

Geochemical Appraisal of Termite-Reworked Clay Soils from Basement Complex Terrain: Implications as Landfill Liners

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Abstract
The geochemical and mineralogical assessment was prompted by the considerable presence of Termitaria overburden on the Basement Complex outcrops in southwest Nigeria with the goal of determining their suitability as landfill liners. The X-Ray Fluorescene (XRF) and X-Ray Diffraction techniques were used to examine ten soil samples. Major oxides and mineralogical values were analysed to determine the effectiveness of soil engineering. Weathering indices and silica/sesquioxide ratios were also measured. The results of the mineralogical investigation showed that kaolinite clay mineral predominated, which is indicative of non-swelling qualities. The outcomes demonstrated that the soil is a true laterite as well as a lateritic soil. Fair carrying capacity was shown by the stability and shear resistance values of 47.15% and 48.11%, respectively. The weathering indices show severe weathering, high clay fraction, strong plasticity, and low hydraulic conductivity with an average of 95% and 0.59 weight percent, respectively. Additionally, the repackaging of the clay soils by termite activity produced greater interlocking and water film resistance. These characteristics make soils an excellent material for landfill liners due to their improved density and bearing capacity, resilience to chemical attack, and reconstructed structure.
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1. Introduction

In order to facilitate the efficient disposal of municipal and industrial solid wastes around the world, landfills are an essential component of every waste management system (WMS) (Yalcin and Demirer, 2002). According to Majolagbe et al. (2017), it has been deemed the safest method of protecting the environment from health risks. The movement of leachate within landfills, the effects of landfill settlement, and sources of groundwater contamination of the aquiferous units make this structure vulnerable to a number of environmental threats (Shackelford, 1990; Manassero et al., 1996; Odukoya and Abimbola, 2010). According to Majolagbe et al. (2017), landfills can be classified as open dumpsites, controlled dumpsites (engineered landfills), and sanitary dumpsites (engineered landfills). Due to their affordability and method of construction, which involves separating garbage from the environment in a closed system, sanitary landfills have been determined to be the most suited type of landfill. However, it has produced significant garbage emplacements and coverings, as well as hydrogeological isolation and control (Kerry et al., 2007; UN-Habitat, 2010; Majolagbe et al., 2017). Public health and environmental risks have been present in areas where liners have not been built (Asiwaju-Bello and Akande, 2002; Odukoya and Abimbola, 2010; Longe and Balogun, 2010). Landfills are covered with liners or covered with an underlayment to lessen the issues caused by leachate coming into touch with groundwater. In most cases, liners consist of a bottom liner, a geosynthetic clay liner (GCL), a geological barrier, and compacted clay and geomembrane (Declan and Paul, 2003; Leite et al., 2003; Frempong and Yanful, 2008; Budihardjo, 2015; Adesina and Tijani, 2017). According to Adesina and Tijani (2017), shales and other geologic materials have also been used as landfill liners. These materials have demonstrated their suitability by effectively combating the soil and groundwater contamination often associated with waste management techniques (Adesina and Tijani, 2017). According to numerous studies (Gullick and Weber, 2001; Tijani and Bolaji, 2007; Charlermyanont et al., 2009; Ige, 2011; Ojuri et al., 2017; Daramola et al., 2018), clay liners are exceptional because of their inherent low hydraulic, high attenuation capacity, affordability, and chemical sorption ability. Some clay soils have the capacity to function as membranes that prevent charged solutes from passing through. Additionally, this membrane behavior causes chemico-osmosis, or the flow of unattended and overdue, the company is then vulnerable to overtime cost, shrunk capacity and productivity, extra queuing time, lost business income, etc. In order to prevent these deteriorative effects, optimising the number of workers can be helpful. As a fundamental branch of knowledge in manufacturing business, workforce management will never fall behind the times.

