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Developing a Correlation for Estimation of Aquifer Layer Using Resistivity Survey with Lithological Logs in Critical Terrain Condition

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Abstract: Vertical Electrical Sounding (VES) study was conducted for 20 points (four sites having five points each) in Damodar River Basin in West Bengal State in India employing Schlumberger Array electrode configuration along with Borehole Litholog. Depth of interpretation was found to be around 25 m at each VES point for the input survey distance of 50 m. From the interpreted resistivity values it can be commented that the points where the soundings were carried out normally had dry sand having variation in moisture content up to a depth of approximately 5 m. But in the case of Site 2 the sand content of the top layer was found to be drier and had bigger gravel and rock particle mixed with sand. From the interpreted results it can be inferred that all the sounding points except three have the existence of a layer saturated with fresh water. Depth to bedrock from VES study was correlated with depth to bedrock from Borehole Lithologs. Therefore this study is significant for both reading public and future workers as the equation developed using the constants and variables can be used to predict depth to Basement Rock in the Terrain prevailing in that region.

Key words: Vertical electrical sounding (VES), borehole litholog, resistivity values, interpretation, regression analysis, correlation co-efficient.

Introduction

Water is a renewable resource which occurs in three forms: liquid, solid and gaseous. Groundwater is essential for irrigation, industry and domestic purpose. Groundwater is an important source for potable water supply, domestic, industrial and agricultural uses; thus there is a necessity to exploit it sensibly so that this resource does not become scarce in near future. The scarcity of groundwater is increasing day by day due to a rapid growth in population, urbanization, industrial and agricultural related activities, natural calamities, etc. The impact of the above said causes on soil and groundwater is becoming alarming with years and has devastating effects on humans and the ecosystem (Ahilan and Senthil Kumar, 2011; Hossain, 2103). Study of groundwater geology is much useful for all the activities of human life. Groundwater is more advantageous than the surface water due to its low levels of concentration of TDS, TSS, turbidity, etc. To meet the demand of water, people are depending more on groundwater yielded by aquifers (Ehirim and Nwankwo, 2010; Hossain, 2013). Purulia is one of the drought prone districts of West Bengal. It has a sub-tropical

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climate nature and is characterized by high evaporation and low precipitation. The increasing demand of water for irrigation, domestic and industrial use is contributing to the water deficiency in the district. Therefore, there is tremendous pressure on the already critical groundwater regime; even total surface and groundwater resources put together are not sufficient to meet the requirement. The main water sources for the district are the Damodar river basin. Therefore it is very important to know the safe yield and aquifer characteristics to make future Water Security Plan for sustainable withdrawal (Roy et al, 2015; SWRE, 2013).

Keeping in view, the present study focuses on finding groundwater potential zones in Raghunathpur-II, Neturia, Santuri blocks of Purulia district of West Bengal, as well as developing a correlation co-efficient and a regression analysis equation between the borehole litholog and sub-soil stratification data as obtained from VES study in that region so that for the terrain type prevailing in that region the data obtained from the VES study may be used to find the litholog of the terrain without further making boreholes in the region thus reducing cost incurred and labour required and thus finding groundwater potential zones economically. The statistical approach adopted in the paper involves the generation and development of a regression analysis equation and correlation co-efficient between the observed values that could be used for correlating and subsequently predicting lithologs from logs obtained from interpretation of VES results in future.

Study Areas

The Damodar river basin is situated between 23°37′43.02″ N latitude and 86°56′08.36″ E longitudes and 23°038′27.43″ N latitude and 86°28′43.97″ E longitudes as given in Figure 1. The study was carried out in the area on Damodar river bed near the three blocks of Purulia district viz., Santuri, Nituria and Raghunathpur-II. A total of 20 VES soundings delineated in Figure 2 using Schlumberger configuration were carried out in the chosen four sites by conducting five VES soundings at each site (Hossain, 2013).

