Correlation Analyses of Particle Size Distribution, and California Bearing Ratio of Lateritic Soil in Benin City

Kayode-Ojo, N.[1] Odemerho, J. O. [1] and Odimegwu T.C [2]

[1]Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.
[2]Department of Civil Engineering, College of Engineering, Gregory University Uturu Abia State, Nigeria.

***Email**: ngozi.kayode-ojo@uniben.edu, janet.odemerho@uniben.edu

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Abstract: This report presents a correlation analysis conducted to investigate the relationship between particle size distribution and the California Bearing Ratio (CBR) of lateritic soil in Benin City. Field and laboratory investigations were conducted to collect one hundred soil samples, analysis on particle size distribution, and CBR tests were employed. Pearson correlation analysis was performed to quantify the linear relationship between CBR and the percentage of fine particles passing through different sieves. The findings indicated a weak negative correlation between CBR and fine sand content, indicating that an increase in fine sand corresponded to a slight decrease in CBR. A moderate negative correlation was found between CBR and silt/clay content, indicating that as the percentage of these particles increased, CBR values decreased, indicating a decrease in subgrade strength. No linear relationship was observed between CBR and coarse sand content. The study provides valuable insights into the relationship between particle size distribution and CBR of lateritic soil in Benin City, which can be useful for geotechnical engineering and construction projects in the region. The results suggest that the presence of finer particles, particularly silt and clay, can significantly influence the load-bearing capacity of the soil. Further research is recommended to validate and refine the observed correlations and to consider other factors that may affect the soil's engineering behaviour.

Keywords: Correlation Analyses, Particle Size Distribution, California Bearing Ratio; Lateritic Soil; Benin City

1. Introduction

During road and pavement construction, the California Bearing Ratio (CBR) is used to assess the strength of subgrade soil or base materials (Katte, et al., 2019). It determines the soil's bearing capacity relative to a standard crushed stone material. Higher CBR values indicate stronger soils that can withstand heavy loads without deformation or failure, while lower values indicate the need for soil improvement or replacement with better materials. CBR testing is performed to ensure that the compacted soil or base materials meet design requirements. The distribution of particle sizes affects soil particle packing density and interlocking (Ibrahim, et al., 2022).

The analysis of multiple soil stability problems, such as bearing capacity, slope stability, lateral pressure on earth-retaining structures, and pavement deformation, greatly relies on a comprehensive comprehension of how soil withstands pressure from loads through the distribution of particles of varying sizes (Andre-Obayanju & Ireaja, 2022; Ojeaga & Afolabi, 2022; Kayode-Ojo & Odiase, 2020). The particle size distribution (PSD) of laterite soil of Benin City, Nigeria, is generally known to be made up of both granular (sands and gravels) and fine (silt and clay) soil particles (Kayode-Ojo & Odemerho, 2023; Omorogieva & Okiti, 2021). The quantity of fine particles in the soil composition fluctuates at different sites, owing to the area's hydrological cycle, which causes fines to wash off at one spot and settle at another (Ogbuagu & Okeke, 2019; Kayode-Ojo & Odemerho, 2023). Since the nature of the soil varies at different points in situ, it is unreliable to pre-define the relationship between soil properties and the type of data distribution at the beginning of geotechnical data analysis (Katte, et al., 2019; Parmezan, et al., 2019). Pearson’s, Spearman’s, and Kendall’s correlation analyses have been applied to assess the strength and significance of the relationship between PSD and CBR results (Iqbal, et al., 2021; Duque, et al., 2020; Adeke, et al., 2021). Pearson's correlation coefficient is a measure of the linear relationship between two continuous variables. The coefficient ranges from -1 to +1, where -1 indicates a perfect negative correlation, +1 indicates a perfect positive correlation, and 0 indicates no correlation. While Spearman's rank correlation coefficient is a nonparametric measure that assesses the monotonic relationship between variables. It is suitable when the relationship between PSD and CBR is not strictly linear. It is beneficial when dealing with ordinal data or when outliers may affect the correlation analysis. Similarly, Kendall’s rank correlation coefficient is another non-parametric measure that assesses the strength and direction of the rank-based relationship between variables. It provides insights into the concordance or discordance of the ranking order between PSD and CBR.

