

Statistical Analysis on Physico-Chemical Properties of Some Nigerian Clay Deposits

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Abstract

Clays are among the most essential industrial minerals due to their unique physicochemical properties and versatile usage. This paper used Statistical Package for Social Sciences (SPSS) software to characterize five clay deposits for their physical and chemical compositions. The package, was employed to carry out the Analysis of Variance (ANOVA) by Post-Hoc multiple comparisons and Kristal Wallis at 5% confidence level for the f- and t-tests respectively. The analysis of variance of the chemical components of the samples by post-hoc ($f_{36} = 52.40$, $p < 0.05$) showed that significant difference exist between the average concentration means. While the Kristal Wallis one sample t-test ($T_{37.38}$ and $p < 0.05$) showed a great degree of significant difference in the p-values of the means of SiO_2 and Al_2O_3 . Pearson bivariate correlation statistical tool was also used to establish if significant positive inter-relationships exist between the parameters in each site of the clay samples at ($p < 0.01$ and $p < 0.05$). The result of the correlation indicates a very significant, strong and positive coefficient p-values above 0.900 between the chemical and physical properties. Pearson bivariate correlation coefficient between the chemical and physical parameters of the clay samples indicates very significant, strong and positive correlations with p-values above 0.900 at ($p < 0.01$ and < 0.05). The overall physicochemical results indicate that most of the clay samples will meet the requirements for some industrial applications with minimal processing.

Keywords

Clay, Kaolinite, Minerals, Physicochemical

1. Introduction

The clay minerals are basically composed of repeating tetrahedral and octahedral

planar sheets. The tetrahedral and octahedral sheets form a polymeric aluminosilicate layer that is mostly crystalline in structure. Impurities such as Fe_2O_3 , TiO_2 , K_2O and Na_2O vary among clay samples from the different locations. Clay minerals share a basic set of structural and chemical characteristics, yet each clay mineral has its own unique set of properties that determine how it will interact with other chemical species [1].

The application of clay materials is influenced by their physical and chemical properties which determine their suitability for specific usage. The geographical location for each clay materials confer unique physico-chemical properties which ultimately determines the type of material produced and its application [2]. Specific physical and chemical properties of clays such as kaolin are also dependent on the environment of deposition, geological origin, geographic source and the material method at the end of processing [3]. The basic physical and chemical properties of clay materials are widely used in both academic and industrial fields. These properties may vary under the influences of both natural processes and human disturbances [4].

Clays are abundant and readily available. They also possess distinct adsorptive characteristics from one origin to another. The adsorption characteristics depend on the chemical and mineralogical composition as well as on textural, structural, and morphological properties [5]. Plasticity is also one of the most important clay properties that are related to different parameters. The most disaggregated clay minerals with major ionic exchange capability are more often plastic in nature. Montmorillonitic minerals are most plastic, than illitics, and least kaolinitics [6]. Clays and clay minerals such as montmorillonite, vermiculite, illite, kaolinite, and bentonite are widely used in process and petroleum industries, engineering and constructions, environmental remediation, ceramics and refractories, pharmaceuticals and agricultural sectors [7].

Nigeria has large quantity of clay minerals that are widely spread across the country. Some of the studies conducted on Nigerian clays are reported in many literatures [8] [9] [10] [11] [12]. This study evaluates the physical and chemical properties of the clay deposits in selected locations in Plateau State, Central Nigeria using statistical analysis.

2. Materials and Methods

2.1. Study Site

The study sites referenced in this research are all located in Plateau State, Central Nigeria. The deposit sites include RarinSho (RC), Major Porter (MP), Kwi (KC), Wereng Camp (WC) and Naraguta (NC). The study areas are bounded between latitudes $8^{\circ}30'$ E and $9^{\circ}00'$ E and longitudes $9^{\circ}30'$ N and $10^{\circ}00'$ N as shown in **Figure 1**. The clays at the deposit sites were classified as kaolinite and ball clays by Nigerian Mining Corporation (NMC). Geographically, the areas are characterized by uneven topographic profile with many hills.

