IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 3, Issue 4 Ver. II (Jul - Aug. 2015), PP 25-30
www.iosrjournals.org

Analysis of Microstructural Properties of Pliocene Aquifer in the Benin Formation, using Grain Size Distribution Data from Water Borehole in Akwa Ibom State, Nigeria

Udoh F.Evans[1], Nyakno J. George[2] and Aniekan M. Ekanem[2]
[1]*Physics Unit, Department of Science, Maritime Academy of Nigeria, Oron*
[2]*Department of Physics, Akwa Ibom State University, Ikot Akpaden, PMB 1169, Uyo, Akwa Ibom State, Nigeria.*

Abstract: *Aquifer microstructural properties were determined using grain size distribution data obtained from core samples collected during a drilled water borehole. The core samples were collected at depths between 50-152ft (21.5-65.4 m), corresponding to the aquifer repositories. Samples were oven dried at* 80^0 *C for 2hrs. Part of the samples was used to obtain porosity for aquifer material, while the other part was analyzed mechanically for particulate size distributions. The effective particulate size distributions at* d_{10}, d_{20} *and* d_{60} *were obtained and used to compute the aquifer uniformity coefficient* (C_u)*.The effective particulate size distributions complemented by eight empirical formulae were deployed to determine hydraulic conductivity of the aquifer. The ratio of the horizontal hydraulic conductivity to vertical hydraulic conductivity yielded anisotropy values for the aquifer. Results show that fractional porosity values ranged from 0.282 to 0.492; uniformity coefficient was between 2.5 and 12; horizontal hydraulic conductivity ranged between 0.343 and 2.511 m/day while the vertical hydraulic conductivity values obtained ranged from 1.320 to 2.907 day/m. Anisotropy values* (A_v) *determined for the aquifer ranged between 0.118 and 1.005. These results suggest that the aquifer is of gravelly sand within the deltaic deposit with no clay intercalation and has good potential for groundwater resources.*

Key words: *Particulate size, Porosity, Uniformity coefficient, Hydraulic conductivity, Anisotropy and Alluvium*

I. Introduction

As groundwater becomes increasingly relied upon as a source of potable water supply in most parts of the world, characterization of microstructural properties of aquifers become pertinent in order to actually determine the effects of dead-end pores which affect groundwater abstraction (Evans et al., 2010; George et al., 2015). In reality, geologic materials are not usually of the same size and shape in all directions for any given formation. Carlson (2006), Khalil and Santos (2009) and Aguilar (2013) noted that, geologic materials usually varies horizontally and vertically, with the horizontal values greater than the vertical values giving rise to anisotropy. These variations can be used to estimate microstructural properties of groundwater aquifers.

It has been observed that, particulate size is a fundamental property of sediments and it exerts the most significant control over microstructural properties of sedimentary aquifers as well as adjoining geomaterials (Freeze and Cherry, 1979; Uma *et al.,* 1989; Vukovic and Soro, 1992; Alyamani and Sen, 1993; Odong, 2013). Aquifers are often characterized by a number of microstructural parameters, which geophysicists have been delineating from subsurface measurements, mostly indirectly and occasionally in direct measurements. The most considered parameters are resistivity, thickness and depth of burial of the desired sediments, permeability, transmissivity, anisotropy, coefficient of uniformity, hydraulic conductivity as well as porosity.

Porosity is the ratio of the volume of the interstices (pores) to the total rock volume. These pores are of great importance in groundwater studies because they serve as water conduits when they are connected to diagenesis. The origin of these pore spaces comes from the very geologic processes that governs the deposition of sediments, but modified after the rock becomes lithified by diagenesis or secondary reformation processes that result in development of fractures, joints, divides or openings. When dealing with subsurface saturated layers (beneath the vadose zone where the pores are filled with air and with water), the water content is comparable to the porosity.

