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DEVELOPMENT OF GEOTECHNICAL PROPERTIES GEO-DATABASE FOR SOIL IN KANO METROPOLIS TO ENHANCE BUILDING CONSTRUCTION

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Abstract
Building collapse is a prevalent and concerning issue that resulted in significant loss of lives and properties in many places in Nigeria including Kano state and determination of Geotechnical properties of soil could play a crucial role in preventing building collapse. This study uses Geographic Information System (GIS) methodologies to create a geospatial database of soil properties in Kano Metropolis. The database, created using Inverse Distance Weighting (IDW) and spatial interpolation techniques, provides 212 sets of soil properties being meticulously mapped across the study area. These meticulously generated maps illustrate various soil characteristics prevalent in the metropolis, offering invaluable insights for preliminary designs and construction planning for buildings within Kano Metropolis. The soils in this area are predominantly classified as CL (Clay of low plasticity), SC (Sandy Clay), and SM (Silty Sand) using Unified Soil Classification System (USCS). The moisture content spans from 2.01 to 46%, specific gravity within the range of 2.32 to 2.75, liquid limits varying between 17.2 and 45%, plastic limits within the range of 10.1 to 40.5%, and linear shrinkage values spanning from 1 to 13%. Furthermore, the shear strength parameters of the soil across the study area varies. The unit weight varies between 15.61 and 22.16 kN/m^3, the cohesion (c) values ranging from 1.28 to 29.1 kN/m^2, and the angle of internal friction (ϕ) spanning from 5.5° to 32.2°. Despite variations in ultimate and allowable bearing capacity with depth, the ultimate bearing capacity (q_{ult}) generally ranges between 108 and 1150 kN/m^2, with the corresponding allowable bearing capacity (q_{all}) falling between 40 and 343 kN/m^2. This research provides valuable geospatial knowledge to engineers, architects, and construction professionals in Kano Metropolis, enhancing decision-making and project planning precision, ultimately contributing to sustainable development and growth of Kano metropolis.

1.0 INTRODUCTION
Soil is considered a versatile material extensively used in the construction of buildings and infrastructure, such as retaining walls, embankments for roads, railways, and dams, among others [1, 2]. Soil characterization is crucial for major construction projects, but traditional methods, such as field and laboratory testing, can be limited in scope and spatial coverage [3]. Thus, geodatabases are utilized for compiling, storing, and analyzing large volumes of multi-dimensional soil data, enhancing design and construction efficiencies through detailed subsurface conditions analyses. Samuel [4] and Masoud, *et al*. [5] demonstrated the benefits of using geodatabases for soil conditions assessment and prediction. They used interpolated Cone Penetration Test (CPT) data to

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optimize pile designs for a highway bridge project. Geodatabases can incorporate data from various sources, such as in-situ testing, laboratory testing, geology maps, and remote sensing. Chiara *et al*., [6] developed an integrated geodatabase of subsurface conditions in Naples, Italy, assessing geotechnical risk and site response analysis.

The absence of comprehensive soil investigations during the design and construction of infrastructures has been linked to numerous failures in these projects [1, 2]. For example, a study by Aghamelu, *et al*., [7] analyzed several building failures in Brazil and found insufficient geotechnical investigation of soils was a major contributing factor. This highlights the importance of thorough soil testing and characterization before construction begins.

The assessment of geotechnical properties of subsoil is indispensable for acquiring the relevant input data essential for the design and construction of foundations for proposed structures. Properties like shear strength, compressibility and permeability dictate the appropriate foundation type, allowable bearing capacity, settlement estimates and construction feasibility [8]. Neglecting the geotechnical characteristics of soils at construction sites has been identified as a significant cause of structural failures [8]. Without understanding the subsurface conditions, foundation systems may be inadequately designed and lead to excessive settlement, bearing capacity failures or slope instability [9].

It may lead to inadequate foundation design, resulting in differential settlement and the development of serious cracks in structures [9]. Christtestimony *et al*., [10] reviewed causes of defect in Malaysian hospital buildings and found the primary cause to be improper accounting of spatial variations in subsurface conditions. This resulted in non-uniform settlement across foundations and significant structural damage. Geodatabases plays great societal impacts in the field of geotechnical engineering; it could help in providing estimate of relevant data required for design and construction of infrastructures in data-scarce regions. For instance Vardanega *et al*. [11] utilizes geodatabase and developed new tools inform of new and updated maps for seismic hazard assessments in the Kathmandu Valley which are data-scarce regions. Geodatabase also plays significant role in disaster management and response [11, 12], urban planning by providing geotechnical information necessary for decision-making processes [13]. Moreover, it facilitate the monitoring and management of existing infrastructure through regularly updating geotechn-ical data related to soil conditions, settlement patterns, and other factors [14]. With geodatabase, engineers can detect potential failure and plan maintenance activities in a timelier manner. This leads to cost-effective maintenance, prolonging the lifespan of infrastructure and minimizing disruptions to society [15]. Geodatabases improve project planning, enable advanced 3D modeling, reduce uncertainty, and lower costs due to improved data availability [16, 17].