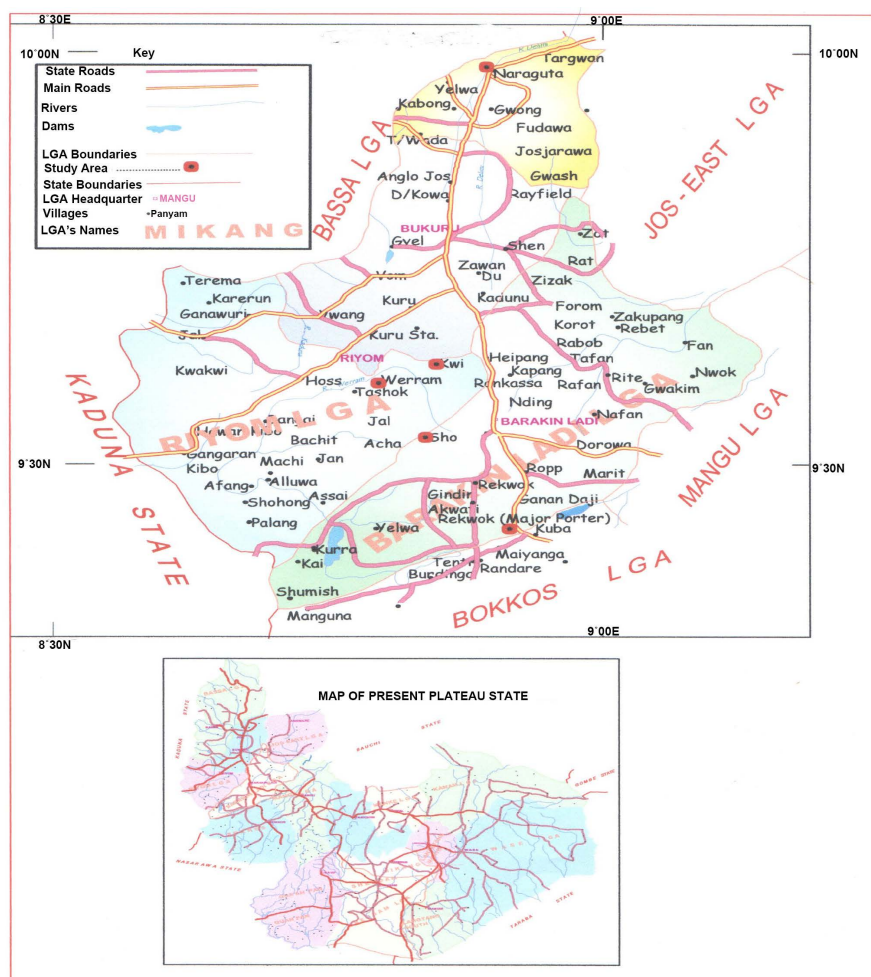


Figure 1. Map of the study sites [Adapted from Ministry of Land and Survey, Plateau State].

2.2. Sample Collection and Determination

The samples were obtained from underground local mines 10 - 20 cm beneath the soil surface. Ten different points within each deposit collected was by randomized sampling. In addition, 5 kg of fresh samples in lump form were obtained randomly from ten different points within each deposit from underground local mines pit at the depth of 10 - 20 cm. The samples were air-dried for several days and crushed using a set of Denver crushers by Denver Equipment Company England. Each crushed sample was thoroughly mixed, coned and quartered. Two opposite composite representatives were obtained and consequently milled and pulverized. These were packaged in small polyethene bags as representatives of the samples for the required tests [11].

