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Geochemical and Geotechnical Appraisal of the Regolith along Ado-Ilawe Road, Ekiti State, Nigeria for Engineering Construction

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Abstract*— Geochemical and geotechnical studies of the in-situ weathering deposits along the basement complex of Ado-Ilawe Road, South-western, Nigeria have been studied with aim of determining the suitability of the deposits for civil engineering construction. Five samples were taken from road cut site, at different horizons/depths based on colour and grain size variation with the aid of digger, shovel and spade. Chemical and geotechnical analyses were carried on the samples. The chemical analysis was carried out on the samples to determine the mineral oxides present in the samples. The geotechnical involved grain size distribution test, Atterberg limits test, specific gravity, linear shrinkage test, firing test, bleaching test, compaction test, water absorption determination, and California Bearing Ratio test (unsoaked). All the analyses were conducted according to British Standard procedures. The results of the chemical analysis revealed the predominant of SiO_2 over other oxides. The SiO_2 contents range from 63.2 to 68.4 %, Al_2O_3 ranges from 9.41 % to 15.3 %, and Fe_2O_3 ranges from 5.21 % to 8.72 %. The analysis revealed the clay minerals are illites, and/or montmorillonite/illite derived from an acidic parent rock. Mineralogical characteristics and chemical trends indicate the increase in degree of maturity with depth. The geotechnical analyses show that liquid limit ranges from 48.5 to 55.0 %, plastic limit is between 24.0 and 31.40 %, linear shrinkage ranges from 0.5 to 1.60, the specific gravity ranges from 2.20 to 2.44. The bleaching test produced no colour change. The samples exhibit moderate water absorption potential, while the values obtained for modulus of rupture, compressive strength, and CBR are below standard for road/building construction, rated as fair to poor foundation material using AASHTO and USCS standard. However, the material fall within specification of ONORM 2074 (1990) as seal/liners for landfill. It is presume that the soil might require some amount of stabilization to qualify it for foundation material for building, road construction, and other civil engineering structural works.

Keywords: *Geochemical, geotechnical, bleaching test, firing test, montmorillonite*

I INTRODUCTION

Rocks when exposed at or near the earth's surface find themselves in a physical and chemical environment often quite different from that in which they were originally formed. The minerals which constitute the rocks may react chemically with the rainwater, groundwater, and dissolved solids and gases of the new near-surface environment to form new minerals which are more nearly in equilibrium with the surface conditions. Some materials may be carried away by solution in groundwater. The end result of these changes is to convert the upper portion of the rock into residual debris more soil-like than rock-like in character and with chemical, mineralogical, and physical properties entirely different from those of the original rock.

In tropical regions where temperature is high and rainfall is abundant, clay minerals or materials usually form. Under such conditions weathering is deep and intense, most weathering products are soluble (even silica). The least soluble product is aluminum oxide which remains on top of the weathering rocks. Even the degree of weathering is a factor of climate, biological activity, topography, parent rock and time to which the rock is subjected, coupled with an action of carbon-dioxide, oxygen, water vapour under relatively warm conditions. These processes break down silicate minerals into clay minerals such as kaolinite and illite. Iron and aluminum oxides are prominent in lateritic soils, and with the seasonal fluctuation of the water table, these oxides result in the reddish-brown color that is seen in lateritic soils [1].

Soil is used as construction material in various civil engineering projects, and it supports structural foundations. Thus, civil engineer must study the properties of soil, such as its origin, grain-size distribution, ability to drain water, compressibility, shear strength, and load bearing capacity [2] as well as its chemical constituents. Laterites for example contribute to the general economy of the regions where they are found. Their scope is very wide and includes civil engineering, agronomic, mining research (iron, aluminum and manganese) deposits. The accumulation of voluminous amounts laterites/clays in Ekiti is as a result of the above mentioned factors has many economic uses, for example in electrical industries for making switches, sockets, conductors, insulators, also it can be used for pottery, ceramic and abrasives purposes and also in civil engineering construction works.

