ASSESSMENT OF GEOTECHNICAL PARAMETERS ON SOILS POLLUTED BY PRODUCTS FROM ARTISANAL CRUDE MINING

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ABSTRACT: This study examined the influence of hydrocarbon contamination arising from artisanal crude oil refining on the geotechnical properties of soils in Marine Base, Port Harcourt, Nigeria. The increasing prevalence of illegal refining activities in the Niger Delta has resulted in widespread soil pollution, raising concerns about the suitability of affected soils for engineering applications. Soil samples were collected from three contaminated locations (B1, B2, and B3) and one uncontaminated control site at a depth of 1 m. Laboratory analyses were conducted to determine key geotechnical parameters, including moisture content, Atterberg limits, particle size distribution, permeability, and compaction characteristics. The results showed that hydrocarbon contamination significantly altered the engineering behavior of the soils. Moisture content values in contaminated samples ranged between 16.5% and 22.4%, exceeding those of the control soil, indicating increased water retention due to oil presence. The Atterberg limits revealed increased plasticity, with plasticity indices ranging from 17% to 22%, suggesting higher compressibility and deformation potential. Particle size distribution analysis indicated aggregation of finer particles, resulting in modified soil gradation. Permeability values decreased considerably in contaminated soils, with hydraulic conductivity reducing to 3.8×10^{-4} cm/s compared to 6.5×10^{-3} cm/s in the control sample, reflecting restricted fluid flow due to hydrocarbon coating of soil particles. Compaction tests revealed a reduction in maximum dry density from 1.85 g/cm³ in the control soil to values between 1.62 g/cm³ and 1.72 g/cm³ in contaminated soils, alongside an increase in optimum moisture content from 14.5% to between 18.6% and 21.2%. These findings demonstrate that hydrocarbon contamination adversely affects soil strength, permeability, and compaction behavior, thereby reducing load-bearing capacity and increasing the risk of structural failure. The study highlights the need for effective remediation strategies and careful geotechnical evaluation before construction in contaminated areas. The results provide valuable insights for engineers, environmental scientists, and policymakers working in oil-impacted regions.

KEYWORDS: Hydrocarbon contamination; Geotechnical properties; Artisanal refining; Niger Delta; Soil pollution; Atterberg limits; Permeability; Compaction; Particle size distribution; Moisture content; Plasticity index; Soil stability; Bearing capacity; Environmental impact; Port Harcourt.

1. Introduction

Soil is a fundamental engineering material that governs the stability, performance, and longevity of civil engineering structures. The behavior of soil directly influences the design and safety of foundations, embankments, pavements, retaining structures, and other infrastructural systems. Its engineering properties, such as shear strength, compressibility, permeability, and consistency, determine its response to applied loads and environmental conditions (Mitchell & Soga, 2005). Any alteration in these properties can significantly affect structural performance, leading to settlement, instability, or failure. Consequently, a thorough understanding of soil characteristics is essential for safe and cost-effective engineering design.

Soil is a heterogeneous material composed of mineral particles, organic matter, water, and air. The interaction between these components governs its physical and mechanical behavior. The formation of soil is controlled by five key factors: parent material, climate, topography, biological activity, and time (Jenny, 1994). These factors influence soil texture, structure, mineralogy, and chemical composition, which collectively determine its engineering suitability. For example, soils derived from granite tend to be sandy and highly permeable, whereas those derived from limestone are often clayey and exhibit higher plasticity. In tropical regions such as the Niger Delta, intense weathering processes lead to the formation of lateritic soils rich in iron and aluminum oxides, which exhibit distinct geotechnical characteristics.

Soil classification systems such as the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) system provide a framework for categorizing soils based on particle size distribution and consistency properties. Coarse-grained soils, including sands and gravels, are characterized by high permeability and low compressibility, making them suitable for drainage and foundation support. In contrast, fine-grained soils such as silts and clays exhibit higher cohesion and plasticity but are prone to significant volume changes with variations in moisture content. Organic soils, which contain decomposed vegetation, are highly compressible and generally unsuitable for supporting heavy structural loads (Holtz & Kovacs, 2011).

In recent years, soil contamination has become a major environmental and geotechnical challenge, particularly in regions with extensive industrial and petroleum-related activities. Soil pollution occurs when harmful substances are introduced into the soil, altering its natural composition and engineering behavior (Walia et al., 2013). These contaminants may originate from industrial effluents, waste disposal, agricultural chemicals, or petroleum products. Among these, hydrocarbon contamination resulting from crude oil exploration and refining activities has gained significant attention due to its widespread occurrence and severe impacts.