2.3. Methods of Analysis

2.3.1. Chemical Analysis

The chemical compositions of the pulverized samples were determined by Energy Dispersive X-ray Fluorescence (EDXRF) of the model PW4030 X-ray photome-

ter that uses a rhodium anode tube. The sample film was placed firmly in a waxed and gold plated sample holder. The Energy Dispersive patterns were obtained with the help of a computer attached to the instrument and each compound recorded in percentage [13].

2.3.2. Loss on Ignition

Loss on ignition was determined according to the Lechler and Desiletes method, [14]. The samples were oven-dried at 110°C. Then 1 g of the sample of clay was placed in preheated, cooled and pre-weighed silica crucibles and heated to 1000°C in a furnace for an hour. The crucibles and contents were removed, cooled in a desiccator to room temperature and weighed again. The loss in weight was calculated.

2.4. Physical Analysis

2.4.1. Plasticity Index of Clay Samples

The Atterberg plasticity method prescribed by [15] was used to calculate the plasticity index of the clay samples from their respective liquid and plastic limits determined.

2.4.2. Particle-Size Analysis

The particle size test was carried out by using the standard Hydrometer method [16]. 50 g of milled oven-dry clay was weighed into a 250 cm³ beakers and mixed with 100 cm³ calgon, then allowed to soak for 30 minutes. The mixed suspension was transferred into a sedimentation cylinder and filled up to mark point with distilled water.

The hydrometer was inserted into the mixture in the cylinder and the readings were taken after interval of 40 seconds twice. After 2 hours, another hydrometer reading and temperature were recorded. After 40 seconds and 2 hours, all the sand and silt particles would have settled and only clay will remain in suspension. The percentages of silt and clay were then calculated and the interpretation of result was made by using a textural triangle.

2.4.3. Drying and Firing Shrinkage of Clays

The clay drying and firing shrinkages were determined from brick bars prepared using a mechanical hydraulic press (model D-7064 Paul Weber) with its accessory moulds and the method adopted was [17].

2.5. Statistical Analysis

The statistical tools employed to carry out the data analysis of this study were the Microsoft 2010 Excel Package and Statistical Package for Social Sciences (SPSS) version 17.0 software. The Microsoft Excel was used to compute the mean and standard deviation generated results while the SPSS was employed to carry out the Analysis of variance (ANOVA) by Post-hoc tampane multiple comparisons F-test and Kristal Wallis T-test all at 5% confidence level. This assisted in determining if significant differences exist in the average means of the concentration

of the compounds from the different sample sites. The p-values that were equal to or less than 0.05 were considered significant.

Correlation Coefficient

Pearson correlation statistical tool was also used to establish if significant positive interrelationships exist between the chemical and physical parameters in each site of the clay samples. The strength of the variables on the scale of -1 (perfect inverse relation) through 0 (no relation) to $+1$ (perfect sympathetic relation) were determined at both confidence levels of 0.01 and 0.05 .

3. Results and Discussion

3.1. Physicochemical Characteristics of the Clay Samples

The results of the chemical and physical analysis of RarinSho (RC), Major Porter (MP), Wereng Camp (WC), Kwi (KC) and Naraguta (NC) clay samples are summarized in **Tables 1-3** respectively. The chemical properties of the samples were determined statistically by analysis of variance (ANOVA) at ($F_{8, 36} = 52.40$, $p < 0.05$) and Krystal Wallis one sample t-test ($T_{8, 37.38}$, $p < 0.01$). The results of chemical analysis shows the different oxide components that indicate also the variations in the means of the concentrations of the compounds contained in the studied clay bodies.

The ANOVA in **Table 1** showed that significant differences exist between the average means of the concentrations of the oxides of the different samples except for few minor constituents whose values are similar. The Krystal Wallis one sample t-test result of the randomized block design model used for major and trace oxides shown in **Table 2** depicted that a greater degree of differences are observed from the p-values of silica (SiO_2) and alumina (Al_2O_3). It shows that these oxides (SiO_2 and Al_2O_3) are significantly more, followed by the p-values of

Table 1. Chemical composition of oxides in the clays.

