technique (Nwankwor et al.,1984; Uma et al.1989; Vukovic and Soro, 1992; Odong, 2007; Cheng and Chen, 2007; Payne et al. 2008). Generally, it is believed that estimates of the hydraulic conductivity of porous saturated sandstone formations can be obtained directly by using key information extracted from particle size distributions in several developed empirical relationships (Vukovic and Soro, 1992; Odong, 2007; Cheng and Chen, 2007; Payne et al., 2008). GSD based techniques are usually applied to porous sand formations and the estimates made are generally assumed to be independent of groundwater flow configurations in the saturated sand media. These GSD empirical techniques are well accepted and routinely used for hydraulic conductivity estimation on a local scale because granulometric analysis well-established procedures in hydrogeological studies and therefore can be performed with a minimum experimentation. Using this technique therefore, hydraulic characteristics of porous media like hydraulic conductivity (K) and specific coefficient can be estimated using GSD of the saturated sediments at the zone of interest using empirical equations which generally relates hydraulic conductivity to some size distribution characteristics of the saturated sediments of interest((Kozeny 1927; Kozeny-Carman 1993; Hazen 1892; Shepherd 1989). Vukovic and Soro (1992) summarized several empirical methods based on grain size distribution with a general formula given in equation 1:

$$K = \frac{g}{v} .C.f. (n).d_{10}^{2} \qquad (1)$$

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 established relationship between kinematic viscosity (V) on one hand and, the dynamic viscosity (μ) and the density of water in the pore spaces (ρ) is expressed in equation 2:

$$V = \frac{\mu}{\rho} \qquad (2)$$

The C, f(n) and *de* values are usually variable and generally depends on the parametric values of the respective grain-size based empirical equations developed by the respective authors. Based on the work of Vukovic and Soro (1992), porosity (n) can be derived from an empirical relationship between porosity and the coefficient of uniformity (U) of granules in the saturated sediment as shown in equation 3:

$$n = 0.255(1+0.83^{u}) \qquad (3)$$

Where the coefficient of Uniformity of the grains (U) is given by equation 4:

$$U = d_{60}/d_{10} \qquad (4)$$

The parameters $\mathbf{d_{60}}$ and $\mathbf{d_{10}}$ in the equation 4 typically represent the grain size diameter in mm for which 60% and 10% of the sample respectively are fines. Studies by previous authors like Hazen 1892 have proposed an empirical equation of the form presented in equation 1 but in this case with the values of the parameters C, f(n) and d_e varying as shown in equation 5 :

$$K = \frac{g}{v} \text{ x } 6 \text{ x } 10^{-4} [1 + 10 (n – 0.26)] \text{x } d_{10}^{2} \qquad (5)$$

The empirical equation by Hazen 1892 was originally derived and developed for the estimation of the hydraulic conductivity of uniformly graded saturated sandstone formations but is also very useful for sediments in the range of fine sand to gravel, provided the sediment has a uniformity coefficient less than 5 and effective grain size between 0.1 - 3mm as shown in equation 6:

$$K = \frac{g}{v} \text{ x } 8.3 \text{ x } 10\text{-}3 \left[\frac{n3}{(1-n)2} \right] \text{x } d_{10}^{2} \qquad (6)$$

The Kozeny-Carman empirical equation which is a modification of the existing GSD empirical equations is one of the most widely accepted and used equation for the estimation of permeability as a function of the saturated soil media characteristics. This equation was originally proposed by Kozeny (1927) and later modified by Carman (1937, 1956) to become the Kozeny-Carman equation as shown in equation 7.
However, it must be noted that the Kozeny-Carman empirical equation is not appropriate for soils with an effective size above 3mm and for all clayey soils (Carrier 2003):

$$K = \frac{g}{v} \text{ x } 6 \text{ x} 10\text{-}4 \log \frac{500}{U} \text{ x } d_{10}^{2} \qquad (7)$$

The Breyer empirical equation is often considered most useful for materials with heterogeneous distributions and poorly sorted grains with uniformity coefficient between 1 and 20, and effective grain size between 0.06 mm - 0.6mm. This method does not consider porosity and therefore, the porosity function takes on the value 1 as shown in equation 8:

$$K= \frac{g}{v} \text{ x } 1 \text{ x } 10^{-2} \, n^{3.283} \text{ x } d_{10}^{2} \qquad (8)$$

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

$$K = \frac{g}{v} \text{ x } 4.8 \text{ x } 10^{-4} \text{ x } d^{\,0.3}{}_{20} \text{ x } d_{20} \qquad (9)$$

The forty (40) different grain size samples from aquifer horizons in drilled holes from various parts of the study area were collected in containers and taken to the laboratory for sieve analysis where the samples were treated and tested for grain size distribution according to the standard procedures of BS1377. Table1 below shows the results of the particle size distribution analyses of the twenty aquifer samples studied. To further analyze the distribution of the particles and to help classify the samples, the test results were then plotted on a semi-logarithmic graph to obtain the grain-size distribution curves for some selected samples as shown in figure1 below. From the grain-size distribution curves, aquifer samples were classified according to particle size using a standard British Soil Classification System, detailed in BS 5930. In this system, aquifer samples are classified into named basic sample-type groups according to size, and the groups are further divided into coarse, medium and fine sub-groups.

