Available online at www.pelagiaresearchlibrary.com

Pelagia Research Library

Advances in Applied Science Research, 2011, 2 (1): 153-162

ISSN: 0976-8610
CODEN (USA): AASRFC

Laboratory estimation of aquifer effective porosities from core samples obtained during borehole drilling in parts of The Niger Delta Region, South-South, Nigeria

[1]George, N.J., [2]Obianwu V.I. and [3]Obot, I.B

[1]Department of Science Technology, Akwa Ibom State Polytechnic, Akwa Ibom State, Nigeria
[2]Department of Physics, University of Calabar, Calabar, Nigeria
[3]Department of Chemistry, Faculty of Science, University of Uyo, Uyo, Nigeria

---

ABSTRACT
In this work, twenty-three core samples of aquifer units constituting fine sand, medium grained sand and gravelly sand were used to estimate the effective porosities in different locations covering ONN, EK and NSI of the southern part of Akwa Ibom State. Effective porosities have been found to range from 2.75 to 40.08% with an average of 23% approximately at the end of the laboratory analysis. The increases in porosities were found to prograde northeast of the entire study area indicating the orientation of high void to volume of sample ratio.

Keywords: Effective porosity, Laboratory measurement, Core samples, Niger Delta and aquifer.

INTRODUCTION

The study of porosity and its distribution is important since this yields information about the amount of fluid that can be stored and how it is being distributed within a formation [1]. Relationship between porosity and other measurable quantities in geophysical exploration, such as resistvity (and the associated formation factor), and other parameters, have long been the subject of much research and many publications. Information about the porosity of a formation is also important in oil exploration because of the relationship between effective porosity and permeability of the formation [2]. Effective porosity is the porosity that is available for the circulation of free fluid. It may be much lower than the total porosity which is the ratio of the volume of voids in the rock or soil to the total volume of the rock or soil. Porosity is a dimensionless quantity expressed as a decimal fraction or percentage [3]. Effective porosity can also be expressed as the ratio of the volume of water that can flow by gravity to the volume of the soil or rock. This definition accounts for the free circulation of fluid in porous consolidated and unconsolidated materials of rock and soil respectively.

Sedimentary rocks/soils contain about 95% of the groundwater. The formation of high porosity and permeability such as unconsolidated sands and gravels or consolidated sandstone, constitute important aquifers. limestones and dolomites are not good aquifer units unless they acquire a substantial secondary porosity due to fracturing or dissolution [4 - 7]. Sometimes poorly cemented chalks or oolitic limestones have a higher intergranular porosity which makes them water bearing formations. Again, unweathered igneous and metamorphic rocks rarely have water potential because their primary porosity is very low [8]. These rocks cannot form aquifers unless they are highly weathered or fractured. The weathered or fractured rocks are often good aquifers provided they have low clay content. This suggests the reason why aquifers in the basement rocks are found along the fractured or weathered zones [9].
According to the principles of fluid dynamics in porous media, [10] has differentiated two kinds of porosities which are: Volumetric porosity (n) and areal porosity (n_A). If the total unit volume V_T of a soil or rock is divided into the volume of the solid portion V_s and the volume of the voids V_v, the volumetric porosity (n) can be expressed as in equation 1;

$$n = \frac{V_v}{V_T} \qquad (1)$$

Similarly, the areal porosity n_A, can be defined for any areal cross section through a unit volume, as

$$n_A = \frac{A_v}{A_T} \qquad (2)$$

where A_v is the total area occupied by the voids and A_T is the total area. Various cross sections within a given unit volume may exhibit differing areal porosities n_{A1}, n_{A2}….The volumetric porosity n, is an average of the various possible areal porosities, n_{Ai}. The porosity n can be an important controlling influence on hydranlic conductivity, K. In sampling programmes carried out within deposits of well-sorted sand or in fractured rock formations, samples with higher n generally also have higher k [11] Unfortunately, the relationship does not hold on a regional basis across the spectrum of possible rock and soil types. Clay-rich soils, for example, usually have higher porosities than sandy or gravelly soils but lower hydranlic conductivities [12].

