



CORRELATION OF STANDARD PENETRATION TEST (SPT) AND CONE PENETRATION TEST (CPT) DATA IN TROPICAL SWAMPY SOILS: A CASE STUDY OF AKURE, SOUTHWESTERN NIGERIA.

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ABSTRACT

Subsurface characterisation in tropical swampy soils is critical for reliable foundation design. This study aimed to investigate the relationship between Standard Penetration Test (SPT) and Cone Penetration Test (CPT) results in lowland swampy soils in Akure, southwestern Nigeria, with the objective of developing locally calibrated empirical correlations for geotechnical design applications. It has been observed that conventional empirical correlations often fail to adequately represent the complex behaviour of waterlogged, organic-rich deposits, necessitating further empirical studies of relationships. Field investigations comprised sixteen SPTs and sixteen 2.5-ton CPTs, with an additional nine 10-ton CPTs conducted at selected locations. Corrected SPT blow counts (N_{60}) were correlated with cone resistance (q_c) using linear and power regression models. For the 2.5-ton CPT, linear regression produced $q_c = 474.37N_{60} + 303.53$ ($R^2 = 0.79$), while the power model yielded $q_c = 636.57N_{60}^{0.8735}$ ($R^2 = 0.80$). For the 10-ton CPT, correlations were moderate ($R^2 \approx 0.53-0.54$), reflecting increased scatter in the data at greater depths. Correlation strength improved with depth as organic influence diminished and soil stiffness increased in clayey sand and sandy clay strata. The results indicated that locally calibrated SPT–CPT relationships effectively capture soil strength trends in swampy tropical deposits. These findings provided a practical basis for geotechnical design in waterlogged lowlands and underscore the importance of site-specific empirical correlations to enhance reliability in foundation engineering within tropical environments. It is therefore recommended that site-specific SPT–CPT correlations be adopted for foundation design in tropical swampy terrains, rather than relying on generalised global correlations, to improve accuracy and reduce geotechnical uncertainty.

KEYWORDS: SPT-CPT correlation, Tropical swampy soils, CPT, SPT, Geotechnical Characterisation

List of Notations/Abbreviations

N_{60} is corrected Standard Penetration Test blow count normalised to 60% hammer energy efficiency.
N is measured by the Standard Penetration Test, blow count.
 E_r is the hammer energy ratio (percentage of theoretical energy delivered during SPT).
 C_N is the overburden correction factor applied to SPT N_{60} values.
 q_c is the cone penetration resistance measured from the Cone Penetration Test (kPa).
RMSE is Root Mean Square Error, a statistical measure used to evaluate the accuracy of regression predictions.
 R^2 is the coefficient of determination, indicating the proportion of variance explained by the regression model.
R is Pearson correlation coefficient, measuring the strength and direction of the linear relationship between variables.
SPT is the Standard Penetration Test, an in-situ geotechnical test used to determine soil resistance to penetration.
CPT is the Cone Penetration Test, an in-situ geotechnical test used to measure soil resistance and stratification continuously.

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INTRODUCTION

Subsurface investigation is a critical component of geotechnical site Characterisation and foundation design. Among the most widely employed in-situ testing methods for evaluating soil strength and stratigraphy are the Standard Penetration Test (SPT) and the Cone Penetration Test (CPT). The SPT, known for its simplicity and adaptability, involves driving a split-spoon sampler into the soil at standardised intervals and recording the number of blows (N-value) required for penetration. It remains a common tool for preliminary geotechnical assessment, particularly in regions with limited access to advanced testing equipment (Skempton, 2016; Zhang *et al.*, 2017). Conversely, the CPT offers a continuous profile of soil resistance with minimal disturbance, measuring cone resistance (q_c), sleeve friction, and pore pressure. Its higher repeatability and automation have led to its widespread application in developed countries and urban geotechnical settings (Lunne *et al.*, 2018; Huang and Zhang, 2020).

Despite the increasing availability of CPT equipment globally, SPT remains dominant in many parts of the developing world due to cost, accessibility, and historical use in local design standards. Consequently, several researchers have attempted to correlate SPT and CPT values to facilitate interpretation across the two systems, especially when only one method is available (Shirazi and Hossain, 2016; Mahmoud *et al.*, 2020). These empirical correlations are often derived from specific soil types and geological environments, typically temperate or arid regions, and are included in standard design manuals, e.g., Robertson and Cabal, 2015.

Tropical, swampy soils, especially in waterlogged regions of sub-Saharan Africa, are characterised by high organic matter content, low shear strength, and variable stratification resulting from seasonal flooding and sedimentation processes (Umar *et al.*, 2024; Gani *et al.*, 2020). These factors affect both the SPT and CPT response in such soils, making site-specific correlation models necessary. In these challenging environments, reliance on global correlations can lead to underestimation or overestimation of critical design parameters, resulting in foundation failures or overly conservative designs. Given these discrepancies, there is a growing consensus on the importance of conducting local correlation studies tailored to the geotechnical and geological realities of specific regions (Kennedy and TrustGod, 2024). For swampy tropical environments such as Akure in southwestern Nigeria, developing localised empirical relationships between SPT and CPT data not only improves design reliability but also deepens understanding of tropical soil behaviour under saturated conditions (Kennedy and TrustGod, 2024; Kennedy, 2024). These studies are particularly essential in regions where urban expansion into marginal lands is accelerating, often without adequate geotechnical input.

A review of the current literature reveals a significant research gap: while many studies have explored SPT-CPT correlations in temperate zones, few have investigated these relationships in tropical swampy soils using comprehensive field data. The absence of robust regional models limits the applicability of standard correlations and underlines the need for context-specific studies.

The main aim of this study is to develop and validate empirical correlations between Standard Penetration Test (SPT) N-values and Cone Penetration Test (CPT) cone resistance (q_c) in tropical swampy soils of Akure, southwestern Nigeria.

