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DETERMINATION OF THE PHYSICOCHEMICAL PROPERTIES AND RADIATION HEALTH HAZARD INDICES OF 'NZU CLAY' OBTAINED FROM AZONOGOGO, DELTA STATE AND UZELLA RIVER IN EDO STATE, NIGERIA

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ABSTRACT
The studies investigate the physicochemical properties and concentration of radioactive elements present in the geophagious 'Nzu clay' samples obtained from Azonogogo, Delta State and Uzella River, Owan West LGA, Edo State. The mineral composition of the clay samples were investigated using XRD while the radioactive elements were determined by using Hiper Pure Gammanium detector with Resolution (FWHM): 2.3 Kev, ^{60}Co at 1.33Mev. The result of the physicochemical properties shows that water absorption and swelling power of processed/finished 'Nzu clay' obtained from Uzella River have the highest values of 2.230±0.000 and 2.070±0.000 respectively. The pH of the raw and processed/finished 'Nzu clay' is 5.150±0.494 and 4.500±0.141 respectively, showing increased acidity in the clay. The levels of radioactive elements in 'Nzu Clay' indicated that the average specific activities of ^{40}K, ^{238}U and ^{232}Th ranged from 54.45±32.45 to 127.60±14.7, 21.35±6.28 to 38.75±4.67 and 26.83±13.94 to 44.51±1.16 respectively. The mean absorbed dose rate and annual Gonadal Equivalent Dose (AGED) of the 'Nzu Clay' was calculated to be 48.86 nGy/h and 207.1Sv/y, respectively. The XRD analysis reveals that the 'Nzu clay' is dominantly composed of the mineral Kaolinite and Quartz. The presence of these radioactive elements, though not beyond the permissible limits put the habitual consumer at health risk on the long run.

Keywords: Geophagious, radioactive, absorbed dose, Hiper Pure Gammanium detector, habitual consumer

INTRODUCTION

The practice of eating clay for gastrointestinal ailments and applying clay for the treatment of skin infections is as old as mankind and one that continues today among traditional ethnic groups as well as numerous animal species (Caraterro, 2002). 'Nzu clay' is a geophagical material available in variety of forms including powder, moulded shapes and blocks. Though the clay is native to Africa, it is available in the UK in ethnic stores and markets. The consumption of 'Nzu clay' cuts across sex and age, among women, especially during pregnancy (Callahan, 2003). The clay is consumed by oral route, and the most severe risk of eating clay is total blockage of the lower intestine, which can only be remedied by surgery (Padilla and de la Torre, 2006).

'Nzu clay' is used for medicinal and cosmetic purposes during pregnancy, as a famine food, as a food additive or condiment and for religious or ceremonial purposes. It has been reported that the consumers of the clay are exposed to radioactive elements that are natural in soil which are known to cause cancer in humans including genetic defects in the children of exposed parents or mental retardation in the children of mothers exposed during pregnancy, and other adverse health effects (EPA, 2007; Abrahams *et al.,* 2012). Analysis of 'Nzu clay' by energy dispersive X-ray fluorescence spectroscopy (EDXRF) showed the presence of 22 elements including lead and aluminium, as well as persistent organic pollutants (Dean *et al*., 2004) and the presence of arsenic using atomic absorption spectroscopy (Campbell and Belfast, 2002). Various radiation health hazard indices analysis is been used in radiation studies to arrive at a reliable conclusion on the health status of a radiated or irradiated person and the environment (Avwiri *et al.,* 2013; Agbalagba and Onoja, 2011; Zarie and Al-Mugren, 2010). This work reports the physicochemical properties of 'Nzu clay' and the radioactive elements in samples of the clay obtained from hills in Azonogogo, Delta State and the riverside of River Uzella in Edo State, Nigeria. Due to the crave for 'Nzu clay' consumption, research should be intensified on the level of toxicity of the clay from different sources.

