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Spatial distribution and variation of the plasticity of soils in Port Harcourt, South Southern Nigeria

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Abstract

Maps illustrating the variance in the plasticity of the soils in Port Harcourt and its surroundings were created using data from 147 soil study reports, primarily the Atterberg Limits, on a scale of 1:5000 meters at depths of 1 to 1.5 meters, 3 meters, and 6 meters. These maps were intended to serve as a rapid reference for land use planning as well as for the planning, designing, and building of civil engineering buildings. Soil samples taken at 1.5, 3 and 6 m depths showed a Natural Moisture Content that clustered around 17.93% with little variation from this average value. At the depth of 1 to 1.5 meters, where the majority of shallow building foundations are positioned, the study's liquid limit results ranged from 22% to 180%, with an average of 45.11%. The average value of the Plasticity index was 22%, with a range of 9.5% to 87%. According to the USCS soil classification, the soils were categorized as CI, CL, and CH, with a few sites having MH-OH. This suggests that the majority of the clays in the Port Harcourt regions are inorganic clays with medium to high plasticity. According to regression analysis, the consistency limits and moisture contents have negligible to marginally significant associations. These engineering geology maps were created to help planners and decision-makers allocate land for civil engineering projects and sustainable land use.

Keywords: Building Foundation; Atterberg Limits; Plasticity; Sustainable Maps

1. Introduction

The southern Nigerian city of Port Harcourt is located in a wetland with several rivers, creeks, and wetlands. From 7,000 in 1921 to 180,000 in 1993 to 2,343,100 in 2015, the population grew [3]. From the estimated 3,000000 in 2020, this population is predicted to increase to almost 5 million by 2030. The town's land usage has been severely strained by this population growth tendency, including regions that were previously deemed waste lands due to the poor engineering qualities of the underlying soils caused by soft soils and excessive rainy circumstances. The fact that traditional maps—geological, geographical, agricultural, etc.—have flaws and are unsuitable for engineering applications is one of the justifications for creating an engineering geological map of towns. Second, basic geological data and well-presented data on the physical features of the environment are required for engineering structure planning. The subsurface engineering characteristics, hydrogeology, geomorphic conditions, and geodynamic processes must all be included in these engineering geological maps. This will make it feasible to assess engineering structures' performance more quantitatively and identify areas for improvement. Port Harcourt does not currently have an engineering geology map, thus creating one at an appropriate size would be significant. Therefore, this effort was done to show the soils' malleability on a map so planners could quickly refer to it for development.

For engineering reasons, geotechnical soils are made up of naturally occurring mineral particles that can be separated mechanically [4]. In terms of geomorphology, engineering soils are created at shallow depths by the weathering and sedimentation of undisturbed bedrock. Even if human activities are becoming more widely distributed, spatially, which relies on social economic and environmental variables, geotechnical parameter is seldom included during the earliest

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stages of territorial planning for soil usage [16]. Since engineering geologists are not often engaged in the development of civil engineering projects, the majority of buildings and roads are built without a careful examination of the geological environment and materials [25]. The creation of engineering geological maps that can provide a summary of the engineering geology of the region to be worked on is crucial because of issues like road settlement and subsidence that have resulted from this [15].

Particularly in tropical nations, engineering geological mapping—a crucial instrument in the majority of mining and civil engineering projects—has not received the attention it merits [18]. The lack of techniques specifically created to address the particular issues of tropical areas is mostly to blame for this state of affairs. Engineering geological mapping is a basic prerequisite for planning, as demonstrated by problems such as differential settlement, which typically result from unfavorable engineering geologic conditions [24]. Surficial material deposits, like residual soils, are crucial to most engineering geological and geotechnical investigations because many engineering activities, from building foundations to roads and bridges, are primarily structured within the top few meters of the earth's surface. [23,10]. An engineering geological map that includes various elements like hydrogeology, geology, geomorphology, and geotechnical properties is necessary to completely understand the geology and geotechnical characteristics of regions that are undergoing rapid population and structural growth [17]. Engineering geological and environmental maps are necessary to support the engineers' need to construct structures and thoroughly assess the current and potential environmental effects [12]. Since the early nineteenth century, geological engineers have primarily worked on geotechnical issues. To address these issues, field data and engineering geological maps are required. By coincidence, the Geographic Information System is the best tool for using computer technology to model the real world [8]. Additionally, thorough engineering geological mapping of the Niger Delta Basin is advised in order to provide the crucial knowledge required for comprehending and resolving the Basin's underlying issues [2].