The porosity, n is closely related to the void ratio e, which is widely used in soil mechanics. The void ratio is defined as:

$$e = \frac{n}{1+n} \quad \text{or} \quad n = \frac{e}{1-e} \qquad (3)$$

The values usually fall in the range 0 – 3. The relationship shows that void ratio, e increases exponentially as porosity n increases as shown in Fig. 1

In this paper an attempt is made to use laboratory analysis on core sample to estimate the porosity distribution of the aquifer in the area where Millennium Development Goals project for groundwater development is sited. This being the baseline study will help in evaluating other hydranlic parameters that characterize the existing aquifers in the zone since porosity is strongly related with other hydraulic parameters.

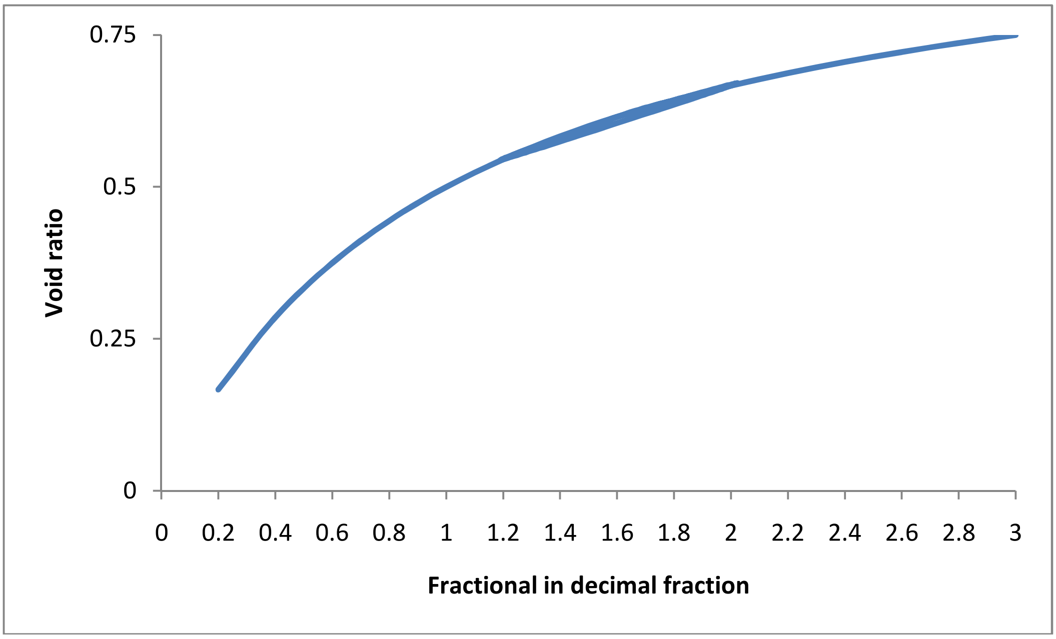

Fig. 1: A graph of void ratio against fractional porosity

Location, geology and hydrogeology of the study area

The study is globally located in Awa Ibom State, southern Nigeria within latitudes $4^0\ 30^1$ and $5^0\ 00^1$N and longitudes $7^0\ 45^i$ and $8^0 30^1$ E (Fig. 2). The area extends across parts of two Nigeria Sedimentary Basins, the Niger Delta and the Calabar Flank. The detailed geology of these basins is given elsewhere [13 – 15]. The Niger Delta, which occupies more than 80 percent of the area is made up of the Akata Formation (shales, intercalated sands and siltstones), the Agbada Formation (sands and sandstones, intercalated with shales) in the middle, and the Benin formation (coarse-grained, gravelly sands with minor intercalations of clay) at the top.

