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Geophysical and Geotechnical Assessment of Subsurface Characteristics Upstream and Downstream Otamiri Watershed Owerri Southeastern Nigeria

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Abstract:- This investigation is motivated by the concern over the siting and stability of engineering structures and anthropogenic activities situated within the watershed area of the Otamiri River in the Imo River basin in Nigeria. Using electrical resistivity inversion and soil sampling, this study research is anticipated to look into the differences between the soil properties and water table in upstream and downstream watershed areas of the Otamiri river. This will lead to different approaches in engineering practices land use planning, watershed management, and better management of water resources within the study area. In order to create a topographic map of the area, GPS was utilised to measure spot elevation and coordinates. Four VES stations were set up to map the subsurface tomography using the electrical resistivity inversion technique. Two composite soil samples that were taken from the VES stations at a depth of 5 metres were examined in a lab. Geotechnical properties measured include shear strength and bearing capacity, liquid and plastic limits, grain size distribution and compaction density. Through the geophysical modelled data we obtained three types of curves, A curve type for VES 1 & 4, QH curve type for VES 2, and UK for VES 3. Common lithology discovered within the study area is sandy-clay, siltstone, sand and gravel. The topsoil from VES 1, 2, 3, and 4 ranged from 1.3-ohm meter to 1223.4-ohm meter. The water table ranged from 19.57m to 54.39m. The geotechnical results revealed a plasticity index of 13.3% to 19.3%, optimum moisture content at 14.0% to 14.4%, and maximum dry density of 1.85mg/m3 to 1.86mg/m3. The trial test showed shear strength at 99.5KN/m2 to 109.8KN/m2 indicating high shear strength and a great tendency to withstand the load. Most measured parameters fell within recommended standard of the federal ministry of Works and housing.

I. INTRODUCTION

Watershed management is a comprehensive strategy to managing watershed resources that combines forestry, agriculture, pasture, and water management with the aim of managing natural resources in a sustainable way. This strategy aims to encourage communication among many stakeholders both inside and outside of a watershed's upstream and downstream regions.

Watershed management issues are linked to national issues such as unrestrained land use patterns, forest loss, land degradation, poor water management, and air pollution. The inappropriate management of upstream areas exacerbates these issues further. In addition to human encroachment on and destruction of forests, urbanisation, logging, and the promotion of particular political interests, these issues are also a result of the lack of upstream and downstream links in planning and implementation. Due to poor people's restricted access and the declining quality of these resources, conflicts between upstream and downstream users of land and water are increasing. Due to the hydrological connections between upstream and downstream regions, it is impossible to guarantee the long-term protection of downstream river banks without also conserving upstream territory.

The area of study is the people of the capital territory of Imo state in southeast Nigeria values the Otamiri watershed. Rich economic and cultural resources are made available to the populace via the river system. Sand is actively mined from the watershed resources for use in developing and constructing roads in the city (in-stream and stream banks mining). The Imo State Water Corporation, the organisation in charge of meeting the domestic and industrial water needs of an estimated 450,000 people living in and around Owerri Capital, gets its water from a river upstream of the course. People who reside downstream in Rivers State as well as upstream in Imo State depend on the river for their livelihood. This demonstrates the value of the Otamiri watershed to locals and others.

The characteristics of the Otamiri River should be further studied so that the responses of the river to any encroachment in the flood plain and more so in the case of future man-made projects may be anticipated and preventive measures as deemed essential may be planned in advance. Due to nearby activities including agriculture, sand mining, dredging, and construction, the Otamiri river's morphological traits have changed through time. The water level has decreased as a result of these actions (that is places once covered with water are now bare land). The likelihood of flooding within its watershed has increased as a result of these physical changes.

Leachate from nearby municipal garbage dumps has been known to contaminate soil for a very long time. Similar to other underdeveloped nations, open dumps are the only method of disposing of solid garbage in cities in Nigeria. The disposal of solid garbage by filling in land depressions was how waste dumps were defined in India. Valleys and excavations are examples of the depressions into which solid waste is frequently disposed of. In southeast Nigeria, which is known for its generally unconfined, porous, and extremely permeable aquiferous systems, the consequences of unlined garbage dump on the host soil and beneath shallow aquifers have been neglected, which is alarming. Agricultural wastes, leaks from underground storage tanks, and poorly planned waste disposal facilities can all contaminate soil and groundwater systems. Waste dumps and microbiological pollution of soil and groundwater systems have both been related to nitrification and acidification of soil and groundwater. Large amounts of garbage are being produced as a result of urbanisation and population growth, and the way in which these wastes are disposed of poses major environmental and health risks.

Auto-mechanic villages, which represent several acres of land mapped out for auto-mechanics as opposed to city-wide automobile workshop practice, are adopted in opposition to the city-wide spread of automobile workshops. This aids in the proper planning and delineation of environmental resources (land) and its management. It makes sure that auto mechanic businesses aren't randomly positioned in an urban or semi-urban setting, leading to the area's environmental damage. The risk to human health and ecosystem from dumping used motor oil on the ground is a major problem in many developing nations.

Every building constructed on Earth has its own substructures. The qualities of the structures and the soil or rock must be taken into account while designing a foundation. As a result, an incredibly crucial factor for the safety, structural integrity, evaluation, and longevity of the superstructure is the nature (i.e., competency, strength, and load capacity) of the soil supporting it.