2. Methodology

2.1 Study Area

This study was carried out in the metropolitan area of Benin City which lies on the Latitude 6°16.931' to 6°29.527'N and Longitude 5°35.010' to 5°38.192'E, the capital city of Edo State, Nigeria. The study areas which lie in the north-western part of the Niger Delta, west of the lower Niger Valley and the southwestern plains, were the University of Benin, Ekiadolor, Airport Road, Ugbor, and Ekosodin.

The study of the PSD and CBR properties of soil in these five locations in Benin City has economic importance by supporting construction and infrastructure development, informing urban planning decisions, promoting geotechnical engineering services, facilitating environmental conservation, and driving research and academic development. Areas such as Ekiadolor and Ekosodin are known for their role as trade centres, educational hubs, employment providers, agricultural centres, and residential areas. The town's diverse economic activities contribute to job creation, income generation, and economic growth, benefiting both the residents and the broader Benin City region. The specific economic benefits derived from the undeveloped site within the University of Benin, Ugbor, and Airport Road, are the collaboration and partnerships with foreign and private investors that can lead to knowledge transfer, technology commercialization, and the creation of spin-off companies, contributing to economic growth and innovation within the city. Understanding soil properties contributes to efficient and sustainable development practices, ultimately benefiting the economy of Benin City.

2.2 Soil Sampling

A total of hundred soil samples were collected from the University of Benin Site B (UNIBEN), Ekiadolor, Airport Road, Ugbor area, and Ekosodin area as seen in Figures 1 and 2. The sample size was decided based on the range of sample sizes recommended from similar research (Garven & Vanapalli, 2006; Surendra & Gurcharan, 2014; Ojuri, 2013; Purwana & Nikraz, 2014; Garven & Vanapalli, 2006; Iyeke, et al., 2016). Using a hand auger, the soil was sampled at 1.5 metres (m) below the surface of the ground. The soils collected were partially moist due to the microclimatic conditions at the site and the seasonal rainfall, even though the water table was not discovered throughout the sampling process for the different locations.

