GEOTECHNICAL CHARACTERIZATION OF RECLAIMED WETLAND SOILS FOR BUILDING BEARING CAPACITY IN OBIO-AKPOR, RIVERS STATE

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Abstract
This study geotechnically characterized reclaimed wetlands soils for building bearing capacity in Obio-Akpor Local Government Area, Rivers State. The study adopted a true experimental research design. Twelve soil samples were collected from six reclaimed wetlands in the study area. The laboratory results obtained from the soil samples were analyzed using mean and charts to answer the research questions, while Analysis of Variance (ANOVA) was employed to test the hypotheses at the 0.05 level of significance. The study found spatial variability in soil properties range: temperature (28.90-30.53°C), pH (7.60-8.42), EC (1,428.67-1,760.50 µS/cm), and organic carbon (1.46-2.17%). Bulk density ranged from 0.96-1.79 g/cm³, with Rukpokwu lowest and Rumuola highest, indicating variations that may affect foundation stability, bearing capacity, and drainage, and performance. Also, the significant differences (p= .026) in soil parameters, and highly significant (p= .001) bulk-density variation, suggests spatial heterogeneity that may affect soil stability and bearing capacity in the study area. The study concludes that spatial variability in soil properties and bulk density may influence foundation stability, and building performance, necessitating site-specific geotechnical assessment in Obio-Akpor reclaimed wetlands. The study recommended that the development-control authorities in Rivers State and Obio-Akpor local government, should require site-specific bulk-density assessment and professional foundation recommendations from qualified geotechnical engineers, civil/structural engineers, and certified soil-testing laboratories before approving low-, medium-, high-rise, and specialized structures on reclaimed wetlands. Alongside, relevant planning authorities should mandate physicochemical soil testing before construction in Rukpokwu, Eligbolo, Eliozu, Minikpeti, Rumunduru, and Rumuola, variations in soil softness, texture, pH, electrical conductivity, and organic-carbon content may affect foundation performance.
Keywords: Geotechnical Characterization, Reclaimed Wetland Soil, Soil Parameters, Bulk Density, Building Bearing Capacity.

Introduction

Urbanization and increasing demand for residential, commercial, institutional, and infrastructural facilities have encouraged the development of marginal lands, including wetlands and reclaimed swampy environments (Oduro et al., 2024). Reclamation through fill materials placement in wet and deep land creates additional development land by transforming waterlogged terrains into construction platforms, yet underlying wetland deposits may continue influencing the reclaimed ground's engineering behaviour (Uwaezuoke et al., 2021). The suitability of reclaimed wetlands for building depends on the engineering properties of their soils, notably soil stratification, moisture content, particle-size distribution, plasticity, cohesion, angle of internal friction, unit weight, compaction, and bulk density, all of which determine shear strength, compressibility, settlement, and bearing capacity (Onugha, 2022; Udosen et al., 2024b). These properties are particularly important in wetland environments, where high groundwater conditions and weak, compressible soil deposits may occur (Chukwuka & Ekeocha, 2022).

Reclamation, therefore, does not necessarily eliminate the engineering limitations of wetland soils. Oyedele and Akinluyi (2021) corroborated that geophysical investigation of a reclaimed Lagos wetland revealed weak and unstable subsurface materials, demonstrating that reclamation may retain geotechnical constraints and necessitate detailed characterization before construction. The reclaimed nature of wetland sites introduces an additional consideration because filling and land modification can alter the original soil profile and produce layers with different densities, materials, and consolidation histories. Consequently, soils occurring at the ground surface may not necessarily represent the engineering properties of deeper foundation-bearing strata. This makes subsurface profiling and depth-specific sampling important components of geotechnical assessment. Hector et al. (2025) engineering-geological modelling study in Obio-Akpor emphasized the need for detailed subsurface understanding, using boreholes and integrated geotechnical characterization and information to develop two- and three-dimensional representations of subsurface conditions.

The Niger Delta presents a particularly important setting for such investigations because its fluvio-deltaic environment contains spatially variable sequences of clay, silt, sand, and other unconsolidated materials. Kennedy (2024), investigating subsurface soils in Mbiama, Rivers State, reported heterogeneous stratigraphy involving clayey sands and gravelly sands and demonstrated relationships between index properties, moisture content, sand content, and dynamic soil characteristics. Similarly, investigations in Yenagoa have identified soft to firm silty clay, clayey sand, peaty clay, and silty sand horizons, emphasizing the variability of foundation conditions within Niger Delta environments (Udom & John, 2023).

The engineering relevance of these conditions is particularly pronounced in Obio-Akpor. Udom and John (2023) investigated foundation subsoils to depths exceeding 20 m in parts of Port Harcourt and Obio-Akpor and identified overlying sandy clay of soft to firm consistency above fine- to coarse-grained sand ranging from loose to dense. Their study included particle-size analysis, Atterberg limits, undrained shear strength, shear-box testing, consolidation assessment, and bearing-capacity calculations. More recently, George et al. (2025) characterized weak soils at Rukpokwu in Obio-Akpor and reported moisture-sensitive, highly plastic soil with relatively low CBR and poor suitability for direct use as foundation or other load-bearing material without treatment. These findings reinforce the need for detailed characterization of reclaimed wetland soils within the local government area rather than relying on generalized regional assumptions.

The presence of insufficient consolidation, high groundwater conditions, weak subsoil, and differential soil characteristics can significantly affect foundation performance and construction in soft-ground environments and reclaimed wetlands in Nigeria (Udom & John, 2023). Global research continues to demonstrate that soft and under-consolidated ground can experience substantial deformation under imposed loads, making settlement assessment an important component of foundation engineering (Wang et al., 2024). Conversely, Akpokodje et al. (2025) assessment of geotechnical testing in foundation design in Nigeria's Delta State observed variations in subsoil strength and moderate load-bearing capacity, demonstrating that particle-size distribution, Atterberg limits, compaction, CBR, cohesion, and frictional properties should inform foundation decisions.

Geotechnical characterization systematically assesses soil physical and mechanical properties, including moisture, particle size, plasticity, density, compaction, cohesion, friction, strength, compressibility, and permeability, to determine engineering behaviour and foundation suitability (Udosen et al., 2024a). These parameters are closely related to bearing capacity because foundation soils must possess sufficient resistance to shear failure while limiting settlement to acceptable levels (Walter, 2025). Recent geotechnical investigations have demonstrated that weak, moisture-sensitive soils with low bearing capacity may require stabilization or other forms of improvement before being used for load-bearing construction (George et al., 2025).