An exploration program's primary objective is to inform the engineer about the subsurface circumstances at the project site. The explorations often give the knowledge needed for a project's safe and cost-effective design and inform the construction engineer about the materials and environmental factors he will face on the job site.

Therefore, a non-intrusive methodology such as the geophysical method, which provides the reaction of the heterogeneous soil particles to some physical parameter that determines the subsoil competency, is necessary for a thorough assessment of the subsoil.

Drilling, cone penetrometer testing, and other geotechnical procedures are typically preferred by civil and building engineers for evaluating the strength of materials for the support of infrastructures like roads, buildings, and dams. Although these procedures are effective, they are costly, may not provide sufficient information about the entire area, and may prevent a decent depth of inquiry. Consequently, it is essential to supplement them with economical geophysical techniques that are frequently used in engineering site assessment. The geologic setup and the presence of a notable contrast in the physical parameters of the subsurface layers typically influence the choice of the geophysical method.

When determining the depth to bedrock or identifying subsurface layers, there is frequently a significant contrast in resistivity or conductivity between the low resistivity (conductive) overburden and the highly resistive (insulating) basement bedrock or competent lateritic hardpan.

The soil is still unsuitable for use in many nations despite all the benefits of earthen materials and architecture, mostly because of the drawbacks of this material and the lack of knowledge about its qualities. The understanding of earthen building requirements and the development of improvements, which entail reference to the local masons and related specialists, are hampered by a lack of knowledge regarding the qualities of building materials. The choice of soil required by engineers and architectural demands is still poorly understood. As a building material for engineering, soil does not yet have the necessary research or consideration.

In most civil engineering building projects, metallic pipe laying is a component. If the host soil medium is corrosive or aggressive, buried pipes may corrode and eventually fail. Low resistivity or high conductivity have been linked to the creation of corrosion cells, which can result in severe corrosion failure. A good electrical conducting channel is indicated by low electrical resistivity, which can be caused by soils with high concentrations of dissolved salts, less aeration, or enhanced electrolyte saturation.

Hydro-geophysical investigations for groundwater in porous and fissured media have regularly used the vertical electrical sounding technique, one of the geoelectric methods. This approach is based on how the earth reacts to the flow of a controlled input current source. It is a reliable and economical geoelectrical technique that offers 1-D electrical impedance measurements of the ground based on surface measurements, which are used to determine the water saturation and lithological information.

The conductivity and resistivity of the subsurface rock mass to electric current passing depend on the geoelectrical methods of mineral study. The usage of an electrical field that exists naturally within Earth or the insertion of artificially generated current through the ground are two methods.

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II. METHODS AND MATERIALS

➢ *Study Area*

One of the major rivers in Nigeria's Imo State is the Otamiri River. The river is named after the god Ota Miri, who is frequently regarded as the most powerful deity in Mbari homes and who owns all the streams that bear his name. The river flows to the Atlantic Ocean at Ozuzu in Etche, in the Rivers State, after passing through Nekede, Ihiagwa, Eziobodo, Olokwu Umuisi, Mgbirichi, and Umuagwo all the way from Egbu past Owerri. The river is 30 kilometres long from its source to where it meets the Uramiriukwa River at Emeabiam (19 mi).

About 10,000 square kilometres (3,900 square miles) in the Otamiri watershed receive 2,250 to 2,500 millimetres of rain annually (89 to 98 in). The watershed has a mean annual temperature of 27 °C (81 °F) and is primarily covered in degraded rainforest flora. Soil quality is declining as tropical rainforests are being converted to grasslands using slash-and-burn techniques.

The river flows through an alternate series of sands, sandstones, and clay shales south of Owerri. Random sand samples taken from the Etche Local Government Area, Rivers State, bank of the Otamiri River between Chokocho and Umuanyaga revealed that 86% of the sand particles fall within the optimal range for glass production.

A smaller portion of the larger Imo River basin is the Otamiri river watershed. The river, which has a length of 105 kilometres, is the main tributary of the Imo River, a significant river that flows through Imo state (Imo State Govt. Ministry of Works & transport, 1984). Imo state has a high population density; according to the data that is currently available, there are 813.54 people living there in a square kilometre (Federal Republic of Nigeria, 2009). The upper portions of the Owerri Capital Territory watershed that are threatened by urbanisation are included in the study area. Communities like Egbu, Owerri, and Nekede Settlement are included.

Vertical electrical sounding stations were (1) Otamiri water works, Egbu (2) St. Joseph's catholic church, Egbu (3) Chemical Engineering Building (FUTO) (4) Otamiri valley base (FUTO).

➢ *Geophysical Process*

The terrameter is powered by a 12Volts battery. The GPS was used to calculate the research regions' coordinates. The potential electrode spacing was maintained constant as the current electrodes were incrementally stretched from the station point until it was required to increase it. The qualities of the subsoil are investigated using a process called electric drilling. The model curves were obtained by applying the apparent resistivity values to the initial manual computation in the Advanced Geosciences Incorporation (AGI) 1D automatic analysis version.

