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EARTH-VAS2 model parameters: An answer to complex aquifer vulnerability studies

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ABSTRACT

Factors that enhance groundwater vulnerability also facilitate contaminant migration. In this study the EARTH-VAS2 model is applied to investigate the migration of contaminants in shallow coastal aquifers of the Benin Formation in Calabar area southeastern Nigeria. The EARTH-VAS2 model uses the parameters of Elevation, Aquifer thickness, Regolith, Transmissivity, Hydraulic conductivity, Vadose zone, Aquifer media, Static water level and Specific capacity to investigate contaminant flow and soil vulnerability to pollution. Estimates from pumping test and Dar-Zarrouk model show the aquifer viability and protective capacity of the aquifer zones. The mean values of parameters from zone A are; Longitudinal conductance (0.1µs), Transverse Resistance (245386.5 ohm-m^2), Aquifer resistivity (1247.3 ohm-m), Transmissivity (1500m^2/day), Hydraulic conductivity (100m/day), Specific capacity (400m^3/day) while parametric mean values of Zone B are: Longitudinal conductance (0.1 µs), Transverse Resistance (700 ohm-m^2), Aquifer resistivity (100 ohm-m), Transmissivity (352m^2/day), Hydraulic conductivity (10 m/day), Specific capacity (40m^3/day). The analysis of chemical pollution indictors of $N0_3^-$ 22.6 – 0.90 (mg/l), EC 301 – 20 (µS/cm), E-coli 5 – 0.01 (mpn/100ml) and Cl^- 11.73 – 0.10 (mg/l) of groundwater samples were used to validate results within areas prone to contamination. Determination of coefficient (R^2) of EARTH-VAS2 parameters point out that Aquifer media, Depth to static water level, Hydraulic conductivity and Transmissivity are the most effective hydrogeological parameters to vulnerability assessment.

INTRODUCTION

The answer to aquifer vulnerability studies has for decades been a concern for groundwater sustainable development. In a quest for groundwater hygiene revitalization, several authors has proposed various intrinsic vulnerability models raging from internal to external pollution system: (Margat 1968), GOD rating system (Forster, 1987), DRASTIC point counting (Aller et al, 1987), SINTACS method (Civita M, 1994), ISIS method (Civita et al, 1995), Vrba and Zaporozec 1994; Sinan and Razack 2009; Polemio et al. 2009; CALOD method (Edet, 2004) and GWPPI model (Amah et al. 2016),etc. However due to wide range of activities of natural and artificial origins, the effect of contaminants to groundwater turn out to be a focal to the diagnosis of the parameters that define the local hydrologic system of the an area. Groundwater vulnerability is defined as the tendency and likelihood for general contaminants to reach the water table after introduction at the ground surface (NRC 1993). In order to map the possible areas of groundwater pollution, a site evaluation tool and groundwater quality assessment model called, EARTH-VAS2 was developed by Akaerue, (2019).

The EARTH-VAS2 is a point count index method modified after some existing aquifer vulnerability methods comprising nine hydrogeological parameters; Elevation, Aquifer thickness, Regolith/Lateritic thickness, Transmissivity, Hydraulic Conductivity, Impact to Vadose Zone, Saturation zone/Aquifer Media character, Depth to groundwater/SWL and Specific Capacity. These hydrogeologic parameters can aid aquifer viability and in turn enhances it vulnerability to general contaminations from the the surface. Conversely, the estimation of the contaminant's migration potential from land surface to groundwater through the unsaturated zones is essential for management of groundwater resources and subsequent land use planning. Hydrological parameters maps provide visual information for probable vulnerable zones which help to protect groundwater resources and also to evaluate the potential for water quality improvement by changing the agricultural practices and land use applications. The concept of geomaterial parameters that aid external pollution introduction into the groundwater can be used in planning, policy analysis, and decision making, viz., advising decision makers for adopting specific management options to mitigate the quality of groundwater resources;

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demonstrating the implications and consequences of their decisions; providing direction for using groundwater resources; highlighting about proper land use practices and activities; and educating the general public regarding the consequences of groundwater contamination (NRC 1993).

Study area

The area lies between Latitudes 4^0 45^I N and 5^0 16^I N and Longitudes 8^0 05^I E and 8^0 50^I E which covers five Local Government Area Council within the Southern Senatorial Zone of Cross River State Nigeria (Figure 1). The area belongs to the lowland and swampland of South-eastern Nigeria (Iloje, 1991) generally characterized by Coastal and alluvium sediment (Edet, 1993). Over the years hydrogeology experts have classified the study area into aquifer zones based on local geological peculiarities. Concurrently, the minor hydro-lithological units of the area are Shallow Gravelly Unit (Zone A) and Deep Sandy Unit (Zone B). Edet, (1993); Edet and Okereke, (2002); Edet, (2004) and Akaerue, (2019).

