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GEOPHAGIC CLAY PREDOMINANCE AND ITS POSSIBLE HEALTH IMPLICATIONS IN THE SOUTH-EAST REGION OF NIGERIA

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Abstract: Geophagy has been a common practice especially in the Southern part of Nigeria and some parts of the world at large. They are earthy/clay materials eaten as food supplements and also adopted for medical purposes. Hence, they are bound to contain trace metal contents that may be harmful to human health which is a great cause for concern among health workers in this modern age. Therefore, geophagic clays from Amawom-Ikwanoin Abia province, South-eastern Nigeria were examined and evaluated for their heavy metal concentration to deduce their quality and possible health implication that is associated with their consumption. Edible clay from south eastern Nigeria was analysed with X-ray Diffraction (XRD), Scanning Electron Microscope (SEM) and Inductively Couple Plasma Mass-Spectrometry (ICP-MS) revealing quartz (SiO_2), kaolinite ($Al_2Si_2O_5(OH)_4$, goethite (FeOH) and pyrite (FeS_2) as the predominant minerals while SEM revealed clay flaky structure specifying an alumino-silicate with sulfur and carbon as impurities. The clay's pH ranges between 3.36 and 4.57, E.C from 52-399 µs/cm revealed its high acidity and signified high ionic contents in the edible clays. The soil Organic Carbon 0.1-5.83% may possibly indicate absorption and retention of contaminants. High concentrations ppm for Cu(19.91), Pb(13.15), Zn(18.4), Ni(5.8), As(9.15) and Hg(126.0) in the clay exceeded the WHO and USEPA recommended dietary intake by humans signifying its likely toxicity. Other associated carcinogenic and non-carcinogenic diseases that could be connected to the high concentrations of mercury, chromium, arsenic, lead and nickel in the edible clay structure which may likely camouflage the taunt and healing properties of kaolinite include renal, respiratory, cardiovascular, gastrointestinal, hepatic, immune, reproductive and dermal systems. For this reason, continuous ingestion of edible clay may lead to bio-accumulation of mercury, chromium, arsenic, lead and nickel in the inhabitants of Amawom, hence, posing serious health challenges that may lead to death.

Keywords: Geophagy, contaminants, Hg-Pb-As-Toxicity.

Introduction

Edible clay consumption by human beings is a questionable albeit sometimes necessary conduct for human beings to survive, it is generally acceptable but sometimes practiced in a clandestine or concealed manner. It is considered an unhygienic and indecent manner of feeding. It has also been regarded as unusual form of hunger for inedible substances such as hair (*trichophagy*), stones (*lithophagy*) or faeces (*coprophagy*) especially in places where food and access to food is both abundant and easy (Klein *et al.,* 2007). Generally, geophagic clays are most commonly collected from exposed banks of springs, streams and rivers or interceptions that are adjacent to fresh-water seepages (Folorunso *et al.,* 2013).

Soil and clay eating sites have been initially exposed through many processes which consist of both local and home-grown animals that search for this clay-soil for their own definite nutritional needs. These clay deposits are exposed with the assistance of these animals and these had been exploited by humans for a long time.

Some definite clay materials have been persistently collected which serve as a common behavioural pattern or as cultural heritage among current geophagic individuals. In recent times, some particular clay types were collected and mixed with obtainable fats from animals and flour powders. This new system of making edible clay presentable either with the addition of sweeteners, food colouring or other materials and these were baked to allow them to dry naturally. These can be distributed into market places to be sold as baked or moulded food items that can be purchased for different households as part of their food supplements (Sing & Sing, 2010).

The premeditated, conscious and intentional habit of ingesting earthy-clay materials known as geophagy has been observed in different continents of the world but is considered strange to some people other parts of the world. This practice may be taken as regular or irregular behaviour depending on the customs and traditions of that society.

In Nigeria for instance, the planned, intended and strategic consumption of geophagic clay is done for cultural, cosmetic, nutritional, medicinal and is a way of life for both humans and animals in some communities.

Hence, these justifications have been proposed for the practice with diverse reasons been connected and appended to people that occupied themselves in this act (Olatunji *et al.,* 2014). This application is prevalent in the southern and southeastern regions of the country with the indigenous names assigned as *Nzu* by the Igbos (Young *et al.,* 2011).

This approach is prevalent in ethnic, ancestral, traditional, customary, conventional, habitual and rural societies but is seen as strange in societies such as Japan and South Korea (Olatunji *et al.*, 2014). In the past, reports have specified that this act had been widespread which covered different parts of the continents especially in the North-South-West and East of Africa. However, in the western part of Africa where these practices have been found prevalent and frequent: We have - Nigeria and Ghana, Eastern sector-Uganda, Southern area-South Africa and the Central part area that covers - Cameroon and Democratic Republic of Congo (Reilly & Henry, 2000).

This practice has been adopted by others in order to suppress hunger due to poverty. Also, humanity distinguishes and discriminates against these procedures as a consequence to starvation, deprivation and a precursor of cerebral disorderliness. The rationale behind the consumption of geophagic clay is multi-faceted and includes nutritional, cosmetic and medicinal reasons. A cultural heritage interpretation may also be attached to this practice which is very common in the southern part of Nigeria. It serves as nutrition for children, cosmetics for pregnant women and as medicine for people with upset stomachs and other gastro-intestinal issues.

Edible clays are derived mainly from Alumino-silicate of the kaolinite ($Al_2Si_2O_5(OH)_4$) clay group which is a product of weathered minerals containing major, trace and rare earth elements. In addition to the nutritional elements (phosporous, potassium, calcium and sodium), some other elements mostly trace metals (Lead (Pb), Cadmium (Cd), Mergury (Hg), Arsenic (As), Nickel (Ni)) are toxic and harmful to humans while some (Cu, Zn) are beneficial to man (Kolawole *et al.,* 2018). The geo-chemical content of any geophagic clay will depend on the chemistry and mineralogy of the parent rock and some geo-chemical factors that are involved in weathering, erosion and soil development sequence. However, this clay is widely used as potent constituent in medicines and curative gastro-intestinal mixtures (Olatunji *et al.*, 2014).

On the other hand, continuous ingestion has been detailed to cause constipation, stomach pains and could be a source of severe toxicity (Schweta *et al.,* 2014). The risk associated to geophagy in practice has it impinge on inhabitants with history of large quantities of ingestion of these geophagic clay that consists of Hg, Pb, As and Cd had been examined (Al-Rmalli *et al.,* 2010; Bonglaisin *et al.,* 2011; Banwar, 2012).

The physiological consequences of geophagy (George & Adams, 2012), mineral/nutritional repercussions (Abrahams *et al.,* 2013; Nyanza *et al.,* 2014), geochemical characteristics and health consequences (Olatunji *et al.,* 2014), heavy metals assessment (Kamunda *et al.,* 2016): Iron supplement (Waswa & Imungi, 2014; Judith *et al.,* 2016) and medicine (Bonglaisin *et al.,* 2017) had also been examined by different workers.

The therapeutic properties of this clay may obscure or conceal with the presence of these potentially toxic metals that may be deleterious to human survival. Therefore, this work is to examine the edibility of the geophagic clay in relation to their mineralogy, chemical constituents, toxicity and the current health status of the addicted inhabitants of Amawom Ikwuano Area, Abia province, South-Eastern Nigeria (Figure 1 (a)).

Sources of Soil Ingestion by Humans

Individuals in any human population or community will ingests at least small quantities of clay/soils through particulate dusts on daily basis and this may likely come from nutritional foods. Generally, foods especially from Nigeria contain small amount of clay/soil materials and may be contaminated in this process and unconsciously ingested.

This is possible because of the modalities and tradition involved and attached to Nigerian nutritional packages. Hence, air/sun drying of food items outdoors such as grains of different kinds, cassava flour preparation, yam flour and others are prone to having a substantial amount of clay or soil particles that will be consumed either directly or indirectly. Clay and soil particles can also adhere to fingers which tips are unwittingly consumed or ingested through hand-to-mouth feeding activities.

Both the old and the young are ingesting significant amount of clay/soil indirectly through this act. On the part of adult, their hands are contaminated through their professional activities which include automobile technicians/mechanics, tincan works, mining, masons, plumbers, farmers and others. Whereas, children have their hands contaminated with clay/soil during different play activities.

Description of the Study Area

Amawom in Ikwuano is a town in Abia province in Nigeria. It is geographically located at coordinates 5°28’0”N and 7°34’0”E. It has an area of 281 km² and it is made up of about 52 different communities and bounded by Ini town of Akwa Ibom by the West and Umuahia at the North.

The town is characterized by a tropical wet and dry climate with relatively constant temperatures throughout the year. The town is chiefly an agrarian community. The catchment area as a state is a commerce/trade centre which serves various economies in the south-eastern region of Nigeria. Unemployment has dragged and hauled a certain percentage of inhabitants into the business of clay excavation, preparation with processing, distribution, sales and marketing in this region. Therefore, with regards to the 2006 Census, it has an estimated population of about 137,993; this has increased to double recently. It is one of the areas in Nigeria that is experiencing continuous growth and development.

