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Article

Geotechnical Assessment of Soil Structural and Chemical Properties on Building Holding Capacity in Reclaimed Wetlands in Obio-Akpor Local Government Area, Rivers State

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Abstract: The study geotechnically assessed soil structural and chemical properties on building holding capacity in reclaimed wetlands in Obio-Akpor Local Government Area, Rivers State. The study adopted the true experimental design. Twelve soil samples were collected from six reclaimed wetlands in the study area. The result obtained from the laboratory analysis of the soil samples was analyzed using mean, and charts to answer the research questions, while Analysis of Variance (ANOVA) was used to test the hypotheses at 0.05 significance. The result showed that soil density ranged from 0.96-1.79 g/cm^3, permeability from 213.33-5900 cm/s, and porosity from 43.47-52.50%, with predominantly granular structures. These structural variations were confirmed by the statistically significant among sampling points ($F = 10.199$, $p = .033$), indicating spatial differences in soil engineering properties. Also, the finding on phosphate ranged from 1.70-1.96 mg/L, sulphate from 1.22-7.42 mg/L, and nitrate from 20.45-63.41 mg/L, is supported with significant differences in micronutrients ($F = 268.356$, $p < .001$). Overall, the findings demonstrate variable structural or physical and chemical soil conditions, highlighting the need for comprehensive site-specific geotechnical assessment, appropriate soil improvement, chemical monitoring, and careful construction decisions to ensure structural stability and durability. The study recommended that the Rivers State Government should mandate geotechnical investigations, soil improvement, and appropriate foundation treatments before approving construction on reclaimed wetlands with unsuitable soil characteristics. Alongside, environmental authorities should require routine soil-chemical assessments, particularly nitrate and sulphate monitoring, in reclaimed-wetland development approvals to identify soil-quality and environmental risks.

Keywords: Geotechnical assessment, soil structural and chemical properties, building holding capacity, reclaimed wetlands, Obio-Akpor

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1. Introduction

Population growth and increasing land demand have encouraged developers to transform areas hitherto deemed unsuitable for construction due to their marshy, waterlogged, and permeable characteristics, into viable residential, commercial, and industrial development sites. Successful land conversion depends on soil density, structure, permeability, porosity, aeration, texture, and consistency, alongside

engineering techniques that enhance wetland bearing capacity for diverse developments [1]. Anika et al. emphasized that assessing the geotechnical suitability of marginal and reclaimed lands before development is essential for promoting safe, sustainable, and appropriate land-use planning and construction practices in Rivers State. Implicitly, geotechnical assessment integrates ethical practices helping to strike a balance between development goals and ecological preservation, while converting land [2].

Reclaimed wetlands are increasingly utilized for urban development in rapidly expanding cities, where pressure on available developable land has encouraged construction on formerly swampy and waterlogged terrains. Smith et al. described reclaimed wetlands as previously marshy, waterlogged and borrow-pit areas that has been recovered, transformed or converted for alternative land uses like residential, commercial, industrial, among other infrastructural projects. However, the high moisture content, compressibility, weak shear strength, and low bearing capacity of reclaimed wetlands, often create substantial construction risks for projects. Thus, careful assessment of soil suitability, environmental conditions, and development requirements before construction is key to the sustainability and stability of the developments on reclaimed wetlands.

The conduct of pre-development assessment and sustainable land-use planning enhances the suitability of reclaimed wetlands to accommodate unending developments as well as guarantees ecological preservation [3]. The engineering suitability of reclaimed wetlands depends strongly on their geotechnical soil properties, as high moisture content, clay and silt concentrations, low shear strength, and high compressibility including phosphate, sulphate and nitrate can compromise foundation stability, increase settlement, and reduce bearing capacity. In the Niger Delta, Abam et al. demonstrated that reclamation of mangrove swamplands around Port Harcourt through hydraulic sand filling requires careful consideration of ground response and consolidation settlement, particularly where soft, compressible soils underlie the reclaimed fill.

Effective wetland reclamation requires comprehensive assessment and improvement of soil density, structure, compaction, permeability, and aeration as well as phosphate, sulphate, and nitrate through suitable fill materials and amendments [4]. These properties determine site-specific suitability, stability, resilience, and bearing capacity for low-, mid-, high-rise, industrial, and specialized structures like bridges and dams. Thus, realizing this purpose is essential for stable, safe, durable, and sustainable development amid rapid urbanization, population growth, and expanding land-use acts.

Sustainable wetland development requires integrated consideration of soil structural or physical and chemical properties, including hydrological, ecological, social, and economic factors. Appropriate planning should identify wetlands suitable for reclamation while preserving areas essential for biodiversity, water storage, agriculture, and ecosystem services. Olufemi et al. found that reclaimed wetland soils in Lagos Island differed significantly from their original conditions, affecting building holding capacity and necessitating complementary geospatial and geotechnical assessments. Similarly, Adeoti and Alalade stressed community participation in reclamation decisions, while Olawuyi et al. highlighted potential implications for water resources and flood risks. Comprehensive environmental and social impact assessments are therefore necessary to identify risks and establish appropriate mitigation measures [5].

Determining soil structural and chemical properties and engineering features is essential for assessing the suitability of reclaimed wetlands for low-, medium-, and high-rise buildings, industrial facilities, and specialized structures like bridges and dams. Aborisade et al. emphasized scientific assessment involving relevant professionals, while Zhang et al. supported interdisciplinary approaches to select proper construction materials and plans that enhance structural integrity and load-bearing capacity. Adunoye et al. stated that comprehensive geotechnical, environmental, hydrological, and social

assessments should precede development. These assessments can guide proper reclamation practices, improve soil stability, reduce settlement risks, and promote sustainable and resilient development of reclaimed wetlands.

