Research Article

Olusola Johnson Ojo*, Suraju Adesina Adepoju, Ayodeji Awe, Adeonipekun Dele Adedoyin, Sikiru Ottan Abdulraman, and Busoye Thomas Omoyajowo

Physicochemical and mineralogical composition studies of clays from Share and Tshonga areas, Northern Bida Basin, Nigeria: Implications for Geophagia

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Abstract: This study is focused on the evaluation of the geophagic characteristics of the sedimentary clay deposits at Share and Tshonga areas, northern Bida Basin, Nigeria. The methods used include particle size distribution, cation exchange capacity (CEC), acidity and alkalinity (pH), X-ray diffractometry, and bulk inorganic geochemical analysis (X-ray fluorescence and inductively coupled plasma mass spectrophotometer). The investigated clays are classified as dominantly clayey–silt with minor clayey–sand type, which conforms with the textural standard of geophagic clays obtained from different parts of the world. The whitish coloration of the clays with an occasional red stain also compares well with geophagic clays from Kenya and parts of South Africa and is therefore considered suitable for consumption. The observed low CEC (1.71–5.06 cmol(+)/kg) and acidic pH (4.54–6.87) values of the clay samples would make them effective against nausea and excessive salivation during pregnancy. The mineralogical compositions of these clay samples show the dominance of kaolinite with minor non-clay minerals, which makes it suitable not only for food detoxification but also as an alleviation of gastrointestinal disorders such as diarrhea. Chemical analysis shows a low percentage per weight of certain elements that are of nutritional value, though not in the present state but better as excipients in the pharmaceutical industry. It was observed, however, that consumption of more of the studied clay may lead to adverse health due to the presence of some heavy metals (Co, Cu, Ni, Cd, Ag, and Pb) with concentrations in excess of the permissible limit.

Keywords: physicochemical, nausea, kaolinite, Geophagia, heavy minerals

1 Introduction

Deliberate human consumption of clay, which is also known as Geophagia [1], is reported to be nearly everywhere but more prevalent among some cultures and pregnant women in sub-Saharan Africa. This is perhaps due to the common belief that it reduces symptoms of severe nausea and vomiting during pregnancy, as suggested by Dreyer et al. [2]. Some studies have shown that many Geophagists consume clayey soil because of its beneficial qualities, which include gastrointestinal distress relief [3], detoxification properties [4], and mineral supplementation [5]. The study of the properties of clays beneficial to human health and pharmaceutical applications has received great interest among researchers during the last two decades [6–9], concluding that clay could absorb dietary and bacterial toxins associated with gastrointestinal disturbance. Other important properties considered by individual Geophagist for clayey soil preference include softness, smoothness and powdery, and these are influenced by the texture [10]. Therefore, the physicochemical characteristics of geophagic soils are important to make a valid assessment of their beneficial or harmful nature.

* **Corresponding author: Olusola Johnson Ojo**, Department of Geology, Federal University, Km. 3, Oye - Afao Road, P.M.B. 373, Oye Ekiti, Nigeria, e-mail: olusola.ojo@fuoye.edu.ng
Suraju Adesina Adepoju: Department of Geology and Mineral Science, Kwara State University, Malete, Kwara State, Nigeria
Ayodeji Awe, Busoye Thomas Omoyajowo: Department of Geology, Federal University, Km. 3, Oye - Afao Road, P.M.B. 373, Oye Ekiti, Nigeria
Adeonipekun Dele Adedoyin: Department of Geology and Mineral Sciences, University of Ilorin, Ilorin, Nigeria
Sikiru Ottan Abdulraman: Department of Material Science and Engineering, Faculty of Engineering and Technology, Kwara State University, Malete, Kwara State, Nigeria

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The study of geophagy is yet to be given wide attention in Nigeria, and among the few ones available include the study of Ibeanu et al. [11], which reported that consumption of clay in Kenya and Nigeria could be used to control excessive secretion of saliva during pregnancy among women. Other related works include that of Ojo et al. [12], who studied the sedimentological, geochemical, and economic appraisal of Maastrichtian claystone facies in Bida Basin and concluded that they are economically viable. The investigated clays in this study are located in Share (longitudes 5°30′–6°30′E; latitudes 8°45′–9°15′N) and Tshonga (longitude 5°14′E; latitude 9°02′N), within the northern Bida Basin. Share is an agrarian community and a local Government headquarters in Kwara state, northern Nigeria. Though the geophagic practice has been reported within the Share community and its environments, there has not been any published scientific report on the geophagic characteristics of the clay and its prevalence. Meanwhile the interaction with local people during field sampling, particularly vendors in the market, confirmed clay consumption by some pregnant women during pregnancy and after delivery. The herb sellers also confirmed that the mixture of clay with palm wine was used to cure some skin infections. Apart from oral consumption, other local uses in the study area include aphrodisiac applications, skin infection prevention and treatment, painting of Fura and Nunu (cow milk) pots by Fulani women and cult initiation portion. Therefore, the main aim of this present study is to determine the textural, physical, geochemical, and mineralogical composition of the clays for geophagic potential.

2 Geological setting

The Bida Basin is a northwestern–southeastern trending intracratonic sedimentary basin extending from Kontagora in its northern part to areas slightly beyond Lokoja in the southern part and delimited in the northeast and southwest by the basement complex (Figure 1a). The Basin has been divided geographically into northern and southern Bida Basins. The northern Bida Basin comprises the basal Campanian Bida Formation, which is mainly conglomerate and sandstone lithologies and deposited in an alluvial to fluvial depositional system [13]. It is overlain by the Maastrichtian Sakpe Formation (ironstone) and Enagi Formation (siltstone, claystone, and sandstone deposited in braided tidal channels and flood plains). The older successions are succeeded by the youngest Batati Formation (Ironstone). Their stratigraphic equivalents in the southern Bida Basin (Figure 2) are the Lokoja Formation (mainly conglomerate and sandstone), Maastrichtian Patti Formation (shale, ironstone, claystone, lignite, and sandstone), and the youngest Agbaja Formation (Ironstone) [14].