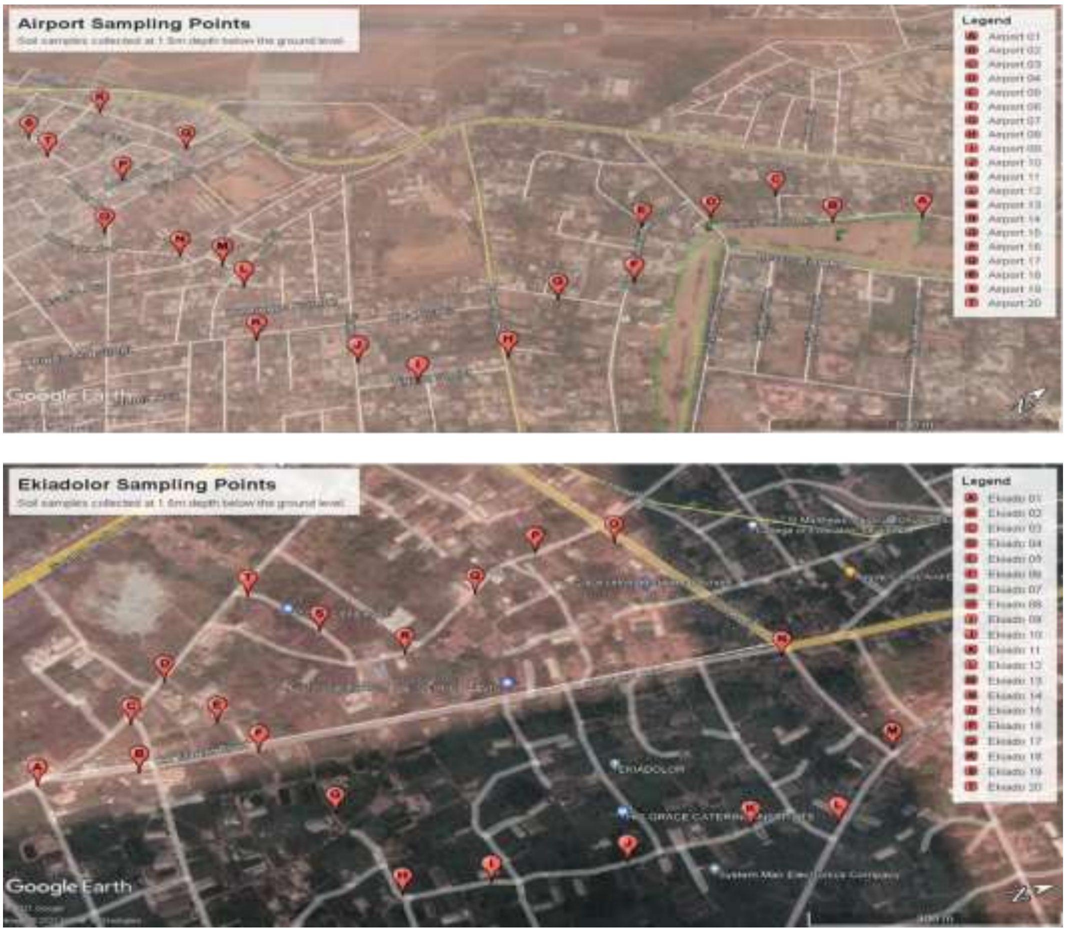

Figure 1. Map of Airport and Ekiadolor Sampling Locations

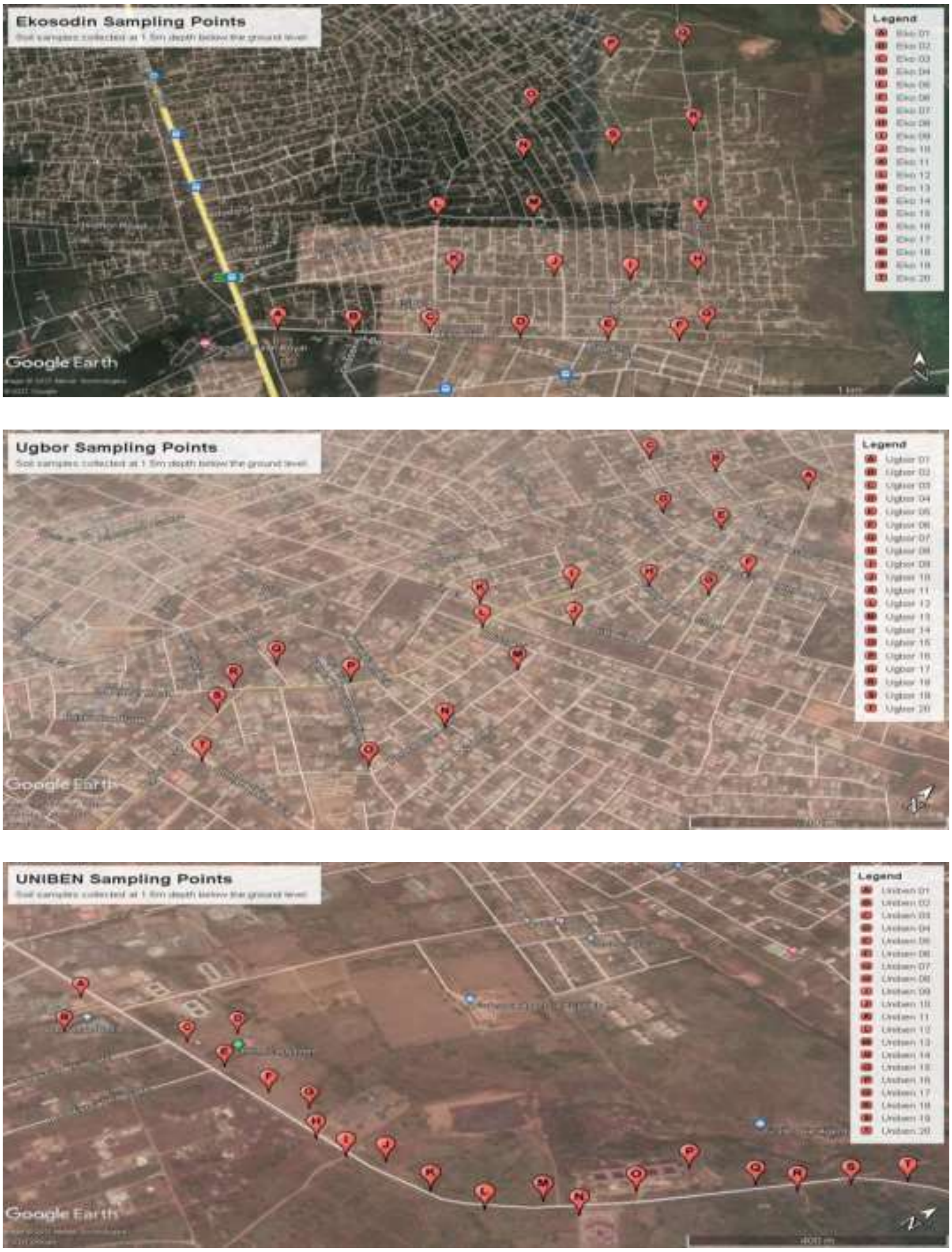

Figure 2. Map of Ekosodin, Ugbor, and Uniben Sampling Locations

2.3 Laboratory Testing of Soil Samples

The laboratory test conducted on the recovered soil included the mechanical sieve analysis and sedimentation test, and the California bearing ratio test. They were carried out according to BS EN 1997-2-2007. The mechanical sieve analysis includes the process of separating soil aggregate into fractions using a set of different standard sieve sizes. The cumulative per cent by weight of soil passing a given sieve is referred to as the percent finer (BS 1377: Part 2, 1990). The percent fine of sieve No 14 (1.18mm), No. 36 (0.425mm) and No. 200 (0.075mm) were selected to generally represent the coarse, medium, and fine-grained soil in the soil classification based on the American Association of State Highway and Transportation Officials (AASHTO) system of classification. Other sieve analysis parameters such as D_{10}, D_{30} and D_{60} were used to determine the effective size, the uniformity coefficient, and the coefficient of gradation (also known as the coefficient of curvature). D_{10} is the effective size of soil through which 10% of the total soil mass is finer and 90% of the particles are coarser than D_{10}. This is the size at 10% finer by weight. Similarly, D_{60} is the particle size at which 60% of the particles are finer and 40% of the particles are coarser than D_{60} size. D_{30} is the size at which 30% is finer by weight and the remaining 70% particles are coarser than D_{30} size. The uniformity coefficient and the coefficient of curvature help to classify the soil as well, as gap or uniformly graded ones. A well-graded soil has a good representation of all particle sizes. A gap-graded soil has excess or deficiency of certain particle sizes. Lastly, uniformly graded soil has particles of the same sizes leaving relatively large voids within them.

The uniformity coefficient Cu is defined as the ratio of D_{60} to D_{10}. A value of Cu greater than 4 or 6 classifies the soil as well-graded. When Cu is less than 4, it is classified as poorly graded or uniformly graded soil.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

The coefficient of curvature is given by the formula:

$$C_c = \frac{{D_{30}}^2}{D_{10} \times D_{60}} \quad (2)$$