Bulk density is particularly relevant within the proposed investigation because it reflects the mass of soil occupying a given total volume and provides useful information concerning soil packing, pore spaces, compaction, and likely load-response behaviour. In reclaimed land, variations in bulk density may indicate differences in the quality and degree of compaction of placed materials and may also reflect changes in the underlying natural deposits (Okwakpam et al., 2024). Thus, bulk density should not be interpreted in isolation but alongside moisture content, grain-size distribution, plasticity, shear-strength parameters, and consolidation characteristics. Recent Nigerian research has demonstrated the importance of integrating multiple geotechnical parameters when evaluating foundation conditions and bearing capacity (Adunoye et al., 2024).

The engineering significance of reclaimed wetland soils is therefore closely associated with their physical and mechanical characteristics. Reclaimed wetland soil performance depends on moisture, grain size, density, plasticity, compaction, shear strength, and consolidation, while Niger Delta variability with depth necessitates site-specific geotechnical assessment for foundation design (Kennedy, 2024). Accordingly, the present study focuses on the geotechnical characterization of reclaimed wetland soils in Obio-Akpor to establish the relationships among soil properties, bulk density, and building bearing capacity. The investigation is intended to provide empirical evidence for evaluating ground conditions and supporting appropriate foundation decisions, particularly where reclamation has altered the natural soil profile.

The study is anchored on Terzaghi's Bearing Capacity Theory, developed by Karl Terzaghi as a fundamental framework for estimating the ultimate bearing capacity of shallow foundations. The theory relates foundation bearing capacity to key soil and foundation parameters, particularly cohesion, angle of internal friction, unit weight, foundation width, and embedment depth (Terzaghi, 1943). Its relevance to this study lies in its capacity to provide a theoretical basis for relating measured geotechnical characteristics of reclaimed wetland soils to their ability to support building foundations (Walter, 2025). Since soil density, strength, moisture conditions, and stratification influence foundation response, the theory provides an appropriate framework for interpreting variations in bearing capacity among the investigated reclaimed wetland locations.

Recent investigations in Obio-Akpor further demonstrate the practical importance of this theoretical and geotechnical framework. Udom and John (2023) identified variable subsurface profiles comprising sandy clay and sand of different consistencies, demonstrating the need for site-specific geotechnical assessment in reclaimed wetlands. Walter (2025) asserted that geotechnical characterization provides essential information for assessing foundation suitability, selecting appropriate foundation systems, minimizing settlement-related risks, and supporting sustainable development of reclaimed wetlands in Obio-Akpor Local Government Area. Overall, this arrangement provides a clearer progression from the broad problem of wetland urbanization, through reclamation and Niger Delta geological conditions, to Obio-Akpor-specific evidence, measurable geotechnical parameters, theoretical foundation principles, and finally the specific rationale and focus of the study.

Problem Specification

The increasing development of reclaimed wetlands creates an important geotechnical challenge because surface reclamation does not necessarily eliminate weak, compressible, or heterogeneous subsoil conditions. International studies have demonstrated that soft and under-consolidated soils can undergo significant consolidation and differential settlement when subjected to structural loading, necessitating detailed assessment of soil deformation and foundation response (Wang et al., 2024).

At the continental level, research on African coastal and wetland environments similarly indicates that problematic soils can create engineering constraints. In Lagos, Oladunjoye et al. (2024) identified potential liquefaction vulnerability in wetland areas and emphasized the engineering implications of problematic coastal soils for infrastructure. Ese et al. (2024) also reported variations in the geotechnical properties of wetland soils in Lagos Mainland, demonstrating the importance of location-specific characterization.

Within Nigeria, Adunoye et al. (2024) demonstrated that bearing capacity assessment requires consideration of measured soil characteristics and foundation conditions, while Abdulmumini et al. (2024) showed that apparently adequate bearing-capacity values may be constrained by excessive settlement revealed through consolidation testing. In Rivers State, Udom and John (2023) found variable sandy-clay and sand strata in Obio-Akpor, with differing consistency and bearing-capacity characteristics. George et al. (2025) further identified weak, moisture-sensitive and highly plastic soils in Rukpokwu, Obio-Akpor. However, a specific investigation integrating geotechnical assessment and bulk density with the bearing-capacity requirements of buildings on reclaimed wetlands across selected parts of Obio-Akpor remains limited. This gap necessitates the present study that geotechnically characterization of reclaimed wetland soils for building bearing capacity in Obio-Akpor, Rivers State.

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

1. What are the soil parameters required to determine the appropriate bearing potentials of varying buildings in reclaimed wetlands in the study area?
2. What is the level of soil bulk density that enhance the bearing capacity of different classes of buildings or structures in reclaimed wetlands in the study area?

Objectives of the Study

The specific objectives of the study are to:

i. identify the soil parameters required to determine the appropriate bearing potentials of varying buildings in reclaimed wetlands in the study area.
ii. ascertain the level of soil bulk density that enhance the bearing capacity of different classes of buildings or structures in reclaimed wetlands in the study area.

Hypotheses

The following hypotheses were tested at 0.05 level of significance.

H_{O1}: Soil parameters did not significantly differ in bearing potentials of varying buildings within reclaimed wetlands in the study area

H_{O2}: Soil bulk density significantly differs in enhancing the bearing capacity of different classes of buildings or structures in reclaimed wetlands in the study area.

Significance of the Study

The study provided site-specific geotechnical information on the engineering condition of reclaimed wetland soils in Obio-Akpor. The findings improved understanding of how soil characteristics and bulk density influence bearing capacity, settlement potential, and foundation suitability. Such information was important for reducing the risks associated with constructing buildings on weak, heterogeneous, or inadequately compacted reclaimed ground.

Civil and geotechnical engineers benefited from empirical soil parameters that can support foundation assessment and preliminary design. Builders, contractors, and property developers will benefit from information that can assist in selecting appropriate construction approaches and identifying potentially problematic ground conditions. Urban and physical planners can use the findings to support evidence-based land-use and development decisions in reclaimed areas. Government agencies and regulatory authorities may apply the results in development control, building approval, and geotechnical-risk management.

Researchers and academic institutions will benefit from additional empirical data on reclaimed wetland soils within the Niger Delta. Finally, building occupants and the wider community may benefit indirectly through improved foundation decisions, reduced risks of excessive settlement and structural distress, and safer utilization of reclaimed land.

