Implications of the Engineering Geological Properties of Soils in the Implementation of the Greater Jos Master Plan, North Central Nigeria

Hannatu N. Wazoh, and Stephen J. Mallo

Abstract — A study of the engineering properties of the subsurface soil in the Greater Jos Master Plan development area has been carried out to address the paucity of engineering data in the area. The study became necessary because the rapid urbanization has led to limited construction land with more ground prone to instability due to reworking by mining and related activities. The study area is located within Latitudes $09^{\circ} 48' 20''$ to $09^{\circ} 53' 20''$ N and Longitudes $08^{\circ} 53' 54''$ to $08^{\circ} 57' 00''$ E and extending over 54km^2 on Naraguta Sheet 168NE. Surface geological mapping was carried out to confirm the existing geology. Geotechnical properties of soils were determined by analysis of soil samples for 38 locations. While 94 static water level measurements provided additional information on groundwater conditions. The area is underlain by the Jos-Bukuru Complex rocks predominantly biotite granites differentiated on the basis of mode of formation, mineralogy and texture. Soils derived from weathering of the rocks revealed gradual decomposition from gravel, sand, and silt-sized particles to lateritic clays. The soils are considered to have low to medium plasticity/compressibility, expansiveness, and swelling potential across all rock types. The static water table depicts fluctuation in the water table varying between 2.9 and 3.9m. These findings are expected to serve as guide in the choice of design and construction and as a baseline subsurface soil compendium for planning and urban development in the Greater Jos Master plan and for further studies.

Key words — Geotechnical, Infrastructural development, Jos, Master Plan, Site Investigation.

I. INTRODUCTION

A. Background to the Study

Increase in housing infrastructures and roads development due to rapid urbanization in Jos metropolis has resulted in reduction of the ground available for new buildings, as the most favourable areas are already occupied. In view of this development, the Government of Plateau State has undertaken to create the 'Greater Jos Master Plan' where marginal lands are being developed for commercial, residential, recreational, and educational purposes [1]. However, these marginal areas are largely covered with soils which could be problematic soils and may be located adjacent to unstable slopes. Some of the areas were previously used for mine workings which may pose as possible areas of collapsing. Large plots of land have been reclaimed from mining pits which have not stabilized for municipal development. According to [2], ground conditions

in mine-out areas require exceptional consideration when engineering construction is intended because such lands undergo long term settlements under their own heavy weight. Thus, the understanding of the engineering properties is fundamental for the stability of civil engineering structures.

In geotechnical engineering, soils with properties that are not safe and cannot be economically used for the construction of civil engineering structures without adopting some stabilization measures are considered to be problematic [3]. These soils exhibit properties like volume change, severe cracking when dried, low bearing capacity when wet as well as low permeability. If these unique properties are not taken into considerations during selection, design, and subsequent construction of the foundations, they could pose major problem to foundations and subsequently lead to failure of the entire structure. According to [4], seasonal moisture changes, percentage of fine materials, Atterberg limits, dry density, permeability, and presence of vegetation trees are responsible for the volumetric changes associated with expansive soils. Hence, the determination of geotechnical properties such as swelling potential, index properties and clay mineralogy are significant to understanding swelling characteristics of soils [5]. The relationship between free swell index and index properties such as liquid limit, plasticity index, activity and shrinkage index provide a more direct relationship for determining swelling characteristics. Inadequate site investigation among other factors like poor drainage, age, climate, and lack of maintenance have been attributed to structural problems and failure of roads built on expansive soils [6]. Soils with low strength, high compressibility and high level of volumetric changes have been identified to cause numerous problems in geotechnical engineering [7]. Studies have revealed problem soils in Nigeria as those which exhibit low strength and high compressibility consequently being expansive and collapsible. Expansive soil is one of Nigeria's prevalent causes of damage to buildings and other construction works [8]. Another contributing factor to continual building failure and foundation collapses is attributed to the lack of sufficient information about the near-surface characterization preceding construction [9]. If adequate information is obtained prior to construction, it will guide in building design, foundation type, settlement rate and sub-soil bearing capacity.

Submitted on July 11, 2021.

Published on August 15, 2021.

H. N. Wazoh, Department of Geology, University of Jos, Nigeria.
(e-mail: hannatuwazoh@gmail.com)

S. J. Mallo, Department of Mining Engineering, University of Jos, Nigeria.

(e-mail: profsmallo@gmail.com)

According to [1], the need to establish the sub-soil condition of areas within the Greater Jos Master plan for stability and firm foundation of engineering infrastructure is of high requirements. Furthermore, some parts of the land previously subjected to mining activities left the land littered with mine spoils and reclaimed land yet to stabilize. These could pose problems to geotechnical engineers and serious limitations to urban expansion and planning as it relates to the Greater Jos Master Plan. As a topic of empirical investigation, the geotechnical studies of the Jos Plateau area have received relatively little attention. However, some few studies have been able to characterize the soils based on some engineering properties. Reference [10] characterized the lateritic soils of part of Jos-Plateau and environs based on their suitability for engineering construction. Reference [11] concentrated on built up areas within the Greater Jos Master Plan with focus on specific engineering structures such as roads and buildings revealing the soils to be of low to medium swelling potential and medium compressibility

making the soils good engineering materials. Reference [12] offered possible suggestions in overcoming further failures in a section of road within the Greater Jos Master Plan.

The instability phenomena and lack of detailed knowledge of the behaviour of the soils of Jos-Plateau represent a challenge to a safe urban planning for the city. This justifies the need for evaluation of engineering properties of the soils with a view to providing relevant data to the Greater Jos Master Plan. This research seeks to determine the engineering geological properties of the subsurface soils and their implications on foundation stability for engineering structures within the development areas of the Greater Jos Master Plan. The study area located within Latitudes $09^{\circ} 48' 20''$ to $09^{\circ} 53' 20''$ N and Longitudes $08^{\circ} 53' 54''$ to $08^{\circ} 57' 00''$ E extending over 54 km^2 situated within the Greater Jos Master Plan cover parts of Jos North, Jos South, and Jos East Local Government Areas (Fig. 1).

Fig. 1. Location Map of the Study Area on the Greater Jos Master Plan Planning Area (Modified after [1]).