Studies by Freeze and Cherry (1976) and Alyamani and Sen (1993) have suggested that, hydraulic conductivity which is a measure of the ease of which a porous material transmit water through its interconnected voids, is empirically related to the particulate size distribution in an aquifers. This relationship is often used to estimate aquifer hydraulic conductivity values especially where direct permeability data are scarce. Hydraulic conductivity values are usually not homogeneous and isotropic. The variability in hydraulic conductivity in the horizontal and vertical directions causes subsurface anisotropy, which is very common in alluvial deposit (Todd and Mays, 2005; Shahid and Hazarika, 2010; Sattar *et al.,* 2014). Such deposits are prominent in the Benin Formation. However, there are other conditions that can introduce subsurface anisotropy which include: facies change, joints, divides, faults, saline water incursions, variation in cementation, thinning or thickening of adjacent geounits, graded bedding, sedimentary structures, fabric (grain orientations), clay lenses and variation in sorting (Helbig, 1993; Prioul *et al.*, 2004; Odoh and Onwuemesi, 2009; Al-Rousan *et al*., 2011).

Groundwater flows by means of mechanical energy, with difference in piezometric pressure, which has been the driving force. The flow of groundwater as well as the transportation of water-soluble pollutants can be modelled in saturated and unsaturated zone of earth materials using the knowledge of geomicrostructural property of a given site. Estimation of microstructural properties of aquifer from grain size of geomaterials has the advantage of being less dependent on the geometry and hydraulic precincts of aquifers. Study area is challenged with borehole water failure, especially during the dry season. Therefore, actions necessary to control this groundwater abstraction bedevilment in the study area are needed in order to maintain sufficient quantity of water all year round in the area.

II. The study area

The study area belongs to the Benin Formation of the Nigerian Niger Delta. It comprises near shore poorly sorted sand. Geologically, the near surface geomaterials are that of alluvial sedimentary deposits (Reyment, 1964; Hosper, 1971; Onyeagocha, 1980; Petters, 1991 and Okiwelu *et al.*, 2011). The study area is drained by local streams and river channels that empty itself into the Atlantic Ocean. The leached sand and near surface gravel deposits in the study area have attracted the populace into sand/gravel mining. This mining activities contaminates the existing surface water in the area, hence, the over dependency of the local community on groundwater.

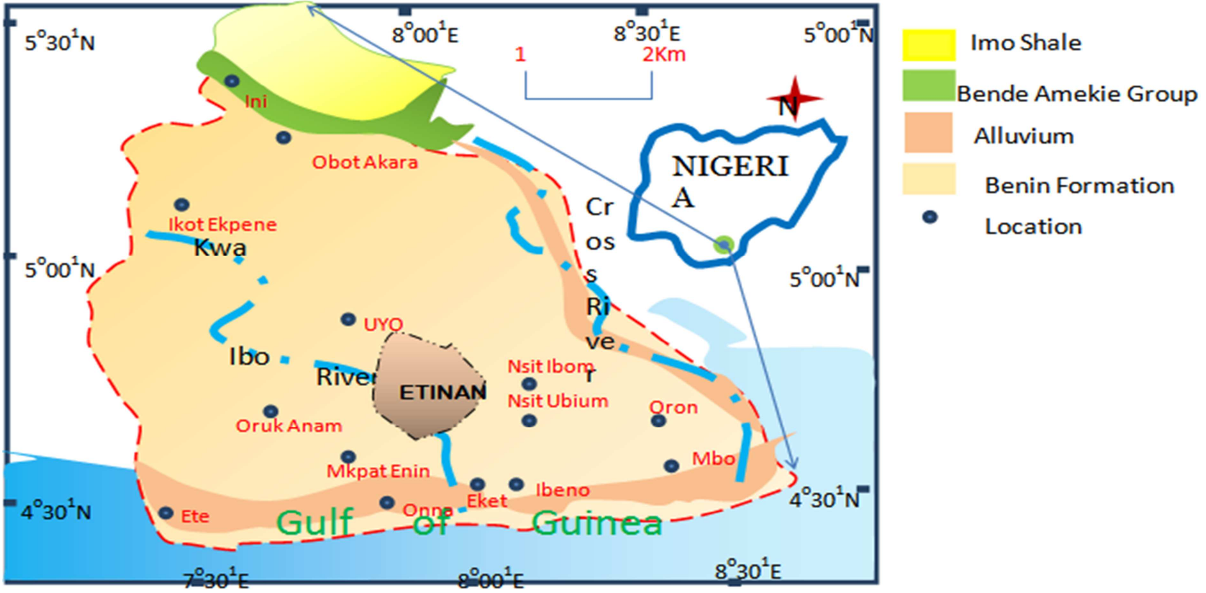

Fig.1: Map of Akwa Ibom State showing Etinan (study location), other settlements and rivers.