2. A review of previous works

In order to create an engineering geological map (derived from information available on soil, geological, geomorphological, hydrogeological, hydrological maps, and geodynamic processes), the first study on the significance of engineering geological mapping in the development of the Niger Delta Basin [2] combined various maps, physical characteristics of the soils, and field observations of both completed and ongoing engineering projects in the area. This helped to demonstrate the map's value in the area's environmental development and management planning.

A similar study, Insights from the Engineering Geological Mapping of Four Basement Rocks Derived Soils, was conducted by [20]. They came to the conclusion that residual soils from granitic and quarzitic rocks are the strongest for foundation and building applications, whilst those from migmatite-gneissic and charnockitic rocks are the weakest.

2.1. Location of study area

Port Harcourt metropolis is situated between Latitude 4°45’N and Latitude 4°55’N, and Longitude 6°55’E and Longitude 7°05’E in the Niger Delta area of Southern. It is located in the transitional belt with usually flat terrain and high tidal effect that influences the drainage efficiency of the region.

Two seasons, dry and wet, are crucial in the research region. However, enough moisture is observed in practically all months. The mean maximum and lowest temperatures of the region is around 34oC and 21oC correspondingly [6].

The Niger Delta is characterized by a broad and uneven distribution of poor soils, which are further diminished in strength by the presence of expanding clays, according to [19]. This leads to foundation issues in homes, embankments, and roadways. The Niger Delta soil particles lose interparticle attractive interactions and the soil structure breaks down as a consequence of the extensive leaching of salt by groundwater and rainfall [21]. Gravel fractions are absent from the majority of Niger Delta soils. Because of their high clay and moisture content, they undergo significant volume fluctuations, which cause them to inflate and shrink excessively. Additionally, the soils are known to have limited bearing capacity and poor compaction qualities, making them unsuitable for foundation work and pavement building [3],[4],[22],[7]. [1] claims that the Niger Delta's structural foundation materials, the quaternary sediments, were deposited under a greater range of hydrologic circumstances, creating a distinct geomorphologic unit. As a result, their shape and technical characteristics are both laterally and vertically varied.

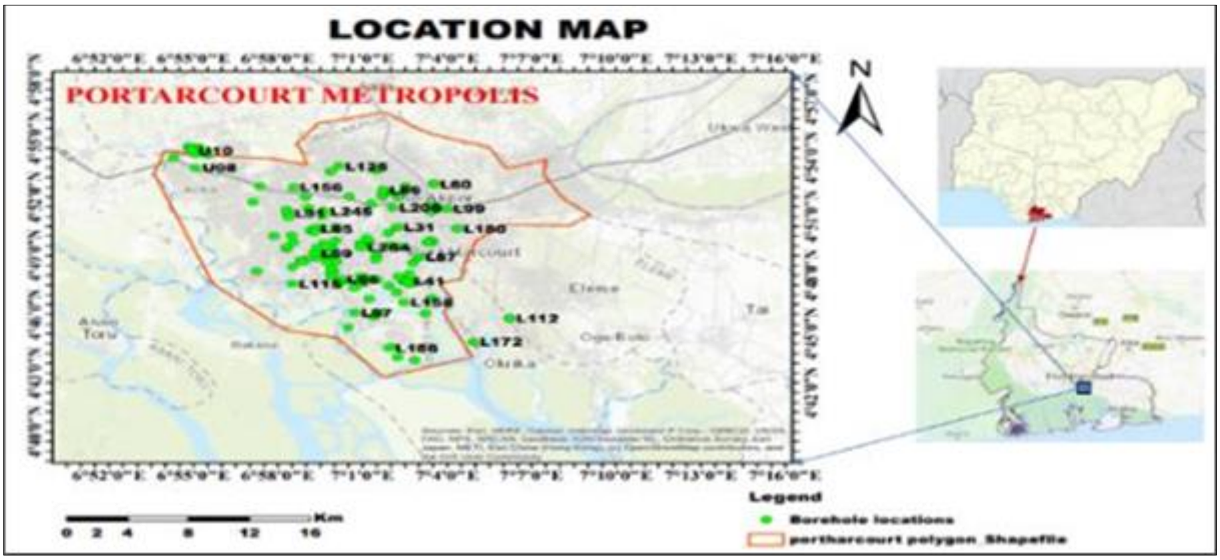

Figure 1 Location Map of study area

3. Materials and methods

In order to quantify the dependence on data from secondary sources, this research employed reports from soil investigations from secondary sources as well as extra data from the author's fieldwork during subsurface investigations. The correctness of the data was checked after 147 sites' soil investigation reports—from Ground scan Services Nigeria Limited and the University of Port Harcourt's physical and planning department—were compiled. Some were then selected based on how trustworthy the sources were. Data on moisture content, plastic, and liquid restrictions were utilized in this investigation.