3 Materials and methods

The informal clay mining activities, as well as pits of about 0.6 m deep, dug at two different levels at Share, aided the accessibility and sampling of the claystone, while part of the road cut exposure provided the accessibility to the clay samples at Tshonga. Representative clay samples collected from the two localities were then subjected to various analyses, which include the color assessment, physicochemical properties (particle size distribution [PSD], pH, and cation exchange capacity [CEC]), geochemical analyses (X-ray fluorescence [XRF], and ICP-MS), and mineralogical analysis (XRD). Prior to laboratory analysis, the selected samples were air-dried, according to the methods of Van Reeuwijk [15], and then disaggregated using an agate mortar and pestle. For the PSD analysis, 100 g of sieved and dried samples were mixed with 200 ml of de-ionized water and 20 ml of sodium hexametaphosphate $(NaPO_3)_6$ (4%) as a deflocculating agent and then dispersed in an ultrasonic bath. This suspension was allowed to stand for 1 h and then transferred to an electrical stirrer for dispersion for 5–10 min. Then, it was placed in a test tube with water until it reached a final volume of 1,000 ml. The sand fraction was separated by wet sieving, passing through a 71-Am nylon sieve, and its dry weight was recorded. The suspension of the fine fraction (clay/silt) was poured into glass tubes and left for sedimentation (settling time: 2 h, fall height: 240 mm) in order to separate the clay fraction (<6 Am) according to Stokes' law, following Moore and Reynolds [16]. The clay fraction weight was estimated by subtracting the weight of the sand and silt fractions from the total rock weight. The three different fractions were retained for further analyses and interpretations.

For the CEC and pH determinations, a leaching tube (Bucher funnel with correct filter paper and Bucher flask with suction pump) was prepared. About 10.0 g of air-dried sieve sample was weighed into a 250 ml beaker and then poured in 1 N of NH_4OAc buffer at pH 7.0 in the leaching tube to leach the soil for 5–7. The solution was allowed to stand overnight. The content was thereafter transferred from the beaker to the Bucher flask and filtered with the aid of a suction pump. The NH_4^+ saturated soil in the leaching tube was then washed with 150 ml of 50% ethyl alcohol, followed by 30 ml of 90% ethyl alcohol to remove the excess NH_4^+. The leachate was discarded and the distillate was titrated with H_2SO_4 standard solutions until the

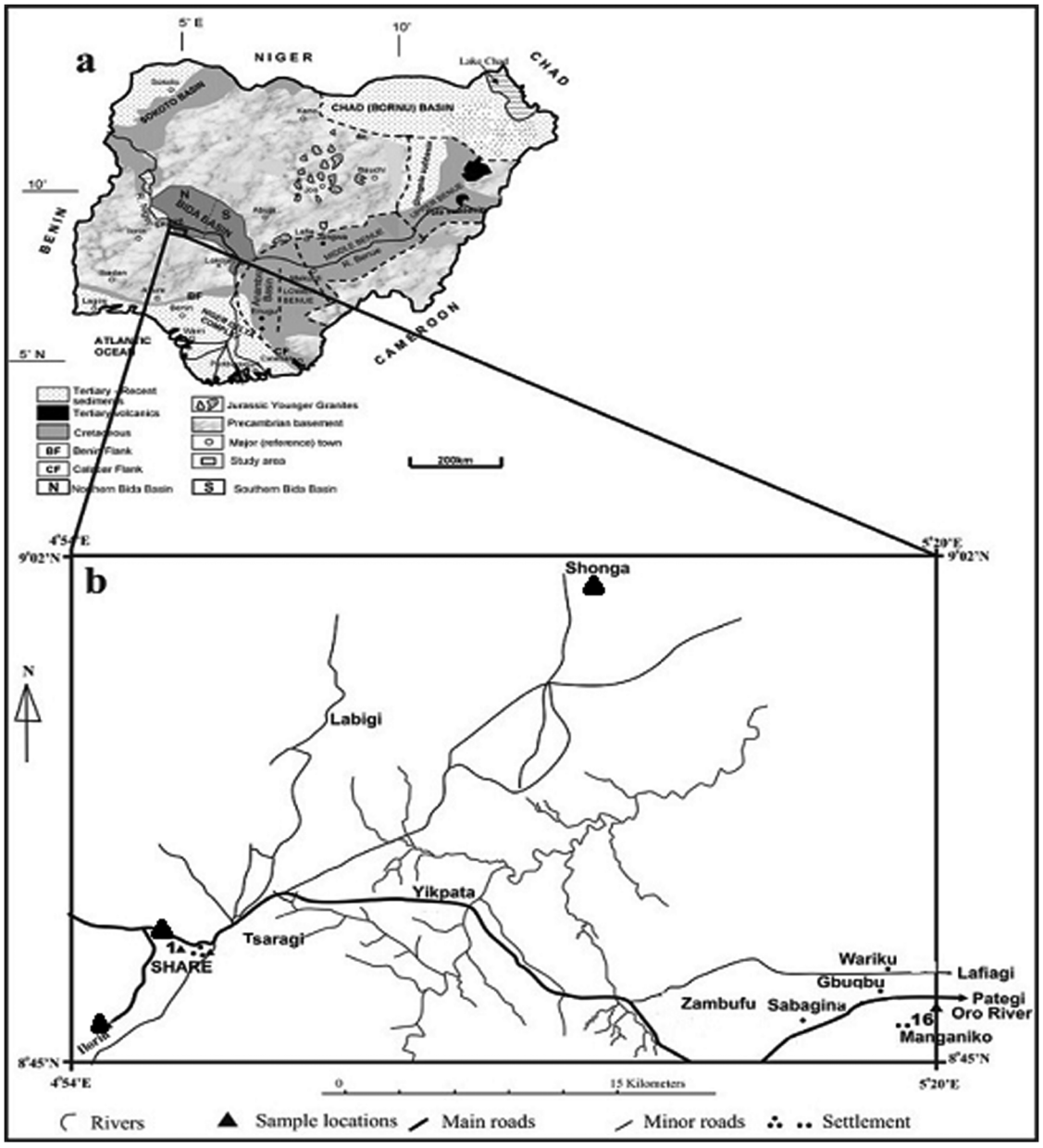


Figure 1: (a) Geological map of Nigeria showing the position of the Bida Basin. (b) Location of the investigated clay samples in Share and Tshonga (after [13]).

solution color changed from orange to pink. From the filtrate, the exchangeable bases (i.e., Na^{+}, Ca^{2+}, Al^{3+}, and Mg^{2+}) were determined by flame emission using distilled water at pH 7 for calibration, and values were calculated in cmolc/kg.

Five whole rock clay samples were also analyzed using XRF and an inductively coupled plasma mass spectrometer at the Acme Analytical Laboratories, Ltd., Canada, to determine the major and trace elements.