III. Methodology

Core samples were collected from a well using the split spoon method at depths ranging from 50 to 150ft and at intervals of 2ft, during the drilling of a community water supply borehole at Ikot Umiang Ede, Etinan, Akwa Ibom State. This depth corresponds to the location of the Pliocene aquifer in the study area and it generated several data within the screen of the well and across large portion of the aquifer. On the whole, a total of 11 core samples were obtained and used for the study. These samples were carefully inspected to ensure the absence of organic debris and every cleaned bulk sample was dried in an oven at 80^{o}C for 2 hours.

The porosities (the volume of void space in geologic materials) of samples were determined using imbibition method. This method involves the displacement of one fluid by another. In this case, the displaced fluid was air while distilled water was used as the displacing fluid. This was necessary to avoid chemical interaction with the sediments. The volume of the displacing fluid was previously measured to enable the computation of voids' volume. After the fluid has displaced all the air, the total volume (sediment and water) was then measured. In order to obtain an estimate of total effective fractional porosity of each sample, a 500 ml graduated cylinder was first filled partially with 100ml volume of water. Thereafter, sediment was carefully added to the cylinder and allowed to settle and compact. Care was taken to avoid air entrapment within the saturated column. The column was compacted slightly by tapping the side of the cylinder with a rubber mallet to approximate natural system packing conditions near surface. The volume of sediment was determined along with the volume of water added. When the water level in the cylinder rose above the surface of the sediment, a correction was made to the water volume added. The fractional porosity of core samples was determined from the relationship

$$\eta = \frac{v_{water}}{v_{bulk}} \tag{1}$$

where η is the porosity, v_{water} is the volume of interstices or voids and v_{bulk} is the total volume or bulk volume.

The evaluation of particle size distribution was carried out by mechanical analysis involving the sieve of samples through several screens until the whole sample is divided into the desired amount of sieves. The percentage by weight of passage of samples was plotted against particulate size distribution (mm) on a semi logarithmic graph paper. The effective particulate size distributions were obtained at d_{10}, d_{20} and d_{60} corresponding to 10%, 20% and 60% finer by weight form the plot. Core sample uniformity coefficient (C_u) was computed from

$$C_u = \frac{d_{60}}{d_{10}} \tag{2}$$

In determining the hydraulic conductivity (*K*), eight (8) empirical formulae described in Vukovic and Soro (1992) and Kasenow (2002) were employed. These formulae have their general form as:

$$K = \frac{g}{v}.C_u.f(n).d_e^2 \tag{3}$$

where *g* is acceleration due to gravity given as 9.81 m/s^2 or 32 ft/s^2, *v* is kinematic viscosity (the ratio of dynamic viscosity to water density) given as $8.0\text{x}10^{-7}$ m^2/s or $8.0\text{x}10^{-6}$ ft^2/s, C_u is sorting coefficient, *f(n)* is porosity function and d_e effective particulate size. The values of C_u, *f(n)* and d_e are dependent on the methods for particulate size analysis. Previous studies had presented the following formulae, which were used for this work and the take the form of equation (3) above, they are:

Hazen (1892), $K = \frac{g}{v}C[(1-10)(\eta - 0.26)]d_{10}^2$ (4)

Beyer (1966), $K = \frac{g}{v}C(B_H \log(500/C_u)d_{10}^2$ (5)

where *C* is conversion factor used to convert *K* from cm/s to m/day given by $6.0\text{x}10^{-4}$, B_H is given as $6.0 \text{ x } 10^{-4}$ and *v*(*n*) is 2.4 when *n* is 0.4.

Vukovic and Soro (1992), $K = 3.49C(n^3/(1-n)^2 \Phi d_{17}^2$ (6)

where Φ is temperature correction, which is taken to be 1.313 at water temperature of 30°C.