Materials and Methods

Geophysical prospecting of groundwater comes under both surface and subsurface exploration. The Schlumberger array is used to ensure deep penetration and for cases of limited manpower and finance in the field (Emmanuel, 2010). For each VES sounding, the distance between potential electrodes MN was kept fixed at 2 m and the distance between current electrodes was increased gradually from 5 m to 50 m (AB/2) with a steep increase of 5 m or 10 m to investigate up to a maximum depth of 30 m (0.3 times of AB distance) below the ground level. Schlumberger Array was used in the study. The output apparent resistivity data of the above sites was found by Microprocessor based signal stacking digital resistivity meter of IGIS, Hyderabad make, Model SSR-MP-AT-S. The axes of all the VES soundings were aligned parallel to the geological strike in order to reduce the effects of lateral variations. Both the survey procedures resistivity profiling and resistivity sounding (VES) have been carried out. Resistivity profiling has been conducted in a grid pattern. The resistivity data have been qualitatively and quantitatively interpreted and analyzed by software package IPI 2 WIN ver.3.1.2 (Ogungbel et al., 2010).

Results and Discussions

The interpretation of the raw data as observed was done by IPI2WIN version 3.1.2. The depth of interpretation is found up to more or less 25 m at each VES point for the input survey distance of 50 m and it is found up to four geo-electric layers. As the study area consists of sand with gravel and rock somewhere, so from the interpreted resistivity values it can be inferred that the points where the soundings were carried out normally formed with dry sand having variation in moisture content up to a depth of approximately 5 m as the resistivity value of the first layers of most of the sounding points lie between 110 and 250 Ω-m. But in the case of Site 2 it is found that the sand content of the top layer are very much drier and contains bigger gravel and rock particles mixed with sand as the resistivity value of the top layer in Site 2 varies between 327 and 6414 Ω-m. As the resistivity value of sandy layer fully saturated with fresh water lies between 10 and 100 Ω-m, from the interpreted results it can be told that all the VES points show the existence of fresh water saturated layer except the three points S2/P4, S2/P5 and S4/P5. The cause of high resistivity of those points may be those areas consists of sedimentary rock below the ground level. The pseudo-cross-section and cross section wise resistivities are shown in Figures 3 and 4.

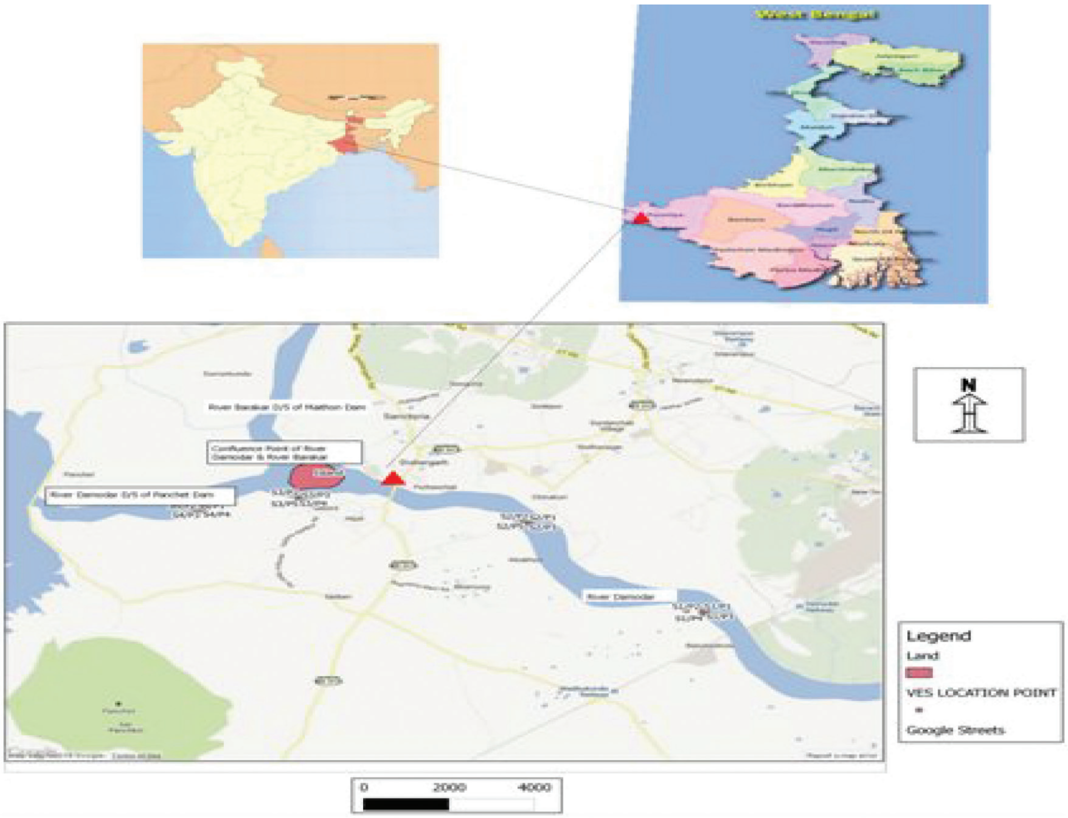

Figure 1: Index map of the study area.