However, only the Benin Formation is exposed in the study area. The Calabar Flank consists mainly of the Albian Awi Formation (conglomeritic sandstone), the Albian Mfamosing Limestone Formation (Shales intercalated with sandstones). The Lower Campanian to Maastrichtian Sediments consist mostly of dark shale with lenses of gypsum, limestone, and siltstone beds, while the Lower Tertiary Sediments are mostly shales with minor limestone and sandstone. Only the Lower campanian to Lower Sediments outcrop in the study area. The stratigraphic setting in the area is shown in Table 1.

Table1 : Stratigraphic relations of geologic unit the area, including type of aquifer after [20]

Age	Formation	Aquifer
Recent	Alluvium Beach ridges	Alluvial Deposit
Pliocene-Pleistocene	Benin Formation	Coastal plain sand
Oligocene-Miocene		
Late Eocene	Ogwashi-Asaba or lignite Formation	
Middle Eocene	Bende-Ameke Group	
Early Eocene-Paleocene	Imo Shale Group	Aquiclude
Maastrichtian	Nsuka Formation Ajali Sandstone	Lower sand

The Benin Formation (Coastal Plain sand), which covers about 80 percent of the area, forms the major aquifer layer. Lithologically, it is made up of coarse to medium grained loose sands and gravels. Thin clay horizons and lenses occur in places disturbing the vertical and horizontal deposition of the aquifer, giving rise to a multi-aquifer system. The aquifer may reach about 300m in the thickness. This aquifer is underlain by thick shale (aquiclude) in the northern sector. A lower sand aquifer underlies the aquiclude (Table 1). The alluvial deposit aquifer overlies the Benin formations in the southern parts of the study area where the core samples for this analysis were collected. The thickness of these aquiferous layers varies from place to place [16].

However, a typical borehole section reveals the following in Table 2.

Table 2: Aquifer thickness of a certain borehole in the area after [17]

Aquifer(s)	Approximate thickness(m)
Alluvial Deposit	20
Coastal plain sand	80-200
Imo shale Aquiclude	40
Lower sand	20

Presently, only the Coastal Plain sand aquifer is being tapped and the core samples were obtained in this aquifer unit. Some hydrological data for this unit are as follows: total depth of boreholes, 42-172m, saturated thickness of aquifer, 39-100m, static water level, 7-55m; yield, 216-5304 m^3/day; transmissivity 200-8300 m^2/day; hydraulic conductivity, 2-28m/day; drawdown, 1.2-42.5m and storage coefficient 0.10-0.30. [18] divided the entire state into three major hydrogeological units (SWL) (Fig. 1): area A < 20cm; B, 20-50m; C > 50m the study area falls in area Fig.2. The main flow directions of the coastal plain aquifer are to the south and southeast.

MATERIALS AND METHODS

Twenty three core samples of aquifers were obtained during borehole drilling in the study area which was sponsored by the Millennium Development Goals (MDG) initiative. A coring machine with sample corer of 750mm diameter was used. The samples collected were cut into cylindrical shapes in order to enable the determination of their volume. Salt and original liquid were removed from the samples by washing them with distilled water. The washing also cleansed the samples of clay and silts that contaminated the samples during coring operation [19].

Since prolonged soaking was unsatisfactory, the samples were put in a desicator and evacuated at a pressure of 0.3mbar for a period of 1hour according to [20]. At the end of this, deaerated distilled water was introduced into the desicator until the water completely covered the samples. The samples were soaked for 24hours. The clean samples were dried in a conventional temperature – controlled oven utilizing a constant temperature of 105 degree Celsius for 16 hours [21]. It was considered that reversible change cannot occur at this point. The dry core samples were cooled off in a dessicator to ambient air temperature prior to being weighed. An electronic top pan balance of the least count error of 0.01g was used to weigh the samples. Before measurement of the wet weight of the samples, the diameter and length of the samples were taken and the average was found. For the saturation of the samples, vacuum pressure of 0. 3mbar was used and the soaking hour was 16hours. This guaranteed proper soaking. The effective porosities for the core samples of aquifers obtained from different wells averagely separated by 2.1km were determined using equation 4.