The quantitative and qualitative determinations of the mineralogical composition of the selected clay samples were performed using X-ray diffraction at the University of Pretoria, South Africa. Prior to XRD processing, about 100 g of each dried clay sample (whole rock) was gently crushed and sieved, while the method of Moore and Reynolds [16] was adopted for the separation of the clay fraction. The samples were later pulverized in a thoroughly cleaned agate ring mill. A glass disc mill-pressed into a steel sample holder was prepared for each sample. Glass discs were made from 0.4 g of the annealed sample powder and 4.0 g of Li-tetra/metaborate while 1.0 g of the binder was added to 6.0 g of the sample material to prepare

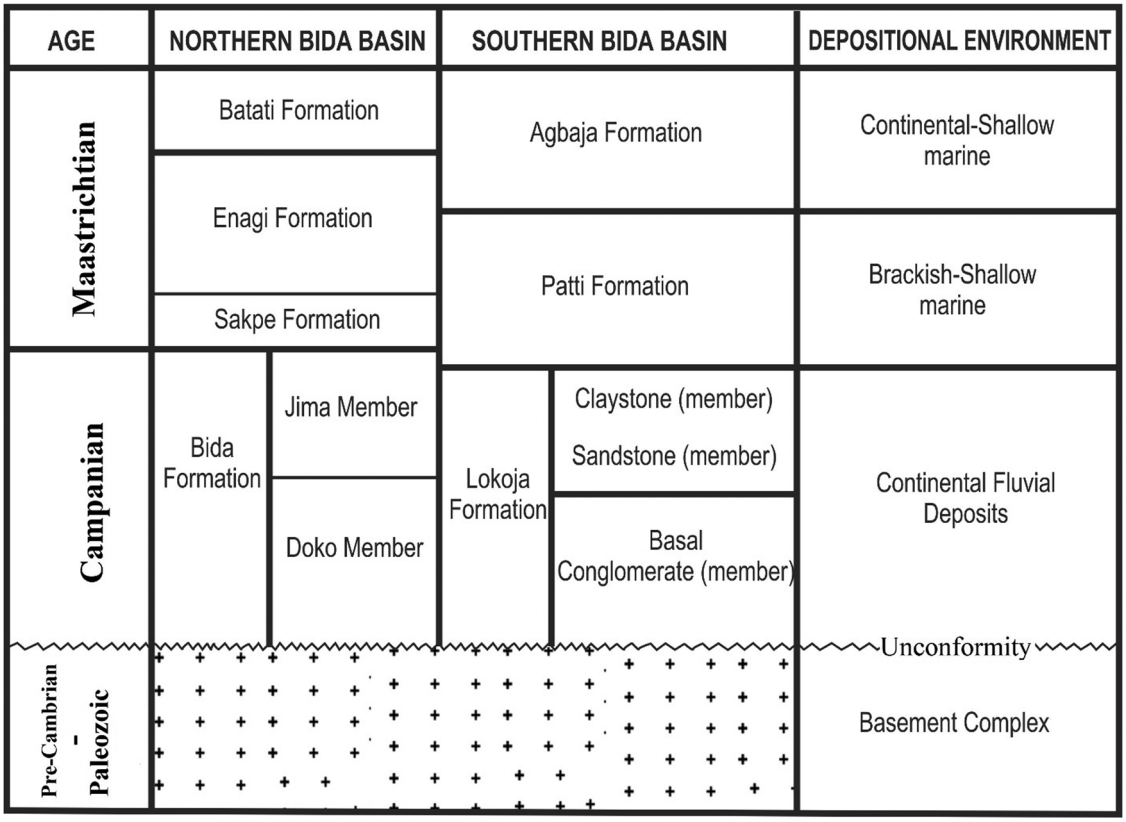


Figure 2: Regional stratigraphic successions in the Bida Basin and their lateral equivalents in the Anambra Basin (after [14]).

the pressed powder tablets. They were then analyzed using a PANalytical X'Pert Pro powder diffractometer in θ–θ configuration with an X'Celerator detector and variable divergence and fixed receiving slits with Fe filtered Co-Kα radiation (λ = 1.789 Å). The analyzed samples were scanned from 0° to 70° at a scanning speed of 0.02° 2θ/s and the 2θ values of the peaks were converted into *d*-spacing (in Å) for Cu Kα radiation. The identified minerals in the analyzed samples were determined using a PHILLIPS PW1840 model diffractometer with nickel-filtered Cu Kα radiation, while their peak values are shown in the charts presented in Table 6. The phases were identified using X'Pert Highscore Plus software. The relative phase amounts (wt%) were estimated using the Rietveld method (Autoquan Program). Errors are on the 3σ level in the column to the right of the amount.

4 Results

4.1 Color

Color is one of the diagnostic parameters and, indeed, the first used by geophagic practitioners to determine geophagic clayey soil suitability and palatability for consumption [17]. It was suggested that the color could be indicative of mineralogical compositions of the geophagic material. The studied clay samples were all in white color (Figure 3), suggesting the presence of minerals like kaolinite and iron-rich minerals like hematite and goethite.

4.2 PSD

The PSD results presented in Table 1 reveal the percentages of the three main components (sand–silt–clay) in the analyzed samples. The components of the clay samples from Share and Tshonga are presented in Table 1 and Figure 4. The results further indicate that all of the clay samples from Share have higher fine to coarse fractions (SHR1A-(86/14)%, SHR1B-(80/20)%, SHR1C-(85/15)%, SHR2A-(66/34)%, and SHR2B-(97/3)%), whereas sample from Tshonga (53/47)% has almost same values for the finer and coarser contents.

The fraction of each component (clay–sand–silt) was also employed to make the ternary plot to determine the textural classification of the studied clay (Figure 4). The clay samples from Share are predominantly clayey and



Figure 3: (a) Exposure of clays at Agbonna Ridge. (b) Exposure of clays at Tshonga Ridge.

Table 1: PSD of the studied clay samples and textural classification

Sample	Color	Sizes (%)				Fractions (%)		Classification
		Gravel	Sand	Silt	Clay	Coarse	Fine	
SHRIA	White	1	13	50	36	14	86	Clayey-silt
SHR1B	White	0	20	43	37	20	80	Clayey-silt
SHR1C	White	0	15	47	38	15	85	Clayey-silt
SHR2A	White	0	34	41	25	34	66	Clayey-silt
SHR2B	White	0	3	55	43	3	97	Clayey-silt
SG1A	White	0	46	27	27	46	54	Clayey-sand

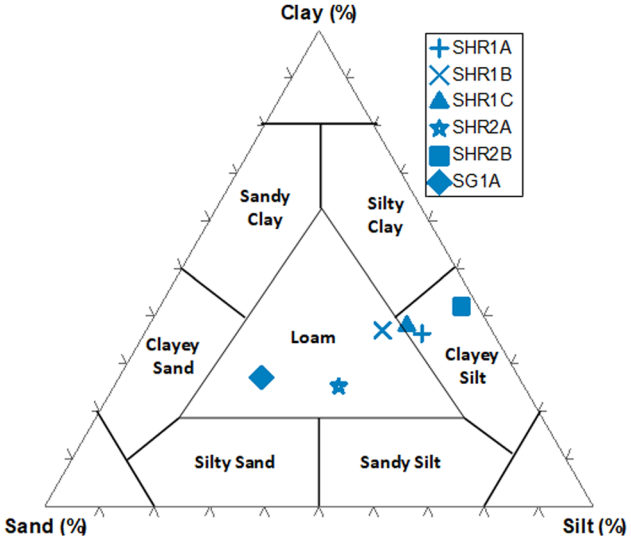


Figure 4: Ternary plot of clay–sand–silt for textural classification of the studied clay samples (after [18]).

silty, while the sample from Tshonga is sandy in composition. Therefore, all the samples exhibit gritty feelings. On the ternary diagram, after Shepard [18], the studied clay samples are generally plotted in the clayey–silt and clay–sand–silt fields (Figure 4).

