Estimation of Aquifer Hydraulic Characteristics from Surface Geo-Electrical Sounding of Affa And Environs Southeastern, Nigeria.

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Abstract

Hydrogeophysical evaluation of Affa and environs, Southeastern Nigeria was carried out to determine the groundwater potential, nature and variation of aquifer conditions as well as hydraulic properties of the area. Twenty-two (22) vertical electrical soundings (VES) were acquired with a maximum half current electrode spacing of 500 metres using ABEM 4000 SAS Terrameter. Eight (8) of the twenty-two (22) VES data were made within the vicinity of existing boreholes for correlation purposes. Computer iterative modeling using 1D Interpex Resistivity Software was applied in the VES data analysis and processing. The interpreted VES results integrated with data from existing boreholes were used to estimate the variation in aquifer hydraulic properties and Dar-Zarrouk parameters. The established results revealed four to seven geo-electric layers. Depth to water table varies from 94.84m to 158.4m while aquifer thickness ranges from 42m to 148m. Similarly, hydraulic conductivity varies 8.1m/day to 16.3m/day, with a mean of 12.22m/day. The aquifer transmissivity ranges from $370m^2$/day to $1484m^2$/day with a mean value of $927m^2$/day. The product of aquifer hydraulic conductivity and conductivity diagnostic value (Kσ) across the study area ranges from $0.00052\Omega^{-1}$ m/day to 0.0290 $\Omega^{-1} m/day$ with mean value of $0.01148\Omega^{-1}$m/day.

Key words: Hydrogeophysical, Aquifer, Hydraulic Properties, geo-electric layers and Southeastern Nigeria

Introduction

Numerous methods are accessible in subsurface (groundwater) hydrology for the assessment and evaluation of the hydraulic characteristics of aquifers, such as hydraulic conductivity, transmissivity and storativity. The most commonly used methods involve conducting pumping tests on existing or newly drilled wells followed by analysis and interpretation of pumping tests data. However, it should be appreciated that such tests are capital and labour intensive, requiring several boreholes, many operatives and a considerable amount of equipment (Hamill and Bell, 1986). Furthermore, the estimation of hydraulic properties is crucial for the reliable simulation of the groundwater flow in aquifers.

The various formulae available for the calculation of aquifer characteristics from pumping test data are valid only if various assumptions about aquifer continuity, thickness homogeneity, isotropic well storage and the nature of the field flow are valid under field conditions (Tizro and Singhal, 1993). Thus the estimation of aquifer parameters may be erroneous in the presence of diverse field conditions. More so, the procedures are time consuming and cost prohibitive if practiced indiscriminately.

The geo-electrical method using Schlumberger technique is an efficient device for determining the underground geologic formation of a region (Zohdy *et al*. 1974; Zohdy, 1989). The utilization of the geo-electrical technique has guided researchers to build up surface resistivity techniques for producing quantitative estimates of the water transmitting characteristics of the aquifer (Griffiths, 1976; Igbokwe *et al*., 2006). Hence, large number of empirical and semi-empirical equations correlating geo-electrical and hydraulic parameters of aquifer, under different geological conditions have been proposed and applied in the literature (Kelly 1977; Niwas and Singhal, 1985). In recent years, resistivities determined from surface measurements have been used to estimate aquifer properties such as yield, hydraulic conductivity and transmissivity (Ekwe *et al.*, 2006; Akpabio *et al.,* 2008; Batayneh, 2009).

Therefore, in the present study, the geo-electrical data obtained through Schlumberger method have been analyzed using existing models as well as the proposed model presented here to account for impact of aquifer anisotropy on the hydraulic parameters of aquifers in Affa and environs. These models were to delineate the possible saturated rock facies (aquifers) and the general distribution of resistivity responses of the subsurface geologic formations underlying this portion of Anambra Basin. The Schlumberger method was adopted because it is easier, faster and cost effective to be carried out in the field and software for the interpretations of the results are readily available.

The present study is expected to help in reducing the number of cases of borehole failures and also provide useful information on the possible sites for groundwater development. This will bring about sustainable water supply to match the geometrical population increase in the area of study. It is expected that this work shall be useful tool for governmental water resources development projects in the area of study.

The area of study is Affa and its environs in Udi Local Government Area and Ukehe in Igbo-Etiti Local Government Area of Enugu Sttate, Nigeria which lie between latitudes $6^{o}26^{l}$N to $6^{o}40^{l}$N and longitudes $7^{o}14^{l}$E to $7^{o}26^{l}$E (Figs. 1 and 1). The areal extent is about 617square kilometers. Affa is about 30km North-West of Enugu town. The area can be accessed by major roads (e.g. Eke - Akpakwume and Ngwo - Ukehe Express ways), minor roads (e.g. Affa – Umuoka, Amofia-Imezi - Amofia-Agu and Amaozalla - Obinagu roads) and foot paths through which field work was made possible.