$$\Phi = \frac{W_w - W_d}{V} \times 100\% \qquad (4)$$

Where Φ = porosity expressed in percentage

W_w = wet weight in gm
W_d = dry weight in gm
V = volume of core sample in cm^3

RESULTS AND DISCUSSION

The result displayed in Table 3 was obtained during the laboratory experiment on the core samples. The effective porosity ranged from 2.75% to 40.08% with an average of 22.86%. The porosities were obtained for aquifers whose geomaterials were of medium-grained sand, fine sand and gravelly sand as these are the abundant aquifer units (Benin Formation) in the study area.

Table 3: Calculation of effective porosity ø for aquiferous core samples

VES Code	Dry weight (g)	Wet weight (g)	Wet weight – Dry weight	Volume of sample (cm^3)	Porosity %	Reference coordinate x(m)	Reference coordinate y(m)
EK_1	216.51	235.71	19.2	100.51	19.10	1285	14153
EK_2	224.31	241.84	17.53	-ditto-	17.44	1530	40402
EK_3	214.78	234.93	20.15	-ditto-	20.05	1620	17995
EK_4	212.50	230.61	18.11	-ditto-	18.02	3105	44803
EK_5	233.86	250.31	16.45	-ditto-	16.37	22039	12455
EK_6	203.86	233.56	29.68	-ditto-	29.51	22597	41084
EK_7	251.21	256.87	5.66	-ditto-	5.63	23960	14812
EK_8	247.34	250.11	2.77	-ditto-	2.75	22966	16018
ONN_1	248.87	253.74	4.87	-ditto-	4.84	0(reference)	0(reference)
ONN_2	232.41	239.72	7.31	-ditto-	7.27	2692	8970
ONN_3	241.07	249.22	8.15	-ditto-	8.10	1452	7908
ONN_4	234.63	244.19	9.56	-ditto-	9.51	1575	4088
ONN_5	202.09	229.73	27.64	-ditto-	27.48	3396	6724
ONN_6	205.10	241.31	36.21	-ditto-	36.00	22497	2446
ONN_7	199.88	239.59	39.71	-ditto-	39.48	22966	8344
ONN_8	185.17	225.48	40.31	-ditto-	40.08	28528	6423
NS_1	240.23	250.44	10.21	-ditto-	10.15	24060	15147
NS_2	165.28	203.43	38.15	-ditto-	37.93	30237	13973
NS_3	214.21	246.66	32.45	-ditto-	32.27	23502	15359
NS_4	212.79	252.11	39.32	-ditto-	39.09	29199	12131
NS_5	194.69	231.47	36.78	-ditto-	36.57	36861	12488
NS_6	198.79	238.89	40.21	-ditto-	39.98	27241	18196
NS_7	205.71	234.16	28.45	-ditto-	28.28	36459	22251

The geomaterial with high porosities were found prograding northeast of the study area on the average Fig.4. This cuts across the three different locations. The lowest porosity (2. 75%) was found in EK_7 locations Table 3. The area did not show unique pattern of increase in porosity.The places with intrinsic high porosities portray the high void to volume ratio of the geomaterial. Figure 4 was drawn using a kriging (interpolation) method. The figure clearly shows on the average, that porosities decrease as we move from north east to the north west of the entire area of the survey. This really follows the direction of drainage pattern which empties into the Atlantic Ocean. The high and low porosities obtained in an unpredicted manner show the inhomogeneity of the formations characterized with intercalation of different materials. This study is diagnostic of the pattern of hydraulic conductivities and hydraulic transmistivities that characterise the aquifer. With the porosity distributions, it is possible to determine the groundwater reserve in the area. Since groundwater availability depends on the thickness and porosity of the geomaterial in which they are found.