The specific objectives are to:

- i. Derive empirical relationships between corrected SPT N-values (N_{60}) and CPT cone resistance (q_c) using field data obtained from swampy soil deposits in the study area.
- ii. Evaluate the degree of agreement and correlation between SPT and CPT results under conditions of high groundwater level and organic-rich soil profiles.
- iii. Develop and propose reliable, site-specific regression equations to estimate soil strength parameters for use in geotechnical design and foundation engineering in similar tropical environments.

STUDY AREA DESCRIPTION

Location

Akure metropolis is the capital and principal city of Ondo State in southwestern Nigeria. The metropolis is situated in the southern part of the Yoruba Hills and lies roughly between Latitudes $07^{\circ} 09'$ and $07^{\circ} 19'N$ and Longitudes $05^{\circ}07'$ and $05^{\circ} 17'E$ and covers an area of about 340 km² (Owoyemi, 1996). The metropolis is located on a gently undulating terrain surrounded by isolated hills and inselbergs. Topographic elevations range from 260 to 470 m above sea level and are drained by several streams and rivers (Owoyemi, 1996).

The study area in this paper is located within the Akure metropolis Latitudes $07^{\circ} 15' 45''$ and $07^{\circ} 17' 25''$ and Longitudes $05^{\circ}09' 10''$ and $05^{\circ}12'$ (Figure 1). Field investigations were conducted within the north-central lowland corridor of Akure metropolis, focusing on neighbourhoods locally known for seasonal water accumulation, shallow groundwater, and proximity to natural drainage channels (Figure 2). The selected areas include Isolo, Araromi, Akure High School, Ade Super Hotels, Shagari Village, Oke-Ogba, Seebi and Futa Southgate. These neighbourhoods are increasingly recognised in urban and hydrological studies of Akure as low-lying and flood-prone zones, where surface water tends to accumulate during the wet season (Yoade *et al.*, 2019). In particular, Isolo has been highlighted by (Yoade *et al.*, 2019) as suffering from drainage backups and inundation during periods of heavy rainfall. Within these neighbourhoods, the Ala River and its tributaries have a significant influence on the hydrology of the lowland zone.

Run-off from adjacent upland terrains drains through channels that traverse or border these communities, causing periodic soil saturation and waterlogging

during the wet season (Fagunloye, 2024). In addition, studies of wetland change in Akure South LGA have showed that wetland extent has been increasing over time, particularly in low-lying areas that include many of these neighbourhoods, indicating ongoing hydrological sensitivity (Omodehin *et al.*, 2021).

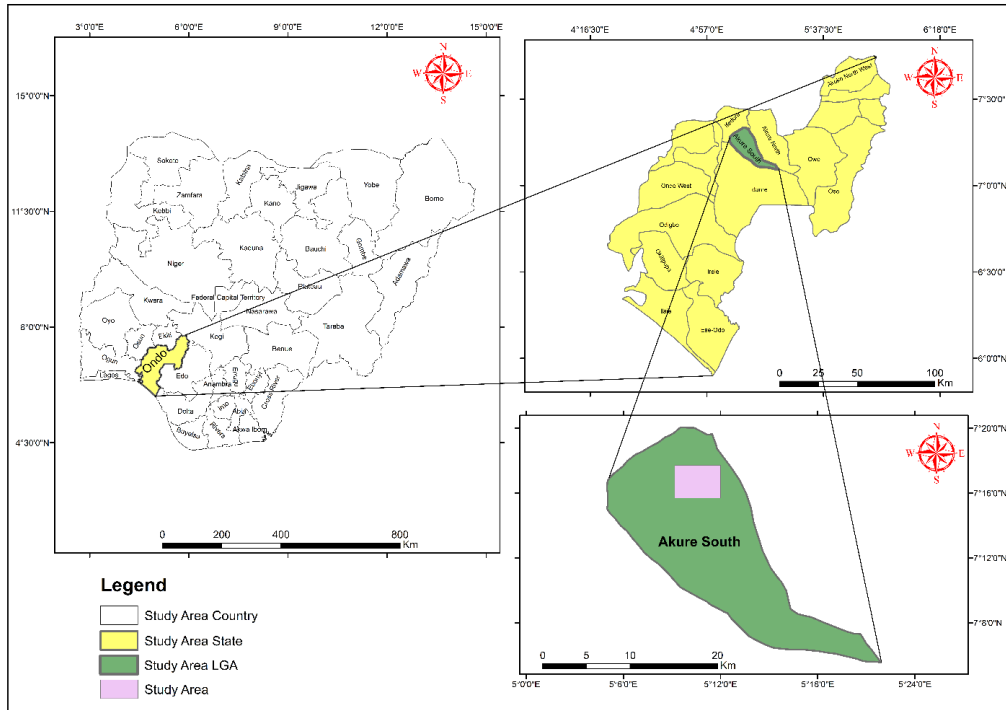


Figure 1: Location map of the study area.