In the geoelectrical survey, four (4) stations were dispersed throughout the research area and utilised Vertical Electrical Sounding (VES) using a Schlumberger electrode array and a maximum electrode spread of 125m. The half current electrode separation (AB/2) was likewise increased starting from 1.5m to 125m for each sounding station in order to get a noticeable potential difference. The potential electrodes' distance from the centre (MN/2) was gradually increased in steps starting from 0.5m to 14m.

➢ *Geotechnical Process*

Boring: Geotechnical investigation took place on 13th July 2021. At each sampling location upstream and downstream, a trial hole was drilled to a depth of 5 m using a hand auger and core sampler. Both disturbed and undisturbed samples were collected and taken to FUTO Erosion Laboratory for analysis. The samples were securely wrapped in airtight polythene bags to conserve the moisture content.

III. RESULTS AND DISCUSSION

➢ *Geophysical Result Discussion*

- *Upstream- Egbu*

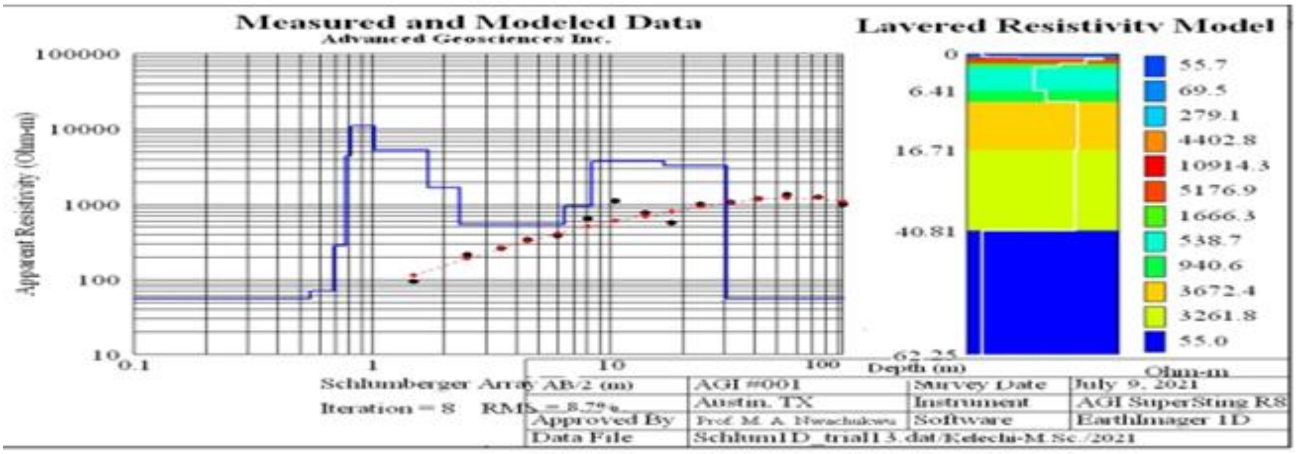

Fig 1 VES 1 Model Result for Otamiri Water Works, Egbu

Table 1 VES 1 Analytical Result in Constrained Sub-Layers

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	1.025	10914.3	Topsoil	Red
2	2.323	1666.3	Sandstone	Green
3	8.347	940.6	Sand	Green
3	16.707	3672.4	Sandstone	Yellow
4	40.81	3261.8	Sand/gravel (Water Table)	Mixed green
5	62.25	55.0	Sand (Aquifer unit)	Blue