Over the years, soil investigations have been conducted for various civil engineering projects, and the records of such investigations are scattered across various government ministries, construction companies, and the laboratories where they were conducted. This fragmented and uncoordinated database could serve as a valuable resource for future projects and potentially reduce project costs. The compilation of this database and its accessibility could revolutionize the construction industry, especially in terms of sourcing and selecting quality materials for construction projects. One approach to achieving this is to collect and store the data in a geospatial database and leverage the capabilities of Geographic Information System (GIS) tools to create various maps displaying the geotechnical properties of soils in a given area [18].

To streamline soil investigation processes, several countries have established well-documented soil database archives, often presented in the form of soil maps [19]. Similarly, research efforts have explored the application of GIS for developing soil maps. For example, Rahman *et al*., [20] proposed an alternative methodology for creating soil maps using the ARC/INFO geographical information system. Moreover, [21] successfully developed a GIS system to manage and disseminate soils information from experimental results, making it easy to access information on soil types at proposed project locations. In a similar vein, Eljamassi [22] investigated the development of a GIS system for collecting, managing, analysing, and visualizing soil data, resulting in the creation of a geotechnical information database.

These maps play a crucial role in anticipating soil behaviour and strength. In developing countries like Nigeria, such soil databases and maps are not widespread, and even when available, they are typically designed for agricultural purposes and may not be suitable for civil engineering applications, such as constructing roads and building foundations. Therefore, geotechnical databases and soil maps have the potential to greatly benefit the construction industry in Kano by offering valuable insights into the type and quality of soils suitable for building foundations. Consequently, this paper aims to develop a geospatial database of Kano Metropolis soil for building construction. The selection of Kano Metropolis is strategic, considering Kano State's status as the most populous state in Nigeria [23]. Furthermore, the influx of people into the area due to insurgency in the North Eastern part of the country and banditry activities in some North western part of the country has resulted in significant expansion [23].

1.1 Study Area

The study area for this research is Kano metropolis, located in Kano State, Nigeria. Kano metropolis comprises eight local government areas (LGAs) - Dala, Fagge, Gwale, Kano Municipal, Kumbotso, Nassarawa, Tarauni, and Ungogo. Geographically, Kano metropolis lies between latitude 11°59’59.57” to 12°02’39.57” N and longitude 8°31’19.69” to 8°33’19.69” E, at an altitude of 472 meters above sea level [24]. The total land area encompassed by the metropolis is approximately 499 km^2.

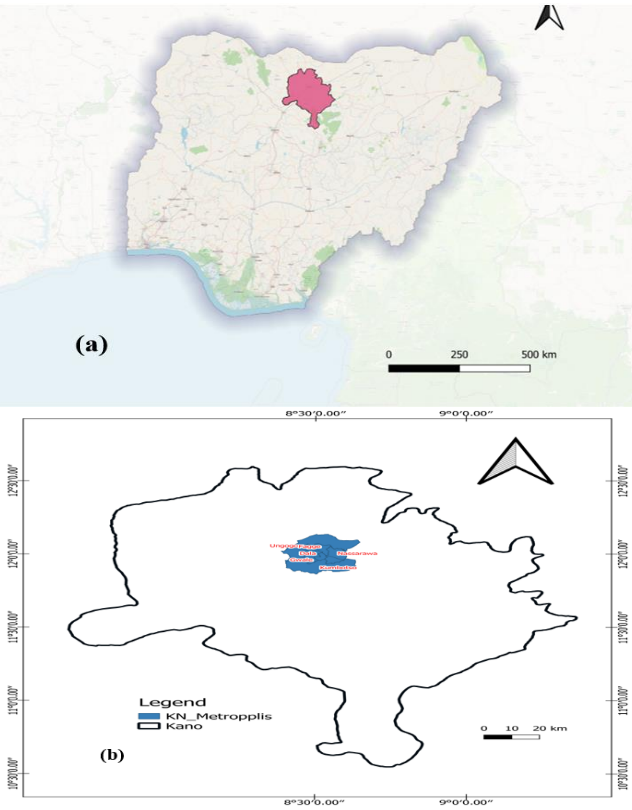

Figure 1: (a) Map of Nigeria showing Kano State and (b) Kano State showing the Study area

The climate of Kano metropolis is characterized as tropical wet and dry. The area experiences a rainy season from May to October, with average annual precipitation around 800 mm. The dry season lasts from November to April [25]. Temperatures are generally high throughout the year, with average highs around 33-35°C and lows around 18-20°C [26].

Kano metropolis is bordered by several LGAs including Minjibir to the northeast, Gezawa to the east, Dawakin Kudu to the southeast, and Madobi and Tofa to the southwest [24]. These neighboring LGAs form a contiguous urban area with Kano metropolis.

Based on 2006 census data, Kano metropolis had a population of 2,826,307 residents [24]. Current projections estimate the population has grown to approximately 4.3 million as of 2020, making it the second largest metropolitan area in Nigeria behind Lagos [27]. This rapid urbanization has created challenges related to infrastructure development, transportation, housing, water access and geotechnical considerations [28].

A map of Kano State showing the boundaries and constituent LGAs comprising Kano metropolis is presented in Figure 1. The need for comprehensive geotechnical characterization across this dense urban region motivated the present study.

