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Geochemical Quantification and Appraisal of Three Genetically Different Derived Lateritic Soils

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study was carried out at Federal Polytechnic; Ado Ekiti in Ekiti state on geochemical appraisal of three different genetically derived lateritic soils from south western Nigeria and their respective engineering performance in 2019. Twelve (12) disturbed soil samples were collected from granite (GDS), gneiss (GNS) and migmatite (MGS) rock terrains. These samples were collected at four different horizons of 0.5m intervals, resulting into a maximum depth of 2.0m for each of the three trial pits for geochemical analysis. The results showed that the soil samples were characterized by high proportion of SiO_2, Al_2O_3 and Fe_2O_3 with an average (SiO_2 + Al_2O_3 + Fe_2O_3) of 94.8% with trace amounts of MnO, MgO, CaO, Na_2O, P_2O_5, TiO_2 and K_2O, indicating a high depletion degree. The geochemical quantification results showed that laterization range from 0.68 to 1.66%, Clayeness from 0.37 to 0.53 %, Siliceousness from 1.88 to 2.70%, Stabilization from 34.30 to 56.57%, Bonding Strength 36.29 to 57.80%, and Weathering Indices from 84.42 to 96.44. The results showed that the GDS has highest Clayeyeness, bonding strength, stabilization, best laterization and lowest

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siliceousness properties, indicating lowest permeability, best bearing capacity and mechanical stability followed by MGS and GNS, respectively. This result revealed that GDS and MGS soils are more suitable as mineral seal while GNS possesses preferred properties as foundation fills.

Keywords: Siliceousness; mineral seal; geochemical quantifications; bonding Strength; laterite.

1. INTRODUCTION

Lateritic residual soils are relatively cheap, common and widely used as construction materials for civil engineering structures [1]. Laterite is characterized with low activity value, high bearing capacity, low hydraulic conductivity, medium compressibility and kaolinite clay minerals with predominant oxides of Alumina (Al_2O_3), Silica (SiO_2) and Iron oxide (Fe_2O_3) [2]. Furthermore, Soils are produced by chemical weathering from the decomposition of different rock types under conditions that produce concentration of iron and aluminium oxides [3]. Ultimately, lateritic soils, particularly where they are mature, furnish a good bearing stratum [2].

Olukoga [4] ascribed the failure of a flexible pavement segment on the Ile-Ife highway to the low specific gravity, CBR and high water absorption capacity of the subgrade material. However, Bell [2] contended that the degree of leaching that occurs during the chemical reactions governs the type of residual minerals that are formed. Furthermore, Adeyemi et al. [5] in their investigation, reported that the relatively low amount of quartz and high amount of alkali feldspar could have been responsible for the high water absorption capacity and low strength of the pegmatite samples from parts of southwestern Nigeria. Meanwhile, Adeyemi (2013) reported using mineralogy, geochemistry and geotechnical properties to investigate lateritic soil developed on quartz schist near Ishara, southwestern Nigeria. He was able to show that major oxides geochemistry and mineralogy also have influence on the behaviors of subgrade soils (lateritic soils). In addition, Okunlola et al. (2014) attributed the enrichment of Fe_2O_3 in each horizon to chemical weathering of the parent rock mafic minerals and ferruginization of Fe bearing minerals of migmatite gneiss examined in Nigeria.

Kamtchueng et al. [6] reported that the relatively high sesquioxide present in these residual soils might act as cementing agent, thereby making the compacted soils relatively brittle. Consequently, Adewole et al. [7] claimed that the lateritic profiles over banded gneiss, granite and porphyritic granite varied with the composition of the parent rocks. Most recently, Owoyemi and Adeyemi [8] in their study reported that the sandstone derived soils (SS) contained essentially quartz grains and exhibited better engineering characteristics than migmatite derived soils (MGS). They also noted that the feldspars and micas present in MGS weathered into plastic and hydrophilic clay minerals, and they concluded that these are likely to have a negative impact on the engineering properties of the derived soils.

The intricacies relationship between the geochemical and engineering properties need more attention in order to shed light into inherit engineering properties of different genetically derived lateritic Soils. Gidigasu (1976) contended that because of the formation of distinct horizons and varying geochemical compositions within the lateritic soil profile, there is need to study the engineering characteristics of residual soils in respect to the underlain parent rock types. Furthermore, majority of the present researches have practically centered on the geotechnical properties without much thoughtfulness to the geochemical properties. Hence, the aim of this work is to find out the geochemical compositions and to quantify the geochemical properties of some lateritic soils with a view to inferred their suitability as construction raw materials and for engineering applications.