4.3 CEC and pH values

The CEC results of the five analyzed geophagic clay samples, as presented in Table 2, vary from 1.71 to 3.81 (cmolc/kg) (Figure 5). The clay samples from Share and Tshonga have relatively low exchange base values (Table 2). Also, the exchange bases of the ion in all the analyzed samples are in the following decreasing orders: $Na^{+} > K^{+} > Mg^{2+} > Ca^{2+}$. The pH values of the studied geophagic clay samples presented in Table 2 reveal that they fall within the acidic range. The strongly acidic nature of all the clay samples (4.39–4.54)

Table 2: Physicochemical properties of the studied geophagic clay samples

Sample	pH	*CEC ($cmol^+/kg$)	Exchangeable cations ($cmol^+/kg$)				**Total exchangeable cations ($cmol^+/kg$)
			Na^+	K^+	Mg^{2+}	Ca^{2+}	
SHR1B	4.39	3.81	17.39	5.13	4.80	1.40	28.72
SHR1C	4.42	3.03	8.7	2.56	3.00	0.60	14.86
SHR2A	4.41	2.88	13.04	2.56	2.40	2.10	20.10
SG1A	4.54	1.71	4.33	2.56	1.40	1.40	9.69

NB: *CEC is the total content of cations that can be adsorbed at a specific pH. **Total exchangeable cation is the total content of cations that can be interchanged.

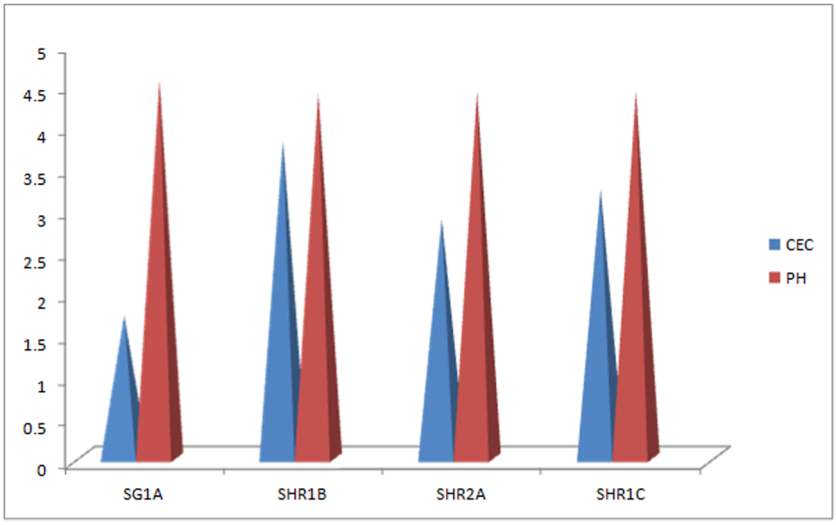


Figure 5: Bar chart showing the relationship of the CEC (cmol(+)/kg) and pH values of the investigated clay samples.

suggests the replacement of cations like Ca^{2+}, Na^+, K^+ and Mg^{2+} with others like H^+ and Al^{3+}. According to Eigbike et al. [19], this may impact the sour taste, which is more beneficial to pregnant women to prevent excessive salivation and nausea. Meanwhile, low CEC (1.71–3.81 cmolc/kg) may render the absorption of cations from the gastrointestinal tract (GIT) impossible, thereby defeating the purpose of consuming the soil.

4.4 Mineralogical compositions

The mineralogical compositions of the studied clay samples are presented in Table 3, and their peaks are presented in Figure 6. The results show that kaolinite $\{Al_2Si_2O_5(OH)_4\}$ is the dominant (ranging from 68.62 to 91.54) among the minerals in all the samples. Other trace and non-clay minerals present include quartz (SiO_2), anatase (TiO_2), and muscovite ($KAl_2(Si_3Al)O_{10}(OH)_2$).

Table 3: Quantitative results (%) of the mineral present in the clay samples

Mineral	SHR1B	SHR1C	SHR2A	SG1A
Kaolinite	90.93	68.62	91.54	91.37
Quartz	2.56	23.49	0.73	0.00
Muscovite	5.30	6.35	4.96	6.49
Anatase	1.21	1.54	2.77	2.14

4.5 Chemical compositions

The chemical composition of the studied clay samples is presented in Tables 4 and 5. Generally, the concentrations of SiO_2 are significantly higher in the Tshonga sample (SG1A-63.74%) compared to those from Share (SHR1B, SHR1C, and SHR2A – 54.85, 51.94, and 63.74%). The alumina (Al_2O_3) concentrations are also significantly high in all the analyzed samples but with relatively low magnesia values.