RESULTS AND DISCUSSIONS

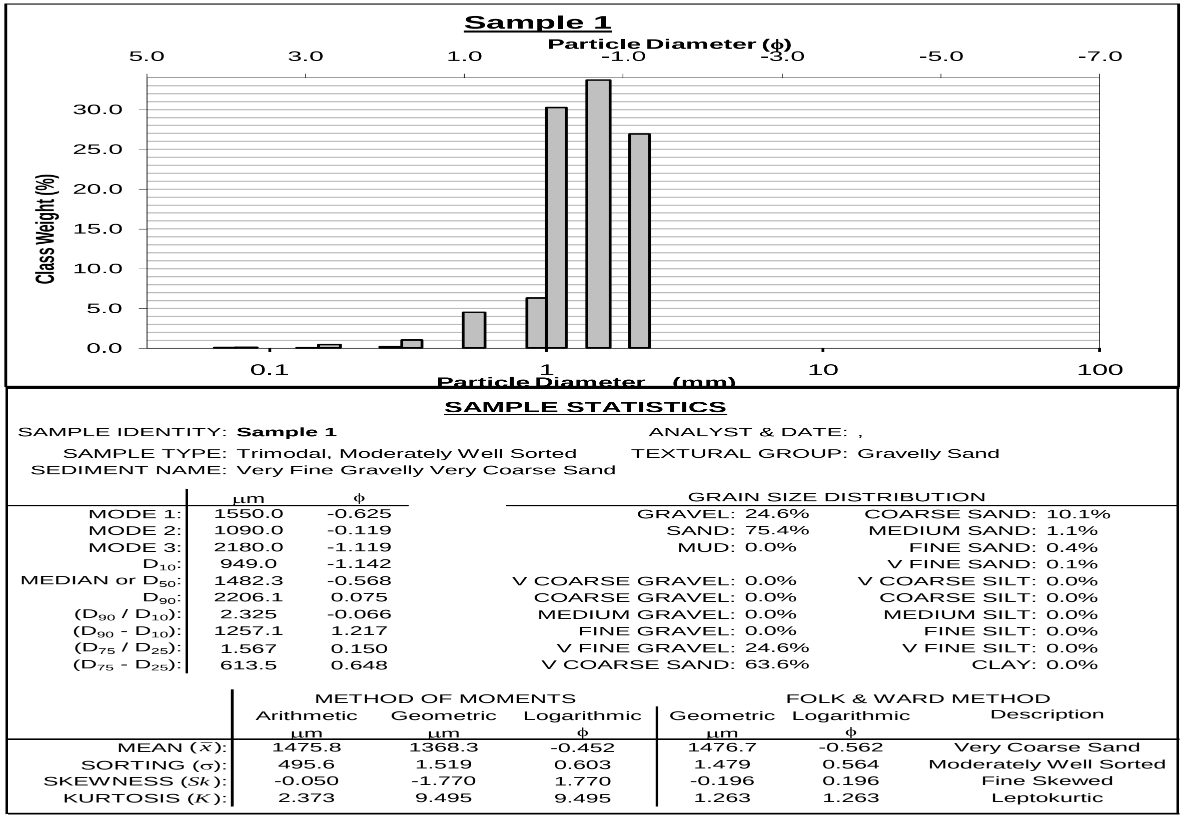
The results of the study revealed that d_{10} values ranges between 0.00018-0.0017 mm with the d_{20} values ranging between 0.00023 -0.0019 mm while the d_{60} values varies from 0.0004-0.0024 mm across the study area. The estimates of hydraulic conductivity made with the different empirical equations revealed a pronounced spatial variation of hydraulic conductivity across the study area. The Hazen equation gave an estimated hydraulic conductivity value which varies from 0.08443- 4.10745 m/day with a mean value of 1.552 m/day while values estimated using the Kozemy- Carman equation estimated hydraulic conductivity values which ranged between 2.682 – 1356.28 m/day with a mean value of 256.04 m/day. Also estimates made using the Brayer empirical equation revealed values of hydraulic conductivity ranging between 0.0247 – 2.388m/day with a mean value of 0.576 m/day while the Slitcher's equations estimated hydraulic conductivity values across the study area ranging from 0.129 – 14.999m/day with a mean value of 2.82 m/day. The USBR equation gave hydraulic conductivity values which ranged between 0.00111 -0.14287 m/day with an average value of 0.46 m/day. These predicted values when compared with available pumping test data from monitoring wells within the study area thus revealed that while the Kozemy-Carman grossly overestimated aquifer hydraulic conductivity values across the area, both the Brayer and USBR equations underestimated the hydraulic conductivity values across the study area. The best estimates which were closer to the pumping test data were given by the Slitcher equation and to a lesser extent the Hazen equation .

Table1. Selected Aquifer hydraulic conductivity calculated from grain size data

Project No	Aquifer Thickness b (m)	d10(m)	d20(m)	d60(mm)	d60(m)	U = d60/d10	n=0.255(1+0.83)^U	Hazen(m/day)	Kozeny - Carman(m/day)	Brayer(m/day)	Slitcher(m/day)	USBR(m/day)	Specific Yield (S =3 x10^{-6})*b
Sample 1-OKWUFURAKU ,AWO IDEMILI	47	0.00095	0.0012	1.8	0.0018	1.894736842	0.801338354	1.876055358	52.76002663	0.708318786	2.354236812	0.049649866	0.000141
Sample 2-AGBAGHARA NSU ORIGH	40.1	0.00018	0.00023	0.4	0.0004	2.222222222	0.976708178	0.085767577	249.5000528	0.024701723	0.161980212	0.001111157	0.0001203
Sample 3-AKWAKUMA	56.8	0.0015	0.0019	2.45	0.00245	1.633333333	0.684242891	3.823193629	32.41493773	1.812911302	3.492036135	0.142867845	0.0001704
Sample 4-OBOUGORAYI	28.1	0.0009	0.0011	1.7	0.0017	1.888888889	0.798511413	1.676350812	45.5476072	0.636073473	2.08854127	0.040644744	0.0000843
Sample 5-UMOWA	131.8	0.001	0.0017	2.4	0.0024	2.4	1.087483799	3.00619784	753.4443576	0.751565428	7.116749926	0.11062002	0.0003954
Sample 6-MBIERI (UMUDURUBIA ACHI)	45	0.0008	0.0015	2.4	0.0024	3	1.562764185	2.909885291	34.58163238	0.460898921	14.99918696	0.082948991	0.000135
Sample 7-UMUKIRIKI(EKEOKWE OKIRIKANWAEKE)	43.9	0.00075	0.00095	1.8	0.0018	2.4	1.087483799	1.690986285	423.8124511	0.422755553	4.003171833	0.029011187	0.0001317
Sample 8-UZUAGBA	71.9	0.00023	0.00034	0.7	0.0007	3.043478261	1.604369387	0.247653901	2.681648947	0.037989031	1.35160908	0.002730252	0.0002157
Sample 9-AMUZARI	69.8	0.0015	0.0018	2.4	0.0024	1.6	0.670597491	3.723680585	28.0383564	1.819441881	3.268306954	0.126161829	0.0002094
Sample 10-EMII	65.1	0.00036	0.00045	1	0.001	2.777777778	1.366378391	0.506757024	11.04323521	0.094736046	1.95338031	0.005202235	0.0001953
Sample 11-AMIRI	12.7	0.00035	0.00045	0.84	0.00084	2.4	1.087483799	0.368259235	92.2969338	0.092066765	0.871801866	0.005202235	0.0000381
Sample 12-UMUAKA(AFOR UMUAKA)	47	0.00095	0.0015	1.85	0.00185	1.947368421	0.827235464	1.951810087	76.7473727	0.704838002	2.613690653	0.082948991	0.000141
Sample 13-UMUEKWUNE	60	0.00064	0.0008	1.4	0.0014	2.1875	0.956427245	1.05734638	846.2989493	0.313186587	1.911273542	0.019539263	0.00018
Sample 14-UMUOZU DURUEZE	27	0.0003	0.00035	0.62	0.00062	2.066666667	0.889076435	0.212680071	23.04890161	0.069535287	0.330343149	0.002918487	0.000081