2. THE STUDY AREA

The study area (Federal Polytechnic Ado Ekiti campus) lies within Latitudes 07° 36' and 07° 38'N and Longitudes 05° 17' and 05° 18'E (Fig.1a) The topographic elevations of Ado Ekiti vary between 300m and 600 m high above the mean sea level (MSL). This area is found in the western plain and ranges due to the folding of the rocks. Generally, the rocks of the basement complex provide rich quality stone for building and engineering constructions. The common bedrock within the campus is made up of Pre-Cambrian Basement rocks such as granite, gneiss, charnokites and migmatite, where as migmatite being the dominant lithology (Fig.1b).The superficial deposit, resulting from the chemical weathering and decomposition of the Pre-cambrian basement rocks is characterized by fine to medium to coarse grained brown to reddish-brown coloured lateritic soils. The terrain is governed by the wet and dry seasons climatically.

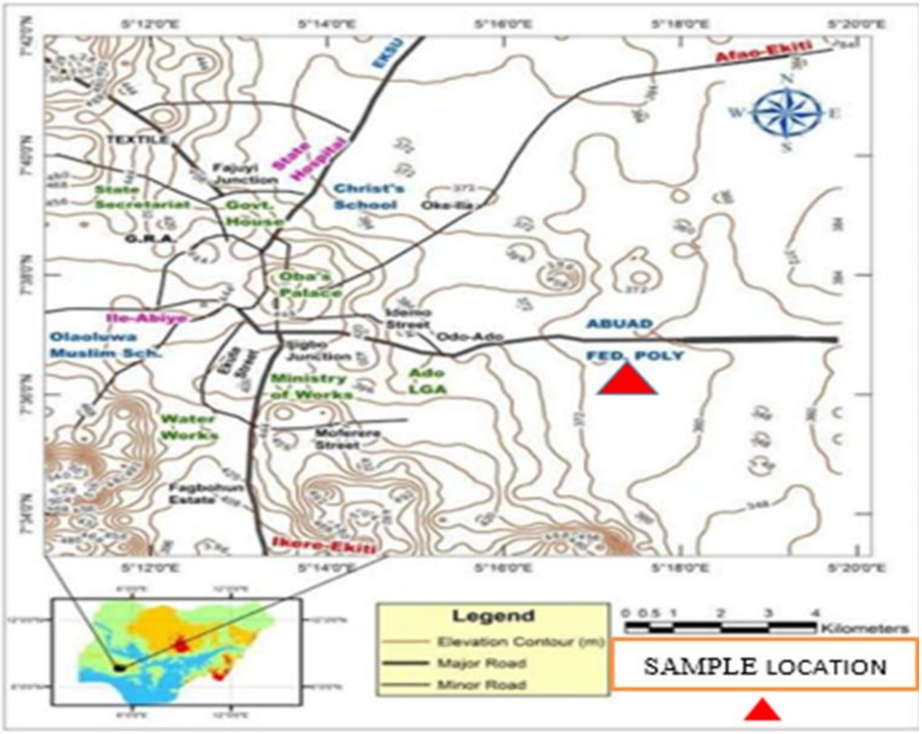

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Fig. 1a. Map of the study area (NGSA, 2006)