It is also one of the most populated areas in the region. The four segments of Ikwuano (after the 2006 Census), Umudike community had a population estimate of about 16,457, Umuariaga-15,982, Amaoba-15,565 and Amawom-15,773, respectively. Though, the population of these settlements had increased with time.

Geomorphological Setting and Geology of the Study Area

The most essential and conspicuous topographic features of the study area is commonly a rippling and undulating topography that is made up of hills and highlands which consist of sandstone and the lowlands that consist of the shale. The

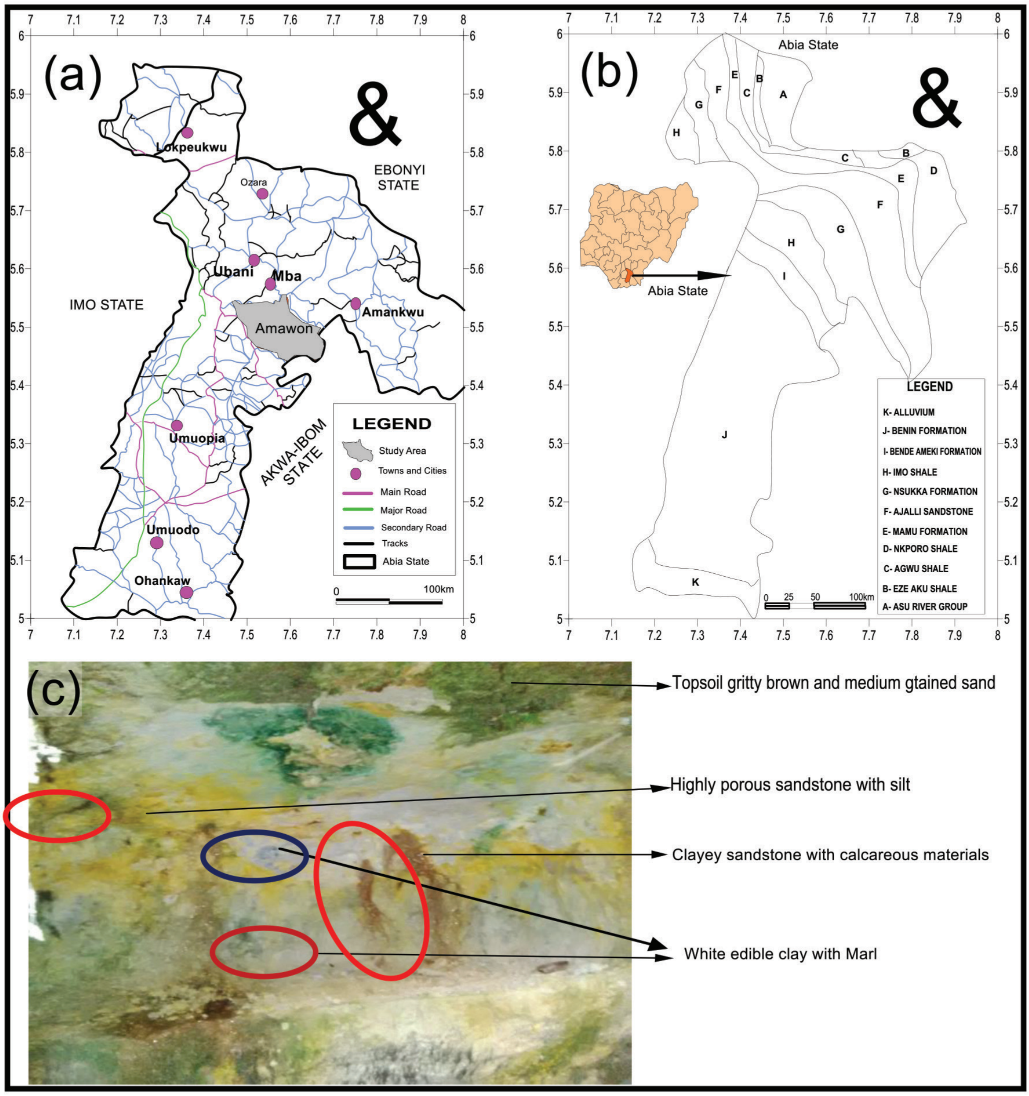

Figure 1: Location and geological map of the study area

highest elevation on the study area is 130m. The drainage pattern is characterised and controlled by rock types, topography and reliefs. The major water bodies that drain the area are streams and rivers while the dominant drainage pattern is dendritic in nature.

The climate of Ameki is humid and it also lies on the tropical rainforest climate. Two major seasons are present in the area which includes rainy and dry seasons. The rainfall range between 1,400 mm - 2,500 m, relative humidity (23%) and temperature 20°C - 27°C (Udoka *et al.,* 2016). The highlands are mostly composed of sandstone while the lowlands typically consist of mud-rocks. These soils are susceptible to leaching due to rainfall.

A culmination of different depositional events resulted in the formation of different sedimentary basins in Nigeria to which the Anambra basin belongs. The Anambra basin has been shaped by a sequence of events that have produced different cycles of sediment. These had largely shaped the nature of sediment, which has defined the stratigraphy of the basin. Geologically, the area falls within Nigeria sedimentary terrain and is underlain by the Bende-Ameki Formation which constitutes the main bulk of Eocene strata.

The Eocene Ameki formation overlies the Paleocene Imo formation and pinched out on both eastwards and westwards. It is considered as the basal stratigraphic unit of the tertiary Niger Delta Basin. Akata Formation as one of the lithological units of the Niger Delta which has been linked to Imo formation as corresponding lithological unit while the Ameki Group (Ameki Formation and Nanka Sands) and the Ogwashi-Asaba Formation are also considered as correlative of the Agbada Formation (Adojoh *et al.,* 2015).

The origin of the Niger Delta Basin resulted from the sea level rise in the Paleocene which halted the filling of the Anambra basin. The Ameki Formation comprises of an alternating sequence of shale, sandy shale, clayey sandstone and fine grained fossiliferous sandstone with thin limestone bands and is about 287 m thick (Ijeh & Onu, 2012). It also composed primarily of highly fossilified grayish-green-sandy-clay with calcareous concretions and white clay sandstone existing in two lithological groups: The lower group consists of fine-to-coarse sandstones with intercalations of calcareous shale while the upper group is characterized with coarse, cross-bedded sandstone, bands of fine, gray-green sandstone and sandy clay (Figure 1 (b)).

Bende-Ameki strata consist of rapidly alternating shale, sandy shale, mudstone, clayey sandstone and fine-grained argillaceous sandstone with limestone bands. In some places, the thickness is about 33 m and it is richly fossiliferous with molluscs, foraminifera and corals predominating all through. The beds dip gently between 5^o and 7^o S; the strata show steeper dips than the underlying Imo Shale Formation which indicates unconformable relationship (Ijeh & Onu, 2012).

Materials and Methods

A total of 20 samples of the edible clay were systematically collected from the clay deposit in Amawom, Ikwuano, Abia province, Southeastern Nigeria. The edible clay samples collected from the markets were air dried at room temperature until a constant weight was obtained. The dried clay was crushed and pulverised in turns using a pestle and mortar. The pulverised clay was thoroughly mixed to achieve homogeneity and sieved using USS No 10 sieves. The equipment used for the homogenisation were cleaned and scoured after each sample was prepared to minimise the possibility of prospective cross-contamination. These were placed in clean polythene bags, sealed to prevent absorption of moisture from the atmosphere.

Laboratory Analysis

10 g of both powdered edible and non-edible geophagic clay samples were measured into conical flask, soaked with 100 ml distilled water for 72 hours to allow the measurements of some physico-chemical parameters (pH, Electrical Conductivity (EC), Cation Exchange Capacity (CEC) and organic carbon) using multi digital-parameters probe metre (Table 1). Hence, mineralogical and elemental constituents of the geophagic clay samples were examined at Acme Laboratory Canada using X-ray Diffraction (XRD), Scanning Electron Microscope (SEM) and Inductively Couple Plasma Mass-Spectrometry (ICP-MS) using the procedures of (Melaku *et al.,* 2005).

The process for the digestion of the geophagic clay samples was based on the standard operating procedures for determining the concentration of metals in and to examine the bio-availability of these elements in earthy materials.

Oral interviews and questionnaires were also conducted, distributed and administered to individuals and different households that practice geophagy to differentiate their health status so as to correlate it with information acquired from analytical results, interpretations and response from health workers. Data were also collected from health care centres on ubiquitous ailments affecting these soil eating individuals.

Inductively Couple Plasma Mass Spectrometry (ICP-MS)

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a technique used for determination of trace metals in various environmental works as well as in the soil samples (Gramowska *et al.,* 2010). Accurate and precise results are germane in environmental studies and analysis. Wet digestion of soil samples with aqua regia was adopted to solubilise the elements in the clay samples. This has been reported to give reproducible, reliable and satisfying results (Melaku *et al.*, 2005).

Wet Acid Digestion and Analytical Procedures of Samples

A collection of about 20 already sieved clay samples were analysed for their total metals concentration after digestion with aqua regia. 3 ml of mixtures in ratio of 1:1:1 HCl - HNO_3-H_2O was added to an aliquot of 0.5 g sample. The mixture was digested at 95°C for 1 hour in a heating block. The digest was filtered using filter paper-Whatman No 4.1 and made up to mark in a 50 ml standard flask before instrumental reading with Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).