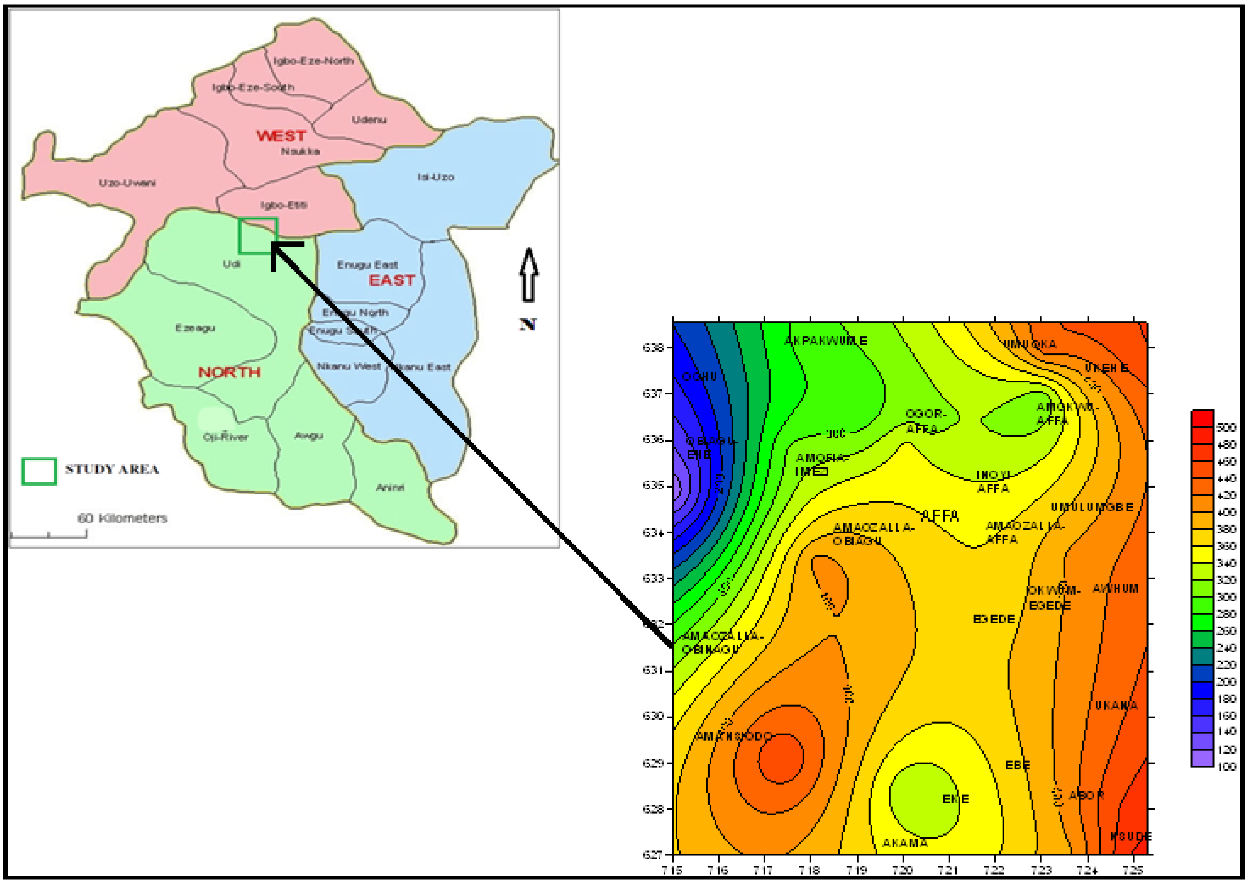

Fig. 1: Location Map of the study area

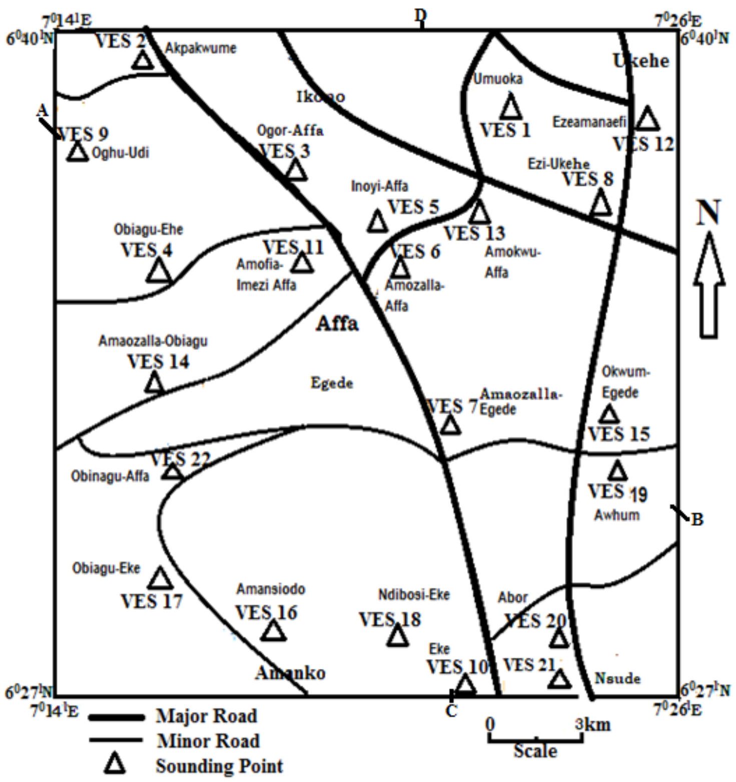

Fig. 2: Accessibility map of the study area showing VES points.

The Geology of Affa and Its Environs

The study area covers Affa, Egede, Eke, Ebe, Akpakume, Nze and Oghu, Umuoka, Ukana, Nsude, Awhum in Udi L.G.A and some part of Ukehe in Igbo-Etiti L.G.A all in Enugu south-eastern Nigeria. These areas are underlain by the Ajalli Formation, Nsukka Formation and westward by Imo Formation (Fig. 3). These formations are exposed at different locations as a result of anthropogenic activities such as road constructions, farming, urbanization and excavation or by agents of denudation such as erosion, flooding and seepages in form of springs. The geologic formations under consideration were evaluated to ascertain their groundwater potential, their subsurface stratigraphic characteristics, their aquifer thickness, geometries, and their hydraulic properties.

However, the study area shows two major types of land forms which consists of high relief green velvety residual hills and ridges and the low land areas. The high relief portion is geologically associated with the outcrops of Ajalli Formation and remnants of Nsukka Formation forming the central to eastern part of the study area and in the western part is associated with exposures of Imo Shale. In general terms the Ajalli Sandstone underlies areas of height above 300m while Nsukka Formation is characterized by green velvety residual hill dotting the area from Oji River to Ankpa facing the north.