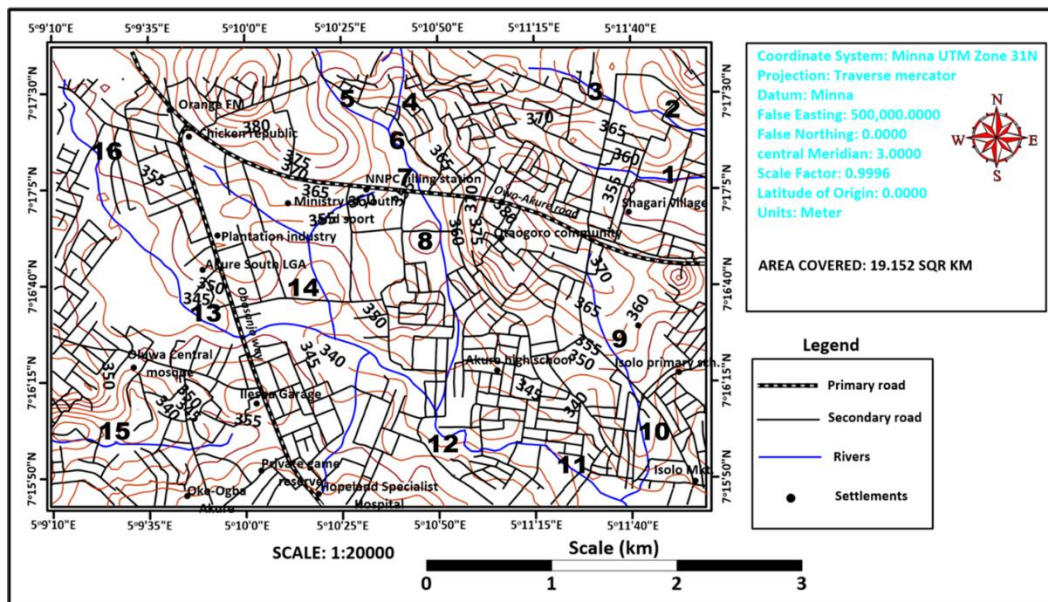


Figure 2: Topographical map of the study area showing study location points modified after Federal Surveys of Nigeria, 1966.

GEOLOGY

The geological mapping and other related studies of Akure have been carried out by several workers, like (Anifowose, 1989; Ademeso, 2009; and Ademeso, 2010). The area is underlain by four of the six petrological units of the Basement Complex of Southwestern Nigeria, as identified by Rahaman, 1988. These are the migmatite-gneiss quartzite complex, charnockitic and dioritic rocks, older granites, and the unmetamorphosed dolerite dikes. Within the specific study area encompassing Isolo, Araromi, Akure High School, Ade Super Hotels, Shagari Village, Oke-Ogba, Seebi, and FUTA South Gate, the subsurface is underlain by granite, porphyritic granite, charnockite, quartzite, and migmatite gneiss (Figure 3). These lithologies were

confirmed through a reconnaissance survey and substantiated by independent geological mapping conducted by AGY Futa Mtech 2016 Group 2, 2018 Unpublished manuscript.

The study area exhibits deep tropical weathering (often exceeding 10 m) developed over the crystalline basement rocks. The typical profile transits from lateritic soil at the surface to sandy clay and then highly weathered saprolite. In the low-lying swampy zones, organic clays and silty sands dominate due to poor drainage and seasonal flooding, resulting in variable strength and compressibility that influence foundation performance and necessitate detailed in-situ testing (Akinola and Ola-Olorun, 2021; Owoeye et al., 2020; and ISDS, 2019).

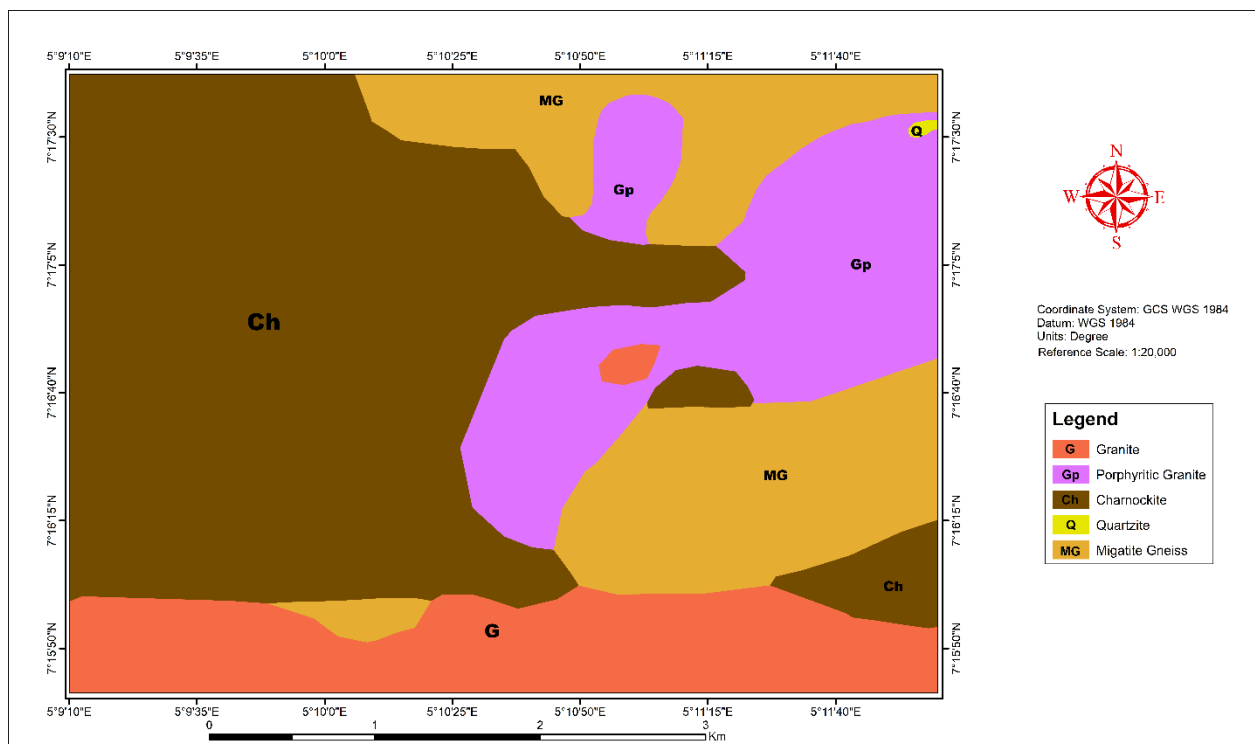


Figure 3: Geological map of the Study area, AGY Futa Mtech 2016 Group 2, 2018 Unpublished manuscript.