A soil with a coefficient of curvature (C_C) between 1 and 3 is well graded if the cu is also greater than 4 for gravels and 6 for sands. For cases where the C_C of soil is less than 1 or greater than 3, the soil is gap-graded.

A sedimentation test is conducted on soil with a percent finer of sieve No. 200 (0.075mm) value greater than 35% (BS 1377: Part 2, 1990). This test is governed by Stokes law on the determination of the rate of settlement of a particle. The most recommended sedimentation test is a hydrometer test. This test determines the distribution of fines such as silt and clay in a soil composition.

The California bearing ratio (CBR) test is a penetration test carried out to evaluate the mechanical strength of soil as a base, sub-base, or sub-grade course material. The CBR test was performed by compacting 5kg of soil in a mould with 2.5kg rammer. A loading machine as seen in Figure 3.9, was used to apply pressure to a standard-area plunger to penetrate the compacted soil sample. The measured pressure is then divided by the pressure required to achieve equal penetration through standard crushed rock material. The ratio of the measured pressure and the standard pressure at 2.5mm and 5.0mm depth were measured at the soaked and unsoaked condition of the compacted soil. CBR was conducted to characterize the soil sample for use as a base, sub-base, or sub-grade material according to the Federal Ministry of Works and Highway (FMWH) specification.

2.4 The Correlation Analyses and Algorithms Used

The correlation analyses were developed on PyCharm IDE through Python programming language. The Python libraries imported were Pandas and Matplotlib. The Pandas package was employed for storing and analysing the dataset in a data frame and the matplotlib was for data visualization. This step began with the storing of the dataset ‘data.csv’ as a Pandas data frame using the already defined Python function ‘pd.read_csv’ and assigning the dataframe to a variable named ‘data’. The bivariate analysis showing the strength of correlation between the variables in the dataset was evaluated by calling the Pandas function ‘data.corr()’. Based on the specification, the correlation function utilized Pearson, Spearman, or Kendall correlation coefficient matrix to measure the strength of the empirical relationship and check for multicollinearity between variables in the dataset.

