



Geochemical, Index, and Strength Appraisals of Granite-derived Residual Soils

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Authors' contributions

This work was carried out in collaboration among all authors. Author COI designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author OOO managed the analyses of the study. Author IAR managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This research work examined the geochemical, index, and strength properties of lateritic residual soils from granitic parent rock in Akure, southwestern Nigeria. The aim is to underscore the potential use of such soils as engineering fills materials. The geochemical method involved the use of X-Ray Fluorescence (XRF). The major oxides determined from this analysis were used for the geochemical quantifications of the soils. Analysis of soil index properties involved consistency limits, grain size distribution and specific gravity tests, while the strength analysis involved compaction and unconfined compressive strength (UCS) tests. Results obtained from the index analysis classified the soil profile into behavioral groups VII and VI. These indicates that the soils are of high to intermediate plasticity and compressibility. The UCS values vary from 272.6 to 377.2 kPa while the shear strength values range from 138.8 to 188.6kPa, indicating good bearing capacity. The geochemical results revealed iron-oxide variations as the major influential constituent within the soil profile. Furthermore, the more lateritized zones correspond with the more competent horizons. The residual soils from the study area are found to be suitable materials in engineering construction works as Sanitary landfills and Subgrade materials.

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1. INTRODUCTION

Granite-derived lateritic residual soils are relatively cheap, common and widely use as construction materials for civil engineering structures [1]. Laterite is characterized with low activity value, high bearing capacity, low permeability, intermediate plasticity and non-swelling clay minerals with predominant oxides of Alumina (Al_2O_3), Silica (SiO_2) and Iron oxide (Fe_2O_3) [2]. These inherited intrinsic properties and qualities of the laterite soil have endeared the engineering properties and performance especially as engineering fills materials in construction works. Inorganic inactive clay, high plasticity, minimum of 30% fines, minimum of 15% of clay, plasticity index > 7% and minimum unconfined pressure of 200kPa are certain geotechnical recommendations for mineral seal [1]. While $LL > 50\%$, $PI \geq 30\%$ and relative compaction $\geq 90\%$ are part of the requirements for suitable subgrade material according to [3]. However, it had been found that inherited intrinsic properties and placement conditions are greatly related to degree of weathering within the lateritic profile [2]. The variability in depletions of the constituent major oxides within the profile of residual soil has consequential effect on the characteristic of the superficial deposits [4]. [5] reported that reduction in ratio of silica (SiO_2) to sesquioxides (Fe_2O_3 , Al_2O_3) results into reduction in engineering property of soil materials. Furthermore, [6] claimed that the Iron oxide present in the soils binds individual soil grains into coarser aggregates of concretionary structure and thereby enhanced the soil mechanical stability. The variability of geochemical compositions within the lateritic soil profile account for the formation of distinct horizons and consequence geotechnical properties. Therefore, more attention should be given to know the effect of varying geochemical compositions in relation to the engineering characteristics of residual soils.

The geotechnical properties have been studied [7,8,9]. However, hardly had any work been reported on geochemical quantifications along with strength characteristics of the distinct horizons and varying geochemical compositions of the soil. This study intends to bridge the gap between the geotechnical and geochemical information and properties of the studied soil.

1.1 Study Area

The study area is located along Akure/Ijare road within Akure Metropolis of Ondo-State. The study location (Ilere-junction) lies within latitudes $07^{\circ}18'$ and $07^{\circ}19'N$ and Longitudes $05^{\circ}08'$ and $05^{\circ}09'E$ (Fig. 1 A & B). The topography of the study area is slightly undulating with rounded low hills, occasional often elongated ridges indicating the characteristics residue setting of a typical basement terrain with an average daily temperature greater than $30^{\circ}C$.

1.2 Geology

The Nigerian Basement Complex (NBC) lies within the remobilized zone of West African craton. The major rock types of the NBC as classified by [10] are (a) migmatite gneiss-quartzite complex; (b) the schist belts which are low to medium grade supracrustal and meta-igneous rocks; (c) the Pan African granitoids (Older Granites) and other related rocks such as charnockitic rocks and syenites and (d) minor felsic and mafic intrusive. Among these, the following lithologies namely; (i) migmatite, (ii) gneiss, (iii) quartzite, (iv) porphyritic biotite granite, (v) charnockitic rocks and (vi) other minor rock types are represented in Akure. The rocks listed (iv) to (vi) have been found to have intruded the migmatite gneiss-quartzite complex. The study location is dominated by medium-coarse grained biotite granite (Fig. 1). The geology of Akure/Ijare road consists of mainly of rock of charnockitic rocks and medium-coarse grained biotite granite. The rocks generally occur as low lying outcrops.