Scope of the Study

The study was geographically restricted to selected reclaimed wetland locations within Obio-Akpor Local Government Area, Rivers State. It focuses on the geotechnical characterization of soils relevant to building foundation performance. The investigation covers selected physical and engineering properties, including natural moisture content, particle-size distribution, specific gravity, Atterberg limits, bulk density/unit weight, compaction characteristics, cohesion, angle of internal friction, and other parameters considered necessary for assessing bearing capacity. The study will examine variations in these properties among the selected sampling locations and relate the observed characteristics to the bearing-capacity requirements of buildings. It will also consider the implications of soil strength, density, moisture condition, and compressibility for foundation suitability. The study does not constitute detailed structural design of individual buildings; rather, it provides geotechnical information that can guide foundation planning and preliminary engineering decisions.

Area of the Study

Location and Extent

The study was conducted in Obio-Akpor Local Government Area of Rivers State, covering about 369 km², comprising approximately 360 km² of land and 9 km² of water. The area is situated between latitudes 4°45′N and 4°55′N and longitudes 6°55′E and 7°05′E, approximately 25 km from the Atlantic Ocean, with a mean elevation of about 12 m above sea level. Traditionally inhabited by the Ikwerre people, the LGA encompasses the Akpor, Evo, Obio, and Apara kingdoms. The 2006 population census recorded 462,350 inhabitants, with the population projected to reach 624,173 by 2016 (NPC, 2007; NPC, 2016; Uwalaka, 2014). Spatially, Obio-Akpor shares boundaries with Emohua, Eleme, Okrika, Ikwerre, and Etche Local Government Areas along its eastern, western, southern, and northern boundaries, respectively (see Figure 1).

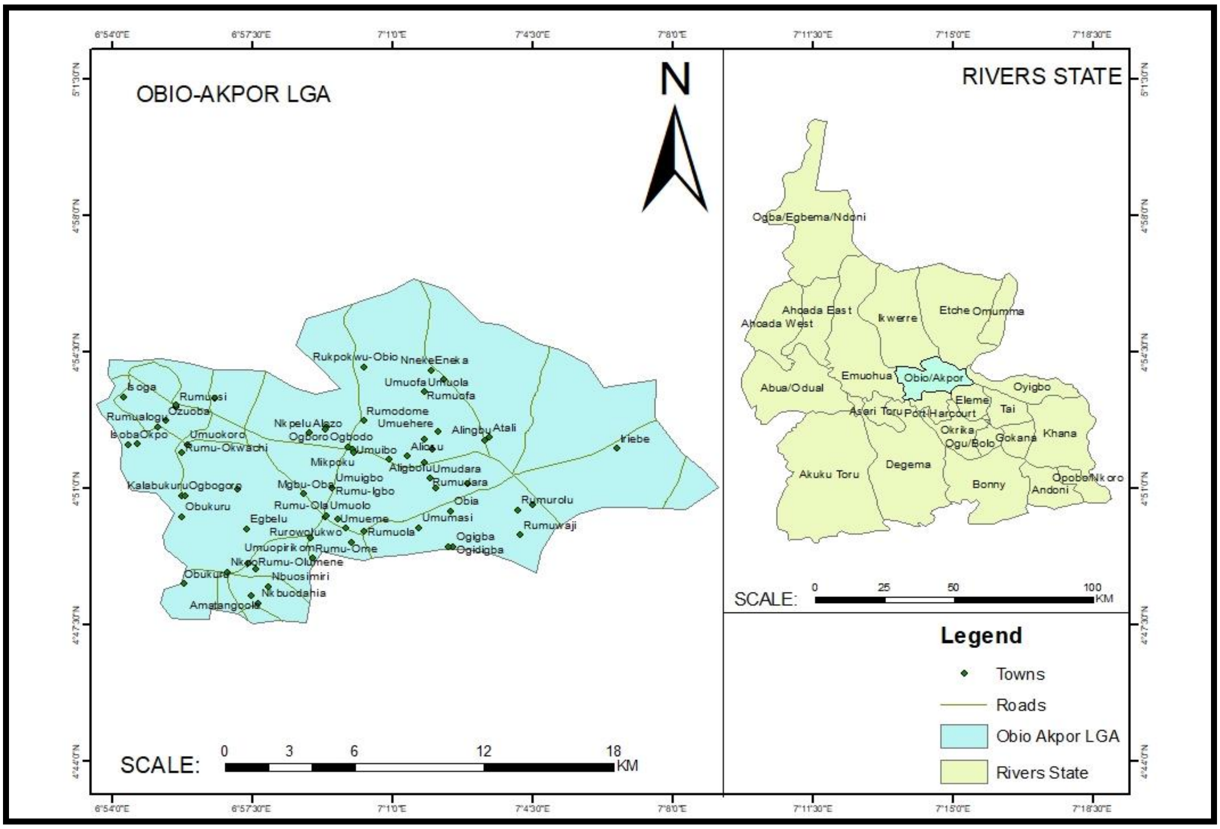

Fig. 1: Rivers State showing Obio-Akpor Local Government Area (Insert) and Obio-Akpor showing the Communities

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

Climatically, Obio-Akpor Local Government Area experiences a tropical humid climate marked by generally high temperatures, two distinct rainfall peaks, and clearly defined wet and dry seasons, with temperatures typically exceeding 18°C (Akukwe & Ogbodo, 2015). Its soils are predominantly deltaic plain soils characterized by acidity, salinity, leaching, and relatively low fertility, while the area's original rainforest and swamp vegetation have been considerably modified by agricultural activities and rapid urbanization. In terms of relief, drainage, and geology, Obio-Akpor is situated on a low-lying coastal plain with an average elevation of approximately 12 m. The landscape is characterized by tidal waterways, poor natural drainage, periodic flooding, and sedimentary formations associated with the Niger Delta. Economically, the area has shifted from traditional activities such as farming, fishing, and hunting toward oil and gas, commerce, construction, brokerage, civil service, and maritime-related activities. These expanding economic activities have contributed to rapid urban growth, increasing population, infrastructure development, and the progressive reclamation of wetlands.

