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MODELLING OF SOIL RESISTIVITY, DRILL DEPTH AND OVERBURDEN THICKNESS IN PREDICTION AND VALIDATION OF SINKING PRODUCTIVE BOREHOLE

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ABSTRACT
Portable water scarcity has constituted a big challenge in Ogbomoso city as a result of increase in population of inhabitants and abandonment of public water supply on the part of government. In view of this, general public have resolved to find alternative means of drilling boreholes to cater for their needs. This study developed models taking into consideration factors that are vital in prospecting for underground water such as borehole depth, overburden thickness and soil resistivity among others. Existing data from 104boreholes were gathered and the aforementioned three parameters from existing wells were modeled to estimate depth and lithological thickness once resistivity is known. The two equations (models) can be used especially to estimate borehole depth and validate it, in and around the study area of Ogbomoso. Statistical was used in the analysis of data pooled from all the wells visited and the result obtained showed that both borehole depths and soil resistivity are moderately correlated with correlation coefficient of 0.31. In the study area, two models were developed, same was tested and it was established to be okay though with minimal error, it is recommended that the models should be used after survey work has been carried out and correlate model results with that of geophysical survey carried out by the geologist.

INTRODUCTION

Huge population spike, industrialization and urbanization in several towns and cities round the world have caused greater demand for clean and safe water for domestic or residential use (Halie & Semir, 2016). Apart from the fact that living things rely on water for survival, it is considered to be food as well as an essential part of life as human beings can survive without food but not without water for some time. Portable water is indispensable in that it is also needed for other purposes such as in agricultural practices, recreational activities, industrial uses and many more. Essentially, water from various existing dams (water works) is abundantly available but it has become moribund over the years for obvious reason which is largely due to government attitudes towards its treatment and incessant power failure which hinders treated pipe-borne water to be pumped by making it available to the entire populace. As a result of its vital needs and essentiality, groundwater is sourced to provide an alternative excellent water quality free of impurities, water-borne diseases, contaminants and poisonous dissolved salts which could pose danger to human wellbeings. Groundwater can be simply described as hidden water that is stored below the ground, the presence of a number of dissolved salts makes it to be conductive and it is somewhat comparable to water on the surface such as in pools, rivers, streams and even lakes which moves downward the soil under the influence of force of gravity though not freely as obstacles and barriers are encountered in the processes.

Groundwater finds its way through the gaps between the soils and through cracks in the solid rocks just like rain water flows on a slope containing grass weaving its way through the stems to reach the drain at the bottom end of the field. The puzzle and precariousness about where it takes its source, its movements and where it goes was wrongly interpreted and as a result, this give room for various fabulous and misrepresentations by the public.

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Groundwater can be found almost everywhere beneath the ground and in rocks below but it is not from the solid rock mass. In true sense of it, groundwater takes it source or arises from surface water which percolates downward into the soil vertically until it can no longer go deeper add it is added to already existing water in the cracks/ joints/ fissure of rock, in this way water start accumulating to a new level termed as 'water table' the level below which all available and interlinked spaces in the soil or rock becomes saturated. Water table is not flat but in slanting form down the valley side and slopes towards the river as it is continually drained by the river. Groundwater may be from well, spring and borehole which is naturally replenished by surface water especially during rainfall, from streams and rivers especially when water from these sources are discharged into water table. It is a long term reservoir of natural water having cycle of residency duration of between days to millennia as against short-term reservoir of water in the atmosphere and that of fresh surface water.