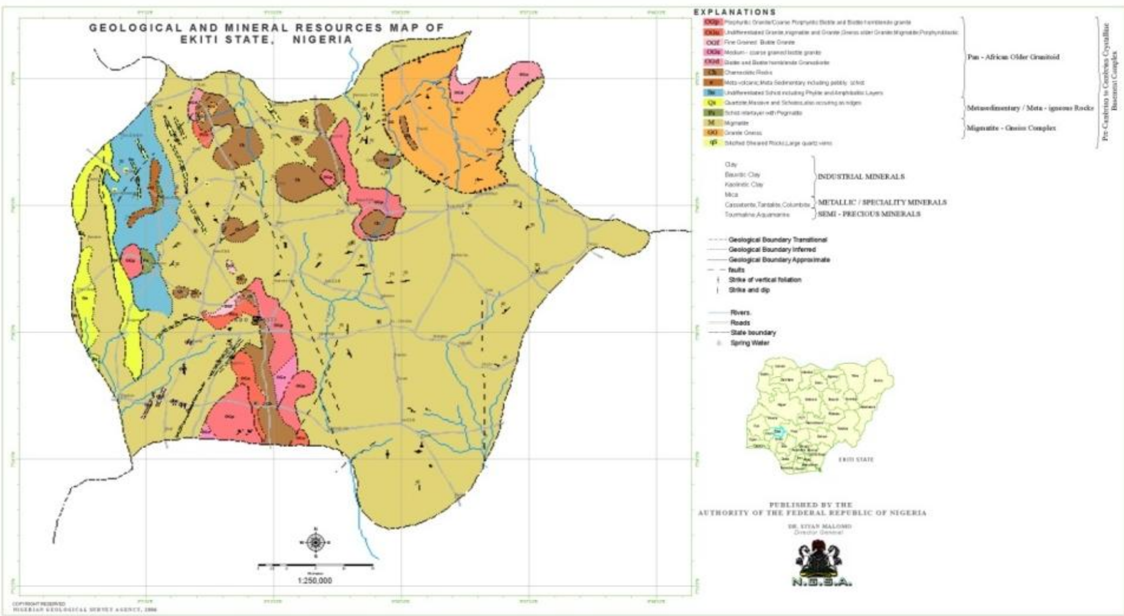

Fig. 1b. Geological map of Ekiti State (NGSA, 2006)

3. MATERIALS AND METHODS

Twelve (12) disturbed soil samples were collected from three rock types namely, granite (GDS), gneiss (GNS), and migmatite (MGS) within the School Campus for major oxides geochemical analysis. The samples were collected from three trial pits, covering four different horizons at 0.5 m intervals along the soil profile upto 2m depths at each trial pits. The samples were kept in separate sample bags and properly labeled. Global Positioning System (GPS) was used to locate the accurate coordinate of the sampling points. The major oxides concentrations were determined and the averages for each profile geochemical composition were evaluated (Table 1). The bulk chemical compositions of the soil samples were determined by X-Ray Fluorescence (XRF) analysis. A Phillips Analytical PW1480 X-Ray Fluorescence spectrometer using a Rhodium Tube as the X-ray source was used. The technique reports concentration as % oxides for major elements. Soil samples were pulverized in a milling pot to achieve particle sizes <75 µm. The samples were dried at 100°C for 12 hours for adsorbed water measurements. The powdered samples were then mixed with a binder (ratio of 1: 9 in grams of C-wax and EMU powder) at a ratio of 2: 9 (2 gram binder and 9 gram sample).The powder mixture was then pelletized at a pressure of 15K bars for 1 minute. Major oxides determined were then used for the geochemical quantitative analysis and evaluation of engineering properties (Table 2).

4. RESULTS AND DISCUSSION

4.1 Geochemical Composition Analysis

The degree of leaching that occurs during the chemical reactions governs the type of residual minerals and materials that form [2]. The results for the geochemical compositions of the studied soil samples are presented in Table 1. The soil samples are characterized by high proportion of SiO_2, Al_2O_3 and Fe_2O_3. Average of these oxides. i.e SiO_2, $+Al_2O_3$, + and Fe_2O is found 91%, 94% and 96% for GNS, GDS and MGS respectively, along with traces of the rest of oxides which are regarded as impurities or associated minerals according to Mukherjee [9].

The observed trend was comparable to those obtained from lateritic soils from other parts of southwestern Nigeria by Adewole et al. [10]. The oxides concentration along each profile is associated with considerable variation, this is in agreement with submission made by Adewole et al. [10], in their study of mineralogical and geochemical trends in the residual soils above Basement Rocks in Ore Area, southwestern Nigeria.

The average concentration of SiO_2 as major oxide is 55.22%, 38.23%, and 48,00% for GNS, GDS and MGS respectively. This shows that there was a relative difference to the initial concentration of 75.24%, 47.30% and 53.86% for GNS, GDS and MGS respectively, at topmost layer, up to 0.5m depth. This shows that there has been depletion in the concentration of SiO_2 within the profile with GNS posing the highest reduction rate of 27% as against 19% and 11% for GDS and MGS. The enhanced value of SiO_2 at the topmost horizon soil may be due to relative rate of depletion of MnO, MgO, CaO, Na_2O and K_2O in the soil horizon along the profile. Hence, free quartz, SiO_2 is present in silicate minerals and their weathering and dissolution apparently led to the enrichment of SiO_2 at the topmost (0.5m) horizon [7]. This suggests that the laterite may be suitable for specified application in engineering construction work due to presence of reasonable amount of silica.