3.0 Results and Discussion

3.1 Particle Size Distribution Results

The sieve and hydrometer analyses showed particle sizes of soil at the different investigated areas ranging from coarse-grained sand to clay. The average percentage of fines categorized under the given soil grain fraction according to the British standards (Das, 2019) or lower than the selected grain diameters: 1.18mm, 0.425mm, 0.075mm, 0.040mm, 0.010mm, 0.003mm, 0.001mm are presented in Table 1 below.

Table 1. The Soil Particle Size Distribution in the Investigated Region

Soil grain type	Sand			Silt			Clay
Soil grain fraction	Coarse	Medium	Fine	Coarse	Medium	Fine	Fine
Grain diameter (mm)	1.18	0.425	0.075	0.040	0.010	0.003	0.001
Ekosodin	96.18	70.43	38.33	31.62	25.46	15.28	11.93
Ugbor	97.22	74.99	47.26	37.57	30.51	24.34	16.67
Uniben	95.87	76.20	46.46	36.61	30.18	22.90	15.70
Ekiadolor	95.19	74.89	51.87	38.36	28.40	24.11	16.18
Airport Road	97.39	74.59	39.31	30.95	25.14	17.41	13.64

The average D_{10}, D_{30} and D_{60} of Ekosodin soil samples were obtained as 0.0007mm, 0.02mm, and 0.3mm from Figure 3, while C_U, and C_C were evaluated as below.

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.3\ mm}{0.0007\ mm} = 429 \quad (3)$$

$$C_c = \frac{{D_{30}}^2}{D_{10} \times D_{60}} = \frac{0.02^2\ mm^2}{0.0007 \times 0.3\ mm^2} = 1.90 \quad (4)$$

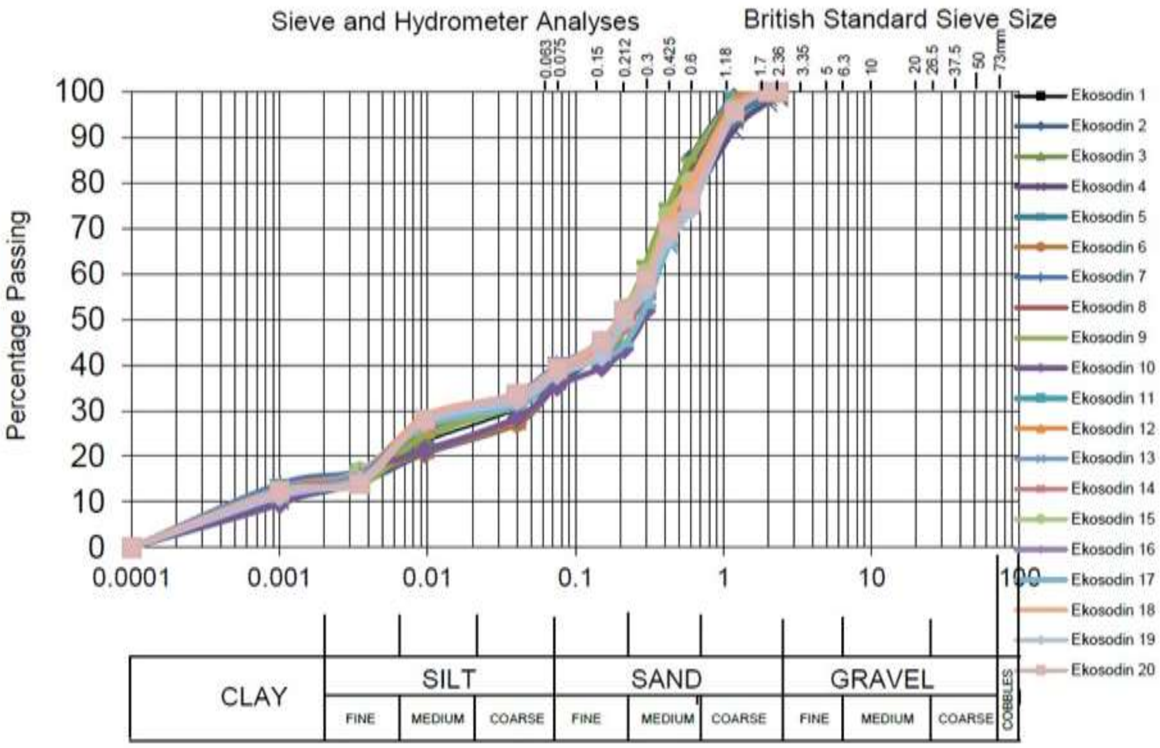

Figure 3. Particle Size Distribution of Soil Samples from Ekosodin Area

Similarly, the average D10, D30, D60, CU, and CC of soil samples from the five sampling locations were obtained and tabulated in Table 2 below.