2. Geology of the Study Area

The research area is surrounded by rocks from the Precambrian Basement Complex and is situated between latitudes 07°00′and 07°52′N and longitudes 04°55 and 05°59′E (Fig. 1). The study area includes the regions of Akoko and Akure (Figures 1). These regions are primarily covered by Granite, Quartzites, Schists, Migmatites, and Quartzites from Nigeria's Basement Complex. Schists typically outcrop weakly; because of its weak resistance to weathering, they are primarily low-lying. In inselbergs and a range of hills, magmatites can be found (Rahaman and Malomo, 1983; NGSA, 2006; Shitta, 2007). The parallel to sub-parallel dark and light bands in the granite/banded Gneisses alternate (Fig. 1). The top soils that cover the majority of crystalline rocks are residual lateritic materials that are typically made up of loose, medium- to coarse-grained mineral matter that ranges in color from greyish to reddish brown and contains some clayey elements (Olabode & Asiwaju-Bello, 2018). However, in places with vegetation cover, the soils are dark in color, perhaps as a result of decomposing flora and fauna. The relief is composed of crystalline foundation rocks that are relatively erratic and undulating in nature. There are various ridges, some of which reach heights of 570 meters. Dendritic drainage patterns predominate in the area, which means that the underlying rocks have relatively uniform resistance to weathering.

3.0 Materials and Methods

3.1 Sampling

Ten (10) distinct locations within the study area provided samples for the examination (Fig. 2). The samples were collected using a disrupted sampling technique. To make sure that the tested samples are accurate representations of the in-situ materials, care was taken when collecting the samples. The unsieved samples were then ready for examination, and milling was done by carefully and softly grinding the sample in order to preserve the structural integrity of the constituent minerals. The samples were transferred to the University of Johannesburg's Department of Metallurgy and Nanomaterials in Johannesburg, South Africa, for geochemical analysis.

Through X-Ray Fluorescence (XRF) analysis, the TRCS samples' overall chemical compositions were identified. For measurements of the adsorbed water, samples were dried in an oven at 100°C for 12 hours. The samples were then ground into a powder and combined with a binder at a ratio of 2: 9 (2 grams of binder and 9 grams of sample), using a ratio of 1:9 in grams of C-wax and EMU powder. The powder combination was subsequently pelletized for 1 minute at 15 Kbars of pressure. The X-ray source was a Rhodium Tube, and the spectrometer was a Phillips Analytical PW1480. For key elements, the approach reports concentration as% oxides. In Table 1, the test results are displayed. Major oxides identified were used for a variety of TRCS engineering behavior classifications and identifications. The comparison of TRCS oxides with typical Kaolin oxide, the ratio of silica to sesquioxides, and weathering indices were also done. The calculation of the Chemical Index of Alteration (CIA), Chemical Index of Weathering (CIW), and Plagioclase Index of Alteration (PIA) using the molecular proportions of the oxides was used to determine the degree of weathering (Nesbitt and Young, 1982; Hanois, 1988; Fedo et al., 1995). It is also feasible to categorize lateritic soils according to the geochemistry of the principal oxides and the silica-sesquioxide molar ratio (SSMR) in accordance with the Rossiter 2004 silica-sesquioxide ratio classification.

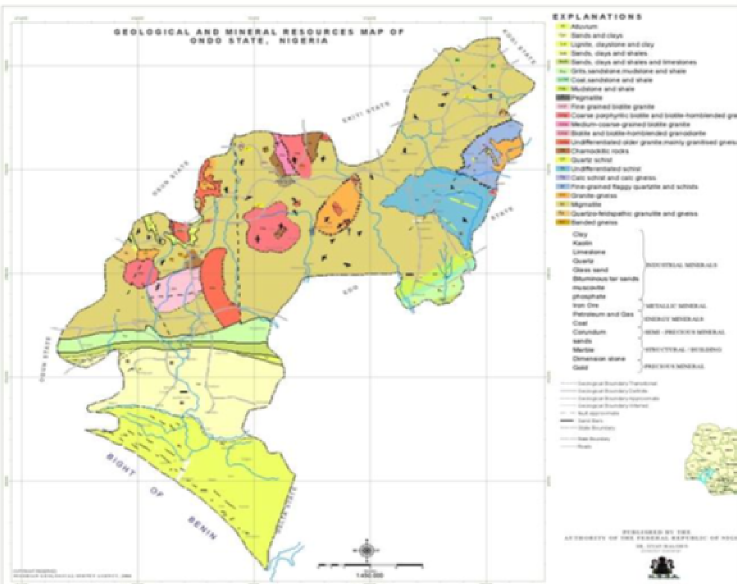

Figure 1. Map of Ondo State (NGSA, 2006)