The aluminum oxide values indicated drastic enrichment from 11.91% at 0.5m to 23.77% at 1.0m for GNS, which is about 50% increment, and then relatively stable across the remaining horizons within the profile, while only slightly variations were observed in the GDS and MGS profiles. This indicates that there is a significant enrichment of aluminum oxide in the GNS profile compared to the GDS and MGS profiles.

The relative enrichment could be explained by the removal of MgO and weathering of Al_2O_3 bearing minerals such as biotite in the GNS. This result suggests that the drastic differences in the concentration of aluminum oxides within the GNS profile may account for relative differences in the engineering properties within the profile and differences in the engineering properties and behaviors among distinguishing genetically different rock types of GNS, GDS and MGS. Iron oxides have an average value of 13.25%, 36.18%, and 27.02% for GNS, GDS and MGS in each profile respectively.

This indicates that GDS has the highest potential of forming more concretionary structure within the pore spaces, followed by MGS and then GNS

[11]. This implies that GDS may produce more stable structure during compaction, which invariably produce desirable engineering properties and enhance its suitability for civil engineering work compared to others.

4.2 Clayeness and Siliceousness

Table 2 gives the result of average weight percentage for clayeness ($Al_2O_3/Si0_2$) and Siliceousness (SiO_2/Al_2O_3) of the soil samples. It was found that GDS has the highest clayeness and lowest siliceousness, followed by MGS and while GNS has the lowest clayeness and highest siliceousness, as seen in Fig. 2. However, these differences though inconsequential, still suggests possible variation in the engineering properties among the three genetically different rock types. Adeyemi et al. [5], reported that the relatively low amount of quartz and high amount of alkali feldspar could result into higher water absorption capacity. This result revealed that GNS possesses the lowest water absorption capacity, which indicates lowest plasticity index property for the soils. Soils with low plasticity and compressibility normally possess low settlement character. Hence, GNS are more suitable materials as foundation fills materials compared to others.

Tables 2 and 3 showed that GNS though has the best Siliceousness (SiO_2/Al_2O_3) properties but has the least bonding properties in terms of iron oxide (Fe_2O_3) compared to the rest. This indicates that GNS may be more to erosion activities compared to GDS and MGS with better bonding property. This result suggests that these soils may have comparative advantages over one another depending on specific area of applications. While, GNS may be more suitable for foundation fills, GDS and MGS are more suitable as minerals seals because of its clayeness and better bonding properties (concretionary structure) that enhance lower permeability and bearing capacity Malomo [11].

Table 1. Major oxides (%) compositions for each profile

OXIDES (%) Depth	GNS 0.5m	GNS 1.0m	GNS 1.5m	GNS 2.0m	GDS 0.5m	GDS 1.0m	GDS 1.5m	GDS 2.0m	MGS 0.5m	MGS 1.0m	MGS 1.5m	MGS 2.0m
SiO_2	75.24	48.7	52.35	44.79	47.3	35.3	32.27	38.42	53.32	46.34	46.85	42.57
Al_2O_3	11.91	23.77	24.7	22.85	24	19.3	17.17	21.23	22.31	19.49	22.81	17.27
Fe_2O_3	7.12	19.34	9.98	15.98	23.3	40.24	45.46	36.14	18.92	29.93	25.53	35.77
MnO	0.24	0.21	0.09	0.16	0.19	0.64	0.55	0.11	0.22	0.27	0.18	0.56
MgO	0	0	0	0	0	0	0	0	0	0	0	0
CaO	0.21	1.71	3.91	2.11	0.26	0.21	0.24	0.22	0.39	0.2	0.25	0.2
K_2O	3.33	4.51	4.32	3.62	3.09	2.13	1.85	2.25	1.8	0.97	1.34	1.12
TiO_2	1.52	0.18	0	0.07	2.43	1.84	1.98	1.47	2.9	2	2.35	2.3
P_2O_5	0.4	0.29	0.24	0.26	0.3	0.26	0.28	0.25	0.34	0.31	0.35	0.27
Na_2O	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
Sum	100.03	98.77	95.65	89.9	100.93	99.98	99.86	100.15	100.27	99.58	99.73	100.13