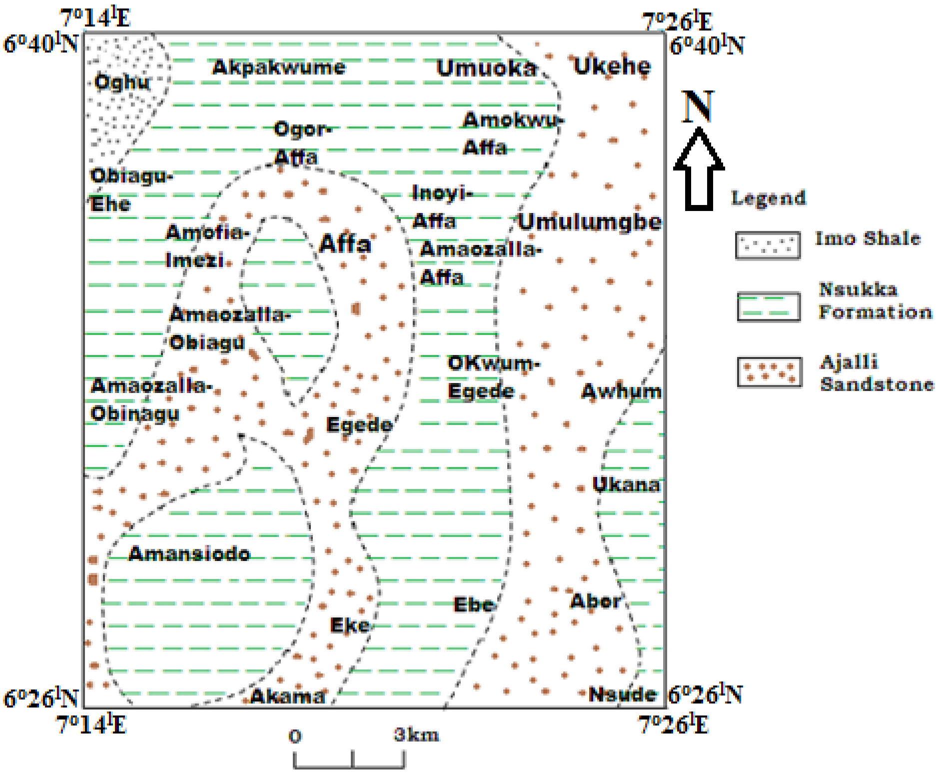

Fig.3: The Geologic Map of the Study Area.

Methodology

The methodology employed in this research work was in stages; conception of a study area and a topic, desk studies, reconnaissance survey and geophysical survey as well as data analysis, data presentation and reporting (Fig.4). Desk studies carried out provided insight on available literature works on estimation of hydraulic parameters of aquifers from vertical electrical sounding and data from the hydrogeological investigations on the project area. Available topographic, political and geologic maps of the research area were also consulted.

A reconnaissance or preliminary survey was carried out to identify important geological spots and to know the feasibility of the designed hydro- geophysical techniques and to have a good geologic appraisal of the research area.

At this stage a good social rapour have been established with the inhabitants of the study area. Vertical Electrical Sounding (VES) was conducted at twenty two stations in the study area using the resistivity meter (OMEGA) for groundwater investigation purposes. The Schlumberger configuration having the maximum half-current electrode spacing (AB/2) ranges from 250 to 500m were used. The survey was conducted along the existing major or minor roads with good stretch and at the vicinity of existing boreholes in the study area. The apparent resistivity values obtained were plotted against half the current electrode spacing on a bi-logarithmic graph in order to determine the depth to aquifers. Many researchers such as Zohdy (1989); Onwuemesi and Egboka (2006); Okoro *et al.* (2010); Ezeh (2011); Anakwuba *et al.* (2014); Chinwuko *et al.* (2015); Osele *et al.* (2016); Chinwuko *et al.* (2016) and others have used this technique efficiently in groundwater exploration. An integrated approach of geo-electrical sounding and hydrogeological surveys has been used to establish the relationship between the geo-electrical and hydraulic parameters of the aquifers in the research area. Data from eight boreholes (Table 3.1) were available on which pumping tests and geophysical logging have been conducted. These data were analyzed and the hydraulic conductivities and water resistivities of the aquifers documented by Enugu Rural Water Supply Authority (ENRUWASA). Similarly, information from existing boreholes was useful in this study for effective delineation and evaluation of the groundwater potentials as well as hydraulic parameters of the aquifer in the research area.

In order to obtain quantitative and qualitative information in ground water flow and its potentials in the area of study, it is essential to estimate the hydraulic characteristics of its aquifer system such as hydraulic conductivity and transmissivity, which are usually obtained either from pumping tests or laboratory experiments where core samples exist. However, alternative cheap and quick approaches have been applied in this work by utilizing non-invasive surface geophysical method. Geophysicists have realized that a correlation exists between hydraulic parameters and electrical properties of aquifers, as both properties are related to the pore space structure and heterogeneity of subsurface layers (Kelly, 1977, Huntley, *et al.*, 1996; Rubin *et al.*, 2005). Niwas and Singhal (1981) established an analytical relationship between aquifer transmissivity and transverse resistance and also between transverse resistance and hydraulic conductivity.

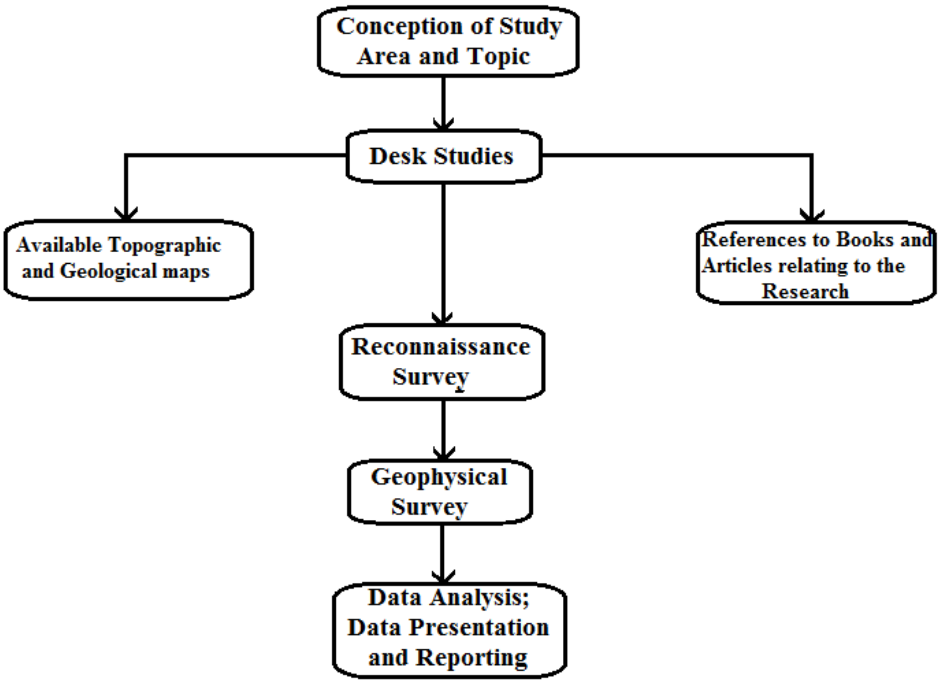

Figure 4: Research Workflow

Table 1: Summary of Borehole Data

Well S/N	Locations	TDD (m)	SWL (m)	EC (Ω/cm)	AT (m)	ρ_w (Ω/cm)	PP (hrs)	DD (m)	R (m)	K (m/day)
1	Akpakwume	160	85	21.81	48.16	458.5	6	10.5	95	11.5
2	Inoyo –Affa	196	96	28.77	81.40	347.6	7	9.2	68	10.2
3	Amofia – Imezi	200	108	24.33	106.33	411.0	6	7.2	55	9.7
4	Amokwu-Affa	140	79	29.67	76.11	337.0	6	9.5	70	9.0
5	Amaozalla – Egede	190	80	16.29	124.30	614.0	7	7.5	60	10.5
6	Eke – Udi	160	85	17.99	128.30	556.0	6	7.0	55	7.8
7	Ukehe	286	95	14.71	56.66	680.0	6	6.5	52	6.5
8	Nsude	200	84	16.39	148.40	610.0	9	6.8	59	9.2