4.0 Results and Discussion

Silicon oxide (SiO2), aluminum oxide (Al2O3), iron oxide (Fe2O3), manganese oxide (MnO), potassium oxide (K2O), titanium oxide (TiO2), sodium oxide (Na2O), and lead oxide (PbO) are the primary oxides found in all of the soils under study (Table 2). The examined soil samples have significant amounts of bases (K2O and CaO) of 0.35-4.95wt% and 0.12-1.25wt%, respectively, as well as high amounts of silica (38.45–51.00 wt%), sesquioxides Al2O3 (22.07–31.08 wt%), and Fe2O3 (12.66–30.88 wt%).

Table.1: Major oxides, Classifications and Engineering properties of the Samples

Name	BT 1	BT2	BT3	BT4	BT5	BT6	BT7	BT8	BT9	BT 10
SiO_2	51.00	50.21	38.45	50.58	49.43	44.42	43.75	39.52	45.47	50.34
Al_2O_3	29.63	28.14	27.16	22.07	28.13	30.55	30.51	22.56	31.08	24.35
Fe_2O_3	12.66	15.37	27.27	17.55	15.47	20.19	20.07	30.88	17.87	20.00
MnO	0.12	0.08	0.38	0.19	0.15	0.17	0.14	0.41	0.16	0.14
MgO	0.56	0.40	0.30	0.40	0.33	0.85	0.42	0.65	0.43	0.40
CaO	1.25	0.32	0.39	0.37	0.37	0.68	0.35	0.24	0.74	0.12
K_2O	1.71	2.24	0.35	4.95	1.00	0.76	1.18	0.41	1.24	1.36
TiO_2	2.10	0.54	4.78	0.95	3.83	1.87	2.64	2.46	2.15	1.60
P_2O_5	0.12	0.20	0.25	0.33	0.27	0.06	0.11	0.33	0.10	0.30
Na_2O	0.09	0.07	0.07	0.06	0.04	0.06	0.07	0.08	0.07	0.07
$SiO_2/Al_2O_3+Fe_2O_3$	1.21	1.15	0.71	1.28	1.13	0.88	0.87	0.74	0.93	1.14
$Al_2O_3/Si0_2$	0.58	0.56	0.70	0.43	0.56	0.68	0.69	0.57	0.68	0.48
SiO_2/Al_2O_3	1.72	1.78	1.41	2.29	1.75	1.45	1.43	1.75	1.46	2.06
Na_2O/K_2O	0.05	0.03	0.2	0.01	0.04	0.07	0.05	0.19	0.05	0.05
$Al_2O_3+Fe_2O_3$	42.29	43.51	54.43	39.62	43.6	50.74	50.58	53.44	48.95	44.35
AFMC	44.1	44.23	55.12	40.39	44.3	52.27	51.35	54.33	50.12	44.87
CIA	90.67	91.45	97.1	80.4	95.23	95.32	95.02	96.87	93.81	94.02
CIW	95.67	99.42	98.33	98.09	98.56	97.64	98.64	98.6	97.46	99.23
PIA	95.42	98.52	98.31	97.55	98.5	97.58	98.59	98.58	97.45	99.18
TDS	3.61	3.03	1.11	5.78	1.74	2.35	2.02	1.38	2.48	1.95