2. MATERIALS AND METHODS

The material used for this study was porphyritic biotite granite-derived residual soil. The soil samples were taken at profile depth A: 0.0 - 1.5 m, B: 1.5 - 2.5 m, C: 2.5 - 4.0 m, D: 4.0- 5.0 m depths of the exposed soil profile respectively (Fig. 2). Labelled and transported to Federal University of Technology Akure (FUTA) for geotechnical analysis while pulverized samples were taken to Engineering and Material Development Research Institute (EMDI), Akure for geochemical analysis. The Index and Strength tests were carried out using British Standard procedures [12]. The Index analysis carried out were moisture content, grain size

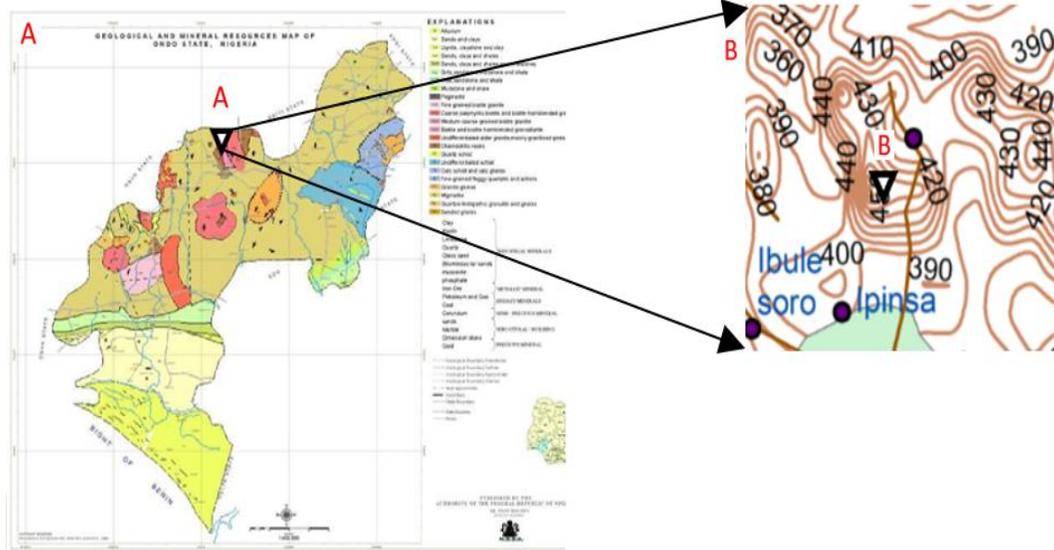


Fig. 1. Map of study location

Fig. 1. (A) Geological Map of Ondo Metropoli [11] (B) Sample location base map

analysis, consistency limits, and Specific gravity. The sieve analysis was conducted on the clay soil using the wet-sieving method [12]. The liquid limit of the samples was determined using the Casagrande apparatus method, in accordance with [12].

The procedure for the determination of the plastic limits and plasticity indices were performed in accordance with [12]. The specific gravities of the samples were determined in accordance with the procedures outlined by [12]. Strength analysis involved Compaction and Unconfined Compressive Strength tests. The compaction characteristics of the samples were determined using the procedures outlined in [12]. The data of the index properties were used to classify the soil following the Unified Soil Classification System (USCS) classification and American Association of State Highway and Transportation Official [13].

2.1 Geochemical {X-Ray Fluorescence (XRF) Analysis}

The bulk chemical compositions of the soil samples were determined by X-Ray Fluorescence (XRF) analysis. The technique reports concentration as % oxides for major elements. The Major oxides determined were used for various classifications and quantifications of the soils engineering properties.