Borehole is considered in this study. It is a specialized well dug narrowly in the ground using drilling machine in other to gain access to the deep seated groundwater. Generally speaking, boring into the ground is not done only to get water but it is also applied in oil and gas exploration, sourcing for geothermal energy, well monitoring for groundwater levels and its quality, survey of subsurface conditions, shallow drainage construction, artificial recharge, waste disposal etc. Boreholes are usually narrow about 150mm (6 inches) in diameter, modern machines that are used in drilling are coupled with compressor to drive a rotating hammer which breaks up the rock into pieces. Exhaust air from the hammer tool blows the broken rock chips and water up to the ground surface. The location of a borehole is predetermined taking into consideration the purpose to which it is meant for considering its quality and long term supply etc which are important factors to be consider when we need borehole for drinking water, irrigation and other purposes. In sinking a borehole, expertise knowledge is needed for hydro-geological assessment to forecast the quantity of water available considering the topography, local vegetation, rock fracturing, local geology, groundwater chemistry, permeability of local aquifers from already existing ones and the point in order to meet up with pumping rate and to decide where to drill, though the location is at times limited by property ownership, which may hinder access to yield point or restriction to the usage of borehole equipment. It is very important practice that a copy of feasibility report should be given to the owner and also keeps a copy with the local authority saddled with the affairs for referral at any point in time when maintenance work is necessary (Douglas, 2013). At the end of drilling, casing is done to support the sides of the bored hole to prevent soft clay, soil, lose gravel and pebbles in transition zone from collapsing into the hole. When it is completed, surge or jet water in form of air in and out is carried out for the purpose of cleaning the bored-hole of mud, sand, pebbles and sediments. Thereafter, an efficient pump of corresponding capacity is installed so as to avoid restricted flow or seizure or low pumping rate. The pump is connected through electric cables to the source of electrical energy, the pump comprises of motor at the bottom above the water intake compartment. As the motor drives the shaft, it in turns rotates a series of propellers in the pump bowls such that water is now pushed up the pipe to the surface. Aquifer test is also carried out to determine the capacity and efficiency of the borehole by pumping at a constant rate and later increased stepwise from say hours to days. Importantly, borehole should be far from potential sources of contaminants of any form for instances; fuel, chemical storage, streams, sewer, leach field and septic tanks in order to ensure good quality of water and the safety of users.

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The target depth known as aquifer can be described as a layer of relatively porous substrate which contains and transmit water or as geological deposit of soil or rock which is permeable to water supply. In such places, voids are usually created by borehole drilling at the regions of saturated pores or cracks of rocks below the water table which allows water to flow into it through the action of gravity until the hole is filled up to the same level as that of water table beneath the ground. It consists of multiple layers but alluvial aquifer or confined layer is the target for commercial quantity of water. It characteristics ranges with the geology, substrate structure and even topography of different locations, however productive aquifers are found in the sedimentary geological formations.

Electrical resistivity investigations were conducted from two bored holes from where it was seen that the soil was stratified, near surface sandy-loam in between 30-70cm, silty loam is found in about 90cm depth and large fraction of sand/stone was found, soil stratification differs in boreholes (Bruce, 2005). Wisam and Hussein (2012) also reported that soil resistivity is an effective tool in delineations of soil layer, it decreases with depth especially in clayey layers due to its water contents. It was discovered that soil resistivity decreases with soil hardness and increase in moisture, the correlation of soil resist data with other geotechnical properties revealed that resist is proportional to sand and dry silts, but indirectly proportional to clay. There are a number of ways by which groundwater could be accessed but four major methods are surface, subsurface, areal and esoteric methods. These methods are sub-divided into various units for instance geophysical survey is one of such under surface method of exploring for groundwater. This is found useful due for two important reasons in that it reveals mapping and serves the purpose of water quality evaluations. It incorporates Vertical Electrical Sounding (VES) and Horizontal Profiling HP activities, it yields both information on existing subsurface thickness in line with water yielding capacities and desire depth with which the drilling needs to go. Al-garni, 2009; Jansen (2011) and Halie & Semir (2016), conducted separate surveys on types of aquifer, depth to aquiferous zones and geoelectric layers. Oladunjoye, Adabanija & Oni (2013) used very low frequency Electromagnetic (VLF-EM) and electrical Resistivity methods to unravel availability of localized groundwater in Ogbomoso to address the ever growing demand for groundwater, different yields were obtained from 3-layers earth models, a strong relationship was noted between geoelectrical successions and lithologic profiles, but no correlation was noticed between layers thickness of resistivity and the lithological profile. Bayowa, Ogungbesan & Mudashir (2019) investigated geophysical Earth fill of Oba dam embankment in Ogbomoso using electrical resistivity approach, the VES revealed that the embankment was under-laid with four geoelectric layers of different resistivity values, no evidence of structural weakness was seen and so it was concluded that the earth fill work on the embankment integrity was good.