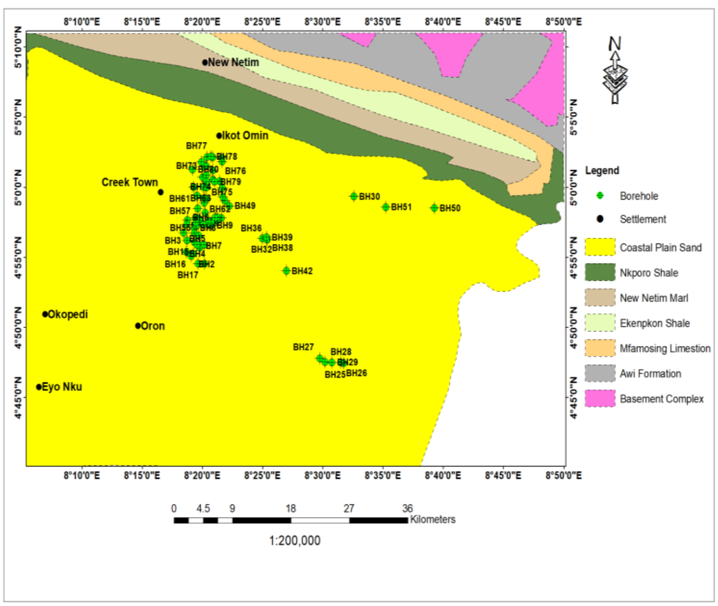

Fig. 1. Geologic Map of the study area showing the sample points areas

The main rivers that dominate the landscape of the study area are the Calabar River in the west, Great Kwa river in the east and Akpayafe river flowing southwards into the Cross River. These rivers are the secondary recharge source to the aquifer while rainfall is the primary source of aquifer recharge (Edet & Okereke, 2002). The mean daily maximum and minimum temperature varies between 21^0C to 32^0C in January and 25.05^0C and 27.4^0C in July and August respectively. The average monthly evaporation ranges between 4.3mm/day in February and 2.3mm/day in July. The soil covering the study area is sub-grade soil of gravelly clay to clayey sand. Generally classifield as (a) the deep lateritic, fertile soils on the Cross River Plain; (b) the sandy heavily leached soils on the older coastal plain which are highly susceptible to gully erosion; and (c) the swampy aquic soils of the lower deltaic coastal plain that is usually flooded during the rainy season. Geologically, the study area is part of the Niger Delta, which is made up of sedimentary rocks. The area is composed of Tertiary to Recent, continental fluvialite sands and clays, known as the Coastal Plain Sands. This formation is characterized by alternating sequence of loose gravel, sand, silt, clay, lignite and alluvium (Short & Stauble, 1967). It is underlain mostly by rocks of the Cretaceous Calabar Flank and precambrian Oban Massif (Figure 2). The Coastal Plain Sands (Benin Formation) is by far the most prolific aquiferous hydrogeologic settings in the area and all the water boreholes are located in this Formation (Esu & Amah, 1999).

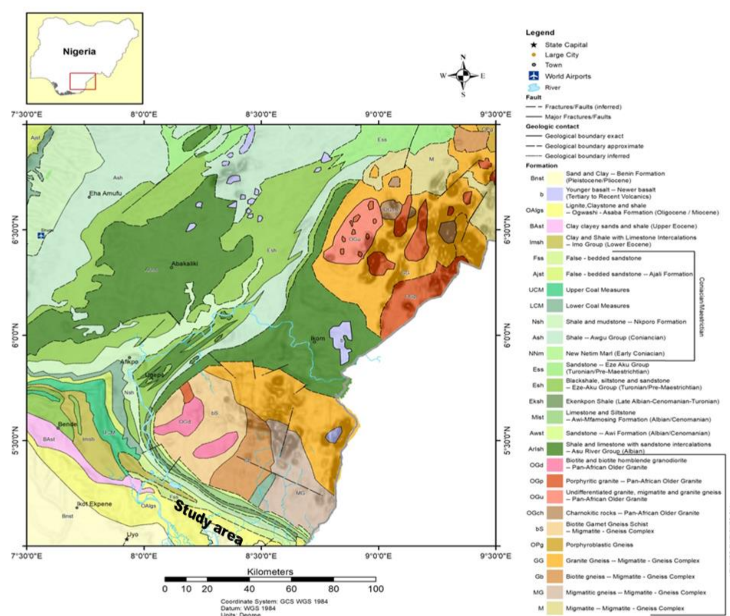

Fig. 2. Regional Geological map showing the study area

MATERIALS AND METHODS

The hydrogeological parameters which control the migration of contaminant to groundwater were selected for the point counting system vulnerability model called EARTH-VAS2 (Akaerue, 2019). Precisely, the litho-logs enable the examination of soil: lateritic zone (R), Vadose zone (V) and aquifer media characters (A), and delineation of aquifer thickness (A). The hydraulic conductivity (H), transmissivity (T) and specific capacity (S) were obtained from the analysis of pumping test data which aid in the evaluation of aquifer hydraulic property (Okon et. al.,2018). The depths to groundwater level (S) were measured from existing boreholes and wells during the field survey using a water level recorder (Type KLT - Du). The biochemical tests provide information on pollution indicators (EC, $N0_3^{-}$, Cl^{-}, E-coli) whereas the Electrical resistivity survey method were used to deduced parameters that evaluate the protective capacity of the overburden layers.

The litho - layers

The litho-layers were evidences through the borehole logging, three major litho-layers were broadly classified: (1) Topsoil or lateritic layer of depth range 0 – 5 meters are merged together in few cases due to identical or related geo-electric property and/or very thin or absent (Okon, 1998; Edet and Okereke 2002; Evans et. al., 2017 and Akaerue 2019).This layer consists of mainly unsaturated materials, except for few locations where static water level is less than 4.5m. Areas where the topsoil layers are composed of lateritic-sand generally has relatively high resistivity and low resistivity are due to lateritic clay (Akaerue 2019). (2) Coarse sand and gravels layers of depth range of 5 – 20 meters. The depth of this layer has mean value of 15meters. This layer is very productive, with tiny multiple aquifers bounded by thin clay horizons. This layer constitutes most parts of the water bearing formation. (3) Fine sands to clay material layer of depth range of 20 meters and above. This layer is also productive but not like the gravel layer. The characteristic of this layer is conspicuous with silt and fine sand with minor presence of lignite in some area (Akaerue 2019).

Pumping test

A pumping test is a field experiment in which a well is pumped at a control rate and water level response (drawdown) is measured in one or more surrounding observation/monitoring wells (Hamill and Bell 1986). Pumping tests are important and most effective tools that provide information on the hydraulic characterization of a borehole and aquifer parameters (Todd 1980; Turner et al 1991). Constant Rate Test was carried out in the study area to give information about the drawdown and aquifer properties resulting from specific pumping rate. Three (24) to six (72) hours constant discharge test was used since the yield is high and the boreholes are sumo pump boreholes and are meant to serve large population. The tests were carried out in some specific locations in the study area, using the single well pumping test approach. The Jacob's straight-line method was used to analyse the pumping test results of drawdown with respect to time in all the existing boreholes in the study area in order to estimate the aquifer hydraulic parameters.

Prior to pumping, the well head was opened and the static water level was measured and recorded using calibrated Dip meter. The pump is then lowered to appreciable depth and Connect to the generator set. A known 20 liters volume of container was set in place to collect discharge and set stop watch to zero start time Pumping was then started, drawdown measured base on scheduled time on the data sheet. The time and water level discharge was Measure and record simultaneously. The exercise was done in two (2) phases namely: 1. Discharge and 2. Recharge/Recovery phase.