Continuation of table 1

Sample 15-EWURU UMUNACHI	25.1	0.00027	0.00033	0.62	0.00062	2.296296296	1.02142303	0.20354256	758.9632263	0.055242395	0.422227447	0.002549079	0.0000753
Sample 16-OKWU URATTA	39.8	0.00019	0.00024	0.39	0.00039	2.052631579	0.881567508	0.084429729	7.9062449	0.027926004	0.128861224	0.001225426	0.0001194
Sample 17-OKPUALA AMAKOHIA	40.2	0.0009	0.0011	1.7	0.0017	1.888888889	0.798511413	1.676350812	45.5476072	0.636073473	2.08854127	0.040644744	0.0001206
Sample 18-UMULU EZIUDO	16.4	0.00035	0.00045	0.78	0.00078	2.228571429	0.980462935	0.325766394	1356.279047	0.093344664	0.62019799	0.005202235	0.0000492
Sample 19-UMUEZE UMOKIRIKA EKWEREAZU	19.7	0.0017	0.0019	2.4	0.0024	1.411764706	0.598493401	4.107448534	17.23172014	2.38788984	2.888364206	0.142867845	0.0000591
Sample 20-UMUTAKU UMUAWUCHI IHITTE UBOMA	10	0.0007	0.001	1.7	0.0017	2.428571429	1.106423518	1.503117149	262.7381419	0.367450778	3.690844024	0.032643838	0.00003



SAMPLE STATISTICS

SAMPLE IDENTITY: **Sample 1**
ANALYST & DATE: ,
SAMPLE TYPE: Trimodal, Moderately Well Sorted
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

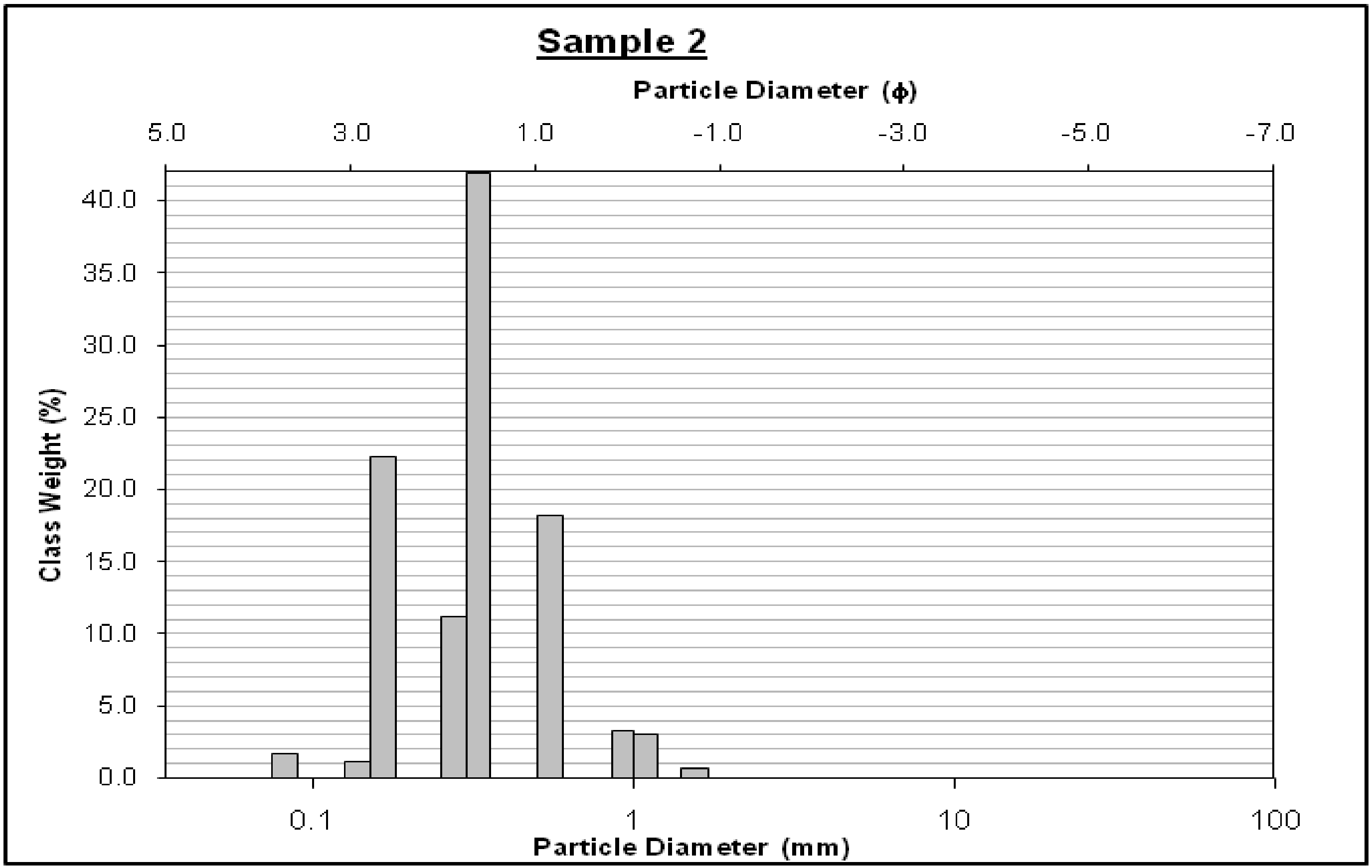
	μm	ϕ
MODE 1:	1550.0	-0.625
MODE 2:	1090.0	-0.119
MODE 3:	2180.0	-1.119
D_{10}:	949.0	-1.142
MEDIAN or D_{50}:	1482.3	-0.568
D_{90}:	2206.1	0.075
(D_{90} / D_{10}):	2.325	-0.066
$(D_{90} - D_{10})$:	1257.1	1.217
(D_{75} / D_{25}):	1.567	0.150
$(D_{75} - D_{25})$:	613.5	0.648