Methodology

Research Design: The study adopted a true-experimental research design, which is appropriate for investigations involving controlled procedures and systematic manipulation or assessment of variables under defined conditions (Nwankwo, 2016). The design enabled careful control of factors that could influence the reliability and validity of the findings. Thus, soil samples were systematically and ethically collected, prepared, and subjected to laboratory analyses. The study examined key soil and geotechnical parameters like temperature, pH, electrical conductivity (EC), colour, texture, consistency, total organic carbon, and bulk density, to evaluate their influence on the bearing capacity and suitability of reclaimed wetland soils for building foundations.

Sample Frame: The sampling frame consisted of fifteen (15) identified reclaimed wetland sites distributed across Minikpeti, Eligbolo, Ogbogoro/Sand-field, Rukpokwu, Rumuokwurushi, Rumueme, Rumuomasi, Elioparanwo, Woji, Eliozo, Mgbuosimini, Rumuigbo, Rumunduru, Mgbuoba, and Rumuola communities in Obio-Akpor Local Government Area, Rivers State. These reclaimed and subsequently developed wetland areas constituted the study population, covering approximately 20,907.34 hectares of the local government (Eludoyin et al., 2011; Onugha, 2017).

Sample and Sampling Technique: Twelve soil samples were obtained from six randomly selected reclaimed wetlands located in Minikpeti, Eligbolo, Rukpokwu, Eliozu, Rumunduru, and Rumuola, representing 40% of the 15 identified reclaimed wetlands in Obio-Akpor Local Government Area. The wetlands were selected to reflect variations in location, size, previous land use, ecological importance, and drainage characteristics. Subsequently, purposive sampling was employed to identify two sampling points within each selected wetland. At each point, soil samples were collected, giving a total of 12 representative soil samples, comprising two samples from each of the six reclaimed wetlands across the six communities.

Instrumentation: The study employed several field data-collection instruments, including an automated GPS, measuring tape, masking tape, field notebook, Ziploc bags, aluminium foil, and hand auger. These instruments were used during field investigations across the six selected reclaimed wetlands in Obio-Akpor Local Government Area. The GPS was used to obtain the Northing, Easting, and elevation coordinates of each sampling location, while the other materials facilitated soil excavation, measurement, labelling, field documentation, sample identification, packaging, and preservation for subsequent laboratory analysis.

Method of Data Collection: The study collected 12 soil samples from six selected reclaimed wetlands in Obio-Akpor Local Government Area using random triplicate sampling followed by compositing. Samples were obtained at depths of 0-15 cm (topsoil) and 15-30 cm (subsoil) with a hand auger, carefully placed in labelled Ziploc bags, transported in a cooler, and preserved at 0-4°C until laboratory analysis. The samples were examined for key soil parameters, including temperature, pH, electrical conductivity (EC), colour, texture, consistency, total organic carbon, and bulk density. Also, GPS measurements were taken at each sampling location to determine the Northing, Easting, and elevation coordinates, which are presented in Table 1 and spatially illustrated in Figure 2.

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).

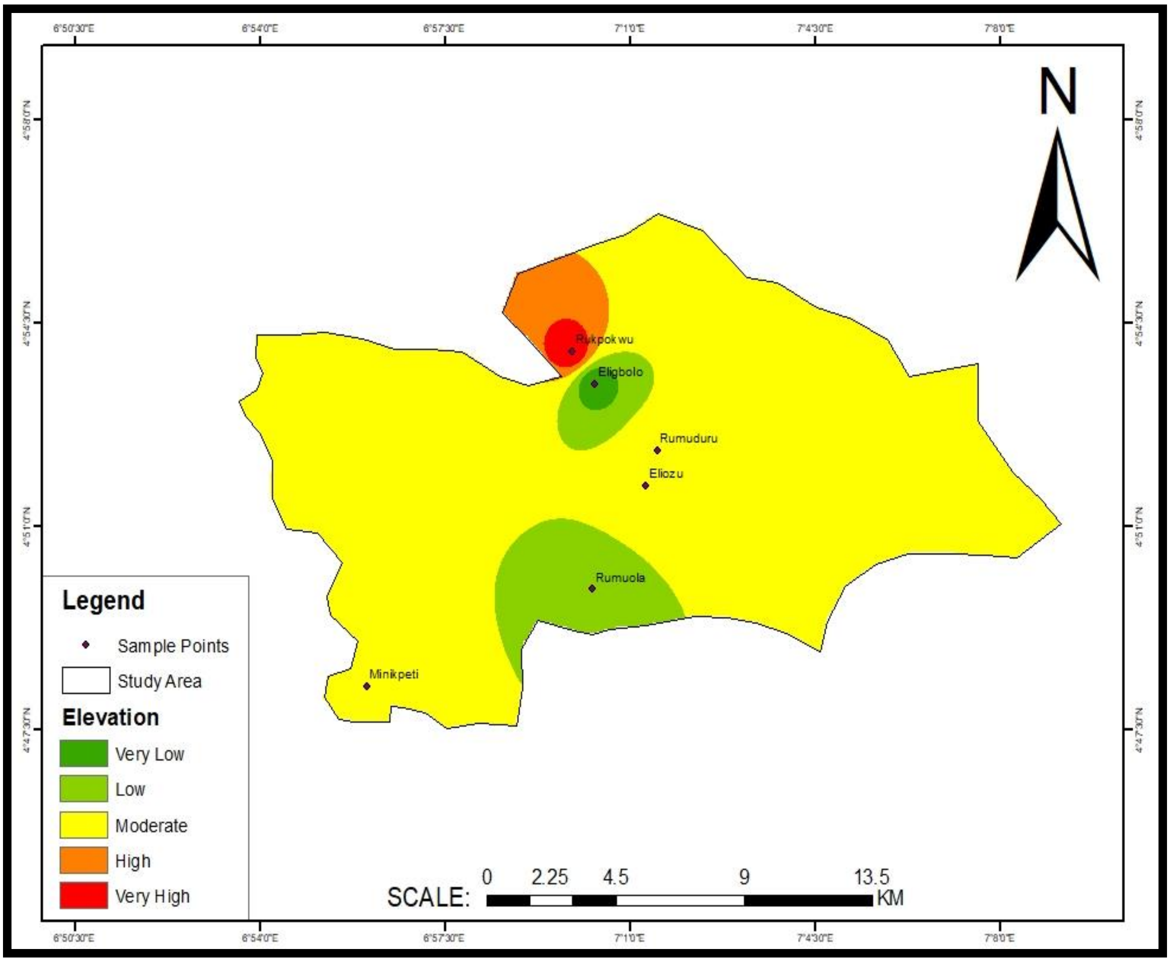

Figure 2: Study Area Map showing the Sampled Points

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

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).