The study area of Ogbomoso metropolis is made up of two local government areas namely; Ogbomoso south and Ogbomoso north is experiencing growth in population and since public supply is not in place, moreover surface water is polluted and not safe, hence the challenges posed by water scarcity have led to absolute dependence on groundwater for domestic and other uses. In 1964, Oba dam was constructed to provide about 4.0million liters per day of pipe borne-water for the inhabitants in Ogbomoso and the surrounding towns and villages, (WCOSO, 1997). In view of the aforementioned, this work tried to look at the way by which an alternative means could be put in place to estimate and validate borehole depth and overburden thickness by developing a model

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by which borehole location could be determined to access groundwater once soil resistivity of the location is predetermined.

MATERIALS AND METHODS

In this study, data from preliminary electrical resistivity surveys carried out in the study area within and around Ogbomoso were gathered during visitations to every 104 wells from where a comparison of soil resistivity, aquiver depth and overburden thickness were analyzed to see how well the data varies and align with one another. Models were developed from data obtained which could be used to predict and revalidate borehole depth and to estimate overburden thickness. soil resistivity serves three purposes, first in surveying sub-surface geological formation of an area to locate ore, bedrock, depth and other geological investigations. Secondly to investigate the impact or the degree of corrosion in underground pipelines, a decrease level in resistivity suggests increase corrosiveness and it also helps in ground activity design for electricity or thunder protector. Soil resistivity values varies across the globe and its localize value depends on the land terrain, soil layers, type of earth, moisture content, topography, soil temperature, chemical composition, concentration of dissolved salt, presence of metals and other buried metals like pipes, tanks, slabs, cable ducts, rail tracks, concrete pipes etc.

Surface investigations is usually carried out by measuring electrical characteristics of the earth because it is conductive and so electrodes are driven into it to measure voltage and current otherwise called resistivity. Wiener Array and the Schlumberger methods are specifically employed, apparent resistivity are actually measured from the field work because the current path may travel through non uniform geologic materials and thus the measurement represents combination of various materials through which current and voltage traverses. Software is then used in the interpretation of the data to determine the various parameters such as drilling point, borehole depth and overburden thickness and other information needed to give reliable guidance on the site in sinking of borehole. Lithology varies from place to in the study area, some areas revealed a complete buried bedrock by the overburden while some is underlain by three geologic layers. Some include the top soil, lateritic clay/partially weathered bedrock, and partially fractured basement. Major aquifer units within the study area consist of the partially weathered and fractured zones of the bedrock which are buried at varying significant depths. Consequent upon geoelectric parameters delineated at those investigated points within the study area, the VES point suggested divers depths which the well could be drilled to have an optimum drill depth ranging from 43 to 125m as in table 1. Some of the yields support domestic use and others are in the category of commercial or industrial benefit. Drilling risk factor was reported to be average, using air drilling method with caution.

DESCRIPTION OF THE STUDY AREA

Ogbomoso metropolis comprising two local government areas of Ogbomoso south and Ogbomoso north was considered in this study because of water scarcity from public source which have led to absolute dependence on groundwater for domestic use. Ogbomoso is in Oyo state in the southwestern part of Nigeria on the route A1, according to Encarta Premium facts and figures, it is categorized as one of the Yoruba city with an estimated population 861,300 in the year 2007. Inhabitants are principally farmer, trader, businessmen, craftsmen, civil servants and earn their living through other

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occupations. Weather features is chiefly tropical with two noticeable rain/wet and dry seasons, under normal condition, it usually rain in the month of may/april through October and dry season usually set in November and ends at the end of march year in year out. Round the year, the temperature is high with an annual mean of about 27^0C, the relative humidity is between 60 – 80% and the vegetation is savannah with several baobab trees (Bayowa, Ogungbesan & Mudashir, 2019). The latitudes and longitude of the study area are 4^o 10’E – 4^o 20’E and 8^o 00’N – 8^o 15’N respectively. It stands within Precambrian complex of southwestern Nigeria of migmatite-gneiss, bandid-gneiss, poorly roblastic biotite gneiss, granite and quartzite (Aina, Olorunfemi & Ojo, 1995). It is on plateau of Yoruba land of elevation of 1200feet (366m). Terrain is gentle undulating with subdendritic drainage pattern, geological basement stands within the southwestern basement complex, rocks are of ancient gneisis-migmatitie and meta-sedimentary series (Afolabi et al, 2013). It consists of medium grained textures to coarsed of no well defined foliation pattern, in form of biotite, hornblende, quartz, plagioclase, microcline and rarely pyroxene. Weathered profiles over the basement rocks is comparatively shallow and corroborated by shallow hand-dug wells of less than 5m resting on basement rocks in the study area. Groundwater flow is majorly southward direction and westwards (Rahaman, 1988).