Udom and John observed that variations in foundation subsoil properties and allowable bearing capacities, underscores the importance of site-specific geotechnical assessments to determine soil suitability, foundation requirements, and safe structural development, especially in reclaimed wetlands across parts of Port Harcourt City and Obio-Akpor. This finding reinforces Okah's assertion that geotechnical assessment before development is essential for identifying soil weaknesses, evaluating bearing capacity, guiding foundation design, minimizing settlement risks, and promoting structural safety and sustainability in reclaimed wetlands [6].

Predominantly silty-clay soils with varying moisture, permeability, phosphate, nitrate, and sulphate found during soil properties assessment in Obio-Akpor, contributed to spatial flood vulnerability, and underlined the need to consider soil texture, moisture, permeability, and structure alongside building bearing capacity when assessing reclaimed wetlands. Conversely, building holding capacity depends on the interaction between structural loads and soil engineering properties. Key factors include bulk density, moisture, texture, porosity, permeability, nitrate, phosphate, sulphate, compaction, shear strength, cohesion, and consolidation, with bulk density strongly influencing soil strength, compressibility, and settlement.

From the foregoing, geotechnical investigation is crucial for evaluating soil structural and chemical properties, and determining their suitability for supporting different building types. Udom and John identified variations in sandy-clay and sand strata, plasticity, shear strength, settlement behaviour, and allowable bearing capacities within Obio-Akpor. Accordingly, assessing soil properties, structural characteristics, and building holding capacity is essential for promoting safe, durable, and sustainable development across reclaimed wetland environments in the study area. The crux of the study therefore provides the basis for the present study, which focuses on evaluating the geotechnical characteristics of reclaimed wetlands in Obio-Akpor Local Government Area and determining their capacity to safely support varying building types.

1.1. Problem Specification

The quest for the growing population to meet their residential, commercial, industrial, and infrastructural development needs has accentuated encroachment into reclaimed wetlands. The reclaiming of wetlands through sand filling alters natural drainage, loading conditions, among other concerns that modify or alter soil behaviour, weaken holding or bearing capacity, and increase construction risks [7]. Accordingly, the manner of reclaiming wetlands creates geotechnical concerns because the natural soils of reclaimed wetlands commonly contain high moisture, fine-grained sediments, organic materials, weak strata, and compressible deposits, which influences the stability of varying constructions and developments in such reclaimed wetlands. However, wetland's soft foundations make it susceptible to flooding, thereby, warranting the consolidation and transformation deformation under loading, while saturated soft soils beneath reclaimed fill can contribute to excessive foundation settlement and instability.

Globally, study on wetland and soft-ground environments reveal that inadequate understanding of subsurface conditions can contribute to excessive settlement, low bearing capacity, differential deformation, and foundation instability. At the continental level, African urban expansion has intensified development pressure on environmentally sensitive and low-lying terrains, while geotechnical investigations frequently identify weak and variable foundation materials [8]. In Nigeria, studies have similarly demonstrated the engineering difficulties associated with wetland and problematic soils. Oladunjoye et al. for example, found that reclaimed Lagos wetlands contained alluvial materials with low shear strength and identified saturated loose sand, loose silty sand,

and high nitrate and phosphate, as unsuitable founding layers without appropriate foundation solutions. Furthermore, Oladunjoye et al. reported concerns regarding liquefaction vulnerability in Lagos wetland soils, highlighting the susceptibility of coastal terrains to geotechnical failure.

At the national level, evidence from southeastern Nigeria demonstrates that high clay content, moisture content, compressibility, and inadequate drainage can adversely affect foundation performance and contribute to settlement and structural distress. Within Rivers State, Udom and John investigated foundation sub-soils in parts of Port Harcourt City and Obio-Akpor and identified soft-to-firm sandy clay overlying variable sand deposits, with calculated shallow-foundation bearing capacities varying across locations. Earlier regional research on Niger Delta subsoils also identified swamp deposits containing highly compressible organic clay and peat-clay mixtures, with relatively low foundation suitability and considerable spatial variability.

Despite these studies, an important local and methodological gap remains . Existing research in Obio-Akpor Local Government Area has assessed foundation sub-soils generally, but there is limited site-specific evidence focusing explicitly on reclaimed wetlands, where imported fill, altered drainage, and underlying natural wetland deposits may interact to determine structural performance. Therefore, this study seeks to provide a focused geotechnical assessment of soil structural properties and building holding capacity in reclaimed wetlands of Obio-Akpor Local Government Area, generating location-specific evidence for safer foundation design, land-use planning, and sustainable development [9], [10], [11].

The quest towards closing the anticipated gap and problem would be articulated with the following questions that guided the study.

1. What is the soil structural or physical properties that enhance the holding potentials of varied buildings in reclaimed wetlands in the study area?
2. How does the nature of chemical or micro nutrients (phosphate, sulphate, and nitrates) in the soil enhance the holding potentials of varied buildings in reclaimed wetlands in the study area?

1.2. Objectives of the Study

The objectives of the study are to

1. determine the soil structural properties that enhance the holding potentials of varied buildings in reclaimed wetlands in the study area [12].
2. examine how the nature of chemical or micro nutrients (phosphate, sulphate, and nitrates) in the soil enhances the holding potentials of varied buildings in reclaimed wetlands in the study area.

1.3. Hypotheses

The formulated hypotheses were tested at 0.05 level of significance.

H_{O1}: Soil structural properties significantly differ in enhancing the holding potentials of varied buildings within reclaimed wetlands in the study area.

H_{O2}: Micro nutrients (phosphate, sulphate, and nitrates) in the soil significantly differ in enhancing the holding potentials of varied buildings across reclaimed wetlands in the study area [13].