Oxides (%)	RarinSho Clay (RC)	Major Porter Clay (MP)	Wereng Camp Clay (WC)	Kwi Clay (KC)	Naraguta Clay (NC)
SiO_2	$62.26^a \pm 0.14$	$55.10^b \pm 0.34$	$50.15^c \pm 0.19$	$46.48^d \pm 0.27$	$41.20^e \pm 0.04$
Al_2O_3	$29.44^a \pm 0.11$	$34.73^b \pm 0.06$	$37.15^c \pm 0.14$	$31.12^d \pm 0.15$	$17.25^e \pm 0.12$
Fe_2O_3	$0.43^a \pm 0.05$	$1.39^b \pm 0.11$	$1.93^c \pm 0.09$	$5.54^d \pm 0.11$	$27.52^e \pm 0.07$
TiO_2	$0.05^a \pm 0.02$	$1.54^b \pm 0.14$	$2.82^c \pm 0.03$	$3.10^c \pm 0.13$	$3.28^c \pm 0.03$
Na_2O	$0.13^a \pm 0.02$	$0.23^b \pm 0.03$	$0.08^a \pm 0.02$	$0.12^a \pm 0.02$	$1.17^c \pm 0.05$
K_2O	$2.19^a \pm 0.04$	$1.97^a \pm 0.08$	$0.13^b \pm 0.02$	$0.33^c \pm 0.03$	$3.10^d \pm 0.04$
CaO	$0.46^a \pm 0.03$	$0.43^a \pm 0.03$	$0.06^b \pm 0.02$	$0.23^c \pm 0.03$	$0.33^d \pm 0.04$
MgO	$0.33^a \pm 0.03$	$0.15^b \pm 0.02$	$0.07^c \pm 0.01$	$0.14^b \pm 0.03$	$0.57^d \pm 0.03$
LOI	$4.30^a \pm 0.16$	$5.22^b \pm 0.16$	$8.38^c \pm 0.09$	$12.43^d \pm 0.08$	$5.13^c \pm 0.09$

a-d = Mean average values within a row with different superscripts are significantly different at 5% level and a-a = Mean average values within a row with the same small letter superscripts are not significantly different at 5% level.

Table 2. Krystal wallis one-sample t-test.

Oxide	t	df	P-Value	Mean
SiO ₂	14.25	4	0.000*	51.00
Al ₂ O ₃	8.709	4	0.001*	30.00
Fe ₂ O ₃	1.44	4	0.223	7.36
TiO ₂	4.17	4	0.014*	2.14
Na ₂ O	1.67	4	0.17	0.35
K ₂ O	2.74	4	0.05*	1.53
CaO	4.61	4	0.001*	0.24
MgO	2.63	4	0.06	0.23
LOI	4.71	4	0.009*	7.09

* = Significantly different and P = Probability value.

Table 3. Physical properties of the clay samples.

Sample Clays	pH	Particle Size (%)			Plasticity (%)			Shrinkage (%)	
		Clay	Silt	Quartz	LL	PL	PI	Drying	Firing
RarinSho Clay	6.0 ± 0.08	67.88 ± 0.09	24.00 ± 0.11	8.12 ± 0.08	57.30 ± 0.32	25.45 ± 0.08	33.68 ± 0.23	1.10 ± 0.09	1.65 ± 0.07
Major Porter Clay	6.1 ± 0.11	73.88 ± 1.00	18.00 ± 0.00	8.12 ± 1.00	45.38 ± 0.28	29.48 ± 0.28	15.90 ± 0.00	1.10 ± 0.00	2.23 ± 0.55
Wereng Camp Clay	5.60 ± 0.13	91.88 ± 1.00	6.00 ± 0.00	2.12 ± 1.00	61.15 ± 0.95	44.05 ± 0.85	17.20 ± 0.00	2.23 ± 0.03	4.99 ± 0.56
Kwi Clay	5.2 ± 0.13	84.88 ± 4.00	14.00 ± 2.00	4.12 ± 1.00	63.90 ± 0.4	28.60 ± 0.00	33.30 ± 0.4	1.14 ± 0.04	2.40 ± 0.00
Naraguta Clay	6.4 ± 0.29	49.88 ± 3.00	43.00 ± 3.00	7.12 ± 0.00	48.03 ± 1.48	23.50 ± 0.8	24.53 ± 2.28	2.22 ± 0.02	3.30 ± 0.00