3.1. Sampling and Data collection

The creation of the map made use of pre-existing information on the engineering and geotechnical index characteristics of the soils in the research region from earlier studies. Moisture content and Atterberg limits (liquid limits, plastic limits, and plasticity index) were among the data taken from the reports. The topographic map of the Port Harcourt region was used as a basis map to create the index characteristics of the soils, and it was extended to a scale of 1:5000. Maps were created at 1.5, 3 and 6 meters below the surface. Computer-assisted software was used for data processing and interpretation. ArcGis (location map construction), Surfer (contour mapping of the research region), Strater (litholog generation), and Google Earth Pro (map production) are examples of Microsoft office products for data preparation, synthesis, and analysis.

4. Presentation of results

Geotechnical Maps of Port Harcourt at different depths was been produced for land use and planning at a scale of 1:5000 meters.

4.1. Natural Moisture Content (NMC)

The statistical overview of clayey soils' natural moisture content at 1.5, 3, and 6 meters is shown in Table 1. The findings show that the values at these depths, which cluster around an average of 17.94%, do not significantly vary.

Table 1 Natural Moisture Content summary result

DEPTH(m)	No of samples	Min	Max	Average	SD
1.5		11.4	66	17.88	9.36
3		10.5	69	18.31	9.18
6		9	55	17.62	7.74

4.2. Atterberg Limits

The Liquid Limits, Plastic Limits, and Plasticity Indicators were calculated for 1 m to 1.5 m, 3 m, and 6 m at the same depths. Table 2 displays the summary findings.

Table 2 Atterberg Limits summary result

	DEPTH (m)	MIN	MAX	AVERAGE	SD
LL	1-1.5	22	180	45.11	14.67
	3	19	76	42.00	7.17
	6	22	73	42.9	7.51
PL	1-1.5	12.5	93	21.92	8.38
	3	10	39	20.34	4.19
	6	12	57	21.19	5.94
PI	1-1.5	9.5	87	22.00	7.79
	3	10.4	37	22.20	4.74
	6	12	60	23.00	7.03

5. Results and discussion

5.1. Natural Moisture Content (NMC)

At 1.5, 3 and 6 meters, the Natural Moisture Content ranged from 11.40% to 66%, 10.50% to 69%, and 9.0% to 55.0%, with averages of 17.88%, 18.31%, and 17.62%, respectively. This is consistent with the range of 16.20% to 21.30% found by [26] in their study conducted in parts of Port Harcourt. Season, clay, organic content, and drainage conditions all affect the soil's insitu moisture content [5]. The soils' water content values that are closer to the plastic limit than the liquid limit are indicative of preconsolidation [9].

Maps showing the variation in the moisture content of the soils are shown in Figs. 2-5.