Dar-zarrouk parameters

The Dar-zarrouk parameters: Transverse resistance (T) and Longitudinal conductance(S), obtained from the geoelectrical parameters were used to determine the overburden protective capacity of the aquifer units in the study area. The combination of subsurface resistivity and thickness into single parameter gives rise to the Dar Zarrouk parameters deployed for the study. Orellana et. al., (1966) and Zohdy (1976) The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underling aquifer (Abiola,et al., 2009). Based on longitudinal conductance values (Austin, et. al., 2017), aquifer overburden protective capacity were zoned into excellent (>10), very good (5 – 10), good (0.7 – 4.9), moderate (0.2 – 0.69), weak (0.1- 0.19) and poor (>0.1). The earth subsurface acts as a natural filter for percolating fluid. Hence, its ability to retard and filter percolating ground surface polluting fluid is a measure of its protective capacity (Austin, et. al., 2017).

RESULTS AND DISCUSSIONS

Elevation: The elevation which is a metrological factor has an effect to contamination migration from surface to subsurface. The effect of this parameter is that, for low slope, contaminant is less likely to become runoff and more likely to infiltrate subsurface vice versa (Appendix 1).The slope and slope variability of a land surface with static water level difference gives the hydraulic head values of the area. Groundwater flow is from area of high hydraulic head to the area of low hydraulic head. As presented in Figure 3. The main flow direction of water in the coastal plain aquifers is southwestern, Edet (1993). Zone B areas has higher hydraulic heads (35 – 50m) than Zone A (0 – 12m) areas with minor variation, Akaerue (2019). Conversely, the groundwater flow direction is from zone B towards Zone A which represents the southern part of the study area. This agrees with Edet's finding (1993), that the coastal groundwater flow direction is southwest ward.

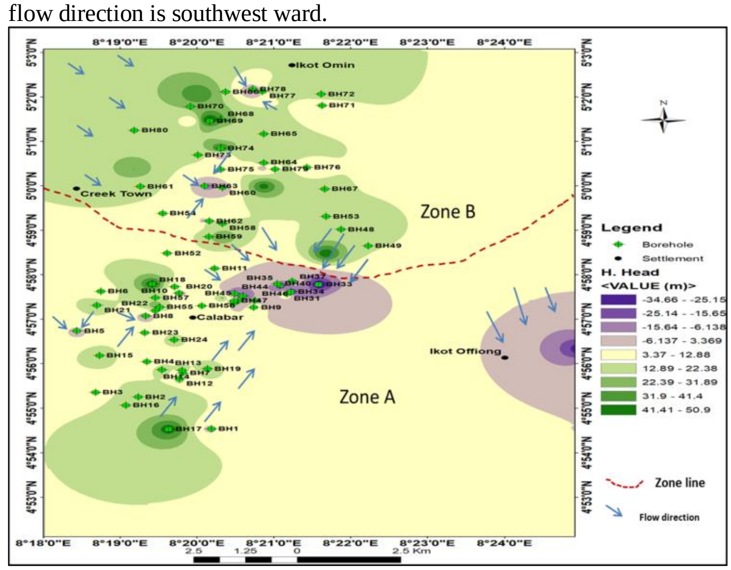

Fig. 3. Hydraulic head map, showing the groundwater flow direction.

Static water level: This refers to the level of water in a well under normal, undisturbed, no-pumping conditions whereas water table level is the level below which the ground is completely saturated with water. Conversely, both are the same, the depth from the ground surface to the water table level is a hydrogeological factor that determines the migration distance that a contaminant will travel before reaching the aquifer. It is assumed that the deeper water tables level the lesser contamination chances to the aquifer. The groundwater resources in the northern region (zone B) of the study area has deeper water table levels (34 – 75m) whereas the southern region (zone A) of the area has shallower water table levels (2.5 - 35m) figure 4 and Appendix 1.

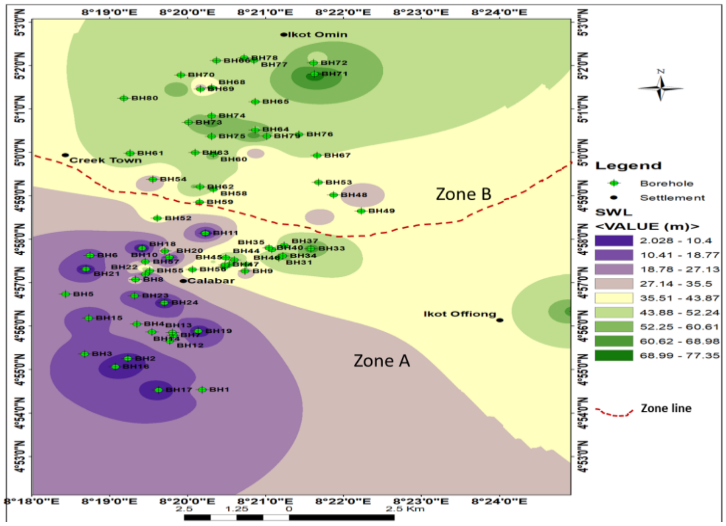

Fig. 4. Static water Level Map of the study area.

Aquifer thickness: Saturated thickness is the vertical thickness of the hydrogeologically defined aquifer in which the pore spaces of the rock forming the aquifer are filled (saturated) with water. This factor defines the degree of extension/dimension of a lithological layer. The thicker the sequence, the higher the dilution effect and the lower is the contamination risk. This is because thickness controls texture and the migration of contaminants into the aquifer. The thickness of the aquifer in the study area is not evenly and well distributed (Appendix 1). Although from the parametric map Figure 5, zone B (21 – 80m) region shows more of thicker aquifers than zone A (9 – 61m).