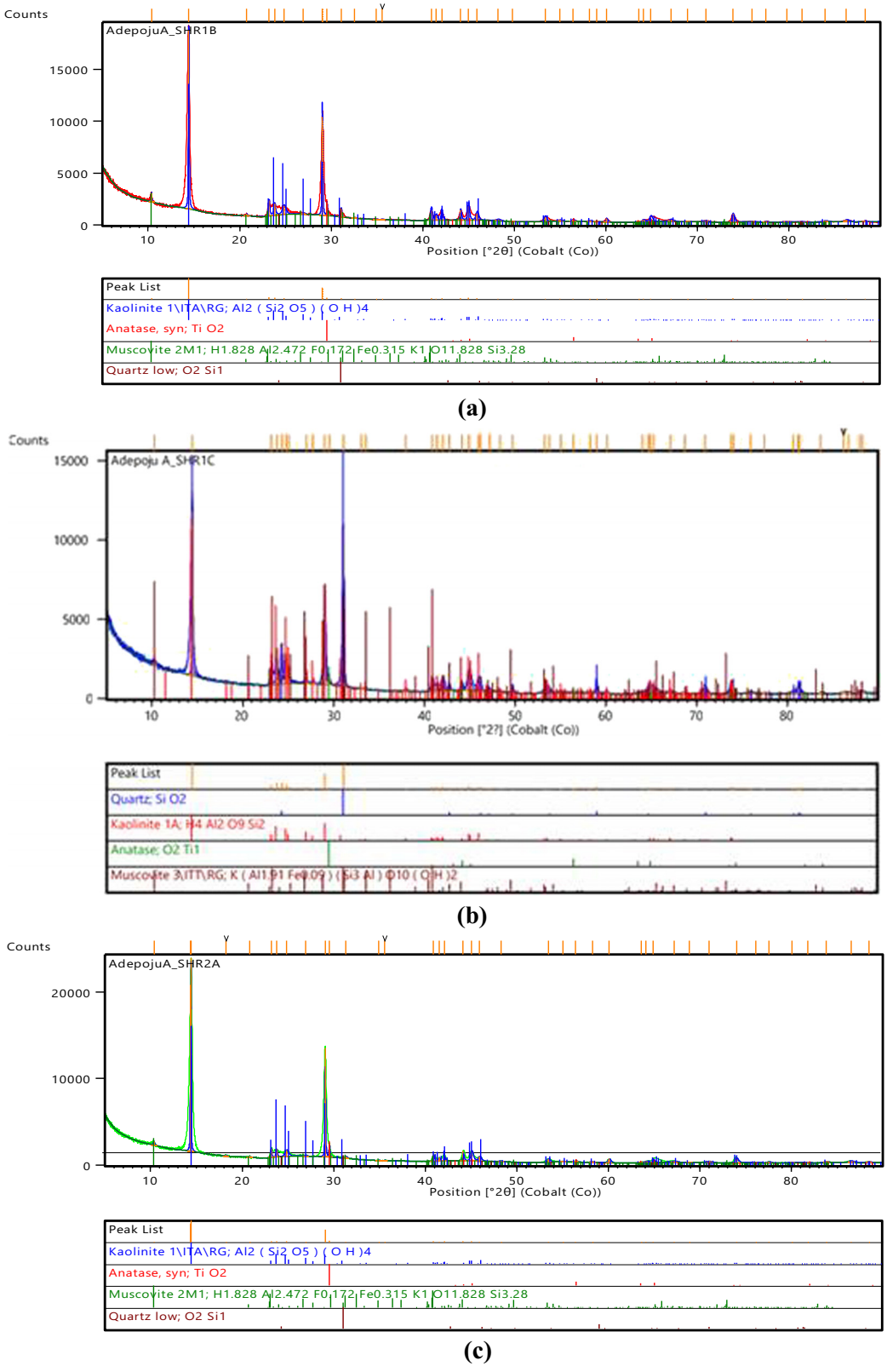
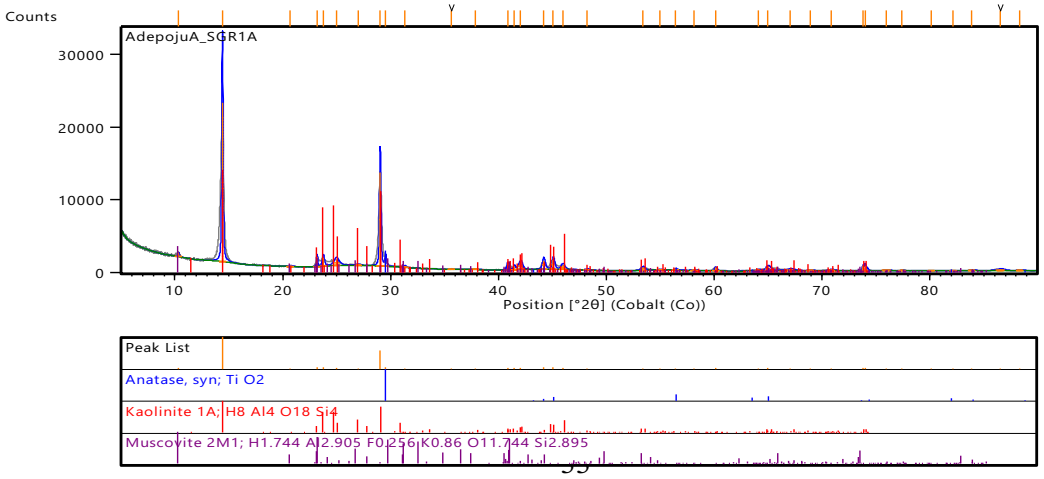


Figure 6: (a) XRD pattern showing the peak of minerals present in (a) sample SHR1B, (b) sample SHR1C, (c) sample SHR2A, and (d) sample SG1A.



(d)

Figure 6: (*Continued*)

Table 4: Major oxide composition of the studied clay compared to some published standards

Oxides	This study				Published data		
	SHR1B	SHR1C	SHR2A	SGIA	1	2	3
SiO_2	54.85	51.94	63.74	78.36	69.87	50.66	55.11
Al_2O_3	30.34	32.46	23.68	13.29	13.94	21.27	24.68
Fe_2O_3	0.78	0.63	0.61	1.06	6.14	7.12	8.41
CaO	0.02	0.02	0.03	0.02	0.59	0.53	0.40
MgO	0.07	0.06	0.06	0.04	0.72	0.18	0.31
MnO	0.01	0.01	0.01	0.01	0.05	0.14	0.05
Na_2O	0.01	0.01	0.01	0.01	0.54	1.72	1.63
K_2O	0.52	0.37	0.39	0.12	1.77	2.59	1.33
TiO_2	1.74	1.84	1.58	1.06	0.91	1.40	0.61

NB: 1 – [21]; 2 – [20]; 3 – [23].

Therefore, the samples could be described as being siliceous. Other oxides of Fe, Na, Ca, and K have relatively low values, and this could be indicative of depletion as a result of intense chemical weathering in the area. A comparison of the studied clay samples with other published data on geophagic materials shows similar SiO_2 concentrations, particularly samples from Kenya [20] and Swaziland [21]. Sample SHR2A is well compared with the sample from South Africa presented in previous studies [21–23] adduced high SiO_2 values in some clay samples due to the presence of considerable amounts of quartz particles; therefore, sample SG1A is more siliceous than others (Table 4). A discrepancy is observed between the concentration values of quartz obtained through X-ray and geochemical analyses of sample SHR1C. This is probably a result of the

Table 5: Trace element composition of the studied clay samples

Element (ppm)	This study				Published data		
	SHR1B	SHR1C	SHR2A	SG1A	A	B	C
Mo	0.02	0.01	0.03	0.02	2.30	1.14	0.05–0.10
Cu	1.22	0.87	0.75	1.68	15.35	24.50	1.00–1.50
Pb	2.57	2.20	2.05	3.82	39.67	32.40	—
Zn	1.00	0.20	0.20	0.30	21.30	30.10	33.00
Ag	22.00	61.00	21.00	2.00	20.00	20.00	—
Ni	0.30	0.40	0.40	0.20	56.60	25.60	0.10
Co	0.10	0.10	0.20	0.10	31.80	10.00	—
Cr	5.30	6.60	5.00	5.10	ND	ND	50.00–200.00
Ba	8.00	7.40	5.30	3.10	133.00	200.00	—
Zr	3.20	4.50	4.40	1.60	ND	ND	0.30

NB: The current data compared with the reference data A and B (sourced from [24]); C (Human Dietary Index [HDI] values sourced from [25]).

laboratory processing of the samples. First, whole-rock geochemical analysis was performed on the samples, and the fragments used for the two analyses were randomly chipped from the different parts of a big lump of the claystone sample. Since the investigated clay sample itself is a bit sandy, it should be noted that the sands (quartz) float randomly in the clay, and therefore, the little fragments chipped randomly for the XRD, and geochemical analyses may have different proportions of sand and clay fractions. This is the most logical explanation for the difference.