Key: TDD-Total depth drilled; SWL-Static water level; EC- Electrical conductivity; AT-Aquifer thickness; ρ_w -Water resistivity; PP-Pumping period; DD-Drawdown; R-Recovery; K-Hydraulic Conductivity

Source: Enugu State Rural Water and Sanitation Agency (ENRUWASA, 2014)

Results and Discussion

Curve types

The study area is characterized by curves HK-type, A-type, K-type, QK and AK-type (Table 2). It is observed that HK-type curve predominate the study area especially areas overlain by Nsukka Formation and Imo Formation. The shape of the geo-electric curves is a particular location of the characteristics of the subsurface geologic layers. The layers resistivity is a function of porosity, moisture content present in the pore spaces and the rock matrix.

Table 2: Classification of VES curve types

VES Curve type	VES N0	VES curve characteristic	Frequency	Percent
K	8,12, 13, 14, 15, 16, 18, 22	$\rho_1 > \rho_2 > \rho_3$	8	36.4
HK	1, 2, 3, 5, 7, 9, 10, 11, 19, 20	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	10	45.5
AK	4, 6,	$\rho_1 < \rho_2 < \rho_3 > \rho_4 > \rho_5$	2	9.1
A	17	$\rho_1 < \rho_2 < \rho_3$	1	4.5
QK	21	$\rho_1 > \rho_2 > \rho_3 > \rho_4 > \rho_5$	1	4.5
Total			22	100

Geo-electric Sections

The modeled interpretation from computer analysis revealed the presence of five to six layers (Fig.5). The layers are top lateritic sand, dry sand, sandy clay, dry sandstone, water saturated sandstone and clay The depth to water table in the study area varies between 98m and 15m and the aquifer thickness was revealed to be lowest in Umunoka area and thickest in Abor and Nsude areas. The central area is predominantly of moderate aquifer thickness of about 120 metres.

Geo-Electric Cross Section with Respect to Mean Sea Level

A cross-section was taken along northwest- south west direction of the area of study (Fig. 5a). Fig. 6a shows a true variation of the different layers delineated through VES. It reveals a thick dry sandstone layer across the area. The depth to water table with respect to mean sea level reveals that VES9 (Oghu) has the shallowest depth of 5.64m while VES19 (Awhum) has the deepest depth of 331.5m. These areas are underlain by Imo shale and Nsukka formation respectively indicating low land shally formation Oghu is underlain by Imo formation Whereas Amofia- Imezi and Awhum is underlain by Nsukka formation indicating low land areas.

More so, at Fig. 6b, the watertable is shallower at VES 13(Amokwu) and VES 6 with depth to watertable with respect to mean sea level ranging from 187.6 to 200.61m, while VES 7 (Amaozalla-Egede) and VES 10 with depth to water with respect to mean sea level approximately 247m is the deepest part. The lethargic fancies are lateritic Overburden, Clayey- sand, sandy clay. Thick dry sand units overlie the water saturated sand units, signifying that the study area is more of unsaturated aquiferous region. Along this profile (C-D) it is clear that the areas are underlain by Ajalli Formation forming a ridge. The aquifer thickness along this cross-section ranges from 42.6m-128.3m.