Hydrology and Drainage

The study area is drained mainly by the Ala River and its tributaries, which form a dendritic-to-subdendritic drainage pattern typical of basement terrains (Figure 4). These channels traverse low-lying corridors across Isolo, Araromi, Oke-Ogba, Shagari Village, and FUTA South-Gate, where poor drainage and sediment accumulation often cause seasonal flooding. Field observations during the dry season revealed shallow groundwater conditions, with water levels ranging

from 0.3 to 0.75 m below ground. The near-surface soils, dominated by organic clays and silty sands, possess low permeability and remain semi-saturated even during dry periods. Consequently, groundwater fluctuations and poor drainage produce variable subsoil strength and compressibility, which are key geotechnical challenges for foundations in these swampy zones (Akinola and Ola-Olorun, 2021; ISDS, 2019).

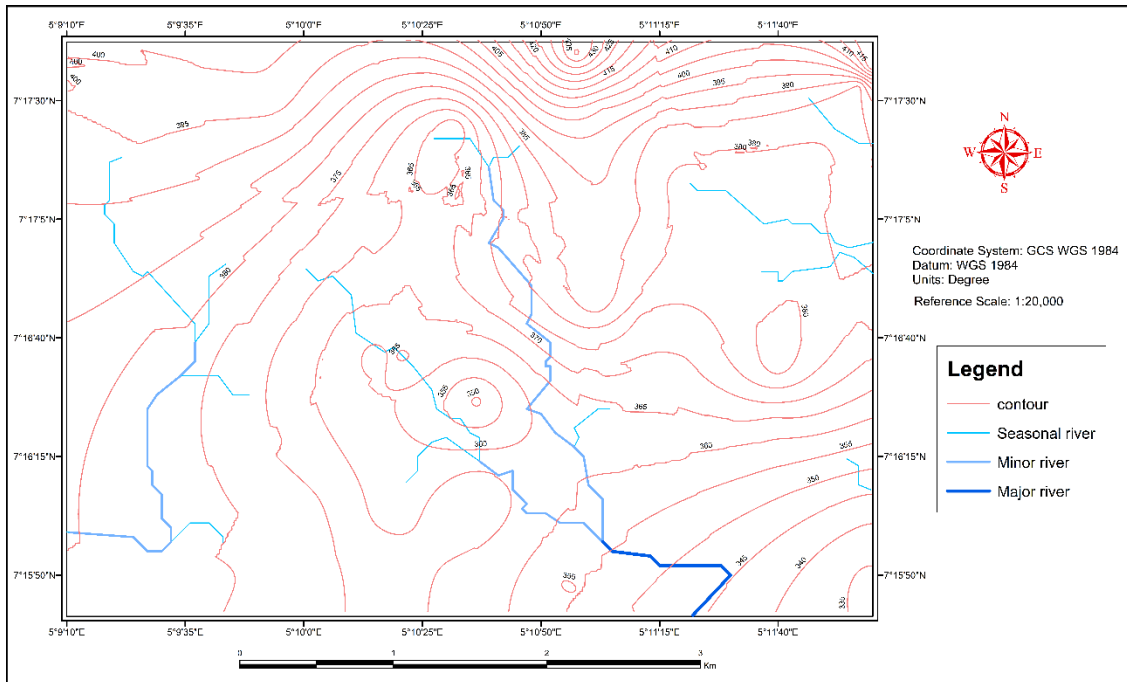


Figure 4: Contour Drainage Map of the Study Area, modified from Federal Surveys of Nigeria, 1966.

MATERIALS AND METHODS

The research objectives were achieved through field and laboratory methods and data analysis.

Field Investigation

The following methods were applied in the field.

SPT Method

The Standard Penetration Tests were carried out in accordance with BS 1377:1975, using a manual percussion rig. A split-spoon sampler with an internal diameter of 25 mm was driven into the soil by repeated blows from a 65 kg hammer falling freely through a height of 760 mm. Tests were conducted at 16 locations, with measurements taken at 0.3 m intervals to depths of 2-3 m. The number of blows required to drive the sampler through the final 300 mm of penetration was recorded as the N-value. To improve the reliability of the results, the measured N-values were corrected for hammer energy and overburden pressure in accordance with standard practices (ISDS, 2019, and Robertson and Cabal, 2015). The energy correction factor was applied to normalise the field energy to 60% efficiency, expressed as:

$$N_{60} = N \times \left(\frac{E_r}{60} \right) \quad (1)$$

where N_{60} = corrected blow count for 60% energy ratio,

N = measured blow count, and

E_r = actual hammer energy delivered (%).

The overburden pressure correction was then applied to account for confining stress variation with depth using:

$$N_1 = N_{60} \times C_N \quad (2)$$

$$\text{Where } C_N = 0.77 \times \log_{10} \left(\frac{2000}{\sigma'_v} \right) \quad (3)$$

, and σ'_v = effective overburden pressure (kN/m^2).

These corrections yielded consistent N_{60} and N_1 values, providing a reliable basis for correlating SPT with CPT data and assessing soil strength and compressibility across the swampy tropical subsoils of Akure.

CPT Method

The cone penetration tests were conducted in accordance with BS 1377:1975 using both 2.5-ton and 10-ton Dutch cone penetrometers to evaluate subsurface resistance and delineate stratification across the study area.

Ton Cone Procedures

The 2.5-ton Dutch cone penetrometer was manually operated using a hydraulic jack system. The cone, having an apex angle of 60° and a base area of 10 cm^2 , was advanced into the ground at 0.25 m intervals. Only cone end resistance (q_c) was measured, as sleeve friction readings were not taken. Penetration continued until the machine reached its maximum capacity or the rod deflection limit was reached.

Ton Cone Procedures

The 10-ton-capacity penetrometer was used in stiffer, deeper deposits. This version measured both cone end resistance (q_c) and sleeve friction (f_s) simultaneously. Readings were obtained at 0.20 m intervals to provide detailed insight into soil layering, relative density, and strength variations. Each test was stopped once the total resistance exceeded the machine's load limit or anchorage failure was observed.