LL = Liquid Limit; PL = Plasticity Limit; PI = Plastic Index.

calcium oxide (CaO) and loss on ignition (LOI). The high amounts of SiO₂, Al₂O₃ and LOI define the clay samples as hydrated alumino-silicate type of minerals [17]. This is attributed to the fact that kaolin clays are principally composed of SiO₂, Al₂O₃ and water, which have a chemical composition of Al₂Si₂O₅(OH)₄, also represented as Al₂O₃·2SiO₂·2H₂O.

The results of the Pearson bivariate correlation coefficient determined between the chemical and physical properties of the clay samples in **Tables 4-8** showed very significant, strong and positive correlations. Most of the correlation values fall within the range of 0.900 and above but less than unity in all the samples.

3.2. Correlation Associations between the Clay Parameters

Interrelationships in clay chemical and physical properties were assessed for each sample site by Pearson Bivariate correlation analysis. Multiple and very strong significant correlations were observed and selected. The correlations determined for RarinSho clay sample shown in **Table 4** were highly significant. Very high significant interactions were observed between silt and PL ($r = 0.953$), K₂O and CaO ($r = 0.942$), Quartz and pH ($r = 0.925$), and Al₂O₃ and PL ($r =$

Table 4. Pearson bivariate correlation for RC sample site.

		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	CaO	MgO	LOI	Clay	Silt	Quartz	LL	PL	PI	pH
SiO₂	R	1															
Al₂O₃	R	-0.081	1														
Fe₂O₃	R	-0.542	-0.457	1													
TiO₂	R	0.566	-0.572	-0.438	1												
Na₂O	R	0.427	-0.683	-0.114	0.896(*)	1											
K₂O	R	-0.609	0.23	0.706	-0.768	-0.408	1										
CaO	R	-0.702	0.339	0.678	-0.923(*)	-0.67	0.942(*)	1									
MgO	R	-0.571	0.604	-0.325	-0.379	-0.605	-0.013	0.209	1								
LOI	R	-0.541	0.477	-0.399	-0.085	-0.21	-0.027	0.049	0.875	1							
Clay	R	0.402	0.764	-0.804	0.05	-0.071	-0.17	-0.223	0.258	0.377	1						
Silt	R	0.141	0.749	-0.044	-0.655	-0.558	0.524	0.524	-0.016	-0.16	0.543	1					
Quartz	R	0.024	0.791	-0.431	-0.247	-0.169	0.317	0.21	0.268	0.445	0.866	0.672	1				
LL	R	-0.533	-0.229	0.785	-0.33	0.111	0.848	0.663	-0.303	-0.112	-0.367	0.122	0.117	1			
PL	R	0.031	0.903(*)	-0.219	-0.641	-0.597	0.468	0.487	0.24	0.14	0.699	0.953(*)	0.822	0.043	1		
PI	R	0.589	0.06	-0.819	0.558	0.139	-0.951(*)	-0.828	0.203	0.123	0.344	-0.3	-0.156	-0.966(**)	-0.213	1	
pH	R	-0.345	0.743	-0.251	-0.365	-0.254	0.462	0.389	0.484	0.671	0.676	0.504	0.925(*)	0.282	0.704	-0.319	1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed) R = Pearson correlation.