Trace element concentrations in the studied clays are presented in Table 5. Trace elements such as Cd, Pb, Co, Cu, Se, and Zn are of nutritional significance to humans, whereas Ni, Pb, and Cr are toxic. The Cu concentration in the clay ranges between 0.75 and 3.53 ppm, while human dietary index (HDI) is necessary for human body functions and ranges from 1.00 to 1.50 mg/kg [25]. However, the clay content for Zn ranges from 0.20 to 2.60 ppm and is very low compared to the human body content of 33 mg/kg body weight. The average Co content in these clays ranges from 0.10 to 0.20 ppm, which is relatively high.

5 Discussion

5.1 Benefits on ingestion

The characteristics of geophagic clayey soil, including color, texture, smell, and taste, as submitted by the previous researchers [10,22,26–28] play an important role in the type of clay that geophagists choose to eat. Fontes et al. [29] opined that the reddish coloration of soils could be used to infer the presence of Fe but not its quantity or bioavailability. Ngole et al. [22] also opined that the preference for reddish or brownish soils by geophagists is based on the assumption of their richness in iron. The white coloration of the studied clay samples, impacted probably by the presence of iron (Fe), may attract the geophagists.

The texture of the geophagic material, which is basically defined based on the weight of clay components present, is very important in the assessment of geophagic materials. Ngole and Ekosse [21] concluded that ingesting soils with high clay content could protect the GIT. The PSD data obtained in this study show that the clay samples from Share are less gritty compared to samples from Tshonga (Figure 4) and this could be a result of the higher quartz content in the clay samples from Tshonga than the clay from Share. Therefore, geophagists would prefer clay from Share to those from Tshonga to avoid complications during ingestion. It is also worth noting that the texture of the investigated clays in this study is similar and compared well with the geophagic soils and clays presented by researchers in parts of Africa and other parts of the world; for example, Free State and Limpopo Provinces of South Africa [30,31] concluded that clay fractions (wt%) in Thailand, Uganda, and Zaire geophagic soils are 28, 16, and 15, respectively, while Aufreiter et al. [32] reported greater clay component (>40 wt%) for geophagic material from China. Mahaney et al. [33] reported that the values ranged from 52 to 88 wt% for the geophagic material from Indonesia. Ngole and Ekosse [34] also documented that geophagic material has up to 39 and 43 wt% clay in Swaziland and South Africa, respectively.

It was reported in previous studies [21,35,36] that soil rich in kaolinite has CEC values below 50 Meq/100 g soil. The relatively low values of CEC and ion exchange bases in the Share and Tshonga clays might be due to the highly weathered nature of the clay samples as transported or secondary clays. The CEC values of the studied clay samples (1.71–3.81) are less than the suggested values and, therefore, indicate the presence of the kaolinite. Hooda and Henry [37] concluded that cations released in the stomach as a result of low pH conditions may be re-absorbed in the intestines through CEC, which is favored by high pH values. Diamond et al. [38] opined that CEC could be considered a toxin-binding surrogate measure because the negative charge in the clay tends to attract the positively charged toxin present and then remove them from the GITs. The pH values of the studied clay samples ranged from 4.39 to 4.54, indicating its acidic nature. Okunlola and Owoyemi [24] concluded that clay samples from Nigeria are characterized by high to mild acidic (2.76–4.76). Mahaney et al. [33] reported that the values ranged from 6.00 to 8.10 pH for geophagic soils from Indonesia, while they ranged between 5.00 and 7.10, as documented in previous studies [21,22] for geophagic soil from South Africa and Swaziland, respectively. According to Abrahams and Parsons [31], soil acidity is responsible for imparting the much desired sour taste in geophagic materials. Omen et al. [39] concluded that the pH of human saliva varies between 5.0 and 8.0; therefore, ingestion of the studied clay may contribute to an increase in the mouth's acidity by the clay's sour taste, which might be beneficial to pregnant women as a means of managing saliva secretion during pregnancy.

The geophagic clays from the present study area are rich in kaolinite (85.80–91.54%), while the non-clay minerals are present in trace amounts. Previous studies [3,40] stated that clay soil with higher kaolinite contents is efficient in the preparation of medication to alleviate diarrhea and mild

intestinal upsets. Slamova et al. [41] also highlighted the use of kaolin as a GIT toxin binder against food detoxification and alleviation of disorders. Based on the above, the studied samples could be used to prepare anti-toxins and gastrointestinal distress relief medications. Due to their richness in kaolinite, the analyzed clays can also be employed traditionally as medicinal clays, e.g., application as a base for some gastritis medicines, as a bio-activities enhancement and as a digestive aid supplement. Following the recommendation by Bergaya et al. [42], the studied clay samples can also be used by the dermatologist for the production of creams and powders for skin protection.

The availability of nutrients supplied to Geophagists upon ingestion of the clay depends on physicochemical characteristics and several other factors [22,26]. The chemical compositions of the analyzed geophagic clayey soils were dominated by SiO_2 (51.94–78.36%) and Al_2O_3 (13.29–30.34%), which could be related to quartz and kaolinite abundances contained in them. According to WHO (1996), one of the reasons used to justify geophagia is the supplementation of chemical nutrients, including Ca, Mg, Fe, and Mn, among others. Mineralogical studies also revealed the presence of higher kaolinite contents in the studied clays, which might be preferable by dermatologists, especially after processing to remove the impurities in the production of creams, powders, and ointments.