Soil Sampling and Classification

Disturbed and undisturbed soil samples were collected from selected borehole locations immediately after the in-situ tests for laboratory analysis. Sampling depths corresponded to identified stratigraphic changes and ranged from 0.5 to 3.0 m. Disturbed samples were obtained using the split-spoon sampler during SPT operations, while undisturbed samples were retrieved in thin-walled tubes for classification and index testing. All laboratory tests were carried out in accordance with the BS 1377:1990 and ASTM 2017 standards. The soil samples were oven-dried, pulverised, and subjected to grain-size analysis, Atterberg limits, and visual inspection to determine their texture and plasticity characteristics. Soils were classified according to the Unified Soil Classification System (USCS) and the AASHTO classification system for engineering correlation purposes (AASHTO, 2008).

Data Analysis

Data analysis involved three main stages: depth matching, statistical correlation, and error evaluation. Corrected Standard Penetration Test values (N_{60}) were paired with corresponding Cone Penetration Test cone resistance (q_c) readings at equivalent depths. Where the test intervals differed, q_c values were interpolated linearly to match the SPT depths, ensuring consistent depth referencing across all data points.

The relationship between q_c and N_{60} was expressed through regression models of the general form:

$$q_c = aN_{60} + b \quad (4)$$

and

$$q_c = aN_{60}^b \quad (5)$$

where a and b are empirical constants derived from regression analysis. Both linear and power-law regressions were evaluated to determine the best-fit relationship between the two in-situ parameters. Statistical computations were carried out using Microsoft Excel (Office 365). The Pearson correlation coefficient (r) and the coefficient of determination (R^2) were used to quantify the strength and reliability of each correlation. Model performance was further evaluated using the Root Mean Square Error (RMSE) to assess predictive accuracy, defined as:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (q_{c,i}^{obs} - q_{c,i}^{pred})^2} \quad (6)$$

where $q_{c,i}^{obs}$ and $q_{c,i}^{pred}$ represent observed and predicted cone resistance values, respectively, and n is the number of paired data points as used by Robertson and Cabal, 2015 and Das and Sobhan, 2018.

The best-fit model for each dataset was selected based on the combined assessment of statistical robustness and predictive performance. Specifically, the model exhibiting the highest coefficient of determination (R^2) and the lowest root mean square error (RMSE) was considered the most reliable representation of the relationship between q_c and N_{60} . In addition, the standard error of estimate (SE) and residual plots were reviewed to confirm the uniformity of error distribution and the absence of systematic bias across depth intervals. This approach ensured that the derived empirical correlations were both statistically valid and geotechnically consistent, making them suitable for practical application within the study area.

RESULTS

Summary of Field Data

Field investigations comprised 16 Standard Penetration Test (SPT) points, 16 Cone Penetration Test (CPT) points using the 2.5-ton rig, and 9 CPT points with the 10-ton rig, distributed across the study area. The groundwater table was encountered at shallow depths ranging from 0.0 to 1.5 m, reflecting the swampy, poorly drained terrain, as summarised in Table 4.1.

Comparative plots of q_c and N_{60} reveal a generally parallel trend across most locations, indicating that both in-situ tests consistently reflected subsurface strength characteristics. The overall pattern showed a progressive increase in q_c and N_{60} values with depth, corresponding to the transition from soft organic clays near the surface to stiffer sandy clays and dense clayey sands at deeper levels. Localised deviations were observed at certain depths, where q_c values exhibited sudden spikes, while the corresponding N_{60} values showed only modest increases. These anomalies likely represent thin sand lenses or stiff inclusions within otherwise fine-grained or organic strata. Such layers tend to register higher cone resistance due to greater particle interlocking and density, while the discrete nature of the SPT may not fully capture these variations over short intervals. Overall, the comparative depth profiles confirm the increasing soil density and stiffness with depth and highlight the influence of depositional and weathering processes on the mechanical behaviour of the tropical swampy soils of Akure.

Table 1: Summary of Field Test Data.