2.0 METHODOLOGY

The study methodology involved three phases. In the first phase, geotechnical data (index and engineering properties) were compiled from 212 locations across the 8 LGAs comprising Kano metropolis. Each LGA was divided into at least five sections representing north, east, west, south and central and data representing each section were collected. These data were either extracted from soil investigation reports conducted in the areas or tested in the laboratory; i.e. for LGAs with fewer data points. The soil investigations reports were obtained from Kano state Ministry of Works and Housing, Kano Urban Planning Development Authority (KNUPDA), construction companies and consultancy firms on projects executed with the metropolis.

According to the reports, the data were determined at varying depth from 0.6 – 2.1m. It was noticed that all parameters considered (moisture content, specific gravity, particle size distribution, Atterberg limits and shear strength parameters) were tested at the depth of sampling (0.6 – 2.1m) according to the standard procedure outlined in BS1377 [29]. Soil sample collected and tested in the laboratory were collected from a uniform depth of 1.5m, and all parameters were also tested at the same depth according to the standard procedure outlined in BS1377 [29]. Global Position

System (GPS) was used to record the location (latitude and longitude) of each point from where soil samples were collected and tested. For the soil data extracted from the secondary sources; their location were traced and GPS was also used and recorded their locations. A total of 146 data set were extracted from the secondary sources and 66 data set were tested in the laboratory.

The second phase checked data for errors through descriptive statistics to identify any outliers or anomalies, thereby checking the accuracy of the data.. Thereafter the bearing capacities were calculated using Terzaghi [30] ultimate bearing capacity equation as follows:

$$q_{ult} = 1.3cN_c + qN_q + 0.4\gamma BN_\gamma \quad (1)$$

Where; q_{ult} = ultimate bearing capacity (kN/m^2), B = width of footing (m), γ = unit weight of soil (kN/m^3), q = effective stress, and N_c, N_q, N_γ = bearing capacity factors.

For the settlement of shallow foundations on soils, previous studies [31, 32] have shown that the maximum settlement at which the bearing capacity is considered allowable is 10% of foundation width and is acceptable if a factor of 2.5 is used. Therefore, in this study, a factor of safety of 3.0 was used to calculate the allowable bearing capacity (Equation 2) and it's assumed that the settlement will not exceed the allowable total settlement of 25mm.

$$q_{all} = \frac{q_{ult}}{FS} \quad (2)$$

Where; q_{all} = allowable bearing capacity (kN/m^2); and FS is factor of safety.

A digitized satellite image was then produced in QGIS [33] using soil parameters and GPS locations of the data points.

The third phase utilized Inverse Distance Weighting (IDW) [34] spatial interpolation in QGIS to estimate soil properties at un-sampled locations across the study area and generate continuous maps of soil parameters. Inverse Distance Weighting (IDW) interpolation is a deterministic method for estimating unknown values at specific locations based on known values from surrounding locations. The basic mathematical formula for IDW is expressed in Equation 3:

$$w_i(X) = \frac{\sum_{i=1}^{N} w_i(X)u_i}{\sum_{i=1}^{N} w_i(X)} \quad (3)$$

Where; $w_i(X)$ are the weights assigned to the known values, which are inversely proportional to the distance from the known point X_i to the unknown point X; $u(X)$ is the interpolated value at the unknown location X; N is the total number of known points used in the interpolation, u_i are the known values at the known points.

The weight $w_i(X)$ for each known point is typically calculated using Equation 4:

$$w_i(X) = \frac{1}{d(X, X_i)^p} \quad (4)$$

Where $d(X, X_i)$ is the distance between the unknown point X and a known point X_i; p is the power parameter, which determines the rate at which the weight decreases with distance.

Trial pits were displayed as points on the maps in relation to their coordinates, overlaid on base maps showing LGAs and boundaries. This allowed for development of a geodatabase and set of maps characterizing the spatial distribution of subsoil conditions across Kano metropolis. To overcome the shortcomings of IDW method, a topology checker plugin validation tool in QGIS to check for topological errors, such as overlapping polygons or lines.

3.0 RESULTS

This section presents the key findings obtained from the spatial interpolation and mapping of geotechnical properties across Kano metropolis. This section is organized into subsections based on the different soil parameters analyzed, including moisture content, Atterberg limits, shear strength, and bearing capacity.

3.1 Descriptive Statistics of the Data

The results presented in Table 1 provide a statistical analysis of primary and secondary data on the geotechnical properties of soils in the Kano metropolis. The primary data shows slightly higher mean values for soil consistency limits, specific gravity and moisture content while the secondary data shows higher mean values for cohesion, angle of friction and unit weight suggesting better shear strength properties. The median and mode values indicate uniformity in soil characteristics, particularly in terms of plasticity and shear strength parameters. The standard deviation and variance indicate greater variability in soil properties, with the secondary data showing a higher standard deviation in all the parameters except the liquid limit, shrinkage limit and moisture content. The variation in the data could be attributed to the number of observations considered and the variability suggest that soil properties can vary significantly within the area, which must be carefully considered in geotechnical analyses and engineering applications to ensure safety and stability of structures.