However, considerable studies have been carried out on the engineering geological properties of the soil by various researchers ([3], [4], [5], [6], [7], most especially investigations on geotechnical and engineering properties of lateritic soils have been researched into in northern, eastern, and southwestern Nigeria ([8], [9], [10], [11], [12], [13], [14], [15], [16], [17]. The results of the investigations of the aforementioned authors have been a tremendous help for most builders/engineers and transportation officials by incorporating some of the findings into their design processes/construction procedures to safeguard against failure of structures and utilities; and also to ensure maximum utilization of various natural resources spanning through the length and breadth of the country. On the basis of this, the geochemical and geotechnical investigation of overburden material along Ado-Ilawe road was undertaken to ascertain the fitness and suitability of the material for road construction and foundation filling material.

The study area is located around Ado – Ilawe Road in Ekiti State southwest Nigeria. The area lies within Lat. 7°37¹ north of equator and Long. 5°12¹ East of Greenwich Meridian. The area is accessible with a major road linking Ado-Ekiti with some minor roads (Fig. 1). There are few topographical variation features observed and most of the area is covered by clay bodies and lateritic deposit which are derived from the basement rock. The drainage pattern in the area is radial. The area also falls within the tropical rainforest of Southwestern Nigeria and physical conditions like temperature, relative humidity, and rainfall show constancy. The region is characterized by heavy rainfall and intense sun radiation ranges from 22 °C to 28 °C with mean value of 26 °C. The area is largely dense or thickly vegetated. The vegetation is mainly trees, shrubs, and climbing plants. The study area (Ado-Ekiti) lies within the basement complex of southwestern Nigeria, which is part of the Nigeria basement complex.

The predominant rocks in the area are of Precambrian age and undifferentiated [18]. They include granites, charnockites, migmatite - gneisses, pegmatites and quartzite. However Migmatite gneiss is the most predominant rock in the area (Figure. 2) occurring as granite gneiss in most places.

II MATERIAL AND METHOD OF STUDY

The method of study involved both fieldwork sampling techniques and laboratory work. These methods were carried out to obtain adequate information on the representative samples collected.

A. Fieldwork and Sampling Method

Five soil samples were collected from road cut sites at different depths within the study area. The samples were collected on the basis of colour and grain size variation. The samples were packed into air-tigh polythene bag and the bags were labeled accordingly to avoid mix-up or any kind of contamination required for chemical and geotechnical analyses.

B. Sample Preparation

The soil samples were sun-dried separately and carefully, without mixed up or contamination for about a week and they were later pulverized. All the samples were selected for the analyses and labeled as: AD-IL-1, AD-IL-2, AD-IL-3, AD-IL-4, and AD-IL-5. The samples were subjected to grain size analysis test, Atterberg Limits test, specific gravity test, hydrometer test, firing test including degree of water absorption after firing and its corresponding volumetric change, bleaching test, Dry density test, Modulus of Rupture, California Bearing Capacity determination, and Unified Compressive Strength determination in accordance with British Standard as outlined in BS 1377 of 1990 [19]. The chemical analysis was also carried out on the samples to determine the mineral oxides that were present in each sample. The sample were initially sieved using 2 mm sieve and 2 g of the sieved sample was taken, after which they were put into digesting tube and digested using HNO_3 and HCl, then with $HClO_4$ and H_2O_2. The samples were heated to dryness and make up with distilled water in a 100 ml volumetric flask. The resultant solution was analyzed using Atomic Absorption Spectrophotometer (AAS). The silicon oxide and Aluminium oxide were analyzed with nitrous oxide while Iron-oxide with oxyacetylene. The steps were repeated for the remaining samples, and the samples were subsequently allowed to stand for at least I hour in the solutions while they were frequently stirred.