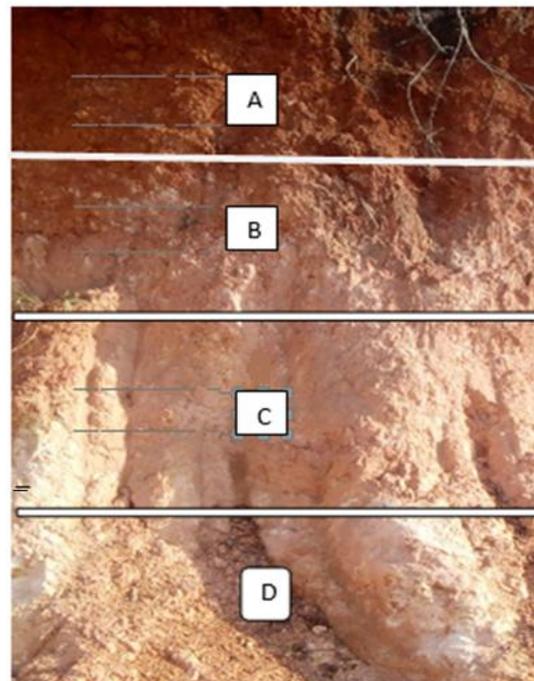


Fig. 2. Different horizons of the lateritic soil profiles

3. RESULTS AND DISCUSSION

3.1 Classification Tests

Grain size distribution analysis results are presented in Table 1. The average amounts of

clay fraction and fines contents was 48.9% and 81.2%. It can be seen that these proportion exceed the recommended 15% clay and 30% fines required to achieve low permeability $\leq 1 \times 10^{-7}$ according [14]. Thus, the studied soils can be used as mineral seal to achieve a low permeability $\leq 1 \times 10^{-7}$. The soil contains adequate amount of sand, which may offer notable protection from volumetric shrinkage and impart adequate strength as well.

3.2 Consistency Limits

The more plastic a soil means the more compressible, higher shrinkage-swell potential and the lower is its permeability will be. The Consistency limits results are presented in Table 2. The liquid limits (LL) values range from 54.6 to 56.3% and 41.1 to 44.2%. While the plasticity index (PI) values vary from 30.30 to 31.2% and 17.20 to 18.95%. This indicates suitable lateritic soil for subgrade materials according to [3], which stipulated $LL > 50\%$ and $PI \geq 30\%$. Furthermore, the results distinguish profile into two distinct behavioral groups VII and VI, horizons (A & B) and (C & D) respectively. Characteristically, behavioral groups VI soil has low plasticity properties compared with VII group see Table 2. This indicates that horizons (A&B) would be more suitable as mineral seal materials compared to horizons (C&D) due to higher plasticity and lower permeability. The Shrinkage limits (SL) ranged from 7.7 to 9.1% indicating low to medium swell potential [15]. These results classify the soils as low to moderately competent geomaterials. Hence, the soils can find application in environmental engineering such as land sanitary fill and dam core construction.

3.3 Activity Values and Inferred Clay Mineral

Table 2 shows that activity values range from 0.33 to 0.67% indicating inactive lateritic according to [16]. Furthermore, the inferred clay mineral (ICM) showed the predominant clay

mineral as kaolinite across the soil profile. This result affirmed the result obtained from activity values, suggesting non-swelling potential properties of the soil according to [17]. These results affirm the suitability of the materials as suitable for mineral seal and subgrade materials.

3.4 Specific Gravity

As shown in Table 2, the Specific gravity decreases down the soil profile. [5] reported that decrease in Specific gravity values has to do with the reduction in degree of laterization and reduction in engineering property of the materials involved. This indicates reduction in the Soils engineering properties down the soil profile.

3.5 Geochemical Studies

3.5.1 Major oxides

The geochemical properties of soils are important and can provide insight into their behavior or reaction with other materials. Table 3 presents results of the oxides composition of the residual clay soil profiles. It shows that silica (SiO_2), alumina (Al_2O_3) and iron (III) oxide (Fe_2O_3) are the dominant oxides. Silica constitute more than 40%, followed by relatively stable alumina of about 30%, and then the Iron oxide which exhibited high degree of reduction down the soil horizons ranging from 31.44% at A horizon to 2.10% at D horizon Table 3. The result revealed Iron oxide as the most depleted oxide among the three dominant and the principal oxide in the profile. Meanwhile, iron oxide present in the soils binds individual soil grains into coarser aggregates of concretionary structure [6]. Therefore, down the soil profile, engineering properties such as unconfined compressive and shear strength reduces due to reduction in the constituent iron oxide content. This indicates that Iron oxide (Fe_2O_3) is the main influential varying oxide along the soil horizons within the lateritic soil profile.