Kozeny (1953), $K = 5400(n^3/(1-n)^2 d_{10}^2)$ (7)

where η is taken to be porosity and *K* is measured in m/day.

United States Bureau of Reclamation (USBR) formula for *K* determination is given as

$$K = \frac{g}{v}(4.8\times10^{-4})d_{20}^{0.3}\times d_{20}^2 \tag{8}$$

Chang and Chen (2000) noted this model to be more appropriate for determining *K* when the sorting coefficient (C_u) is less than 5.

Pavchich formula, $K = C - d_{17}^2$ (9)

Slichter (1898), $K = 4960n^{3.287}d_{10}^2$ (10)

Terzaghi (1925), $K = \frac{g}{v}CR((n-0.13)^2/(1-n)^{\frac{1}{3}})d_{10}^2$ (11)

where R is an empirical coefficient which is a function of the nature of particle surface and it assumes an average value of $8.4 \text{ x } 10^{-4}$ (Kasenow, 2002).

Effective horizontal hydraulic conductivity (K_h)was calculated using the formula

$$K_h = \frac{\sum t_i K_i}{\sum t_i} \tag{12}$$

where t is the layer thickness of the *ith* layer. Also the vertical hydraulic conductivity (K_v) was determined from the relationship

$$K_v = \frac{\sum t_i}{\sum t_i / K_i} \qquad (13)$$

The ratio of K_v in Equation 13 to K_h in Equation 12 enabled the estimation of the aquifer vertical anisotropy (A_v) in Table 1.

IV. Results and discussion

Aquifer's microstructural properties determined from core samples obtained between depth 50ft (16.0m) and 152ft (49.0m) of the aquifer studied are shown in Table 1. Result shows that the coefficient of uniformity within the depth investigated ranged from 2.5 to 12.0, with most section of the aquifer having uniformity coefficient great than 4. This is an indication that, the aquifer grains within depths of investigation are predominately poorly sorted. This result is not surprising since it is typical of the Benin Formation characterized by intercalations of sediments with various facies changes as detailed in Reyment, (1964); Hosper, (1971); Onyeagocha, (1980); Petters, (1991) and Okiwelu *et al.* (2011).

Table 1: Summary of aquifer microstructural properties at various depths

S/N	Depth range (ft)	Grain size (mm)			C_u	η	K_h (m/day)	K_v (m/day)	A_v
		d_{10}	d_{20}	d_{60}					
1	50-52	0.14	0.28	0.35	2.500	0.498	2.511	2.498	1.005
2	60-62	0.12	0.25	0.40	3.333	0.392	1.214	1.583	0.767
3	70-72	0.13	0.29	0.36	2.769	0.407	1.548	1.646	0.940
4	80-82	0.19	0.47	1.05	5.526	0.346	1.444	1.692	0.853
5	90-92	0.11	0.38	0.90	8.182	0.311	0.481	2.078	0.232
6	100-102	0.12	0.40	0.80	6.667	0.329	0.653	1.531	0.427
7	110-112	0.13	0.50	1.22	9.385	0.299	0.519	1.924	0.270
8	120-122	0.19	0.39	1.25	6.579	0.330	1.219	1.320	0.923
9	130-132	0.12	0.44	1.32	11.000	0.288	0.412	2.424	0.170
10	140-142	0.13	0.47	1.30	10.000	0.295	0.496	2.015	0.246
11	150-152	0.11	0.30	1.32	12.000	0.282	0.343	2.907	0.118

$C_u > 4$ = Poorly sorted; $C_u < 4$ = Well sorted, Source (Field work, 2014)

The values of the horizontal hydraulic conductivity obtained ranged from 0.343-2.511 mday^{-1}, while the value for vertical hydraulic conductivity is between 1.32 and 2.498 mday^{-1}. These values show that there is high horizontal and vertical flow tendency of air and water in the aquifer studied. The anisotropy values (0.118 - 1.005) determined, suggest alluvial sediment with some gravel intercalations. This is in support of Zaslavsky and Rogowski, (1969); Todd and Mays (2005) and Odong (2013) who reported that, anisotropy value between $0.1 \leq 0.6$ suggest alluvial sediments. The value of anisotropy that is as low as 0.01 suggests clay while values approaching unity may indicate gravelly sand. A contour plot of the variation of the horizontal conductivity (K_h) and vertical anisotropy (A_v) with depth along the major aquifer is displayed in Fig. 2.