0.903) all at ($p < 0.05$). There was also a moderate level of significant correlation between TiO₂ and Na₂O ($r = 0.896$) at ($p < 0.05$). The chemical analysis of this sample showed that the value of SiO₂ was much higher than normal, chiefly due to the quantity of silt and quartz present from its size analysis. The association also indicates that the content of silt and Al₂O₃ contribute positively to the increase of the plastic limit of the sample. The site also indicates that the increase in the concentration of K₂O resulted to the slight rise of that of CaO.

Similarly, some interrelationships occurred between the physical and chemical properties of Major Porter clay sample. The most positive significant correlations amongst the oxides concentration was observed between Fe₂O₃ and TiO₂ ($r = 0.995$) at ($p < 0.01$) shown in **Table 5**. Significant correlations were also observed between Fe₂O₃/TiO₂ and clay ($r = 0.977, 0.972$), also at ($p < 0.01$), and K₂O and Clay ($r = 0.952$) at ($p < 0.05$). Clay and PI ($r = 0.950$) also associated at ($p < 0.05$). There was also a strong double significant association between Fe₂O₃/TiO₂ and the plastic index of the sample at ($r = 0.958; p < 0.05$). The sample in this site was notably observed to contain an appreciable amount of Fe₂O₃ and SiO₂. The low LOI value of the sample is attributed to the amount of quartz obtained from its size analysis.

Table 6 shows a very strong significant interactions between Fe₂O₃ and clay ($r = 0.967, p < 0.01$), Al₂O₃ and TiO₂ ($r = 0.916$), and SiO₂ and TiO₂ ($r = 0.900$) at ($p < 0.05$) in Wereng Camp clay deposit. Also observed was the significant

Table 5. Pearson bivariate correlation for MP sample site.

		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	CaO	MgO	LOI	Clay	Silt	Quartz	LL	PL	PI	pH
SiO ₂	R	1															
Al ₂ O ₃	R	-0.349	1														
Fe ₂ O ₃	R	0.919(*)	-0.101	1													
TiO ₂	R	0.949(*)	-0.133	0.995(**)	1												
Na ₂ O	R	-0.478	-0.4	-0.587	-0.567	1											
K ₂ O	R	0.916(*)	-0.379	.894(*)	0.915(*)	-0.191	1										
CaO	R	0.375	-0.151	0.634	0.567	-0.2	0.534	1									
MgO	R	0.358	0.061	0.643	0.568	-0.53	0.377	0.919(*)	1								
LOI	R	0.645	-0.046	0.841	0.791	-0.672	0.591	0.841	0.938(*)	1							
Clay	R	0.901(*)	-0.226	0.977(**)	0.972(**)	-0.405	0.952(*)	0.701	0.626	0.801	1						
Silt	R	-0.536	-0.568	-0.748	-0.724	0.836	-0.438	-0.383	-0.579	-0.686	-0.623	1					
Quartz	R	-0.613	-0.293	-0.858	-0.813	0.772	-0.565	-0.716	-0.853	-0.921(*)	-0.782	0.907(*)	1				
LL	R	-0.72	-0.308	-0.727	-0.763	0.529	-0.662	-0.035	-0.086	-0.329	-0.651	0.779	0.58	1			
PL	R	0.715	0.049	0.831	0.835	-0.198	0.881(*)	0.537	0.394	0.523	0.876	-0.631	-0.656	-0.776	1		
PI	R	0.847	0.05	0.958(*)	0.958(*)	-0.478	0.897(*)	0.576	0.539	0.714	0.950(*)	-0.779	-0.82	-0.827	0.947(*)	1	
pH	R	-0.936(*)	0.655	-0.779	-0.816	0.211	-0.893(*)	-0.362	-0.256	-0.525	-0.818	0.214	0.378	0.474	-0.579	-0.674	1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). R = Pearson Correlation.

Table 6. Pearson bivariate correlation for WC sample site.