Table 1. Results of some physical properties for clay

Horizon	Clay %	Silts %	Fines %	Sand %	Gravel %	Coarse %
A	46.9	27.2	74.1	24.8	1.1	25.9
B	55.5	20.6	76	23.9	0	23.9
C	40.7	45.6	86.3	13.7	0	13.7
D	52.6	35.7	88.4	11.6	0	11.6
Average	48.9	32.3	81.2	18.5	0.3	18.8

Table 2. Specific gravity, consistency limits properties and classifications of the studied soils

Terrain	Specific gravity %	Liquid limit %	Plastic limit %	Plasticity index	Shrinkage limit %	Linear shrinkage %	Activity value	ICM	USCS	AASHTO & GI	BG
A	2.72	56.3	25.1	31.2	9.1	11.4	0.67	K	CH	A-7-5(7)	VII
B	2.68	54.6	24.3	30.30	7.7	11.4	0.55	K	CH	A-7-6(7)	VII
C	2.67	44.2	25.3	18.95	8.6	9.6	0.47	K	CI	A-7-6(2)	VI
D	2.66	41.1	23.9	17.20	8.6	9.6	0.33	K	CI	A-7-6(2)	VI
Average values	2.68	49.05	24.65	24.41	8.50	10.5	0.51	K	CI	A-7-6(4)	VI

Table 3. Major oxides of the soil profiles

Name	A	B	C	D
SiO ₂	40.61	52.20	51.29	47.91
Al ₂ O ₃	31.3	38.71	38.71	36.89
Fe ₂ O ₃	31.44	18.93	17.87	2.10
MnO	0.06	0.04	0.03	0.00
MgO	0.00	0.00	0.00	0.00
CaO	0.09	0.12	0.13	0.12
K ₂ O	0.20	0.16	0.21	0.01
TiO ₂	0.92	4.22	0.67	0.00
V ₂ O ₅	0.03	0.04	0.03	0.03
Na ₂ O	0.06	0.05	0.06	0.01

3.6 Geochemical Quantification

3.6.1 Lateritization

The results of average silica-sesquioxide molar ratio (SSMR) values by w% of the studied soil samples are presented in Tables 4 and Fig. 3. The values range from 0.64 to 1.23, indicating true laterites soils [18]. However, the result suggests that A horizon is the most lateritized. This is attributed to more of ferric oxide up the soil profile (Table 4). This suggests better crystallization of accumulated sesquioxides in the pore spaces and the formation of concretionary structure [6] in upper the horizons.

3.7 Bonding Resistance and Stabilization Properties

Table 4 and Fig. 3 show the results of the stabilization and bonding strength according to [19]. The value of the stabilization property by wt% ranges from 62.74 at horizon A to 38.99 at horizon D. The result shows reduction in soil structural formation (matrix) resulting into weak mechanic stability down the profile with UCS values ranging from 377.2 to 272.6kPa. Therefore, the soil profile possesses the highest stabilizing potential at upper horizons A and B. This is attributed to the reduction in the Iron

oxide content down the profile which reflected in strength parameters (Table 5). The bonding strength results also show similar trend with the stabilization property. This indicates highest shearing resistance and bearing capacity at Uppermost horizon (A) and least at the lower horizon (D) [2]. This may have accounted for the better MDD and UCS as reflected in the strength tests (Table 4 and Fig. 3).

3.8 Strength Characteristics Compaction Properties

Table 5 and Fig. 4 show a decrease in the MDD and increase in the OMC values down the soil profile across horizons except for slight variation between horizon C and D. The observed trend in MDD vs OMC may be attributed to the percentage of fines and coarse particles occurrence in the soil samples along the profile (Table 1) in addition to degree of lateritization (Table 4). This indicates better densification and compatibility properties resulting from the filling of available voids in the soil with silica grains and concretionary structure [6,20]. Horizon A had the best engineering properties according to [21]. The samples taken from horizon B exhibit lowest engineering properties within the profile. Hence, Lateritic soils from A will then be more suitable as geomaterials than others.