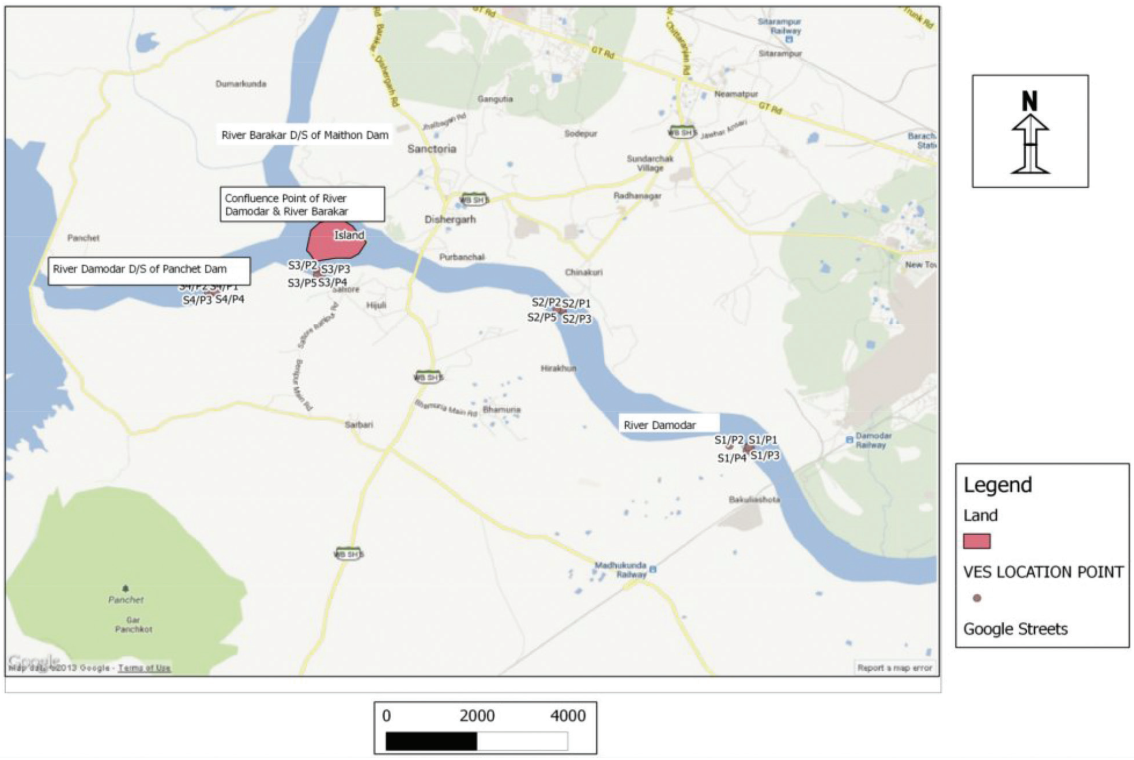

Figure 2: VES location points in the study area.