ID	Depth range (m)	GWL (m)	Type of Test	No of Data Points	Remarks
BH1	0 - 2.0	0.6	SPT	7	Silty gravelly Sands
BH2	0 - 2.5	0.3	SPT	8	Silty gravelly Sands
BH3	0 - 3.0	0.6	SPT	10	Silty gravelly Sands
BH4	0 - 2.0	0.9	SPT	7	Silty gravelly Sands
BH5	0 - 2.5	0.9	SPT	8	Silty gravelly Sands
BH6	0 - 3.0	0	SPT	10	Waterlogged/Organic/clayey silty sands
BH7	0 - 3.0	0.6	SPT	10	Organic/Clayey silty sands
BH8	0 - 3.0	0.6	SPT	10	Clayey silty gravelly sands
BH9	0 - 1.5	0.9	SPT	5	Clayey silty gravelly sands
BH10	0 - 1.5	0.9	SPT	5	Organic/Clayey silty sands
BH11	0 - 2.5	1.5	SPT	8	Clayey silty sands
BH12	0 - 2.0	1.2	SPT	7	Organic/Clayey silty gravelly sands
BH13	0 - 2.5	0.9	SPT	8	Clayey silty sands
BH14	0 - 2.0	0.6	SPT	7	Gravelly silty sands
BH15	0 - 2.0	0	SPT	7	Waterlogged/Gravelly sands
BH16	0 - 1.5	0.9	SPT	5	Organic/Silty gravelly sands
CPT_2P5_1	0.25 - 2.0	0.6	2.5 Tons CPT	8	Silty gravelly Sands
CPT_2P5_2	0.25 - 2.0	0.3	2.5 Tons CPT	8	Silty gravelly Sands
CPT_2P5_3	0.25 - 2.0	0.6	2.5 Tons CPT	8	Silty gravelly Sands
CPT_2P5_4	0.25 - 2.0	0.9	2.5 Tons CPT	8	Silty gravelly Sands
CPT_2P5_5	0.25 - 2.0	0.9	2.5 Tons CPT	8	Silty gravelly Sands
CPT_2P5_6	0.25 - 2.0	0	2.5 Tons CPT	8	Waterlogged/Organic/clayey silty sands
CPT_2P5_7	0.25 - 2.0	0.6	2.5 Tons CPT	8	Organic/Clayey silty sands
CPT_2P5_8	0.25 - 2.0	0.6	2.5 Tons CPT	8	Clayey silty gravelly sands
CPT_2P5_9	0.25 - 1.0	0.9	2.5 Tons CPT	4	Clayey silty gravelly sands
CPT_2P5_10	0.25 - 2.0	0.9	2.5 Tons CPT	8	Organic/Clayey silty sands
CPT_2P5_11	0.25 - 1.25	1.5	2.5 Tons CPT	5	Clayey silty sands
CPT_2P5_12	0.25 - 1.5	1.2	2.5 Tons CPT	6	Organic/Clayey silty gravelly sands
CPT_2P5_13	0.25 - 2.0	0.9	2.5 Tons CPT	8	Clayey silty sands
CPT_2P5_14	0.25 - 2.0	0.6	2.5 Tons CPT	8	Gravelly silty sands
CPT_2P5_15	0.25 - 2.0	0	2.5 Tons CPT	8	Waterlogged/Gravelly sands
CPT_2P5_16	0.25 - 1.25	0.9	2.5 Tons CPT	5	Organic/Silty gravelly sands
CPT_10_1	0.2 - 3.0	0.6	10 Tons CPT	8	Silty gravelly Sands
CPT_10_2	0.2 - 3.2	0.6	10 Tons CPT	8	Organic/Clayey silty sands
CPT_10_3	0.2 - 2.6	0.6	10 Tons CPT	8	Clayey silty gravelly sands
CPT_10_4	0.2 - 2.0	0.9	10 Tons CPT	4	Clayey silty gravelly sands
CPT_10_5	0.2 - 2.0	0	10 Tons CPT	8	Waterlogged/Gravelly sands
CPT_10_6	0.2 - 4.0	0.9	10 Tons CPT	6	Clayey silty sands
CPT_10_7	0.2 - 1.2	0.9	10 Tons CPT	5	Organic/Silty gravelly sands
CPT_10_8	0.2 - 3.0	1.2	10 Tons CPT	6	Organic/Clayey silty gravelly sands
CPT_10_9	0.2 - 4.2	1.5	10 Tons CPT	5	Clayey silty sands

Correlation Between SPT and CPT Results

Both linear and power regression models were developed to establish empirical relationships between the corrected Standard Penetration Test blow counts (N_{60}) and Cone Penetration Test cone resistance (q_c) for the tropical swampy soils of the study area. Separate correlations were derived for the 2.5-ton and 10-ton CPT datasets to account for differences in machine capacity and penetration characteristics.

Linear Correlation Model

A linear regression model of the form

$$q_c = aN_{60} + b \tag{4}$$

was established in Microsoft Excel, where q_c represents cone resistance (kPa), and N_{60} is the corrected SPT blow count.

For the 2.5-ton CPT, the relationship obtained was:

$$q_c = 474.37N_{60} + 303.53 \quad (R^2 = 0.7895, R = 0.8886, RMSE = 989.95) \tag{7}$$

For the 10-ton CPT, the linear regression yielded:

$$q_c = 834.22N_{60} - 492.33 \quad (R^2 = 0.5396, R = 0.7346, RMSE = 707.11) \tag{8}$$

The linear trend indicates a strong positive correlation between q_c and N_{60} , particularly for the 2.5-ton CPT data. The lower coefficient of determination (R^2) for the 10-ton CPT suggests that soil variability and stratification at greater depths may have influenced cone resistance response, as commonly reported in tropical lateritic and swampy deposits Robertson and Cabal, 2015.

Power Correlation Model

To capture potential nonlinearity, a power regression model of the form

$$q_c = aN_{60}^b \tag{5}$$

was also fitted to the data.

For the 2.5-ton CPT, the power relationship gave:

$$q_c = 636.57N_{60}^{0.8735} \quad (R^2 = 0.7970, R = 0.8927, RMSE = 866.33) \tag{9}$$

For the 10-ton CPT, the relationship was:

$$q_c = 525.49N_{60}^{0.9996} \quad (R^2 = 0.5307, R = 0.7285, RMSE = 3386.52) \tag{10}$$

The power model provided a slightly better statistical fit than the linear model for the 2.5-ton CPT, as evidenced by a higher R^2 and lower RMSE values. This implies a nonlinear increase in cone resistance with increasing SPT resistance, a behaviour consistent with tropical soils, where density and stiffness increase rapidly with depth due to compaction resulting from overburden pressure and weathering (Lunne *et al.*, 2018; Clayton *et al.*, 1995). However, the 10-ton CPT showed a weaker power correlation, likely due to greater scatter in data from deeper horizons, where transitions from clayey sand to dense sandy layers produce abrupt variations in q_c .

Comparative Interpretation

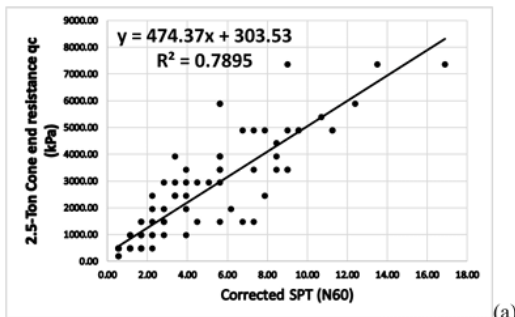
Both correlation models revealed positive relationships between q_c and N_{60} , confirming that SPT and CPT results are mutually consistent indicators of soil strength in the swampy tropical deposits of Akure. The 2.5-ton CPT correlations, particularly the power model, demonstrate a stronger and more consistent fit, suggesting that the test better reflects the behaviour of soft-to-medium soils predominant in the upper layers.