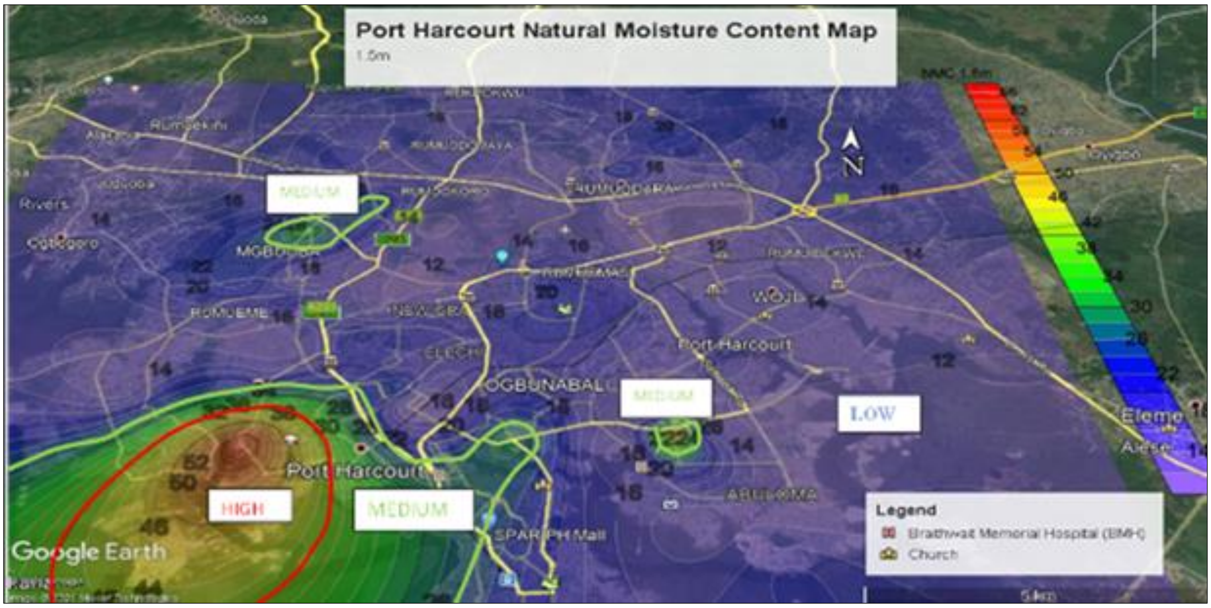

Figure 2 Natural Moisture Content Map of Port Harcourt at 1.5m

Figure 3 Natural Moisture Content Map of Port Harcourt at 3m

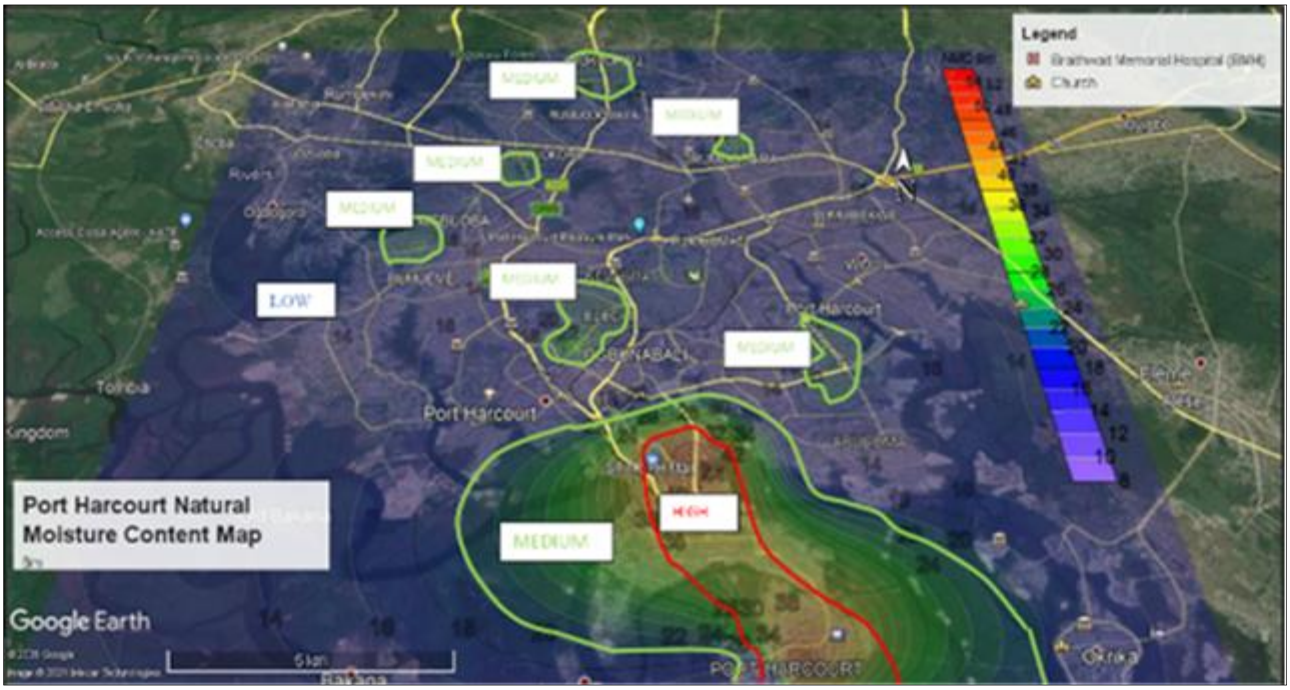

Figure 4 Natural Moisture Content Map of Port Harcourt at 6m

5.2. Atterberg limits

The soils are categorized as CI, CL, and CH by the USCS, with MH-OH present in a few places (see to figs. 5–7). According to [11], the majority of the clays found in Port Harcourt are inorganic clays with medium to high flexibility. At the depth of 1 to 1.5 meters, where the majority of shallow foundations are positioned, the study's liquid limit results ranged from 22% to 180%, with an average of 45.11%. The average value of the Plasticity index was 22%, with a range of 9.5% to 87% (Table 2). The Liquid Limit value was in line with the 28%–71% range that Ezenwaka et al. (2014) found. The range of 15.66% to 21% found by [26] is consistent with the average Plasticity Index values of 22%, 22.3%, and 23% at depths of 1.5 m, 3 m, and 6 m, respectively. The maps are shown in Figures 8–13.