TABLE OF RESULTS

In those reports, both horizontal resistivity profiling and that of Verttical Electrical Sounding measured from the sites were subjected to two-phase interpretation process of curve-matching and iterating inversion (layered earth modeling) methods, Futhermore, the apparent resistivity measured were plotted against the electrode spacing to obtain curves at different locations. Measured values of resistivity, overburden thickness and borehole depths from 104 sites visited within the study area were reported in table 1. These pooled results were used to develop two models through which prediction and/or validation of borehole depth could be made.

Table 1: Resistivity, Overburden thickness and borehole depth from the study area.

S/N	Resistivity (Ωm)	Lithology Thickness (m)	Borehole Depth (m)
1.	1200.7	95.0	70.0
2.	83150	98.0	50.0
3.	1437.9	35.0	70.0
4.	1214.3	90.0	60.0
5.	12312.4	86.0	70.0
6.	621.8	94.0	80.0
7.	46958.1	98.0	100.0
8.	2062.8	48.0	47.0
9.	2628.7	14.0	60.0
10.	763.6	90.0	60.0
11.	322.1	77.0	50.0

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12.	2149.6	87.0	47.0
13.	601.2	97.0	60.0
14.	272.8	97.0	60.0
15.	13944.2	81.0	60.0
16.	7642.4	89.0	50.0
17.	886.0	94.0	60.0
18.	563.8	85.0	60.0
19.	6892.6	99.0	50.0
20.	4705.2	96.0	70.0
21.	556.3	86.0	70.0
22.	1947.5	82.0	50.0
23.	398.6	82.0	60.0
24.	691.9	94.0	60.0
25.	460.5	47.0	80.0
26.	4001.4	84.0	70.0
27.	11925.4	81.0	60.0
28.	4496.2	28.0	80.0
29.	2663.9	71.0	70.0
30.	196.6	74.0	43.0
31.	3120.7	80.0	70.0
32.	1355.3	81.0	70.0
33.	1359.2	94.0	80.0
34.	2699.7	79.0	45.0
35.	2443.7	80.0	50.0
36.	9591.9	80.0	70.0
37.	4496.2	68.0	45.0
38.	6336.7	42.0	60.0
39.	8642.9	94.0	60.0
40.	9181.0	98.0	65.0
41.	14634.0	72.0	80.0
S/N	**Resistivity (Ωm)**	**Lithology Thickness (m)**	**Borehole Depth (m)**
42.	975.4	76.0	50.0
43.	28394.3	80.0	68.0
44.	14117.2	66.0	100.0
45.	1050.3	77.0	58.0
46.	3179.7	22.0	80.0
47.	538.5	81.0	58.0
48.	330.2	85.0	60.0

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49.	1599.8	80.0	60.0
50.	4382.8	79.0	60.0
51.	440.1	81.0	48.0
52.	623.2	85.0	60.0
53.	175.1	91.0	50.0
54.	8384.0	93.0	70.0
55.	401.7	51.0	48.0
56.	3561.8	38.0	50.0
57.	608.1	79.0	70.0
58.	7416.0	77.0	80.0
59.	25913.8	62.0	100.0
60.	49398.6	55.0	70.0
61.	5282.8	108.0	70.0
62.	4853.4	84.0	60.0
63.	2518.0	87.0	50.0
64.	1743.4	77.0	58.0
65.	10591.7	98.0	55.0
66.	8695.1	80.0	48.0
67.	3094.2	86.0	60.0
68.	69.0	94.0	50.0
69.	19916.1	110.0	60.0
70.	1403.6	58.0	50.0
71.	514.9	80.0	70.0
72.	469.7	76.0	48.0
73.	6392.6	81.0	48.0
74.	2093.6	96.0	60.0
75.	758.2	76.0	48.0
76.	1486.7	90.0	50.0
77.	432.8	96.0	48.0
78.	8439.9	76.0	50.0
79.	39.1	94.0	50.0
80.	4339.5	88.0	60.0
81.	9352.1	85.0	50.0
82.	1541.3	66.0	53.0
83.	4327.2	88.0	60.0
S/N	**Resistivity (Ωm)**	**Lithology Thickness (m)**	**Borehole Depth (m)**
84.	4148.6	80.0	80.0
85.	753.8	91.0	70.0