Where: GNS, gneiss derived soil; GDS, granite derived soil; MGS, migmatite derived soil

Table 2. Geochemical quantification of three different genetically derived lateritic soils

OXIDES (%)	Properties	GNS (AVE)	GDS (AVE)	MGS (AVE)
$SiO_2/Al_2O_3+Fe_2O_3$	Laterization	1.66	0.68	1.01
Al_2O_3/SiO_2	Clayeness	0.37	0.53	0.43
SiO_2/Al_2O_3	Siliceousness	2.70	1.88	2.31
$Al_2O_3+Fe_2O_3$	Stabilization	34.30	56.57	47.87
AFMC	Bonding Strength	36.29	57.80	49.01
CIA	Weathering	77.53	88.00	93.80
CIW	Weathering	91.3	97.34	98.88
CIA + CIW/2	Weathering Index	84.415	92.67	96.44

AFMC = $Al_2O_3 + Fe_2O_3 + MgO + CaO$; CIA = $\{Al_2O3 / (Al_2O_3 + CaO^* + Na_2O + K_2O)\} \times 100$; CIW = $\{Al_2O_3 / (Al_2O_3 + CaO^* + Na_2O)\} \times 100$

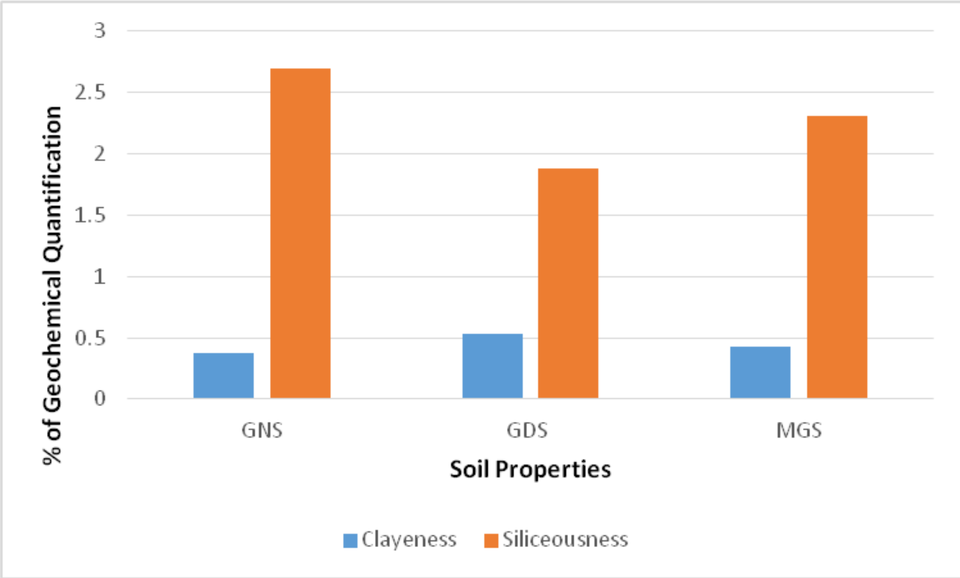

Fig. 2. Soil properties

Table 3. Nature of soil type for the three genetically different soils [12]

GENETIC	SiO_2	Al_2O	Fe_2O_3	Al_2O_3+Fe_2O_3	$SiO_2/(Al_2O_3+Fe_2O_3)$	NATURE
GNS	56.77	21.05	13.25	34.3	1.66	Lateritic
GDS	38.23	21.23	36.14	56.57	0.68	True laterite
MGS	48.11	20.85	27.02	47.87	1.01	True laterite

Where: GNS, gneiss derived soil; GDS, granite derived soil; MGS, migmatite derived soil.