The vertical hydraulic conductivity indicates somewhat decreasing values with depth. The result for the study is a pointer to subsurface lateral flow, and it is important in water quality sustenance by limiting the vertical absorptive capacity of the earth strata. For multiple layered earth materials, the hydraulic conductivity perpendicular to the earth layers is lower than the conductivity parallel to soil layers. Therefore, lateral conductivity is determined by the layer (within 50ft or 21.5m) with the highest conductivity, while the vertical conductivity is controlled by the layers with lowest hydraulic conductivity. This layer is present at depths below 120ft (51.6m) in the aquifer depth of the study area.

The subsurface anisotropy values evaluated tend to decrease with depth. This further predicts subsurface lateral flow. Zaslavsky and Rogowski (1969) and Odong (2013) found the combined effects of slope and soil anisotropy caused by subsurface lateral flow in both saturated and unsaturated subsurface sediment conditions. The efficacy of anisotropy obtained for the study was established by correlating it with values of coefficient of uniformity (sorting) of the site, which yielded a correlation coefficient factor of 0.85 (Fig. 3). Also, correlation coefficient factor of 0.74 was achieved (Fig. 4) as a result of correlating anisotropy values with porosity. The high correlation coefficient among the aquifer properties shows that, results obtained for the study could be relied upon for sustainable groundwater development and management.

The study reveals that, anisotropy is not a static quality; rather, it changes over depth of the aquifer. This can alter the direction of soil water flow as well as water flow redistributed solutes. Therefore, anisotropy needs to be accounted for in a variety of land-use decisions. It is a factor in watershed response to evapotranspiration and precipitation effects; leachate migration and aquifer performance. Land use professionals need to be aware of such processes which naturally or artificially alter the hydrogeologic/hydrologic characters of earth's materials. For sustainable groundwater management, hydrologic and hydrogeologic evaluation targeting at geomaterial indices of anisotropy are needed to be periodically updated.

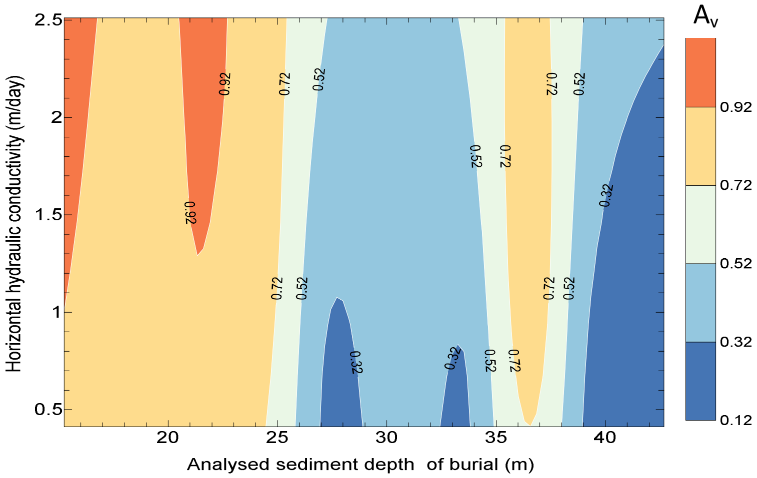

Fig.2: The trend of distributions of aquifer repository anisotropy at various horizontal conductivity and depths of burial