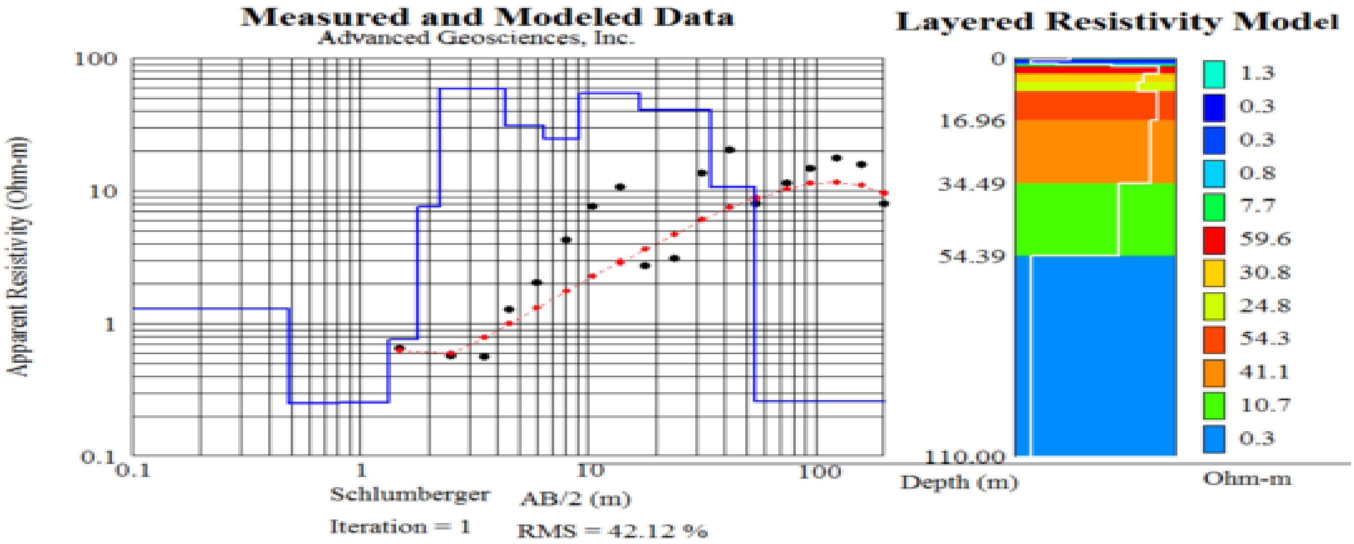

Fig 2 VES 2 Model Result for St Joseph's Catholic Church Egbu

Table 2 VES 2 Analytical Result in Constrained Sub-Layers

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	0.8	0.30	Topsoil	Mixed blue
2	2.25	7.7	Siltstone	Green
3	9.78	24.8	Sand/gravel	Orange
4	16.9	54.3	Sandstone	Red
5	34.4	41.1	Sandstone	Red-brown
6	54.4	10.7	Siltstone (water Table)	Green
7	110	0.3	Sand (Aquifer unit)	Blue

- *Downstream – FUTO*

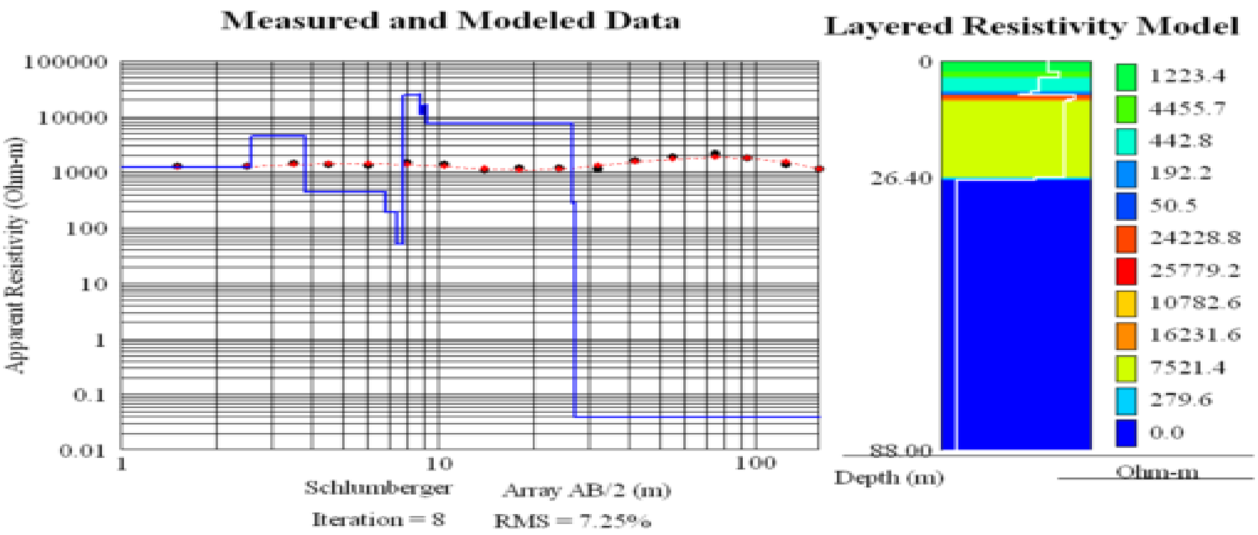

Fig 3 VES 3 Model Result for Chemical Engineering Building (FUTO)

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Table 3 VES 3 Analytical Result in Constrained Sub-Layers

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	1.12	1223.4	Topsoil	Green
2	3.7	4455.7	Sandy-clay	Green
3	6.6	442.7	Sandy-clay	Light blue
4	9.1	16231.6	Sand/gravel	Orange
5	26.40	279.6	Sand (Water Table)	Light blue
6	88.0	0.0	Sand (Aquifer unit)	Blue