Table 1: Descriptive statistics of the data set

Data	Primary					Secondary				
Observation	66					146				
Statistics	Mean	Medium	Mode	Standard deviation	Variance	Mean	Medium	Mode	Standard deviation	Variance
LL (%)	30.56	30	24	8.42	70.85	30.23	30.6	30	5.26	27.68
PL (%)	20.52	20	20	5.53	30.55	20.02	19.8	20	7.70	59.29
PI (%)	10.89	10	9	4.28	18.30	10.16	11.13	12	7.82	61.10
LS (%)	5.70	5.62	4	1.97	3.88	5.11	5	5	1.63	2.67
G_S	2.60	2.60	2.59	0.08	0.01	2.58	2.6	2.6	0.10	0.01
MC (%)	40.26	31.5	23.8	51.74	2676.98	19.71	23.6	31.9	13.31	177.15
c (kN/m^2)	14.23	12.35	12	7.48	55.99	15.09	12	12	7.68	59.02
ϕ (°)	20.17	19	19	6.51	42.44	20.98	19	19	6.54	42.73
γ (kN/m^3)	18.08	18.235	18.35	0.95	0.91	18.74	18.73	19.1	1.62	2.61
q_{ult} (kN/m^2)	565.83	424.37	371	458.70	210402.74	676.13	511	659	702.59	493626.84
q_{all} (kN/m^2)	189.16	141.455	115	152.57	23277.72	225.37	170	220	234.18	54839.48

3.2 Moisture Content

The moisture content in Kano metropolis as presented in Figure 2 ranged from 2.01 to 60.7%, with higher values predicted in parts of Kumbotso and Ungogo LGAs, and lower values in Dala and Fagge LGAs. The majority of the metropolis had intermediate moisture contents ranging from 16.7 to 31.4% (see Figure 2). These trends align with typical soil types, with higher moisture found in clayey soils and lower moisture in sandy soils. Variations in moisture content can be attributed to geology, hydrologic conditions, and weathering processes. The map provides insights into water retention characteristics and drainage conditions, which will impact geotechnical design. Higher moisture areas may require drainage systems and lower permeability, while lower moisture zones would have higher permeability. These findings are in agreement with the published data [25].

3.3 Specific Gravity

The range of specific gravity values in Kano metropolis as presented in Figure 3 is between 2.32 and 2.75, with high specific gravity in areas like Kano Municipal, Dala, and Ungogo Local Governments. The majority of specific gravity values fall within the 2.53 to 2.64 range, including Fagge, Gwale, Kumbotso, Tarauni, Nasarawa, and Ungogo LGAs. The variation in specific gravity values is relatively limited across different locations. The normal range for specific gravity values is 2.65 to 2.67 for sand, 2.67 to 2.70 for silty sand, and 2.70 to 2.80 for organic clay. The established normal range for specific gravity values is 2.65 to 2.67 for sand, 2.67 to 2.70 for silty sand, and 2.70 to 2.80 for organic clay [27]. Understanding the specific gravity of soil within the study area is crucial, as it offers valuable insights into the soil's composition and characteristics. This information is particularly pertinent for engineering and construction applications, as it aids in making informed decisions regarding foundation design, material selection, and construction methods, ultimately contributing to the success and durability of civil engineering structures within the region.

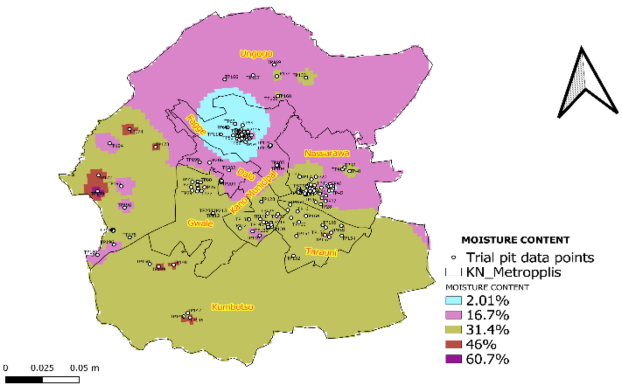

Figure 2: Spatial variation of moisture content

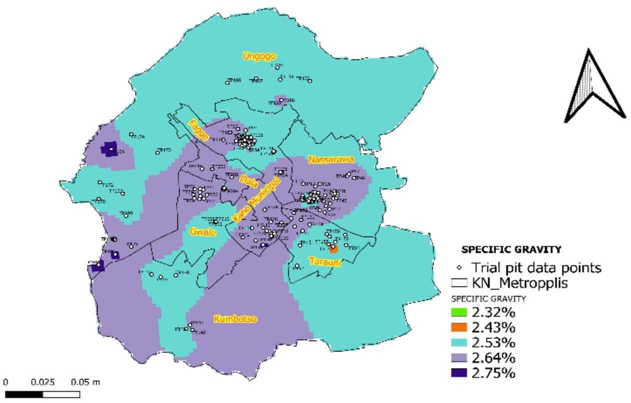

Figure 3: Spatial variation of specific gravity

3.4 Liquid Limit

The study predicts higher moisture contents in parts of Kumbotso and Ungogo LGAs, while lower moisture contents are found in Dala and Fagge LGAs. The

LGAs of Tarauni, Nassarawa, and Kumbotso have moderately high liquid limits between 26.5 to 35.7% as presented in Figure 4. The lower liquid limits in surrounding LGAs indicate more sand or silt-based soils. According to American Association of State Highway and Transportation Officials (AASHTO) soil classification, liquid limits above 35% are considered high plasticity clays, while those below 25% indicate low to medium plasticity. Higher plasticity soils in central LGAs may experience greater shrink/swell behaviour and require additional mitigation measures. Lower plasticity soils may have higher bearing capacity and less consolidation settlement under loading. This information can help tailor geotechnical design based on soil type variation across the metropolis and provide better delineation of zones that may require different foundation, excavation, or ground improvement approaches. The results are in line with published data [35].