		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	CaO	MgO	LOI	Clay	Silt	Quartz	LL	PL	PI	pH
SiO ₂	R	1															
Al ₂ O ₃	R	0.898(*)	1														
Fe ₂ O ₃	R	0.596	0.375	1													
TiO ₂	R	0.900(*)	0.916(*)	0.416	1												
Na ₂ O	R	0.785	0.754	0.858	0.742	1											
K ₂ O	R	-0.429	-0.13	-0.416	0	-0.163	1										
CaO	R	-0.836	-0.532	-0.837	-0.593	-0.727	0.685	1									
MgO	R	-0.007	-0.224	-0.169	0.15	-0.283	0.173	-0.079	1								
LOI	R	0.417	0.602	0.13	0.763	0.515	0.639	-0.055	0.224	1							
Clay	R	0.506	0.235	0.967(**)	0.235	0.731	-0.591	-0.834	-0.224	-0.124	1						
Silt	R	0.782	0.823	0.115	.942(*)	0.475	0.099	-0.406	0.343	0.756	-0.063	1					
Quartz	R	-0.698	-0.813	0.148	-0.73	-0.242	0.147	0.253	-0.011	-0.398	0.231	-0.83	1				
LL	R	-0.222	0.102	-0.023	-0.224	0.158	0.203	0.379	-0.926(*)	-0.04	-0.02	-0.37	0.12	1			
PL	R	-0.308	-0.254	0.469	-0.357	0.314	0.128	0.065	-0.585	-0.118	0.483	-0.62	0.721	0.647	1		
PI	R	0.044	0.083	-0.555	-0.133	-0.474	-0.456	0.13	-0.14	-0.479	-0.418	0.049	-0.557	-0.021	-0.629	1	
pH	R	-0.292	-0.004	-0.307	-0.39	-0.167	-0.036	0.454	-0.882(*)	-0.356	-0.219	-0.433	-0.033	.882(*)	0.339	0.433	1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). R = Pearson correlation.

Table 7. Pearson bivariate correlation for KC sample site.

		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	CaO	MgO	LOI	Clay	Silt	Quartz	LL	PL	PI	pH
SiO ₂	R	1															
Al ₂ O ₃	R	0.641	1														
Fe ₂ O ₃	R	-0.367	-0.027	1													
TiO ₂	R	0.225	0.312	-0.425	1												
Na ₂ O	R	0.471	0.171	0.548	-0.374	1											
K ₂ O	R	0.309	0.293	0.049	-0.748	0.31	1										
CaO	R	0.477	0.663	-0.32	-0.221	-0.075	0.794	1									
MgO	R	0.168	0.098	0.493	-0.884(*)	0.671	0.85	0.4	1								
LOI	R	-0.07	0.003	-0.838	0.349	-0.890(*)	-0.052	0.375	-0.546	1							
Clay	R	-0.314	0.109	0.355	0.659	-0.145	-0.815	-0.582	-0.61	-0.195	1						
Silt	R	-0.49	-0.768	-0.48	-0.244	-0.595	-0.018	-0.128	-0.192	0.588	-0.428	1					
Quartz	R	-0.542	-0.185	0.335	0.559	-0.266	-0.882(*)	-0.737	-0.653	-0.129	0.953(*)	-0.159	1				
LL	R	-0.285	-0.804	0.02	0.1	0.103	-0.623	-0.893(*)	-0.316	-0.236	0.2	0.381	0.394	1			
PL	R	-0.926(*)	-0.769	0.476	-0.189	-0.219	-0.471	-0.754	-0.168	-0.193	0.403	0.401	0.637	0.582	1		
PI	R	-0.657	-0.27	0.608	0.268	-0.08	-0.721	-0.762	-0.377	-0.363	0.877	-0.189	0.944(*)	0.394	0.771	1	
pH	R	-0.930(*)	-0.811	0.357	-0.139	-0.316	-0.506	-0.751	-0.25	-0.079	0.374	0.498	0.626	0.612	0.991(**)	0.728	1

*Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). R = Pearson Correlation.