Results and Discussions

Physico-chemical Properties

The pH of the edible clay ranges from 6.6 - 7.0 indicating that the clay materials are slightly acidic while the non-edible clays vary from 3.9 - 4.2. Generally, the pH values of all the samples fall below the recommended standard of Nigeria Industrial Standard, 2007-(6.5-8.5), United State Environmental Protection Agency, 2009 - (6.5 to 8.5) and World Health Organization, 2004-(6.5-9.5) indicating an acidic edible clay and signifies high ionic contents of the clay. This might be contributions from various halides coming together to increase the acidic contents of the edible clay. Uptake of metals in earthy soils and clay materials by plants can be controlled by either high or low pH and organic matter content (Abrahams, 2002).

Furthermore, there is high anxiety vis-à-vis the possibility of anthropogenic CH_3Br and some other ethyl halide groups where Br is released into soil from fumigants and get into soils (Ibekwe & Ma, 2011; Wanjugi & Harwood, 2013). High-F comprising clays can also add to clay poisoning capabilities (Sing & Sing, 2010). Although, not all edible clays are enriched in fluoride but its concentration is controlled by apatite. Raised concentrations of elements in earthy clays aided by increased pH result not only from the weathering of geochemically anomalous parent rock materials, and mineral ore bodies but also, from human activities such as urban growth, mining and agricultural processes (Kolawole *et al.*, 2018). These actions may have consequences to human health, with excessive concentrations of elements entering the food chain. Generally, the decreasing levels (0.13%, 0.11% and 0.10%) of organic carbon in the edible clay samples with depth suggest an inorganic origin while the concentration of organic carbon in the non-edible clay (5.02%-5.88%) were higher than (Nigeria Industrial Standard, 2007) recommended value; this suggests other anthropogenic sources onto the soil. The soil organic carbon (O.C) 0.1%-5.83% may possibly indicate absorption and retention of contaminants.

The effects of Soil Organic Matter (SOM) include improvements related to soil structure, aggregation, water retention, absorption and retention of pollutants and provision of cation exchange sites which may be associated with N, P, S, Pb, As and Hg. These attributes reflect in the Amawom edible clay. Changes in organic matter content affect the bioavailability of elements. The CEC in the edible clay samples shows ratings that are interpreted to be normal ranging from 6.11-7.56 cmol/kg indicating most minerals present as kaolinite when compared with 2007-Nigeria Industrial Standard. This specifies kaolinitic clay associated with C and

S signifying impurities that may affect clay quality and human health status.

Geophagic Clay Mineralogy (X-ray Diffractometer)

The X-ray diffractograms analyses of twenty edible clay samples show Kaolinite dominating the geophagic clay which signifies it as the most widely occurring clay minerals. It also allows for the detection of secondary minerals formed by both hypogene and supergene processes.

The Amawom geophagic clay consist of kaolinite ($Al_2Si_2O_5(OH)_4$), goethite ($FeO(OH)$), pyrite (FeS_2), siliceous (SiO_2) clay and lateritic materials (Figure 2) with their lattices which vary from monoclinic, triclinic, orthorhombic, cubic and hexagonal respectively. These minerals may be the product of feldspars (microcline, orthoclase) and mica (biotite, muscovite) decomposition and alterations with other primary minerals (Marathe *et al.,* 2012).

This is reflection of Amawon edible clay. These collections of minerals surmise the origin of the edible clays to be of sedimentary origin which can be linked to the physiographic setting and the presence of different lithologic units present in the area. It also signifies that secondary type as a consequence of the presence of secondary minerals might be a product of weathering and other earth surface processes. These reasoning were portrayed in Equations 1 and 2, respectively, specifying most significant clay mineral as kaolinite which might have been enclosed were being examined both in edible and non-edible clays (Ekosse & Jumbam, 2010).

The high siliceous content of the geophagic clay might have come from the intercalated arkosic sandstone of the Benin formation. Also, considering the high silica content in edible clay (Ekosse *et al.,* 2010) reported another possible formation mechanism for kaolinite which could have been generated from the alteration of feldspathic sandstones that are rich in quartz. Hence, X-ray Diffraction (XRD) analysis confirmed the presence of quartz, kaolinite, goethite and pyrite (Figures 2 (a-d)).

Conversely, the presence of goethite-$FeO(OH)$ and pyrite-FeS_2 may indicate the levels of compaction and the consequences of cementation and lithification on the stability of the secondary minerals within the white clay.

Scanning Electron Microscope (SEM)

Multiple information on the edible clay include superficial micro-structure, component analysis and crystal structure features derived from SEM analysis at the same time. Hence, the results from SEM analysis effectively revealed the mineral crystal lattice and acquisition and inclusions of some trace element contents. It also exposed Al, Si, Fe and O_2 as the main constituents in the white clay platy morphology. Carbon and Ti observed from the edible clay signifie impurities (Figures 3 (a-c)).

The carbon impurities range from 6.46% - 29.76% within the edible clay samples. In addition, Cu and Fe observed in the edible clay indicate elements inclusion from weathering of minerals that have not leached away (Figures 3 (a-c)).

$$\underset{\text{K-feldspar}}{2KAl_3Si_3O_{10}(OH)_2} + 2H^+ + 3H_2O \rightarrow \underset{\text{Kaolinite}}{3Al_2Si_2O_5(OH)_4} + 2K^+ \quad \text{………… } \textbf{Equation 1}$$

$$\underset{\text{Kaolinite}}{2KAlSi_3O_8} + 2H^+ + 9H_2O \rightarrow \underset{\text{Mica}}{Al_2Si_2O_5(OH)_4} + 2K^+ + 4H_4SiO_4 \quad \text{………… } \textbf{Equation 2}$$

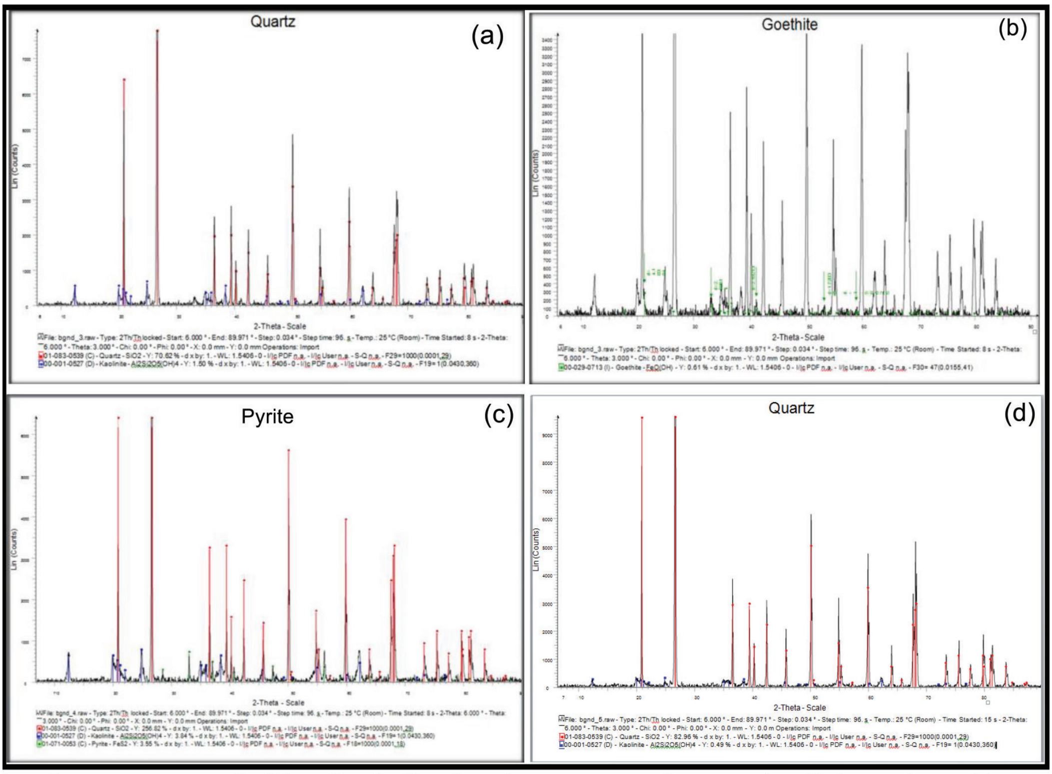

Figure 2: XRD of white clay indicating the presence of quartz, kaolinite and goethite

Major and Trace Metal Contents

Reports on Cations Exchange Capacity (CEC) revealed kaolin to be the lowest among the clay minerals, this indicates that exchange-able of calcium (Ca), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) are not very active (Ekosse & Jumbam, 2010).

Therefore, since active and potent elements in medicine are present in the edible clay (ECD 10 and ECD 15): This can be beneficial and useful elements act as appendages to mineral nutrients and provided good benefits and assistance that may also serve as curative to some gastro-intestinal problems. In relation to clay particles, organic matter is also similar with negatively charged spots which are centres that can embrace and hold cations. This signifies the reason for soils with high Cations Exchange Capacity (CEC) resulting from organic matter content that is pH dependent. An organised way of increasing the soil Cations Exchange Capacity is to increase its organic matter content. Therefore, this correlated with high CEC recorded at areas where the pH was high.