Table 4. Geochemical quantification and engineering properties

Name	A	B	C	D	Properties
SiO ₂ /Al ₂ O ₃ + Fe ₂ O ₃	0.65	0.91	0.91	1.23	Lateritization
Al ₂ O ₃ + Fe ₂ O ₃	62.74	57.64	56.58	38.99	Stabilization
AFMC	62.83	57.76	56.71	39.11	Bonding strength

AFMC = Al₂O₃ + Fe₂O₃ + MgO + CaO

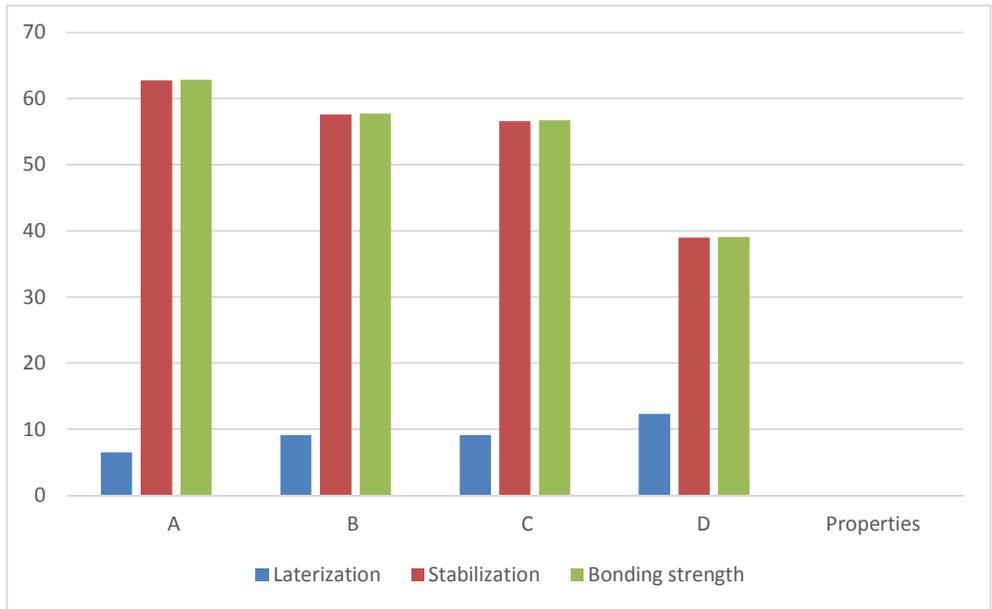


Fig. 3. Showing the geochemical quantification and engineering properties

Table 5. Strength parameters

Horizons	MDD (%)	OMC (%)	UCS (kPa)	Shear strength (kPa)
A	1772	22.4	377.2	188.6
B	1691	23.5	377.2	188.6
C	1562	27.4	288.9	144.5
D	1599	26.3	272.6	138,8
Average	1656	24.9	329.0	165