1.4. Significance of the Study

The study would benefit civil/structural engineers, geotechnical engineers, urban planners, environmental managers, developers, government agencies, and prospective property owners by providing site-specific information on soil structural properties and building holding capacity in reclaimed wetlands of Obio-Akpor. The findings would support appropriate foundation design, land-use planning, reclamation practices, and construction decisions, while reducing risks associated with settlement, subsidence,

foundation failure, and structural instability. Government and regulatory agencies would use the findings to strengthen development-control and environmental-management practices [14]. Developers and property owners would benefit from improved knowledge for selecting suitable sites and building types. The study would also provide useful baseline information for researchers and contribute to sustainable wetland development.

1.5. Scope of the Study

The study focuses on assessing the geotechnical and structural properties of reclaimed wetland soils in Obio-Akpor, including bulk density, moisture content, texture, permeability, compaction, shear strength, and bearing capacity, with emphasis on their suitability for different building types.

1.6. Area of the Study

1.6.1. Location and Extent

The study was conducted in Obio-Akpor Local Government Area, Rivers State, covering approximately 369 km², comprising 360 km² of land and 9 km² of water. Geographically, it lies between latitudes 4°45′N-4°55′N and longitudes 6°55′E-7°05′E, about 25 km from the Atlantic Ocean, with an average elevation of 12 m above sea level [15]. The area is traditionally inhabited by the Ikwerres and comprises Akpor, Evo, Obio, and Apara kingdoms. The 2006 census recorded 462,350 inhabitants, while projections estimated the population at 624,173 in 2016 (NPC, 2007; NPC, 2016; Uwalaka, 2014). Furthermore, in terms of geographical boundaries, Obio-Akpor Local Government Area is bounded in the East by Emohua, Eleme, Okrika as well as Ikwerre and Etche Local Government Areas in the East, West, South, and North respectively (see Figure 1) [16].

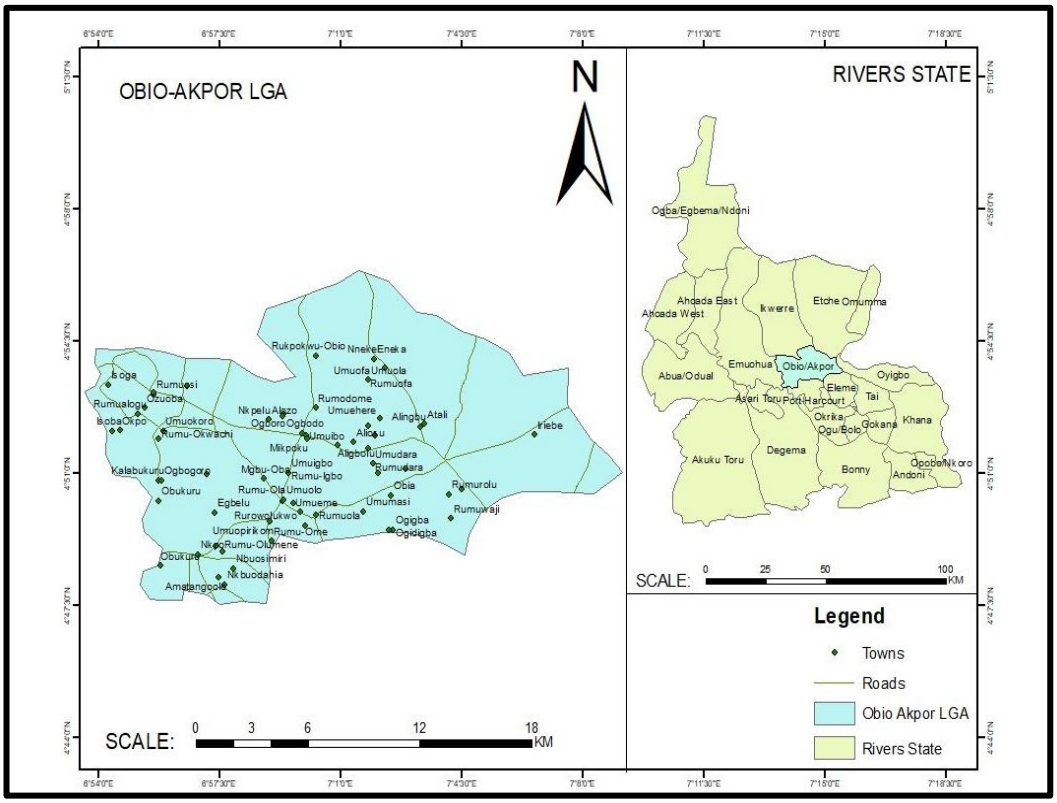


Fig. 1: Rivers State showing Obio-Akpor Local Government Area (Insert) and Obio-Akpor showing the Communities

Source: Cartography and GIS, Dept of Geography and Env. Mgt. UNIPORT (2025)

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In terms of climate, Obio-Akpor Local Government Area has a tropical rainy climate characterized by high temperatures, double rainfall maxima, and distinct rainy and dry seasons, with temperatures generally remaining above 18°C [17]. The soil and vegetation of Obio-Akpor comprises deltaic plain soils that are acidic, saline, leached, and relatively low in fertility, while its original rainforest and swamp vegetation have largely declined due to agriculture and urbanization. For relief, drainage and geology, Obio-Akpor is a low-lying coastal plain averaging about 12 m elevation, characterized by tidal rivers, poor drainage, seasonal flooding, and sedimentary formations associated with the Niger Delta. For economic activities, Obio-Akpor has transitioned from traditional farming, fishing, and hunting to predominantly oil and gas, commerce, construction, brokage, civil service, and maritime activities, stimulating rapid urbanization, population growth, infrastructure expansion, and wetland reclamation [18].

2. Materials and Methods

2.1 Research Design

The study adopted a true-experimental research design. According to Nwankwo, true-experimental design is appropriate for studies involving controlled experimental procedures, particularly where researchers can effectively regulate factors that may threaten the validity of the investigation. In this study, validity was ensured through systematic and ethical collection, preparation, and analysis of soil samples. The investigation focused on key soil structural parameters, including bulk density, permeability, porosity, soil structure, and aeration, as well as selected soil chemical or micronutrients such as phosphate, sulphate, and nitrates that were carefully controlled and analyzed to determine their building holding capacity or potentials.