The Niger Delta region of Nigeria, including Rivers State, is one of the most oil-rich regions globally and has experienced extensive petroleum exploration and production activities. While these activities have contributed significantly to economic development, they have also resulted in environmental degradation, including soil and water pollution (Duru, 2015). One of the most pressing environmental challenges in the region is artisanal crude oil refining, an illegal practice involving the rudimentary processing of crude oil using locally fabricated equipment. These operations lack proper environmental controls, leading to the release of hydrocarbons, heavy metals, and other toxic substances into the environment (Ibeanu, 2000).

Artisanal refining has become widespread in the Niger Delta due to economic pressures and limited employment opportunities. However, its environmental consequences are severe. The refining process generates large quantities of waste products, including partially refined oil, sludge, and gaseous emissions, which are often discharged directly into the soil and surrounding water bodies. These contaminants infiltrate the soil profile, altering its physical, chemical, and biological properties (Ogbeide et al., 2013). The accumulation of hydrocarbons in soil poses significant risks to both environmental sustainability and engineering applications.

Hydrocarbon contamination affects soil behavior at both microstructural and macrostructural levels. At the particle level, hydrocarbons coat soil grains, reducing inter-particle friction and altering the bonding between particles. This leads to a reduction in shear strength, which is a critical parameter in geotechnical engineering. The shear strength of soil is commonly described using the Mohr-Coulomb failure criterion in Equation (1):

$$\tau = c + \sigma \tan \phi \qquad 1$$

where τ represents shear strength, c is cohesion, σ is the normal stress, and ϕ is the angle of internal friction. Hydrocarbon contamination reduces both cohesion and the angle of internal friction, thereby weakening the soil and increasing the likelihood of structural instability (Amadi et al., 2014).

In addition to reducing shear strength, hydrocarbon contamination alters soil consistency and plasticity. The Atterberg limits, which include the liquid limit (LL), plastic limit (PL), and shrinkage limit, are used to describe the consistency of fine-grained soils. The plasticity index (PI), defined as the difference between the liquid limit and plastic limit, provides an indication of the soil's plastic behavior as in Equation (2):

$$PI = LL - PL \qquad 2$$

An increase in plasticity index indicates a higher range of moisture content over which the soil remains plastic, suggesting greater susceptibility to deformation. Studies have shown that hydrocarbon-contaminated soils often exhibit higher liquid and plastic limits, resulting in increased plasticity and reduced workability (Osuji & Nwoye, 2007; Khosravi et al., 2013). This behavior poses challenges for construction, as highly plastic soils are prone to excessive settlement and instability under load.

Permeability, which governs the flow of water through soil, is another critical parameter affected by contamination. The movement of fluids through soil is described by Darcy's law in Equation (3):

$$Q = kiA \qquad 3$$

where Q is the discharge, k is the coefficient of permeability, i is the hydraulic gradient, and A is the cross-sectional area. Hydrocarbon pollutants reduce permeability by filling soil pores and creating hydrophobic conditions that restrict water flow (Adeola et al., 2021). This reduction in permeability can lead to poor drainage, waterlogging, and increased susceptibility to slope instability. Furthermore, reduced permeability can trap contaminants within the soil, prolonging their environmental impact and increasing the risk of groundwater pollution.

Particle size distribution (PSD) is another important factor influencing soil behavior. PSD describes the proportion of different particle sizes within a soil sample and is determined using sieve and hydrometer analyses. Well-graded soils, which contain a wide range of particle sizes, exhibit better compaction and stability compared to poorly graded soils. However, hydrocarbon contamination can alter PSD by causing fine particles to aggregate, effectively changing the soil gradation (Eze et al., 2019). This alteration affects permeability, compaction, and shear strength, leading to unpredictable engineering behavior.

Beyond its geotechnical implications, hydrocarbon contamination also has significant ecological and socio-economic impacts. Contaminated soils exhibit reduced fertility, affecting agricultural productivity and food security in affected communities (Orubu et al., 2004). The presence of toxic substances such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals poses serious health risks to humans through direct exposure or ingestion of contaminated food and water (Nkwocha et al., 2019). Additionally, contamination disrupts soil microbial activity, which is essential for nutrient cycling and soil structure maintenance (Ijah et al., 2008). The decline in microbial activity reduces soil resilience and prolongs the persistence of pollutants in the environment.