GRAIN SIZE DISTRIBUTION

GRAVEL:	24.6%	COARSE SAND:	10.1%
SAND:	75.4%	MEDIUM SAND:	1.1%
MUD:	0.0%	FINE SAND:	0.4%
		V FINE SAND:	0.1%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	24.6%	V FINE SILT:	0.0%
V COARSE SAND:	63.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1475.8	1368.3	-0.452	1476.7	-0.562	Very Coarse Sand
SORTING (σ):	495.6	1.519	0.603	1.479	0.564	Moderately Well Sorted
SKEWNESS (Sk):	-0.050	-1.770	1.770	-0.196	0.196	Fine Skewed
KURTOSIS (K):	2.373	9.495	9.495	1.263	1.263	Leptokurtic

(a)



SAMPLE STATISTICS

SAMPLE IDENTITY: **Sample 2**
ANALYST & DATE: ,
SAMPLE TYPE: Trimodal, Moderately Sorted
TEXTURAL GROUP: Sand
SEDIMENT NAME: Moderately Sorted Medium Sand

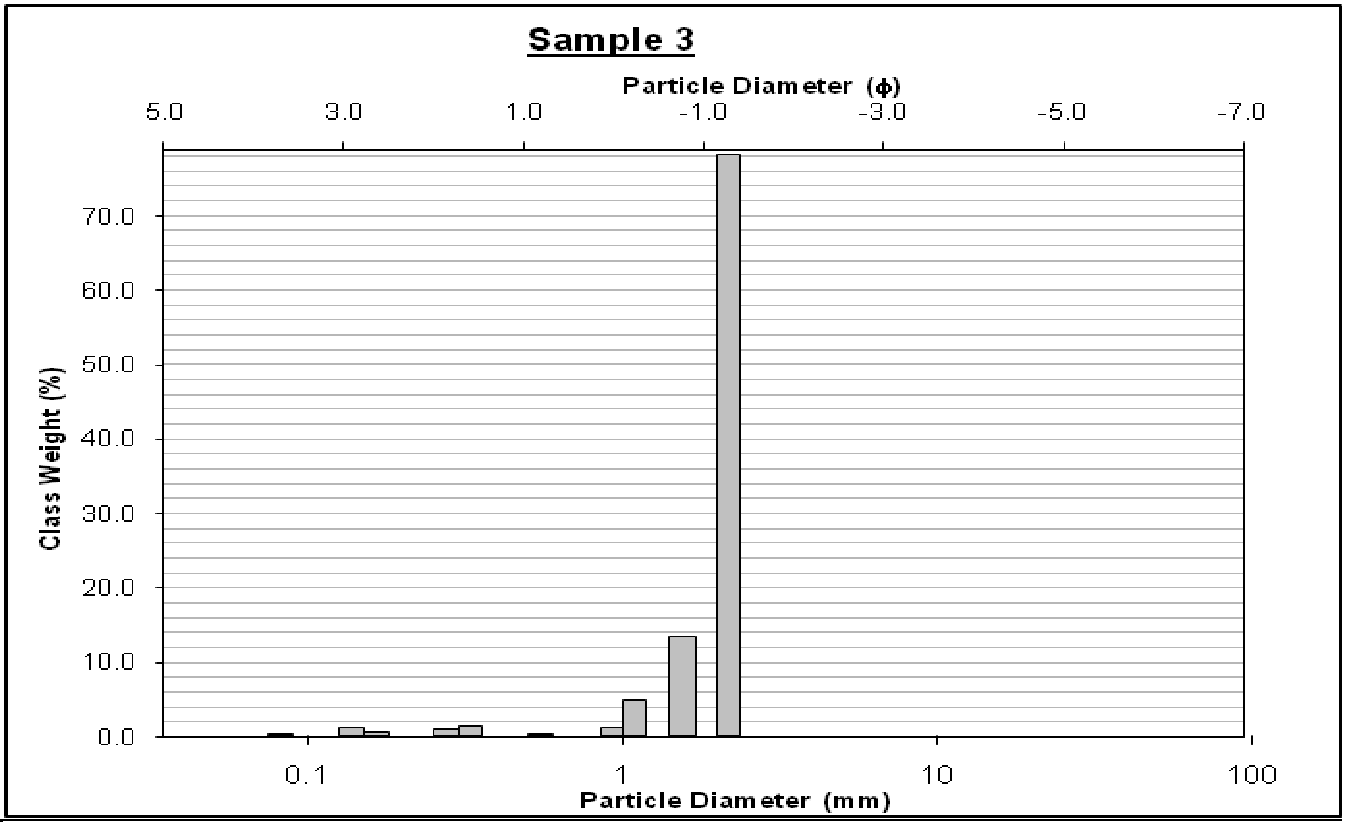
	µm	φ
MODE 1:	327.5	1.616
MODE 2:	165.0	2.605
MODE 3:	550.0	0.868
D_{10}:	159.1	0.788
MEDIAN or D_{50}:	318.2	1.652
D_{90}:	579.1	2.652
(D_{90} / D_{10}):	3.641	3.366
$(D_{90} - D_{10})$:	420.1	1.864
(D_{75} / D_{25}):	1.973	1.655
$(D_{75} - D_{25})$:	174.9	0.980

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	21.2%
SAND:	100.0%	MEDIUM SAND:	50.1%
MUD:	0.0%	FINE SAND:	23.5%
		V FINE SAND:	1.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	3.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic µm	Geometric µm	Logarithmic φ	Geometric µm	Logarithmic φ	Description
MEAN ($\bar{x}$):	367.5	314.8	1.667	307.2	1.703	Medium Sand
SORTING (σ):	229.8	1.708	0.772	1.765	0.820	Moderately Sorted
SKEWNESS (Sk):	2.184	0.269	-0.269	0.047	-0.047	Symmetrical
KURTOSIS (K):	9.227	3.277	3.277	1.084	1.084	Mesokurtic