2.2 Sample Frame

The sample frame comprised fifteen (15) identified reclaimed wetland sites located across communities such as Minikpeti, Eligbolo, Ogbogoro/Sand-field, Rukpokwu, Rumuokwurushi, Rumueme, Rumuomasi, Elioparanwo, Woji, Eliozo, Mgbuosimini, Rumuigbo, Rumunduru, Mgbuoba, and Rumuola in Obio-Akpor Local Government Area, Rivers State. The reclaimed and developed wetlands constituted the sample frame, covering approximately 20,907.34 hectares of Obio-Akpor Local Government Area.

2.3 Sample and Sampling Technique

Twelve soil samples were collected from six randomly selected reclaimed wetlands in Minikpeti, Eligbolo, Rukpokwu, Eliozu, Rumunduru, and Rumuola communities, representing 40% of the 15 identified reclaimed wetlands in Obio-Akpor Local Government Area. Second, triplicate soil samples were randomly collected from each selected wetland and composited into representative samples. Sampling points considered location, size, land-use history, ecological significance, and waterbody drainage, ensuring the six wetlands represented the study area's wetland diversity. In final phase, purposive sampling was used to select two (2) sampling points in each of the six (6) selected reclaimed wetlands wherein soil samples were collected. This constituted a sample of 12 soil samples (comprising 2 soil samples from each of the 6 selected reclaimed wetlands) collected from six (6) communities in the study area.

2.4 Instrumentation

The study used six data-collection instruments such as automated GPS, measuring tape, masking tape, field notebook, Ziploc bags, aluminium foil, and hand auger. These were employed during fieldwork at six selected reclaimed wetlands in Obio-Akpor Local Government Area. The GPS specifically recorded the Northing, Easting, and elevation

coordinates of each sampling point, while the remaining materials supported soil sampling, measurement, identification, documentation, and proper sample preservation.

2.5 Method of Data Collection

The study collected 12 soil samples from six selected reclaimed wetlands in Obio-Akpor, using random triplicate sampling followed by compositing. Samples were collected at 0-15 cm (topsoil) and 15-30 cm (subsoil) depths using a hand auger, stored in Ziploc bags, transported in a cooler, and refrigerated at 0-4°C before laboratory analysis. The collected soil samples were analyzed to structural parameters, including bulk density, permeability, porosity, soil structure, and aeration, as well as soil micronutrients such as phosphate, sulphate, and nitrates. Equally, the GPS was used to determine the coordinates (via Northings, Easthings, and Elevation) of the area where the soil samples were collected (Table 1) and Figure 2 for the presentation of the coordinates in the study area map below.

Table 1. Sampling Points Locations Northings Easthings Elevation of the Sampled Community

S/N	Sample Point	Location/ Community	Waterbody Drained	Northings	Easthings	Elevation	GPS	Nature of Built-up Area
1	001	Rukpokwu	Mini Owhou	$04^0.898'\ 15''$	$006^0\ 988'\ 98''$	17M	2m	Residential
2	002	Eligbolo	Mini Por	$04^0\ 890'\ 74''$	$007^0\ 005'\ 42''$	16M	3m	Residential
3	003	Eliozu	Mini Egolo	$04^0\ 861'\ 47''$	$007^0\ 021'\ 56''$	10M	3m	Industrial/ Commercial
4	004	Minikpeti	Mini Ndai	$04^0\ 803'\ 88''$	$006^0\ 933'\ 47''$	10M	3m	Residential/ Institutional/ Industrial
5	005	Rumunduru	Mini Wodugbam	$04^0\ 871'\ 57''$	$006^0\ 025'\ 07''$	10M	3m	Residential
6	006	Rumuola-Control	Mini Olau	$04^0\ 036'\ 66''$	$007^0\ 002'\ 36''$	13M	3m	Residential

Source: Researcher's Field Work (May, 2025).