III RESULTS AND DISCUSSION

A. Geochemical Tests Results

The chemical analysis carried out on the soil samples is to determine the major mineral oxides (SiO_2, Fe_2O_3, and Al_2O_3) that are present in each samples. Table 1 shows the percentage oxide composition in the samples. The results showed that the percentage of SiO_2 ranges from 59.25 to 68.41 % indicative of silica-rich weathered material of the basement rocks. Since the samples contain high content of silica (greater than 66 %) then it is from an acidic parent rock. The results also showed that the samples are composed mainly of SiO_2 and Al_2O_3 with low Fe_2O_3 due to differential degree of weathering, depth and intensity of weathering in studied site. However, the % content of Iron-oxide increases with depth signifying increase in degree of laterization and soil maturity. Using ”[20]” Silica-Alumina ratio as a classification criterion in Table 2, the soils are non lateritic.

B. Geotechnical Test Results

The engineering behavior of soils, whether formed under arctic, temperate or tropical conditions, is determined by certain physical characteristics designated as engineering properties. The grain-size distribution characteristics show that the soils are generally poorly graded (Fig. 3). From the grading curves, the soil can be classified as fine graded soil, as they are generally consisting of fines (clay/silt material). The % passing 0.075 mm sieve size is generally greater than 55 % signifying high amount of fines (Table 3). The hydrometer test (Table 4) conducted for the fines (clay and silt portion of the samples) showed that AD-IL-3 and AD-IL-5 have % clay fraction greater than 30 % while the values of other samples are less than 15 %. These results indicated that the fines of the sampled soils are concentrated within the silt group. All the studied soils also met the >20% clay content specified by Oeltzshner (1992) as they all contains clayey fractions ranging between 0 % and 32 %.

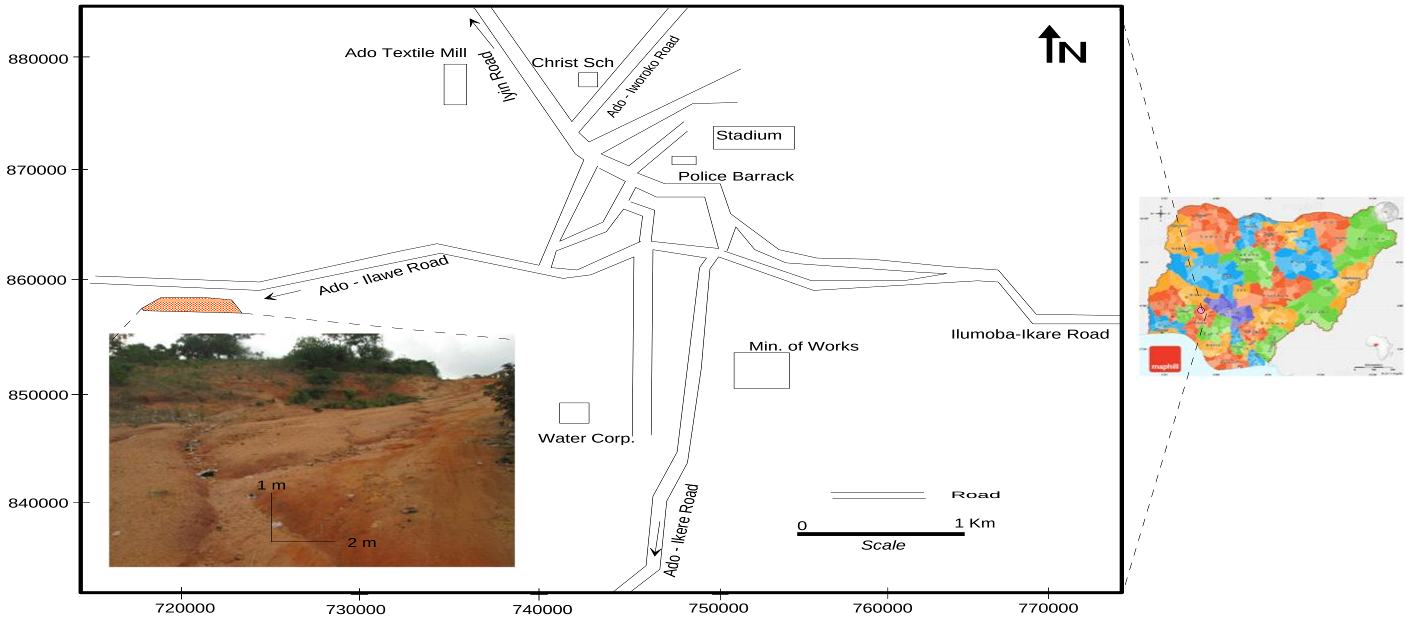

Figure 1: *Location map of the study area. Inset: The Studied overburden material*