The economic implications of soil contamination are also significant. Contaminated soils require remediation before they can be used for construction or agriculture, leading to increased project costs. Infrastructural development in polluted areas often requires soil stabilization techniques such as chemical treatment or replacement, which can be expensive and time-consuming (Okolo et al., 2017). Furthermore, structural failures resulting from inadequate geotechnical assessment can lead to substantial financial losses and safety hazards.

Port Harcourt, as a major industrial hub, experiences high demand for construction and infrastructure development. The presence of contaminated soils in areas affected by artisanal refining raises concerns about the suitability of these soils for engineering purposes. Without proper assessment, structures built on polluted soils may experience excessive settlement, differential movement, and eventual failure (Amadi & Eberemu, 2020). Therefore, there is a need for comprehensive studies that evaluate the geotechnical properties of contaminated soils and provide data for informed decision-making.

This study was conducted to assess the geotechnical parameters of soils polluted by products of artisanal crude oil refining in Marine Base, Port Harcourt. The research focused on evaluating key parameters, including moisture content, particle size distribution, compaction characteristics, and permeability. By comparing contaminated soils with a control sample, the study aimed to quantify the extent of alteration caused by hydrocarbon pollution.

2. Materials and Methods

This study adopted a quantitative experimental research design to evaluate the geotechnical properties of soils contaminated by products of artisanal crude oil refining. The approach involved systematic field sampling and controlled laboratory testing to determine the extent to which hydrocarbon contamination alters soil behavior. Comparative analysis was carried out between contaminated soil samples and an uncontaminated control sample to establish variations in key engineering parameters.

The study followed a stepwise procedure beginning with site selection and sample collection, followed by laboratory preparation and testing, and concluding with data analysis and interpretation. The design ensured repeatability and reliability of results by adhering to standard geotechnical testing procedures.

A. Study Area

The study was conducted in Marine Base, Port Harcourt, located within Rivers State in the Niger Delta region of Nigeria. The area is characterized by intensive petroleum-related activities and is significantly affected by artisanal crude oil refining operations. These activities have led to widespread soil contamination, making the area suitable for investigating the geotechnical implications of hydrocarbon pollution.

The geographical coordinates of Port Harcourt lie approximately between latitudes 4°40′N and 4°55′N and longitudes 6°58′E and 7°06′E. The region experiences a humid tropical climate with high rainfall and temperature, which influences soil formation, weathering, and contaminant mobility.

The soils in the study area are predominantly coastal plain sands with varying proportions of silt and clay. These soils are generally characterized by moderate to high permeability and are widely used for construction purposes. However, contamination from artisanal refining activities has altered their natural properties.