Metal Levels in Amawom Edible Clay

Different environmental factors control edible clay quality such as weathering, erosion and transportation which greatly influence clay-particles sizes and qualities due to elements and ions mobility. The high concentration of these toxic metals might impact the effluents from washing of agricultural and chemicals implements, hazardous materials and fossil fuel wastes.

Metal contents in geophagic clay samples were determined by ICP-MS and presented in Table 1. The amount of calcium (Ca), iron (Fe), potassuim (K) and zinc (Zn) characterise the essential metal contents while Hg, Pb, As and Ni represent the potentially harmful elements (PHEs). The existence of these PHEs in the

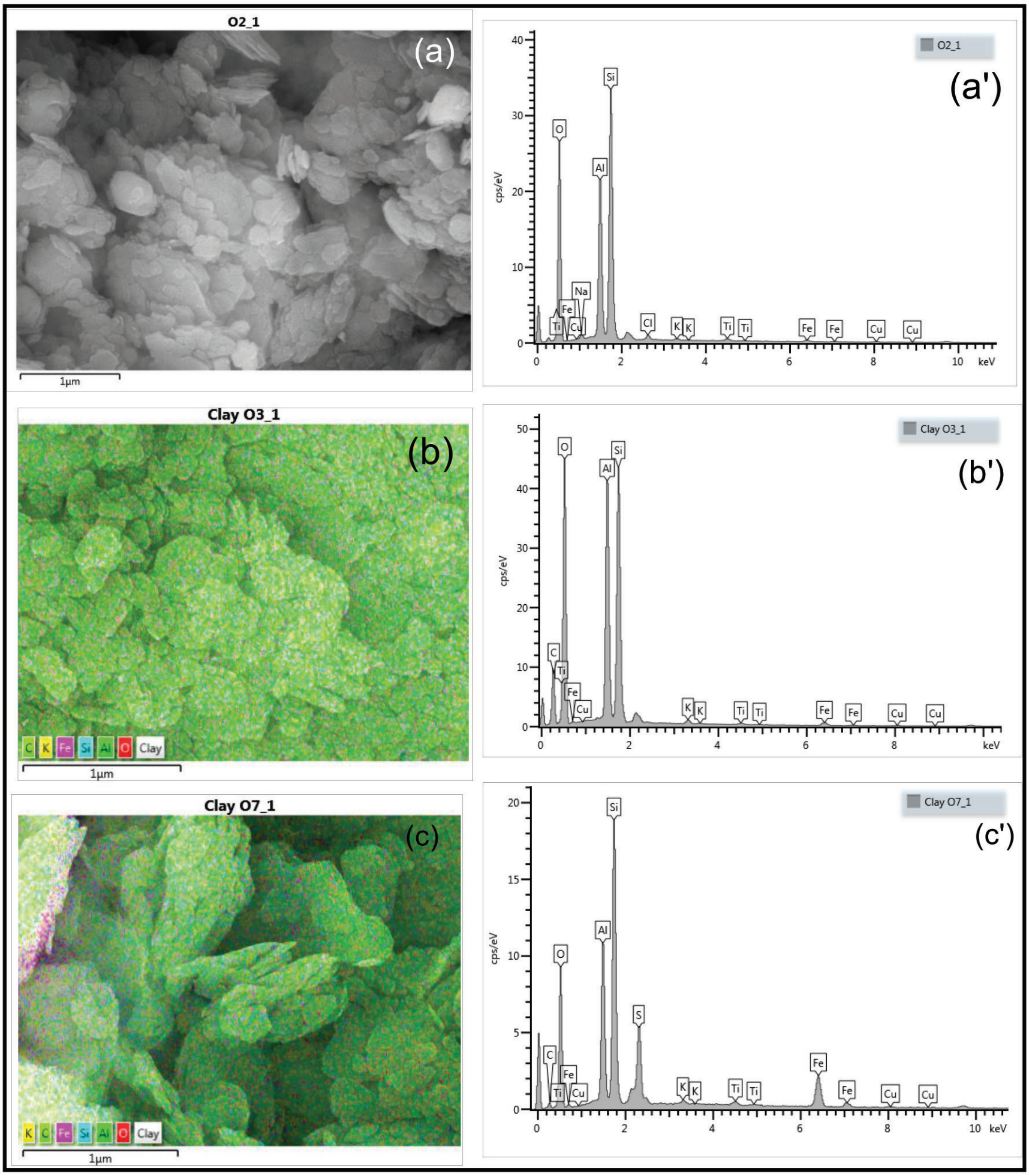

Figure 3: Scanning electron microscopy of white clay specifying its elemental composition and mineralogy

edible clay samples has become a threat to human health. As a result of this, these metals need to be monitored in order to avert an outbreak of diseases that have been cloaked.

The highest Cu concentration recorded in both the edible (ECD-71.91 ppm) and the non-edible (NED-79.4 ppm) samples, respectively. This specifies that there are some hot spots in this locality such as ECD-10. This was higher than the Cu contents in ASC-50 ppm and that of Calabar-19.3 ppm and Cameroon-58 ppm which was reported by (Ekosee & Jumbam, 2010; Olatunji *et al.,* 2014).

It demonstrates that the disproportionate intake of Cu could be linked to harsh mucosal pain with corrosion of renal damages. It also

Table 1: Major oxides variations in the white clay of the study area

Oxides	**ECD 1**	**ECD 2**	**ECD 3**	**ECD 4**	**ECD 5**	**ECD 6**	**ECD 7**	**ECD 8**	**ECD 9**	**ECD 10**
SiO_2	75.41	78.02	76.15	74.16	61.07	74.12	73.16	75.59	77.23	72.69
Al_2O_3	0.83	0.76	0.81	0.70	1.34	0.85	1.11	0.98	1.21	2.76
$FeO+Fe_2O_3$	3.34	0.90	1.36	0.76	10.10	1.47	7.55	3.99	1.20	0.49
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.00
K_2O	1.00	0.91	0.98	0.84	1.62	1.02	1.34	1.18	1.46	3.32
CaO	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04
MgO	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
MnO	19.37	19.37	20.66	23.49	25.82	22.49	16.78	18.20	18.07	20.66
TiO_2	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
P_2O_5	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00
pH	6.6	6.8	6.9	6.7	6.7	6.9	7.0	7.0	6.9	6.8
Ec	70	52	187	107	399	130	119	58	53	66
CEC	6.42	6.11	7.56	6.68	6.93	7.42	7.4	6.22	4.49	6.48
Org carbon	0.13	0.11	0.10	0.30	0.19	0.13	0.11	0.10	0.30	0.19
Oxides	**ECD 11**	**ECD 12**	**ECD 13**	**ECD 14**	**ECD 15**	**NED 16**	**NED 17**	**NED 18**	**NED 19**	**NED 20**
SiO_2	77.29	6.11	74.69	71.46	73.51	12.68	66.69	54.66	36.97	39.88
Al_2O_3	0.60	2.06	1.23	2.72	0.62	2.06	0.43	0.42	0.59	0.66
$FeO+Fe_2O_3$	0.65	3.99	0.92	0.43	0.68	3.83	1.30	1.77	2.28	4.37
Na_2O	0.00	0.01	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.73	2.48	1.48	3.28	0.75	2.48	0.52	0.50	0.71	0.80
CaO	0.03	0.07	0.03	0.10	0.03	0.13	0.01	0.01	0.01	0.01
MgO	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
MnO	20.66	85.21	21.16	21.95	24.37	78.75	30.98	42.60	59.39	54.22
TiO_2	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.02
P_2O_5	0.01	0.03	0.02	0.00	0.01	0.03	0.01	0.01	0.01	0.02
pH	6.9	6.8	6.9	6.7	6.8	3.9	4.1	3.8	4.3	4.2
Ec	70	52	187	107	399	430	119	558	453	466
CEC	4.95	6.36	6.68	6.93	7.37	7.23	8.97	9.62	7.45	8.18
Org carbon	0.13	0.11	0.10	0.30	0.19	5.02	5.36	5.17	5.43	5.88

Note: ECD = Edible clay, NED = Non edible clay

affects and causes severe pains on gastro-intestinal through neural disorder (World Health Organization, 1993). The continuous consumption of this edible clay can be injurious to consumers' health and endangers inhabitant lives.

Pb had been the most toxic metal and not classified as part of micronutrients, as it presents high toxicity to the environment when the tolerable concentration is exceeded. Prolonged edible clay consumption may end up in damaging the health conditions of individual consumers. This may be connected to kidney and liver damage and finally heart seizure of the consumers which may perhaps lead to death (Bonglaisin *et al.,* 2011). It might also lead to complex teething troubles because of its systemic toxicity that have been associated to carcinogens, neuro-toxicity and let down in generative issues in adults.

The concentration of Zn is not significant in the clay sample but with the exception of ECD-15. Zinc is concentrated in the non-edible clay (NED-124.7 ppm) than that of the edible type. Generally, this metal is indispensable for its curative and medicinal capabilities in human health which had been regarded to be safe with usage and different applications (World Health Organization, 1993).