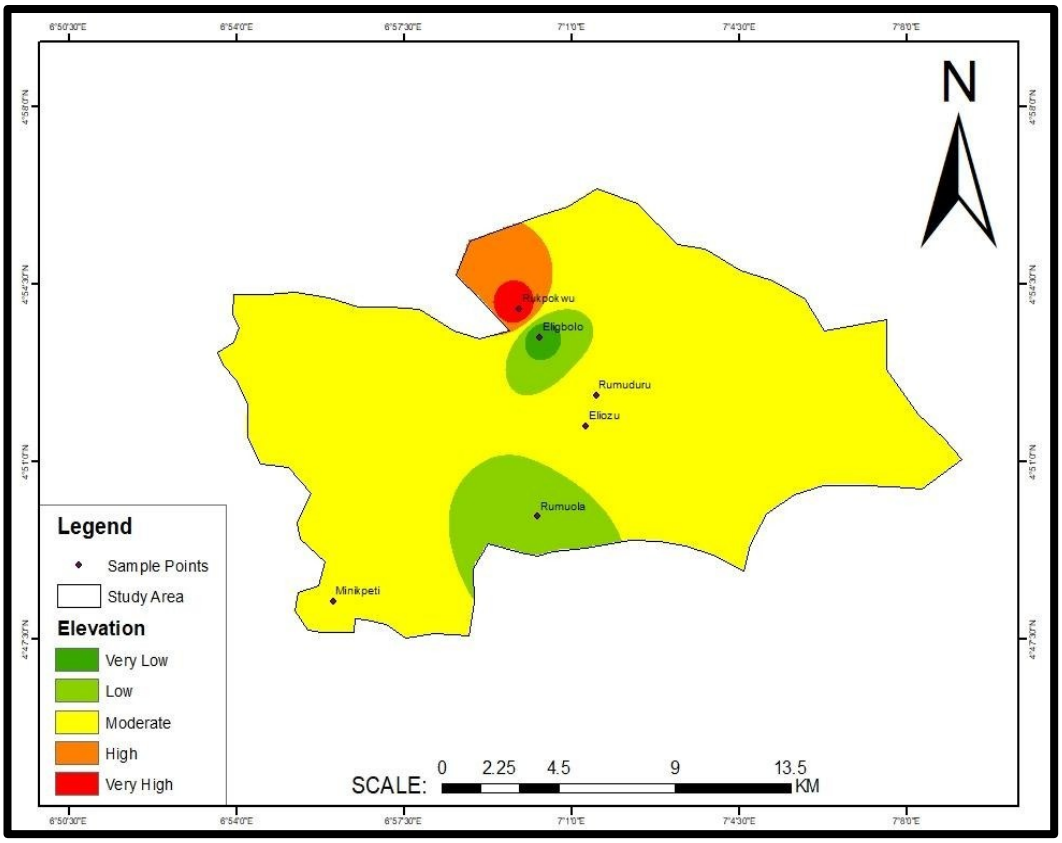


Figure 2. Study Area Map showing the Sampled Points

2.6 Laboratory Analysis of Soil Parameters

The laboratory analysis involved air/oven-drying, crushing, sieving, and chemical digestion where applicable. Soil pH and electrical conductivity were measured using calibrated portable meters, while moisture content was determined gravimetrically after oven-drying at 105°C to constant weight (Edori & Iyama, 2017). Samples were analyzed for density, structure, texture, permeability, porosity, aeration, consistency, colour, pH, temperature, total organic carbon, and electrical conductivity. Samples were properly labelled, preserved at 0-4°C, and analyzed using topsoil and subsoil samples. Laboratory analyses were conducted at the Department of Biology Research Laboratory, Ignatius Ajuru University of Education, Rumuolumeni, Port Harcourt.

2.7 Data Analysis

Descriptive statistics, including means, and charts were used to answer the research questions, while ANOVA tested Hypotheses 1-2. Standard APHA procedures guided the analysis of physical properties of the collected soil samples (APHA, 2005; Kosamu et al., 2011).

3. Results

Research Question 1: What is the soil structural or physical properties that enhance the holding potentials of varied buildings in reclaimed wetlands in the study area?

Table 2: Mean Concentration of the soil structural or physical parameters that are required to enhance the holding potentials of varying buildings in reclaimed wetlands in the study area

SP	Density (g/cm^3)	Permeability (cm/s)	Porosity (%)	Structure	Aeration ($g/cm^2/min$)
	$\bar{x}$±SE	$\bar{x}$±SE	$\bar{x}$±SE		$\bar{x}$±SE
SP 1	0.96± 0.03	5900.00±806.64	43.47±0.33	Columnar	32.47±0.42
SP 2	1.16± 0.09	1091.67±317.84	44.67±0.46	Granular	35.67±0.42
SP 3	1.32± 0.05	396.67±4.94	45.62±0.40	Blocky	35.88±0.17
SP 4	1.35± 0.04	1315.00±232.30	52.50±0.99	Granular	39.52±0.52
SP 5	1.33± 0.04	411.67±17.21	46.50±0.94	Granular	36.27±1.67
SP 6	1.79± 0.05	213.33±15.20	43.64±1.25	Granular	35.90±0.63
Pooled $\bar{x}$±SE	**1.31±0.05**	**1486.11±232.36**	**46.07±0.66**	Granular/ Columnar/	**35.95±0.64**
SON (2017)	1.8-2.0	10^{-3}-10^{-6}	30-50%	Blocky	-
ASTM (2011)	1.8-2.0	10^{-3}-10^{-6}	30-50%	Granular/ Columnar/ Blocky	-

Source: Author's Computation, 2025.

Legend:

SP = Sampling Points

SP1 = Rukpokwu Community (Sampling Point 1)

SP2 = Eligbolo Community (Sampling Point 2)

SP3 = Eliozu Community (Sampling Point 3)

SP4 = Minikpeti Community (Sampling Point 4)

SP5 = Rumunduru Community (Sampling Point 5)

SP6 = Rumuola Community (Sampling Point 6)

Table 2 presents soil structural or physical parameters, density, permeability, porosity, structure, and aeration, across six reclaimed wetlands in Obio-Akpor and compares them with Standards Organization of Nigeria (SON, 2017) and ASTM (2011) guidelines. Density ranged from 0.96 g/cm^3 at Rukpokwu (SP1) to 1.79 g/cm^3 at Rumuola (SP6), while permeability varied considerably [19]. Porosity ranged from 43.47% to 52.50%, with granular, columnar, and blocky structures, and aeration values ranging from 32.47 to 39.52 $g/cm^2/min$. Minikpeti (SP4) exhibited the highest porosity and favourable density, while Rukpokwu (SP1) showed the lowest density and weaker support conditions. Rumuola (SP6) recorded the highest density but comparatively low permeability, suggesting possible drainage limitations [20]. Overall, pooled values were 1.31 g/cm^3 density, 1486.11 cm/s permeability, 46.07% porosity, and 35.95 $g/cm^2/min$ aeration. Comparison with SON and ASTM standards showed substantial discrepancies and variations (density and permeability), emphasizing the need for careful geotechnical assessment and possible soil improvement before construction [21]. The graphical illustration of Table 2 in Figure 3 below.