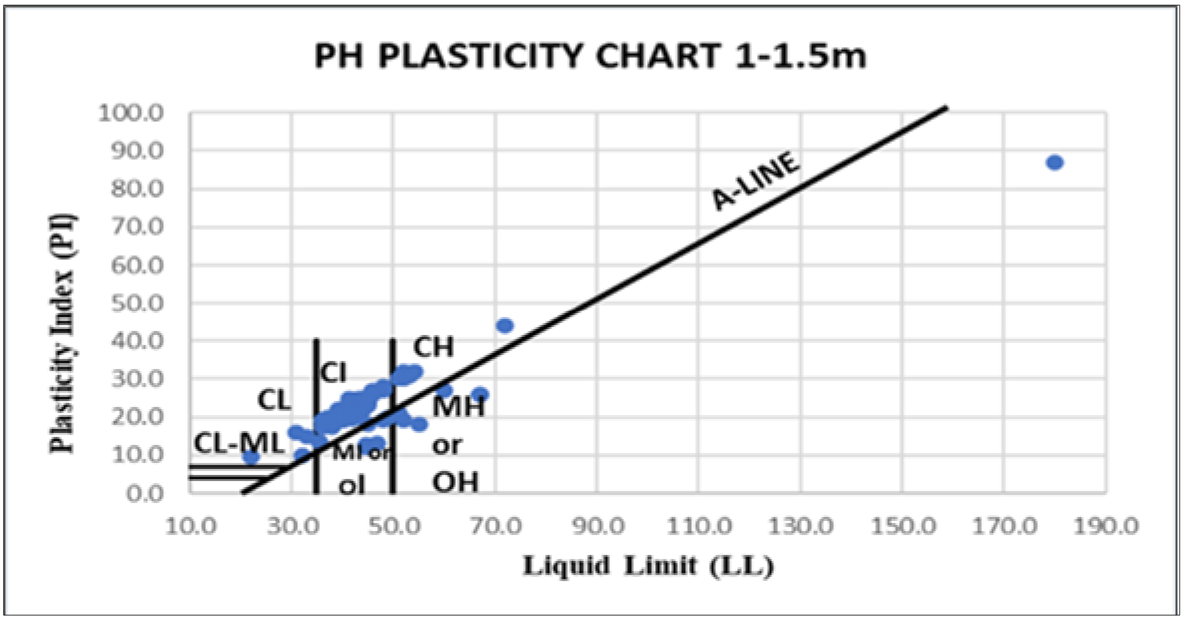

Figure 5 Port Harcourt Plasticity Chart at 1m-1.5m depth

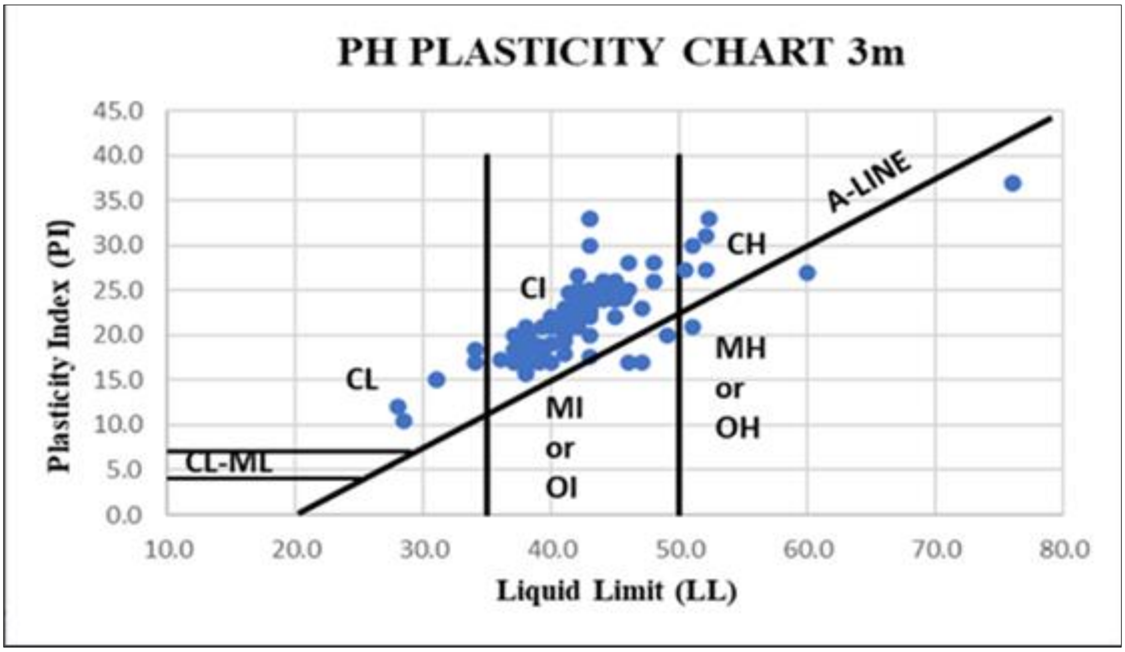

Figure 6 Port Harcourt Plasticity Chart at 3m depth

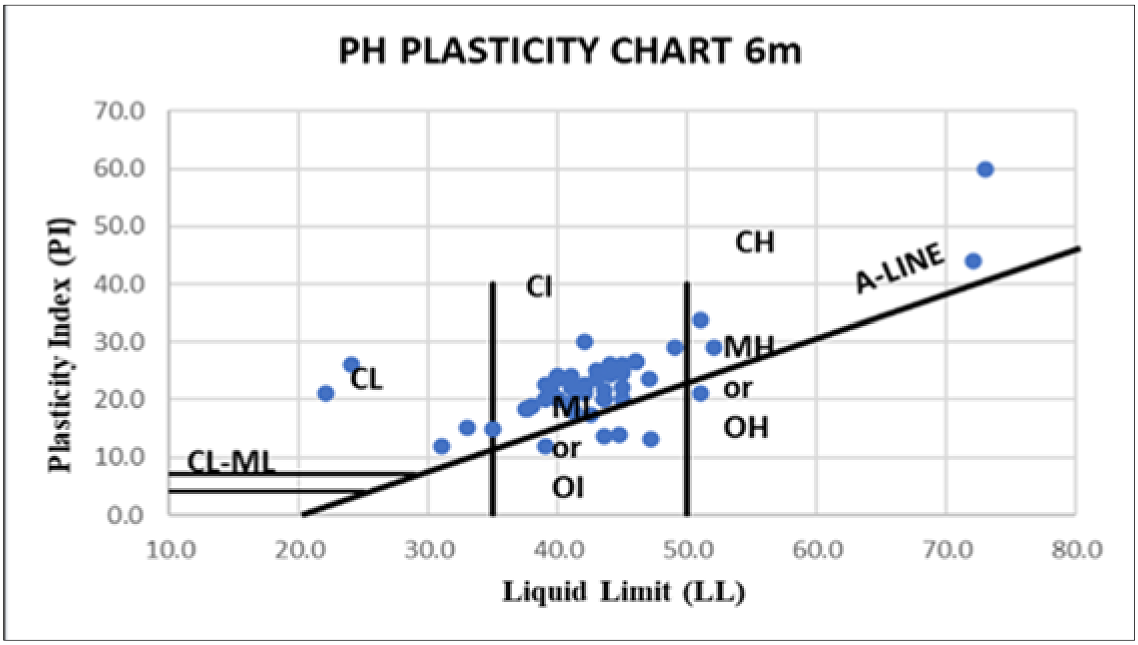

Figure 7 Port Harcourt Plasticity Chart at 6m depth

The USC classes of the soils shown on the plasticity chart agree with the position of the soils at the various depths on the maps. A large proportion of the data shows MI soils.