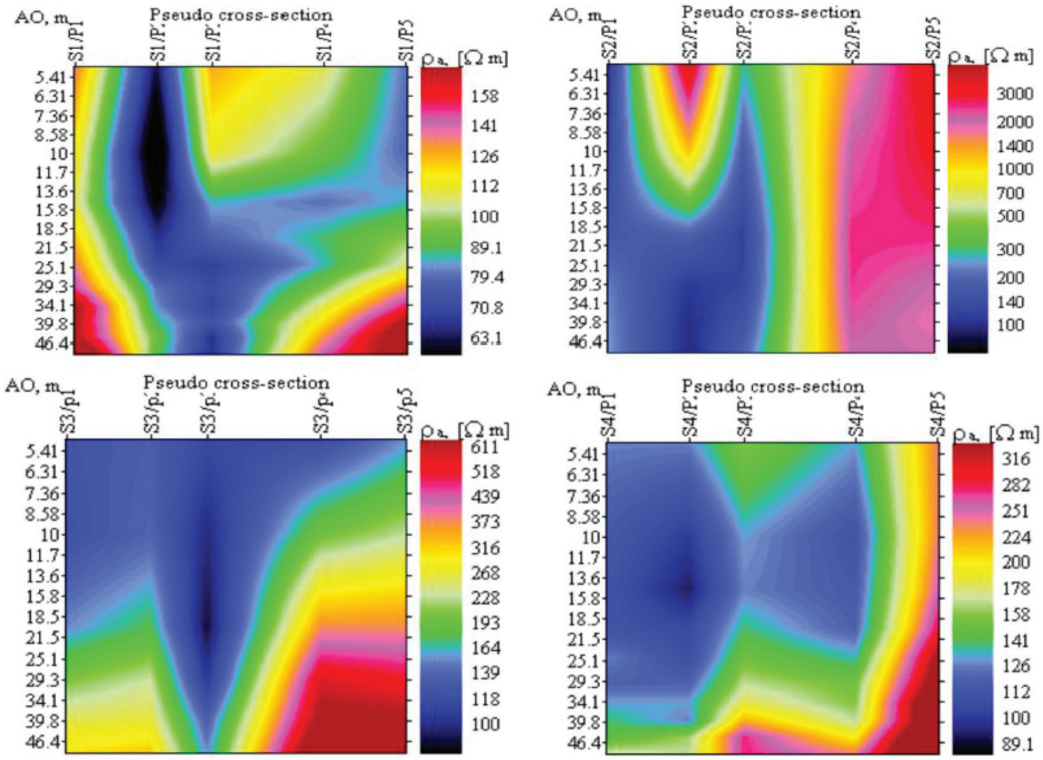

Figure 3: Pseudo cross-sections of the soundings of four sites for study area (Damodar river bed).

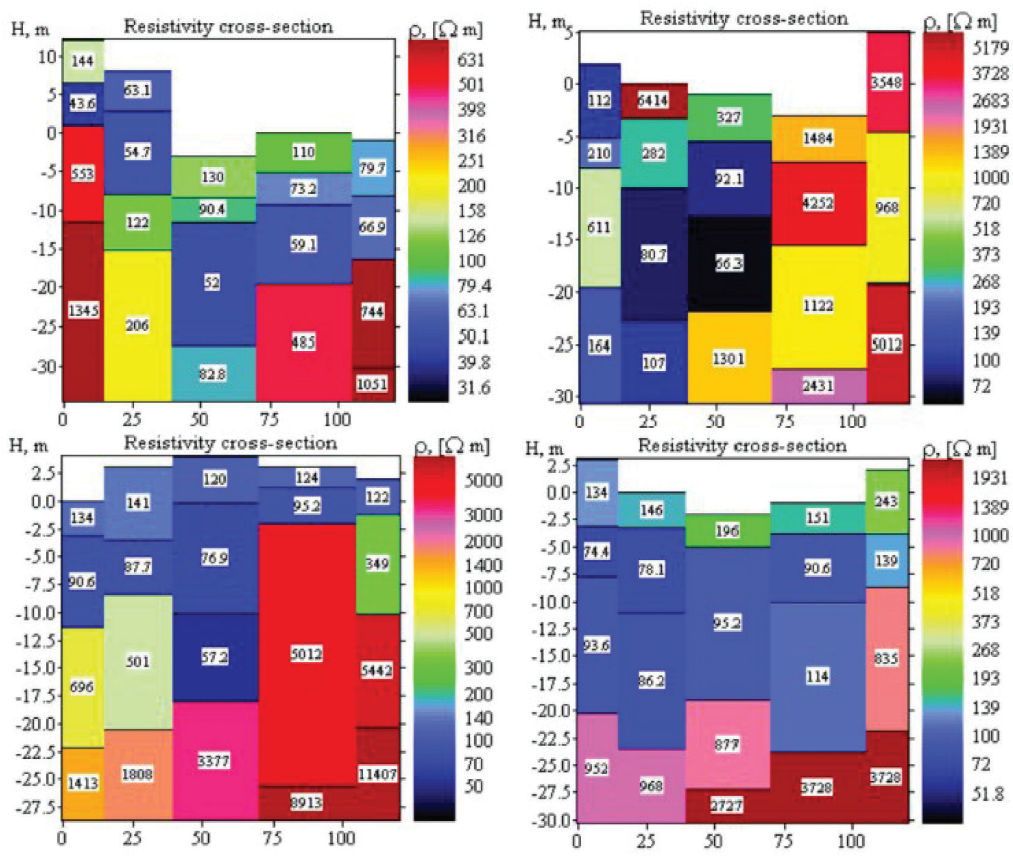

Figure 4: Resistivity cross sections of four sites in study area (Damodar river bed).