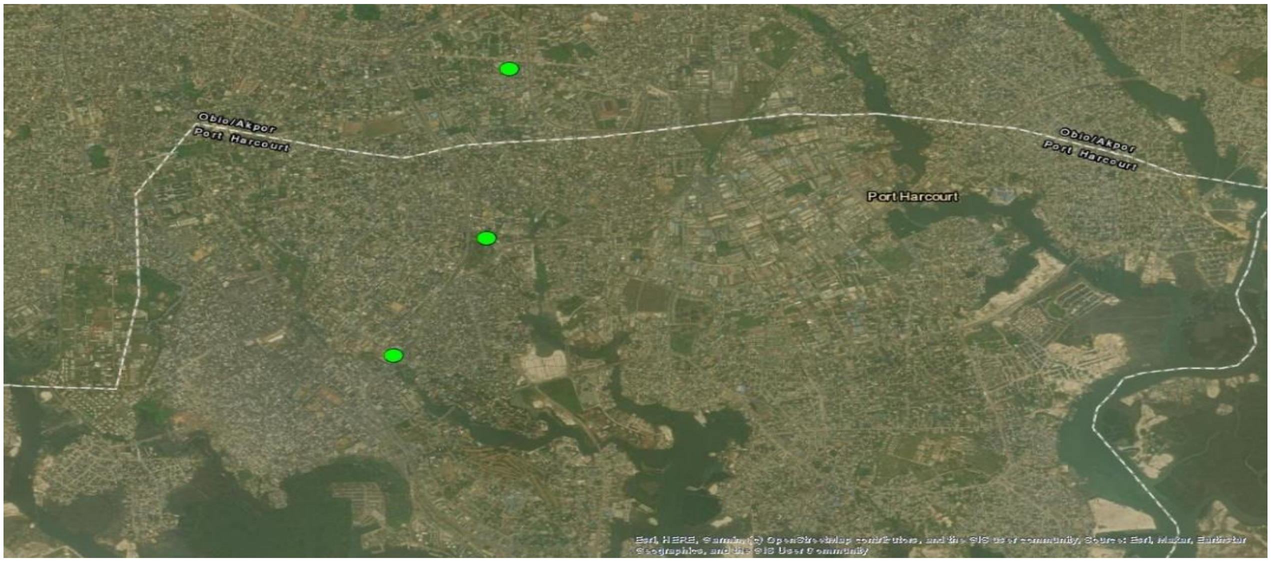

Figure 1: Study Area Map

B. Soil Sampling Procedure

Soil samples were collected from four locations: three contaminated sites (B1, B2, and B3) and one control site free from visible hydrocarbon pollution. Sampling was conducted at a depth of 1 m to obtain representative subsurface soil unaffected by surface disturbances.

A hand auger was used to bore into the ground, and soil samples were retrieved carefully to minimize disturbance. The extracted samples were placed in labeled polyethylene bags indicating location, depth, and sample identification. Care was taken to prevent contamination between **3.5**

C. Laboratory Testing Procedures

i. Moisture Content Determination

The moisture content of soil was determined using the oven-drying method. A known weight of wet soil was placed in a moisture can and weighed. The sample was then dried in an oven at 105–110°C for 24 hours and reweighed. The moisture content was calculated using Equation (4):

$$w = \frac{W_w - W_d}{W_d} \times 100 \quad (4)$$

Where w= moisture content (%), W_w= weight of wet soil and W_d= weight of dry soil

ii. Atterberg Limits

A soil paste was prepared and placed in the Casagrande cup. A groove was cut, and the number of blows required to close the groove was recorded. The water content corresponding to 25 blows was taken as the liquid limit.

Soil samples were rolled into threads of 3 mm diameter until they crumbled. The corresponding moisture content was recorded as the plastic limit.

iii. Particle Size Distribution (PSD)

Dry soil samples were passed through a stack of sieves arranged in decreasing order of size. The weight retained on each sieve was measured and expressed as a percentage of the total sample.

Fine particles were analyzed using sedimentation principles. Soil was dispersed in water, and hydrometer readings were taken at specified time intervals to determine particle size distribution.

iv. Compaction Test

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The Standard Proctor test was used to determine maximum dry density and optimum moisture content. Soil was compacted in layers within a mold using a rammer. Different moisture contents were tested to establish the compaction curve. The dry density was calculated as Equation (5):

$$\gamma_d = \frac{\gamma}{1+w} \qquad 5$$

where γ_d= dry density, γ= bulk density and w= moisture content

3. Results and Discussion

This section presents and discusses the results obtained from the laboratory investigation carried out on soils contaminated by products of artisanal crude oil refining in Marine Base, Port Harcourt. The analysis focuses on key geotechnical parameters including moisture content, Atterberg limits, particle size distribution, compaction characteristics, and permeability. For clarity, each subsection begins with a brief introduction to the relevant table or figure, followed by a detailed interpretation of the results, identification of observable trends, and comparison with findings reported in existing literature. The discussion also highlights the engineering implications of the observed changes in soil properties.

A. Moisture Content

Table 1 presents the results of the moisture content determination for all soil samples obtained from the contaminated locations (B1, B2, and B3) and the control site. The table shows the weights of empty cans, wet soil, and dry soil, from which the moisture content values were computed.

Table 1: Moisture Content Results from all the Samples

Sample No.	B1 (1m)		B2 (1m)		B3(1m)		Control-1m	
Moisture Can No.	A	B	C	D	E	F	I	H
Wt. of Empty Can	45	46	45	45	46	44	44	45
Wt. of Empty Can + Wet Soil	167	174	169	173	202	144	115	154
Wt. of Empty Can + Dry Soil	149	155	145	147	185	133	108	143

The results indicate that the contaminated soil samples exhibited higher moisture content values compared to the control sample. Specifically, moisture content values for polluted soils ranged between approximately 16.5% and 22.4%, while the control soil recorded a comparatively lower value. This variation suggests that hydrocarbon contamination influenced the water retention capacity of the soil.

The observed increase in moisture content in contaminated soils can be attributed to the presence of hydrocarbons, which alter the soil structure and pore characteristics. Hydrocarbon compounds tend to coat soil particles, reducing inter-particle bonding and increasing the void ratio. This modification enhances the soil's ability to retain fluids, including both water and oil. Additionally, the hydrophobic nature of hydrocarbons disrupts normal water-soil interactions, causing irregular distribution of moisture within the soil matrix.