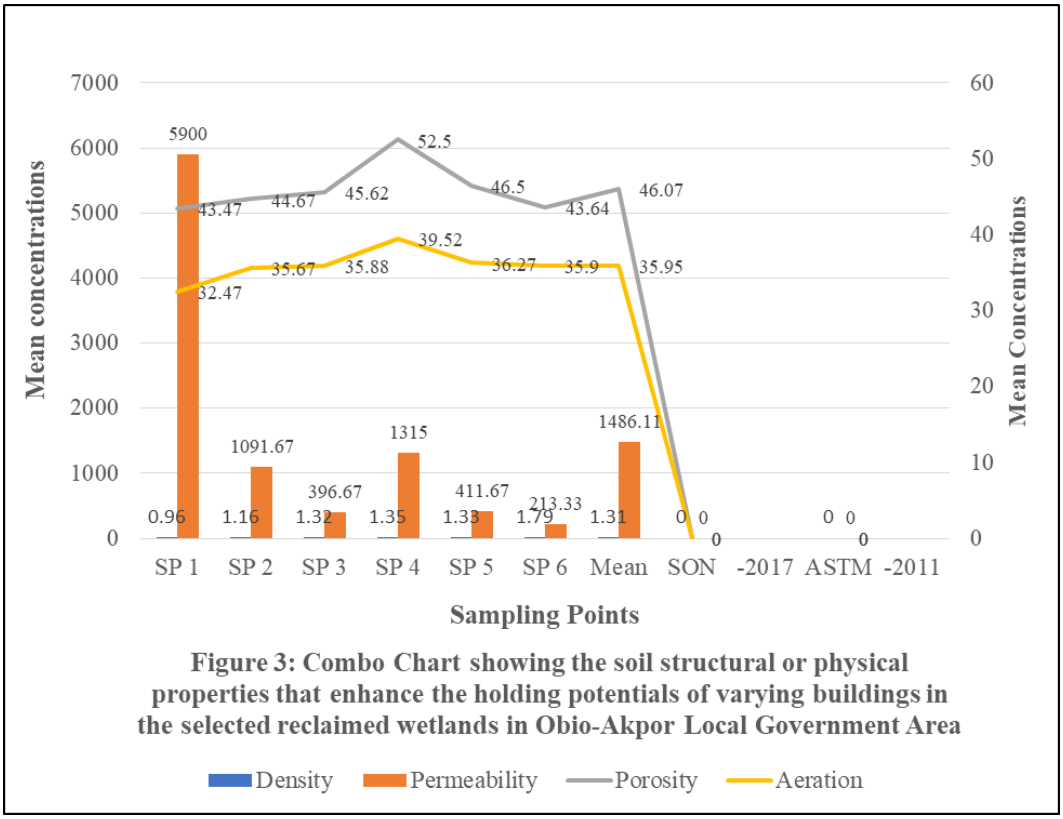


Figure 3: Combo Chart showing the soil structural or physical properties that enhance the holding potentials of varying buildings in the selected reclaimed wetlands in Obio-Akpor Local Government Area

The Combo Chart in Figure 3 shows the structural or physical parameters that are required to enhance the holding potentials of varying buildings in the selected reclaimed wetlands in Obio-Akpor Local Government Area compared with the SON and ASTM standards. It further shows that SP1 (i.e. Rukpokwu Community) had higher mean permeability than SP2, SP3, SP4, SP5, and SP6, Also, SP3 (i.e. Eliozu Community) had the highest concentration for Porosity, SP6 (i.e. Rumuola Community) had the highest value for Density, while SP4 (Minikpeti Community) had the highest concentration for Aeration in the soil of reclaimed wetlands in Obio-Akpor Local Government Area of Rivers State [22], [23].

Research Question 2: What is the nature of chemical or micro nutrients (like phosphate, sulphate, and nitrates) in the soil that enhance the holding potentials of varied buildings in reclaimed wetlands in the study area?

Table 3: Mean Concentration of nature of chemical or micro nutrients (like phosphate, sulphate, and nitrates) in the soil that enhance the holding potentials of varied buildings in reclaimed wetlands in the study area

SP	**PO_4^{3}** (mg/L)	**SO_4^{2}** (mg/L)	**Nitrates** (mg/L)
	$\bar{x}$±SE	**$\bar{x}$±SE**	**$\bar{x}$±SE**
SP 1	1.82± 0.06	1.22± 0.01	48.12± 0.36
SP 2	1.84± 0.05	7.42± 0.06	39.15± 0.30
SP 3	1.70± 0.02	3.13± 0.01	20.45± 0.59
SP 4	1.96± 0.01	2.46± 0.01	44.41± 0.07
SP 5	1.72± 0.02	5.39± 0.01	63.41± 1.00
SP 6	1.75± 0.06	2.65± 0.02	23.57± 0.00
Pooled $\bar{x}$±SE	**1.83± 0.03**	**3.56± 0.02**	**38.03± 0.33**
SON (2017)	< 5	250	20

ASTM (2011)	< 2	100	20

Source: Author's Computation, 2025.

Legend:

SP = Sampling Points

SP1 = Rukpokwu Community (Sampling Point 1)

SP2 = Eligbolo Community (Sampling Point 2)

SP3 = Eliozu Community (Sampling Point 3)

SP4 = Minikpeti Community (Sampling Point 4)

SP5 = Rumunduru Community (Sampling Point 5)

SP6 = Rumuola Community (Sampling Point 6)

Table 3 shows the results for the nature of chemical or micro nutrients (like phosphate, sulphate, and nitrates) in the soil in reclaimed wetlands in the study area including SON (2017) and ASTM (2011) standards for soil physicochemical properties [24]. It further shows that the mean phosphate concentrations remain fairly consistent, ranging between 1.70 ± 0.02 mg/L (SP3) and 1.96 ± 0.01 mg/L (SP4), with a pooled mean of 1.83 ± 0.03 mg/L, below the ASTM guideline of < 2 mg/L. Sulfate concentrations vary from 1.22 ± 0.01 mg/L (SP1) to 7.42 ± 0.06 mg/L (SP2), with a pooled mean of 3.56 ± 0.02 mg/L, within the SON and ASTM limits of 250 mg/L. This indicates limited risk of sulfate-induced soil degradation. Nitrate levels range between 20.45 ± 0.59 mg/L (SP3) and 63.41 ± 1.00 mg/L (SP5), with a pooled mean of 38.03 ± 0.33 mg/L, exceeding the SON and ASTM limits of 20 mg/L. Elevated nitrate levels could indicate anthropogenic impacts, potentially affecting soil strength over time [25]. The graphical illustration of the result in Table 4.5 is presented in Figure 4 below.