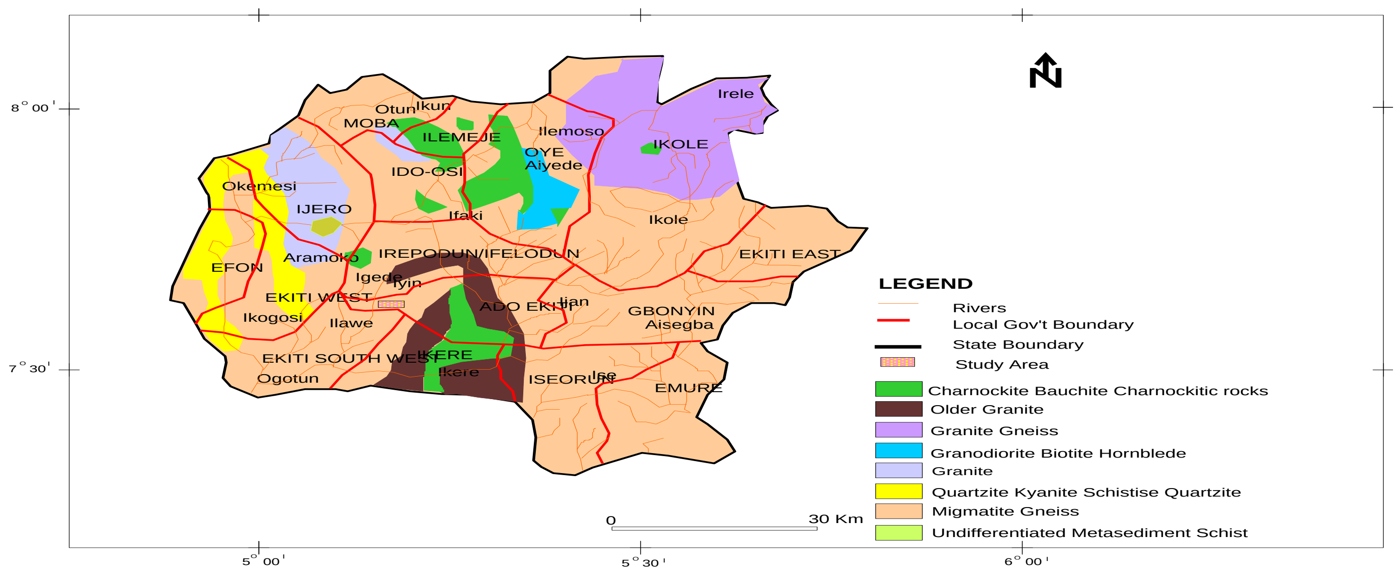

Figure 2: *Geological map of Ekiti State showing Migmatite Gneiss rock underlying the Study area*

Table 1: *Results of the Geochemical Analysis*

Samples	Oxides %			Depth of Sampling (m)
	SiO_2	Al_2O_3	Fe_2O_3	
AD-IL-1	68.41	9.56	7.60	1
AD-IL-2	63.20	15.30	5.21	3
AD-IL-3	66.41	9.41	8.72	5
AD-IL-4	61.20	10.32	12.33	6
AD-IL-5	59.25	9.44	14.22	7

***Table 2:** Classification of Soil Types based on Silica-Alumina Ratio [20]*

Soil Type	SiO_2/Al_2O_3
Laterite soil	1.33 or less
Lateritic soil	1.33 – 2.00
Non lateritic soil	2.00 and Over