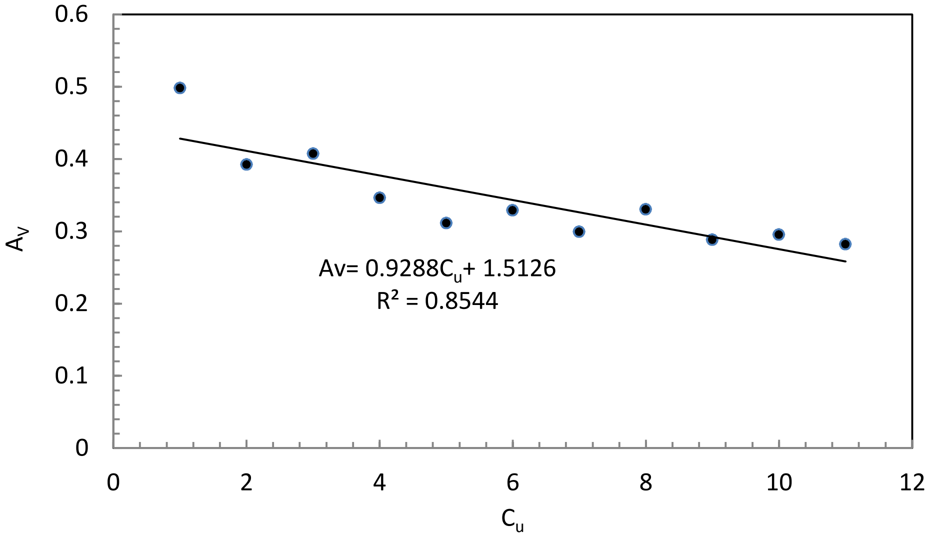

Fig. 3: Graphical relationship of anisotropy (A_v) with sorting coefficient (C_u)

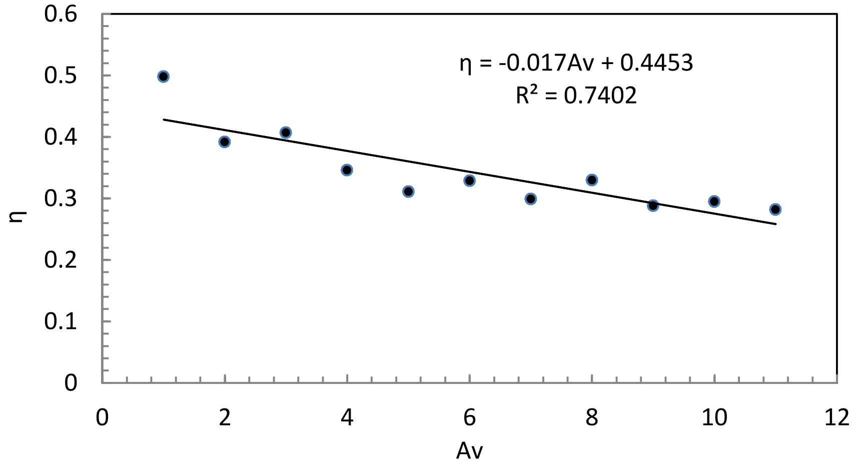

Fig. 4: Graphical relationship of anisotropy (A_v) with porosity (η)

References

[1]. Al-Rousan, T. Al-Hattamleh, O. & Al-Dwairi, R. (2011). Effect of inherent anisotropy on shear strength following crushing of natural aqaba subgrade sand. Jordan Journal of Civil Engineering, 5(3), 431-444.

[2]. Alyamani, M. S. &Sen, z. (1993). Determination of hydraulic conductivity from grain size distribution curves. Groundwater, 31, 551-555.

[3]. Beyer, W. (1966). Hydrogeologischeuntersuchungenbei der ablagerrung von was serchadstoffen. ZeitschriftfuerAngewandteGeologie, 12(11), 599-606.

[4]. Carlson, D.A. (2006). Systematic variability of hydraulic conductivity within theMississippi River alluvial aquifer in Northeastern Louisiana. Gulf Coast Association of Geological Societies, 56, 121-136.

[5]. Evans, U.F., George, N.J., Akpan, A.E., Obot, I.B., Ikot, A.N., 2010: A study of superficial sediments and aquifers in parts of Uyo local government area, Akwa Ibom State, Southern Nigeria, using electrical sounding method. E-Journal of Chemistry **7**(3), 1018-1022.

[6]. Freeze, R. A. & Cherry, J. A. (1979).Groundwater. Prentice Hall Inc., New Jersey.