B. Geology of the Area

The Greater Jos Master Plan area is underlain by Precambrian Basement Complex rocks which occupy valleys and lowland areas. In some places the Basement Complex rocks have been intruded by Precambrian to Late Paleozoic Pan-African Granites (Older Granite), diorite and charnockites which occupy about 20% of the surface. The Younger Granites Ring Complex rocks which occupy nearly 50% of the Jos Plateau intruded into the basement rocks [13]. The granites of the Jos Plateau are made up of alkali feldspar granites in association with rhyolites, minor gabbros and syenites. They occur as sub-volcanic intrusive complexes of ring dykes and related annular and cylindrical intrusions [14]. The development areas of the master plan being investigated lie within the Jos-Bukuru Complex and are mainly Younger Granites with occurrence of lateritized Older Basalts which have decomposed to lateritic clays and overlain by a thick cap of lateritic ironstone. The rock units are distinguished on the basis of mode of formation, mineralogy and texture and are Shen hornblende-fayalite, Jos biotite, N'gell biotite, Delimi biotite and Rayfield Gona biotite granites and Older Basalt (Fig. 2). The mineralogical compositions of the rocks are mainly quartz, feldspars, biotite and hornblende in the granite and feldspar, pyroxene, and olivine in the basalt with occurrence of some accessory minerals. The geology and the degree of weathering of rocks play a major role on the engineering behaviour of residual soils as foundation materials. This is greatly facilitated by taking into account the soil forming processes by which nature has created the various types of soils. Majority of engineering structures are founded on these residual soils resulting from weathering and decomposition of parent rock materials. Such soils vary considerably in characteristics and behaviour due to local variations in rock mineralogy, topography, rainfall, groundwater conditions and erosion processes. The soils associated with these rocks are basically clays, lateritic clays or laterite emerging from the weathering of the minerals in the rocks.

Fig. 2. Geology Map of the Study Area (Nigerian Geological Survey Agency, 2012).

II. MATERIALS AND METHODS

Basic geological mapping of the basalts and granites (parent rocks of the residual soils being investigated) were carried out. The boundaries between the soils and rocks were approximately inferred. The SPOT imagery was used to

generate the current geology map in relation to the weathering of the rocks. Areas previously mined and being reworked indicated by the presence of mine dumps and ponds were identified and marked out during the mapping.

A. Soil Sampling and Laboratory Tests

Once the trial pit was dug to the required depth, the topsoil was evacuated, while a hand shovel was used to collect disturbed soil samples and put into a polythene bag. Undisturbed soil sample was obtained by driving sample tubes into the trial pits in an undisturbed state. The samples were collected at a depth of between 1.0 and 3.0 m, sealed and taken to the laboratory for further visual examination and laboratory testing for field classifications and for determination of pertinent engineering properties. Fig. 3 shows the various sampling points.

Fig. 3. Soil Sampling Points.

B. Laboratory Analysis

The tests were carried out according to the procedures described in the relevant sections of [15]-[17]. Each soil sample is being classified on the basis of texture and plasticity in accordance with the Unified Soil Classification System (USCS).

1) Sieve Analysis

The Standard grain size analysis test determines the relative proportions of different grain sizes as they are distributed among certain size ranges [15]. Representative sample of 500 grams of the natural soil was oven dried and passed through a series of electrical sieves.

The result of the mechanical analysis was represented on a semi-logarithmic plot known as particle size distribution curve.

2) Atterberg Limits

The portion of air dried sample passing the British Standard sieve number 40 (0.425 mm) was used for these tests [16]. The sample was mixed with ordinary tap water up to plastic limit for about five minutes and left over night for 24 hours. Samples weighing 200g were passed through sieve 0.425 mm then mixed with distilled water to produce a uniform paste.

The two halves of the soil gradually flow together as the cup is repeatedly dropped [18]. The number of blows to close the groove was recorded. Small samples were taken from the centre of the closed groove for moisture content determination. This test was repeated four more times on each properly mixed paste with addition of dry powdered samples and the number of blows that closed each groove and corresponding moisture content for the soil was recorded. The moisture content at each stage was established and a graph of moisture content against specified number of blows was plotted. The best straight line between these points was drawn, and the moisture content corresponding to 25 blows on this line was taken as the liquid limit of the sample. Part of the soil sample paste of about 30 g was formed into a thread, approximately 6mm in diameter between the first finger and thumb of each hand. The thread was then placed on a glass plate and rolled with the tips of the fingers at one hand until its diameter was reduced to 3mm under a constant pressure. The thread was then remolded between the fingers. This procedure was repeated until the thread of soil sheared both longitudinally and transversely at a diameter of 3 mm. The procedure was repeated using three more parts of the sample and the percentage water content of all the crumbled soil was determined as a whole. This water content (to the nearest integer) is defined as the plastic limit of the soil [19].

About 40 g of the material used for the liquid limit test was taken and mixed properly with tap water to a creamy paste that can be placed in the shrinkage mould and smoothed off with a spatula without any air voids. The mould plus the paste was oven dried for 24 hours and the difference in the length of the paste was measured to give the shrinkage limit of the soil.

3) Compaction Test

The mould was filled with soil and excess soil was carefully trimmed off to the top of the mould. The weight of the mould and the soil was determined and recorded. The difference between this weight and that of the empty mould gave the weight of the compacted material. The mixture was compacted in a Standard proctor mould in three layers. Each layer received equal blows of 25 blows from a 2.5 kg rammer falling from a height of about 0.3005 m (1ft). The process was repeated at higher water content for each of the percentage mixtures and the dry densities were determined [20]. The maximum dry density values were gotten from the peak point of the compaction curve and its equivalent moisture content, also known as the optimum moisture content.

4) Triaxial Shear Strength Test

The undisturbed samples collected were extruded from the tubes into a mould where it was being removed and weighed (wet weight). The sample was covered with a rubber membrane to prevent loss or gain of moisture and set up in

the triaxial chamber cell where pressures of 15, 30 and 45 KN/m² respectively were used as confining pressures for the tests. The axial loading was applied electrically at a constant rate through a proving ring of known constant. The values of the major (ϕ_1) and minor (ϕ_3) principal stresses were used to construct the Mohr's circle of stresses with the normal on the x-axis and the shear strength on the y-axis. The Mohr's rupture envelope was obtained by drawing the tangent to the circles. The tangent intercepted at the y-axis and the y intercept gave the value of cohesion, c (intercept of the failure envelope), while the slope of the failure plane or the tangent line gave the angle of internal friction (γ) of the soil.

C. Descriptive Statistical Analysis

Descriptive statistical analysis was used to provide basic information about the geotechnical properties. It was also used to highlight the potential relationships between them. This was presented in the form of measure of central tendency and variability as mean, standard deviation, and range. The Statistical Package for Social Sciences [21] version 7 was used to perform the analysis.

D. Groundwater Condition

A measuring tape with a weight attached to the end was used for the measurements of the static water level of 95 hand dug wells during the wet and dry seasons. The tape was lowered into the well until part of the weight was below the water. A sound suggested that the water level had been touched. The depth below sea level, the elevation above sea level (in metres) and a GARMIN Map78s Portable Global Positioning System (GPS) unit were used to determine the location coordinates of the wells.