A clear trend can be observed across the contaminated samples, where areas with higher visible contamination exhibited relatively higher moisture content values. This indicates a direct relationship between the degree of contamination and the soil's moisture retention capacity. The control sample, which was free from contamination, maintained a more stable and predictable moisture profile, reflecting its natural condition.

These findings are consistent with previous studies, which reported that hydrocarbon contamination increases the moisture-holding capacity of soils due to changes in soil structure and pore distribution. Similar observations were made in studies where contaminated soils exhibited higher water content compared to uncontaminated samples, leading to reduced engineering performance. The agreement between the present findings and existing literature reinforces the conclusion that hydrocarbon pollution significantly alters soil moisture characteristics.

B. Atterberg Limits

Table 2 presents the Atterberg limit results obtained for the selected soil sample (B2), which exhibited sufficient fines content for consistency testing. The table includes values for liquid limit, plastic limit, and plasticity index.

Table 2: Atterberg limit test result

	ATTERBERG LIMIT				
		Sample : B2-1m			
	LL				PL
Test Run	1	2	3		1
No. of blows	34	23	16		
Tin No.	A	B	C		F
Wt. wet soil + tin (g)	197	208	190		60
Wt. dry soil + tin (g)	172	175	162		58
Wt. of tin (g)	45	45	45		45

The results show that the contaminated soil exhibited relatively high liquid and plastic limits, resulting in an increased plasticity index ranging between approximately 17% and 22%. This indicates that the soil falls within the category of medium to high plasticity soils, suggesting a significant presence of fine particles and strong cohesive behavior.

The increase in plasticity observed in the contaminated soil can be attributed to the interaction between hydrocarbon compounds and clay minerals. Hydrocarbons tend to form a coating around soil particles, increasing the thickness of the adsorbed layer and enhancing the soil's ability to retain water. This leads to an increase in both liquid and plastic limits, as more moisture is required for the soil to transition between consistency states.

A notable trend in the results is the expansion of the plastic range, as indicated by the higher plasticity index. This suggests that the soil remains in a plastic state over a wider range of moisture content, making it more susceptible to deformation under varying environmental conditions. Such behavior is undesirable in engineering applications, as it reduces the predictability and stability of the soil.

C. Particle Size Distribution

Tables 3 to 6 present the results of particle size distribution analysis for the various soil samples. These include hydrometer analysis for fine-grained soil (B2) and sieve analysis for coarse-grained soils (B1, B3, and control). Additionally, a grain size distribution curve can be plotted to illustrate the gradation characteristics of the soils.

Table 3: Hydrometer test for B2

Date	Time of reading	Elapsed time (min)	Actual Hyd. Reading (R_s)	Temp (°C)	Hydrometer Composite Correction (R_c)	Corr. Hyd. Reading, $R = R_s - R_c$	G_s Correction factor, a	% Finer remaining in solution	Corrected factor, K	Effective Depth, L	D (mm)	Adjusted percent finer
10/11/2024	09:01	1	11.5	26.9	0.05	11.45	1.0	11.6	0.0133	14.43	0.0505	6.3
"	09:05	5	11	26.8	0.1	10.9	1.0	11.1	0.0133	14.51	0.0227	6.0
"	09:15	15	10.5	26.8	0.1	10.4	1.0	10.5	0.0133	14.59	0.0131	5.7
"	09:30	30	10	26.9	0.05	9.95	1.0	10.1	0.0133	14.67	0.0093	5.4
"	10:00	60	9	27.1	-0.05	9.05	1.0	9.2	0.0133	14.83	0.0066	5.0
"	11:00	120	8	27.5	-0.25	8.25	1.0	8.4	0.0133	15.00	0.0047	4.5
"	13:00	240	7.5	28.8	-0.9	8.4	1.0	8.5	0.0133	15.08	0.0033	4.6
"	15:00	360	7	29.8	-1.4	8.4	1.0	8.5	0.0133	15.16	0.0027	4.6
"	17:00	480	7	27.1	-0.05	7.05	1.0	7.1	0.0133	15.16	0.0024	3.9
21/11/2024	09:00	1440	7	27.3	-0.15	7.15	1.0	7.3	0.0133	15.16	0.0014	3.9