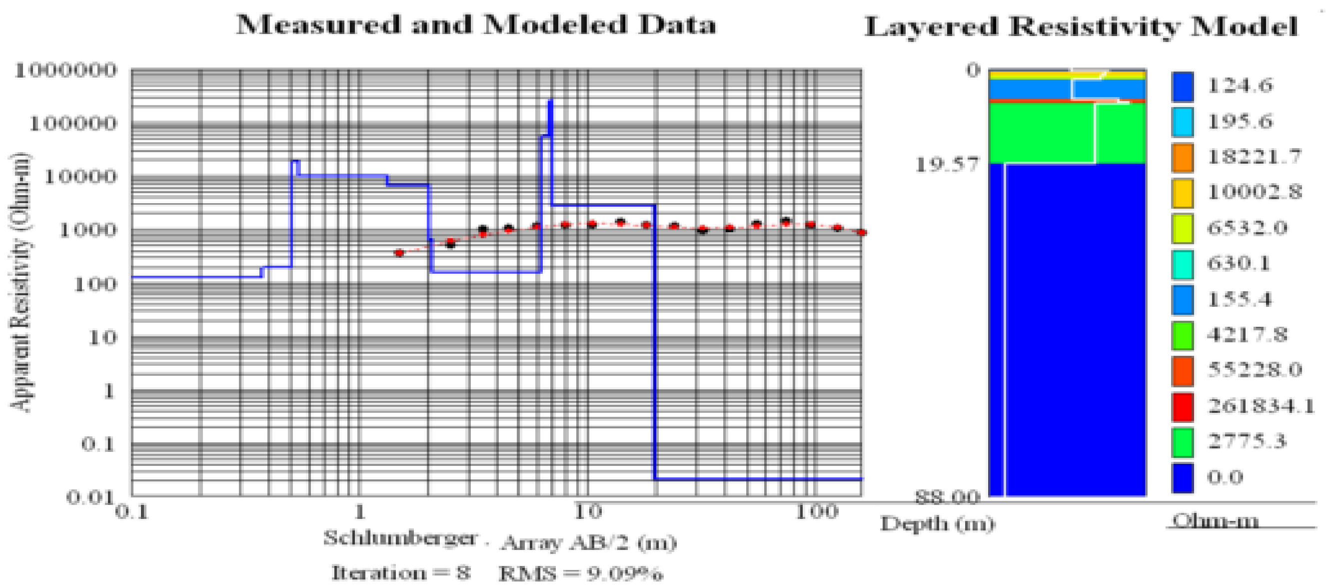

Fig 4 VES 4 Model Result for Otamiri Valley Base (FUTO)

Table 4 VES 4 Analytical Result in Constrained in Sub-Layers

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	1.38	10002.8	Topsoil	Orange
2	2.1	630.1	Sand	Light blue
3	6.0	261834.1	Sandstone	Red
4	19.57	2775.3	Sand (Water Table)	Green
5	88.00	0.0	Sand (Aquifer unit)	Blue

Table 5 Summary of VES Results

	Upstream		Downstream	
Properties	**Ves 1**	**Ves 2**	**Ves 3**	**Ves 4**
Station Location	Otamiri water works, Egbu	St Joseph Catholic church, Egbu	Chemical Engineering Building (FUTO)	Otamiri valley base (FUTO)
Elevation (ft)	112	189	195	101
Coordinates (N Degree)	05^0 30.447/	05^0 89.463/	05^0 23.04/	05^0 23. 031/
Coordinates (E Degree)	07^0 00.552/	07^0 14.963/	06^0 59.375/	06^0 59.289/
The resistivity of Top Soil (Ohms)	10914.3	0.3	1223.4	10002.8
The thickness of Top Soil (m)	1.025	0.8	1.12	1.38
Depth To Water Table (m)	40.8	54.4	26.4	19.6
No of Constrained Layers	6	7	6	5
Types Of Layers	Sandy soil, sand, siltstone, sandstone	Sandy clay, sand, siltstone, sandstone, gravel	Sandy clay sandstone, sand, siltstone sand/gravel	Sandy clay, siltstone, sand/gravel, sandstone
Curve type	A	QH	HK	A

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- The curve types, true geoelectric layer resistivities, and depth parameters were gotten and analysed.

The results of the curve matching and computer modelling of the field data have shown that the character of each of the VES curves would be determined through the shape of the curve of each of the soundings. Four electric-sounding data were obtained. By implication, both the features of each of the layers and their maximum depth of penetration would easily be ascertained by simply observing each of the VES curves. The reason is that a VES curve's shape is dependent on the quantity of layers found in the subsurface as well as their thickness and relative resistivity (Osemeikhian et al., 1982).

The obtained curve types are the A curve type for VES 1 upstream, the VES 4 downstream, the QH curve type for VES 2 upstream, and the HK curve type for VES 3 downstream.

The characteristics of the layers between the surface and the maximum depth of penetration were explained by the form of the curve for each sound. This is because the number of layers visible in the subsurface, their thickness, and their ratio of resistivity determine how a VES curve will always look (Osemeikhian et al., 1982).

The layer on top of which a typical civil engineering foundation is built is the topsoil. Sand and laterite elements make up the stratum. According to Akintorinwa and Adeusi (2009), the more competent the demarcated topsoil units are, the higher the layer's resistivity value.

The topsoil layers of VES 1, 2, 3, and 4 were found to have resistivities of 10914.3Ωm, 0.3Ωm, 1223.4Ωm, and 10002.8Ωm respectively which are good and show higher competence except for VES 2. This shows the presence of salts or contaminants in the top soil of VES 2. These areas are suitable as engineering materials except VES 2 which will have to be filled to the required depth with a more suitable material.

According to the classification of soil resistivity in terms of corrosivity made by Baeckmann and Schweak (1975) and Agunloye (1984), the top soil layer's VES 1, 3, and 4 indicate low corrosivity, whereas VES 2 indicates strong corrosivity.

Common bedrock materials encountered within the study area are sandy clay, silt stone, sandstone, sand, gravel, and clay. Multiple layers of sandstone and silt stone were observed commonly in most of the study areas. These are sedimentary rocks composed mainly of silt-sized particles and sand-sized (0.0625mm - 2mm) silicate grains. These layers are also associated with high resistivity values, indicating that they have low permeability and porosity and good protection for aquifers from contamination through infiltration into the ground.

Topographic low areas include Nekede and Futo, obinze, Umuagwo, and Umuekwunne in the Land use map of the otamiri watershed. Otamiri river drains from upstream areas Egbu, Naze to downstream areas Nekede, Ihiagwa and Obinze, Umuagwo and Umuekwunne.