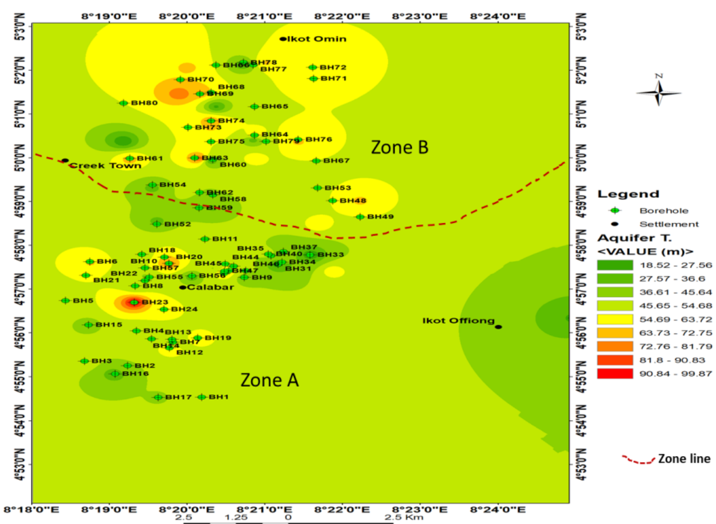

Fig. 5. Aquifer Thickness Map of the study area

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Lateritic thickness: The peculiarity of the study area is the occurrence of a lateritic layer which lies above the unsaturated zone but below the soil layer in some locations (Edet., 2004).This layer protruded southern ward from the estuary region of the study area towards the northern region and later thin-out. Soil laterization is the weathering process by which soils and rocks are depleted of soluble substances, such as silica-rich and alkaline components and enriched with insoluble substances, such as hydrated aluminum and iron oxides. They develop by intensive and long-lasting weathering of the underlying parent rock which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils. Thus thick lateritic layers are slightly permeable, which can serve as an aquitard. However the thicker the layer, the better the contaminant attenuation capacity. The zone B (6 – 16m) region has thick lateritic layer than Zone A (0.5 – 7m), figure 6 and Appendix 1.

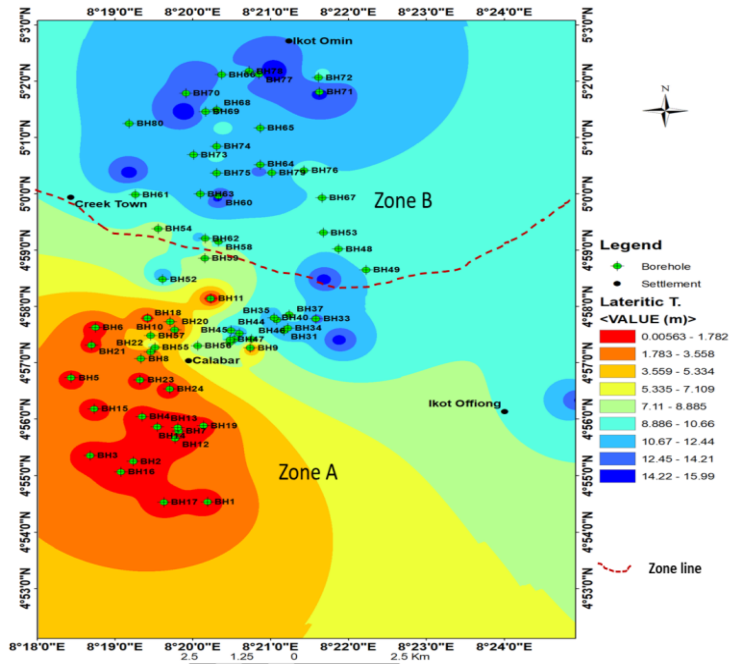

Fig. 6. lateritic thickness distribution map of the study area.

Vadose zone media: The unsaturated layer is sandwiched between the aquifer media and the lateritic layer. The filtration system nature of this zone is composed of a fine sandstone, sandy clay, thin lateritic and clayey sand. Due to ferrigunized effect, the colour range is from reddish to brown clayey sand and brown to greyish sand. Aside the litho-logs data, the Dar-zarrouk deduced parameter of longitudinal conductance were used to evaluate the conduit effectiveness of this media (Austin, et. al., 2017). Conversely the zone B region has higher longitudinal values (0.5038 – 0.9818 μs) than zone A, region (0.1213 – 0.5037 μs) (Figure 7 and Appendix 1). The effect of this is that aquifer within zone B are more likely to be protected from contaminant migration from the surface.

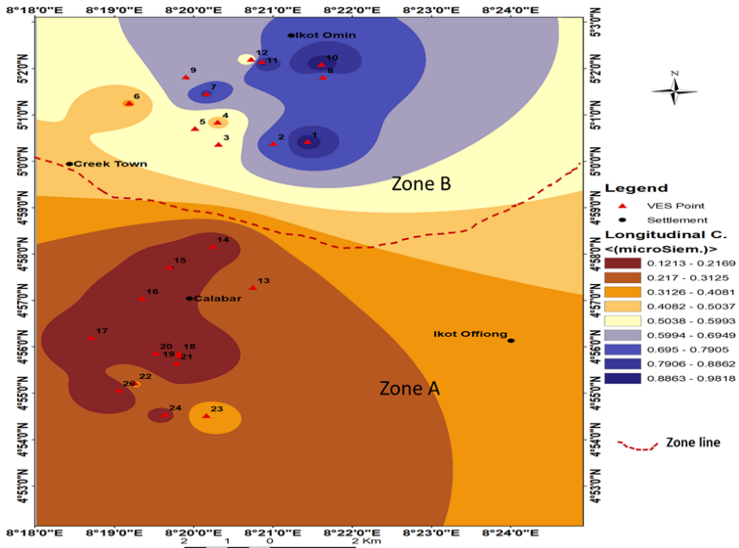

Fig. 7. Longitudinal conductance distribution map of the study area.

Aquifer media: The consolidated or unconsolidated rock which serves as the water-bearing unit. Two water-bearing units are being exploited in the area (Edet and Okereke, 2002). The first is the upper gravelly layer composed of medium to coarse to gravelly sand protruding southern ward marked by shallow depth (Zone A). The second is the semi-confined lower sandy unit which is composed of fine grain, silt/clay sand protruding northern ward (Zone B). Aside the litho-logs data, the Dar-zarrouk deduced parameter of Transverse resistance were used to evaluate the conduit effectiveness of this media. Aquifer media in zone A has effective conduit property than zone B. Figure 8 and Appendix 1, indicate that transverse resistance value which is synonymous to aquifer Transmissibity is higher in zone A (205 – 264 ohm-m) compare to zone B (29 – 59 ohm-m).