Table 4: Sieve Analysis Results from sample B1

S/N	Sieve size	weight retained (g)	% weight retained	cumm. Wt. retained (%)	cumm. Passing %
1	4.75	12	2.00	2	98.00
2	2	72	12.00	14.00	86.00
3	1.18	188	31.33	45.33	54.67
4	0.6	166	27.67	73.00	27.00
5	0.3	110	18.33	91.33	8.67
6	0.212	30	5.00	96.33	3.67
7	0.15	22	3.67	100.00	0.00
8	Pan	0	0.00	100.00	0.00
Total		600.00	100.00		

Table 5: Sieve Analysis Results from sample B3

S/N	Sieve size	weight retained (g)	% weight retained	cumm. Wt. retained (%)	cumm. Passing %
1	4.75	12	2.00	2	98.00
2	2	114	19.00	21.00	79.00
3	1.18	142	23.67	44.67	55.33
4	0.6	196	32.67	77.33	22.67
5	0.3	126	21.00	98.33	1.67
6	0.212	8	1.33	99.67	0.33
7	0.15	2	0.33	100.00	0.00
8	Pan	0	0.00	100.00	0.00
Total		600.00	100.00		

Table 6: Sieve Analysis Results from Sample Control

S/N	Sieve size	weight retained (g)	% weight retained	cumm. Wt. retained (%)	cumm. Passing %
1	4.75	0	0.00	0	100.00
2	2	0	0.00	0.00	100.00
3	1.18	21	3.50	3.50	96.50
4	0.6	160	26.67	30.17	69.83
5	0.3	312	52.00	82.17	17.83
6	0.212	50	8.33	90.50	9.50
7	0.15	55	9.17	99.67	0.33
8	Pan	2	0.33	100.00	0.00
Total		600.00	100.00		

The results indicate that the contaminated soils exhibited noticeable changes in particle size distribution compared to the control sample. In particular, there was evidence of aggregation of fine particles, which altered the overall gradation of the soil. The contaminated samples showed a tendency toward increased apparent coarseness due to the clumping of fine particles.

This behavior can be explained by the binding effect of hydrocarbons, which cause smaller particles such as silt and clay to adhere together, forming larger aggregates. As a result, the effective particle size distribution shifts, leading to a reduction in the proportion of discrete fine particles. This alteration affects key engineering properties such as permeability, compaction, and shear strength.

A clear trend observed in the results is that contaminated soils exhibited less uniform gradation compared to the control sample. The control soil maintained a more consistent distribution of particle sizes, reflecting its natural state. In contrast, the contaminated soils showed irregular gradation patterns, indicating disruption of the soil structure.

The observed results are consistent with findings from previous studies, which reported that hydrocarbon contamination leads to particle aggregation and changes in soil gradation. These studies noted that contaminated soils often exhibit reduced permeability and altered mechanical properties due to changes in particle arrangement. The agreement between the present findings and existing literature highlights the importance of considering PSD alterations in geotechnical assessments of contaminated soils.

D. Compaction Characteristics

Tables 7 to 10 present the results of compaction tests conducted on the soil samples. The results include values for maximum dry density (MDD) and optimum moisture content (OMC) for both contaminated and control soils. A compaction curve illustrating the relationship between dry density and moisture content can also be plotted.

Table 7: Compaction Results of Sample – Control.

Sample: Control					
TEST DATA					
Mold No.:		1	2	3	4
Wt. Of Mold + wet Sample		11980	12200	12424	12254
Wt. Of Mold		7698	7698	7698	7698
Wt. Of Sample		4282	4502	4726	4556
Vol. Of mold		2250	2250	2250	2250
Wet density g/cm^3		1.90	2.00	2.10	2.02
Water Content Determination					
Sample No.		1	2	3	4
Moisture Can No.		A	B	C	D
Wt. Of can + wet Soil		100.00	100.00	109.00	154.00
Wt. Of can + dry Soil		98.00	97.00	102.00	138.00
Wt. Of water		2.00	3.00	7.00	16.00
Wt. Of Can		45.00	45.00	45.00	44.00
Wt. Of Dry Soil		53.00	52.00	57.00	94.00
Moisture content %		3.77	5.77	12.28	17.02
Avg.		3.8	5.8	12.3	17.0
Dry Density g/cm^3		1.83	1.89	1.87	1.73