(b)



SAMPLE STATISTICS

SAMPLE IDENTITY: **Sample 3**

ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Well Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

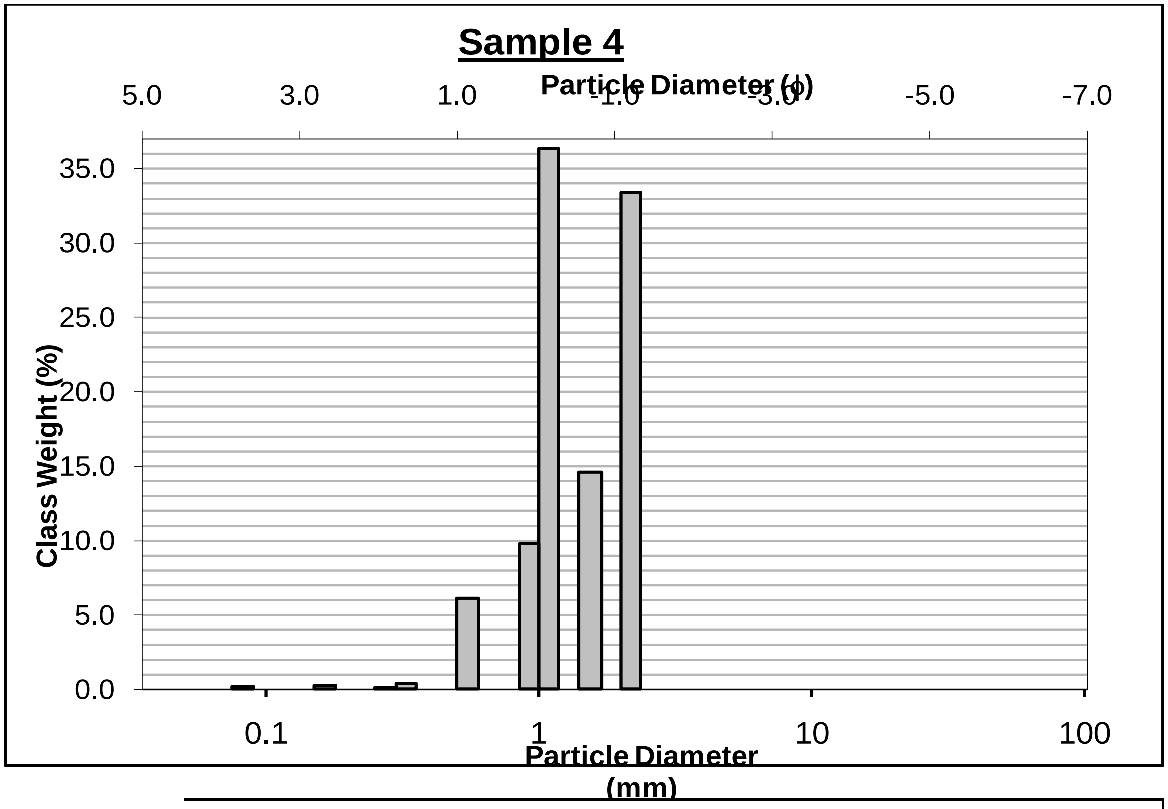
	μm	ϕ
MODE 1:	2180.0	-1.119
MODE 2:	1550.0	-0.625
MODE 3:		
D_{10}:	1410.6	-1.207
MEDIAN or D_{50}:	2115.4	-1.081
D_{90}:	2308.9	-0.496
(D_{90} / D_{10}):	1.637	0.411
(D_{90} - D_{10}):	898.3	0.711
(D_{75} / D_{25}):	1.116	0.864
(D_{75} - D_{25}):	231.6	0.158

GRAIN SIZE DISTRIBUTION

GRAVEL:	75.6%	COARSE SAND:	1.2%
SAND:	24.4%	MEDIUM SAND:	1.9%
MUD:	0.0%	FINE SAND:	1.5%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	75.6%	V FINE SILT:	0.0%
V COARSE SAND:	19.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1949.5	1817.9	-0.862	1944.4	-0.959	Very Coarse Sand
SORTING (σ):	468.1	1.599	0.677	1.256	0.328	Very Well Sorted
SKEWNESS (Sk):	-2.241	-3.950	3.950	-0.698	0.698	Very Fine Skewed
KURTOSIS (K):	7.673	19.89	19.89	3.146	3.146	Extremely Leptokurtic

(c)



SAMPLE STATISTICS

SAMPLE IDENTITY: **Sample 4**
ANALYST & DATE: ,
SAMPLE TYPE: Polymodal, Moderately Well Sorted
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

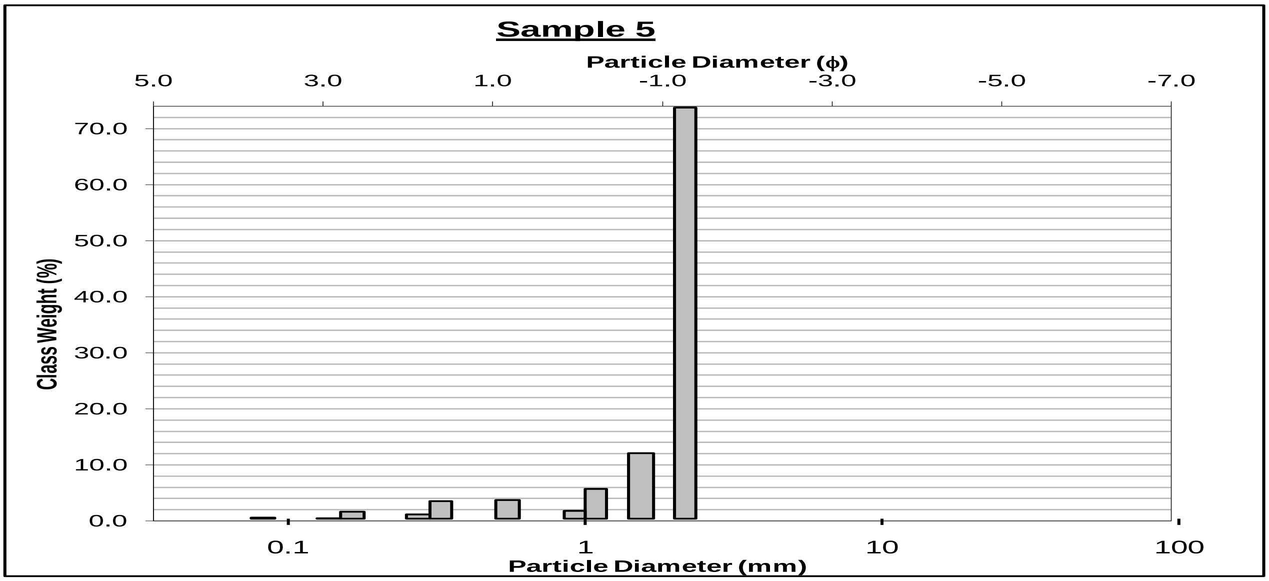
	μm	ϕ
MODE 1:	1090.0	-0.119
MODE 2:	2180.0	-1.119
MODE 3:	1550.0	-0.625
D_{10}:	890.8	-1.164
MEDIAN or D_{50}:	1171.7	-0.229
D_{90}:	2241.3	0.167
(D_{90} / D_{10}):	2.516	-0.143
$(D_{90} - D_{10})$:	1350.5	1.331
(D_{75} / D_{25}):	1.993	0.055
$(D_{75} - D_{25})$:	1033.6	0.995