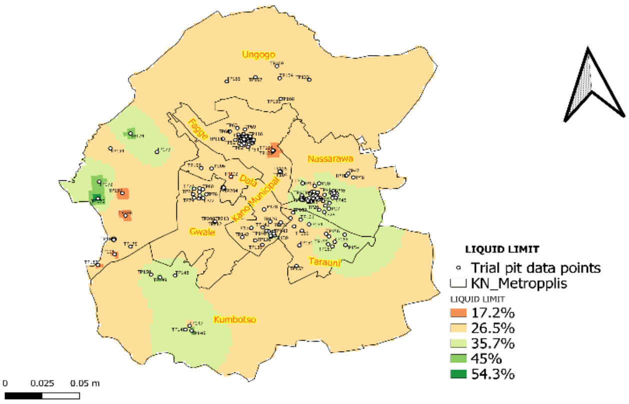

Figure 4: Spatial variation of liquid limit

3.5 Plastic Limit

The spatial variation of plastic limit is presented in Figure 5. Plastic limit values ranging from 10.1 to 40.59%, reflects the diversity of the soil types in the study area. Kumbotso LGA has the widest range, between 17.7 and 32.9%, likely due to the presence of diverse soil types like sandy loams, silty clays, and clay loams. Fagge and Nasarawa LGAs have a narrower range, between 17.7 and 25.3%, suggesting similar soil types. Dala, Gwale, Kano Municipal and Tarauni LGAs have a specific soil type, possibly lean clays or silty clays. Ungogo Local Government has a wider range, ranging from 10.1 to 32.9%, suggesting a mix of soil types, including sandy loams, silty clays, and clay loams. Figure 6 shows variation of plasticity index of the soil from the study area. From this Figure, the plasticity index generally ranges from 6- 43%. The plasticity index found around Fagge, Kumbotso, Nasarawa and Ungogo LGAs varies from 6 – 15%; while that of Dala, Gwale, Kano Municipal and Tarauni falls within 6%. The results are in line with published data [35].

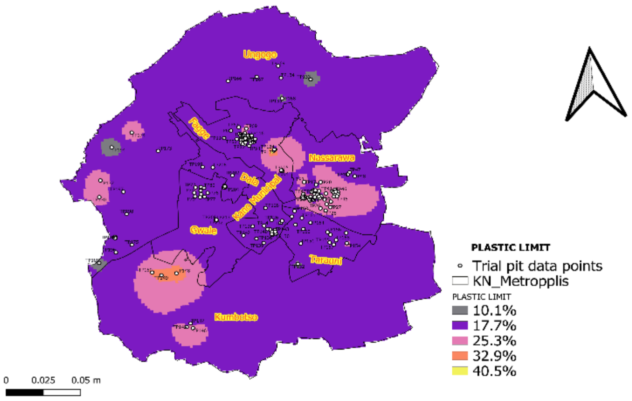

Figure 5: Spatial variation of plastic limit

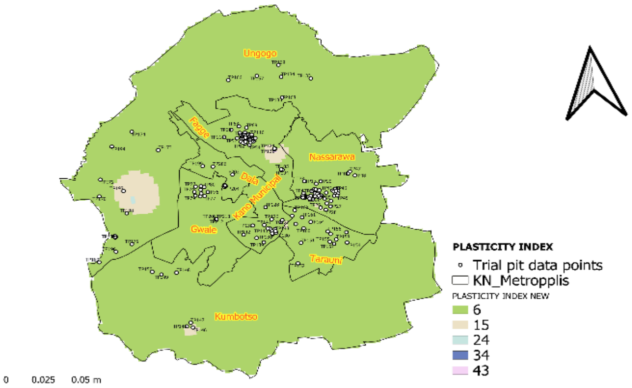

Figure 6: Spatial variation of plasticity index

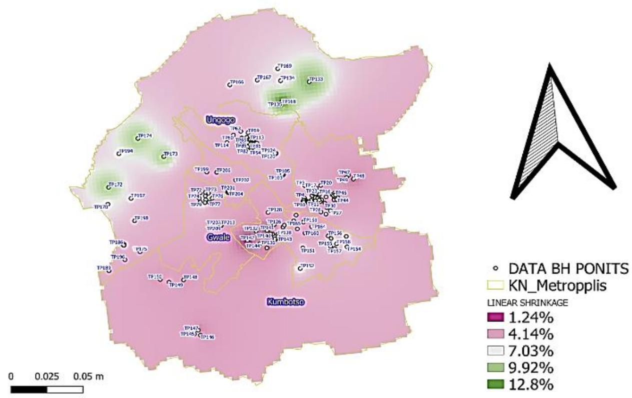

Figure 7: Spatial variation of shrinkage limit

3.6 Shrinkage Limit

Figure 7 presents the variation in linear shrinkage within the study area. The linear shrinkage values range from 1.24 to 12.8%. Ungoggo LGA has high linear shrinkage. Kano Municipal and Nasarawa LGAs have low linear shrinkage. Tarauni's linear shrinkage ranges from 4.14 to 7.03%. That of the remaining LGAs fall within the 4.14% range. Understanding linear shrinkage is crucial for assessing soil compaction, settlement, and its impact on construction projects. High linear shrinkage can lead to undesirable soil movement and cracking in structures, making this information crucial for engineers and construction professionals. This detailed mapping and analysis can empower decision-makers in the construction industry, making informed choices regarding construction techniques, material selection, and foundation design, ensuring the stability and durability of civil engineering structures in the study area.