III. RESULTS AND DISCUSSION

The summary of the soil sampling points, sampling depth, rock types and geotechnical properties is presented in Table I. Thirty eight (38) soil samples were collected across the different soil derived rock types in the study area. Nineteen (19) of the samples were collected from the N'gell biotite granite derived soils because 50% of the study area is occupied by this rock type. Seven (7) samples each were collected from the Jos and Delimi biotite granite derived soils, three (3) from Rayfield gona biotite granite and two (2) from the lateritized older basalts derived soil.

A. Grading Characteristics

The percentage fines values range between 5.4 and 99%, sand is 1-91.8 %, and gravel is 0-78 % (Table II). The percentage of fines is >50% in locations 7, 25, 27, 28, 29,31, 32, 33, 34, 35, 36, 37 and 28 in areas around Latya, Kwang, Katon Rikkos and Dura. While locations 1, 3, 9, 10, 11, 16 and 17 in areas around Rayfield, Kwang, Gold and Base and Zot Shen have fines ≥ 20 -30%. This has further classified the soils based on the Unified Soil Classification System (USCS) as both well-graded (21.1%) and poorly-graded (78.9%) as indicated by Fig. 4a, b, c, and e.

The Jos biotite granite derived soil (Fig. 4a) shows larger proportion of sand-sized particles than clay-silt and gravel-sized. However, a few areas indicate high fines making those

locations poorly graded. The ranges of the grain size distribution are as follows: Gravel (3.3-26.2%); Sand (27-87.1%); Fines (8.1-66%). The soils are a combination of well-graded sand and gravelly sand (5-12% fines) at locations 18, 20 and 22 in Zot Shen, Dwei Du and Dura;

clayey sand, poorly graded sand-clay mixture (locations 1, 7, 8, 14, 15 in Rayfield and Dwei Du), and silty sand, poorly graded sand-silt mixture (locations 16, 34 in Zot Shen and Dura) with >12% fines.

TABLE I: SUMMARY OF GEOTECHNICAL PROPERTIES OF SOIL

Sample No./ Location	Sieve Analysis			LL (%)	PL (%)	PI (%)	LS (%)	Compaction Characteristics		Strength Parameters		Rock Type	Sampling Depth
	Gravel (%)	Sand (%)	Fines (%)					MDD (kg/m ³)	OMC (%)	γ (°)	C_u (KN/m ²)		
SP1, Behind Rayfield golf club	24.7	50.7	24.6	39.4	26.8	12.6	9.0	1.82	16	25	19	Rayfield Gona biotite granite	1.5
SP2, kwanga B	7.80	59.3	32.9	45.6	28.0	17.6	9.7	1.8	13.1	15	30	N'gell biotite granite	2.1
SP3, kwang	0.60	75.6	23.8	38.3	20.5	17.8	9.0	1.87	13.1	17	33	Delimi biotite granite	2.0
SP4, Kwang	8.10	76.3	15.6	31.7	21.4	10.3	7.0	1.79	18.9	19	31	N'gell biotite granite	3.0
SP5, Shaka	13.1	74.4	12.5	38.6	30.4	8.2	7.6	1.95	14.6	16	32	N'gell biotite granite	1.0
SP6, Kwang	0.70	54.9	44.4	47.6	36.7	10.9	9.2	1.60	23.1	20	17	Delimi biotite granite	1.2
SP7, Latya Rayfield resort	5.5	42.9	51.6	43.8	22.7	21.1	9.1	1.72	21.9	22	19	Jos biotite granite	2.0
SP8, Hei Rayfield	10.2	71.3	18.5	35.1	23.7	11.4	7.4	1.88	16.8	15	33	Jos biotite granite	1.0
SP9, Gold and Base	3.70	74.2	22.1	28.4	20.0	8.4	7.1	2.05	11.9	28	15	N'gell biotite granite	1.8
SP10, Rayfield New layout	0.70	77.4	21.9	28.0	20.6	7.4	7.0	2.05	11.9	21	17	N'gell biotite granite	1.0
SP11, Kwang Catholic cathedral	3.77	72.4	23.9	46.9	27.0	19.9	10	1.83	17.0	15	32	N'gell biotite granite	3.5
SP12, GuraTopp	13.4	67.8	18.8	36.6	24.1	12.5	9.4	1.76	15.3	23	18	N'gell biotite granite	1.5
SP13, Gold and Base	32.8	49.2	18.0	54.8	42.3	12.5	10.3	1.76	15.3	19	25	N'gell biotite granite	1.3
SP14, Fwapwa Dyenburuk	26.2	56.9	16.9	51.5	NP	NP	NP	1.75	20.0	24	15	Jos biotite granite	1.1
SP15, Dwei Du	3.70	64.2	32.1	22.8	9.1	13.7	7.0	1.89	12.0	15	28	N'gell biotite granite	1.2
SP16, Zot Shen	15.0	55.5	29.5	44.5	40.7	3.8	9.4	1.70	20.9	21	18	Jos biotite granite	1.5
SP17, Zot Shen	1.70	74.8	23.5	48.2	28.0	20.2	10.0	1.63	22.1	33	9	N'gell biotite granite	1.0
SP18, Housing estate Shen	5.80	83.7	10.5	39.0	27.5	11.5	8.9	2.11	8.2	37	9	Jos biotite granite	1.0
SP19, Dura	19.3	80.1	10.6	37.9	28.5	9.9	7.4	1.69	7.3	27	25	N'gell biotite granite	1.0
SP20, Dwei Du	3.30	86.5	10.2	45.8	28.5	17.3	8.5	1.86	15.6	30	11	Jos biotite granite	1.0
SP21, Latya	0.50	91.8	7.7	37.9	28	9.9	7.6	2.02	16.9	34	15	N'gell biotite granite	1.5
SP22, Dura	4.80	87.1	8.1	33.8	21.9	11.9	7.2	1.99	10.9	37	5	Jos biotite granite	1.9
SP23, Shaka	6.20	88.4	5.4	37.5	28.5	9.0	7.4	1.82	8.4	-	-	N'gell biotite granite	1.9
SP24, Rayfield	15.0	48.0	37	41.2	32	9.2	11.1	1.82	16	23	41	N'gell biotite granite	1.6
SP25, Kwang	8.0	38.0	54	47.8	37.7	10.1	10.9	1.74	18.1	-	-	N'gell biotite granite	1.4
SP26, Kwang	25.0	41.0	34	46.8	34.7	12.1	10	1.87	14.7	-	-	Delimi biotite granite	1.8
SP27, Housing estate Zot	13.0	34.0	53	51.0	37.2	13.8	10.7	1.89	17.3	30	21	Delimi biotite granite	1.5
SP28, Liberty dam	11.0	37.0	52	48.0	36.0	12.0	10.2	1.57	23.8	14	28	Older basalt	1.3
SP29, Liberty dam	5.0	40.0	55	48.2	37.6	10.6	10.0	1.54	22.7	17	24	Delimi biotite granite	1.0
SP30, Zot kwang	78.0	13.0	9	30.3	22.5	7.8	5.7	1.88	15.8	-	-	Delimi biotite granite	1.5
SP31, Latya	1.0	11	88	42.6	33.7	8.9	11.4	1.67	18.6	41	0	Rayfield gona biotite granite	1.0
SP32, Latya	7.0	40	53	37.5	28.7	8.8	7.1	1.80	15.0	34	27.6	Rayfield gona biotite granite	1.0
SP33, Latya	18	14	68	41	30.1	10.9	9.3	1.62	13.5	20	34.5	N'gell biotite granite	1.2
SP34, Dura	7	27	66	45.5	35.5	10	10	1.72	18.6	29	13.9	Jos biotite granite	1.3
SP35, Kwang	1	7	92	44.2	26.5	17.7	17.9	1.66	16	25	34.5	Delimi biotite granite	1.5
SP36, Kwang	0	1	99	38.0	23.0	15	10.7	1.72	14.5	12	20.7	N'gell biotite granite	1.8
SP37, Kwang	1	27	72	37.1	28.0	9.1	17.7	1.78	19.4	25	27.6	N'gell biotite granite	1.7
SP38, Zot Kwang	16	28	56	39.0	28.9	10.1	14.3	1.81	15.7	43	0	N'gell biotite granite	1.0