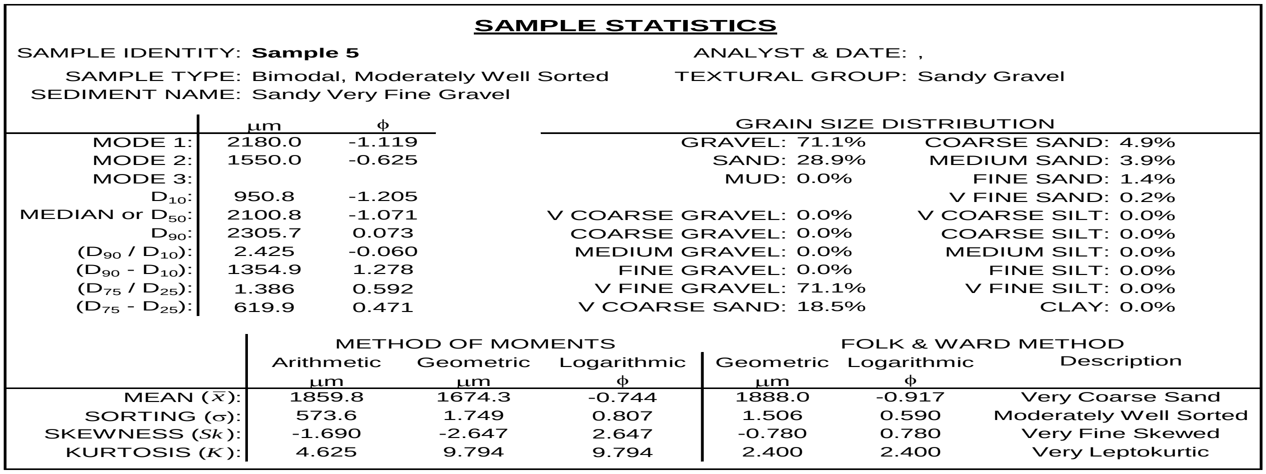
GRAIN SIZE DISTRIBUTION

GRAVEL:	32.1%	COARSE SAND:	15.7%
SAND:	67.9%	MEDIUM SAND:	0.5%
MUD:	0.0%	FINE SAND:	0.2%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	32.1%	V FINE SILT:	0.0%
V COARSE SAND:	51.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1457.6	1334.5	-0.416	1361.0	-0.445	Very Coarse Sand
SORTING (σ):	555.7	1.550	0.633	1.507	0.592	Moderately Well Sorted
SKEWNESS (Sk):	0.145	-1.069	1.069	0.264	-0.264	Coarse Skewed
KURTOSIS (K):	1.740	6.338	6.338	0.838	0.838	Platykurtic

(d)





SAMPLE STATISTICS

SAMPLE IDENTITY: **Sample 5**
ANALYST & DATE: ,
SAMPLE TYPE: Bimodal, Moderately Well Sorted
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

	µm	ϕ
MODE 1:	2180.0	-1.119
MODE 2:	1550.0	-0.625
MODE 3:		
D_{10}:	950.8	-1.205
MEDIAN or D_{50}:	2100.8	-1.071
D_{90}:	2305.7	0.073
(D_{90} / D_{10}):	2.425	-0.060
$(D_{90} - D_{10})$:	1354.9	1.278
(D_{75} / D_{25}):	1.386	0.592
$(D_{75} - D_{25})$:	619.9	0.471

GRAIN SIZE DISTRIBUTION			
GRAVEL:	71.1%	COARSE SAND:	4.9%
SAND:	28.9%	MEDIUM SAND:	3.9%
MUD:	0.0%	FINE SAND:	1.4%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	71.1%	V FINE SILT:	0.0%
V COARSE SAND:	18.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic µm	Geometric µm	Logarithmic ϕ	Geometric µm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1859.8	1674.3	-0.744	1888.0	-0.917	Very Coarse Sand
SORTING (σ):	573.6	1.749	0.807	1.506	0.590	Moderately Well Sorted
SKEWNESS (Sk):	-1.690	-2.647	2.647	-0.780	0.780	Very Fine Skewed
KURTOSIS (K):	4.625	9.794	9.794	2.400	2.400	Very Leptokurtic

(e)