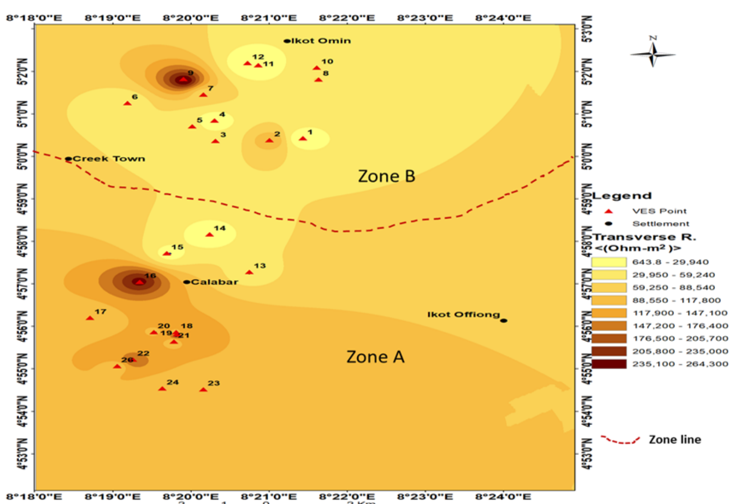

Fig. 8. Transverse Resistance distribution map of the study area

Aquifer hydraulic properties: Transmissivity, Hydraulic conductivity and Specific capacity are the properties/parameters that designate the relationship between the earth media permeability, thickness and fluid velocity. Conversely, the migration of a contaminant depends on the degree and extent of media permeability. A thick sequence media with low degree of intrinsic permeability will eventually attenuate contaminant migration whereas a thin media with high degree of directional permeability will lead to high contaminant velocity per unit area and thickness and per unit change in hydraulic head. Thus these properties express the easiness in fluid flow and generally productivity within the coastal aquifer. From the parametric map figure 9 – 11 and Appendix 1, aquifer within zone A, region has good hydraulic property (T: 1300 m^2/day, K: 135m/day, SC: 250m^3/day) compare to zone B (T: 80m^2/day, K: 1.3m/day and SC: 80m^3/day) and this can facilitate easiness to contaminant migration within the area.

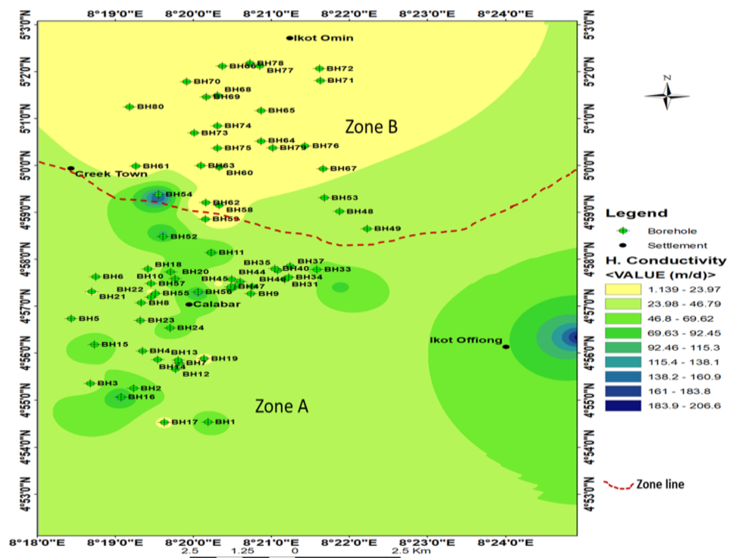

Fig. 9. Hydraulic conductivity distribution map of the study area

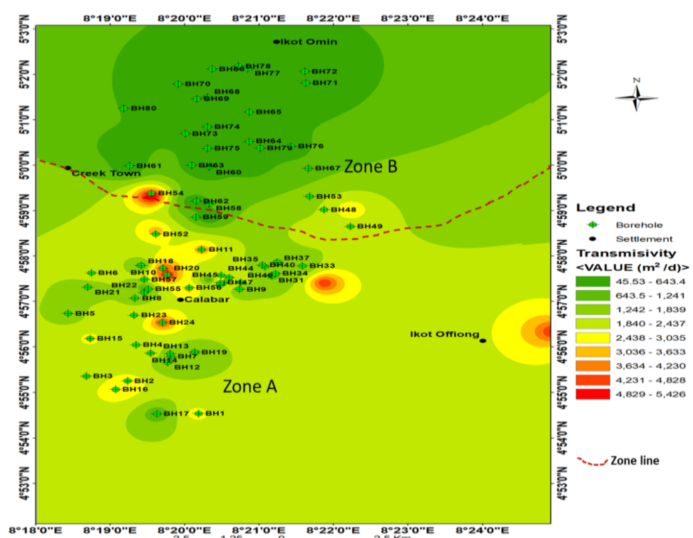

Fig. 10. Transmissivity distribution map of the study area

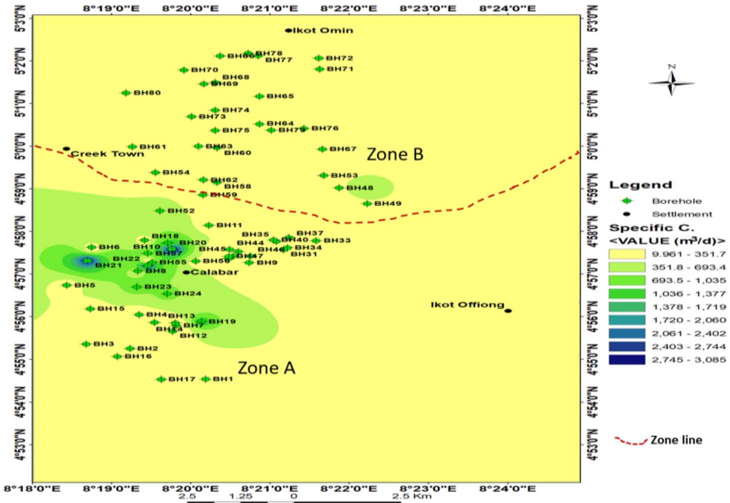

Fig. 11. Specific capacity distribution map of the study area.