Table 2. The Gradation of Soil from the Different Sampling Locations

Sampling Location	D_{10}	D_{30}	D_{60}	C_U	C_C	Remark
Ekosodin	0.00070	0.020	0.30	429	1.90	Well-graded
Ugbor	0.00040	0.007	0.26	650	0.47	Gap-graded
Uniben	0.00040	0.010	0.25	625	1.00	Well-graded
Ekiadolor	0.00035	0.014	0.20	571	2.80	Well-graded
Airport Road	0.00040	0.020	0.30	750	3.33	Gap-graded

A well-graded soil has a value of CU greater than 6.0 and a CC value between 1.0 and 3.0. This information explains a soil consisting of a representative of all grain sizes in a good complementary quantity (BS 1377: Part 2, 1990). While a gap-graded soil has a value of CU greater than 6.0 but a CC value lesser than 1.0 or greater than 3.0. This information explains a soil consisting of a representative of all grain sizes, but some fractions are either missing or in very small or excess quantity (BS 1377: Part 2, 1990). This also showed a closely packed soil in terms of quantity of particle sizes leaving relatively large voids due to the missing or small quantity of some intermediate particle sizes.

3.2 California Bearing Ratio Parameters

The average California bearing ratio values of the soil samples from different locations at the unsoaked (US) and soaked (S) conditions were evaluated and presented in Table 3.

Table 3. The Average soaked California Bearing Ratio

Table 3: The Average soaked California Bearing Ratio Sampling **ID**	**Ekosodin**		**Ugbor**		**Uniben**		**Ekiadolor**		**Airport Rd.**	
	US	**S**	**US**	**S**	**US**	**S**	**US**	**S**	**US**	**S**
1	14.6	9.37	13.3	7.78	14.6	8.99	12.3	8.19	14.6	8.81
2	14.4	8.08	13.8	8.27	13.8	8.36	13.8	8.14	14.8	8.93
3	14.4	8.75	14.6	8.20	14.7	8.18	13.5	8.28	14.5	8.45
4	14.6	9.78	13.2	8.03	14.2	8.97	13.2	8.55	14.2	9.23
5	15.9	9.08	13.4	7.82	14.4	8.21	15.2	8.66	15.2	9.61
6	18.2	9.64	12.7	8.64	13.7	8.64	13.7	8.24	14.7	9.65
7	13.5	9.04	13.2	8.14	12.9	8.87	13.9	8.64	13.6	8.64
8	13.3	8.41	12.9	8.36	13.5	8.00	12.9	8.66	12.9	8.36
9	14.3	8.90	13.9	7.90	14.0	8.65	14.4	8.90	13.9	8.65
10	14.9	9.51	14.1	8.51	13.5	8.51	14.0	8.51	14.8	9.11
11	14.3	8.37	13.4	8.55	13.6	8.17	13.7	8.60	13.7	8.30
12	14.0	9.31	14.0	8.04	14.1	8.41	14.1	8.32	14.2	9.03
13	15.4	9.50	13.4	7.67	12.4	8.03	15.1	8.05	13.4	8.27
14	14.0	8.98	14.0	8.40	13.2	8.53	13.6	8.60	14.0	9.13
15	13.8	8.29	13.5	8.54	13.8	8.62	14.0	8.54	13.7	8.48
16	13.4	8.41	13.9	8.27	13.4	8.13	14.1	8.41	14.4	8.36
17	14.0	9.19	13.0	8.19	14.3	8.19	14.4	8.92	14.2	8.89
18	13.2	8.64	13.2	8.01	13.2	8.31	13.1	8.26	13.0	8.44
19	13.2	8.29	13.2	8.39	13.2	8.24	13.2	8.62	13.4	8.47
20	14.2	8.61	14.3	8.46	14.2	8.81	14.1	8.76	14.4	8.73

The soil samples obtained from the 100 points across Benin City had an unsoaked CBR range of values of 12.00% to 18.66%. This conformed to the range of unsoaked CBR values (9% to 29%) obtained by Andre-Obayanju and Ireaja (2022) from soil samples collected along 20th Street BDPA, Benin City. After soaking for 96 hours, the CBR values of soil samples from the