The zones that have lower porosities are also expected to have lower void ratios. In all the places, fine sand aquifer had the highest porosity (40.08%) followed by medium grained sand aquifer while the gravelly sand had the least values like 2.75%, 4.84% and so on as shown on Table 3.

This is a confirmation of the fact that fine grained sands have high porosities while coarse – grained materials have lower porosities.

However, since porosity does not necessary mean permeability most of the materials that are porous may not be permeable as their pore spaces may not be interconnected. The maximum void ratio in the area is approximately 0.3 while the lowest is 0.03 approximately (from field data).

During the analysis, non of the materials had zero effective porosity and this shows high sand to clay ratio. This is evident on the fact that the major aquifer units have minor intercalation of clay and silt. Effective porosities between 30 and 40% indicate the presence of sand and gravelly sand. The uneven occurrence of lower effective porosity values indicates uneven distribution of clay and silty materials that usually intercalate with high yielding aquifer units. Areas with porosity greater than 10% but lower than 30 percent indicate fine sand units. These zones were found to contain minor clay during the processing of the core samples.

The process of cementation and compaction can also be the good reason for lower porosities found in the southeastern part of the study area. This is because in clastic rocks, primary porosities are generally hindered by cementation and compaction which increases with age of the formation.

CONCLUSION

The ultimate objective of the present investigation was to estimate the aquifer effective porosity using the core samples of the aquifer unit obtained during bore hole drilling in the Niger Delta region of southern Nigeria. This was done as a baseline study to estimate the values in order to see its distribution along the Delta. These results show clearly that the region has porosities ranging between 2.25 to 40.08% with an average value of 23% approximately. The lower porosities have been interpreted to be due to cementation and compaction and also due to minor intercalation of materials whose pore spaces are not interconnected within the area. These materials may be clay, shale or silt.

Table 3 and the contour maps in Figs. 4 and 5 show that effective high porosities have been found in aquifer units to increase in the north east of study area.

With 23% average value of effective porosity in the entire area, groundwater reserve is deemed to have been prolific in the area. Materials during drilling and borehole data have revealed that the major aquifer units in the area include the fine sand, medium grained sand and gravelly sand. The data obtained in this work are significant as they shall be used along with other aquifer parameters for groundwater management in the area.

Besides, the effective porosities obtained in this work shall be used to estimate other parameters such as formation factor and other site dependent constants that are used in the study of fluid flow in hydrogeology or reservoir analysis in oil companies.

REFERENCES

[1] Salem, H.S., *Energy source*, (**2001**), 23,589-596.
[2] Archie G.E, *Trans. Am. Inst. Mm. Metal and Petr. Eng*; (**1942**). 146,54-62.
[3] Niwas, S; de Lima, O.A.L; *Groundwater*, (**2003**), 41(1), 94-99.
[4] Tsagarakis, P. K; Dialynas, E.G; Angelakis, N. A; *Agriculture Water Management*, (**2004**), 66(1), 35-47.
[5] Worthing ton, P.F; *Journal of Applied geophysics*, (**1993**), 30, 215-228.
[6] Frohlic, R, Kelly, W.E; Wiley press, (**1993**), 324.
[7] Mazac, O, cislerova, M, Vogel, T, *Journal of Hydrology*, (**1993**), 103, 117-126.
[8] De Lima, O. A. L; Sharma, M. M; *Geophysics*, (**1990**), 50, 1347-1356
[9] Satpathy, B.N. and Kanungo, Dv, *Geophysical Prospecting*, (**1976**), 24, 725-736.
[10] Bear, J; America Elsevier New York, (**1972**), 403.
[11] Freeze, Q.A. and cherry J. A. Groundwater, New Jersey: Printice-Hall, (**1979**), 604.
[12] Sen, P. N; Goode, P.A; Sibbit, A; *Journal of Applied physics*, (**1988**), 63, 4832-4840.
[13] Short R.C. and Stauble, A. *J. American Applied physical Geology Bulletin*, (**1967**), 51, 761-779.
[14] Murat, R.C, African Geology, University of Ibadan, Nigeria, (**1972**), 251- 268.
[15] Ramaanathan, R. M. and Fayose, A. E., Vieweg-Verlag, (**1989**), 55-75
[16] Edet A.E and Okereke C.S. *Journal of African Earth science*, (**2002**), 35, 433-443
[17] ESU, O. E, Okereke, C.S and Edet A. E. *Global Journal of Pure and Applied sciences*, (1999), 5(91), 8996.
[18] Tahal Consultants, Rural water supply in Mainland. Technical report, (**1980**), 114.
[19] Hago A. H. Unpublished M.Sc Thesis, University of Putra, Malaysia (**2000**).
[20] Emerson D.W. *Proc. Aust. Inst. Mining and Metall*, (**1969**), 230, 51-62.
[21] Gale house, J.S, New York, Wiley inter science, (1971), 653.
[22] Chapellier D. Well logging in hydrogeology (1st ed.) Rotterdam A.A. Balk Ema, (**1976**).