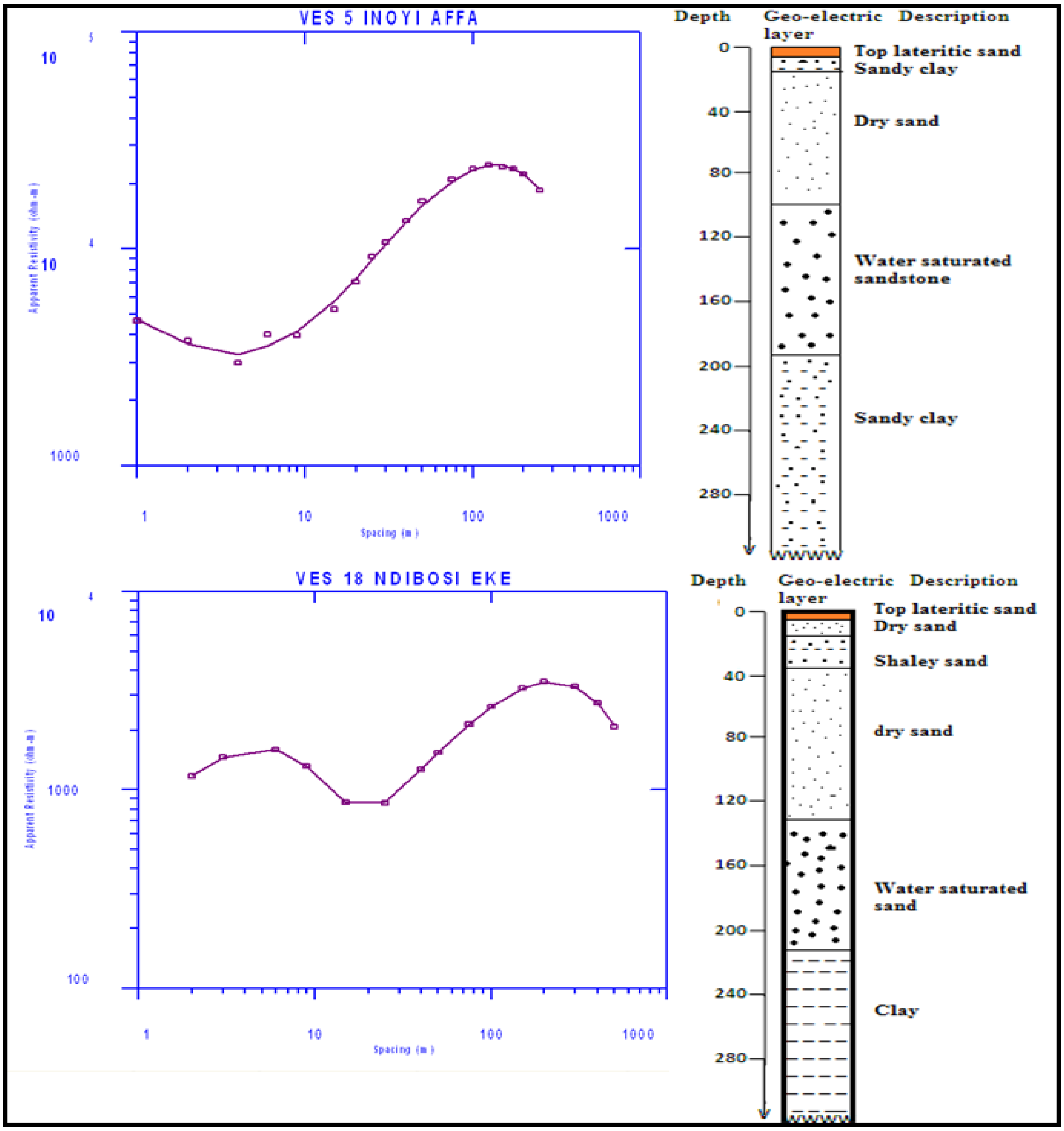

Fig. 5: Sounding curve and descriptive section for VES 5

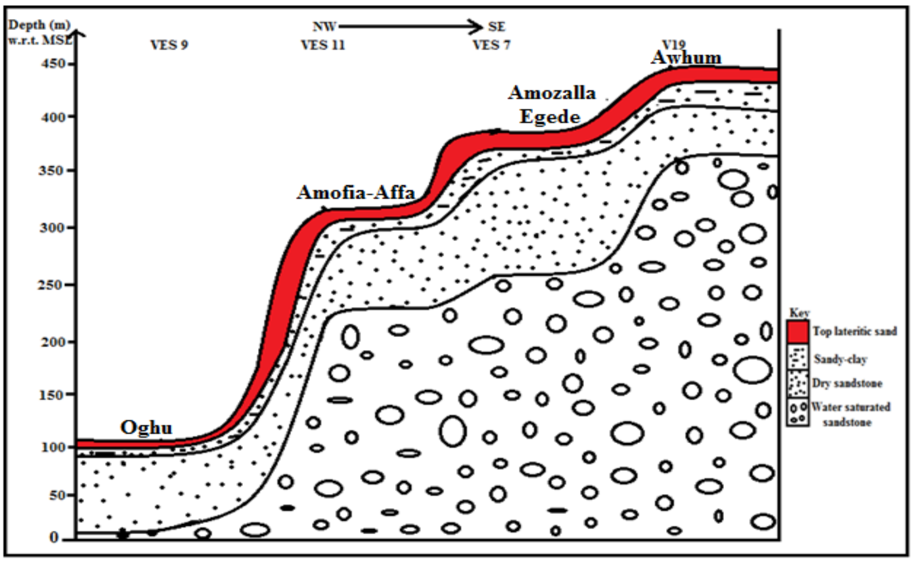

Fig. 6a: Profile A-B: cross-section taken along northwest- southeast direction

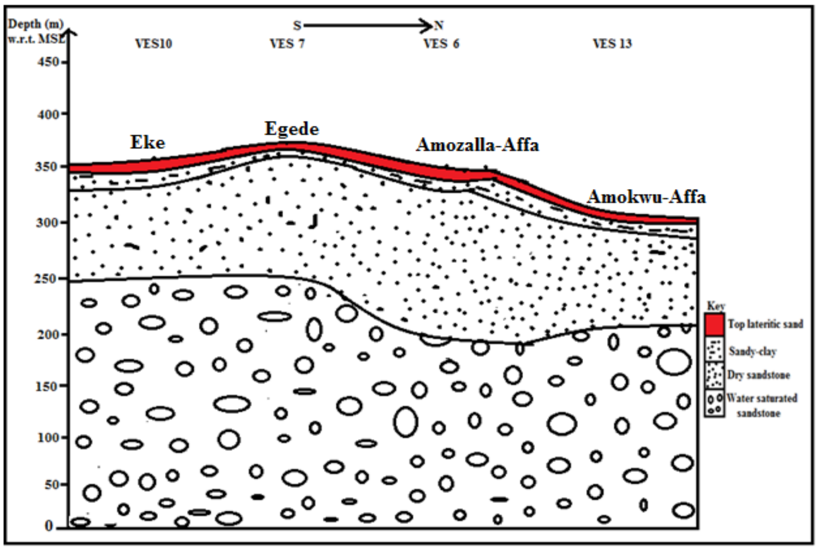

Fig. 6b: Profile C-D taken along South to North

Comparison of VES Curves With Borehole Lithologic Logs

The correlation of borehole log located near one of the sounding stations at Akpakwume at VES 2 (Fig.7a), shows that the overburden thickness in the lithologic section is 22.5 meters while in geo-electric section, it is 0.56 metres. In the underlying layers, the geo-electric units confirm inhibition and integration of some lithologic units from the borehole log. Therefore, the depth to water from the geo-electric unit is 113.6 meters which differs slightly with that of borehole depth of 116.8 meters. There is a good correlation between geo-electric section and borehole section at Akpakwume (Fig. 7a).

However, at Amokwu-Affa axis, the first layer consists of thin layer of top lateritic with apparent resistivity of 916.2Ω and thickness of 0.72m estimated at the VES interpretation while the borehole log reveals 19.7m thick (Fig. 4.23b). The succeeding layers consist of clayey-sand, gritty reddish clay unit with apparent resistivity of 1,142Ω and a thick column of dry whitish sand with apparent resistivity of 3,797. The aquiferous layer consists of well graded friable sand that is water saturated with apparent resistivity of 1,150Ω. Hence, the water table varies a little from the geo-electric unit with value of depth being 101.39 metres in the geo-electric section and 106.43 meters in lithologic unit. The last layer whose base was not reached has a resistivity value of 913.6Ω-m and it is interpreted as sandy clay.

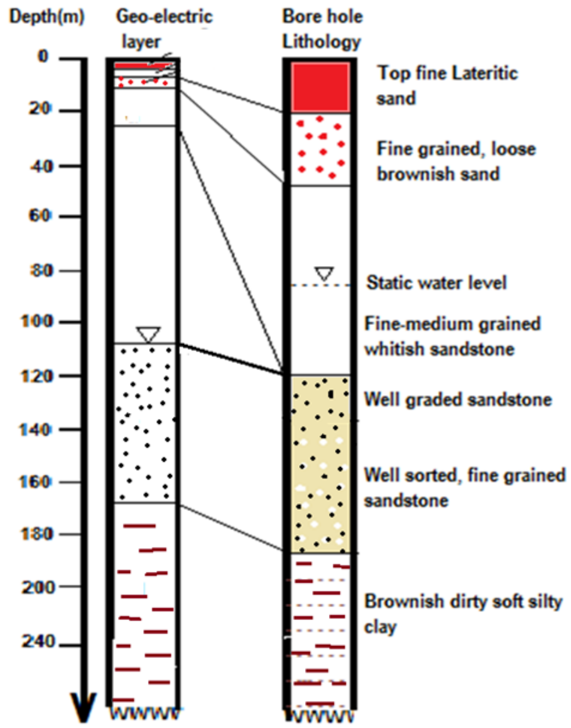

Fig.7a: The Comparison of Akpakwume VES curve with the borehole lithologic log.