LL: Liquid Limit; PL: Plastic Limit; PI: Plasticity Index; SL: Shrinkage Limit; NP: Non Plastic; MDD: Maximum Dry Density; OMC: Optimum Moisture Content; ϕ : Angle of Friction; C_u : Cohesion.

TABLE II: DESCRIPTIVE STATISTICS FOR GEOTECHNICAL PROPERTIES

	N		Mean	Std. Deviation	Minimum	Maximum
	Valid	Missing				
Fines	38	0	36.0816	25.34744	5.40	99.00
LL	38	0	40.8395	7.10072	22.80	54.80
PL	37	1	28.5676	6.79310	9.10	42.30
PI	37	1	11.9973	3.94585	3.80	21.10
LS	37	1	9.5189	2.61872	5.70	17.90
MDD	38	0	1.8008	.13577	1.54	2.11
OMC	38	0	16.0763	4.06418	7.30	23.80
C_u	34	4	21.4353	10.20647	.00	41.00

Fig. 4a. Summary of Particle Size Distribution Curves on Jos Biotite Derived Soil

Fig. 4b. Summary of Particle Size Distribution Curves on N'gell Biotite Derived Soil.

Fig. 4c. Summary of Particle Size Distribution Curves on Delimi Biotite Derived Soil.

Fig. 4d. Summary of Particle Size Distribution Curves on Rayfield Gona Biotite Derived Soil.

Fig. 4e. Summary of Particle Size Distribution Curves on Older Basalt Derived Soil.

Percentage fines on N'gell biotite granite derived soil (Fig. 4b) are relatively low but sand-sized particles are generally high. However, a few locations indicate high fines. The size ranges are as follows: Gravel (0-32.8%); Sand (1-91.8%); Fines (5.4-99%). The soils are a combination of both well graded sand, and gravelly sand with little fines (5-12%) at locations 19, 21 and 23 around Dura, Latya and Shaka areas. It is clayey sand and poorly graded sand-clay mixture at locations 4, 9, 11, 15, 17, 36 around Kwang, Gold and Base, Dwei Du, and Zot Shen areas. It is poorly graded gravel and sand-silt mixture at location 2 (Kwanga B). It is silty sand and poorly graded sand-silt mixture at locations 10, 12, 24, 25, 33, 37, 38 around Rayfield, Guratopp, Latya and kwang areas and silty gravel and poorly graded gravel/sand-silt mixture at location 13 around Gold and Base (>12% fines).

The Delimi biotite granite derived soil (Fig. 4c) show gravel ranging between 0.6 and 78%, while sand and fines show 7-75.6% and 9-92%, respectively. This soil recorded the highest percentage of gravel at Zot kwang (location 30) where the soil is lateritic and well-graded gravel with little fines of <12% and clayey sand, poorly graded sand-clay mixture at locations 3 and 35 in Kwang (>12% fines). At locations 6, 26, 27 around kwang and Zot Shen it is silty sand, poorly graded sand-silt mixture (>12% fines).

The Rayfield gona biotite granite derived soil (Fig.4d) recorded a higher percentage of fines against the Jos, N'gell and Delimi biotite granites. The grain size distribution ranges are as follows: Gravel (1-24.7%); Sand (11-50.7%); fines (24.6-88%). Locations 1 and 31 around Rayfield and Latya are clayey sands, poorly graded sand-clay mixtures while location 32 around Latya is silty sand, poorly graded gravel/sand-silt mixtures with >12% fines. The percentage of fines on the Older Basalt derived soil is higher than the sand and gravel-sized particles ranging between 52 and 55% (Fig.4e). The sand-sized particle ranges between 37 and 40% while gravel ranges between 5 and 11%. The soils are silty sand and poorly graded gravel/sand-silt mixtures at locations 28 and 29 around Katon Rikkos. The presence of sand and gravels in the Older basalt derived soils could be due to the reworking of the area by mining activity and road construction which involved transporting of laterites from other areas which could have mixed with the soils.

B. Atterberg Limits

The liquid limit (LL) ranges from 22.8 to 51.5% and the plastic limit (PL) ranges from 9.1 to 42.3% (Table II). Soils with higher percentages of fines indicate increasing liquid limits values as revealed by locations 7, 25, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37 and 28 in areas around Latya, Kwang, Katon Rikkos and Dura. The plasticity chart classification is displayed in Fig. 5 with the soils varying in plasticity from non-plastic to up to 21.1%. Some samples plot above the A-line (locations 1, 3, 4, 7, 8, 9, 11, 15, 17, 22, 31, 35, 36) indicating clayey content while some plotted below the A-line (locations 2, 5, 6, 10, 12, 13, 16, 18, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30, 32, 33, 34, 37, 38) signifying silty content. Those that plotted on the left side of the vertical line have liquid limit (LL) values ranging from 22.8 to 48.2% for all locations while locations 13, 14 and 25 plotted on the right-hand side of the line with LL >50% signifying high compressibility across all these locations.

Fig. 5. Casagrande Plasticity Chart for Studied Soils.

The plasticity index (PI) ranges from 7.4 to 21.1% and falls in the low to medium swelling potential soil rating based on Tables III and IV. Soils around Rayfield, Kwang, Latya, Gold and Base, Dura and Zot Shen have low to medium plasticity while soils from katon Rikkos and Guratopp showed medium plasticity. However, some soils from Zot Shen, Latya and Fwatpwa-Dyemburuk revealed slightly higher values above the maximum range.