Despite all this, another depressing repercussion that cannot be disregarded which is unavoidably derived from the excessive intake above the normal dosage and Permissible Daily Intake (PDI) of 10mg had been reported harmful (Hooda *et al.,* 2002). This may be invariably linked with various health challenges such as abdominal pain, nausea, dizziness, lack of muscular coordination and renal failure (World Health Organization, 1993).

However, Cr has been linked to body absorption of carbohydrate, despite its presence as one of the micronutrients. It also acts as cancer-causing agent to some organs in human body when the tolerable level is exceeded (Ekosse & Jumbam, 2010).

Concentrations for Ni, Co, As, Cr, Ag and Hg were observed in both edible and non-edible clay and range from Ni-0.6-5.8; 1.5-51.6 ppm, Co=0.1-9.8; 0.6-30.5 ppm, As=0.5-21.6; 1.5-12.69, Cr=7.4-30.1; 11.2-41.1 ppm Ag=4-179; 8-217 ppm and Hg=11-7.27; 77-9.49 ppm, respectively.

This was found to be notably high signifying contaminated clay. The presence of high concentration of these toxic metals is considered a display of very effective and active clay adsorbing capacity due to its particle size. The values for minimum and maximum typify that these potentially harmful elements were not squarely dispersed in both the edible and the non-edible kaolinitic clays.

This could result from differential contamination of rain water run-offs due to human activities at the upstream and on the deposit. This irregular distribution of metals may also come from variations in leaching or contamination by water flowing from nearby springs and streams that are controlled by seasonal changes.

Relationship between Trace Metals in Edible Clay and Human Health

The curative consequences of clay eating are multifarious specifically among the edible clay individual because of the huge amounts of clay that can be consumed. An excessive consumption of clay can lead to many health hazards because the significance of geophagy is that the quantity that is consumed and the mineral nutrients equilibrium in individual may be exaggerated.

The gut, which is the muscular tube or oesophagus which links to the abdominal sac or belly is vital body parts that work as channels and transitory storage spaces for materials that enter the body through the mouth opening. The abdomen churns and temporarily stores consumed materials in the abdominal sac. With this, both useful and toxic substances can be absorbed.

Extremely, toxic materials will possibly cause morphological changes within this body parts especially in the mucosae of the internal organs (Abrahams, 2002). Therefore, clay incidence within the gastrointestinal and the stomach will come across acidity systems with transfer of elements through cation interchange (Abrahams, 2002). Hence, solubility of iron occurs through this process while other important elements that are beneficial to consumers are transferred by means of the clay consumed. Eating of clay (geophagy) symbolizes thirst created by a dietary shortage suggesting an adequate supply that can be derived from consumed earthy materials while an excess may result to deadly toxicity.

Different discoveries have indicated that edible clay may compromise the integrity of the gastro-oesophageal tract because some of this edible clay were found to contain toxic materials such as Pb, As, Al and Hg. Lead (Pb) consumption has been involved in constipation, nausea, vomiting and *gastritis* and has also been found to cause ulcers when large amounts are consumed (Murata *et al.,* 2009).

Arsenic has been implicated in gastric distress and stomach upset (Smith *et al.,* 1992) and aluminium has been shown to be associated with constipation, impaction, *colic* pain, *anorexia*, nausea and gastrointestinal irritation (Ganrot, 1986). *Colic* pain may be accompanied by sweating and vomiting. It has been described as a form of pain that jerks and stops brusquely. It ensues due to muscular shrinkages of colon, gall bladder or urethra hollow tube in an attempt to relieve an obstruction by forcing content out.

However, geophagic clay often has ability to move and stream Fe^{2+} and some vital elements through human system. Most edible clays are rich in K^{+} and when large quantities from these clays are enhanced, these elements are engaged; they served as probable nutrient supplier that can serve as food which may be linked with infections from these sources.

Also, this can be connected to some element's insufficiency such as the case of iron insufficiency. This has been linked to clay consumption, ensuring decreased content of this nutrient element in the alimentary canal and gastrointestinal tract which has been traced to clay consumption (Olatunji *et al.,* 2014). Other nutrient element in this category with Fe is Zn: On the other hand, poverty which includes inadequate feeding and deprived nutrition has been the major factor for Zn paucity in human system and earthy material which might have been a reflection that contributed immensely to Zn dearth in humans. Zinc shortages have been observed to have a connection with retarded growth and impaired sexual development (Abrahams, 2012).

Mercury (Hg) has many sources which include emissions from coal and other materials such as hospitals with medical wastes. These are key contributors to most environmental problems and it is becoming worrisome to human existence. It can also be obtained from power stations and incinerators when these are released to the environment continuously, they become a threat.

A substantial percentage (≥70%) of environmental Hg are generated from different human activities that include a variety of industrial processes such as zinc, alloy metals, steel, other metals production and product recycling. This metal is used by various domestic, industrial and health products. This is also unconfined in the environment through natural phenomena such as weathering of minerals, materials released from volcanoes and anthropogenic processes.

Hence, based on this negative impact on the environment, safer alternatives in the replacement of this metal have been going on. Gaseous inorganic ionic Hg has been reported to have a shorter atmospheric period which can be inhaled and deposited on land and water forms. Hg can also be remobilized and released into other geological media which are of considerable significance to climate change.

The oesophagus is prone to injury (Ekong *et al.,* 2012) and the presence of these substances may increase the susceptibility to injury. This increased susceptibility to injury may lead to advance physiological and tissue damage to the stomach and the oesophagus due to the increased vulnerability to other toxins that may be consumed. Furthermore, (Dean *et al.,* 2004) have reported adverse properties of the PHEs that can affect the oesophagus tract. In addition to this, the edible clay (chalk) had been reported to be largely composed of kaolin, a substance known to coat the gastrointestinal tract (Ekong *et al.,* 2012).

Edible clays (kaolin) adsorb drugs and other materials as well as potentially harmful elements and toxins; thereby decreasing their bioavailability and this may kick start the different occurrences of diarrhea (Onyekweli *et al.,* 2003). The changes in tissues experienced in the gut and the stomach may reflect an outcome in the consumption of edible clay (Ekong *et al.,* 2012).

Correlation between Microorganisms in Edible Clay and Human Health

The body surfaces of any healthy human-being which include both the outer and the inner parts such as skin, *sinuses* and lungs and the alimentary canal are occupied with a glut of different species of microorganisms (Sing & Sing, 2010). Observations made by Sing and Sing (2010) revealed that the microbial cells that are located in or on a healthy human-being *(microbiome)* are greater, higher and even outnumber the body's own cell count in a great magnitude.

Four dominant bacteria phyla have been reported in the human gut, they are: *Firmicutes, Bacteroidetes, Actinobacteria* and *Proteobacteria* (Rinninella *et al.,* 2019). Apart from these, those microorganisms that have been established on human internal and external body surfaces are also frequently observed in earthy materials such as clay (Pennisi, 2008; Grice *et al.,* 2008). Since these microbes have both positive and negative impacts, specific or selected numbers of micro-organisms have been found to support the immune system by defending the body from harmful micro-organisms.

Various types of these microorganisms are indispensable occupants of the gastro-intestinal tracts which start from the mouth through the saliva to the stomach. In general, human-beings are born newly in a germ-free and hygienic form without any *microbiota* in the gut, but the *microbiome* is introduced as an import of environmental acquaintances and contacts which start from infancy during breast feeding and from hand-to-mouth in the transfer of food.

Increments in the *microbiome* colony is achieved through edible clay consumption, by particulate dust which floats through the air; some of these come to rest and settled on the skin while some are inhaled into the respiratory system. Edible clays in association with some micro-organisms are ingested as soil residues through vegetables and fruits derived or planted on this clay deposit. This can be described as wilful geophagy or accidental geophagy.

Other areas include edible clay that have been made into powder, tablet or capsule form that have been contaminated with some common gut bacteria which can also serve as threat to human lives (Gill *et al.,* 2006).

Bacteria such as *Escherichia coli*, *Enterococcus* and *Klebsiella* are micro-organisms that have been recognized on human internal and external body surfaces and are detected in some of these edible clays, this is in line with the studies of (Pennisi, 2008; Grice *et al.,* 2008).

Environmental and Public Health Challenges

Pregnant women particularly are in distress in these circumstances as toxic metals such as Pb, As, Cr and Hg can be moved from one part to other parts of the body. Therefore, engaging or forcing the health of the unborn baby into pronounced and inordinate risk. It is possible that not all the toxic metals present in the edible clay will be bio-accessible in line with the multifarious contents of this clay which consists of both the organic and inorganic toxic elements. This indicates apart from the total material unrestricted and free to the soil for plant uptake. Report from other areas revealed that the bio-availabilities of some toxic elements in soils were higher than those of other trace metals (Sungura *et al.,* 2014).

The Pb content determined in this research range from 4.98-71.91 ppm which is higher than the values reported by other workers from other parts of the world. These create a major health concern for users of this material (Murata *et al.,* 2009). This has been linked with various diseases (Laurer *et al.,* 1993; Mishra, 2009). Generally, Pb in Nigeria has become a cumbersome problem and elevated values had been reported in soils, sediment particulate matter, effluents and water (Odewande & Abimbola, 2008; Abrahams, 2012). This metal is generally sourced from improved industrialization, paints, Pb-based chemicals and fuels.