From the interpreted results up to four geo-electric layers in case of this study area (Damodar river bed) formed with sand, gravel and rock mixture it is found that the area is dominated by five types of geo-electric curve type viz., QH, HA, AK, KH and AA as shown in Table 1. Out of the five curve types the area is mostly dominated by the curve types HA ($\rho 1>\rho 2<\rho 3<\rho 4$) and QH ($\rho 1>\rho 2<\rho 3<\rho 4$) having percentage of occurrence value 55% and 30% respectively i.e., a total of 85% out of 100% highlighted in Table 2 in the study area.

Table 1: Interpreted curve type at each VES point for the study area (Damodar river bed)

Site location	*VES points*	*Resistivity details*	*Curve type*
Site 1	S1/P1	ρ1>ρ2<ρ3<ρ4	HA type
	S1/P2	ρ1>ρ2>ρ3<ρ4	QH Type
	S1/P3	ρ1>ρ2>ρ3<ρ4	QH Type
	S1/P4	ρ1>ρ2>ρ3<ρ4	QH Type
	S1/P5	ρ1>ρ2<ρ3<ρ4	HA type
Site 2	S2/P1	ρ1<ρ2<ρ3>ρ4	AK Type
	S2/P2	ρ1>ρ2>ρ3<ρ4	QH Type
	S2/P3	ρ1>ρ2>ρ3<ρ4	QH Type
	S2/P4	ρ1<ρ2>ρ3<ρ4	KH Type
	S2/P5	ρ1>ρ2<ρ3<ρ4	HA Type
Site 3	S3/P1	ρ1>ρ2<ρ3<ρ4	HA Type
	S3/P2	ρ1>ρ2<ρ3<ρ4	HA Type
	S3/P3	ρ1>ρ2>ρ3<ρ4	QH Type
	S3/P4	ρ1>ρ2<ρ3<ρ4	HA Type
	S3/P5	ρ1<ρ2<ρ3<ρ4	AA Type
Site 4	S4/P1	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P2	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P3	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P4	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P5	ρ1>ρ2<ρ3<ρ4	HA Type

Table 2: Occurrence of various curve types for the study area (Damodar river bed)

Curve type	*Frequency*	*Percentage of occurrence (%)*
QH	6	30
HA	11	55
AK	1	5
KH	1	5
AA	1	5

Correlation of VES Results and Borehole Data

The success of any geo-electrical resistivity survey depends on the verification of subsurface truth. VES success relies on the careful interpretation and integration of the results with the other geologic and hydro-geological data for the site. Two basic measurements were carried out in the quantitative assessment of groundwater resources in the study area viz., borehole data and VES survey. Therefore, lithological information obtained from the same VES points was used to calibrate the VES field data interpretation results. For this purpose, lithological samples were obtained vertically at 1 m depth interval at each station after conducting VES survey. To correlate the VES interpretation results with the borehole data, borehole modelling is prepared using Groundwater Modelling System (GMS) version 6.0 software. Two types of model are prepared: one type of model prepared using the borehole data collected from the field and the other type of model is prepared using the interpreted resistivity values and layer thickness by checking the resistivity values from the standard table (Palacky, 1987). All inputs are given to the material observed in the field or found from the interpretation results of the IPI2win software and then given input to GMS version 6.0 in a certain format which needs to be given in that software and borehole models are created using borehole modelling tool of the software (Ogungbel et al., 2010; Palacky, 1987; GMS, 2006). The results obtained from the borehole modelling are tabulated in Table 3.

The observed borehole model depicts that sand of different grade with gravel is found upto maximum 10 m depth (as shown in Figures 5 to 8) and the Interpreted borehole model depicts that sand and gravel mixture of various grade either saturated or partially saturated with water was found upto maximum 35 m depth approximately.