Results

Research Question 1: What are the soil parameters required to determine the appropriate holding potentials of varying buildings in reclaimed wetlands in the study area?

Table 2: Mean Concentration of the soil parameters required to determine the appropriate holding of varying buildings in reclaimed wetlands in the study area

SP	Temp °C	pH	EC (µS/cm)	Colour	Texture	Consistency	Total Organic Carbon (%)
	$\bar{x}$±SE	$\bar{x}$±SE	$\bar{x}$±SE				$\bar{x}$±SE
SP 1	30.25± 0.04	8.01± 0.06	1481.50± 11.14	Very Dark Brown	Silt Clay	Soft	1.57±0.06
SP 2	29.88± 0.05	7.94± 0.03	1593.17± 27.23	Dark Brown	Loamy	Soft	1.92±0.03
SP 3	28.90± 0.20	7.88± 0.01	1654.00± 3.47	Dark Yellowish Brown	Clay Loam	Soft	1.90±0.01
SP 4	30.36± 0.04	7.82± 0.03	1670.50± 14.90	Very Dark Brown	Clay Loam	Soft	2.17±0.09
SP 5	30.53± 0.05	7.60± 0.01	1760.50± 15.08	Dark Brown	Clay Loam	Soft	1.87±0.04
SP 6	29.68± 0.00	8.42± 0.01	1428.67± 18.49	Dark Yellowish Brown	Clay Loam	Slightly Hard	1.46±0.05
Pooled $\bar{x}$±SE	**29.93± 0.06**	**7.95± 0.03**	**1598.06 ± 15.05**	Dark Brown	Sandy Loam- Clay Loam		**1.82±0.05**
SON	25.00-	5.5-7.5	< 2000			Soft (< 8)	< 1

(2017)	31.00						
ASTM (2011)	25.00-31.00	5.5-7.5	< 2000	Dark Brown		Soft (< 8)	< 1

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 shows noticeable spatial variation in the measured soil parameters across the six reclaimed-wetland sampling points. SP1 (Rukpokwu) recorded 30.25±0.04°C, pH 8.01±0.06, EC of 1,481.50±11.14 µS/cm, very dark-brown colour, silt-clay texture, soft consistency and 1.57±0.06% TOC. SP2 (Eligbolo) had 29.88±0.05°C, pH 7.94±0.03, EC 1,593.17±27.23 µS/cm, dark-brown colour, loamy texture, soft consistency and 1.92±0.03% TOC. SP3 (Eliozu) recorded 28.90±0.20°C, pH 7.88±0.01, EC 1,654.00±3.47 µS/cm, dark-yellowish-brown colour, clay-loam texture, soft consistency and 1.90±0.01% TOC.

At SP4 (Minikpeti), temperature was 30.36±0.04°C, pH 7.82±0.03, EC 1,670.50±14.90 µS/cm, with very dark-brown, clay-loam and soft soil containing 2.17±0.09% TOC. SP5 (Rumunduru) recorded the highest temperature (30.53±0.05°C) and EC (1,760.50±15.08 µS/cm), pH 7.60±0.01, dark-brown clay-loam, soft consistency and 1.87±0.04% TOC. SP6 (Rumuola) recorded 29.68±0.00°C, the highest pH (8.42±0.01), lowest EC (1,428.67±18.49 µS/cm), dark-yellowish-brown clay-loam, slightly hard consistency and lowest TOC (1.46±0.05%). Overall, pooled values of 29.93±0.06°C, pH 7.95±0.03, EC 1,598.06±15.05 µS/cm and TOC 1.82±0.05% indicate generally acceptable temperature and EC conditions, but predominantly soft, fine-textured soils warrant further bearing-capacity assessment before construction. In a nutshell, the findings from Table 2 suggest that the soil parameters in the reclaimed wetlands are mostly within acceptable limits for supporting various types of buildings. Regular monitoring and management of these soil parameters are essential to ensure the sustainability and safety of structures in these reclaimed wetland environments. The graphical representation of Table 2 is presented in Figure 3 below.

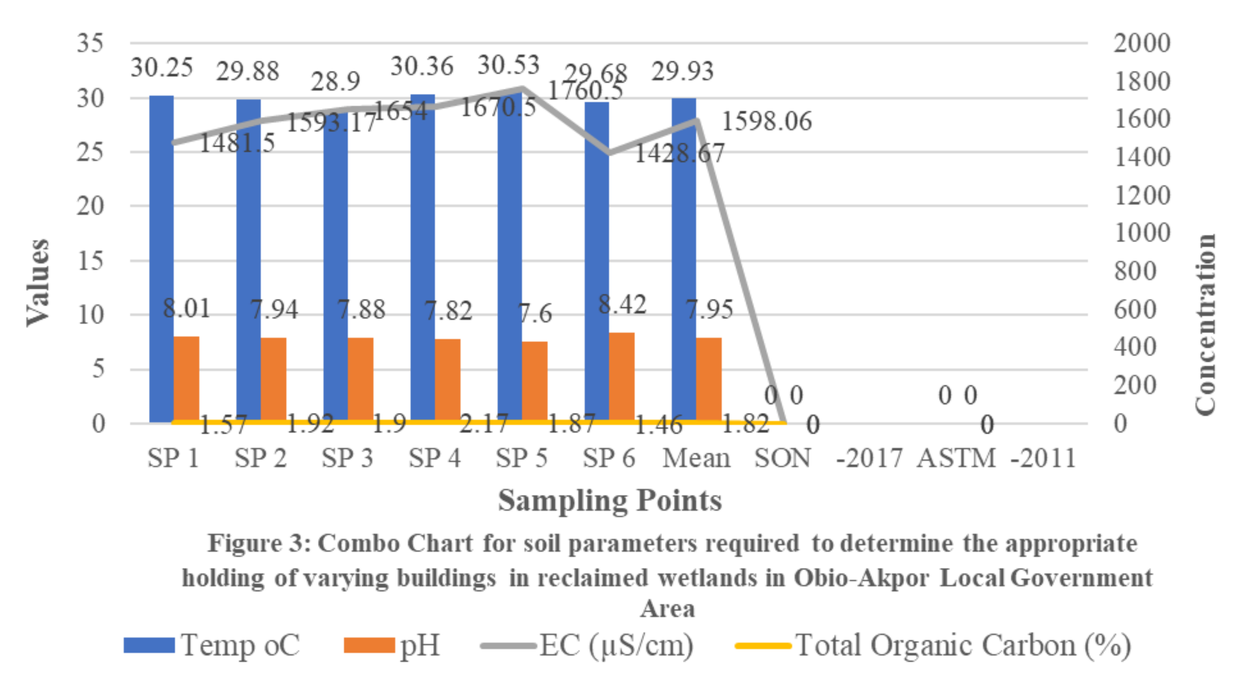

Figure 3: Combo Chart for soil parameters required to determine the appropriate holding of varying buildings in reclaimed wetlands in Obio-Akpor Local Government Area