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

This suggests that the soils that have been modified by termites contain a significant amount of oxides. The significant amount of oxides causes them to accumulate and cling to the clay minerals' surfaces, functioning as natural cements and forming water-stable micro-aggregates. As a result, it will become denser and have less permeability. The termite-reworked earth products are now more frequently used as landfill liners due to the significant amounts of oxides they contain. According to Adesina and Tijani (2017), the termitaria reworked soils contain ferruginized minerals, potassium feldspar, and a predominance of quartz and kaolinite, which may account for the higher values of Fe2O3, SiO2, and K2O.Geochemical Classification of Clay Mineral type. Table 1 shows the main elemental oxides of the investigated samples in comparison to other research studies and standard kaolin. The findings identified kaolinite as the most common form of clay mineral. The SiO2/Al2O3 ratio of 1.71wt% (Table 1) and consistency restrictions in respect to the clay mineralogy of the investigated soils (Table 3) confirmed this. Low base exchange capacity, the least amount of swelling and shrinkage, and minimal layer charge are all suggested. This demonstrated that the TRCS materials would have the lowest affinity for moderate amounts of water induced expansion (Daramola et al., 2018). Kaolinite's stacked crystal structure gives rise to its blocky appearance, bigger size, and lower surface-to-volume ratio compared to other clay minerals. Kaolinite is the least electrochemically active and least flexible clay mineral because of its limited surface area and low negative surface charge. The crystal edges of this mineral group make up 10 to 20% of the total crystal area due to the blocky structure of kaolinite particles (Mukherjee, 2013). In this way, kaolinite can fix some negative ions (Deer et al., 1966). Kaolinite has a lesser affinity for water, a smaller dispersivity, and does not acquire as low a permeability upon aeration than other clay minerals. On the other hand, compared to other clay minerals, it may exhibit less sensitivity to chemicals since it is not as electrochemically active. The permeability of a kaolinitic clay liner may be higher than that of liners made of other clays, although it may not be as sensitive to changes in moisture content or chemical attack.

Table 2: Consistency limits in relation to clay mineralogy (Ikubuwaje and Obasi, 2019)

Soil Type	Liquid Limit (L1) %	Plastic Limit (PL)% Range	Inferred clay mineral(s)
SRWS	33.3 – 43.5	17.5 – 24.20	Kaolinite
BRWS *	36.3 – 53.70	18.5 – 31.0	Kaolinite

Silica-Sesquioxide Molar Ratio Classification

According to Tables 3 and 5, the silica-sesquioxide molar ratio (SSMR) ranges from 0.71 to 1.28. According to Rossiter's classification based on the silica-sesquioxide ratio published in 2004, the outcomes belong to the category of real laterite and lateritic soil. The silica/sesquioxides ratio of true laterites is always less than 0.94, that of lateritic soils goes from 0.94 to 2.0, and that of tropical soils that aren't lateritic is typically higher than 2.0. demonstrating a high degree of laterization. According to Rahardjo et al. (2004), laterite is the result of in-situ weathering of igneous, sedimentary, and metamorphic rocks, which are typically found in unsaturated environments.

The bonding of soil components and creation of concretionary structure are typically caused by the crystallization of accumulated sesquioxides in the pore spaces (Malomo, 1989). Due to the development of a coat and a decrease in compressibility, the considerable sesquioxide content found in the tested soils as revealed by statistical analysis presented in table 6 does not constitute a threat to settlement. These characteristics explain why all of the examined termitaria samples are suitable for use as landfill liners. Cementation compounds of Ca, Mg, Al and Fe

The entire amount of Ca, Mg, Al, and Fe in a soil were referred to by Sridharan and Allam in 1982 as cementation compounds. In comparison to the calculated value from conventional Kaolin oxide, which was 47.8 w% (Tables 3 and 5), the average value for TRCS was 48.11 wt%. This suggests a 90% increase in cementing agents as well as potentially significant shear strength. According to Sridharan and Allam (1982), the quantity and presence of cementing chemicals directly affect the shear strength of soils. The statistical analysis shown in Table 6 confirms the importance of this attribute for the examined soils. Increased cementing agent concentrations, particularly calcite, will increase the termitaria's compression resistance and shear strength while decreasing permeability. Increased interparticle desiccation bondingQuick lime (CaO)

According to Tables 3 and 5, the average concentration of CaO oxides in the TRCS was found to be significantly greater than the average concentration of kaolin clay (0.12 wt%). The TRCS's engineering properties will be enhanced by the observed increase in CaO (quick lime), which will eventually cause a decrease in moisture content, liquid limits, and plasticity. According to Marsh and Greenwood (1995), an increase in calcite content causes the liquid limit to fall. As a result, the moisture content and void ratio are reduced, and density and shear strength are raised. the prevalence of cementing agents is rising, especially calcite, will enhance the strength.