Correlation and Regression Analysis

The predicted depth to the basement from VES study has been compared with the depth borehole logs respectively using correlation and regression analyses.

As per Erricaker, 1971 the expression or correlation co-efficient may be written as,

$$\tau_{xy} = \frac{\mathrm{Cov}(x, y)}{\delta x; \delta y}, -1 \le \tau_{xy} \le 1 \qquad (1)$$

where Cov (x, y) is covariance and δx and δy are standard deviation of x and y respectively.

Table 3: Results as obtained from borehole modelling

Borehole name	*Depth range (m)*	*Material*
Site 1 (S1)	0-3	Fine sand yellowish colour
	3-6	Coarse sand yellowish colour
	6-9	Fine sand yellowish colour
	9-12	Coarse to medium sand yellowish colour
	12-15	Coarse to medium sand greyish colour
	15-18	Medium to fine yellowish colour
	18-20	Coarse sand yellowish colour
Site 2 (S2)	0-3	Medium to coarse sand
	3-6	Medium sand with small size gravels
	6-9	Medium to coarse sand with small size gravels
	9-12	Medium to coarse sand
	12-15	Medium sand
	15-18	Medium sand
	18-21	Sandy clay
	21-25	Coarse sand greyish colour with small size gravels
	25-28	Medium sand greyish colour
	28-31	Sandy clay
	31-35	Sticky clay
Site 3 (S3)	0-3	Coarse to medium yellowish
	3-6	Coarse to medium yellowish
	6-9	Medium to fine sand yellowish
	9-12	Medium to fine sand yellowish
	12-15	Fine sand yellowish
	15-18	Coarse sand yellowish
	18-22	Coarse sand yellowish
Site 4 (S4)	0-3	Coarse sand
	3-6	Coarse to medium sand
	6-9	Coarse sand
	9-12	Coarse to medium sand
	12-15	Coarse sand reddish colour
	15-18	Coarse to medium sand greyish colour
	18-21	Coarse sand reddish colour
	21-27	Sandy clay greyish colour

Table 4: Depth to basement rock as estimated from the two methods of hydrogeological studies

Site	*Average depth to basement rock as estimated from VES interpretation (m)*	*Depth to basement rock as estimated from borehole log (m)*
S1	23.956	20
S2	22.8074	35
S3	23.726	22
S4	23.7	27

Now, the mathematical equation which describes the relationships between the two variables (depth or thickness of the sub-soil stratifications in this case) is defined by regression equation (Erricaker, 1971; Ojo and Ademilue, 2013).

$$y = mx + c \tag{2}$$

$$\Sigma y = Nm + c\Sigma xn \tag{3}$$

$$\Sigma xy = mx + c\Sigma x^2 \tag{4}$$

where m and c are constants, y and x are variables and N, the number of items. The relationship between the predicted depth to the basement from VES study and depth to basement from the borehole logs (Table 3) has been calculated. A correlation coefficient,

$$\tau_{xy} = -0.95248 \tag{5}$$

is obtained and the relationship between the predicted depth and the actual depth to basement is expressed by regression equation,

$y = -12.56\,x + 321.9$, with Regression co-efficient (R^2) = 0.907

Here, y = Depth to basement rock as estimated from borehole litholog and x = Depth to basement rock as estimated from VES interpretations.

Conclusion

It should be noted that the fact that the correlation coefficient is not equal to one signifies that the sub-soil Litholog as interpreted from the VES study is not the same as the Litholog obtained from borehole and should not be treated as same. However, there exists a relation between the sub-soil layer as interpreted from the VES study and the borehole lithologic layer. The regression equation can be used to convert the results obtained from VES study to borehole log with great accuracy. Thus with the use of VES studies in the region in near