3.7 Unit Weight

The variation of unit weight of the soil in the study area is presented in Figure 8. From this Figure the unit weight of soil in the study area ranges from 15.61 – 22.16 kN/m^3. The study reveals that the soil's density varies across different areas. High unit weight values are found in areas like Fagge and Ungogo LGA, with values ranging from 18.9 to 20.5 kN/m^3, indicating denser soil conditions. Conversely, the majority of the areas have values between 17.25 and 18.88 kN/m^3, as seen in Dala, Gwale, Kumbotso, Nasarawa, and some parts of Ungogo LGAs. Tarauni Local Government has a unit weight of 17.25 kN/m^3. This variation is crucial for geotechnical factors, affecting soil compaction, settlement, and foundation load-bearing capacity. Higher unit weight areas often require different construction approaches and materials. Understanding these variations help engineers and construction professionals make informed decisions about foundation design and construction methods, ultimately contributing to the stability and durability of civil engineering structures in the study area. These results are in line with published data [37].

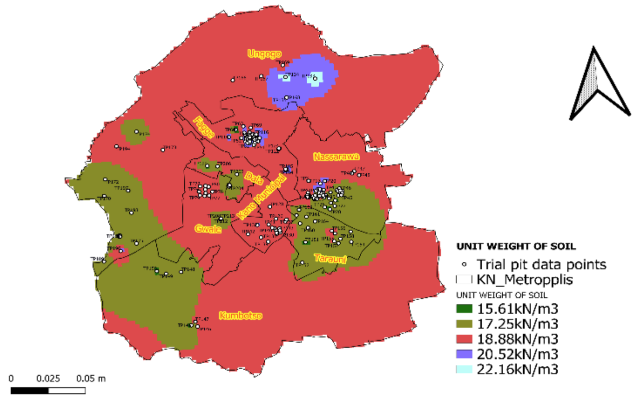

Figure 8: Spatial variation of unit weight

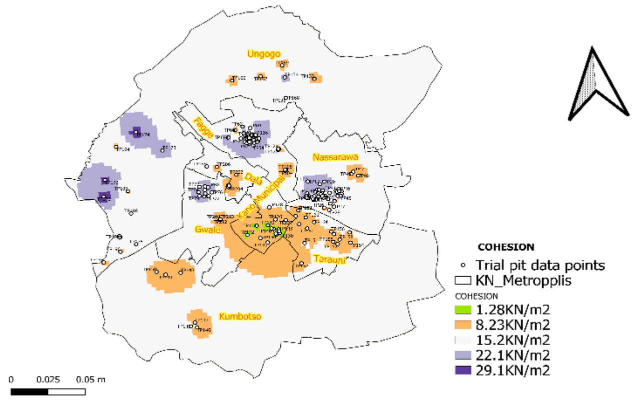

Figure 9: Spatial variation of soil cohesion

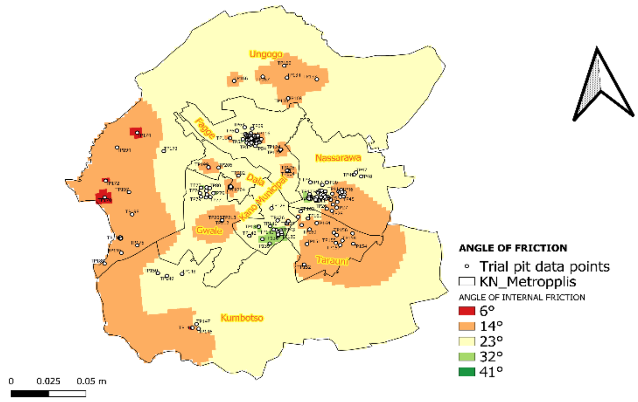

Figure 10: Spatial variation of angle of internal friction (ϕ)

3.8 Cohesion (*c*) of the Soil

Ccohesion (*c*) is crucial in geotechnical engineering, as it affects soil shear strength and stress resistance. As presented in Figure 9, the cohesion values range from 1.28 to 29.1 kN/m^2, with high values in areas like Fagge, Gwale, and Nasarawa LGAs, indicating a high clay content. Low values are shown in Dala, Kumbotso, and Tarauni LGAs, while Kano Municipal has low cohesion values. Understanding these variations is crucial for engineers and construction professionals to tailor construction methods, materials, and design approaches to suit the specific soil conditions in each region. This knowledge ensures the long-term performance and safety of civil engineering structures within the study area. The variation in cohesion is of paramount importance in geotechnical engineering, as it influences foundation stability, retaining structures, and slope stability. These results are in line/agreement with published data [11].