The Combo Chart in Figure 3 shows the soil parameters required to determine the appropriate holding of varying buildings in reclaimed wetlands in Obio-Akpor Local Government Area compared with the SON and ASTM standards. It further shows that SP5 (i.e. Rumunduru Community) had a higher mean Temperature than S12, SP2, SP3, SP4, and SP6, Also, SP6 (i.e. Rumuola Community) had the highest concentration for pH, SP5 (i.e. Rumunduru Community) had the highest value for EC, while SP4 (Minikpeti Community) had the highest concentration for total organic carbon (TOC) in the soil of reclaimed wetlands in Obio-Akpor Local Government Area of Rivers State.

Research Question 2: What is the level of soil bulk density that enhance the bearing capacity of different classes of buildings or structures in reclaimed wetlands in the study area?

Table 3: Mean Concentration of the level of soil bulk density required to enhance the bearing capacity of different classes of buildings or structures in the selected reclaimed wetlands in the study area

Soil Density in Sampling Points	SON Approved Limit for Density in Soil for Varying Buildings				
	Low-Rise Building (1.2-1.4 g/cm^3)	Mid-Rise Building (1.4-1.6 g/cm^3)	High-Rise Building (1.6-1.8 g/cm^3)	Specialized Buildings (1.5-1.7 g/cm^3)	Heavy Infrastructure (1.7-2.0 g/cm^3)
SP 1	0.96 g/cm^3	0.96 g/cm^3	0.96 g/cm^3	0.96 g/cm^3	0.96 g/cm^3
SP 2	1.16 g/cm^3	1.16 g/cm^3	1.16 g/cm^3	1.16 g/cm^3	1.16 g/cm^3
SP 3	1.32 g/cm^3	1.32 g/cm^3	1.32 g/cm^3	1.32 g/cm^3	1.32 g/cm^3
SP 4	1.35 g/cm^3	1.35 g/cm^3	1.35 g/cm^3	1.35 g/cm^3	1.35 g/cm^3
SP 5	1.33 g/cm^3	1.33 g/cm^3	1.33 g/cm^3	1.33 g/cm^3	1.33 g/cm^3
SP 6	1.79 g/cm^3	1.79 g/cm^3	1.79 g/cm^3	1.79 g/cm^3	1.79 g/cm^3

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 presents the mean soil bulk-density values across six sampling points and compares them with the stated density ranges for different building and infrastructure classes. SP1 (Rukpokwu) recorded the lowest density of 0.96 g/cm^3, followed by SP2 (Eligbolo) at 1.16 g/cm^3. Both values are below the specified low-rise building range of 1.2–1.4 g/cm^3, suggesting relatively loose soil conditions. SP3 (Eliozu) recorded 1.32 g/cm^3, while SP4 (Minikpeti) and SP5 (Rumunduru) recorded 1.35 g/cm^3 and 1.33 g/cm^3, respectively. These values fall within the recommended low-rise range but remain below the specified ranges for mid-rise, high-rise, specialized buildings and heavy infrastructure. In contrast, SP6 (Rumuola) recorded the highest bulk density of 1.79 g/cm^3. This value falls within the high-rise building range (1.6–1.8 g/cm^3) and approaches the lower threshold for heavy infrastructure (1.7–2.0 g/cm^3), although it exceeds the stated specialized-building upper limit of 1.7 g/cm^3. Overall, the considerable spatial variability demonstrates that foundation suitability differs among the reclaimed wetlands and therefore requires site-specific geotechnical evaluation. The graphical representation of the result in Table 3 is presented in Figure 4 below.

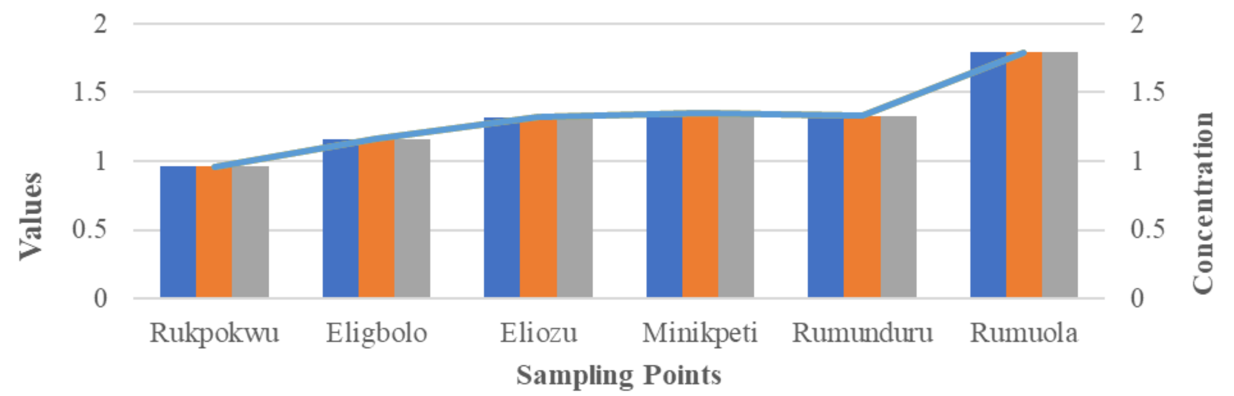

Figure 4: Combo Chart on the level of soil bulk density required to enhance the bearing capacity of different classes of buildings or structures in the selected reclaimed wetlands in Obio-Akpor LGA

Figure 4 show the Combo Chart on the SON approved limit or level of soil density required to enhance the bearing capacity of different classes of buildings or structures in the selected reclaimed wetlands in Obio-Akpor Local Government Area. It further shows that Rumuola Community (i.e. SP 6) had the highest (i.e. best) soil density for low-rise, mid-rise, high-rise, and heavy infrastructure buildings. While Rukpokwu Community (i.e. SP 1) had the least soil density for low-rise, mid-rise, high-rise, and heavy infrastructure buildings in reclaimed wetlands in Obio-Akpor Local Government Area of Rivers State.