Mercury is toxic without any biochemistry or physiology importance but varies from 0.01-0.73 ppm and 0.08-0.95 ppm, respectively in both edible and non-edible types suggesting contamination. Combinations of Hg with other elements may form either organic or inorganic Hg-compounds converted into bio-accumulating toxins by micro-organisms in soils (Rice *et al.,* 2014). The inorganic Hg is the most dangerous and harmful (Bonglaisin *et al.,* 2011) and has its concentration surpassing the maximum permissible level (0.03 ppm) from oral intake. This specifies toxic and non-edible clay that may become injurious to the brain, kidneys, foetuses, memory, tremors and vicissitudes in vision and hearing performances which can lead to ultimately death (Bonglaisin *et al.,* 2011).

However, the upcoming generations that consume this clay may become grieved of some of these exhibitions of ailments once the vulnerability level for Hg is high. Cd concentration is lower than the detection limit. The major minerals in this geophagic clay include kaolin, illite and quartz but it was found to be free of salt and very low in organic carbon (0.3%) but the presence of these materials in both the edible and non-edible clay may be economical.

Therefore, minerals present might be useful for industrial purpose and can be a pathway to relief the economy, if it is adequately processed. As a result, it is considered to be nutrients packed due to its high concentrations of essential elements. Reports have shown that Hg is present in the clay and this has been part of the clay constituents. The risks associated with geophagic clay consumption are likely to be greatly exacerbated for consumers in Amawon area especially those who are already exceeding their daily intake of Hg from the consumption of these contaminated earthy materials.

Nickel causes environmental and occupational pollution and its concentration exceeded the tolerable limit especially in NED-18 (Table 2) which may increase the risk of lung cancer, cardiovascular with neurological deficits. Cobalt is beneficial and serves as an essential component in vitamins also present both in edible and non-edible clay. Mostly detached from pigments, batteries and sterilising medical equipment into runoffs and deposited on clays and sediments.

The presence of Arsenic and Nickel signify contamination and toxicity because tolerable value of 0.01 ppm is exceeded. This may bio-accumulate in humans with varying manifestation of gastrointestinal complications, cardiovascular disturbances, nervous system damage and cancer of the bladder, liver, lungs, skin and eventually death (Jaishankar *et al.,* 2014). Silver enters human body through ingestion and are compositionally similar to clay minerals and also have a high cation exchange capacity (Williams & Haydel, 2010).

Virtually all the locations were contaminated with Ag since it exceeded the 0.10 ppb recommended by USEPA. The possible health effect is the advancement of an irreversible pigmentation of the skin-(*argyria*) and that of the eyes-(*argyrosis*). This is a condition of the face and skin caused by excessive exposure to Ag-based chemical compounds where the skin turns purple.

The most proliferating illness in Amawom is gastrointestinal disorders with 42.1% of respondents which may justify the geophagic attitude among the inhabitants. Therefore, the occurrence of kaolinite in the edible clay can be linked to the mineral potency as useful orthodox antacid which is being sought after by any ailing consumers. This has provided respite and good assistance from gastrointestinal diseases (Gonzalez *et al.,* 2004).

Also, this potency is employed as useful ingredients in medical and modern pharmaceuticals mixtures with different brand names such as *Magsil, Gestid, Mismag, Mist Kaolin* and *Gelusil* in the treatment of gastrointestinal cases. These have been found to be very effective as good curative remedy and as conventional antacid.

Edible clays have been reported to be inactive through pH range of 6.5-8 M in human gastro-intestinal tract system spanning through slightly acidic and alkaline environments respectively (Oomen *et al.,* 2000; Ekosse & Jumbam, 2010; Olatunji *et al.,* 2014).

Table 2: Trace metal distributions in the white clay of the study area (ppm)

	ECD 1	**ECD 2**	**ECD 3**	**ECD 4**	**ECD 5**	**ECD 6**	**ECD 7**	**ECD 8**	**ECD 9**	**ECD10**
Cu	3.59	1.57	1.87	1.37	4.61	2.38	3.71	2.47	2.91	71.91
Pb	8.29	6.91	7.63	7.27	31.10	8.2	13.69	12.61	4.98	10.84
Zn	2.4	2.2	2.9	2.2	3.5	3.1	2.1	1.9	2.2	18.4
Ag (ppb)	5	4	4	5	11	5	9	10	18	179
Ni	0.9	0.9	1.1	0.7	5.8	1	1.6	0.9	0.6	5.8
Co	0.5	0.3	0.5	0.3	9.8	0.5	2.2	0.5	0.1	1.9
As	4.8	0.7	1.1	0.7	21.6	3.2	11.4	6.9	11.6	10.3
Mo	1.46	0.45	0.52	0.18	1.24	0.85	0.96	0.65	1.12	0.35
Cr	12.4	7.5	9.7	7.4	17	9.4	19.8	13.1	30.1	15.1
Au (ppb)	1.5	0.4	1.5	0.3	0.7	<0.2	0.4	0.5	0.4	1.3
Hg (ppb)	30	20	21	19	17	24	24	19	22	7269
U	0.3	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.5	1.5
Th	5.1	4.7	5.6	5.2	5.5	5.1	5.6	5.1	5.7	5.5
Min	0.3	0.2	0.3	0.18	0.3	0.3	0.2	0.2	0.1	0.35
Max	30	20	21	19	31.1	24	24	19	30.1	7269
Mean	7.1	4.7	5.3	4.6	10.7	6.2	7.9	6.2	8.7	990.7
	ECD 11	**ECD 12**	**ECD 13**	**ECD14**	**ECD15**	**NED16**	**NED17**	**NED18**	**NED19**	**NED20**
Cu	1.97	4.91	2.42	2.95	18.89	5.29	2.14	2.31	79.4	4.52
Pb	5.38	5.67	12.43	4.97	10.62	85.94	4	3.08	3.74	3.81
Zn	2	7.8	1.8	2.3	48.5	7.9	74.5	3.5	4.7	7.1
Ag (ppb)	5	10	10	16	168	12	9	8	15	217
Ni	0.8	3.2	0.8	0.6	5.4	3.1	1.5	51.6	3.5	2.1
Co	0.3	0.7	0.4	0.1	2	0.6	0.6	30.5	0.7	0.7
As	0.4	1.8	5.5	1.6	0.5	12.69	3.6	6.6	3.4	8.5
Mo	0.15	1.26	0.65	1.12	0.35	0.76	0.26	1.62	0.73	1.48
Cr	7.6	26.8	12.3	28.2	13.7	24.2	11.2	12	13.4	41.1
Au (ppb)	0.2	0.7	0.5	0.4	1.3	0.2	0.2	0.2	0.3	0.6
Hg (ppb)	11	33	21	32	63	9487	210	115	77	110
U	0.4	0.5	0.4	0.5	1.2	0.5	0.5	0.4	0.6	0.7
Th	3.8	6.4	5.3	5.4	5.1	6.2	5.7	4.4	6.5	5.3
Min	0.15	0.5	0.4	0.1	0.35	0.2	0.2	0.2	0.3	0.6
Max	11	33	21	32	168	9487	210	115	79.4	217
Mean	3.3	9.1	6.3	8.5	33.8	1275.6	35.6	23.6	19.2	41.4

Note: ECD = Edible clay, NED = Non edible clay

The kaolin clay characteristically becomes chemically inactive and tasteless based on the different chemical medium which they passed from the mouth through gastrointestinal tracts to the stomach. This closed system may slow down the caustic behaviour of this edible clay in the gastrointestinal sacs. The alkaline character of the saliva in the mouth neutralises the effect of slightly acidic clay, which becomes distasteful and smooth in the mouth.

Extracted information from questionnaires certifies geophagy usage as medicinal, cultural, nutritional and cosmetic purposes (Kutalek *et al.,* 2010). Nevertheless, those between 16-50 years of age were the most vigorous, in sourcing, processing and using this edible clay. Geophagia can be linked with anaemia (10.2%), dysentery (16.5%), hypertension (19.3%), cardiac failure (CF)-4%, respiratory tract infections (RTI)-3%, pneumonia (PN)-2.8 % (Figure 4).

Presence of alkalis (Na^+) in edible clays might have been the cause of hypertension and cardiac failures in this study. Mixtures of obscured side effects might have eventually lead to death while colon damage due to abrasiveness, lacerations, perforations and ruptures were ascribed to high SiO_2 percentages in the clay (Ekong *et al.,* 2012). Practically, two thirds (≥68%) of the respondent class obtained their edible clay insitu from this communities while 70-75 g of clay was consumed in a day. People that have high attraction and addiction consumed the edible clay three times a day.

About 10% of the respondents indicated that they resorted to geophagy for stave off hunger or as medicine at 82% whereas people with high level of civility, decency and affability are 62%. However, calculated Average Daily Intake (ADI) by (Nkansaha *et al.,* 2016) indicated about 75 g of clay is being consumed on daily basis in Amawom which is a little above the reported 70 g that is consumed in Ghana (Samlafo, 2017).

Conclusion

Potassium, calcium, iron and zinc were found to be indispensable nutrients in edible clay where, kaolinite is present as the most potent minerals in rendering curative action against gastrointestinal problems. Therefore, the beneficial values of these nutrients were moderately small compared to the tolerable limits predetermined by WHO and FAO standards.