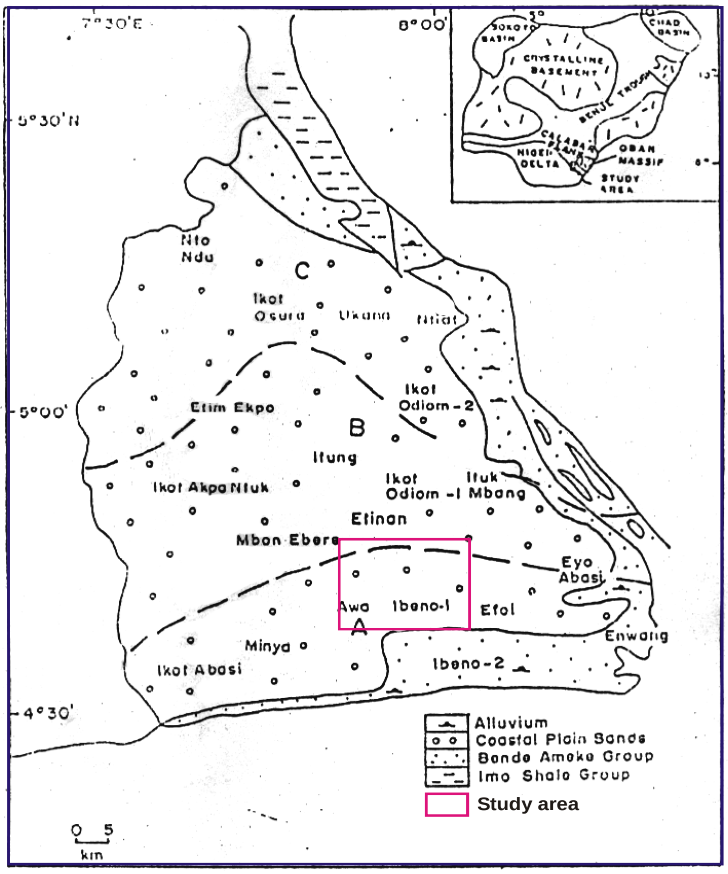

Fig. 2: Map of Akwa Ibom State showing the geology, hydrogeology and location of the study.