Table 3:Ave. Geochemical Properties of TRCS

Name	BT	Properties
Associated Minerals	26.31	CEC
$Al_2O_3/Si0_2$	0.59	Clayeyeness
SiO_2/Al_2O_3	1.70	Siliceousness
CIA	95.63	
CIW	98.16	Weathering
PIA	97.97	
Mineralogy	Kaolinite	Clay Mineral
Al_2O_3 + Fe_2O_3	47.15	Stabilization
AFMC	48.11	Shear Strength
SiO_2/ $Al_2O_3 + Fe_2O_3$	1.00	Laterization
Nature of Soil	Lateritic	Classification

ii. Aluminum and Iron oxide ($Al_2O_3 + Fe_2O_3$)

In clay engineering, the mixture of aluminum and iron oxide is known as stabilizer (Goldberg, 1989). Compared to normal kaolin's average value of 35.05 wt%, the TRCS has an average value of 47.15 wt% (Tables 3 and 5). This suggests that stronger stabilizer characteristics may improve the material's bearing capacity. Aluminum and iron oxide reduce the crucial coagulations, clay dispersion, water uptake, and clay swelling while boosting microaggregation to stabilize clay minerals (Goldberg, 1989). Cementation requires iron oxides (Shadfan et al., 1985). Cementation requires iron oxides (Shadfan et al., 1985). Iron oxides crystallize during cementation in the spaces between the particle matrices. According to Shadfan et al. (1985), this crystal intergrowth may result in extremely persistent and non-dispersible relationships between the matrix of particles. The physical qualities of soils are improved by the presence of Al and Iron oxide minerals, which also increases aggregate stability, permeability, and friability.

Classification of the Weathering Indices

The geochemical data (Table 5) showed that the Chemical Index of Alteration (CIA) and Chemical Index of

Weathering (CIW) values ranged from 90.60 to 97.10% and 95.67 to 99.42%, respectively with the exception of BT4, which had a CIA value of 80.40%,. The results of these indices show that mobile cations (Na, K, and Ca) have been extensively washed and that feldspar has completely transformed into clays (kaolinite). Plagioclase Index of Alteration (PIA) values range from 95.42 to 99.18%, which further supports the idea that feldspars have completely weathered into clays. The results from each of these indices show the level and intensity of weathering that the termite-reworked soil components have experienced (Fedo et al., 1995). The outcomes also suggest residual enrichment of products high in aluminum and a well-drained environment. The considerable Al2O3 contents (average of 27.42%) and the moderate Al2O3/Si02 ratio (relative clayeyness of 0.59%) must be explained by this. suggests significant clay buildup and content enrichment in the clay fraction. This confirms the applicability of the termite earth reworked materials as landfill liners by increasing the clay's flexibility with low permeability and cohesion properties. In actuality, the weathering process promotes greater moisture levels, the severing of interparticle connections, and sensible remolded conditions. This progressive degrading and softening is usually accompanied by reduction in strength and deformation modulus with a general increase in plasticity and destruction of microstructure (Winkerkon and Tschebotarioft, 1993). However, termites' activities have been found to modify the weathered soils physically and chemically in a greater proportion (Heikens et al., 2001). The innate modification nature of termites will enhance its usage as landfill liner irrespective of the degree of weathering as observed in the higher values of weathering indices

5. Conclusion

The geochemical characterisation of these soils in order to evaluate uses as landfill liners was inspired by the quantity of termite-reworked clay soils and the rising wastes created in the research locations. According to an assessment of the examined clay bodies' lining potential based on their chemical properties, they are acceptable for contaminant and pollution management. The outcomes showed that the termitaria clays are genuine laterite and kaolinite clay in nature. The soils' higher shear strength and permissible bearing capacity were shown to be significantly influenced by increased cementation components (Ca, Mg, Al, and Fe). As landfill liners, the soils will be more stable as a result. Significant alumina levels and a clayeyness of 0.59% imply significant clay enrichment and buildup in the particles. As a result, density is increased and permeability is decreased. This also improves high adsorption or ion exchange capacity and aids cohesion and adhesion during compaction. Significant TDS content in the soils predicts low dispersivity and low erositivity, making the soils appropriate as landfill liners for preventing internal erosion and seepage. The clay under study shows high levels of weathering, a sign of a well-drained environment. However, termite activity resulted in better interlocking, pore space plugging, and resistance to water film, increasing compressive strength by a significant amount. These changes also increased density and resistance to chemical attack, rebuilt microstructure and macrostructure, and prevented further weathering. The TRCS's geochemical study evaluation has shown that the material is suitable for use as landfill liners

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