Approximately, 40% women of reproductive age were active in geophagy. Calculated Average Daily Intake (ADI) revealed

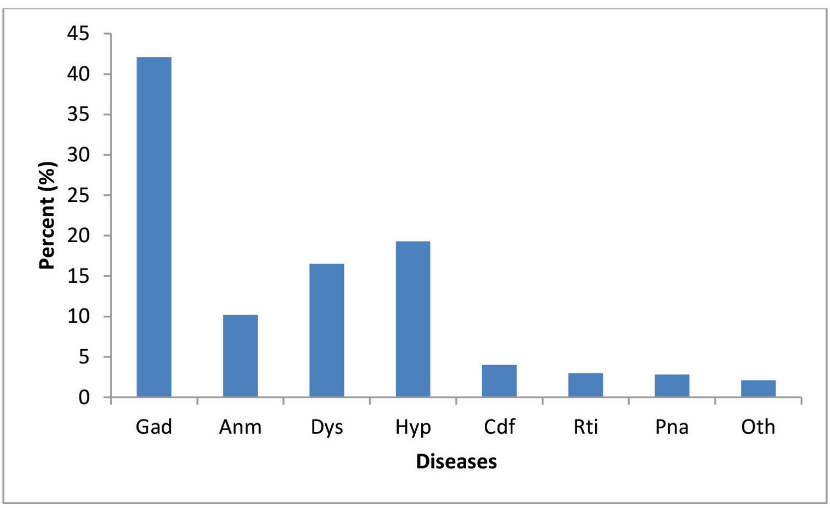

Figure 4: Predominant environmental and health implications observed in the area

Notes: Gad = Gastro intestinal disorder, Anm = Anaemia, Dys = Dysentry, Hyp = Hypertension, Cdf = Cardiac failure, RTI = Respiratory track infections, Pna = Pneumonia, Oth = Others

75 g of clay consumed daily; this is above the recommended value suggested by WHO/FAO which is worrisome and serve as an indication of threat to human health based on the presence of the PHEs in this clay.

Apart from the major elements, some associated trace metals that are toxic which were adsorbed due to the clay particles size, could greatly reduce the edible clay quality. This work until this time exposed clay consumed by geophagist that, it can be a source of Hg exposure that has never been formerly deliberated in risk evaluation work.

The immediate manifestation of Pb, As, Cr and Hg in the edible clay is similarly a cause for health apprehension or distress since it is ingested always and continuously in greater quantity. Furthermore, potentially harmful element such as Pb, As, Cr and Hg were comparatively high and might bio-accumulate in human body systems and consequently, affect geophagist health.

Continuous and regular chemical checks should be imbibed on edible clays since influx of PHEs into this clay might have occurred at any period of sedimentation, deposition and lithification; this will prevent sudden occurrence of health challenges that may be associated with ingestion of heavy metals in this geophagic clay.

A thorough sensitisation for the populace living in this area is important. This would give them an insight into the long-time effect of geophagic-clay on their health. The edible clay might be beneficial for industrial purpose. It could also be a pathway to relief and a respite to the economy. Therefore, continual investigation is mandatory to define the bio-availability of these toxic metals from the clay.

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References

Abrahams, PP. W. (2002). Soils: Their implications to human health. *The Science of the Total Environment*, *291*(1-3), 1-32. DOI: 10.1016/s0048-9697(01)01102-0

Abrahams, P. W. (2012). Involuntary soil ingestion and geophagia: A source and sink of mineral nutrients and potentially harmful elements to consumers of earth materials. *Appllied Geochemistry*, *27*(5), 954-968. DOI: 10.1016/j.apgeochem.2011.05.003

Abrahams, P. W., Davies, T. C., Solomon, A. O., Trow, A. I., & Wragg, J. (2013). Human geophagia, Calabash Chalk and Undongo: Mineral element nutritional implications. *PLoS ONE*, *8*(1), e53304: DOI: 10.1371/journal.pone.0053304

Adojoh, O., Lucas, F. A., & Dada, S. (2015). Palynocycles, palaeoecology and systems tracts concepts: A case study from the Miocene Okan-1 Well, Niger Delta Basin, Nigeria. *Applied Ecology and Environmental Sciences*, *3*(3), 66-74.DOI:10.12691/aees-3-3-1

Al-Rmalli, S. W., Jenkins, R. O., Watts, M. J., & Haris P. I. (2010). Risk of human exposure to arsenic and other toxic elements from geophagy: Trace element analysis of baked clay using inductively coupled plasma mass spectrometry. *Environmental Health, 9*(1), 79. DOI:10.1186/1476-069X-9-79.

Banwar, L. M. (2012). A case report on Geophagia in Transkei region of South Africa. *African Health Sciences,12*(4), 566-568. DOI: 10.4314/ahs.v12i4.27

Bonglaisin, J. N., Chelea, M. 1., Tsafack, T. J. J., Djiele, P. N., Lantum, D. N., & Ngondé, E. M. C. (2017). Assessment of haemoglobin status and transplacental transport of lead and calcium during geophagy. *Journal of*

Nutritional Disorders and Therapy, *7*(1), 1-7. DOI:10.4172/2161-0509.1000e130.

Bonglaisin, J. N., Mbofung, C. M. F., & Lantum, D. N. (2011). Intake of lead, cadmium and mercury in Kaolin-eating: A quality assessment. *Journal of Medical Scinces, 11*(7), 267-273. DOI: 10.3923/jms.2011.267.273.

Dean, J. R., Deary, M. E., Gbefa, B. K., & Scott, W. C. (2004). Characterisation and analysis of persistent organic pollutants and major, minor and trace elements in Calabash chalk. *Chemosphere*, *57*(1), 21-25. DOI:10.1016/j.chemosphere.2004.05.023

Ekong, M. B., John, E. E., Mbadughal, C. C., Bassey, E. I., & Ekanem, T. B. (2012). Effect of Calabash Chalk on the histomorphology of the Gastro-Oesophageal tract of growing Wistar Rats**.** *Malaysia Journal Medical Sciences, 19*(1), 30-35. DOI: 10.21315

Ekosse, G. E., de-Jager, L., & Ngole, V. (2010). Traditional mining and mineralogy of geophagic clays from Limpopo and Free State provinces, South Africa. *African Journal of Biotechnology*, *9*(47), 8058-8067. DOI: 10.5897/AJB10.296

Ekosse, G. E., & Jumbam, D. N. (2010). Geophagic clays: Their mineralogy, chemistry and possible human health effects. *African Journal of Biotechnology, 9*(40), 6755-6767. DOI: 10.5897/AJB09.1777

Folorunso, A., Ariyo, S. O., & Ayolabi E. A. (2013). Mapping Precambrian Aquifer Architecture in fractured hydrogeological setting with vertical electrical sounding. *Journal of Geography and Geology*, *5*, 202-215. DOI:10.5539/v5n3p202

Ganrot, P. O. (1986). Metabolism and possible health effects of aluminum. *Environmental Health Perspectives*, *65*, 363-441. DOI: 10.1289/ehp.8665363

George, G., & Adams, A. (2012). Physiological effects of geophagy with reference to iron nutritional status in pregnant women: A case study in selected antenatal clinical in KSD municipal area of Eastern Cape, South Africa. *3rd International Conference on Biology, Environment and Chemistry*, *46*(21), 96-99. DOI: 10.7763/IPCBEE.

Gill, S. R., Pop, M., Deboy, R. T., Eckburg, P. B., Turnbaugh, P. J., Samuel, B. S., Gordon, J. I., Relman, D. A., Fraser-Liggett C. M., & Nelson, K. E. (2006). Metagenomic analysis of the human distal gut microbiome. *Science*, *312*, 1355-1359. DOI:10.1126/science.1124234

Gonzalez, R., Demedina, F. S., Martinez-Augustin, O., Nieto, A., Galvez, J., & Risco, S. (2004). Anti-inflammatory effect of diosmectite in hapten-induced colitis in the rat. *British Journal of Pharmacology, 141*(6), 951-960. DOI:10.1038/sj.bjp.0705710

Gramowska, H., Krzyzaniak, I., Baralkiewiez, D., & Goldyn, R. (2010). Environmental applications of ICP-MS for simultaneous determination of trace elements and statistical data analysis. *Environmental Monitoring Assessment*, *160*(1-4), 479-490. DOI 10.1007/s10661-008-0712-9.