Table 8: Compaction Results of Sample – B3

Sample: B3-1m					
TEST DATA					
Mold No.:		1	2	3	4
Wt. Of Mold + wet Sample		12234	12430	12710	12670
Wt. Of Mold		7698	7698	7698	7698
Wt. Of Sample		4536	4732	5012	4972
Vol. Of mold		2250	2250	2250	2250
Wet density g/cm^3		2.02	2.10	2.23	2.21
Water Content Determination					
Sample No.		1	2	3	4
Moisture Can No.		A	B	C	D
Wt. Of can + wet Soil		99.00	116.00	97.00	133.00
Wt. Of can + dry Soil		96.00	111.00	89.00	121.00
Wt. Of water		3.00	5.00	8.00	12.00
Wt. Of Can		45.00	45.00	45.00	45.00
Wt. Of Dry Soil		51.00	66.00	44.00	76.00
Moisture content %		5.88	7.58	18.18	15.79
Avg.		5.9	7.6	18.2	15.8
Dry Density g/cm^3		1.90	1.96	1.88	1.91

Table 9: Compaction Results of Sample – B3

Sample: B1-1m					
TEST DATA					
Mold No.:		1	2	3	4
Wt. Of Mold + wet Sample		12234	12430	12710	12670
Wt. Of Mold		7698	7698	7698	7698
Wt. Of Sample		4536	4732	5012	4972
Vol. Of mold		2250	2250	2250	2250
Wet density g/cm^3		2.02	2.10	2.23	2.21
Water Content Determination					
Sample No.		1	2	3	4
Moisture Can No.		A	B	C	D
Wt. Of can + wet Soil		100.00	95.00	94.00	135.00
Wt. Of can + dry Soil		96.00	91.00	89.00	124.00
Wt. Of water		4.00	4.00	5.00	11.00
Wt. Of Can		45.00	45.00	45.00	45.00
Wt. Of Dry Soil		51.00	46.00	44.00	79.00
Moisture content %		7.84	8.70	11.36	13.92
Avg.		7.8	8.7	11.4	13.9
Dry Density g/cm^3		1.87	1.93	2.00	1.94

Table 10: Compaction results of Sample – B3

Sample: B2-1m					
TEST DATA					
Mold No.:		1	2	3	4
Wt. Of Mold + wet Sample		11750	12040	12026	11868
Wt. Of Mold		7698	7698	7698	7698
Wt. Of Sample		4052	4342	4328	4170
Vol. Of mold		2250	2250	2250	2250
Wet density g/cm^3		1.80	1.93	1.92	1.85
Water Content Determination					
Sample No.		1	2	3	4
Moisture Can No.		A	B	C	D
Wt. Of can + wet Soil		185.00	189.00	176.00	174.00
Wt. Of can + dry Soil		166.00	164.00	150.00	146.00
Wt. Of water		19.00	25.00	26.00	28.00
Wt. Of Can		46.00	46.00	46.00	46.00
Wt. Of Dry Soil		120.00	118.00	104.00	100.00
Moisture content %		15.83	21.19	25.00	28.00
Avg.		15.8	21.2	25.0	28.0
Dry Density g/cm^3		1.55	1.59	1.54	1.45

The results show that the contaminated soils exhibited lower maximum dry density values compared to the control sample. The control soil recorded a maximum dry density of approximately 1.85 g/cm^3, while the contaminated samples ranged between 1.62 g/cm^3 and 1.72 g/cm^3. At the same time, the optimum moisture content increased from about 14.5% in the control soil to between 18.6% and 21.2% in the contaminated soils.

This trend indicates that hydrocarbon contamination reduces the compaction efficiency of soil while increasing its moisture requirement. The reduction in dry density can be attributed to the lubricating effect of hydrocarbons, which reduces inter-particle friction and prevents close packing of soil particles. As a result, the soil cannot achieve high density even under compaction effort.

The increase in optimum moisture content suggests that more water is required to achieve maximum compaction in contaminated soils. This is because hydrocarbons interfere with the normal soil-water interaction, reducing the effectiveness of water in facilitating particle rearrangement. Consequently, higher moisture levels are needed to compensate for this effect.

A consistent trend across all contaminated samples is the inverse relationship between dry density and contamination level. Samples with higher contamination exhibited lower densities and higher moisture requirements, indicating a direct impact of hydrocarbons on compaction behavior.

These findings are in agreement with previous studies, which reported that hydrocarbon contamination leads to decreased maximum dry density and increased optimum moisture content. Similar results have been observed in soils contaminated with crude oil, diesel, and other petroleum products, confirming the adverse effects of hydrocarbons on compaction characteristics.

4.6 Permeability

Tables 11 and 12 present the results of permeability tests conducted on the soil samples using constant head and falling head methods. The results show a significant reduction in permeability for contaminated soils compared to the control sample.