The average HDI of Fe suggested by the World Health Organization [25] is 18 mg/kg (ppm), which is higher than the measured concentrations in the studied samples (0.03–0.58 ppm). Mn contents in clays from Share and Tshonga range from 1.00 to 2.00 ppm (mg/kg), and this compares relatively well with the range of HDI values (2.00–5.00 mg/kg) suggested by the World Health Organization [25]. Therefore, clay samples from Share and Tshonga fit into the geophagic material consumption class. The concentration of Mo in the analyzed clay ranges from 0.01 to 0.03 ppm (mg/kg) and compares favorably well with the HDI values (0.05–0.10 mg/kg) suggested by the World Health Organization [25] but less than the average values obtained from Asaba and Benin geophagic materials [24]. Also, the measured concentrations of Zn in the analyzed samples (0.20–2.60) are lower compared to the values from Asaba and Benin clays [24] as well as average HDI (10.00–15.00 mg/kg) values suggested by the World Health Organization [25]. Also, the required HDI of Cr concentration (50–200 ug or 0.05–0.20 ppm), as suggested by the World Health Organization [25], is low compared to the concentrations measured in the studied clay samples (5.00–7.70 ppm). The consumption of the studied clay samples, therefore, has the potential to supply an adequate amount of the trace nutrients required by the body for proper functioning.

5.2 Health risk

Consumption of the geophagic clay or soil impacts negative implications on the geophagist's health. The texture of the clay sample SG1A, which indicates a relatively high amount of sand, may affect the dental enamel during mastication and cause teeth breaking and destruction. The coarse texture of these geophagic materials shows that they may also cause abdominal complications, such as intestinal perforations, constipation, and ulcers. King et al. [43] reported that ingesting coarse-textured soils might cause complications that are detrimental to the teeth and gums during mastication. Also, Barker [44] concluded that the coarse nature of clay could cause an adverse effect on the gastrointestinal lining of the geophagist with the possibility of perforating the sigmoid colon during ingestion.

The occurrence of heavy metals like Co, Cu, Ni, Cd, Ag, and Pb in geophagic clays may cause adverse effects like an increase in the gastrointestinal pH of geophagist and then lead to complications in the system. According to George and Ndip [45], high CEC content or high heavy metals in clay may cause iron deficiency anemia due to decreasing absorption and bioavailability of iron and hypokalemic myopathy by gastrointestinal potassium depletion. A comparison of trace element concentrations in the studied clay with an adequate daily intake in the human body reveals that some elements have relatively high values, which are above the permissible levels. For example, the concentration of Cu in the studied clay is higher (0.75–3.53 ppm) than the daily intake necessary for human body functions (1.0 ppm), as suggested by the World Health Organization [25]. Also, Zr (1.60–4.50 ppm) and Ni (0.20–2.40 ppm) are relatively higher than the required intake values necessary for human body functions (Zr – 0.3 ppm and Ni – 0.1 ppm). This means that consumption of the investigated clays with a concentration of heavy metals exceeding the maximum permissible limit may lead to adverse health effects, including the damaging of the central nervous system, loss of vision, hearing and mental retardation, kidney reproductive system, tubular growth, kidney damage, cancer, diarrhea, and incurable vomiting, which may finally lead to death.

6 Conclusions

We conclude from the comprehensive evaluation of the textural, physicochemical, mineralogical and chemical characteristics of the geophagic clays from Share and Tshonga, north-central Nigeria, as follows:

(i) The geophagic clay varies in color from whitish to light-grayish, with occasional brown stains. The textural characteristics are dominated by silty–clay with minor sandy–clay. Low CEC and exchangeable bases with acidic pH values for all the clay samples indicate their suitability for consumption by pregnant women to overcome nausea and excess salivation.
(ii) The geophagic clay samples are rich in kaolinite and, therefore, have the potential to be used for skin protection in the form of body cream, powder, and ointments. Clays have palliative, protective, and detoxifying properties.
(iii) The major and trace element compositions are uniformly low, while some of the trace element contents are relatively high compared to the adequate daily intake of trace elements in the human body. The few trace elements (Co, Cu, Ni, Cd, Ag, and Pb) that show comparatively higher amounts of toxic constituents compared to standard values for human consumption might pose a serious health threat to the geophagist.
(iv) The Share and Tshonga clays have relatively high SiO_2 and Al_2O_3 content as well as low Ca, Mg, Na, and K nutrients; therefore, they can be used as excipients in pharmaceutical preparations and manufacturing industry.

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References

[1] Ekosse G-IE. Mineralogical constituents of geophagic soils and clays. In: Ekosse GE, Ngole VM, de Jager L, Fosso-Kankeu E, editors. Human and Enzootic Geophagia: Ingested soils and Practices. Germany: LAP LAMBERT Academic Publishing; 2015. p. 71–92.
[2] Dreyer MJ, Chaushev PG, Gledhill RF. Biochemical investigations in geophagia. J Roy Soc Med. 2004;97(1):48–53.
[3] Wilson MJ. Clay mineralogical and related characteristics of geophagic materials. J Chem Ecol. 2003;29(7):1525–47.
[4] Callahan GN. Eating dirt. Emerg Infect Dis. 2003;9(8):1016–21.
[5] Hooda PS, Henry CJK, Seyoum TA, Armstrong LDM, Fowler MB. The potential impact of soil ingestion on human mineral nutrition. Sci Tot Environ. 2004;333:75–87.
[6] Carretero MI, Gomes CSF, Tateo F. Clays and human health. In: Bergaya F, Theng BKG, Lagaly G, editors. Handbook of clay science: Developments in clay science. Vol. 1. Amsterdam: Elsevier; 2006. p. 717–41.
[7] Droy-Lefaix MT, Tateo F. Clays and clay minerals as drugs. In: Bergaya F, Theng BKG, Lagaly G, editors. Handbook of clay science: Developments in clay science. Vol. 1. Amsterdam: Elsevier; 2006. 743–52.
[8] Gomes CSF, Pereira Silva JB. Minerals and human health. Benefits and risks. (OsMinerais e a Saúde Humana. Benefícios e Riscos) (in English and Portuguese). Portugal: Centro de Investigação-Minerais Industriais e Argilas, Departamento de Geociências da Universidade de Aveiro, Campus Universitário de Santiago; 2006. p. 142.
[9] Walker ARP, Walker BF, Sookaria FI, Canan RJ. Pica. J R Soc Health. 1997;1147(5):280–4.
[10] Ekosse G-IE, Junbam ND. Geophagic clay: Their mineralogy, chemistry and possible human health effects. Afr J Biotech. 2010;9(40):6755–7.
[11] Ibeanu GEL, Dim LA, Mallam SP, Akpa TC, Munyithya J. Non-destructive XRF analysis of Nigerian and Kenyan clays. J Radioanal Nucl Chem. 1997;221(1–2):207–9.
[12] Ojo OJ, Adepoju SA, Adewole MT, Abiola AO. Sedimentological and geochemical studies of Maastrichtian clays in Bida Basin, Nigeria: Implication for resource potential. Centrepoint J (Sci Ed). 2011;17(2):71.88.
[13] Ojo OJ. Depositional environments and petrographic characteristics of Bida Formation around share-pategi, northern Bida Basin, Nigeria. J Geog Geol. 2012;4(1):224–41.
[14] Ojo OJ, Akande SO. Sedimentology and depositional environments of the Maastrichtian Patti Formation, Southeastern Bida Basin, Nigeria. Cret Res. 2009;30:1415–25.
[15] Van Reeuwijk LP. Procedures for soil analysis. International Soil Reference and Information Centre (ISRIC), The Netherlands, Technical paper No. 9; 2002.
[16] Moore DM, Reynolds RC. X-Ray diffraction and the identification and analysis of clay minerals. Oxford: Oxford University Press; 1989. p. 332.
[17] Ekosse G-IE, Anyangwe S. Mineralogical and particulate morphological characterization of geophagic clayey soils from Botswana. Bull Chem Soc Ethiop. 2012;26(3):373–82.
[18] Shepard FP. Nomenclature based on sand-silt-clay ratios. J Sediment Pet. 1954;24:151–8.
[19] Eigbike CO, Nfor BN, Imasuen IO. Physico-chemical investigations and health implications of geophagial clays of Edo State, Mid-Western Nigeria. J Geol Geosci. 2013;3:140.