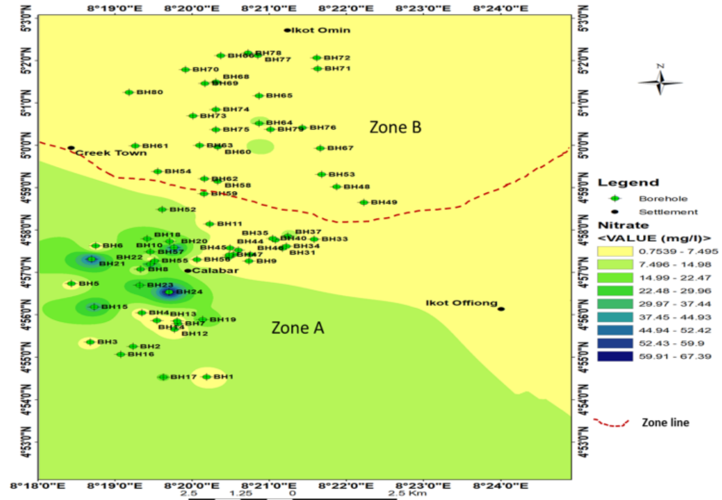

Fig. 13:.Nitrate distribution map of the study area

Physicochemical pollution indicators: (Nitrate 0.10 – 13mg/l, Chloride 0.32 – 8mg/l and Electrical conductivity 4 – 602 µS/cm): These are natural and induced chemicals found in groundwater in higher concentrations above WHO standards for domestic purposes generally cause by; (i) Groundwater interaction with geological materials, (ii) industrial discharge, (iii) urban activities, (iv)agriculture, (v) groundwater pumpage, and (vi) disposal of waste. Figure 12 – 14 and Appendix 1, shows the distribution of the three physicochemical parameters analysed from the groundwater in the study area.

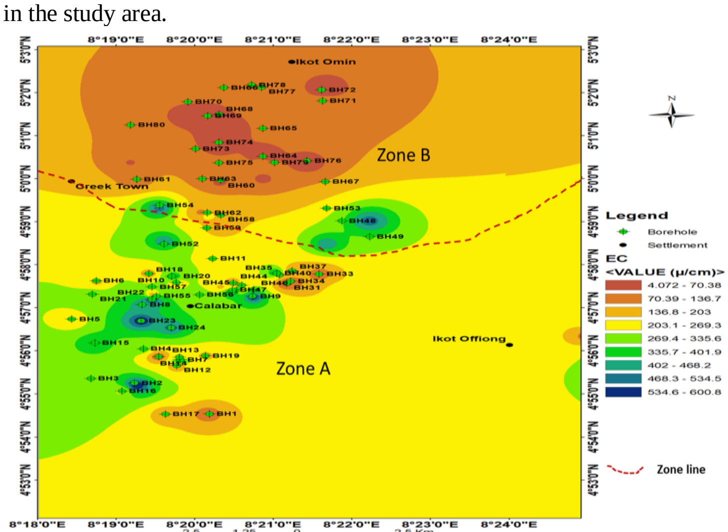

Fig. 12. Electrical conductivity distribution map of the study area.

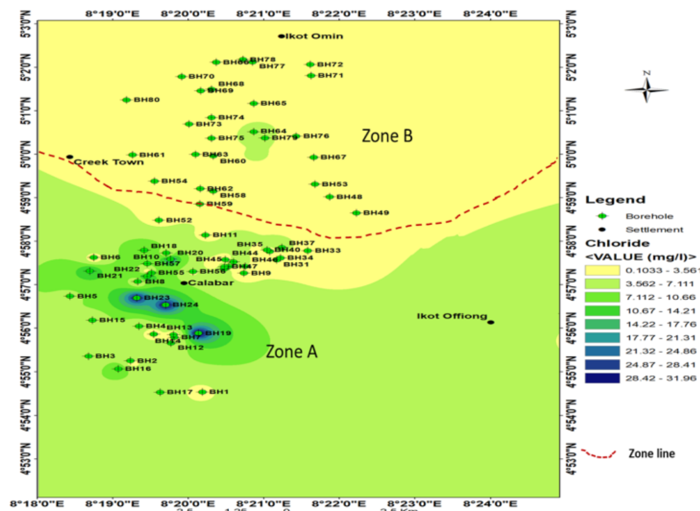

Fig. 14. Chloride distribution map of the study area.

Vulnerability status of the study area based on EARTH-VAS2 input parameters model.

From the hydrogeological analysis of EARTH-VAS2 parameters, Zone A areas show high to moderate value (35 and above) in vulnerability rating to surface contamination compare to zone B (35 and below) (Figure 15 and appendix 1). The hydrogeological parametric values of Zone A show prolific aquifers (Figure 9 – 11, and Appendix 1). Thus the areas were the parametric values are viable to groundwater accumulation correlate with the areas where we have high values of Nitrate, Electrical Conductivity, and chloride accumulations in the analyzed water samples (Figure 12 – 14,). The physicochemical constituents, naturally supposed to be attenuated before reaching the water table if the depth to the water table is deep and the thickness of the overlying layer to the aquifer is high (Edet., 2004). But because the depth to water table within Zone A area is very shallow and the overlying layer thickness is thin with high permeable lithology, the migration of this pollution indicator of physicochemical constituents became obviously conspicuous in the groundwater sample collected around borehole within the Zone A. Conversely the higher the permeability and thinner the sequence of the Vadose zone, the lower the dilution effect and the higher the contamination risk to groundwater vice versa.

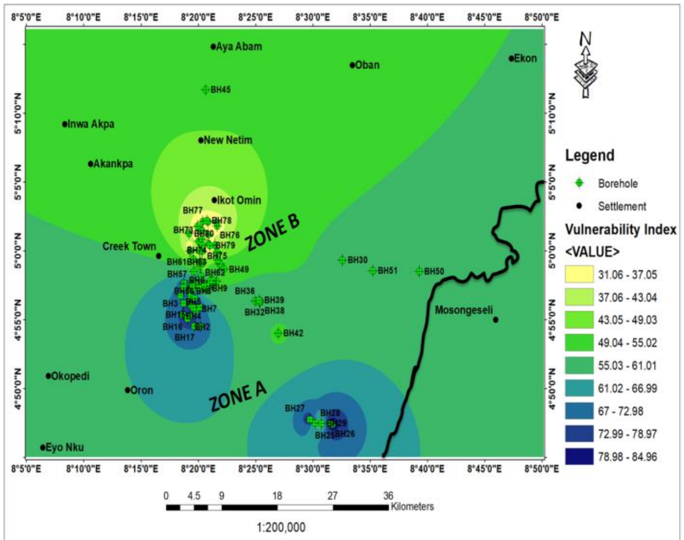

Figure 15 : EARTH-VAS2 Vulnerability Map of the study area

Correlation between earth-vas2 and hydrogeological parameters.