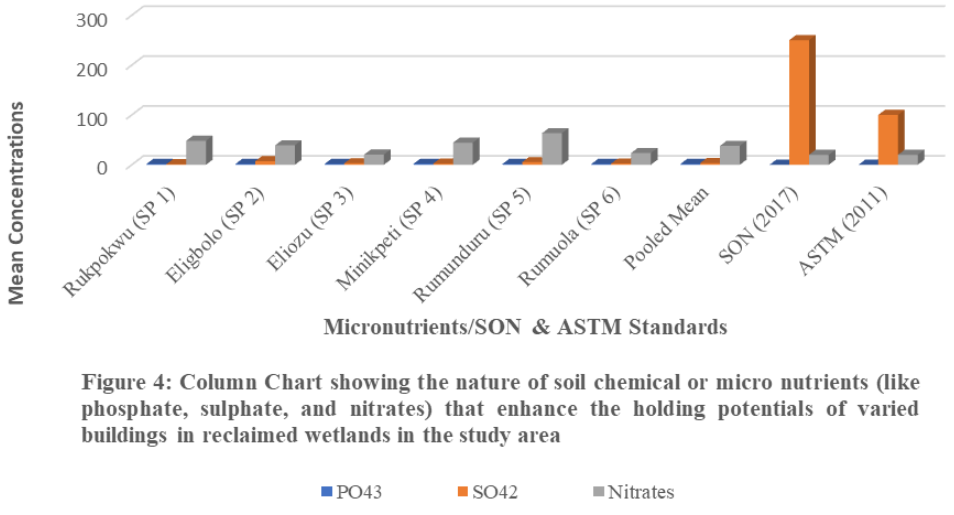


Figure 4: Column Chart showing the nature of soil chemical or micro nutrients (like phosphate, sulphate, and nitrates) that enhance the holding potentials of varied buildings in reclaimed wetlands in the study area

Figure 4.5 presents the SON and ASTM-approved limits for soil micronutrients required to support the bearing capacity of different building classes in selected reclaimed wetlands. Rumunduru (SP5) recorded the highest micronutrient levels, followed by Rukpokwu (SP1), indicating relatively better conditions for low-, mid-, high-rise, and heavy infrastructure. Rumuola (SP6) recorded the lowest micronutrient levels, suggesting comparatively less favourable soil conditions for supporting these structures in Obio-Akpor reclaimed wetlands [26].

Hypothesis 1: Soil structural or physical properties significantly differ in enhancing the holding potentials of varied buildings within reclaimed wetlands in the study area.

Table 4: Summary of Analysis of Variance (ANOVA) on the difference in the soil structural or physical properties in enhancing the holding potentials of varied buildings within reclaimed wetlands in Obio-Akpor Local Government Area Rivers State

Source of Variation	Sum of Squares (SS)	Df	Mean Square	F. Ratio	P-value	Decision
Between Groups	74.788	5	14.958	10.199	.033[b]	S
Within Groups	374.184	30	12.473			
Total	**448.972**	**35**				

Decision Rule: *If p<.05 retain H_a, else reject H_a., S= significant, p<.05, NS= Not Significant, p>.05.*

Table 4 presents the ANOVA results on differences in soil structural properties influencing the holding potentials of varied buildings in reclaimed wetlands in Obio-Akpor Local Government Area, Rivers State [27]. The result indicates an F-value of 10.199, significant at $P < 0.05$, confirming significant differences in soil structural properties. Thus, variations in density, permeability, porosity, and aeration significantly influenced the holding potentials of different buildings within the reclaimed wetlands, demonstrating their importance for structural stability and development.

Hypothesis 2: Micro nutrients (like phosphate, sulphate, and nitrates) in the soil significantly differ in enhancing the holding potentials of varied buildings across reclaimed wetlands in the study area.

Table 5: Summary of Analysis of Variance (ANOVA) on the difference in the micro nutrients (like phosphate, sulphate, and nitrates) in the soil in reclaimed wetlands in Obio-Akpor Local Government Area Rivers State

Source of Variation	Sum of Squares (SS)	Df	Mean Square	F. Ratio	P-value	Decision
Between Groups	398.485	1	398.485	268.356	.000[b]	S
Within Groups	50.487	34	1.485			
Total	**448.972**	**35**				

Decision Rule: *If p<.05 retain H_a, else reject H_a., S= significant, p<.05, NS= Not Significant, p>.05.*

Table 5 presents the summary of the Analysis of Variance (ANOVA) examining differences in soil micronutrient concentrations, including phosphate, sulphate, and nitrates, and their influence on the holding potentials of different building types across reclaimed wetlands in Obio-Akpor Local Government Area, Rivers State [28]. The result yielded an F-value of 268.356, which is significant at $P < 0.05$. This indicates that the concentrations of these micronutrients significantly differed in their contribution to the holding potentials of low-rise, mid-rise, high-rise, specialized buildings, and heavy infrastructure (Table 3) within the reclaimed wetlands.

4. Discussion

The results in Table 2 reveal considerable variation in the structural properties of reclaimed wetland soils and their implications for building stability. Permeability ranged from 5900.00±806.64 cm/s at Rukpokwu (SP1) to 213.33±15.20 cm/s at Rumuola (SP6), with a pooled mean of 1486.11±232.36 cm/s [29]. These values exceed SON (2017) and ASTM (2011) recommendations, suggesting potential drainage and foundation problems, consistent with Oluwatosin and Akintola. The result also agrees with Adeyemi et al. who noted that low permeability may restrict water movement, causing poor drainage and waterlogging; hence, site-specific drainage is essential [30].