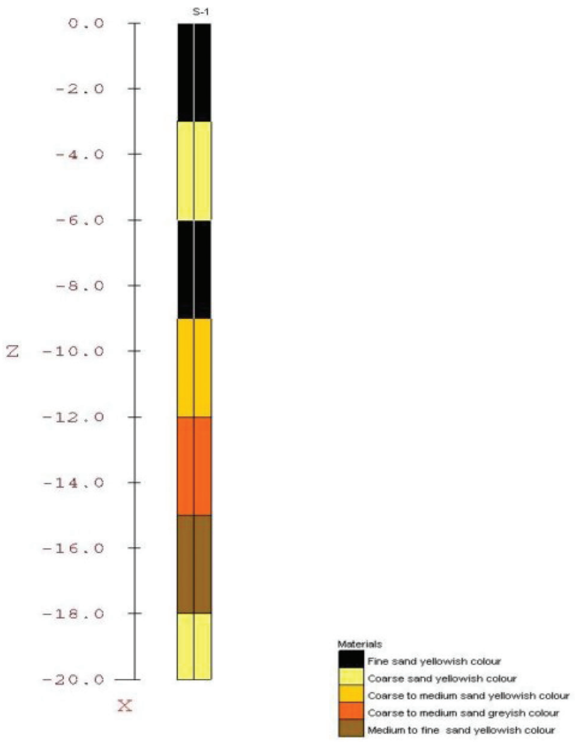

Figure 5: Borehole litholog modelling for Site 1 (S1) as obtained from GMS version 6.0.

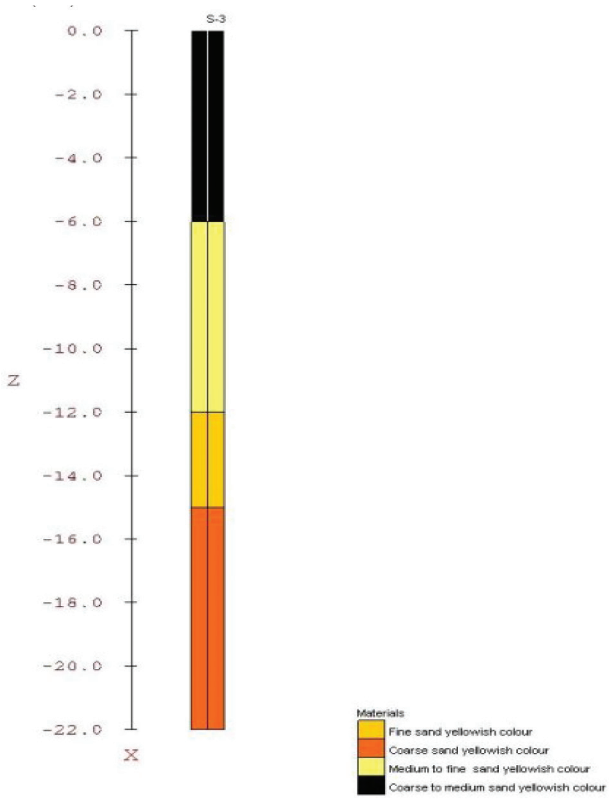

Figure 7: Borehole litholog modelling for Site 3 (S3) as obtained from GMS version 6.0.

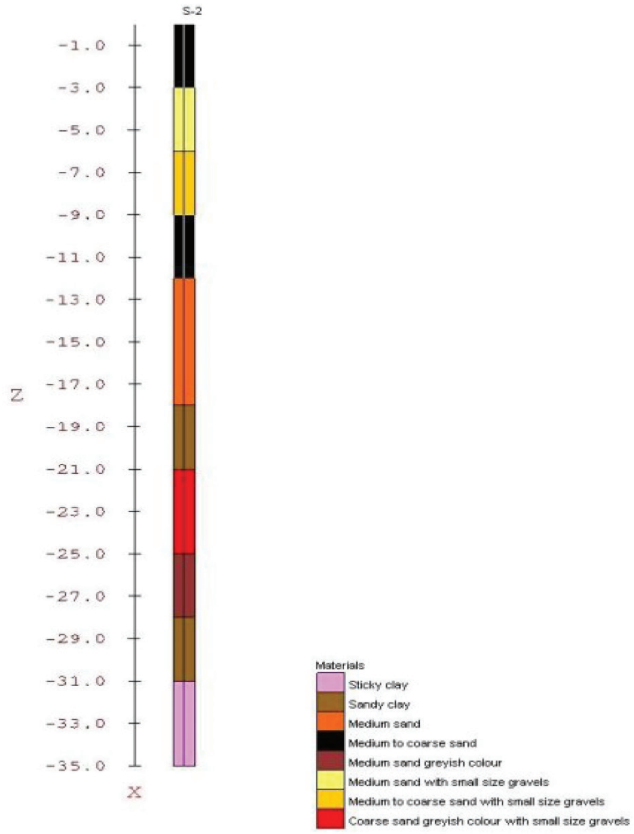

Figure 6: Borehole litholog modelling for Site 2 (S2) as obtained from GMS version 6.0.