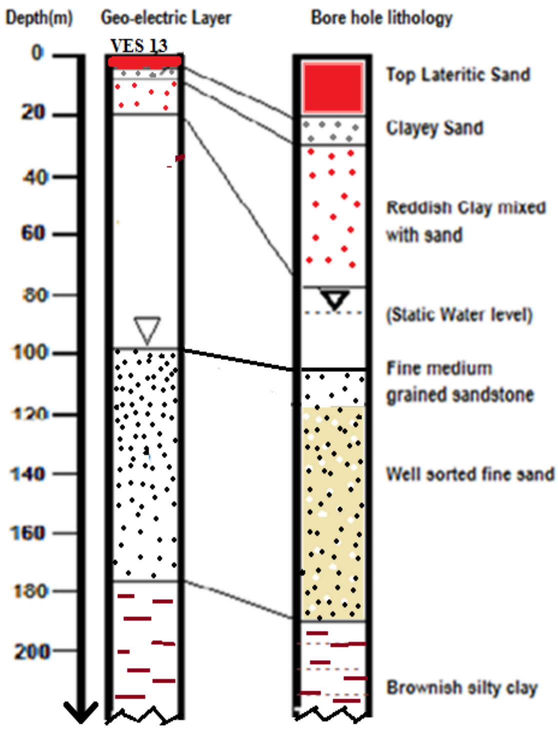

Fig. 4.23b: The Comparison of Amokwu-Affa VES curve with the borehole lithologic log.

Watertable map with respect to mean sea level

Depth to the water table map produced suggests that the depth to watertable with respect to mean sea level is higher in Ukana, Affa, Amaozalla, Obiagu and Nsude areas while at Eke, Ebe, Awhum, Ogor and Oghu areas the depth to water table with respect to mean sea level to be shallow (Fig. 8). There is a correlation between depth to water table and the thickness of the weathered red earth (lateritic overburden). It is evident from the depth map that the deeper watertable is found in areas where thick layers of lateritic overburden and inliers of the Ajalli Formation exist.

The Aquifer hydraulic characteristics maps

From the hydraulic conductivity and transmissivity maps (Figs. 9 and 10), communities around Nsude, Abor, Ukana, Egede Affa have high values of transmisivity as an indication of high hydraulic conductivity and thick aguiferous unit. The aquifer transmissivity values around Nsude, Abor Egede,Affa and Eke are high (1,132 - 1,484 m^2 /day) where as they are low (369.68 - 667.9 m^2/day) around Umuoka, Ukehe, Amokwu, Oghu, Akpakwume and Ogor indicating low yield area. However, moderate values (703.3m - 982.5 m^2/day) exist in areas around lnoyi-Affa, Amofia- imezi Amaozalla Obinagu- Affa, Awhum, Amansiodo, Ebe and Ndiobosi- Eke indicating moderate yield of the aquifer to wells.

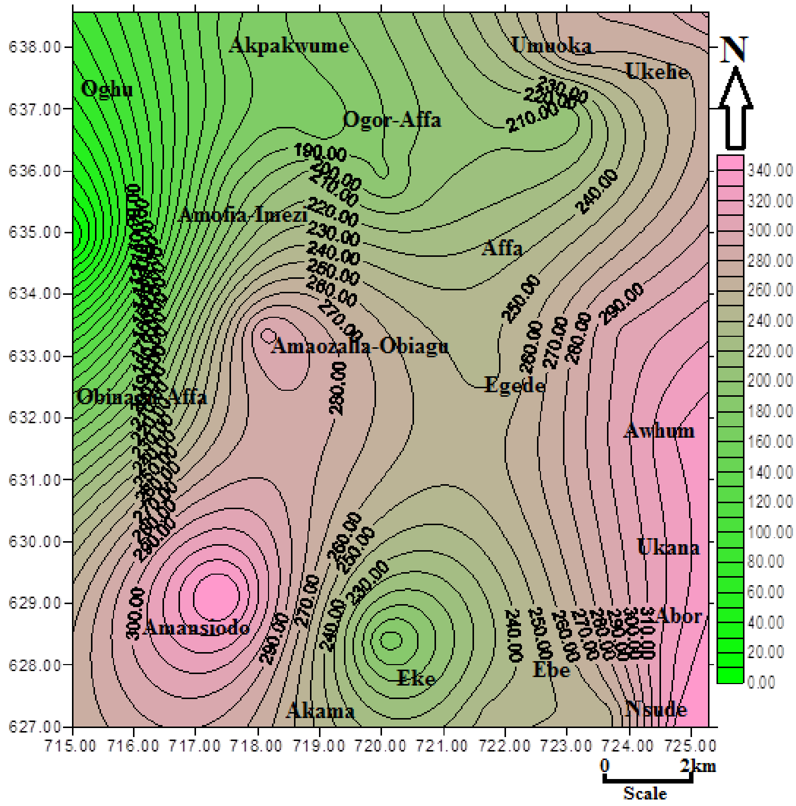

Fig. 8: Watertable map of the study area w.r.t MSL

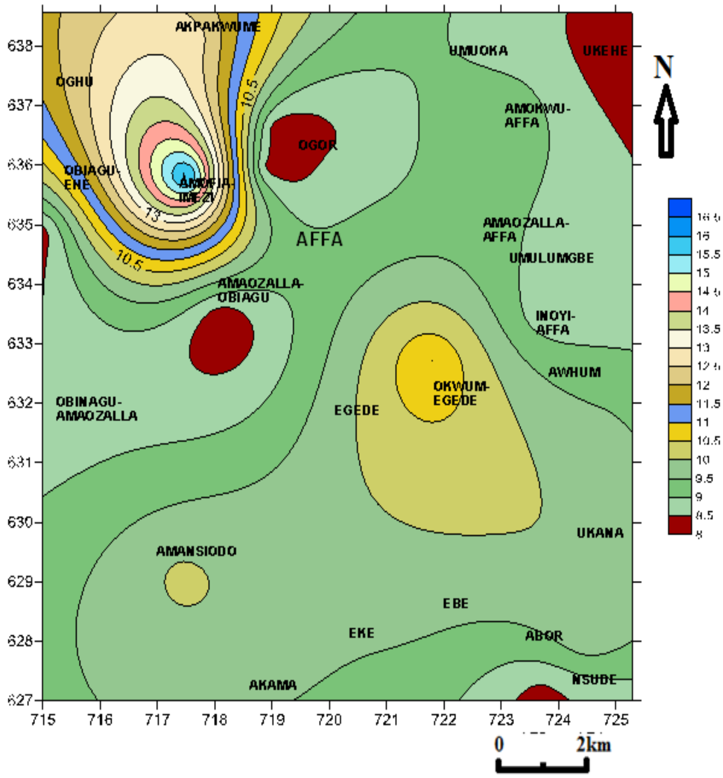

Fig. 9: The Hydraulic conductivity map of the area.