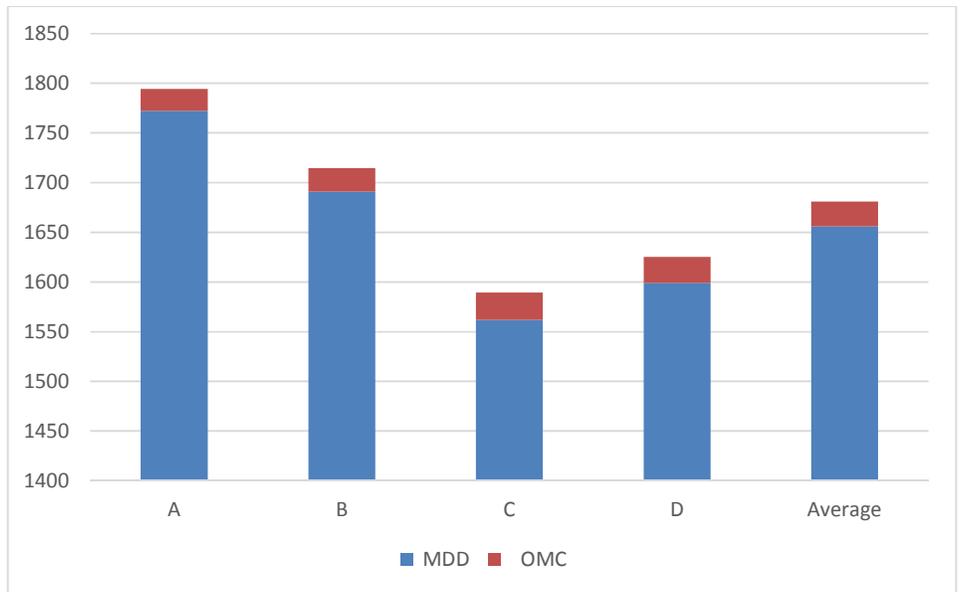


Fig. 4. Showing the compaction parameters of the studied soil

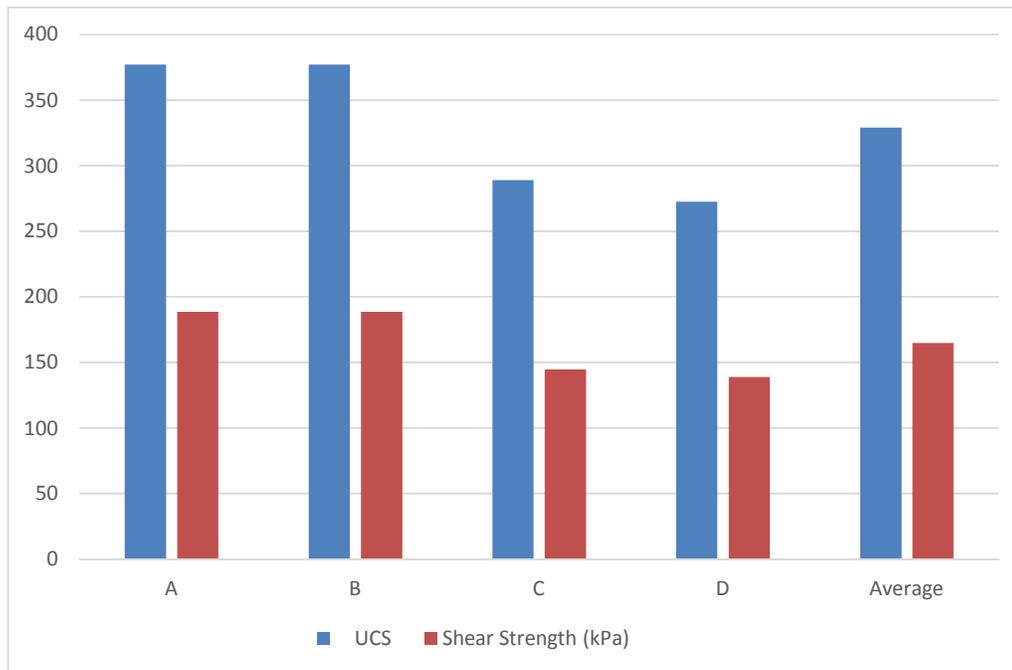


Fig. 5. Showing the strength parameters of the studied soil horizons

3.9 Strength Characteristics

The results of the unconfined compressive strengths (UCS) and the Shear Strength values are presented in Table 5. The UCS value ranges from 272.6 to 377.2kPa and the Shear strength value ranges from 138.8 to 188.6kPa. The result trend showed reduction in the strength parameters down the soil profile. This is in agreement with [22]. This may be attributed to degree of laterization and accumulation of coarse content particles. This indicates better bearing capacity of the soil samples in horizons upward the profile. The results obtained revealed that all the horizons material possess more than the required minimum standard of 200kPa UCS recommended by [23] for mineral seal. However, the horizons A and B have the same value and preferred qualities for civil engineering construction materials (Fig. 5).

4. CONCLUSIONS

The following conclusions can be drawn from the investigation of the geochemical, Index, and Strength appraisals of porphyritic granite-derived residual soil:

1. The index properties classified the soil horizons into soil of intermediate and high

plastic and compressibility with inactive clay mineral.

2. The strength parameters showed that all the horizons possess required minimum UCS strength for mineral seal.
3. The iron oxide variation within the soil profile accounts for the distinction among the horizons.
4. The more lateritized zones correspond with the more competent horizons.
5. The residual soil can be used as a suitable material in engineering construction works as Sanitary landfills and Subgrade materials.

5. RECOMMENDATIONS

The upper horizon within especially 0 – 1.5 m is recommended for use as construction materials for civil engineering works. Further analysis could be done on the engineering properties in other to determine the load bearing capacity.

The geochemical quantification analysis give insight into major oxides influence on soil matrix (macro and micro structures) and the consequence on the soil engineering behaviors

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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