3.9 Angle of Internal Friction (ϕ)

The angle of internal friction (ϕ) of the soils in the study area ranges from 6 to 41°, with clay soil having a true angle of internal friction of 26° (see Figure 10). Granular soils have an angle of internal friction ranging between 28° to 50°. Higher angles of internal friction are found in areas like Kano Municipal, Fagge, and some parts of Nassarawa LGAs, while most areas have frictional angles between 14 and 23°. The distribution of grain size, angularity, and particle interlocking also affect a soil's friction angle. The angle of internal friction is a shear strength parameter that quantifies a soil's shear strength used for geotechnical designs and is determined through experimental analysis like the triaxial test. According to the Coulomb theory, the ultimate shear strength of soil is determined by soil internal friction angle and soil cohesion. These results are in line/agreement with published data [11].

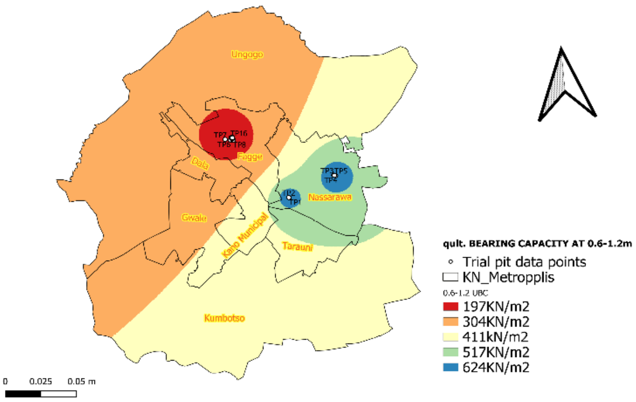

Figure 11: Spatial variation of ultimate bearing capacity at 0.6 -1.2 m depth

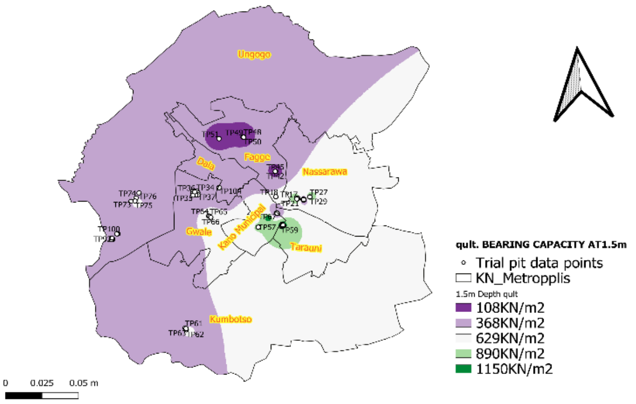

Figure 12: Spatial variation of ultimate bearing capacity at 1.5m depth

3.10 Ultimate Bearing Capacity

The variation of ultimate bearing capacity of soil at 0.6 – 1.2 m depth is presented in Figure 11. The ultimate bearing capacity of the soil in the study area was assessed at different depths, with results presented in Figures 11, 12, and 13. At the depth of 0.6 - 1.2 meters, the ultimate bearing capacity ranges from 197 to 624 kN/m^2. Areas with high bearing capacity include Nasarawa LGA, ranging from 517 to 624 kN/m^2, while Fagge LG exhibits lower bearing capacity, varying from 197 to 304 kN/m^2. Kano Municipal LG has an ultimate bearing capacity of 411 kN/m^2, and Dala has 304 kN/m^2. Tarauni's bearing capacity varies from 411 to 517 kN/m^2, and Gwale, Kumbotso, and Ungogo LGAs have a bearing capacity ranging from 304 to 411 kN/m^2, respectively. Based on the results, Nasarawa LG has the highest bearing capacity, followed by Kano Municipal, Tarauni, Kumbotso, Gwale, Ungogo, Dala, and Fagge LGAs. At a depth of 1.5 m, the ultimate bearing capacity ranges from 108 to 1150 kN/m^2. Higher bearing capacity areas are observed in Kano Municipal and Tarauni LGAs, ranging from 649 to 890 kN/m^2. Lower ultimate bearing capacity is found around Fagge LG, ranging from 108 to 368 kN/m^2. Gwale, Kumbotso, Nasarawa, and Ungogo LGAs have ultimate bearing capacity ranging from 368 to 629 kN/m^2, while Dala LG has a bearing capacity of 368 kN/m^2, respectively.

At the depth of 2.0 to 2.1 m, the ultimate bearing capacity ranges from 228 to 886 kN/m^2. Kano Municipal LG exhibits high ultimate bearing capacity, ranging from 392 to 886 kN/m^2. Nasarawa LG has a bearing capacity ranging from 228 to 886 kN/m^2, while Fagge and Tarauni LGAs show ultimate bearing capacity varying from 228 to 721 kN/m^2. Kumbotso LG has an ultimate bearing capacity of 721 kN/m^2, and Dala and Ungogo LGAs have a bearing capacity ranging from 392 to 557 kN/m^2. Lower ultimate bearing capacity is found around Gwale LG, ranging from 228 to 392kN/m^2. These results are in line/agreement with published data [36, 37].