Geophysical results through layered resistivity after being modelled showed the water table upstream at both VES stations at Egbu to be at 40.81m and 54.39m respectively, while the water table downstream at VES stations in FUTO was observed to be at 26.40m and 19.57m. This data shows that the otamiri upstream watershed has deeper aquifer units which indicate that a water well drilled in this area is at a safer depth and also less prone to contamination from surface activities, while the otamiri downstream watershed shows shallow aquifer units, thereby making the aquifer units downstream more prone to contamination from the surface.

- *Geotechnical Result Discussion*

Table 6 Summary of Geotechnical Results

S/N	Soil Property	Upstream (Sample A)	Downstream (Sample B)
1	Moisture content	11.4	16.2
2	Bulk unit wt. mg/m^3	1.95	1.77
3	Dry unit wt. (mg/m^3)	1.75	1.59
4	Atterberg limits		
	Liquid limit (LL) %	43.6	37.5
	Plastic limit (PL) %	24.3	23.3
	Plasticity index (PI) %	19.3	13.2
5	**Grain size distribution**		
	Fines	15.2	29.3
	Sand (%)	69.7	84.8
	Gravel (%)	0	0
6	**Compaction test**		
	O.M.C (%)	14.4	14.0
	M.D.D. (mg/m^3)	1.86	1.85
7	Shear strength (KN/m2)	109.8	99.5

The geotechnical investigation reveals that soil properties across the site are fairly even. There are minimal variations in the geotechnical parameters measured.

- *Soil Structure*: is used to describe how the soil's particles are packed or dispersed within the soil mass. Aspects of the structure include layers, joints, fissures, slickenside, voids, pockets, cementation, etc.

- *Soil Texture:* The laboratory analysis conducted for soil texture is the gradation test also known as the grain size distribution test.

One of the factors used to determine if a soil is suitable is its grain size. Grain size analysis data can be used to forecast soil-water movement. The goal of the grain-size analysis is to ascertain the relative distribution of the various grain sizes within a given soil mass.

- ✓ The grain size test indicates that the samples are predominantly sand, with fair proportions of fines (clay-silt content) for cohesion.
- ✓ The grain size analysis shows that the upstream is made up of fines 15.2% and sand 69.7%, while the downstream is made up of 29.3% fines and 84.8% sand. Both had zero gravel present.
- ✓ This shows that the downstream topsoil contains more fines and sand than the upstream topsoil.
- ✓ The moisture content at the upstream soil was observed to be at 11.4% while the downstream was at 16.2%. This means that the downstream soil had more water content than the upstream soil, as a result of the downstream having a higher water table compared to the upstream.
- ✓ Soil consistency(atterberg limits): explains the basic physical state of the soil at different moisture contents as shown by how they react to mechanical stress. The Atterberg limit test was used to determine the soil consistency for this project.
- ✓ This test for the upstream showed a liquid limit of 42.5%, a plastic limit of 24.3%, and a plasticity index of 19.3. While the downstream showed a liquid limit of 37.5%, a plastic limit of 23.3%, and a plasticity index of 13.2.
- ✓ The Nigerian federal government mandates that soils used as building foundations must have plasticity index values of less than 20% and liquid limits of less than 30%.
- ✓ Consequently, neither upstream nor downstream soil should be used as building foundation material. Due to low levels of the fine fraction, both soils' liquid limits are positive, indicating that the soils can transition from one state of consistency to another with little change in water content.
- ✓ The results of these tests, which yielded plasticity index values for upstream and downstream of 19.3 and 13.2, respectively, demonstrate that upstream soil has a higher capacity for swelling than downstream soil, and buildings constructed upstream are more likely to develop cracks than buildings constructed downstream. Since the soils have low plasticity, they are likely to have high permeability (Nwachukwu and Osoro, 2013).
- ✓ The upstream soil measured at 1.86 mg/g and 14.4% for the Standard Proctor Compaction test, whereas the downstream measured at 1.85 mg/g and 14.0%. Between the upstream and downstream, there was no discernible difference, and both fall within the acceptable standard recommended by the Federal Ministry of Works and Housing (FMWH) 1972 for foundation material.
- ✓ Working on the geotechnical characteristics of soils in areas of Imo state, including those within the research region, Okunade (2007) observed MDD values between 1.7 and 2.1Mg/m3 and OMC values between 9 and 24%. The study of Okunade supports our conclusions on OMC and MDD. Therefore, it should be noted that the soil should be compacted to calculate OMC and MDD in order to get maximum strength for any engineering work within the region (Onunkwo, Uzoije, & Onyekuru 2014).

Shear strength: This expression in soil mechanics refers to the maximum amount of shear stress that a soil can withstand. The friction and interlocking of soil particles, as well as possible cementation or bonding at particle contacts, all contribute to the soil's shear resistance. The particulate material may expand or shrink in volume due to interlocking as a result of shear stresses. The strength and particle density of t soil will both decrease with volume expansion; in this scenario, the peak strength would be followed by a drop in shear stress.

The shear strength obtained from this study showed an upstream shear strength of 109.8KN/m2 and downstream shear strength of 99.5KN/m2, which is acceptable within a reasonable limit. The upstream soil exhibited higher shear strength compared to the downstream soil.