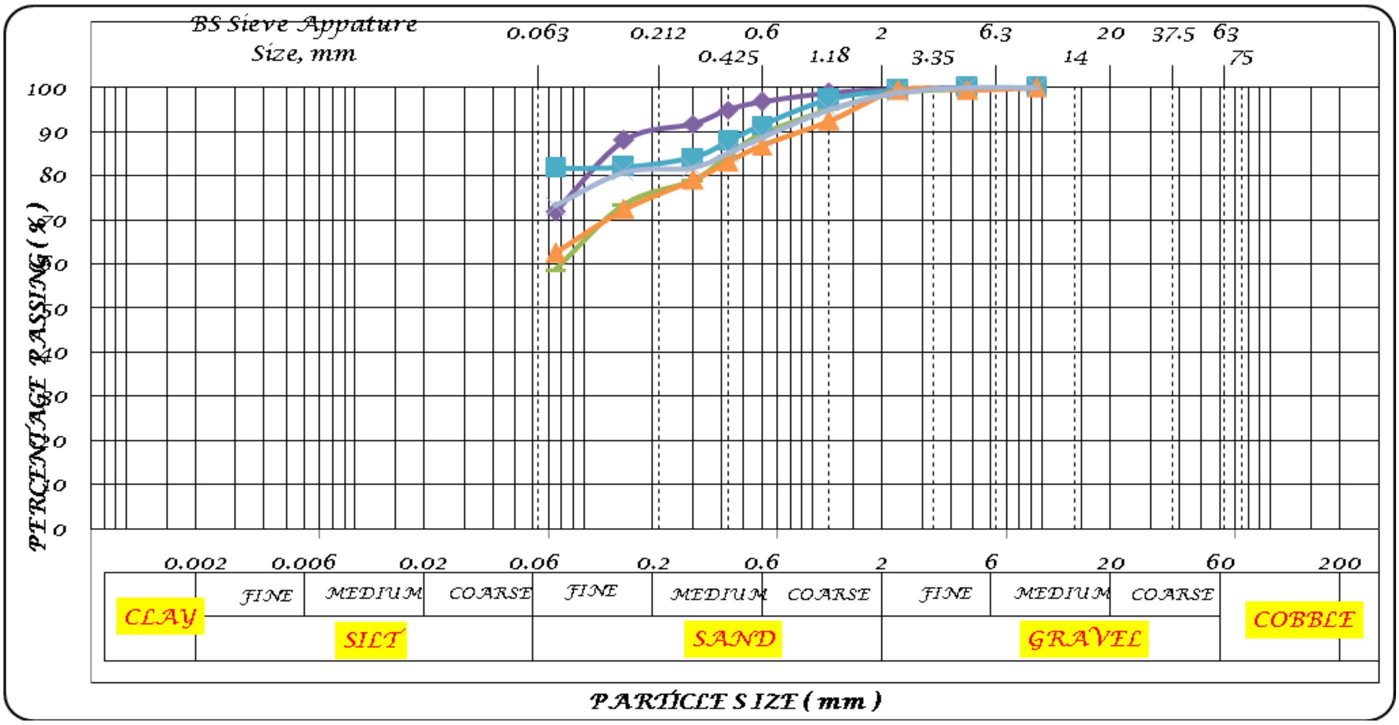

***Figure 3:** Grain size Analysis Curves for the Sampled Soils*

***Table 3:** Results of the Grain size Analysis conducted on the Sampled Soils*

Sieve size (mm)	Samples No. / % Passing				
	AD-IL-1	**AD-IL-2**	**AD-IL-3**	**AD-IL-4**	**AD-IL-5**
9.50	100	100	100	100	100
4.75	99.8	99.9	100	99.5	100
2.36	98.9	99.7	99.5	99.4	98.9
1.18	95.1	98.9	97.5	92.5	95.1
0.60	89.5	96.9	91.5	86.8	88.7
0.425	84.5	95.0	87.9	83.2	85.2
0.30	79.0	91.8	84.2	79.2	81.9
0.15	73.5	88.1	82.1	72.5	80.9
0.075	58.6	71.9	81.7	62.5	73.2

It is also worthy to note that the largest particle diameter recorded by the tested soils is ≤5mm, this is smaller than the specification of ONORM 2074 [22] who recommended soils with largest grain size less than or equal to 63mm for liner in landfills.