[20] Gichumbi JM, Ombaka O, Gichuki JG. Geochemical and mineralogical characteristics of geophagic materials from Kiambu, Kenya. Inter J Mod Chem. 2012;2(3):108–16.
[21] Ngole VM, Ekosse G-IE. Physico-chemistry, mineralogy, geochemistry and nutrient bio-accessibility of geophagic soils from Eastern Cape, South Africa. Sci Res Essays. 2012;7(12):1319–31.
[22] Ngole VM, Ekosse G-IE, de Jager L, Songca SP. Physicochemical characteristics of geophagic clayey soils from South Africa and Swaziland. Afr J Biotech. 2010;9:5929–37.
[23] Ekosse G-IE, Ngole VM, Longo-Mbeza B. Mineralogical and geochemical aspects of geophagic clayey soils from the Democratic Republic of Congo. Inter J Phys Sci. 2011;6:7302–13.
[24] Okunlola OA, Owoyemi KA. Compositional characteristics of geophagy in soils of Nigeria. In: Ekosse G-IE, de Jager L, editors. Book of Abstracts, 1st International Conference: Geophagia in Southern Africa, Central University of Technology, Bloemfontein, Free State, South-Africa. 2011. p. 290–305.
[25] World Health Organization. Trace elements in human nutrition and health. Geneva, Switzerland: World Health Organization; 1996.
[26] Reilly C, Henry J. Geophagia: why do humans consume soil? Br Nutr Found. 2001;25(2):141–4.
[27] Young SL, Wilson MJ, Hillier S. Toward a comprehensive approach to the collection and analysis of pica substances, with emphasis on geophagic materials. PLoS ONE. 2008;3:1–13.
[28] Young SL, Wilson MJ, Hillier S, Delbos E, Ali SM, Stolzfus RJ. Differences and commonalities in physical, chemical and mineralogical properties of Zanzibar geophagic soils. J Chem Ecol. 2010;36:129–40.
[29] Fontes MFP, Ldeu A, Carvalho Jr IA. Color attributes and mineralogical characteristics, evaluated by radiometry of highly weathered tropical soils. Soil Sci Soc Am J. 2005;69:1162–72.
[30] Ekosse G-IE, de Jager L, Ngole V. Traditional mining and mineralogy of geophagic clays from Limpopo and Free State provinces, South Africa. Afr J Biotech. 2010;9(47):8058–67.
[31] Abrahams PW, Parsons JA. Geophagy in the tropics: an appraisal of three geophagical materials. Environ Geochem Health. 1997;19:19–22.
[32] Aufreiter S, Hancock RGV, Mahaney WC, Stambolic-Robb A, Sanmugadas K. Geochemistry and mineralogy of soils eaten by humans. Int J Food Sci Nutr. 1997;48:293–305.
[33] Mahaney WC, Milner MW, Mulyono HS, Hancock RGV, Aufreiter S, Reich M, et al. Mineral and chemical analyses of soils eaten by humans in Indonesia. Int J Environ Health Res. 2000;10:93–109.
[34] Ngole VM, Ekosse G-IE. Using Physico-chemical properties of soils ingested to explain some reasons forwarded to justify human geophagia. In: Ekosse G-IE, de Jager L, editors. Book of Abstracts, 1st international Conference: Geophagia in Southern Africa, Central University of Technology, Bloemfontein, Free State, South-Africa; 22nd-24th October 2008. p. 28.
[35] Abrahams PW. Geophagy (soil consumption) and iron supplementation in Uganda. Trop Med Int Health. 1997;2:617–23.
[36] Hooda PS, Henry CJK, Seyoum TA, Armstrong LDM, Fowler MB. The potential Impact of Geophagia on the bioavailability of iron, zinc and calcium in human nutrition. Environ Geochem Health. 2002;24:305–19.
[37] Hooda PS, Henry CJK. Geophagia and human nutrition. In: MacClancy J, Henry J, MacBeth H, editors. Consuming the inedible: Neglected dimensions of food choice. New York, NY, USA: Berghahn Books; 2007. p. 89–98.
[38] Diamond J, Bishop KD, Gilardi JD. Geophagy in New Guinea birds. Ibis. 1999;141:181–93.
[39] Omen AG, Sips AJ, Groten AM, Dick JP, Sijm TJM, Tolls THM. Mobilization of PCBs and lindane from soil during in vitro digestion and their distribution among bile salt micelles and proteins of human digestive fluid and the soil. Environ Sci Tech. 2000;34:297–303.
[40] Vermeer DE, Farrell RE. Nigerian geophagical clay: a traditional antidiarrheal pharmaceutical. Science. 1985;227:634–6.
[41] Slamova R, Trckova M, Vondruskova H, Zraly Z, Pavlik I. Clay minerals in animal nutrition. Appl Clay Sci. 2011;51:395–8.
[42] Bergaya F, Theng BKG, Lagaly G. Handbook of clay science: Developments in clay science 1. Amsterdam, The Netherlands: Elsevier; 2006.
[43] King T, Andrews P, Boz B. Effect of taphonomic processes on dental microwear. Am J Physic Anthropol. 1999;108(3):359–73.
[44] Barker OB. Tooth wear as a result of pica. Br Dent J. 2005;199(5):271–3.
[45] George G, Ndip E. Prevalence of Geophagia and its possible implications to health - A study in rural South Africa. 2nd International Conference on Environmental Science and Development, IPCBEE. Vol. 4. 2011.