IV. CONCLUSION

This research was carried out to investigate the variation in the soil properties and water table upstream and downstream watershed areas of the otamiri river using electrical resistivity inversion and soil sampling. The curve types identified are A, QH, and HK curve type with the A curve being the higher having two out of 4 VES curves that were obtained. The geotechnical analysis found results obtained on natural moisture content, bulk and dry unit weight, atterberg limits, compaction test, grain size and shear strength to conform with Federal Ministry of Works and Housing (FMWH) of Nigeria 1972.

The geotechnical investigation reveals that soil properties across the site are fairly even. There are minimal variations in the geotechnical parameters measured.

The grain size test indicate that the samples are predominantly sand, with fair proportions of fines (clay-silt content) for cohesion. The Atterberg limit tests revealed that the site has a low plasticity index and swelling capacity. This alone means that swelling and shrinking characteristics will not be of concern in this study area.

The shear strength result is acceptable within a reasonable limit. A shallow strip foundation is recommended to a depth of 2.5 m. This is justified by the geophysics result of 2.25 m. It is therefore obvious that a foundation to a depth of 2.4-3.0 m, and down to 6 m will be suitable, resting on a sandstone bedrock.

➢ *The Contribution to the Knowledge of this Study Includes:*

- The use of geophysical and geotechnical surveys to ascertain the properties of the subsurface.
- Increased Awareness to stakeholders and researchers on the effect of anthropogenic activities upstream and downstream on their watershed.

REFERENCES

[1]. Abdul, A., Syed S. A., Nazish, N., Waqas, A., Sarfraz, K., Muhammad, Y. K. and Muhammad, W. (2016). Correlation of electrical resistivity of soil with geotechnical engineering parameters at Wattar area district Pakistan. Journal of Himalayan Earth Sciences. 49(1): 124-130.

[2]. Akintorinwa O. J. and Adesoji J. I. (2009). Application of geophysical and geotechnical investigations in engineering site evaluation. International Journal of Physical Sciences Vol. 4 (8), pp. 443-454, August 2009.

[3]. Amadi A. N, Olasehinde P. I., Okosun E. A., Okoye N. O., Okunlola I., A., Alkali, Y. B., Dan-Hassan M. A. (2012). A Comparative Study on the Impact of Avu and Ihie Dumpsites on Soil Quality in Southeastern Nigeria. American Journal of Chemistry 2012, 2(1): 17-23 DOI: 10.5923/j.chemistry.20120201.05.

[4]. British Standards (BS) 1377, (1990). Specification for Roads and Bridges in Nigeria. 2, pp. 137-275.

[5]. Chukwuocha N. B (2015). Analysis of Structural Changes in Land Use and Land Cover of Otamiri Watershed in Owerri, South East Nigeria. Journal of Environment and Earth Science www.iiste.org ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) Vol.5, No.6, 2015.

[6]. Cosenza, P., Marmet, E., Rejiba, F., Cui, Y. J., Tabbagh, A., Charlery, Y. Correlations between geotechnical and electrical data: A case study at Garchy in France. Journal of Applied Geophysics, 60, 2006, pp. 165–178.

[7]. Egboka, B. C. and Uma, K. O. (1985). Water Resources of Owerri and Its Environs, Imo State. Nigeria. Journ.Min. Geol. 22: 57-64.

[8]. Eyankware MO, Ogwah C, Selemo AOI (2020) Geoelectrical Parameters for the Estimation of Groundwater Potential in Fracture Aquifer at Sub-Urban Area of Abakaliki, SE Nigeria. Int J Earth Sci Geophysics.

[9]. Fahad, I.S. and Syed E.A. (2012). Integrating Geo-Electrical and Geotechnical Data for Soil Characterisation. International Journal of Applied Physics and Mathematics, 2(2):104-106.

[10]. Federal Ministry of Works and Housing (1972): Highway Manual Part 1 Road Design, Federal Ministry of Works and Housing, Lagos.

[11]. Gay D. (2001) GEOTECHNICAL INVESTIGATIONS. Coastal Infrastructure Design, Construction and Maintenance (CDCM). Design of Marine Structures September 24 –28, 2001.

[12]. Geotechnical engineering. (2008, December 31). New World Encyclopaedia. Retrieved 17:43, July 23, 2021. Giridhar M.V, Mohan S. & Kumar D. A (2020). Comparative assessment of surface and groundwater quality using geoinformatics. Advances in Environmental Research, Vol. 9, No. 3 (2020) 151-160 DOI: https://doi.org/10.12989/aer.2020.9.3.151.

[13]. Habeeb, A.Q., Olabambo A. A. and Oladipupo S. O. (2012). Investigation of the Geotechnical Engineering Properties of Laterite as a Subgrade and Base Material for Road Constructions in Nigeria. Civil and Environmental research.2(8):23-32.

[14]. Ibe, K. M. and Njemanze G. N. (1998). The Impact Of Urbanization And Protection Of Water Resources, Owerri, Nigeria. Journal of Environmental Hydrology. 6(9): 52-61.

[15]. Ibeneme, I. L., Nwankwo, E. J. and Oparaocha J. O. (2014). Geoelectrical and Geotechnical Evaluation of Foundation Beds at Naze, Owerri South eastern Nigeria. Journal of Earth Sciences and Geotechnical Engineering. 4, (3): 77-94.

[16]. Igboekwe M.U, Okwueze E.E and Okereke C.S (2006). Delineation of Potential Aquifer Zones from Geoelectric Soundings in AKWA IBOM River Watershed, South eastern, Nigeria. Journal of Engineering and Applied Sciences, 1: 410- 421.