4.3 Laterization

The results of average silica-sesquioxide molar ratio (SSMR) values by weight percentage of the studied soil samples are presented in Table 3 and Fig. 3. It shows that the laterization degree is highest in the GDS (0.68) and lowest in GNS (1.66), lower value implies higher degree of laterization according to Rossiter [12]. Probably due to the occurrence of ferric oxide content. This affirms that GDS had the highest enrichment of Fe_2O_3 content followed by MGS and GNS. While GNS has the lowest degree of laterization, it also has the least possible formation of concretionary structure within the pore spaces of the lateritic soil and the lowest bearing strength. Olukoga [4] noted that low specific gravity is an indication of a low degree of laterization resulting into poor engineering properties. The formation of concretionary structure within the pore spaces of the soil matrix will directly affect the permeability properties of the soil; hence, more laterization will result into lower hydraulic conductivity and low permeable soils are more suitable as mineral seal.

According to Kamtchueng et al. [6], the relatively high sesquioxide present in these residual soils may act as cementing agent, thereby making the compacted soils relatively brittle. This implies that GDS may produce denser and more stable structure during compaction, which invariably produces desirable engineering properties and enhance its suitability for civil engineering work, therefore suggesting GDS is more suitable for civil engineering work compared to others. For instance, as land sanitary fills and slurry agent due to denser and more stable structure during compaction, which also result in low permeability properties.

4.4 Stabilization Properties

The combination of aluminum and iron oxides has been referred to as stabilizer in clay engineering [13]. It can be noted from Table 4 and Fig. 4 that GDS pose the highest stability properties and GNS pose the least, which affirm the laterization findings. This trend was in agreement with observation made by Adeyemi and Oyeyemi [14] after compaction of GNS and GDS samples that resulted into more fines content and low strength parameters for GNS. Malomo [15] defined mechanical instability characteristics as the susceptibility of grains of a soil to break down when its level of mechanical energy is slightly increased. The drastic increment of 37% in fines of GNS to 15% of GDS ratio 2.5 as observed by Adeyemi and Oyeyemi [14] suggest that GDS has better mechanical stability properties due to formation of concretionary structure, micro aggregation, less water takes up and clay swelling, followed by MGS soil samples and by those of GNS ones [11,13]. Hence, GDS and MGS are more suitable for civil engineering applications especially as sub-base materials than GNS derived soils, since this segment of pavement is constantly subjected to axle load vibration.

4.5 Bonding Strength

The greatest engineering threats to the lateritic soil always arise from the strength characteristics inherit by the clay content [16]. Sridharan and Allam [17], referred to total content of Ca, Mg, Al and Fe elements in a soil as cementation compounds. The results of bonding strength as presented in Table 4 and Fig. 4 show 36.29%, 57.80% and 49.01% for GNS, GDS and MGS respectively. This observation is attributed to more amount of Fe_2O_3. This implies that GDS soil samples possess the best engineering property in terms of strength parameters, which were in agreement with Adeyemi and Oyeyemi [14]. The findings of that study reported 60% reduction in California Bearing Ratio (CBR) of GNS compared to 27% in that of GDS Derived soils after soaking, similar trend was also noted in cured unconfined compressive strength (UCS) results. This suggests that GDS and MGS materials are more suitable as engineering geomaterials. This attested to the fact that the properties of the parent rocks strongly influence the residual soil.

4.6 Weathering Indices Properties

The average result of the two weathering indices (CIW and CIA) of the soil samples is presented in Table 2 above. The average weathering indices of 84%, 93% and 96% were estimated for GNS, GDS and MGS respectively. This result suggests moderate degree of weathering intensity for GNS and advance stage of weathering intensity for both GDS and MGS according to Nesbitt and Young [18].