The linear shrinkage values vary between 5.7 and 17.9% implying the soils' tendencies of expansion is from low to medium rating across all rock types based on Table V.

TABLE III: ENGINEERING CLASSIFICATION USING PLASTICITY INDEX (PI) (AFTER [36])

Plasticity Index Range	Index Classification	Cassagrande Plasticity Classification	Studied Soils
<10	Low	Low plasticity/ low compressibility/high competence	5, 9, 10, 15, 19, 20, 21, 23, 24, 30, 31, 32, 37
10-20	Medium	Medium plasticity/medium compressibility/moderate competence	1, 2, 3, 4, 6, 8, 11, 12, 13, 14, 18, 22, 25, 26, 27, 28, 29, 33, 34, 35, 36, 38
>20	High	High plasticity/high compressibility/low competence	7, 14, 17

TABLE IV: RELATIONSHIP BETWEEN THE PLASTICITY INDEX AND SWELLING POTENTIAL (AFTER [35])

Plasticity Index (%)	Swelling Potential	Studied Soils
0 – 15	Low	1, 4, 5, 6, 8, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31, 32, 35, 36, 37, 38
15 – 25	Medium	2, 3, 7, 11, 17, 20, 35,
25 – 35	High	-
> 35	Very high	-

TABLE V: PROPOSED EXPANSIVE SOIL RATING (AFTER [39])

Liquid Limit (LL)	Plasticity Index (PI)	Linear Shrinkage (LS)	Expansive Rating	Studied Soils
<35	<18	<8	Low	3, 4, 5, 15, 22, 23, 30, 32
35-45	18-25	8-13	Medium	1, 2, 6, 7, 8, 9, 11, 12, 13, 16, 17, 18, 19, 20, 21, 24, 25, 26, 27, 28, 29, 31, 33, 34, 35, 36, 37, 38
45-60	25-35	13-18	High	
>60	>35	>18	Very high	

A. Compaction Characteristics

This indicates that the soil achieved a maximum dry density (MDD) value of between 1.54 and 2.11 kg/m³ and optimum moisture content (OMC) of 8.2 and 23.8% (Table II). The compaction curves (Fig. 6a, b, c, d, and e) present a wide range of curves across the rock types.

It shows the highest bulk density to which the soil may be compacted by a given force and the water content of the soil that is best for utmost compaction. All the granite rock types showed variation of high and low density/moisture content values. The lowest density (1.54 and 1.57 kg/m³) was recorded on the basalt derived soils while the highest density (2.1 kg/m³) was recorded on the N'gell Biotite Granite derived soils. Soils from Older Basalts (locations 28 and 29) indicate the lowest dry density values with rise in moisture

content which could be due to the high fines content in the soils.

Fig. 6a. Summary of Compaction Curves on Jos Biotite Granite.

Fig. 6b. Summary of Compaction Curves on N'gell Biotite Granite.

Fig. 6c. Summary of Compaction Curves on Delimi Biotite Granite.

Fig. 6d. Summary of Compaction Curves on Rayfield Gona Biotite Granite.

Fig. 6e. Summary of Compaction Curves on Older Basalt.

B. Soil Cohesion and Shear Strength Parameters

The shear parameters (cohesion, C_u and frictional angle of resistance, γ) are the main factors responsible for the strength of soil and they range from 12 to 43° and from 0 to 41 KN/m² respectively (Table II). It can be observed that high frictional angles varying between 30° and 43° and low frictional angles varying between 12° and 29° are spread across all the rock types. The soils with higher frictional values show lower compressibility, plasticity and swelling potential values across all rock types. The strength parameters show great variation with the index properties.

C. Groundwater Characteristics

The static water level records for both dry and raining season varied between 2.3 and 11.2 m with a mean of 5.6 m and a standard deviation of 1.8 3m. The wet season records a peak level of 2.7 m and lowest level of 0.0 m with a mean of 0.9 m and a standard deviation of 0.66 m.

IV. DISCUSSION

The relationship between geology and engineering properties of soils showed that rocks containing feldspars and quartz (felsic rocks) weather to kaolinite-bearing sandy soils, quartz being the sand fraction [22] and [23]. Reference [22]

also revealed that rocks containing ample mafic minerals (basalts) weather to montmorillonite-bearing silty soils, and most weathering products are separated by solution. Depending on the parent rock (felsic or basic) and grade of weathering, the type and amount of clay in the soil are basic guiding factors on the soil behaviour. Montmorillonite rich soils have shown high susceptibility to swelling because of the weak bonding between particles which makes water flow separate the particles as noted by [24]. The presence of sand and gravel-sized particles in the soils analyzed is therefore attributed to the resistance of quartz during weathering of the granitic parent rock. This means that the sand and gravel-sized materials decrease along with the increasing degrees of weathering resulting in the higher content of fines at different locations of the study area. However, the presence of sand and gravel-sized particles in the basalt derived soils cannot be ascribed to the mineralogy of the parent rock but could have been due to the reworking of nearby granitic derived soils and road construction that mixed with the basaltic derived soil. Study by [25] stated that the implication of higher percentage of fines in an engineering material is that the finer soil particles can be easily eroded away by water thereby decreasing the bonding between soils and making compaction difficult. This implies that areas around Latya, Kwang, Katon Rikkos and Dura with fines >50% will be more susceptible to erosion effect compared to the other areas. Percentage of fines is also used as an effective barrier material in waste disposal facilities. A soil is expected to contain appreciable quantities of fines that will enable it yield low hydraulic conductivity values when compacted. Some of these soils have values within the ≥ 20 -30% recommended by [26] and [27] for excellent hydraulic conductivity and as barrier for landfills. Soils from locations 1, 3, 9, 10, 11, 16 and 17 (Rayfield, Kwang, Gold and Base and Zot Shen) satisfy this criterion. However, with some modifications or reconstitution the hydraulic conductivity of the other locations can be improved. According to the Unified Soil Classification System [28], the soils can be classified as having low to intermediate compressibility with the LL ranging from 22.8–51.5%. The works of [10]–[12] also agree with the current study on the low to intermediate compressibility of the soils. However, locations 13 (Gold and Base), 14 (Fwatpwa) and 27 (Zot Shen) showed high compressibility of >50%. Reference [29] showed that clay gives soil higher compressibility resulting to settlement of foundation. The Casagrande plasticity chart (Fig. 5) placed soils from locations 13, 14 and 27 in the silty and not the clayey group of soils. Thus, the high compressibility displayed by these locations could be attributed to high water retention in the soils and not due to clay content.