The greater scatter in the 10-ton CPT correlations may be attributed to stratification effects and to the larger cone's higher tip resistance at greater depths. Overall, the results support the application of CPT–SPT correlations for local calibration of design parameters in tropical and waterlogged environments, as recommended by Robertson and Cabal (2015) and Das and Sobhan (2018).

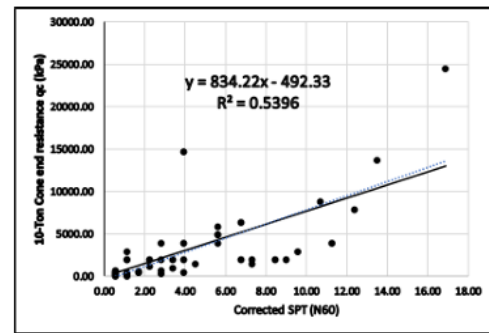
Table 2: Summary of Regression Parameters for SPT-CPT Correlations.

CPT Type	Model Type	Equation Form	R^2	R	RMSE (kPa)	q_c Range (kPa)	Remarks
2.5-ton	Linear	$q_c = 474.37N_{60} + 303.53$	0.7895	0.8886	989.95	196.13-7354.99	Strong correlation; linear model suitable for shallow fine-grained soils.
2.5-ton	Power	$q_c = 636.57N_{60}^{0.8735}$	0.7970	0.8927	866.33	196.13-7354.99	Best statistical fit; captures nonlinearity in soft-to-stiff transitions
10-ton	Linear	$q_c = 834.22N_{60} - 492.33$	0.5396	0.7346	707.11	0 – 24516.63	Moderate correlation; reflects soil variability at deeper strata
10-ton	Power	$q_c = 525.49N_{60}^{0.9996}$	0.5307	0.7285	3386.52	98.07 – 24,516.63	The nonlinear trend is evident but is affected by heterogeneity and depth effects.

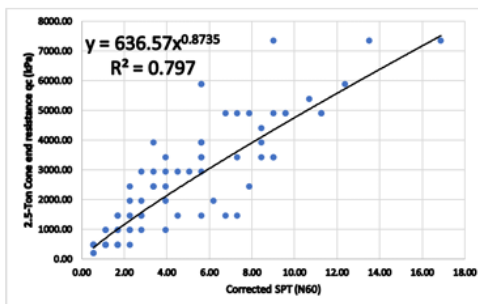
Figure 5: Linear and power correlation relationships between cone resistance (q_c) and standard penetration resistance (N_{60}) for both 2.5-ton and 10-ton CPT data sets in the swampy soils of the study area.



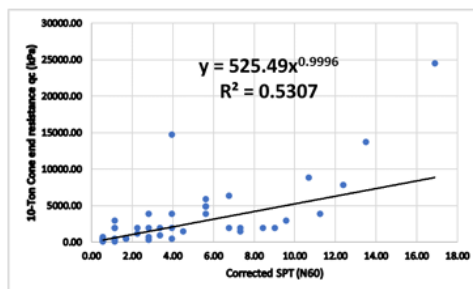
(a)



(b)



(c)



(d)

Soil-Type Sensitivity

The reliability of SPT–CPT correlation depends strongly on soil type. Within the 0 – 3 m investigation depth, three soil zones were observed: organic clay, clayey sand, and silty sand. Each zone exhibits distinct mechanical behaviour that affects correlation accuracy between q_c and N_{60} .

Organic Clay

Organic clay layers, present at shallow depths (typically 0 – 0.5 m), contain high moisture content and organic matter that reduce soil stiffness. These conditions lead to low and variable q_c and N_{60} results, causing scatter in regression data. ISDS, 2019 report that weathered tropical soils with high organic content show variability in penetration resistance, affecting in-situ test reliability. This soft behaviour is further influenced by the persistently high groundwater and poor drainage within Akure's swampy zones (Skempton, 1986) which promote seasonal saturation and cyclic softening of near-surface deposits. The depth plots for these layers often deviate significantly from trendlines, reducing correlation strength.

Clayey Sand

From roughly 0.5 m to 1.5/2 m, clayey sand was predominant. These soils present improved strength, cohesion, and density, producing more consistent q_c and N_{60} responses. In this interval, both CPT and SPT show better agreement, yielding higher R^2 and lower RMSE values. This is consistent with findings by Robertson and Cabal, 2015 who note that cohesive-granular composites often yield higher correlation reliability in CPT vs SPT.

Silty Sand

Between about 1.5/2 m and 3 m, silty sand becomes more evident. These soils often possess moderate fines with sand, and allow faster pore pressure

dissipation during CPT, but also exhibit variability in grain size and saturation. This variability may introduce noise into the q_c – N_{60} correlation, especially for deeper CPT data (Lunne *et al.*, 2018). As depth increases, stiffness rises, and correlation tends to improve, but local q_c fluctuations remain due to heterogeneity.

Comparative Interpretation

Overall, the clayey sand interval shows the strongest and most reliable q_c – N_{60} correlation, followed by silty sand, with organic clay being most problematic. When developing empirical conversion models or using SPT/CPT for design in the study area, data from clayey sand zones are most trustworthy. Organic clay zones should be used cautiously, as their variable behaviour may reduce predictive accuracy.

Depth Dependency

The correlation between q_c and N_{60} exhibits a clear depth-dependent trend within the 0–3 m profile investigated. In the upper 0.5 m, dominated by soft organic clays and silty materials, penetration resistance values are generally low and scattered due to high water content and variable organic composition. Consequently, both q_c and N_{60} show weak correlation in this zone, consistent with observations that organic-rich swamp deposits often produce highly variable in-situ test results due to their compressibility and sensitivity (Robertson and Cabal, 2015; Das and Sobhan, 2018).