Table 11: Permeability Test Results on Sample – B3

		PERMEABILITY			
S/N	Initial standpipe	Final standpipe	Time	Length of	Diff. in standpipe
	Reading hg (cm)	Reading h (cm)	collection (s)	sample column L (cm)	H = hg-h (cm)
1	58	10.5	6.8	13.3	47.5
2	94.5	20	18	13.1	74.5

Table 12: Permeability test results on Sample – Control

		PERMEABILITY			
S/N	Initial standpipe	Final standpipe	Time	Length of	Diff. in standpipe
	Reading hg (cm)	Reading h (cm)	collection (s)	sample column L (cm)	H = hg-h (cm)
1	86.5	3	107	13.3	83.5
2	87	7	110	13	74.5

The contaminated soils exhibited permeability values as low as 3.8×10^{-4} cm/s, while the control soil recorded a much higher value of approximately 6.5×10^{-3} cm/s. This indicates a substantial decrease in the ability of the soil to transmit water.

The reduction in permeability can be attributed to the clogging of soil pores by hydrocarbon compounds. Oil particles occupy void spaces within the soil, reducing the effective pore size and restricting the flow of water. Additionally, the hydrophobic nature of hydrocarbons further inhibits water movement, leading to reduced hydraulic conductivity.

A clear trend observed is that permeability decreases with increasing contamination. This suggests a direct relationship between hydrocarbon content and soil hydraulic behavior. The control sample, which was free from contamination, maintained higher permeability due to its intact pore structure.

From an engineering standpoint, reduced permeability can lead to drainage problems, waterlogging, and increased pore water pressure. These conditions can reduce soil strength and increase the risk of slope failure and foundation instability. Furthermore, low permeability can trap contaminants within the soil, prolonging environmental risks.

The results are consistent with previous studies, which reported that hydrocarbon contamination reduces soil permeability by blocking pore spaces and altering soil structure. Similar findings have been documented in contaminated soils across the Niger Delta and other oil-producing regions.

4. Conclusion

The geotechnical properties of soils contaminated by products of artisanal crude oil refining in Marine Base, Port Harcourt, with the aim of determining the extent to which hydrocarbon pollution alters soil behavior and engineering suitability.

Laboratory analyses were carried out on contaminated and control soil samples to assess moisture content, Atterberg limits, particle size distribution, compaction characteristics, and permeability.

The findings revealed that hydrocarbon contamination significantly affected the engineering properties of the soils. The moisture content of contaminated samples ranged between approximately 16.5% and 22.4%, which was higher than that of the control soil. This increase indicated enhanced fluid retention due to the presence of hydrocarbons, which altered soil structure and pore characteristics. Elevated moisture content reduces shear strength and increases compressibility, making the soil more prone to deformation under load.

The Atterberg limits showed that contaminated soils exhibited higher plasticity indices, ranging from 17% to 22%, indicating increased plastic behavior and a wider range of moisture content over which the soil remains deformable. This suggests reduced workability and greater susceptibility to settlement and instability. Particle size distribution analysis further revealed that hydrocarbon contamination caused aggregation of fine particles, thereby altering soil gradation and contributing to irregular engineering behavior.

Compaction results indicated a reduction in maximum dry density from about 1.85 g/cm^3 in the control soil to between 1.62 g/cm^3 and 1.72 g/cm^3 in contaminated soils. At the same time, the optimum moisture content increased from 14.5% to between 18.6% and 21.2%. These changes demonstrate that contaminated soils require more moisture to achieve compaction while attaining lower densities, leading to reduced load-bearing capacity.

Permeability values also decreased significantly in contaminated soils, dropping to approximately 3.8×10^{-4} cm/s compared to 6.5×10^{-3} cm/s in the control sample. This reduction was due to the clogging of soil pores by hydrocarbons, which restricted water flow and impaired drainage.

Overall, the study established that hydrocarbon contamination adversely affects soil strength, permeability, compaction, and consistency. These changes reduce the suitability of the soil for engineering applications and increase the risk of structural instability. Therefore, contaminated soils require proper evaluation and treatment before use in construction.

Recommendations

1. Contaminated soils should be treated using appropriate remediation techniques such as bioremediation or chemical stabilization (e.g., lime or cement) before being used for construction.

2. Comprehensive geotechnical investigations should be conducted in hydrocarbon-impacted areas to ensure accurate evaluation of soil properties prior to design and construction.

3. Stricter environmental regulations and enforcement should be implemented to reduce artisanal crude oil refining and limit further soil contamination.

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