Study of expansive soils by [30] showed that a liquid limit of up to 80% caused soil settlement in Canada. Other studies by [30]–[34], [24], and [6] recorded liquid limit values of 54 to 83% and classified the soils as expansive soils with greater compressibility tendencies. These values are far greater than values obtained from the current study and as such proof that the studied soils are not related to expansiveness. The plasticity values of the soils fall in the low to medium plasticity ($PI < 25\%$) based on the engineering classification of soils by [35] and [36]. The low plasticity soils are considered low compressibility and high competence while

the medium plasticity soils are considered moderate compressibility and moderate competence for foundation. For the soils to be useful as sub-base and sub-grade material, [37] and [38] recommended that the plasticity index should be less than the upper limit of 25%. Thus, all the studied soils are suitable for sub-base and sub-grade foundation materials because they have <25% plasticity index. The low to medium compressibility and swelling potential of the soils makes it less susceptible to differential settlement of foundation. By integrating the liquid limit, plasticity index and linear shrinkage, the expansive rating of locations 1, 2, 6, 7, 8, 9, 11, 12, 13, 16, 17, 18, 19, 20, 21, 24, 25, 26, 27, 28, 29, 31, 34, 35, 36, 37, 38 fall in the medium rating while 3, 4, 5, 15, 22, 30 and 32 fall in the low rating giving a general rating of low to medium tendency of expansiveness. This is in line with the rating of expansive soils by [39]. Reference [31] noted that physical properties such as liquid limit, plasticity index, linear shrinkage, moisture content are able to predict if a soil contains expansive clay without necessarily knowing the clay mineralogy. However, [40] noted that the shrinkage characteristics of a soil can help to delineate clay mineralogy (montmorillonitic-illitic-kaolinitic) of a soil being investigated. From the results of the Casagrande plasticity chart of the studied soils, the samples that plotted on the clay side of the chart also fall in the low to medium shrink-swell rating. Thus, it can be deduced that the clays present in the studied soils are likely not to be expansive clays. Their swelling and expansive ratings are similar to values related to kaolinite as studied by [41], and [7]. Thus, foundation settlement in the study area would not be attributed to soil shrink-swell characteristics but probably from water logging/poor drainage or structural problems.

The compaction test seeks to suggest the right combination of moisture (OMC) and load (compaction effort) on a soil that would result in increased density and thus improve its suitability in construction projects. Results indicated that the soil achieved an MDD value of 1.54-2.11 kg/m³ and OMC of 8.2-23.8%. These values are the maximum bulk density to which the soil may be compacted by a given force and the water content of the soil that is optimum for maximum compaction. If the soil is either drier or wetter than these values, the compaction will be more difficult. The lower densities observed on the basalt derived soils implies the granite derived soils would have higher densities compared to the basalt derived soils. Also, the basalt derived soils showed higher moisture content against the granite derived soils. Reference [42] opined that generally MDD decrease while OMC increases with increase in fines, but this does not agree with results of the study area. Only samples 28 and 29 showed an increase in OMC with increase in percentage fines.

The usefulness of soil for construction purposes is highly dependent on shear strength which has two components, cohesion (C_u) and angle of internal friction. There is no correlation between cohesion and amount of fines. Unlike the report of [43] that says there is an increase in cohesion with increase in clay content. This implies that if the hydrometer analysis for clay fraction determination is carried out on the studied soils, the clay percentage would not have any significant influence on the cohesion. In consonance with [44] that high angle of internal friction of soil encountered at

depth makes the soil competent for engineering foundation. This implies there will be variable competence on all soil types across the study area in terms of shear strength. Thus, areas with high internal friction values will have high competence. The shear parameters obtained are not fundamental properties of the soils; they can only be used to estimate the soil strength by substituting them into the bearing capacity formulae for soils at a known width and foundation depth.

Investigating the effects that changes in the groundwater regime will have on the engineering performance of soil and rock masses for foundation stability is significant prior to engineering construction [45]. Reference [46]) emphasized the importance of understanding the highest and lowest groundwater level for the purpose of design and construction of engineering structures. The depth to the static water level may change as the amount of water flowing into and out of the saturated zone changes. Measurements of static water level in hand dug wells in the study area showed that the static water level within the area is relatively shallow with a mean value of 5.5 m in the dry season and 0.9 m in the wet season. The measurements show that the depth to the water table increases and decreases during the wet and dry seasons respectively indicating fluctuation in the groundwater table. Groundwater levels in the study area were observed to vary from one season to the other and from one location to another. This could be attributed to discharge and evapo-transpiration exceeding recharge in the dry season, thereby decreasing the water in storage, and lowering the water levels. This agrees with the works of [47]-[50] on the fluctuation of groundwater condition which is due to climatic and human activity. According to [51], greater settlement would be experienced where foundation level is below the water table. If the water table fluctuates, additional settlement may occur. Thus, from the static water level measurements data of the study area, some parts of Rayfield, Latya, Shaka and Kwang may undergo higher settlement for shallow foundations because the water table will rise above the foundation depth during the wet season. In agreement with Shahriar *et al* [48], seasonal fluctuations like heavy rainfalls or floods will raise the water table of these areas to or beyond the footing level and produce additional settlements of shallow foundations.

V. CONCLUSION

The geotechnical properties are significantly influenced by the parent rock mineralogy and its degree of weathering as indicated by the variation in the physical properties of the soils. The presence of gravel and sand-sized particles is an indication of the mineralogy of the parent rock. Soils from granitic origin are generally high in sand-silt particles except in few cases whereas, the basalt derived soils showed silt-clay content. Irrespective of parent rock and mineralogical factor, all the studied soils exhibit low to medium swelling potential, compressibility, and expansiveness. However, soils developed over parent rocks of similar mineralogical composition showed variation between low and medium swelling potential, compressibility, expansiveness, density, and shear strength parameters due to variation in the degree of weathering. This goes further to indicate that the soils do

not contain expansive clays that will cause differential settlement caused by shrink-swell and compressibility properties. Though, the parent rock plays a significant role in engineering behaviour of soils, to a larger extent the degree of weathering and reworking of the soils by mining activity has played a greater significance in the studied soils. Groundwater characterization indicates a relatively shallow water table that fluctuates across the study area. Hence foundations within the zone of influence of shallow water table will be susceptible to settlement.