Figure 2(a-e). Selected percentage composition of the Aquiferious samples

The results of hydraulic conductivities from the grain-size data were compared to those obtained from the pumping test. Though grain-size methods mainly rely on particle size, which is considered the most important parameter for the determination of hydraulic conductivity (Song et al, 2009), they however yielded much lower values of hydraulic conductivity in this study, with differences of up to approximately two orders of magnitude. The main reason for such poor predictions may be associated with the domain of applicability of grain-size techniques with respect to types of sediments. The use of the USBR and Hazen techniques has been considered inaccurate due to their failure to reproduce low values of hydraulic conductivity (Vukovic andSoro 1992). There may be several reasons for this behavior including the fact that the USBR technique uses a different estimation of the effective grain diameter of (d_{20}) instead of d_{10}, in addition to its assumption of the value of porosity to be one (1). These attributes are also associated with the Breyer technique which gave similar results to USBR. Based on the results of this study therefore, the usage of the USBR method in the study area is not advisable. The Slichter method is the only valid method for the domain of applicability, as it generally gives the values of estimated hydraulic conductivity similar to the pumping test data (Dodds and Ivic,1988). Theoretical assumptions for the grain size and the coefficient of grain uniformity were satisfied most often by the Slichter method and sometimes by the Beyer method but not at all for the others. The results confirm that estimates of hydraulic conductivity from empirical methods based on grain-size analysis are not in good agreement with those obtained from pumping test data except that of the Slitcher. This therefore means that the only advisable method for the estimation of *K* from grain-size analyses in this study therefore would be the Slichter method. This indicates that empirical methods for estimating hydraulic conductivity from grain size data may not be reliable within non-homogenous granular aquifers. However hydraulic information may be obtained from a greater concentration of sites within the study area using the Slitcher method thereby enriching the regional groundwater database. This approach requires an input of a high density of K estimates for the aquifers to ensure a good calibration and accuracy of the model for accurately predicting groundwater flow. If the models are built for homogenous aquifers, it could be expected that no scale effects should be observed thereby allowing the use of K information from hydraulic tests, empirical methods or both.

The quantitative analysis of the grain size distribution curves was based on the determined grading characteristics such as d_{10}, $d2_0$, and d_{60}. From these geometric values, the effective size, uniformity coefficient, coefficient of sorting and coefficient of gradation were derived. Uniformity coefficient (Cu) is equal to d_{60}/d_{10}. Soils with Cu less than or equal to 3 are considered to be “poorly graded” or “uniform”. Coefficient of gradation (Cc) = $(d_{30})^2/(d_{60} \times d_{10})$. For well−graded soils, Cc is approximately equal to 1. The parameter d_{10} is referred to as the "effective size" of the soil. Empirically, d_{10} has been strongly correlated with the permeability of fine−grained sandy soils.

CONCLUSION

The percentage composition of the soil samples is presented in Figures (2a)- (2e) and shows that samples 2 and 3 have the highest percentage of coarse size grains with 100% and 75.6% respectively, while samples 1 and 4 and 5 have the greatest percentage of coarse grain fractions with 75.4% , 67.0% and 71.1 respectively. However, all forty samples are basically classified as medium sand because greater proportions of all the samples have grain size diameters between 0.2 – 0.5mm. Also, all the samples show uniform soil condition since uniformity coefficient is less than 3 and the grading curves are designated uniform grading curves as coefficient of gradation ranges from 0.5 to 2.

The mathematical expression of the six empirical formulae used in the estimation of hydraulic conductivity in this study and their applicability is presented in table 1. Hydraulic conductivity of aquifer based on the grading characteristics of the samples will generally lead to underestimation or overestimation of the hydraulic conductivity values unless the appropriate empirical equation is used. Therefore for the study area which represent a wide range of geological formations, Slitcher formula and to a limited extent the Hazen empirical equation are the best equations for estimating hydraulic conductivity from GSD techniques. However, the Breyer empirical formula is the best for the estimation of highly heterogeneous soil samples while the United States Bureau of Reclamation (USBR) formula grossly underestimated the hydraulic conductivities in comparison to the other empirical equations used.

Acknowledgement

The Authors are gratiful to the Management of Tertiary Education Trust Fund (TETFUND) for supporting this Research and sponsoring it 100% through the 2020 National Research Fund grant cycle(TETF/ES/DR&D-CE/NRF2020/SETI/111/VOL.1).

References

Alyamani MS, Sen Z(1993). Determination of Hydraulic Conductivity from Grain Size Distribution Curves. Ground Water. 31:551-555.

Boadu FK(2000). Hydraulic Conductivity of Soils from Grain-Size Distribution: New Models. J. Geotechnical and Geoenvironmental Engineering.

Carman PC(1956). The flow of Gases through Porous Media. Butterworths Scientific Publications, London.

Carrier WD (2003). Goodbye, Hazen; Hello, Kozeny-Carman. J. Geotechnical and Geoenvironmental Engineering. Pp.1054.

Cheng C, Chen X(2007). Evaluation of Methods for Determination of Hydraulic Properties in an Aquifer- Aquitard System Hydrologically Connected to River. Hydrogeology J. 15: 669-678.

Cirpka OA(2003). Environmental Fluid Mechanics I: Flow in Natural Hydrosystems.

Ebong ED, Akpan AE, Onwuegbuche AA (2014). Estimation of geohydraulic parameters from fractured shales and sandstone aquifers of Abi (Nigeria) using electrical resistivity and hydrogeologic measurements. J Afr. Earth Sci. 96:99–109

Ejiogu BC, Opara AI, Nwosu EI, Nwofor OK, Onyema JC, Chinaka JC (2019) Estimates of aquifer geo-hydraulic and vulnerability characteristics of the Imo State and environs, Southeastern Nigeria, using electrical conductivity data. Environ Monit Assess

Ejogu BC, Opara AI, Nwosu EI, Nwafor OK, Onyema JC, Chinaka JC(2019). ‘Estimates of aquifer geo-hydraulic and vulnerability characteristics of Imo State and environs, Southeastern Nigeria, using electrical conductivity data’. Environ. Monit. Asses. 191: 238. https://doi.org/10.1007/s10661-019-7335-1.

Ekwe AC, Onu NN, Onuoha KM(2006). Estimation of Aquifer Hydraulic Characteristics from Electric Sounding Data: The case study of Middle Imo River Basin Aquifers, South Eastern Nigeria. J. Spatial Hydrology. 6(2): 121-132.

Ekwe AC, Opara AI(2012). Aquifer Transmissivity from Surface Geo-electrical Data: A Case Study of Owerri and Environs, Southeastern Nigeria. J.Geological Society of India. 80: 123-129.

Ekwe AC, Opara AI, Okeugo CG, Azuoko GB, Nkitnam EE, Abraham EM, Chukwu CG, Mbaeyi G(2020). Determination of Aquifer Parameters from Geosounding data in Parts of Afikpo Sub-basin, southeastern Nigeria. Arab J. Geosci. 189 (13): 1-15.