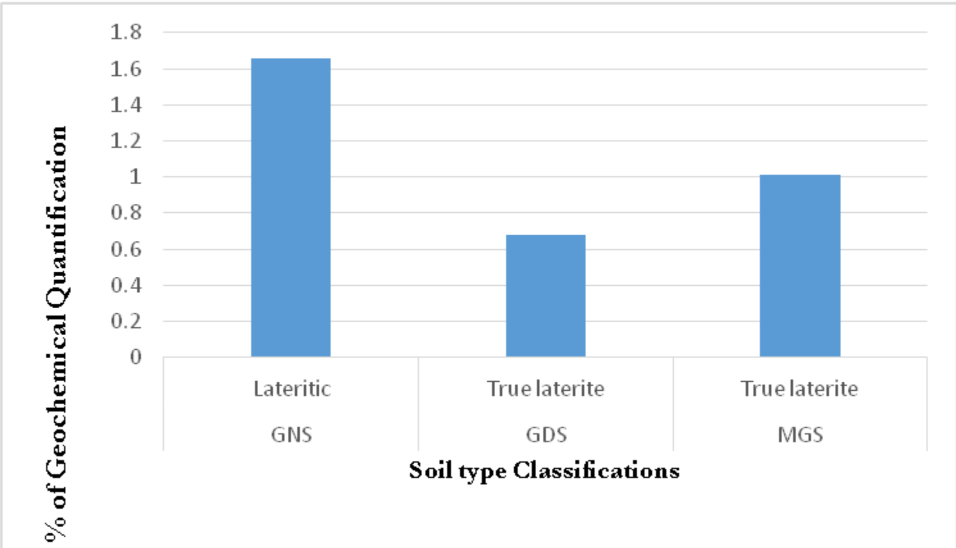

Fig. 3. Soil type classification

Table 4. Bonding strength after (Sridharan and Allam,1982)

GENETIC	Al_2O_3	Fe_2O_3	Stabilization	MgO	CaO	Bonding Strength	Ranking
GNS	21.05	13.25	34.30	0.00	1.99	36.29	least
GDS	21.23	36.14	56.57	0.00	0.58	57.80	highest
MGS	20.85	27.02	47.87	0.00	0.22	49.01	high

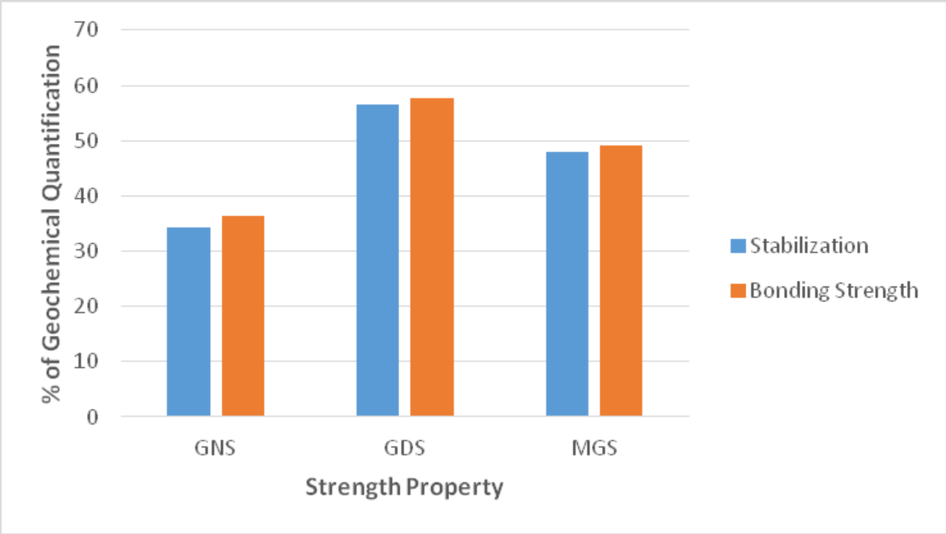

Fig. 4. Strength property for the studied soils

The values showed that nearly all the primary minerals have decomposed to form secondary minerals such as kaolinite. This trend is similar to the weathering of the Abeokuta banded gneiss and granitic rocks reported by Bolarinwa and Elueze (2004) suggesting that GDS and MGS may produce good bearing stratum according Bell [2]. Lateritic soils, particularly where they are mature, furnish a good bearing stratum. The advanced stage of weathering produce kaolinite clay mineral, known as least or non-active clay mineral suggesting less swelling and shrinkage for GDS and MGS samples compared to the GNS derived soils. This characteristic is significant in civil engineering construction work especially for road projects.

5. CONCLUSION

The results classified granite (GDS) and gneiss (MGS) as true laterite and migmatite (MGS) as lateritic soils in nature. Furthermore, the true laterite soils have higher clayeness content which enhances their, plasticity, moldability and workability making they more suitable as slurry, grouting and mineral seal while lateritic soil may be use as foundation fills. In addition, the strength parameters revealed that the true laterite possess higher bearing capacity, therefore, they may be use as sub base materials while the lateritic soil may be suitable as sub grade material provided other criteria are fulfill. In conclusion, the varying geochemical properties of lateritic soils have influence on their engineering properties and consequently, the geochemical quantification analysis shed light into the effect and influence of geochemical parameters on engineering properties and performance of lateritic derived soils.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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