REFERENCES

- [1] Fola Konsult Limited, "Greater Jos Master Plan, Plateau State Government of Nigeria," pp. 1-110, 2009.
- [2] R. D. Krebs, and C. E. Zipper, "Foundation for housing and reclaimed mines land," *Virginia Cooperative Extension Publication*, vol. 460, no. 115, 2009.
- [3] T. Adejumo, M. Alhassan, and I. Boiko, "Physico- mechanical properties of some major weak soils in Nigeria," *Electronic Journal of Geotechnical Engineering*, vol. 17, pp. 2435-2441, 2012.
- [4] B. Kalantari, "Engineering significant of swelling soil," *Research Journal of Applied Sciences, Engineering and Technology*, vol. 4, no.17, pp. 2874-2878, 2012.
- [5] A. S. Rao, B. R. Phanikumar, and R. S. Sharma, "Prediction of swelling characteristics of remolded and compacted expansive soils using free swell index," *Journal of Engineering Geology and Hydrogeology*, vol. 37, pp. 217-226, 2014.
- [6] M. M. Zumrawi, "Pavement design on expansive clay subgrades," *University of Khartoum Engineering Journal*, vol. 3, no.1, pp. 52-58, 2013.
- [7] N. Ural, "The importance of clay in geotechnical engineering: current topics in the utilization of clay in industrial and medical application," *Intech Open*, 2018, ch. 5, pp. 8-102. Available: <https://doi.org/10.5772/intechopen.75817>.
- [8] A. Bolarinwa, "Geotechnical properties of major problem soils of Nigeria," Available: <http://engrdemol.hubpages.com/hub/geotechnical-properties-of-Nigerian-soils>, September 2010.
- [9] K. D. Oyeyemi, O. M. Olofinnade, A. P. Aizebeokhai, O. A. Sanuade, M. A. Oladunjoye, A. N. Ede, ... W. A. Ayara, "Geoengineering site characterization for foundation integrity assessment," *Congent Engineering*, vol. 7, no.1, pp. 1-16, January 2020. Available: <https://doi.org/10.1080/23311916.2020.111684>.
- [10] U. A. Lar, H. N. Wazoh, S. J. Mallo, and A. S. Chup, "Geotechnical Characterization of lateritic soils in Jos and Environs," *Nigerian Mining Journal*, vol. 9, no. 1, pp. 7-17, September 2011.
- [11] H. N. Wazoh, "Compaction behaviour and classification properties of soils of Kwang/Sheh, Jos-Plateau, North-central Nigeria," *Journal of Multidisciplinary Engineering Science Studies*, vol. 3, no. 2, pp. 1405-1408, February 2017.
- [12] H. N. Wazoh, S. S. Daku, and F. G. Samuel, "Investigative study of possible causes of failure of a section of road in Jos-Plateau, North Central Nigeria," *Journal of Multidisciplinary Engineering Research Science Studies*, vol. 2, no.11, pp. 1128-1132, November 2016.
- [13] C. A. Onyeonuna, "Interpretation of ring structures in Jos Plateau using Nigeria Sat 1 imagery," *International Journal of Mathematics and Physical Sciences Research*, vol. 4 no. 2, pp. 95-104, March 2017.
- [14] O. I. Ejeh., and C. F. Ugbe, "Fracture systems in the Younger Granite rocks around Fobur, Northern Nigeria: Product of residual stress?," *Global Journal of Geological Sciences*, vol. 8, no. 1, pp. 57-64, August 2010.
- [15] *British Standards*, 1377, part 1-9, "Methods of testing for soils for civil engineering purposes," British Standard Institute, Milton Keynes, 1990.
- [16] *British Standard*, 1377, part 2, "Methods of test for soils for civil engineering purposes: classification tests," British Standard Institute, Milton Keynes, 2000.
- [17] *British Standards*, 772, part 1, "Methods of test for masonry units: Determination of compressive strength," British Standard Institute, London, 2011.
- [18] R. F. Craig, *Craig's Soil Mechanics*, London: Spon Press, 2004, ch.1, pp. 7-21.
- [19] J. A. Knappet, and R. F. Craig, *Craig's Soil Mechanics*, London: Spon Press, 2012, ch. 1, pp. 3-37.
- [20] *Standard Tests Methods for Laboratory Compaction Characteristics of Soil using standard effort*, ASTM-D International, 698, West Conshohocken, PA, 2007. <https://doi.org/10.1520/D0698-12E02>.
- [21] Statistical Package for the Social Sciences (SPSS), (2019). Version 7.
- [22] S. F. Obermeier, and W. H. Langer, *Relationship between geology and engineering characteristics of soils and weathered rocks of Fairfax County and Vicinity, Virginia*, Tech. Rep., no. 1344, U. S. Geological Survey, 1986. <https://doi.org/10.3133/pp1344>.
- [23] H. W. Nesbeitt, C. M. Fedo, and G. M. Young, "Quartz and feldspar stability, steady and non-steady-state weathering and petrogenesis of siliclastic sands and muds," *The Journal of Geology*, vol. 105, pp. 173-191, 1997. <https://doi.org/10.1086/515908>.
- [24] U. Calik, and E. Sadoglu, "Engineering properties of expansive clayey soil stabilized with lime and perlite," *Geomechanics and Engineering*, vol. 6, no. 4, pp. 403-418, 2014.
- [25] A. C. Amagu, S. N. Eze, K. Jun-ichi, and M. O. Nweke, "Geological and geotechnical evaluation of gully erosion at Nguza Edda, Afikpo Sub-basin, Southeastern Nigeria," *Journal of Environment and Earth Science*, vol. 12, pp. 148-158, 2018.
- [26] D. E. Daniel, "Clay liners", In D.E. Daniel (Ed.), *Geotechnical practice for waste disposal*, London: Chapman and Hall, 1993, pp.131-163.
- [27] K. J. Osinubi, K. J. Eberemu, A. O. Bello, A. O., and A. Adzegah, "Effect of fines content on the engineering properties of reconstituted lateritic soils in waste contaminant application," *Nigerian Journal of Technology*, vol. 31, no. 3, pp. 277-287, 2012.
- [28] *Standard practice for classification of soils for engineering purposes (Unified Soil Classification system)*, American Society for Testing and Materials, ASTM-D2487 (2006). ASTM International, West Conshohocken, PA. <https://doi.org/10.1520/D2487-00>.
- [29] N. C. Brady, and R. R. Weil, "The Nature and Properties of Soil," New Delhi, India, Pearson Prentice Hall, 2002.
- [30] S. Azam, M. Ito, and R. Chowdhury, "Engineering properties of an expansive soil," *Proceedings of the 18th International Conference on Soil mechanics and Geotechnical Engineering*, pp.199-202, Paris, 2013.
- [31] J. Christodoulou, "Engineering properties and shrinkage limit of swelling soils in Greece," *Journal of Earth Science and climate Change*, vol. 6, no. 5, pp. 1-6, 2015. <https://doi.org/10.4172/2157-7617.1000279>.
- [32] A. H. Gally, "Engineering behaviour of lime treated high sulphate soils," MSc. thesis, University of Texas, Arlington, 2012.
- [33] S. Diop, F. Stapelberg, K. Tegegn, S. Ngubelanga, and L. Health, *A review of problem soils in South Africa*, Tech. Rep., No. 0062, Council of Geosciences, Cape Town, South Africa, 2011.
- [34] M. M. Zumrawi, A. O. Addelmarouf, and A. E. A. Gamwel, "Damages of buildings on expansive soils: diagnosis and avoidance," *International Journal of Multidisciplinary and Scientific Emerging Research*, vol. 6 no. 2, pp. 108-115, 2017.
- [35] S. A. Ola, "Mineralogical properties of some Nigerian residual soils in relation with building problems," *Engineering Geology*, vol. 15, pp. 1-13, 1981.
- [36] G. O. Adeyemi, and A. I. Oyediran, *Subsoil geotechnical investigations of five proposed building sites at the Mini Campus of the Adekunle Ajasin University*, Tech. Rep., Adekunle Univeristy, Akungba Akoko, Ondo State, 2004.
- [37] G. O. Adeyemi, "Geotechnical properties of lateritic soil developed over quartz schist in Ishara area southwester Nigeria," *Journal of Mining and Geology*, vol. 38, no.1, pp. 65-69, 2002.
- [38] G. M. Olayanju, "Engineering geophysical investigation of a flood zone: A case study of Alaba Layout, Akure, southwestern," *Nigeria Journal of Geology and Mining Resource*, vol. 3, no. 8, pp. 193-200, 2011.
- [39] R. Tadanier, and V. V. Nguyen, "Index properties of expansive soils in New South Wales," presented at the 5th International Conference on Expansive Soils, Adelaide, South Australia, 1984.
- [40] A. B. Cerato, and A. J. Lutenege, "Shrinkage of clays," *Proceedings of the 4th International Conference on unsaturated soils*, vol. 147, no. 1, pp. 1-12, Phoenix, 2006. [https://doi.org/10.1061/140802\(189\)89](https://doi.org/10.1061/140802(189)89).
- [41] M. Alhassan, A. M. Mustapha, and E. Mesaiyete, "Influence of clay mineralogy on plasticity of lateritic soils," *Journal of Mechanical and Civil Engineering*, vol. 11, no. 93, pp.13-21, 2014. <https://doi.org/10.9790/1684-11341821>.
- [42] S. O. Odunfa, A. O. Owolabi, P. O. Aiyedun, P., and Q. M. Sadiq, "Geotechnical assessment of pavement failures along Lagos-Ibadan express way," *FUOYE Journal of Engineering and Technology*, vol. 3 no. 2, pp. 114-117, 2018.
- [43] A. M. Dafalla, "Effects of Clay and Moisture Content on Direct Shear Tests for Clay Sand Mixtures," *Advances in Materials Science and Engineering*, 2013. <https://doi.org/10.1155/2013/562726>.