Based on British Standard BS 1377 [19] if percentage fine is less than 35 %, it is adjudged a good sub grade. However the sampled soils showed a range greater than 35 %, therefore can be classified as unsuitable foundation material. Since the amount of fines is inversely proportional to the engineering performance of most lateritic soils ([23], [24]), it is presume that the soil might some amount of stabilization to qualify it for foundation material for building and road construction. The Atterberg limits help to indicate and appreciate the behavior of the various soil samples. It tells about the strength and compressibility potential of the soil on which engineering and structural purposes depend. The liquid limit values ranges from 48.5 –57.0 %, plasticity limit between

24.0 and 31.4 % and the plasticity index between 19.7 and 30.7. Hence all the soils lie above the arbitrary A-line and falls within the field of inorganic clays with intermediate plasticity and high plasticity on the Casangrande [25] plasticity chart (Fig. 3), and Intermediate - high plasticity by Unified Soil Classification System (Table 5), while the AASHTO [26] classification rating indicates fair to poor rating. Subsequently, the obtained values (Plasticity) can be generally classified as high plastic soils in Table 6 [27]. The presence of high content of clay, especially active clay minerals generally corresponds to a decrease in the size of micro scale pores that subsequently lower the hydraulic conductivity of the soil. The soils fulfil the liquid limit and plasticity index values requirement suggested by Seymour and Peacock [28] as they posses liquid limit less than 90% and plasticity index less than 65% recommended for soils to be used as liners in landfills. However, soils with high liquid limit and plasticity index are considered suitable

Table 4: *Results of the Hydrometer Test Conducted on the Sampled Soils*

AD-IL-1		AD-IL-2		AD-IL-3		AD-IL-4		AD-IL-5	
Particle size (mm)	**% Finer**	**Particle size (mm)**	**% Finer**	**Particle size (mm)**	**% Finer**	**Particle size (mm)**	**% Finer**	**Particle size (mm)**	**% Finer**
0.074	93.2	0.053	96.6	0.073	99.8	0.073	49.6	0.073	70.3
0.054	91.5	0.038	91.5	0.060	97.3	0.060	47.4	0.058	66.4
0.041	81.4	0.022	69.5	0.004	91.8	0.043	45.2	0.041	65.2
0.031	67.8	0.016	64.4	0.031	88.1	0.030	45.2	0.029	63.9
0.023	59.3	0.012	54.9	0.023	80.7	0.022	44.2	0.021	62.2
0.017	49.2	0.009	40.7	0.017	73.4	0.016	44.2	0.016	57.5
0.013	42.4	0.005	18.7	0.013	73.4	0.012	39.9	0.011	55.0
0.009	30.5	0.002	15.3	0.009	66.1	0.008	35.5	0.009	48.6
0.005	10.2	-	-	0.004	31.2	0.005	15.1	0.005	34.7
0.002	8.5	-	-	0.002	31.2	0.002	12.9	0.002	32.0