100 points were reduced to a range of 7.67% to 9.78%. For soil samples collected from Ekosodin, CBR-soaked values ranged from 8.08% to 9.78%. For soil samples collected from Ugbor, CBR-soaked values ranged from 7.67% to 8.64%. For soil samples collected from Uniben, CBR-soaked values ranged from 8.00% to 8.99%. For soil samples collected from Ekiadolor, CBR-soaked values ranged from 8.05% to 8.92%. For soil samples collected from the Airport, CBR-soaked values ranged from 8.27% to 9.65%. Comparing these values with the general specifications of sub-grade materials for roads by the Federal Ministry of Works (FMWH, 2013), which stated that soil with CBR soaked values greater than five (5.0) are suitable subgrade material for road pavement. Therefore, the soil in the investigated areas fits as a good subgrade material.

3.3 Bivariate Analyses of the Dataset

The variable columns in the dataset were identified into two groups, dependent and independent variables. The dependent variables were columns c and CBR. While the independent variables were columns 1.18, 0.425, 0.075, 0.040, 0.010, 0.003 and 0.001. The bivariate analysis showed the correlation between any two variables in the dataset. As seen in Table 4 below, the Pearson correlation coefficient matrices showed all possible correlation and collinearity in the dataset.

Table 4. Pearson Correlation Coefficients Matrices of the Dataset

	1.18	**0.425**	**0.075**	**0.040**	**0.010**	**0.003**	**0.001**	**CBR**
1.18	1.00	0.19	-0.28	-0.28	-0.29	-0.22	-0.21	0.00
0.425	0.19	1.00	0.48	0.37	0.25	0.51	0.51	-0.29
0.075	-0.28	0.48	1.00	0.90	0.60	0.84	0.78	-0.46
0.040	-0.28	0.37	0.90	1.00	0.75	0.81	0.77	-0.47
0.010	-0.29	0.25	0.60	0.75	1.00	0.70	0.70	-0.51
0.003	-0.22	0.51	0.84	0.81	0.70	1.00	0.84	-0.44
0.001	-0.21	0.51	0.78	0.77	0.70	0.84	1.00	-0.47
	1.18	**0.425**	**0.075**	**0.040**	**0.010**	**0.003**	**0.001**	**CBR**
CBR	0.00	-0.29	-0.46	-0.47	-0.51	-0.44	-0.47	1.00

A (negative) moderate correlation of -0.44 to -0.51 exists between the independent variables (columns 0.075, 0.040, 0.010, 0.003 and 0.001) and column CBR. A no, weak negative and weak negative correlation existed between the column CBR and columns 1.18 and 0.425 respectively. The positive and negative correlation explains a direct and inverse relationship between the variables respectively (Gogtay & Thatte, 2017). While the statistical inverse relationship between the CBR and the independent variables except column 1.18 is moderately strong to predict the latter.

Collinearity is the presence of a strong correlation between independent variables (Gogtay & Thatte, 2017). As observed in Table 3 above, it occurred between the columns 0.075, 0.040, 0.010, 0.003 and 0.001. This showed the dependency of the distribution of the fine content passing sieve size 0.075mm on the percentage fine passing sieve size 0.075mm. In other words, the presence of column 0.075 alongside columns 0.040, 0.010, 0.003 and 0.001 created a redundancy in the dataset.

4. Conclusions

The particle size distribution analyses of laterite soil in some areas of Benin City showed a grain distribution across coarse-grained sand to clay. Soil samples from Ekosodin, Ekiadolor and Uniben site B area were observed to be well graded. However, at Ugbor and Airport Road area, the semi-well-graded soil consisted of a representative of all grain sizes, but some fractions were either missing, in small or excess quantity. The soil samples across the five areas in Benin City had an unsoaked CBR range of values of 12.00% to 18.66%. After soaking for 96 hours, the CBR was reduced to a range of 7.67% to 9.78%. The Federal Ministry of Works (FMWH, 2013) stated that soil with CBR-soaked values greater than five (5.0) are suitable subgrade material for road pavement. Therefore, the soil in the investigated areas fits as a good subgrade material. The Pearson correlation analyses showed that the statistical linear inverse relationship between the CBR and the independent variables (columns 0.075, 0.040, 0.010, 0.003 and 0.001) was moderately strong to predict the latter.

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