In this research, R establishes the relationship between the EARTH-VAS2 index value and their input parameters (aquifer media & thickness, Transmissivity, hydraulic conductivity and specific capacity, etc.). From Table 1, R is 0.965 for EARTH-VAS2 versus Aquifer Media; meaning there is a strong relationship or perfect relationship between the EARTH-VAS2 and Aquifer Media. Also the coefficient of determination (R^2) enables us to know the percentage of variation between EARTH-VAS2 index and its input parameters. Also, from the Table 1, R^2 is 0.9312; meaning that the variation in EARTH-VAS2 model is 93% influenced by aquifer media. Thus, correlation between EARTH-VAS2 model and hydrogeological parameters for each borehole data point show a strong relationship. The implication of this is that the factors that facilitate groundwater viability in the study area (coastal environment) may likely enhance contaminant migration to the aquifer. However, Aquifer thickness shows a low or weak correlation values (R = 0.047; R2 = 0.2%), this can be attributed to the fact that, contribution of the aquifer thickness to EARTH-VAS2 model is low.

Table 1. Summarized correlation data between EARTH-VAS2 index and input parameters

PARAMETERS	R	R^2
Aquifer Media, Swl, Lateritic Character.	0.965	0.931 (93%)
Aquifer Thickness	0.047	0.002 (0.2%)
Transmissivity	0.748	0.559 (56%)
Hydraulic Conductivity	0.749	0.561 (56%)
Specific Capacity	0.637	0.406 (40%)

CONCLUSION

A modified vulnerability index model called EARTH-VAS2 parameters was used in other to ascertain the potential risk of the aquiferous units to surface contamination. EARTH-VAS2 is acronyms for nine parameters of Elevation, Aquifer thickness, Regolith, Transmissivity, Hydraulic conductivity, vadose zone, aquifer Media, Static water level and specific capacity. The hydrological Zone A (62.5%) covers the entire Calabar South L.G.A, Akpabuyo L.G.A, Southern part of Calabar Municipality L.G.A and extends up to Bakassi L.G.A; Whereas the hydrological Zone B (37.5%) covers the northern part of Calabar Municipality L.G.A and Southern part of Odukpani L.G.A. Hydrogeologic unit Zone A appears more prolific to groundwater availability with high risk of surface to subsurface groundwater contamination Whereas groundwater resources within Zone B environment are not as prolific as zone A, with low risk of groundwater contamination.

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Appendix 1. EARTH-VAS2 input data for the study area

LOCATION	ELEVATION (m)	AQUIFER ZONE	AQUIFER MEDIA	SWL (m)	HYDRAULIC HEAD (m)	AQUIFER THICKNESS (m)	TRANSMISSIVITY (m^2/d)	HYDRAULIC CONDUCTIVITY (m/d)	SPECIFIC CAPACITY (m^3/d)	UNSATURATED MEDIA	LATERITIC THICKNESS
BH_01	22	A	G-CS-MS	20	2	48	2595	54.06	113	RCSL	1
BH_02	25	A	G-CS-MS	3.0	22	45	2930	65.1	28.5	RCSL	0
BH_03	21	A	G-CS-MS	18	3	50	1840	36.8	258	RCSL	1
BH_04	23	A	G-CS-MS	20	3	45	1950	43.3	51.6	RCSL	1
BH_05	21	A	G-CS-MS	20.8	1	50	1560	31.2	93.2	RCSL	1
BH_06	23	A	G-CS-MS	15	8	65	2412	37.1	91	RCSL	0.5
BH_07	24	A	G-CS-MS	20.5	4	40	1180	29.5	29	RCSL	0.5
BH_08	25	A	G-CS-MS	30	-5	45	1629.5	36.2	344	RCSL	2
BH_09	41	A	G-CS-MS	30	10	35	1156	33.03	9	RCSL	2
BH_10	41	A	G-CS-MS	35	6	65	4388.2	67.5	970	RCSL	2
BH_11	16	A	G-CS-MS	4	12	45	3416	75.9	114	RCSL	0
BH_12	39	A	G-CS-MS	25	14	67	1439	21.47	28	RCSL	1
BH_13	37	A	G-CS-MS	20	17	50	1881	22.4	228	RCSL	0.5
BH_14	36	A	G-CS-MS	20	16	50	2207	44.14	110	RCSL	1
BH_15	32	A	G-CS-MS	13	19	40	2590	64.75	91	RCSL	1
BH_16	23	A	G-CS-MS	3	20	30	3000	100	87	RCSL	1
BH_17	50	A	G-CS-MS	4	46	45	845	18.7	120	RCSL	1
BH_18	52	A	G-CS-MS	2	50	45	900	20	121	RCSL	1
BH_19	18	A	G-CS-MS	2	16	60	1098	18.3	1344	RCSL	1
BH_20	19	A	G-CS-MS	5		81	5100	63.75	3100	RCSL	1
BH_21	23	A	G-CS-MS	4.6	18.4	55	1180	21.45	2550	RCSL	1
BH_22	20	A	G-CS-MS	12	8	45	1180	26.22	2550	RCSL	1
BH_23	23	A	G-CS-MS	13	10	100	2100	21	890	RCSL	0.5
BH_24	18	A	G-CS-MS	2.4	15.6	60	4331	72.1	890	RCSL	0.5
BH_25	23	A	G-CS-MS	3	20	50	3550	71	750	RCSL	0.5
BH_26	19	A	G-CS-MS	12	7	45	2700	60	990	RCSL	0.5
BH_27	20	A	G-CS-MS	2	18	35	1190	34	158	RCSL	1
BH_28	42	A	CS-MS-FS	44	-2	60	1200	20	20	LCLS	12
BH_29	40	A	CS-MS-FS	34	6	20	1200	60	56	LCLS	14
BH_30	32	A	CS-MS-FS	50	18	27	1306	48.37	60	LCLS	9
BH_31	25	A	CS-MS-FS	50	25	18	926	18.5	7.7	LCLS	12
BH_32	34	A	CS-MS-FS	67	-33	25	5190	207.6	51.4	LCLS	15
BH_33	32	A	CS-MS-FS	67	-35	20	1180	59	32.2	LCLS	13
BH_34	27	A	CS-MS-FS	60	-33	40	1175	29.38	105	LCLS	12
BH_35	27	A	CS-MS-FS	64	-37	40	2409	60.23	52.5	LCLS	13
BH_36	45	A	CS-MS-FS	40	5	45	1580	35.1	58	LCLS	8
BH_37	51	B	CS-MS-FS	45	6	41	960	23.4	52	LCLS	8
BH_38	69	B	CS-MS-FS	43	26	40	1456	36.4	67	LCLS	8
BH_39	34	A	CS-MS-FS	36	-2	33	1639	49.67	52	LCLS	8
BH_40	29	A	CS-MS-FS	21	8	55	1112	20.23	67	LCLS	12
BH_41	30	A	CS-MS-FS	33.3	-3.3	65	1450	22.3	52	LCLS	5
BH_42	33	A	CS-MS-FS	52.4	-19.4	41	1456	35.5	420	LCLS	10
BH_43	31	A	CS-MS-FS	53	-22	50	2240	44.8	367	LCLS	12
BH_44	28	A	CS-MS-FS	50.1	-21.9	56	2581	46.1	103	LCLS	12
BH_45	43	A	CS-MS-FS	54	-11	60	3000	50	103	LCLS	13
BH_46	50	B	CS-MS-FS	30	-20	45.8	3509	76.6	258	LCLS	10
BH_47	51	B	CS-MS-FS	23.6	27.4	55	3400	61.8	40	LCLS	12
BH_48	49	B	CS-MS-FS	47.1	1.9	60	4678	77.96	84	LCLS	15
BH_49	50	B	CS-MS-FS	30.3	19.7	65	2800	43.08	545	LCLS	10
BH_50	40	A	CS-MS-FS	23.7	16.2	45	5780	128.4	436	LCLS	8