[17]. Joab M. J, &Andrews M. (2009). Investigating Slope Failures Using Electrical Resistivity: Case Studies. The Journal of the Association of Professional Engineers of Trinidad and Tobago Vol.38, No.1, October 2009, pp.66-75.

[18]. Kumari Sudha a M. Israil S. Mittal J. Rai (2009). Soil characterization using electrical resistivity tomography and geotechnical investigations Journal of Applied Geophysics 67 (2009) 74–79 SCIENCE DIRECT 2009.

[19]. McCarthy, John E. and Zachara, John M., "Subsurface transport of Contaminants" (1989). US Department of Energy Publications. 175.

[20]. Mohd H. B., Rosli, B. S., Devapriya, C. W. and Mohamad, F.B. (2012).Integral analysis of geoelectrical (resistivity) and geotechnical (spt) data in slope stability assessment.Academic Journal of Science, 1(2):305– 316.

[21]. Nwachukwu M. A. (2010). ANALYTICAL AND GEOPHYSICAL ASSESSMENTS OF HEAVY METALS DISPERSION FROM AN AUTOMOBILE MECHANIC VILLAGE AND ITS POLLUTION PREVENTION.Conference Paper · April 2010 DOI: 10.4133/1.3445522.

[22]. Nwachukwu, M. A., Aslan, A. and Nwachukwu, M. I. (2010). Application of Geographic Information System (GIS) in sustainable groundwater development, Imo River Basin Nigeria. International Journal of Water Resources and Environmental Engineering Vol. 5(6), 310-320.
[23]. Nwachukwu M. A, Feng H. and Achilike K. (2010). Integrated study for automobile wastes management and environmentally friendly mechanic villages in the Imo River basin, Nigeria. African Journal of Environmental Science and Technology Vol. 4(4), pp. 234-249.
[24]. Nwachukwu M. A. and Osoro E. (2013). Assessment of environmental hazards: Linking borrow pits, gully erosion, and road failure. Journal of Civil Engineering and Construction Technology.4(6): 199-210.
[25]. Nwoko C. O, Njoku-Tony R. F, Nlemedim P. U, & Ihugba U. A. (2017) Assessment of the Distribution Pattern of Poly Aromatic Hydrocarbons around Nekede Auto-mechanic Village, Imo State, Nigeria. Journal of Chemical, Environmental and Biological Engineering. Vol. 1, No. 2, 2017, pp. 27-33. doi: 10.11648/j.jcebe.20170102.11
[26]. Ogbomida E. T, & Emeribe C. N (2013). Impact of urbanization on Nwaorie and Otamiri Rivers in Owerri, Imo State, Nigeria. Advances in Environmental Research, Vol. 2, No. 2 (2013) 119-129 DOI: http://dx.doi.org/10.12989/aer.2013.2.2.119.
[27]. Ola, P.C. (1981). Parameters For the Rating of The Engineering Properties of Atterberg Limits. InternationalJournalon Technical Structures.pp 24-30.
[28]. Onunkwo, A. A., Uzoije, A.P. and Onyekuru, S. O. (2014). Engineering Properties and Uses of Soil Derive from Maastritchian Ajali Formation in A Part of Southeast Nigeria. British Journal of Environmental Sciences. 2(4):.11-28.
[29]. Osemeikhian, J.E. (1982): Geophysical methods for determining groundwater aquifer.
[30]. Osuagwu J. C., Nwachukwu A. N., Nwoke H. U., Agbo K. C. (2014). Effects of Soil Erosion and Sediment Deposition on Surface Water Quality: A Case Study of Otamiri River.Asian Journal of Engineering and Technology (ISSN: 2321 – 2462) Volume 02 – Issue 05, October 2014.
[31]. Pandit B. H, Wagley M. P, Neupane R. P, & Adhikary B. R (2007). Watershed Management and Livelihoods: Lessons from Nepal. Journal of Forest and Livelihood 6(2) September 2007.
[32]. Samouëlian, A., Cousin, I., Tabbagh, A., Bruand, A., and Richard, G. (2005). Electrical resistivity survey in soil science: a review. Soil Tillage Res., 83(2), 173-193.
[33]. Sultan Awad Sultan and Fernando, A Monteiro Santos 2008 1D and 3D resistivity inversions for geotechnical investigation J. Geophysics. and Eng.5 1 doi:10.1088/1742-2132/5/1/001.
[34]. Utom A.U., Odoh B.I., Okoro A.U (2012): Estimation of Aquifer Transmissivity Using Dar Zarrouk Parameters Derived from Surface Resistivity Measurements: A Case History from Parts of Enugu Town (Nigeria). Journal of Water Resource and Protection, 4, 993-1000.
[35]. Wightman, W. E., Jalinoos, F., Sirles, P., and Hanna, K. (2003). "Application of Geophysical Methods to Highway Related Problems." Federal Highway Administration, Central Federal Lands Highway Division, Lakewood, CO, Publication No. FHWA-IF-04-021, September 2003. ZOHDY A. R., (1975). Automatic Interpretation of Schlumberger Sounding Curves, Using Modified Dar Zarrouk Functions. United States Government Printing Office, Washington.