- [44] M. O. Ofomola, R. E. Iserhien-Emekeme, I. O. Okocha, and T. O. Adeoye, "Evaluation of subsoil competence for foundation studies at site III of the Delta state University, Nigeria," *Journal of Geophysics and Engineering*, vol. 15, no.3, pp. 638, February, 2018.
- [45] F. G. Bell, J. C. Cripps, and M. G. Culshaw, "A review of the engineering behaviour of soils and rocks with respect to groundwater," *Groundwater in Engineering Geology special publication*, London, vol. 3, pp. 1-23, 1986. Available: <http://egsp.lyellcollection.org/>.
- [46] N. D. Umar, I. G. Idris, and A. I. Abdullahi, "Groundwater fluctuation in response to climatic variation and its geotechnical implication in part of Awgu shale, central Benue trough, Nigeria," *International Journal of Advanced Geosciences*, vol. 6, no. 2, pp.178-183, 2018. <https://doi.org/10.14419/ijag.v6i2.12660>.
- [47] C. J. Taylor and W. M. Alley, "Ground-water-level monitoring and the importance of long-term-water-level data," U.S. Geological Survey Circular 1217, Denver, Colorado, 2001.
- [48] M. A. Shahriar, N. Sivakugan, A. Urquhart, M. Tapiolas, and B. M. Das, "A study on the influence of groundwater level on foundation settlement in Cohesionless soil," *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical engineering*, Paris, 2013.
- [49] Y. Yihdego, C. Danis, and A. Pafford, (2017). Groundwater engineering in an environmentally sensitive urban area: assessment , landuse change/infrastructure impacts and mitigation measures. *Hydrology*, vol. 4, no. 37, pp. 1-19, 2017. <https://doi.org/10.3390/hydrology40830037>.
Y. Shao-feng, Y. Shuang-en, W. Yu-bai, P. Dafeng, S. Dong-li, and J. Jianzhong, "Seasonal variations in groundwater level and salinity in coastal plain of Eastern China influence by climate," *Journal of Chemistry*, vol. 90510, pp. 1-8, 2015. <https://doi.org/10.1155/2015/905190>.
- [50] F. G. Bell, *Engineering Geology*, Amsterdam: Elsevier Ltd.2007, ch.9, pp. 1-453-539.

Hannatu Nanman Wazoh holds a Bachelor Degree in Geology and Mining (1999), and a Master's degree in Hydrogeology/Engineering Geology (2010) from the Department of Geology, University of Jos, Nigeria.

She is a Lecturer with sixteen years' experience at the Department of Geology, University of Jos, Nigeria and a PhD Candidate in the same Department. Her research interests are in the field of engineering geology, engineering geophysics, hydrogeology and site investigation. She has published research papers in both local and internationally peer reviewed Journals.

Mrs. Wazoh is a Corporate Member of Nigerian Mining and Geosciences Society (NMGs), Registered Member of Council of Mining Engineers and Geoscientists (COMEG), and a Corresponding Member of the Young Members' Presidential Group (YMPG) of International Society for soil Mechanics and Geotechnical Engineers (ISSMGE).

Steven Jackdell Mallo is a Professor of Mining Engineering in the Department of Mining Engineering, University of Jos. He holds a Master of Science and PhD degrees from the St Petersburg Mining Institute, Russia with specialisation in Design and construction of Deep Metal Mines. He holds a Master in Business Administration (MBA) and a Master of International Affairs and Diplomacy (MIAD) from the Ahmadu Bello University Zaria, Nigeria.

He attended the prestigious National Institute for Policy and Strategic Studies Kuru, Nigeria (2003).

Professor Mallo is a Fellow of the Nigerian Society of Engineers a chartered Manager. He is a 2009 holder of Nigerian National Honour. He has published works in Scientific Journals and authored books on Mineral Deposit Assessments. He served as a Member, National Committee for the establishment of Roadmap for the Development of Minerals in Nigeria. He has been Head of Department, Pioneer Dean of Faculty of Mining Engineering, University of Jos, Rector of Plateau State Polytechnic, and acting Vice-Chancellor, Plateau State University, Nigeria.