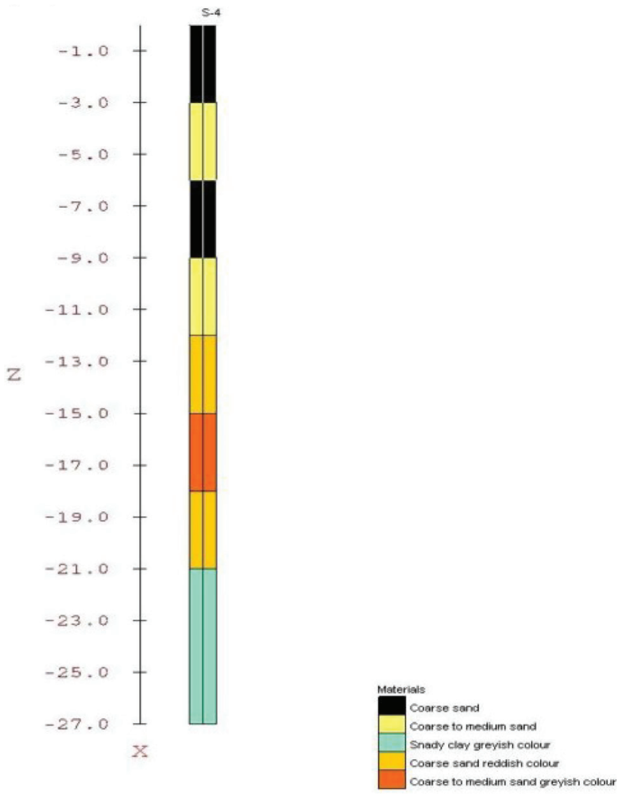

Figure 8: Borehole litholog modelling for Site 4 (S4) as obtained from GMS version 6.0.

future sub-soil Lithologs can be prepared without doing borehole thus saving money and manpower. Moreover quicker results could be obtained referred by Ojo and Ademilue (2013).

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Calendar of Events

International Conference on Innovations in Chemical, Biological and Environmental Sciences (ICBES-2017)
16th and 17th January 2017
Pattaya, Thailand
Website: http://cecabs.org/conference/161
Contact person: Conference Secretary: Carol Phillips
Organized by: International Centre of Excellence in Chemical, Agricultural and Biological Sciences

3rd International Conference on Environment and Bio-Engineering (ICEBE 2017)
21st to 23rd January 2017
Bangkok, Thailand
Website: http://www.icebe.org/
Contact person: Ms. Mickie Gong
Organized by: CBEES

International Conference on Energy and Environmental Science (ICEES 2017)--Ei, Scopus
22nd to 24th January 2017
Bangkok, Thailand
Website: http://www.icees.org/
Contact person: Ms. Lauren Ching
Organized by: Thammasat University

4th International Conference on Civil, Environment and Waste Management (CEWM-17)
23rd and 24th January 2017
Manila, The Philippines
Website: http://caeer.org/conference.php?slug=CEWM-17&sid=3&catDid=141
Contact person: Ms. Lipsa Zheng
Organized by: International Association of Civil, Agricultural & Environmental Engineering Researchers

8th International Conference on Environmental Science and Development (ICESD 2017)
8th to 10th February 2017
Frankfurt, Germany
Website: http://www.icesd.org/
Contact person: Ms Eve Lee
Organized by: Frankfurt University of Applied Sciences, Germany

9th edition of the International Conference Air and Water Components of the Environments
17th to 19th March 2017
Cluj-Napoca, Romania
Website: http://aerapa.conference.ubbcluj.ro/Engleza/index.htm
Contact person: Gheorghe Serban
Organized by: Babes-Bolyai University, Faculty of Geography

International Conference on Environmental and Energy Engineering (IC3E 2017)
22nd to 24th March 2017
Suzhou, China
Website: http://www.ic3e.net/
Contact person: Beca Feng

4th International Conference on Coastal and Ocean Engineering (ICCOE 2017)
28th to 30th March 2017
Osaka, Japan
Website: http://www.iccoe.org/
Contact person: Ms. Mickie Gong
Organized by: CBEES