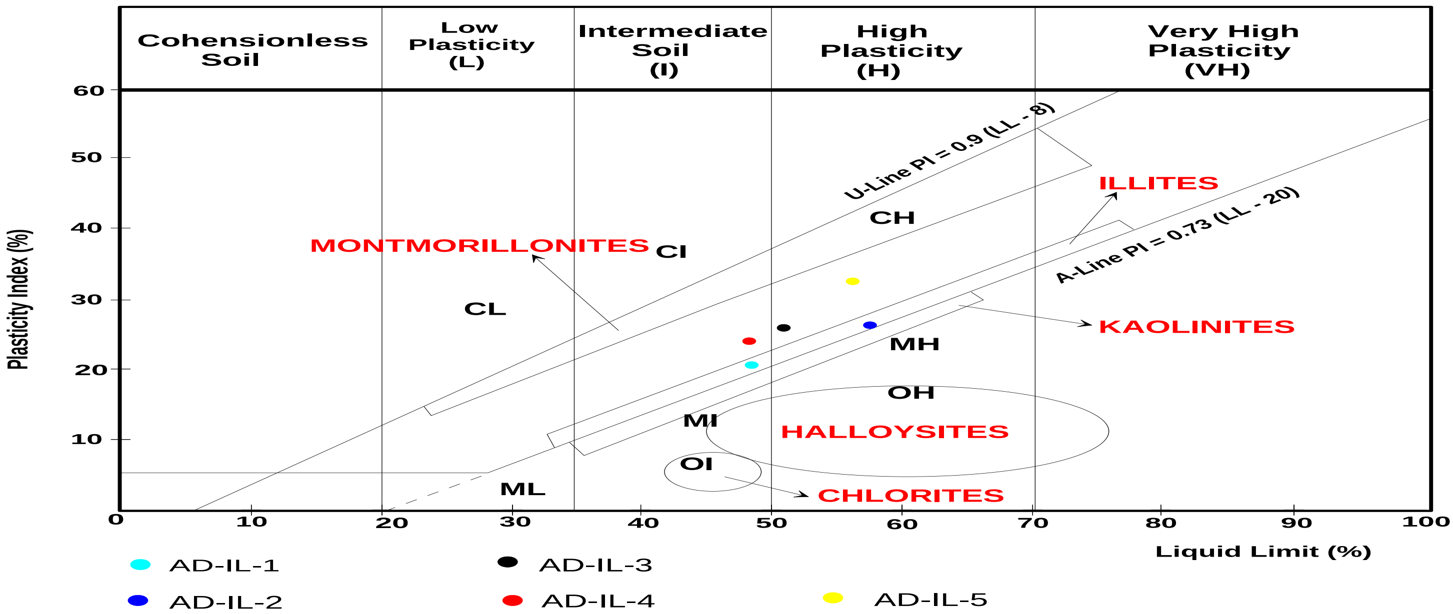

Figure 3: *Casangrade Plasticity Chart and Corresponding Clay Groups of the Sampled Soils [29]*

for mineral seals in sanitary landfills as they are expected to possess low hydraulic conductivity [30]. However, as usage for road and building construction, the sampled soils generally fall below the recommended Liquid limits of 50 % maximum, Plastic limits of 30 % maximum, Plasticity index of 20 % maximum for foundation/subgrade material. for highway construction. However all the soil samples exhibit low shrinkage potential (Table 5) corresponding to medium good soils. All the soil samples fall within illites and illite/montmorillonite clay minerals. The basic structural unit of illite is similar to that of montmorillonite except that some of the silicons are always replaced by aluminum atoms and the resultant charge deficiency is balanced by potassium ions. The potassium ions occur between unit layers. The bonds with the non-exchangeable K+ ions are weaker than the hydrogen bonds, but stronger than the water bond of montmorillonite. Illite, therefore, does not swell as much in the presence of water as does montmorillonite. The lateral dimensions of illite clay particles are about the same as those of montmorillonite, 1000 to 5000 A, but the thickness of illite particles is greater than that of montmorillonite particles, 50 to 500 A. Water can enter between the sheets, causing them to expand significantly and thus the structure can break into 10 A thick structural units. Soils containing a considerable amount of montmorillonite minerals will exhibit high swelling and shrinkage characteristics [27].

The specific gravity is the measure of weight of a substance compared with weight of equal volume of water. Table 7 presents the results of the specific gravity of the analyzed samples. The specific gravity values of the soils tested range between 2.20 and 2.44 (Table 6). The result shows moderately low values which indicate a fine grained material and coincidized with the standard specific gravity range for silt/clay (1.5 – 2.7). This clearly indicates low degree of soil maturity and laterization

Table 5: *Results of the Atterberg Limits test, Linear Shrinkage, and the Corresponding Soil Samples Classification/rating*

Sample No.	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**	**Linear Shrinkage (change in length after drying) (mm)**	**AASHTO Classification/Rating**	**USCS**
AD-IL-1	48.5	28.8	19.7	1.00	A-7-6 /Fair to poor)	CI
AD-IL-2	57.0	31.4	25.6	0.50	A-7-6/(Fair to poor)	CH
AD-IL-3	51.5	27.7	23.8	1.40	A-7-6/(Fair to poor)	CH
AD-IL-4	48.5	24.0	24.5	1.00	A-7-6/(Fair to poor)	CI
AD-IL-5	55.0	24.4	30.7	1.60	A-7-6/(Fair to poor)	CH