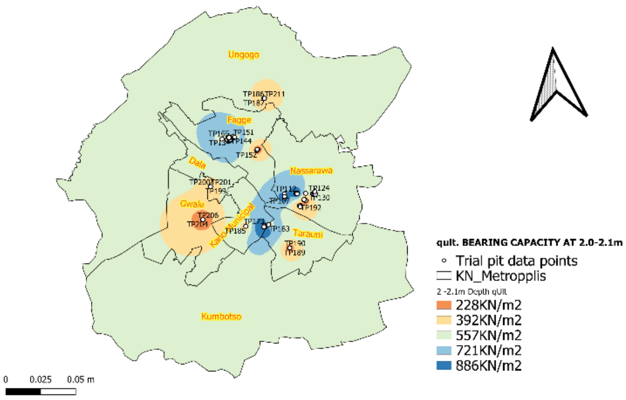

Figure 13: Spatial variation of allowable bearing capacity at 2.0 – 2.1m depth

The allowable bearing capacity at 1.5 and 2.0 – 2.1m depths are presented in Figures 14 and 15. The trend of allowable bearing capacity is similar to that of ultimate bearing capacity. At 1.5m depth, the allowable bearing capacity varies from 40 to 343kN/m^2. Tarauni LGA was found to be area with high bearing capacity (191 to 342 kN/m^2) while Fagge LGA has low bearing capacity (40 to 115kN/m^2). Other 6 LGAs possessed bearing capacity ranging from 195 to 267kN/m^2. At 2.0 – 2.1m depth, the allowable bearing capacity varies between 70 to 295kN/m^2. Kano Municipal possessed high bearing capacity (186 to 295kN/m^2), while Gwale Local

Government possessed low bearing capacity (70 to 131kN/m^2). Other LGAs possessed bearing capacity 131 to 240kN/m^2. These results are in agreement with the published results. It’s generally observed that both allowable and ultimate bearing capacities at 1.5m depth is higher than that of 2.0 – 2.1m depth, this could be attributed to the fact that water table in Kano metropolis is close to the ground surface.

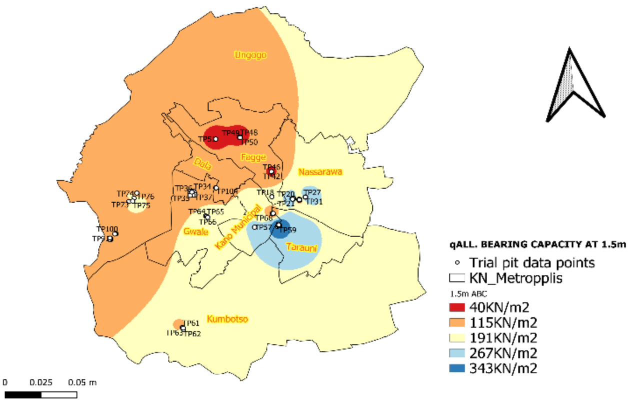

Figure 14: Spatial variation of allowable bearing capacity at 1.5m depth

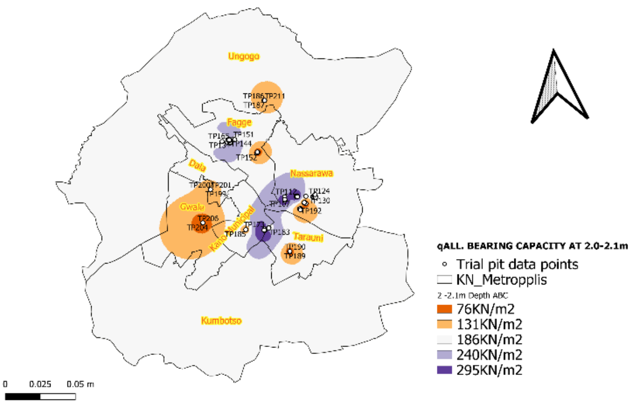

Figure 15: Spatial variation of allowable bearing capacity at 2.0 – 2.1m depth

4.0 CONCLUSSIONS

The geospatial analysis of soil properties in Kano Metropolis using GIS techniques has provided valuable insights for construction planning and design. Based on the map produced, the following conclusions were drawn.

(i) The moisture content of the soil within the study area ranges from 2.01 to 46% and specific gravity ranges from 2.32 – 2.75.

(ii) The map of Atterberg limit indicate that soils from Kano Metropolis possessed liquid limit values that ranges from 17.2 to 45%, plastic limit that ranges from 10.1 to 40.5%, plasticity index that ranges from 6.0 to 43% and linear shrinkage values that ranges from 1.24 to 12.8% and the soils within the study area are majorly classified as CL, SC and SM according to Unified Soil Classification System (USCS).

(iii) The soil within the study area possessed cohesion (c) values that ranges from 1.28 to 29.1 kN/m^2 and corresponding angle of internal friction (ϕ) that ranges from 5.5 to 32.2°. Although there is variation in the ultimate and allowable bearing capacity with depth; the ultimate bearing capacity (q_{ult}) generally varies between 108 to 1150kN/m^2 and the corresponding allowable bearing capacity (q_{all}) ranges between 40 to 343kN/m^2.

(iv) The ultimate and allowable bearing capacity maps at different depths provide essential information for foundation design, with Nasarawa Local Government exhibiting high bearing capacity and Fagge Local Government showing lower values.

(v) The research provides valuable data for construction projects in Kano Metropolis. The geospatial database and maps are essential tools for future projects, enhancing decision-making and contributing to the city's growth.

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