Hypothesis 1: Soil parameters did not significantly differ in the bearing capacity of varying buildings within reclaimed wetlands in the study area.

Table 4: Summary of Analysis of Variance (ANOVA) on the difference in the Soil parameters of the bearing capacity of varying 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	79.261	5	15.852	1.286	$.026^{b}$	S
Within Groups	369.711	30	12.324			
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 shows the summary of Analysis of Variance (ANOVA) on the difference in the soil parameters holding potentials of varying buildings in reclaimed wetlands in Obio-Akpor Local Government Area Rivers State (i.e. the study area). The result shows that F is 1.286 which is significant at $P < 0.05$ because the value of P is less than 0.05. This result indicates that the soil parameters holding potentials of varying buildings differed in reclaimed wetlands in Obio-Akpor Local Government Area Rivers State. This implies that the concentration of soil parameters such as Consistency, Temperature, Total Organic Carbon, pH, and Electrical Conductivity (Table 4.3) significantly differed and contributed to the holding potentials of varying buildings in reclaimed wetlands in Obio-Akpor Local Government Area Rivers State.

Hypothesis 2: Soil bulk density significantly differs in enhancing the bearing capacity of different classes of buildings or structures in reclaimed wetlands in the study area.

Table 5: Summary of Analysis of Variance (ANOVA) on the difference in the soil density in enhancing the bearing capacity of different classes of buildings or structures 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	1.529	5	1.529	25.77	$.001^{b}$	S
Within Groups	.356	30	.013			
Total	**1.885**	**35**				

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

Table 5 shows the summary of the Analysis of Variance (ANOVA) on the difference in the soil bulk density in enhancing the bearing capacity of different classes of buildings or structures in reclaimed wetlands in Obio-Akpor Local Government Area Rivers State (i.e. the study area). The result revealed a highly significant difference in soil bulk density among the six sampling points, with between-group variation of 1.529 and within-group variation of 0.356, resulting in $F(5, 30) = 25.77$, $p < .001$. Therefore, the null hypothesis that there is no significant difference in soil bulk density among the sampling points was rejected at the 0.05 level of significance. This implies that the soil bulk density significantly contributed to the bearing capacity of the varying categories of buildings such as low-rise, mid-rise, high-rise, specialized buildings, and heavy infrastructure (Table 3) in reclaimed wetlands in Obio-Akpor Local Government Area Rivers State.

Discussion of Findings

Table 2 revealed considerable spatial variation in soil temperature, pH, EC, colour, texture, consistency, and TOC. Although pooled temperature (29.93°C) falls within SON (2017) and ASTM (2011) ranges, foundation suitability depends on moisture, texture, and engineering properties. This interpretation is consistent with recent Nigerian geotechnical investigations (Udom & John, 2023; Kennedy, 2024), showing that variations in subsurface conditions can substantially influence engineering behaviour and foundation performance. Udom and John's investigation of foundation subsoils in parts of Port Harcourt and Obio-Akpor identified variations in sandy clay and sand strata, consistency, plasticity, shear strength and consolidation behaviour, demonstrating the importance of location-specific soil assessment.

The pooled pH of 7.95 and site variation from 7.60 at Rumunduru (SP5) to 8.42 at Rumuola (SP6), indicate predominantly neutral-to-moderately alkaline conditions, likely reflecting parent materials, drainage, and reclamation history. This finding agrees with Adebisi et al. (2021) that the alkaline pH suggests spatially variable chemical conditions associated with reclamation and parent materials, potentially influencing foundation-material durability and corrosion processes. Dickson et al. (2022) also reiterated that soil chemistry alkaline pH conditions may influence soil–foundation material interactions and durability. Equally, Ahmed et al. (2024) investigation of Okpulor soils in Rivers State revealed that alkaline soil chemistry, necessitates evaluating the geotechnical and geoenvironmental characteristics of soils.

Electrical conductivity ranged from 1,428.67-1,760.50 µS/cm, with a pooled value of 1,598.06 µS/cm, remaining below the SON and ASTM limit of 2,000 µS/cm. This suggests acceptable conductivity, although spatial variation reflects differences in soluble ions, soil-water conditions, and reclamation materials. Ahmed et al. (2024) likewise demonstrated that moisture, bulk density, grain-size distribution and other index properties interact to influence soil behaviour in Rivers State. Furthermore, the observed soil colours ranged from very dark brown to dark yellowish brown, with textures varying from silt clay to loamy and clay loam, indicating differences in mineral composition, organic matter, reclamation conditions, and consistency. This finding has direct implications for building support because consistency provides an indication of the relative resistance of soil to deformation. Udom and John (2023) similarly reported soft-to-firm sandy clay overlying sand within parts of Obio-Akpor and emphasized the significance of subsurface stratification and consistency in foundation assessment.

Total organic carbon varied from 1.46% at Rumuola to 2.17% at Minikpeti, with a pooled value of 1.82%. The relatively higher TOC at Minikpeti may reflect greater organic accumulation or differences in reclamation history. Thus, organic-rich soils can exhibit different compressibility and strength characteristics from mineral soils, making their assessment important before construction. This finding agrees with the finding by Pei et al. (2022) that spatial TOC variation reflects differing organic accumulation and reclamation histories, potentially influencing compressibility, strength, settlement, and foundation performance.

Overall, Table 2 demonstrates that the reclaimed wetlands are not geotechnically homogeneous. The combined influence of texture, consistency, pH, EC, temperature and TOC therefore supports the need for site-specific investigation rather than assuming uniform foundation conditions throughout Obio-Akpor. This agrees with Adunoye et al. (2024), who found substantial differences in bearing capacities among construction sites and concluded that bearing capacity depends strongly on the characteristics of the foundation soil.

Table 3 demonstrates marked spatial differences in soil bulk density across the six reclaimed wetlands, with values ranging from 0.96 g/cm^3 at Rukpokwu (SP1) to 1.79 g/cm^3 at Rumuola (SP6). This variation is important because bulk density provides an indication of the degree of soil packing and, indirectly, its resistance to deformation. The low density recorded at Rukpokwu suggests relatively loose soil conditions, whereas the substantially higher density at Rumuola indicates a more compact soil profile. This finding agrees with Ahmed et al. (2024) study, which found that bulk-density differences in Rivers State soils were associated with variations in porosity and permeability, reinforcing the importance of density as an index of soil condition.