Figure 8 Plasticity Index (PI) Map of Port Harcourt at 1m-1.5m

Figure 9 Plasticity Index (PI) Map of Port Harcourt at 3m

Figure 10 Plasticity Index (PI) Map of Port Harcourt at 6m

Figure 11 Liquid Limit (LL) Map of Port Harcourt at 1m-1.5m

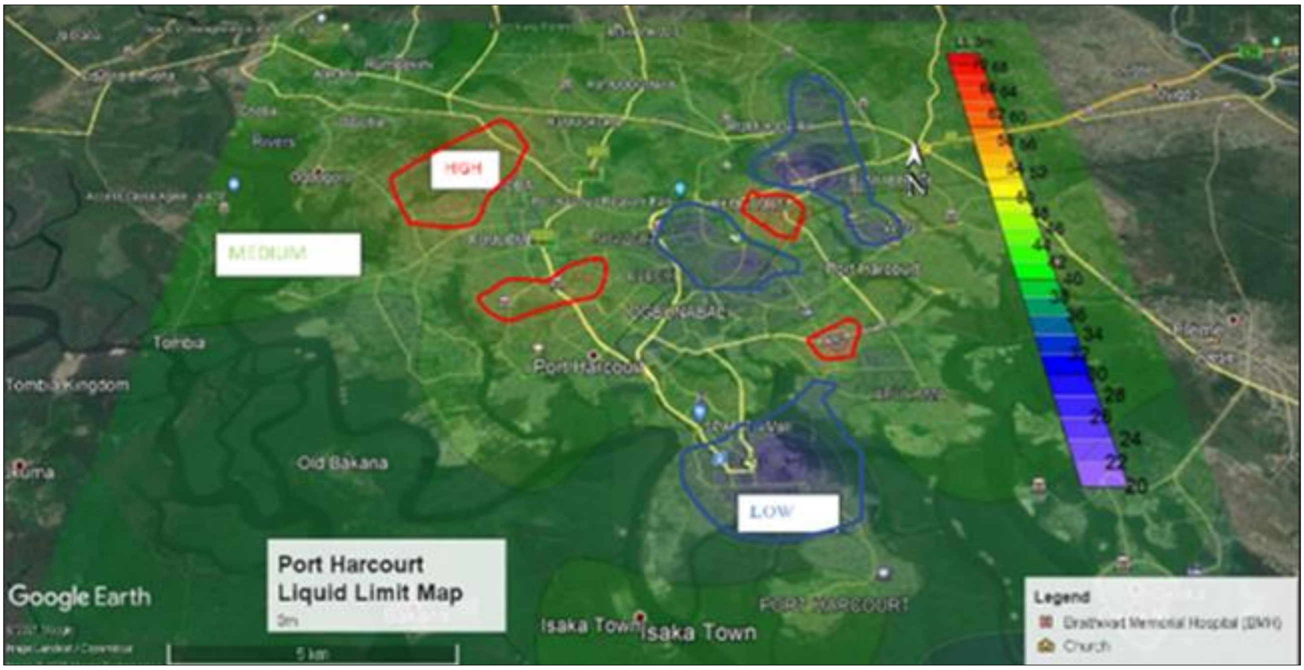

Figure 12 Liquid Limit (LL) Map of Port Harcourt at 3m

Figure 13 Liquid Limit (LL) Map of Port Harcourt at 6m

Table 3 Linear Regression Analysis summary result

ATTERBERG LIMITS (%)		R^2	r (correl)	p (sig)	Equation
	LL	0.0095	-0.10	0.10691	Depth = -0.0156LL + 3.6468
	PL	0.006	-0.08	0.20189	Depth = -0.0205PL + 3.4023
	PI	0.0001	-0.01	0.84104	Depth= -0.0032PI + 3.0416

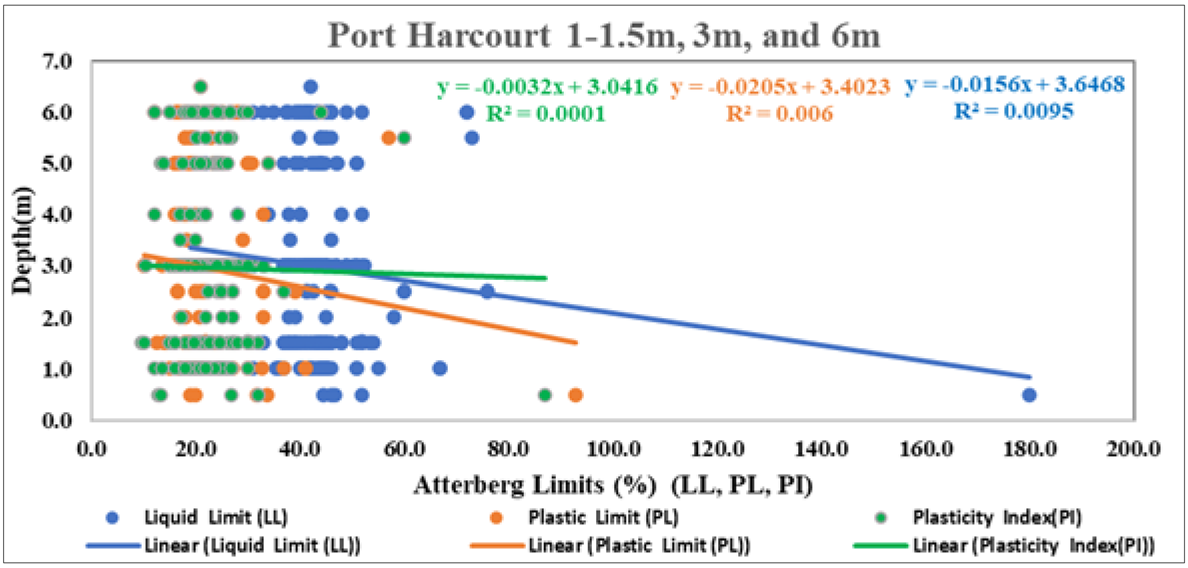

Figure 14 Variability plots of depth against Liquid limits, Plastic limits and Plasticity index in Port Harcourt