BH_51	**37**	**A**	**CS-MS-FS**	**42.8**	**-5.8**	**30**	**3456**	**115.2**	**194**	**LCLS**	**10**
BH_52	**48**	**B**	**CS-MS-FS**	**40**	**8**	**34**	**3310**	**97.35**	**532**	**LCLS**	**12**
BH_53	**78**	**B**	**CS-MS-FS**	**30.5**	**48**	**60**	**2248**	**37.47**	**58**	**LCLS**	**15**
BH_54	**41**	**A**	**CS-MS-FS**	**30**	**11**	**34**	**5432**	**159.76**	**67**	**LCLS**	**8**
BH_55	**50**	**B**	**CS-MS-FS**	**50**	**0**	**70**	**4567.9**	**65.25**	**197**	**LCLS**	**13**
BH_56	**52**	**B**	**CS-MS-FS**	**45**	**7**	**30**	**3218**	**107.27**	**181**	**LCLS**	**8**
BH_57	**82**	**B**	**MS-FS-CLS**	**50**	**32**	**45**	**897**	**19.9**	**23**	**TLCLS**	**8**
BH_58	**70**	**B**	**MS-FS-CLS**	**45**	**25**	**45**	**501**	**11.1**	**19**	**TLCLS**	**8**
BH_59	**63**	**B**	**MS-FS-CLS**	**44**	**19**	**35**	**200.1**	**5.7**	**35**	**TLCLS**	**8**
BH_60	**73**	**B**	**MS-FS-CLS**	**40**	**33**	**35**	**45**	**1.29**	**36**	**TLCLS**	**8**
BH_61	**67**	**B**	**MS-FS-CLS**	**53**	**14**	**67**	**70**	**1.04**	**59**	**TLCLS**	**10**
BH_62	**37**	**A**	**MS-FS-CLS**	**47**	**-10**	**80**	**398**	**4.98**	**13**	**TLCLS**	**11**
BH_63	**54**	**B**	**MS-FS-CLS**	**55**	**-1**	**56**	**400**	**7.124**	**25**	**TLCLS**	**12**
BH_64	**75**	**B**	**MS-FS-CLS**	**30**	**45**	**58**	**286**	**4.93**	**48**	**TLCLS**	**12**
BH_65	**71**	**B**	**MS-FS-CLS**	**50.3**	**21**	**65**	**200**	**3.07**	**41**	**TLCLS**	**12**
BH_66	**60**	**B**	**MS-FS-CLS**	**45.7**	**15**	**26**	**100**	**3.85**	**31**	**TLCLS**	**10**
BH_67	**69**	**B**	**MS-FS-CLS**	**48.7**	**21**	**60**	**78**	**1.3**	**33**	**TLCLS**	**10**
BH_68	**53**	**B**	**MS-FS-CLS**	**55**	**-2**	**30**	**50**	**1.67**	**22**	**TLCLS**	**15**
BH_69	**83**	**B**	**MS-FS-CLS**	**32**	**51**	**70**	**90**	**1.28**	**12**	**TLCLS**	**12**
BH_70	**65**	**B**	**MS-FS-CLS**	**60**	**5**	**80**	**100**	**1.25**	**11**	**TLCLS**	**16**
BH_71	**79**	**B**	**MS-FS-CLS**	**78**	**1**	**52**	**200**	**3.85**	**18**	**TLCLS**	**15**
BH_72	**81**	**B**	**MS-FS-CLS**	**65**	**16**	**60**	**121**	**2.01**	**19**	**TLCLS**	**14**
BH_73	**86**	**B**	**MS-FS-CLS**	**45**	**41**	**65**	**133**	**2.05**	**28**	**TLCLS**	**13**
BH_74	**61**	**B**	**MS-FS-CLS**	**67**	**-6**	**65**	**190**	**2.92**	**35**	**TLCLS**	**10**
BH_75	**98**	**B**	**MS-FS-CLS**	**50**	**48**	**70**	**180**	**2.25**	**12**	**TLCLS**	**12**
BH_76	**56**	**B**	**MS-FS-CLS**	**45**	**11**	**65**	**456**	**7.02**	**15**	**TLCLS**	**10**
BH_77	**65**	**B**	**MS-FS-CLS**	**67**	**-2**	**30**	**70**	**2.33**	**14**	**TLCLS**	**13**
BH_78	**40**	**B**	**MS-FS-CLS**	**45**	**-5**	**32**	**50**	**1.42**	**45**	**TLCLS**	**12**
BH_79	**67**	**B**	**MS-FS-CLS**	**50**	**17**	**65**	**78**	**1.2**	**34**	**TLCLS**	**16**
BH_80	**80**	**B**	**MS-FS-CLS**	**48**	**32**	**21**	**90**	**4.29**	**40**	**TLCLS**	**15**

<u>LEGEND</u>:

G-gravelly > *CS-coarse sandy* >* MS-medium sandy* > *FS-fine sandy/silty* > *CLS- clayey sandy*

RCSL - Thin clayey Sand +coarse +gravelly+ thin Lateritic Layer

TLCLS - Thick Lateritic sand + Lateritic Clay + clay + fine + medium sand + silt intercalation*