Grice, E. A., Kong, H. H., Renaud, G., & Young, A. C. (2008). A diversity profile of the human skin microbiota. In Bouffard, G. G., Blakrsley, R. W., Wolfberg, T. G., Turner, M. L., Segre, J. A. *NISC Comparative Sequencing program*, *18*(7), 1043-1050. 10.1101/gr.075549.107

Hooda, P. S., Henry, C. J. K., Seyoum, T. A., Armstrong, L. D. M., & Fowler, M. B. (2002). The potential impact of geophagia on the bioavailability of iron, zinc and calcium in human nutrition. *Journal Environmental Geochemistry Health, 24*, 305-319. DOI:10.1023/A:1020542810334

Ibekwe, A. M., & Ma, J. (2011). Effects of fumigants on microbial diversity and persistence of E. Coli O_{15}:H_7 in contrasting soil microcosms. *Science of Total Environment*, *409*(19), 3740-3748. DOI:10.1016/j.scitotenv.2011.06.033

Ijeh, I., & Onu, N. (2012). Appraisal of the aquifer hydraulic characteristics from electrical sounding data in Imo River Basin, South Eastern Nigeria: The case of Imo shale and Ameki Formations. *Journal of Environment and Earth Science*, *2*(3), 1-17. DOI:10.4172. https://www.iiste.org/Journals/index.php/JEES/article/view/1645

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, *7*(2), 60-72. DOI**:** 10.2478/intox-2014-0009

Johns, T. (1999). The chemical ecology of human ingestive behaviors. *Annual Review of Anthropology*, *28*, 27-50. DOI-10.1146/annurev.anthro.28.1.27.

Judith, W., Asiko, L., & Ngugi, L. W. (2016). Geophagy amidst compulsory iron supplemention among pregnant women attending ant-natal clinics in Likuyani Sub-County (Kenya). *Jounal of Food and Nutritional Disorder*, *5*(3). DOI:10.4172/2324-9323.1000197

Kamunda, C., Mathuthu, M., & Madhuku, M. (2016). Health risk assessment of heavy metals in soils from Witwatersrand Gold Mining Basin, South Africa. *International Journal of Environmental Res. Public Health*, *13*, 663; DOI:10.3390/ijerph 1307 0663.

Klein, N., Fröhlich, F., & Krief, S. (2007). Geophagy: Soil consumption enhances the bio-activities of plants eaten by chimpanzees. *The Science of Nature* (*Naturwissenschaften*), *95*(4), 325-31. DOI 10.1007/s00114-007-0333-0

Kolawole, T. O., Olatunji, A. S., Jimoh, M. T., & Fayemila, O. T. (2018). Heavy metal contamination and ecological risk assessment in soils and sediments of an industrial area in South- western Nigeria. *Journal Health and Pollution*, *8*, 1-16. DOI: 10.5696/2156-9614-8.19. 180906

Kutalek, R., Wewalka, G., Gundacker, C., Auer, H., Wilson, J., Haluza, D., Huhulescu, S., Hillier, S., Sager, M., & Prinz, A. (2010). Geophagy and potential health implications:

Geohelminths, microbes and heavy metals. *Transactions of The Royal Society of Tropical Medicine and Hygiene*, *104*(12), 787-795. DOI:10.1016/j.trstmh.2010.09.0 02

Laurer, G. R., Gang, Q. T., Lubin, J. H., Li, J. Y., Kan, C. S., Xiang, Y. S., Jian, C. Z., Yi, H., De, G. W., & Blot, W. J. (1993). Skeletal Pb-210 levels and lung-cancer among radon-exposed tin miners in southern china. *Health Phys, 64*(3), 253-259. DOI:10.1097/0000 4032-199303000-00003

Marathe, N. P., Shetty, S. A., Lanjekar, V. B., Ranade, D., & Shouche, Y. (2012). Changes in human gut flora with age: An Indian familial study. *BMC Microbiology*, *12*(1), 1-10. DOI:10.1186/1471-2180-12-222

Melaku, S., Dams, R., & Moens, L. (2005). Determination of trace elements in agricultural soil samples by inductively coupled plasma-mass spectrometry: Microwave acid digestion versus aqua regia extraction. *AnalyticaChimicaActa, 543*(1-2), 117-123.DOI.10.1016/j.aca.2005.04.055

Mishra, K. P. (2009). Lead exposure and its impact on immune system: A review. *Toxicology Vitro, 23*, 969-972. DOI: 10.10 16/j.tiv.2009.06.014

Murata, K., Iwata, T., Dakeishi, M., & Karita, K. (2009). Lead toxicity: Does the critical level of lead resulting in adverse effects differ between adults and children. *Journal of Occupational Health*, *51*(1), 1-12. DOI: 10.1539 /joh.k8003

Nkansaha, M. A., Korankyea, M., Darkoa, G., & Dodd, M. (2016). Heavy metal content and potential health risk of geophagic white clay from the Kumasi Metropolis in Ghana. *Journal of Toxicology Report*, *3*, 644-651. DOI: 10.1016/j.toxrep.2016.08.005

Nyanza, E. C., Joseph, M., Premji, S. S., Thomas, D. S. K., & Mannion, C. (2014). Geophagypractices and the content of chemical elements in the soil eaten by pregnant women in artisanal and small scale gold mining communities in Tanzania. *BMC Pregnancy and Child Birth*, *14*(144), 1-10. DOI: 10.1186/1471-2393-14-144

Odewande, A. A., & Abimbola, A. F. (2008). Contamination indices and heavy metal concentrations in urban soil of Ibadan metropolis, southwestern Nigeria. *Environmental Geochemistry and Health*, *30*(3), 243-54. DOI: 10.1007/s10653-007-9112-2

Olatunji, A. S., Olajide-Kayode, J. O., & Abimbola, A. F. (2014). Evaluation of geochemical characteristics and health effects of some geophagic clays southern Nigeria. *Journal of the Society for Enivironmental Geochemistry and Health, 36*(6), 1105-1014. DOI:10.1007/s10653-014-9619-2

Onyekweli, A. O., Usifoh, C. O., Ukonrobo, L. O., & Zuofa J. D. (2003). Adsorptive property of kaolin in some drug formulations. *Trop J Pharm Res*, *2*(1), 155-159. DOI: 10.4314/tjpr.v2i1.14580

Oomen, A. G., Sips, A. J. A. M., Groten, J. P., Dick, T. J. M., Sijm, T. H. M., & Tolls, J. (2000). 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. Technol*., *34*(2), 297-303. DOI:10.1021 /es970512m.

Pennisi, E. (2008). Bacteria are picky about their homes on human skin. *Science*, *320*(5879), 1001- 10.1126/science.320.5879.1001

Reilly, C., & Henry, J. (2000). Geophagia: Why do humans consume soil? *Nutrition Bulletin, 25*(2), 141-144. DOI: 10.1046/j.1467-3010. 2000.00032.x

Rice, K. M., Walker, E. M., Wu, M., Gillette, C., & Blough, E. R. (2014). Environmental mercury and its toxic effects. *Journal of preventive Medicine and Public Health*,*47*(2), 74-83. DOI: 10.3961/jpmph.2014.47.2.74

Rinninella, E., Raoul, P. Cintoni, M., Franceschi, F., Miggiano, G., Gasbarrini, A., & Mele, M.C. (2019). What is the healthy gut microbiota composition? A changing ecosystem across age, environment, diet, and diseases. *Microorganisms*, *7*(1), 14. DOI: 10.3390 /microorganisms7010014

Samlafo, V. B. (2017). Comparative analysis of leachable heavy metals in earthenware clay deposit in the Central and Volta Regions of Ghana. *American Journal of Chemistry*, *7*(4), 145-151. DOI:10.5923/j.chemistry.20170704.03

Schweta, A., Gulsheen, K., Sanjay, C., & Preeti, D. (2014). Eating everything except food (PICA): A rare case report and review. *Journal of international society of preventive and Community Dentistry (JISPCD), 4*(1), 1-4. DOI:10.4103/2231-0762.127851

Sing, D., & Sing, C. F. (2010). Impact of direct soil exposures from airborne dust and geophagy on human health. *International Journal of Environmental Research and public Health, 7*(3), 1205-1223· DOI: 10.3390/ijerph7031205

Sungura, A., Soylakb, M., & Ozcana, H. (2014). Investigation of heavy metal mobility and availability by the BCR sequential extraction procedure: Relationship between soil properties and heavy metals availability. *Chemical Speciation and Bioavailability*,*26*(4). DOI: 10.3184/095422914X14147781158674

Udoka, U. P., Nwankwor, G. I., Ahiarakwem, C. A., Opara, A. I., Emberga, T. T., & Inyang, G. E. (2016). Morphometric Analysis of sub-watersheds in Oguta and environs,

South-eastern Nigeria using GIS and remote sensing data. *Journal of Geosciences And Geomatics*, *4*(2), 21-28. DOI: 10.12691/jgg-4-2-1.

Wanjugi, P., & Harwood, V. J. (2013). The influence of predation and competition on the survival of commensal and pathogenic fecal bacteria in aquatic habitats. *Environ mental Microbiolology*, *15*(2), 517-526. DOI:10.1111/j.1462-2920.2012. 02877.x

Waswa, J., & Imungi, J. K. (2014). Prevalence and predictors of geophagy among adolescent girls in Likuyani District of Kakamega County. *Jounal of Food and Nutritional Disorder*, *3*(4). DOI:10.4172/2324-9323.10 00148

Williams, L. B., & Haydel, S. E. (2010). Evaluation of the medicinal use of clay minerals as antibacterial agents. *International Geology Review*, *52*(7/8), 745–770. DOI:10.1080/ 00206811003679737

Young, S. L., Sherman, P. W., Lucks, J. B., & Pelto, G. H. (2011). Why on earth? Evaluating hypotheses about the physiological functions of human geophagy. *The Quarterly Review of Biology*, *86*(2), 97-120. DOI: 10.1086/659884