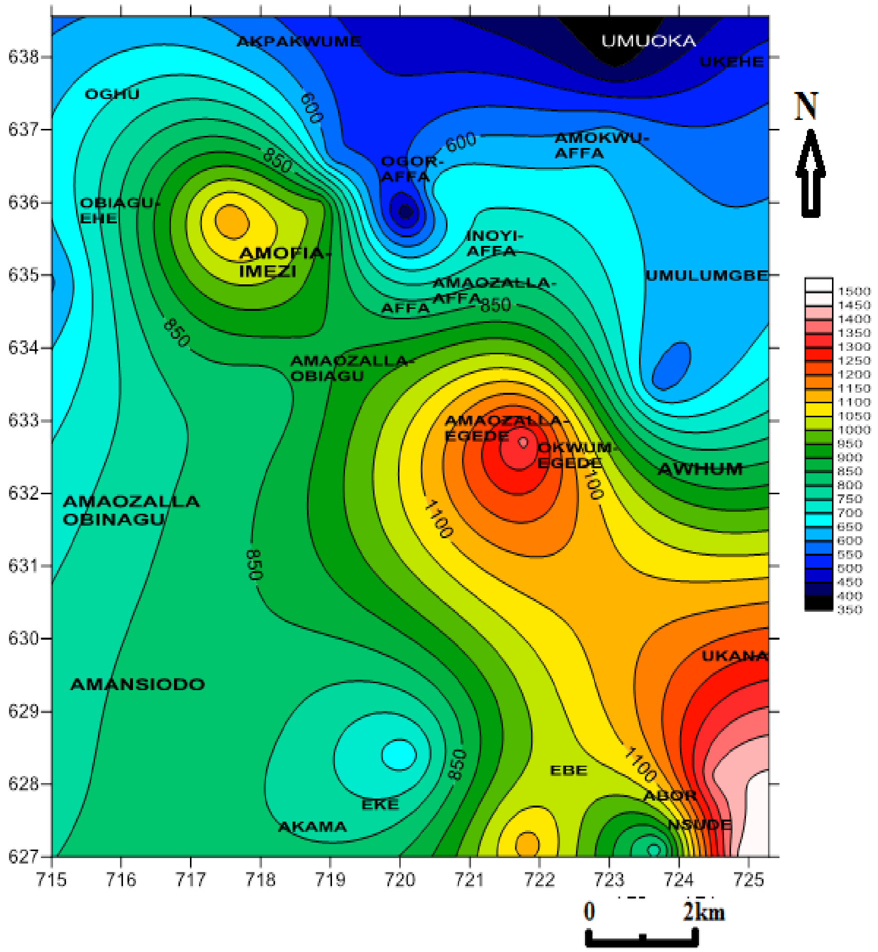

Fig. 10: The Transmissivity map of the area

Da-Zarrouk parameters (Transverse resistance and Longitudinal conductance) maps

Figs. 11 and 12 show that the aquifer unit conductance is high (0.043 - 0.254) in areas around Egede, Awhum, Affa, Eke, Amokwu, Abor, Nsude and Obinagu- Affa where as they are low (0.002-0.036) around Akpakwume, Umuoka, Ukehe, Amaozalla, Ehe and Amofia-Imezi. The central area, mid western and south-eastern areas are areas of high to moderate longitudinal conductance values which are probable areas underlain by very thick to moderately thick conducting sediments where we have inliers (that is where remnants of Nsukka Formation and/or Imo Formation cap the older Ajalli Formation). These areas include Awhum, Nsude, Abor and Ebe, in south–west, Egede, Affa, Amaozalla-Obiagu and Oghu in the western axis and Ukehe in the north eastern portions of the study area. These are best prospects for groundwater development.

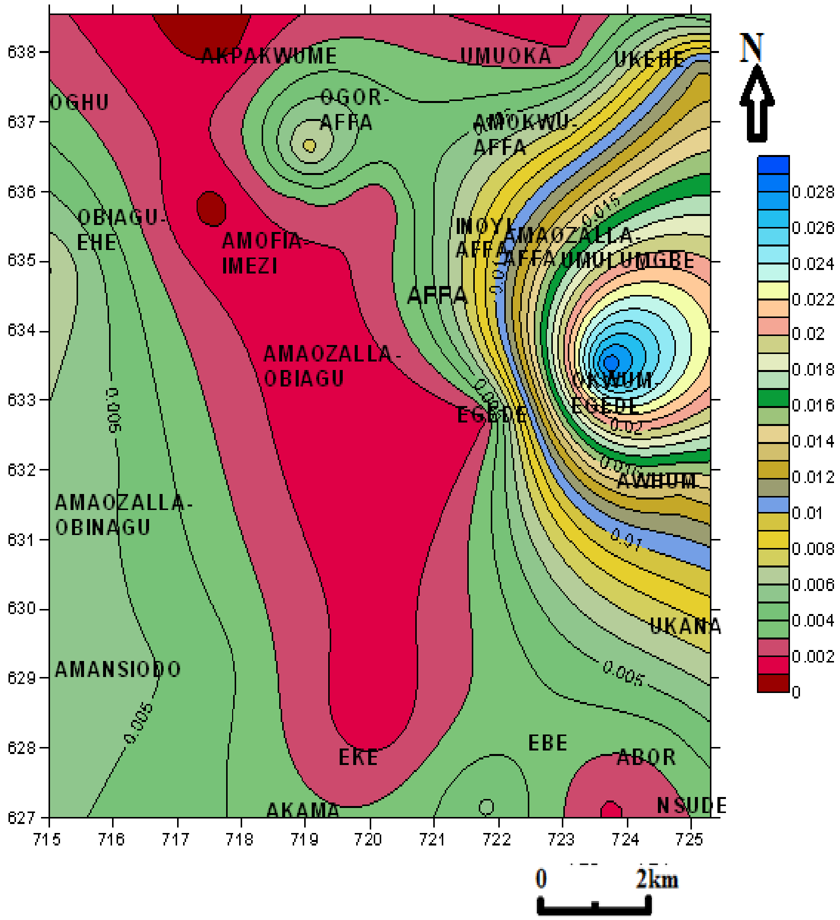

Fig. 12: Kσ-value map of the area

Kσ Variation across the Study Area.