The results of the linear regression analysis are displayed in table 3 and fig. 14

The association between Liquid Limit and soil depth was predicted using the plot of depth versus Liquid Limit means depth. Table 3 provides a summary of the findings. R2 is 0.01 at a depth of 1.5 meters. This indicates that the Liquid Limit of the soils at 1.5m only accounts for 1% of the overall difference in the depth at 1.5m. A weak negative linear connection is shown by the correlation coefficient, r. The association was barely statistically significant, as shown by the P value.

The linear equation is given as;

Depth = -0.0156LL + 3.6468 ……… (2)

To predict a rise in the Plastic Limit of soils at a depth of 1.5 meters in Port Harcourt, the depth is plotted against the Plastic Limit. Only 1% of the total variation in depth at 1.5 meters can be explained by the Plastic Limit of soils at that depth, according to the linear regression analysis's R2 value.

The linear equation is given as

Depth = -0.0205PL + 3.4023 ……….. (3)

Depth is utilized to predict a growth in the Plasticity Index of soils at a depth of 1.5 meters in Port Harcourt, according to the plot of depth against Plasticity Index. R2 is 0.0001 based on the linear regression study. This indicates that the Plasticity Index of the soils at 1.5m only accounts for 0% of the overall variance in the depth at 1.5m.

The linear equation is given as

Depth= -0.0032PI + 3.0416 ……….(4)

-0.01 is the correlation coefficient, or r. A weak negative linear connection is shown by this. The analysis's P value, which is 0.84, indicates that the association was not statistically significant.

6. Conclusion

The soils are categorized as CI, CL, and CH in accordance with USCS soil classification, with MH-OH present in a few places.

Accordingly, the majority of the clays found in Port Harcourt are inorganic clays with medium to high flexibility.

The depth versus Liquid Limit plot predicts the rise in the Liquid Limit of soils in Port Harcourt at a depth of 1.5 meters. R2 is 0.01 according to the linear regression study. This indicates that the Liquid Limit of the soils at 1.5m only accounts for 1% of the overall difference in the depth at 1.5m. -0.10 is the correlation coefficient, or r. A weak negative linear connection is shown by this.

The depth versus Plastic Limit plot predicts the rise in the Plastic Limit of soils in Port Harcourt down to a depth of 1.5 meters. R2 is 0.01 according to the linear regression study. This indicates that the Plastic Limit of the soils at 1.5m only accounts for 1% of the overall difference in the depth at 1.5m. -0.08 is the correlation coefficient, or r. A weak negative linear connection is shown by this.

The depth versus Plasticity Index plot predicts the rise in the Plasticity Index of soils at a 1.5-meter depth in Port Harcourt. R2 is 0.0001 based on the linear regression study. This indicates that the Plasticity Index of the soils at 1.5m only accounts for 0% of the overall variance in the depth at 1.5m. -0.01 is the correlation coefficient, or r. A weak negative linear connection is shown by this.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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Author's short Profile

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	**Oghonyon Rorome** He specializes in geophysics programme at the Department of Geology, University of Port Harcourt. He was involved in the seismic exploration activities carried out by ''United Geophysical Nigeria'' in parts of the Niger Delta Province. He combined ideas relating to seismic refraction and reflection alongside aeromagnetic and gravity methods in geophysics for solving geological problems in relation to hydrogeological, engineering and environmental problems. He has conducted a lot of research on borehole geophysical exploration relating to water supply and quality problems in the Niger Delta and Southeastern regions of Nigeria. He loves teaching exploration geophysics relating to mineral and hydrocarbon activities as well as other related disciplines in geology. He took part in the ''2008 Shell Geosciences Summer School'' that exposed an immense knowledge in hydrocarbon exploration for reserve estimation and other reservoir attributes. He was part of the team sponsored by Nigerian Association of Petroleum Explorationists, Society of Exploration Geophysicists (The internal society of applied geophysics) and Exxon Mobil in 2014 for a training on ''Making a difference with 4D-Practical Applications of Time-Lapse Seismic Data.