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86.	448.5	68.0	50.0
87.	351.6	74.0	48.0
88.	187.5	92.0	48.0
89.	12492.1	90.0	48.0
90.	8689.3	94.0	50.0
91.	6477.9	92.0	48.0
92.	10521.0	114.0	125.0
93.	4853.4	84.0	60.0
94.	601.2	95.0	60.0
95.	53095.8	58.0	100.0
96.	3369.3	92.0	48.0
97.	3850.4	94.0	60.0
98.	29665.7	71.0	60.0
99.	254.5	94.0	50.0
100.	1459.4	95.0	60.0
101.	1284.9	88.0	50.0
102.	10750.8	95.0	68.0
103.	7871.2	87.0	60.0
104.	565.1	83.0	48.0

RESULTS AND DISCUSSION

From the various reports at different borehole sites, the electrical resistivity survey showed that most of the locations within the study area revealed three main geologic layers of top soil, laterite layer/partially weathered bedrock and partially fractured bedrock with the varying resistivity, thickness and depths.

As desired in this study, three essential factors viz; resistivity of the location, overburden thickness and the depth where to which optimum yield could be gotten as reported in table 1 were correlated in this study. Results of these factors from the boreholes visited were analysed using statistical tools in generating or developing models which could serve as a predictor for locating a borehole. The main idea is that, once the resistivity of the location is measured, borehole depth can be easily calculated in the study area. General equation of a straight line is:

$$\mathbf{Y} = \boldsymbol{mx} + \mathbf{c}$$ Where:

Y is the dependent variable *m* is the gradient or slope *x* is the independent variable and *c* is the intercept on y-axis

In this stydy, the desired depth of the well is represented by *D* and it is taken to be the dependent variable from where its value can be estimated once the resistivity is known. Resistivity (ρ) here stand for independent variable. From the data obtained, values of

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the slope and the intercept are given as follows: Slope was calculated to be 0.0004 and intercept equals 58.74.

Hence the model which connects both the depth (*D*) and resistivity (ρ) is:

$$\mathbf{D = 0.0004\rho + 58.74} \qquad \textbf{(1)}$$

Essentially, the two data sets obtained in terms of the depths and resistivity were correlated and the evaluated correlation coefficient of 0.311 was gotten, hence this show that both sets of data have moderately positive relationship. Furthermore, another model was obtained connecting overburden thickness (T) and resistivity (ρ). The equation which connects the two variables is given to be:

$$\mathbf{T = 6.15^{-6}\rho + 80.82} \qquad \textbf{(2)}$$

A negligible correlation exists between two data sets of overburden thickness and the resistivity of the study area. These two equations can be employed in the study area in extrapolating desired depth to which a well should be sank in order to have a good yield of groundwater from the well. This will go a long way in making a comparisons with the calculated value from the Weiner Array cum Schlumberger measurements especially the first equation, it was tested and found to be having high feliabilty factor than that of secondequation. It is so and evident even from correlation coefficient which was found to be moderately related positively.

CONCLUSION

Various reports considered from 104 wells within the study area revealed various geologic layers. Distinct saturated layer (aquifers) were delineated on each site with divers values of VES 1 and 2 impressing various saturation points in line with the measured resistivities. Different geoelectric parameters delineated at the investigated points within the study area suggested points at which drilling could get to obtain optimum yields. Fractures were suspected at varying depthsbeyond or within the basement, thus enhancing the possibility of encountering productive reservoirs, depending on interconnectivity of fractures. Measured resistivities ranges from 39.1 to 83150.0 Ωm, while the lowest and highest value of overburden thickness is 14m and 111m respectively. The borehole depth was reported to be within 43 and 125meters.
Two models were obtained obtained, the first relates depth with resistivity $D = 0.0004\rho + 58.74$and the second show the dependency of overburden thickness on the relativity $T = 6.15^{-6}\rho + 80.82$. The two models was tested and was found to be useful as predictor and in validating of survey work carried out previously to drill the well.

RECOMMENDATION

It is hereby recommended that the models should be used in determining and validating borehole depth and overburden thickness particularly in the study area.

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