On the basis of the Kσ-values across the study area, Niwas and Sighal (1981) suggested that in areas of similar geologic setting and water quality, Kσ-values remain fairly constant. It can be seen from the product of hydraulic conductivity and aquifer conductivity (Kσ) of the study area, (Figs. 11 and 12): Eke, Egede, Inoyi, Amofia-Imezi, Akpakwume and Umuoka areas are hydrogeologically homogeneous with Kσ-values varying between 0.0005 and 0.01these areas are grouped into Zone A. This Zone A has the best water quality from VES interpretation compare to other Zones and the zone is designated to be Ajali Sandstone. The average Kσ-value of this hydraulic zone is 0.0053. Amansiodo, Obinagu-Amaozalla, Obiagu-Ehe, Amaozalla- Obiagu, Akama, Ebe, Abor, Nsude, Okwum-Egede,- Amokwu, Ogor and Ukehe areas are grouped into Zone B. This zone has Kσ-values ranging from 00.02 to 0.07 with average value of 0.045. Zone C representing areas around Abor, Ukana, Awhum, Umulumgbe and Ezeamanefi-Ukehe has the highest Kσ-values varying from 0.08 to 0.26 and a mean value of 0.17. This zoning can be attributed to geological formation underlying the area of study and physiography. Zone A covers areas underlain by the residual hills doting the study area referred to as inlying plateau (Nsukka Formation), Zone B may represent areas underlain by Nsukka Formation and Imo Formation at the central area and northwest flanks respectively (Fig. 12). The Zone C may represent the areas with the Ajalli Formation exposed at the surface with surface runoff coefficient amounting to about zero percent (Fig. 11 and Fig. 12).

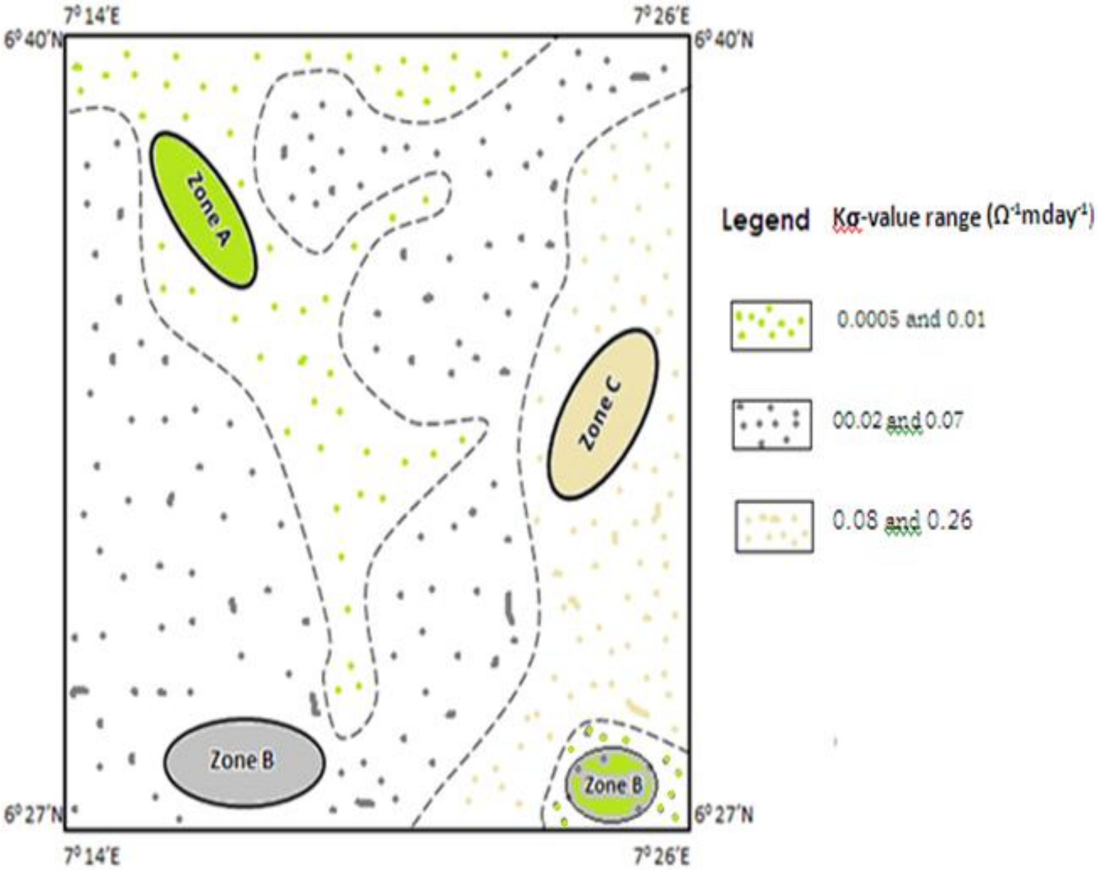

Fig.12: Water quality map deduced from VES

Conclusions

This study has revealed the groundwater potential, hydro-geophysical and groundwater hydraulic properties of Affa and the environs. The result reveals a total depth to water range of 94.84m at Amofia (VES 11) and 158.4m at Amozalla (VES 6) respectively. This in line with the borehole data acquired from the study area, there is a high correlation. Also, the high values of transmissivity (369.7m^2/day – 1484m^2/day) and hydraulic conductivity (8.14m/day-16.32m/day) within the study area is an indication of productive area for groundwater development with high water yield capacity. Similarly, good correlations exist between the aquifer hydraulic conductivity and transverse resistance which is an indication of the competence of this method. The areas with high transverse resistance, hydraulic conductivity and transmissivity are expected to give favourable borehole yield. More so, the close agreement of the interpreted VES data with the geologic information from borehole data gives an indication of the usefulness and competence of the present study in evaluating aquifer hydraulic properties in the scarcity of boreholes and/or borehole data in order to minimize cost.

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