[7]. George, N.J., Emah, J.B., Ekong U.N., 2015.Geohydrodynamic properties of hydrogeological units in parts of Niger Delta, southern Nigeria. J. Afr. Earth Sci. 105, 55-63.

[8]. 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,34, 539-556.

[9]. Helbig, K. (1993). Simultaneous observation of seismic waves of different polarization indicates subsurface anisotropy and might help to unravel its cause. Journal of Applied Geophysics, 30(12), 1-24.

[10]. Hosper, J.(1971). Gravity field and the structure of the Niger Delta, Nigeria.*Geological Society of America's Bulletin, 76*, 407-422.

[11]. Kasenow, M. (2002). Determination of hydraulic conductivity from grain size analysis. Water Resources Publication, Highland Ranch, Colorado.

[12]. Kozeny, J. (1927). Uberkapillareleitung des wassers in Boden, SitzungsberAkad.Naturwiss Kl.Abt.za, 136, 271-306.

[13]. Mohamed, A. K., Fernando, A. &Monterio, S. (2009). Influence of degree of saturation in the electric resistivity–hydraulic conductivity relationship. Surv.Geophys , 30, 601–615.

[14]. Odong, J. (2013). Evaluation of empirical formulare for determination of hydraulic conductivity based on grain size analysis. International Journal of Agriculture and Environment, 1, 1-8.

[15]. Odoh, I. B. &Onwuemesi, A. G. (2009). Estimation of anisotropic properties of fractures in Presco Campus of Ebonyi State University, Abakaliki, Nigeria using azimuthal resistivity survey method. Journal of Geology and Mining, 1(8), 172-179.

[16]. Onyeagocha, A. C. (1980). Petrography and depositional environment of the Benin Formation.Journal of Mining and Geology, 17 (2), 147-151.

[17]. Okiwelu, A., Evans, U. &Obianwu, I. (2011).Geoelectrical investigation of externalcorrosion of earth buried pipeline in the coastal area of Gulf of Guinea. Journal of American Science, 7 (8), 221-226.

[18]. Petters, S. W. (1991). Regional geology of Africa lecture notes in Earth Science, 40, Heidelberg, Springer-Verlag.

[19]. Prioul, R. Bakulin, A. &Bakulin, V. (2004). Nonlinear rock physics model for estimation of 3D subsurface stress in anisotropic formations: theory and laboratory verification. Geophysics, 69 (2), 415-425.

[20]. Reyment, R. A. (1964). Review of Nigerian Cretaceous-Cenezoic stratigraphy.*Journal of the Nigeria Mining, Geological and Metallurgical Society, 1*, 61-80.

[21]. Sattar, G. S. Keramat, M. &Shahid, S. (2014). Deciphering transmissivity and hydraulic conductivity of the aquifer by vertical electrical sounding (VES) experiments in Northwestern Bangladesh. Applied Water Science. DOI: 101007/s/3201-014-0203-9.

[22]. Shahid, S. &Hazarika, M. K. (2010). Groundwater droughts in Northwestern District of Bangladesh. Water Resources Management, 24, (10), 1989-2006.

[23]. Slichter, C. S. (1898). Theoretical investigations of the motion of groundwaters. United States Geological Survey, 19th Annual Report

[24]. Terzaghi, K. & Peck, R. B. (1964).Soil Mechanics in Engineering Practice. John Wiley, New York.

[25]. Todd, D. K. & Mays, L. W. (2005).Groundwater Hydraulic Conductivity. John Wiley and Sons, New York.

[26]. Uma, K.O. Egboka, B. C. &Onuoha, K. M. (1989).New statistical grain size method for evaluating the hydraulic conductivity of sandy aquifers. Journal of Hydrogology, 108, 367-386.

[27]. Vukovic, M. &Soro, A. (1992).Determination of hydraulic conductivity of porous media from grain size composition.Water Resources Publication, Littleton, Colorado.

[28]. Zaslavsky, D. &Rogowski.A.S. (1969). Hydrologic and morphologic implications of anisotropy and infiltration in soil profile development. Soil Science Society Proc. 33:594-599.