Between 1 m and 3 m depth, the soils transition into sandy clay and clayey sand strata, where both q_c and N_{60} increase steadily, and the correlation improves significantly. This behaviour reflects a progressive reduction in organic influence and an increase in density and stiffness with depth.

The improved alignment of the two test parameters at deeper levels suggests that SPT and CPT respond more consistently in firmer, less compressible soils (Clayton *et al.*, 1995).

Overall, the results indicate that correlation reliability in the tropical swampy soils of Akure increases with depth, as near-surface heterogeneity and seasonal moisture variation diminish. This trend is consistent with local studies that have linked subsurface stratification and shallow groundwater fluctuations to variations in soil response and foundation performance within Akure's flood-prone lowlands (Skempton, 1986; Ademeso and Ogunjobi, 2021).

DISCUSSION

Interpretation of Correlation Strength and Form

The results showed a strong positive correlation between cone resistance (q_c) and corrected SPT blow count (N_{60}) in the 2.5-ton CPT data: $R^2 = 0.7895$ (linear), improving slightly to $R^2 = 0.7970$ in the power model, and a lower RMSE for the power model (866.33 vs. 989.95 kPa). This suggests that a power relationship better captures the nonlinear increase in q_c as soils densify or stiffen, particularly in sandy clay and clayey sand layers. For the 10-ton CPT data, the correlations are weaker: $R^2 = 0.5396$ (linear) and $R^2 = 0.5307$ (power), with a significantly higher RMSE in the power model (3,386.52 kPa) compared to the linear model (707.11 kPa), indicating less reliable predictive power at deeper or more variable depths.

Comparison with Global and Regional Models

Global CPT–SPT correlation models, like Lunne *et al.* (2018), often adopt power laws because they better reflect soil behaviour under penetration. The fact that the 2.5-ton data conform better to the power model is consistent with these standards. Similarly, the nonlinear q_c – N_{60} relationships frequently yield better fits in residual soils. However, the relatively low correlation in the 10-ton data in this study suggests that local soil heterogeneities and test-depth variability may reduce the predictive strength of universal models.

Why Tropical Swampy Soils Behave Differently

Tropical swampy soils are strongly influenced by organic content, high saturation, and variable drainage conditions. In the upper 1 m, organic clays retain significant moisture and exhibit low effective stress, causing both q_c and N_{60} to be erratic and weakly correlated. As depth increases (1–3 m), soils often transition to sandy clay and clayey sand horizons that are denser, better drained, and less compressible, leading to improved consistency between the two test parameters.

The peculiar response of tropical swamp soils in Akure reflects not only their hydrological setting but also the post-depositional processes that have shaped their present composition. ISDS, 2019 observed that prolonged tropical weathering in the Akure area produces clayey sand and silty materials derived from basement rocks, with varying mineral compositions

and degrees of alteration. These materials, when saturated, develop heterogeneous strength characteristics that influence both SPT and CPT responses. Additionally, Owoeye *et al.*, 2020 noted that seasonal flooding and waterlogging in Akure accentuate near-surface variability, further weakening the q_c – N_{60} correlation in organic-rich horizons.

Application of Findings in Foundation Design

The empirical q_c – N_{60} relationships developed in this study are valuable tools for foundation design in tropical environments. Where only CPT data are available, the derived equations can help estimate equivalent SPT values for use in bearing capacity and settlement analysis. For shallow foundations in swampy soils, understanding that near-surface layers (< 1 m) are unreliable for direct load support is crucial; improvement methods such as replacement, preloading, or light raft foundations may be necessary. In contrast, the deeper sandy clay and clayey sand layers (1–3 m), which show stronger q_c – N_{60} correlation, are more dependable for design applications (Clayton *et al.*, 1995).

CONCLUSION

This study developed empirical correlations between Standard Penetration Test (SPT) blow counts (N_{60}) and Cone Penetration Test (CPT) cone resistance (q_c) for the tropical swampy soils of Akure, southwestern Nigeria. Both linear and power regression models were evaluated for the 2.5-ton and 10-ton CPT datasets. The 2.5-ton CPT data exhibited stronger statistical performance ($R^2 = 0.79$ for linear; $R^2 = 0.80$ for power) than the 10-ton CPT results, indicating a more consistent response in the soft-to-medium cohesive and sandy layers prevalent in the upper 3 m. The positive correlation between q_c and N_{60} confirms that both in-situ tests are compatible indicators of soil strength, responding similarly to increases in density and stiffness. The improved performance of the power model supports findings by Robertson and Cabal (2015) and Das and Sobhan (2018), who noted nonlinear q_c – N relationships in fine-grained and partially saturated soils. The observed depth-dependent improvement in correlation further reflects a progressive decline in organic influence and moisture variability with depth, consistent with earlier observations of tropical lowland soils (Owoeye *et al.*, 2020; ISDS, 2019).

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

- i. The locally derived SPT–CPT correlations should be adopted as preliminary design tools for estimating missing in-situ test parameters in swampy tropical soils of Akure and similar geological settings. This will improve the reliability of bearing capacity and settlement predictions for shallow foundation design.

ii. Geotechnical engineers and practitioners working in tropical lowland environments are encouraged to prioritize site-specific calibration of empirical correlations rather than relying solely on generalized global models, due to the strong influence of local soil conditions on penetration resistance behaviour.

iii. Future investigations should extend the depth of study beyond the upper 3 m to include deeper lateritic and fully weathered basement profiles in order to capture the full stratigraphic transition and improve model robustness.

iv. Additional laboratory-based geotechnical parameters such as undrained shear strength, consolidation characteristics, and compressibility behaviour should be integrated with in-situ test data to develop more comprehensive predictive models for foundation analysis.

v. The spatial coverage of future studies should be expanded to other lowland and flood-prone communities within Ondo State to build a more representative regional geotechnical database for tropical swamp environments.

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