For low-rise buildings, the 1.2-1.4 g/cm^3 benchmark includes SP3 (1.32), SP4 (1.35), and SP5 (1.33), while SP1 (0.96), SP2 (1.16), and SP6 (1.79) fall outside. The 1.4-1.6 g/cm^3 mid-rise range was not consistently attained. The researchers reiterate from these results, suggesting that density alone cannot justify assigning a building category to a reclaimed wetland; foundation depth, soil stratification, shear strength, settlement and groundwater conditions must also be considered. This interpretation is strongly supported by Udom and John (2023), whose investigation in Port Harcourt and Obio-Akpor found different soil layers and calculated allowable bearing capacities of 69-101 kN/m^2 for shallow foundations at selected locations. They also reported settlement differences and recommended deeper pile foundations where shallow bearing capacity was inadequate, particularly for heavier or taller structures. More recent evidence from Adunoye et al. (2024) similarly showed that bearing capacity varied substantially across selected Nigerian construction sites and depended on soil characteristics and foundation type. The Table 3 findings emphasize that reclaimed wetlands with inadequate bulk density may require further geotechnical investigation and appropriate ground-improvement or foundation measures before development.

Table 4 revealed statistically significant differences in soil parameters among reclaimed wetlands ($p = .026$). Therefore, the null hypothesis was rejected, indicating spatial variability that may influence building bearing capacity and foundation-support conditions. The statistical result supports the descriptive variation observed in Table 2, where temperature, pH, EC, soil colour, texture, consistency and TOC differed among sampling points. The finding is consistent with Udom and John (2023), who demonstrated substantial spatial differences in geotechnical properties within Port Harcourt and Obio-Akpor, including moisture content, plasticity, shear strength, consolidation and soil stratification. Kennedy (2024) likewise reported heterogeneous soil stratigraphy in the Niger Delta, with changes from clayey sands to gravelly sands and corresponding differences in plasticity and other geotechnical properties.

The significant result suggests that reclaimed wetlands exhibit varied soil characteristics, with differences in texture, consistency, chemistry, and organic content potentially influencing soil response to structural loading. This finding further supports the need for site-specific geotechnical characterization before assigning particular building types to reclaimed wetlands. This finding also agrees with Adunoye et al. (2024), who demonstrated that variations in engineering soil characteristics were associated with differences in calculated bearing capacity across Nigerian construction sites.

Table 5 indicates significant differences in soil bulk density among reclaimed wetlands, with between-group variation of 1.529, within-group variation of 0.356, $F(5, 30) = 25.77$, and $p < .001$. The null hypothesis is rejected. Densities ranged from 0.96 g/cm³ at Rukpokwu to 1.79 g/cm³ at Rumuola, reflecting differences in reclamation history, compaction, soil texture, moisture conditions, depositional characteristics, and bearing capacity. The finding also corresponds with Udom and John (2023), whose Port Harcourt–Obio-Akpor investigation found contrasting loose, medium-dense and dense sand layers and different allowable bearing capacities at investigated locations. Also, Ahmed et al. (2024) similarly reported variations in bulk density, natural moisture content and grain-size properties in Rivers State soils, emphasizing their relevance to porosity, permeability and general geotechnical behaviour. More recently, Abdulmumini et al. (2024) demonstrated through geotechnical investigation in Nigeria that foundation decisions must account for soil characteristics and settlement behaviour rather than relying solely on apparent bearing strength. Overall, Table 5 confirms that bulk density is a significant differentiating property among the reclaimed wetlands and should therefore be incorporated into foundation assessment, structural classification and sustainable development decisions.

Conclusion

The study concludes that the reclaimed wetlands of Obio-Akpor Local Government Area exhibit considerable spatial variability in soil physicochemical and structural properties, with important implications for building holding capacity and foundation performance. The observed differences in temperature, pH, electrical conductivity, texture, consistency, colour, organic carbon and bulk density demonstrate that reclaimed wetland soils cannot be treated as a uniform foundation medium. The predominance of soft and clay-related soil textures at several sampling points further indicates the potential for compressibility, settlement and reduced structural stability where adequate ground improvement is not undertaken.

The variation in bulk density also demonstrates that some locations may provide comparatively better support conditions than others, while areas with lower density require greater engineering attention before construction. The statistical results further confirm significant spatial differences in soil characteristics and density, reinforcing the importance of location-specific assessment. Therefore, safe development of reclaimed wetlands requires systematic geotechnical investigation, appropriate soil stabilization and compaction, suitable foundation selection, effective drainage, and compliance with relevant construction standards. These measures are essential for achieving safe, durable and sustainable development in Obio-Akpor Local Government Area.

Recommendations

1. The Rivers State Ministries of Environment and Physical Planning and Urban Development, Obio-Akpor Local Government, in partnership with Standard Organization of Nigeria (SON), and relevant environmental and building-control authorities, should review the current “Building Code” by making comprehensive physicochemical soil testing mandatory before approving construction on reclaimed wetlands, particularly in Rukpokwu, Eligbolo, Eliozu, Minikpeti, Rumunduru, and Rumuola, where variations in soil softness, texture, pH, electrical conductivity, and organic-carbon content may affect foundation performance.
2. Development-control authorities in Rivers State and Obio-Akpor Local Government, should require site-specific bulk-density assessment and professional foundation recommendations from qualified geotechnical engineers, civil/structural engineers, and certified soil-testing laboratories before approving low-, medium-, high-rise, and specialized structures on reclaimed wetlands.
3. The Rivers State and Obio-Akpor development authorities should institutionalize mandatory geotechnical investigations and independent soil-testing certification before construction approval on reclaimed wetlands, with foundation designs based on statistically verified site-specific soil conditions.

Contribution to Knowledge

1. The study establishes that reclaimed wetlands within Obio-Akpor exhibit distinct spatial variations in physicochemical characteristics, demonstrating that localized soil assessment is essential for determining development suitability rather than relying on generalized wetland classifications.
2. The study demonstrates that bulk density varies substantially among reclaimed-wetland locations, providing empirical evidence that building suitability and foundation requirements should be matched to location-specific soil density conditions.

3. The study provides statistical evidence that spatial differences in soil parameters and bulk density are significant, establishing that variability in reclaimed-wetland soils is a critical determinant of building-support conditions and should inform location-specific engineering decisions.

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