Table 8. Pearson bivariate correlation for NC sample site.

		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	CaO	MgO	LOI	Clay	Silt	Quartz	LL	PL	PI	pH
SiO ₂	R	1															
Al ₂ O ₃	R	0.757	1														
Fe ₂ O ₃	R	-0.525	-0.209	1													
TiO ₂	R	-0.38	-0.085	0.977(**)	1												
Na ₂ O	R	-0.24	0.213	0.202	0.279	1											
K ₂ O	R	-0.452	-0.351	-0.176	-0.376	-0.385	1										
CaO	R	-0.936(*)	-0.772	0.289	0.101	-0.001	0.724	1									
MgO	R	0.639	0.202	0.046	0.154	-0.556	-0.543	-0.671	1								
LOI	R	-0.914(*)	-0.462	0.745	0.631	0.399	0.31	0.778	-0.605	1							
Clay	R	-0.857	-0.648	0.237	0.035	-0.093	0.846	0.974(**)	-0.677	0.733	1						
Silt	R	-0.841	-0.547	0.384	0.186	-0.084	0.812	0.931(*)	-0.628	0.796	0.978(**)	1					
Quartz	R	-0.885(*)	-0.85	0.337	0.252	0.332	0.163	0.773	-0.516	0.696	0.61	0.524	1				
LL	R	-0.994(**)	-0.696	0.497	0.347	0.278	0.499	0.942(*)	-0.709	0.926(*)	0.880(*)	0.868	0.849	1			
PL	R	0.832	0.703	-0.203	-0.133	-0.524	-0.154	-0.721	0.684	-0.665	-0.567	-0.468	-0.961(**)	-0.82	1		
PI	R	-0.802	-0.631	-0.032	-0.214	0.069	0.81	0.933(*)	-0.826	0.608	0.933(*)	0.85	0.669	0.834	-0.702	1	
pH	R	0.274	-0.036	-0.498	-0.367	0.372	-0.569	-0.367	0.069	-0.452	-0.52	-0.668	0.187	-0.307	-0.292	-0.223	1

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); R = Pearson Correlation.

correlation between TiO_2 and silt ($r = 0.942$; $p < 0.05$). The significant strong association of Fe_2O_3 and TiO_2 can be explained from their appreciable quantities as impurities in the sample. The high concentration of TiO_2 in the sample is due to its close association to the small quantity of the silt.

The most significant and very strong positive relationship amongst the properties in Kwi clay sample was between PL and pH ($r = 0.991$, $p < 0.01$). There was also a strong correlation between clay and quartz ($r = 0.953$, $p < 0.05$) and between quartz and PI ($r = 0.944$; $p < 0.05$) as shown in **Table 7**. The sample also indicated numerous negative correlations at different strengths but not considered. The interrelationship in this deposit has shown that the sample has the lowest pH in **Table 3** contributing to the positive increase of its PL value.

Table 8 reveals many positive correlations in Naraguta clay deposit. The highest significant relationship was between clay and silt ($r = 0.978$), Fe_2O_3 and TiO_2 ($r = 0.977$), CaO and clay ($r = 0.974$) all at ($p < 0.01$). There was also a positive significant relationship between CaO and LL ($r = 0.942$). Other significant associations were found between CaO, clay and PI of the sample at ($r = 0.933$; $p < 0.05$). Also strongly significant was the correlation between LOI and LL ($r = 0.926$; $p < 0.05$). The high concentrations of Fe_2O_3 and TiO_2 at 28% and 3% respectively indicate a very high level of impurities. The moderate values of LOI, LL, and PL observed could all be attributed to the very high amount of SiO_2 and quartz.

4. Conclusion

The very strong and high positive correlations in the clay properties reveal the amount and level of the oxide concentrations which consequently influence their physical properties and thereby their quality and functions. The results of the chemical and physical properties show that all the samples are suitable for various industrial applications.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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