Porosity ranged from 43.47±0.33% at SP1 to 52.50±0.99% at Minikpeti (SP4), with a pooled mean of 46.07±0.66%. Although generally within the 30–50% range recommended by SON and ASTM (2011), higher porosity may increase water retention and foundation weakening during heavy rainfall. This agrees with Lehmann et al. and Schultz et al. who emphasized the importance of porosity for water retention, aeration, and soil performance. Sharma et al. similarly identified 30-50% as generally suitable for construction. Soil structures varied among columnar, granular, and blocky forms. Granular structures in SPs 2, 4, 5, and 6 provide better aeration, compaction, and stability, supporting Olujimi et al and Agim et al. Aeration ranged from 32.47±0.42 to 39.52±0.52 g/cm²/min, indicating generally adequate conditions, consistent with Kumar et al [31]. Overall, the researchers reiterate that the variability in these parameters necessitates site-specific geotechnical assessment and appropriate foundation and drainage measures prior to conclusion

The results in Table 3 show marked spatial variation in soil micronutrients across the reclaimed wetlands. Phosphate ranged from 1.70±0.02 mg/L (SP3) to 1.96±0.01 mg/L (SP4), with a pooled mean of 1.83±0.03 mg/L, remaining below SON (2017) and ASTM (2011) limits. Sulphate varied from 1.22±0.01 mg/L (SP1) to 7.42±0.06 mg/L (SP2), with a mean of 3.56±0.02 mg/L, also within permissible limits [32]. However, nitrate ranged from 20.45±0.59 mg/L (SP3) to 63.41±1.00 mg/L (SP5), averaging 38.03±0.33 mg/L and exceeding the 20 mg/L standards. This pattern agrees with Azeez et al. who reported substantial nitrate, phosphate and sulphate movement and leaching in Nigerian soils. Similarly, Nafagha-Lawal et al. found nutrient enrichment in Bonny Estuary sediments associated with anthropogenic inputs. The finding aligns with Amin et al. that elevated nitrate may therefore indicate nutrient loading and potential environmental stress, while the generally moderate phosphate and sulphate levels suggest comparatively lower enrichment. Overall, the researchers agreed that the results demonstrate spatially variable nutrient conditions requiring continued monitoring and appropriate wetland management [33].

The ANOVA result in Table 4 indicates a significant difference in soil structural parameters influencing the holding potentials of varied buildings in reclaimed wetlands in Obio-Akpor LGA, Rivers State. This finding demonstrates that variations in density, permeability, porosity, and aeration can substantially affect foundation performance. Okwakpam et al. similarly reported that variations in bulk density, porosity, and permeability influence infiltration behaviour in Port Harcourt wetlands [34]. Recent evidence from Lagos wetlands further shows that problematic saturated and loose soils can reduce foundation competence and increase structural vulnerability. Likewise, Okah found weak, compressible swamp soils in Rivers State unsuitable for conventional shallow foundations without appropriate consideration of soil conditions. These comparisons support the present finding that site-specific geotechnical assessment is essential for safe and sustainable construction in reclaimed wetlands.

The ANOVA result in Table 5 revealed a statistically significant difference in soil micronutrient concentrations between the compared groups, with an F-ratio of 268.356 and a p-value of .000 ($p < .05$). Thus, the null hypothesis is rejected, indicating that

phosphate, sulphate, and nitrate concentrations vary significantly across the reclaimed-wetland soil groups [35]. This finding is consistent with evidence from Rivers State showing that wetland soils possess distinct chemical characteristics and nutrient profiles compared with upland soils. Similarly, recent research in Rivers State found that swamp reclamation alters soil physicochemical conditions and generally reduces nutrient content compared with natural swamps. Evidence from Obio-Akpor also demonstrates variability in available phosphorus and other soil-quality indicators across land-use types [36]. Therefore, the significant ANOVA result suggests that reclamation and associated changes in soil conditions may influence nutrient distribution, with implications for soil quality and sustainable wetland management.

5. Conclusion

The findings from Tables 2 and 3 indicate that the reclaimed wetland soils exhibit considerable variability in their physical structural and chemical properties, with important implications for their suitability as foundation materials for buildings. The observed differences in soil density, permeability, porosity, structure, and aeration suggest that the reclaimed sites do not possess uniform engineering characteristics. The generally low density relative to recommended standards may indicate inadequate compaction and the presence of relatively loose soil materials, potentially reducing their ability to provide stable support for structural loads. Although the measured porosity generally falls within the acceptable reference range, the substantial variation in permeability suggests differences in drainage and water movement across the sites, which may influence soil stability and settlement behaviour.

The chemical characteristics presented in Table 3 also demonstrate variation in phosphate, sulphate, and nitrate concentrations among the sampling points. While phosphate concentrations generally remain within the referenced standards, the observed nitrate levels indicate potential environmental concerns where concentrations exceed recommended limits. Overall, the findings suggest that reclaimed wetlands in the study area possess heterogeneous soil conditions that may influence building holding capacity and long-term foundation performance. Consequently, comprehensive geotechnical investigation, appropriate soil improvement, adequate drainage, and site-specific foundation design are necessary before construction on reclaimed wetland soils.

Based on the findings of the study, the following recommendations were proffered

The Rivers State Government, through relevant planning and building-control authorities, should require comprehensive geotechnical investigations and appropriate soil improvement or foundation treatment before approving construction on reclaimed wetlands, particularly where soil density, permeability, and structural characteristics are unsuitable for supporting building loads.

Environmental and planning authorities should incorporate routine soil-chemical assessment into reclaimed-wetland development approvals and monitoring, particularly for nitrate and sulphate concentrations, to ensure that construction activities and land-use decisions consider both soil quality and potential environmental risks.

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