Emberga TT, Omenikolo AI, Opara AI, Onyekuru SO, Agoha CC(2021). Comparative Assessment of Analytical Models used for Geo-Hydraulic Estimation in Imo River Basin, Nigeria. Online J. Earth Sci. 15: 1-16.

Freeze J, Cherry JA(1979). Groundwater. Prentice-Hall Inc., Engle Wood Cliffs, New Jersey. Pp. 491.

Freeze RA, Cherry JA(1979). Groundwater. Prentice Hall Inc., Englewood Cliffs, New Jersey.

Hazen A(1892). Some Physical Properties of Sands and Gravels, with Special Reference to their Use in Filtration. 24th Annual Report, Massachusetts State Board of Health, Pub.Doc. No.34, 539-556

Herbert RR, Kitchinq R(1981). Determination of Aquifer Parameters from Large-Diameter Dug Well Pumping. Groundwater. 19(6).

Kasenow M(2002). Determination of Hydraulic Conductivity from Grain Size Analysis. Water Resources Publications, LLC, Highland Ranch, CO, USA. Pp. 83.

Kozeny J(1927). Uber Kapillare Leitung Des Wassers in Boden. Sitzungsber Akad.Wiss.Wien Math.Naturwiss.Kl., Abt.2a, 136:271-306 (In German).

Krasny J(1993). Classification of Transmissivity Magnitude and Variations. Groundwater. 31(2).

Maier HR, Dandy GC(2000). Neural networks for the prediction and forecasting of water resources variables: A review of modelling issues and applications. Environmental Model. Software. 15: 101 – 124.

Mendosa FG, Steenhuis ST, Todd WM, Parlange JY(2003). Estimating Basin-Wide Hydraulic Parameters of a Semi-Arid and Mountainous Watershed by Recession-Flow Analysis. J.Hydrology. 279(1): 57-69.

Niwas S, Singhal DC(1981). Estimation of aquifer transmissivity from Dar Zarrouk parameters in porous media. Hydrology. 50:393–399.

Nwankwor GI, Cherry JA, Gillham RW(1984). A Comparative Study of Specific Yield Determinations for a Shallow Sand Aquifer; Ground Water. 22(6):764 – 772. DOI: 10.1111/j.17456584.1984.tb01445.x

Nwosu LI, Nwankwo CN, Ekine AS(2013). Geoelectric investigation of the hydraulic properties of the aquiferous zones for evaluation of groundwater potentials in the complex geological area of Imo State, Nigeria. Asian J.Earth Sci. 6: 1–15.

Odong J(2007). Evaluation of Empirical Formulae for Determination of Hydraulic Conductivity based on Grain-Size Analysis. J. Am. Sci. 3(3): 54-60.

Oli IC, Ahairakwem CA, Opara AI, Ekwe AC, Osi-Okeke I, Urom OO, Udeh HM, Ezennubia VC(2020). Hydrogeophysical assessment and protective capacity of groundwater resources in parts of Ezza and Ikwo areas, southeastern Nigeria. Int. J. Energy and Water Resources, 1-15. https://doi.org/10.1007/s42108-020-00084-3.

Opara AI, Ekeh DR, Onu NN, Ekwe AC, Akaolisa CZ, Okoli AE, Inyang GE(2020). Geo‑ hydraulic evaluation of aquifers of the Upper Imo River Basin, Southeastern Nigeria using Dar Zarrouk parameters. Int. J. Energy and Water Resources. https://doi.org/10.1007/s42108-020-00099-3w.

Pinder GF, Celia MA(2006). Subsurface Hydrology. John Wiley & Sons Inc., Hoboken, New Jersey.

Shepherd RG(1989). Correlations of Permeability and Grain Size. Groundwater. 27(5): 663-638.

Sinha R, Israil M, Singhal DC(2009). A hydrogeological model of the relationship between geoelectric and hydraulic parameters of anisotropic aquifers. Hydrogeol. J. 17: 495-503.

Terzaghi K, Peck RB(1964). Soil Mechanics in Engineering Practice. Wiley, New York.

Todd DK, Mays LW(2005). Groundwater Hydrology. John Wiley & Sons, New York.

Ugada U, Ibe KK, Akaolisa CZ, Opara AI(2013). Hydrogeophysical evaluation of aquifer hydraulic characteristics using surface geophysical data: a case study of Umuahia and environs, Southeastern Nigeria.

Ugada U, Ibe KK, Akaolisa CZ, Opara AI(2013). Hydrogeophysical evaluation of aquifer hydraulic characteristics using surface geophysical data: a case study of Umuahia and environs, Southeastern Nigeria.

Ugada U, Opara AI, Emberga TT, Ibim FD, Omenikoro AI, Womuru EN (2013). Delineation of shallow aquifers of Umuahia and environs, Imo River Basin, Nigeria, using geosounding data. Journal of Water Resource and Protection. 5:1097-1109. Available:http://dx.doi.org/10.4236/jwarp.2 013.511115

Uma KO(1989). An appraisal of the Groundwater Resources of the Imo River Basin: Nigerian J. Mining and Geol. 25 (1, 2): 305-315.

Uma KO, Egboka BCE, Onuoha KM (1989). New Statistical Grain-Size Method for Evaluating the Hydraulic Conductivity of Sandy Aquifers. Journal of Hydrology, Amsterdam. 108: 367-386.

Uma KO, Egnoka BCE, Onuoha KM (1989). New Statistical Grain size method for evaluating the hydraulic conductivity of sandy aquifers. J. Hydrology, Amsterdam. 16(108): 367- 386.

Urom OO, Opara AI, Usen OS, Akiang FB, Isreal HO, Ibezim JO, Akakuru OC(2021). Electro-geohydraulic estimation of shallow aquifers of Owerri and environs, Southeastern Nigeria using multiple empirical resistivity equations. Int. J. Energy and Water Resources. https://doi.org/10.1007/s42108-021-00122-B.

Vukovic M, Soro A(1992). Determination of Hydraulic Conductivity of Porous Media from Grain-Size Composition. Water Resources Publications, Littleton, Colorado

Vukovic M, Soro A(1992). Determination of hydraulic conductivity of porous media from grain-size composition: Water Resources Publications, Littleton, CO. Pp. 83.