Table 6: *Classification of Soil According to Plasticity Index [27]*

Plasticity Index	**Plasticity**
0	Non-Plastic
<7	Low-Plastic
7-17	Medium-Plastic
>17	Highly Plastic

Table 9 presents other physical and mechanical attributes of the studied soil sample. The soils recorded moderately maximum dry density values ranging from 1520 to 1795 kg/m³ these values generally conform to less than 1700 kg/m³ specified by ONORMS 2074 [22], except AD-IL-5 taken at 5 m from the surface recorded a maximum dry density greater than 1740 kg/m³ suggested by [31] for road construction. The water absorption rate after firing varies from 24.5 to 29.1 % indicating moderately low absorption potential. Modulus of rupture and compressive strength of the soils vary between 97 – 168 N/m² and 98-119 N/m² respectively.

These values correspond to the low specific gravity and dry density obtained for all the samples. The values of the CBR indicate the presence of clayey layers as they vary from 66 to 78 %. These values are below the 80 % specified by FMWH [32]. These soils can be used only as filler material for embankment construction and not preferable to be used for road/building construction, as they possess low load bearing and strength characteristics. However blending the soil with gravels/sands can improve the CBR values. Table 10 shows result of the bleaching test conducted on the samples. All the samples were unchanged when immersed in different concentration of Hydrochloric acid, which invariably means they might not change in reaction with acidic rain.

IV CONCLUSION

The geochemical result of the sampled soils shows that they are non-lateritic soils but with increasing maturity and laterization with depth. The clay mineral contents of the sample fall within the illite, and montmorillonite/illite group which makes them unsuitable for road/building construction unless they are blended with amount of sand/gravel. The geotechnical results corroborate the geochemical results. The geotechnical also shows that the soils are rated as fair to poor foundation material using AASHTO and USCS. However, the material fall within specification of ONORM 2074 (1990) as seal/liners for landfill. it is presume that the soil might require some amount of stabilization to qualify it for foundation material for building, road construction, and other civil structural works.

Table 7: *Result of the Specific Gravity Conducted on the Sampled Soils*

Samples	AD-IL-1	AD-IL-2	AD-IL-3	AD-IL-4	AD-IL-5
Specific gravity	2.44	2.44	2.20	2.41	2.33

Table 8: *Classification of Soil According to Linear Shrinkage*

Linear Shrinkage (%)	**Quality of Soil**
0	Good
<7	Medium good
7-17	Poor
>17	Very poor

Table 9: *Physical and Mechanical Properties of Sampled soils after Firing Test*

Test/Sample No.	**AD-IL-1**	**AD-IL-2**	**AD-IL-3**	**AD-IL-4**	**AD-IL-5**
Temp. of Firing (°C)	950	950	950	950	950
Dwell time of firing (°C)	2	2	2	2	2
Dry Density (kg/m³)	1530	1520	1695	1682	1665
Volumetric Shrinkage (%)	6	4	4	3	1
Water Absorption (%)	29.1	26.2	27.6	24.5	24.9
Modulus of Rupture (N/m²)	121	97	154	155	168
Compressive Strength (N/m²)	98	101	104	118	119
CBR (un-soaked %)	66	69	74	74	78

Table 10: *Result of the Bleaching Test obtained for the Studied Soil Samples*

Samples	**Initial Colour**	**Colour in 1% HCl**	**Colour in 5% HCl**	**Colour in 10% HCl**
AD-IL-1	Whitish Brown	Unchanged	Unchanged	Unchanged
AD-IL-2	Yellowish Brown	Unchanged	Unchanged	Unchanged
AD-IL-3	Pinkish Brown	Unchanged	Unchanged	Unchanged
AD-IL-4	Dark Brown	Unchanged	Unchanged	Unchanged
AD-IL-5	Pink	Unchanged	Unchanged	Unchanged

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