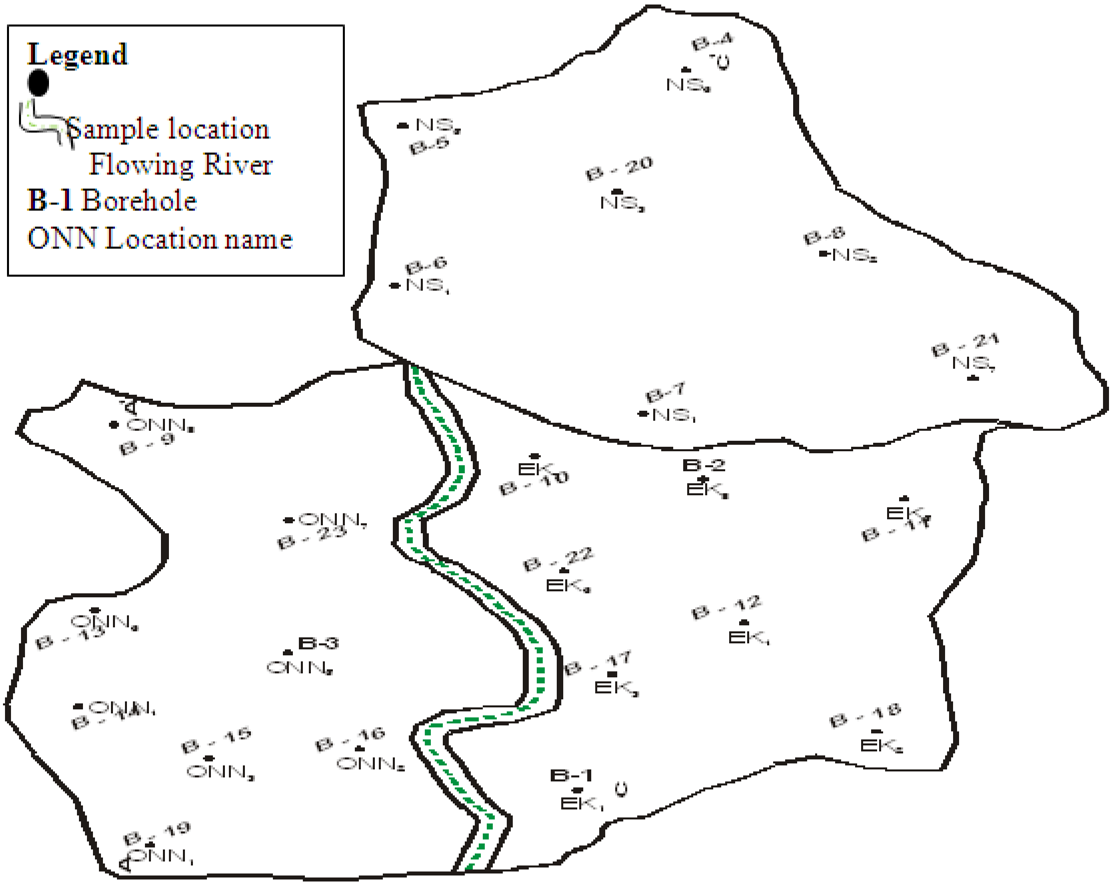

Fig 3: Map showing a study locations and sample points of borehole where the core samples were collected during drilling

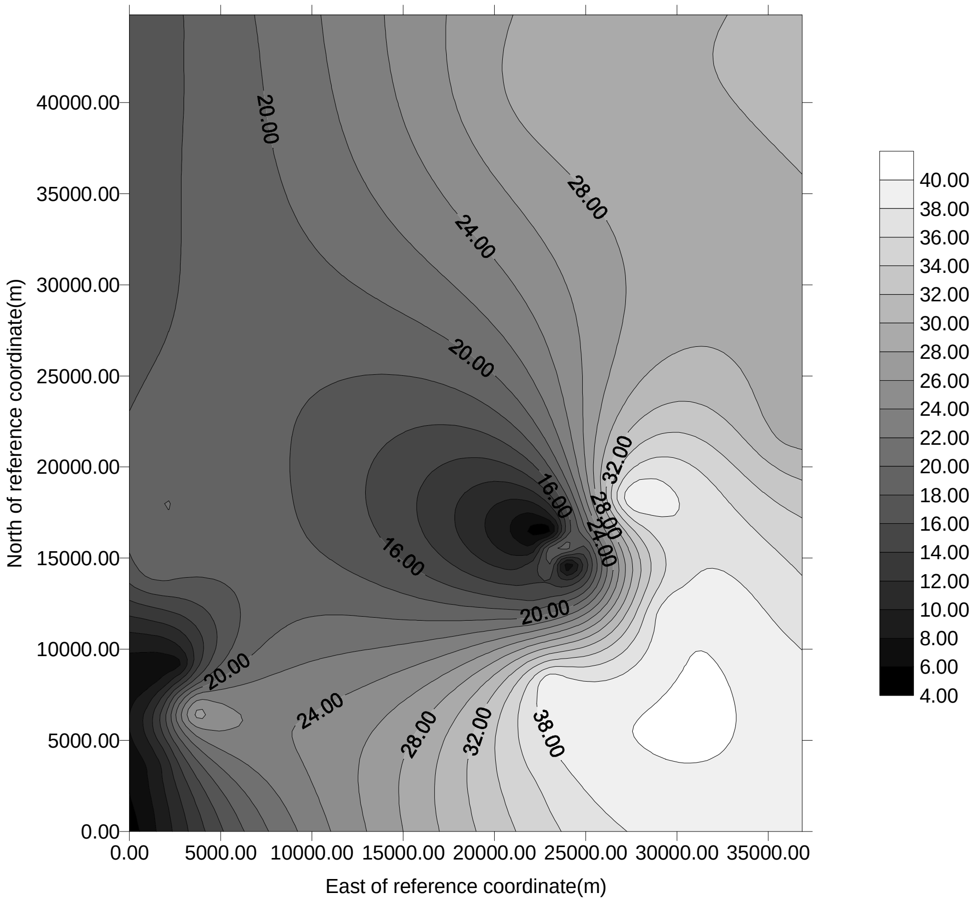

Fig.4: 2-Dimensional Porosity distribution contour in the study area

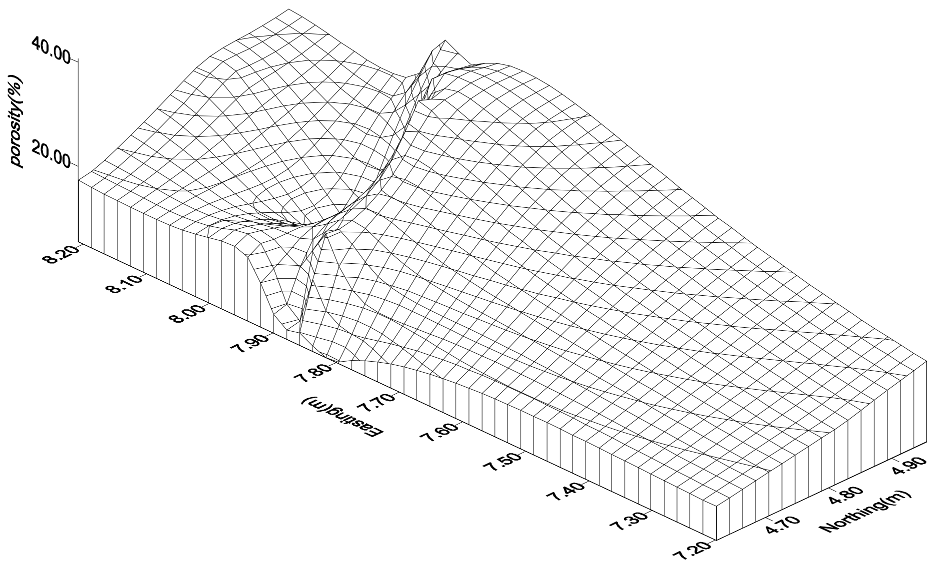

Fig.5: 3-Dimentional representation of porosities in the study area increase of the study area