MATERIALS AND METHOD

Sample Collection

Raw 'Nzu clay' was collected from each of the two 'Nzu clay' hills in Azonogogo village in Ika South Local Government Area, Delta State Nigeria, using randomized sampling technique. A portion of the each raw clay obtained was processed to finished 'Nzu clay'. Also, sample of already processed 'Nzu clay' sourced from the riverside of Uzella river, in Owan west LGA of Edo State was collected (n =10 for each sample type). The samples are coded as: R1(HS)- raw clay from hill 1 of Azonogogo, F1(HS)- finished/processed clay from hill 1 of Azonogogo, R2(HS)- raw clay from hill 2 of Azonogogo, F2(HS)- finished/processed clay from hill 2 of Azonogogo, and FC(WS)- finished/processed clay from riverside of Uzella river.

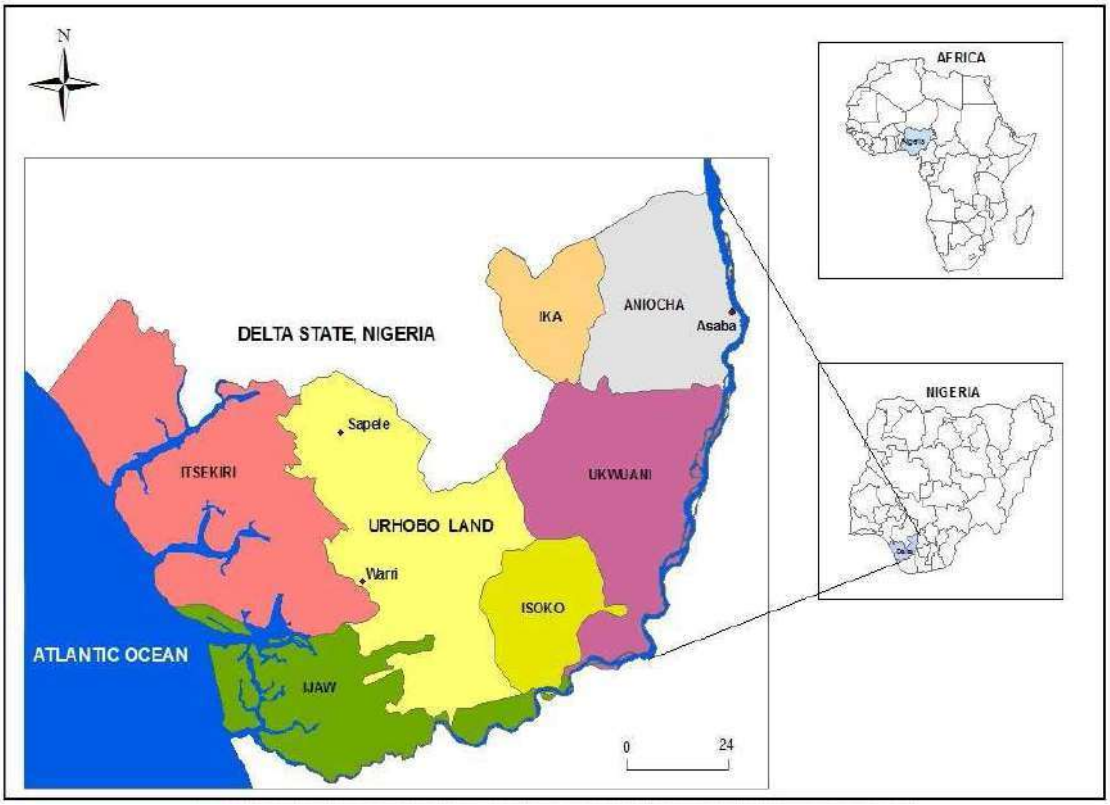

Figure 1: Map of Delta State showing Ika Local Government Area

Figure 2: 'Nzu clay' samples sourced from hill and riverside [R1(HS)- Raw clay from hill of site 1 (ash-white), R2(HS)- Raw clay from hill of site 2 (reddish-ash), FC(WS)- Processed/finished 'Nzu clay' from Uzella riverside]

Figure 3: Raw 'Nzu Clay' hill in Azonogogo village, Ika South LGA Delta State

Sample Preparation

All glassware and plastic used for collection and preparations were cleaned by soaking in 10% nitric acid (HNO_3) for 12 h and then rinsed several times with distilled water. The 'Nzu clay' samples were then oven-dried at 40°C for 48 h prior to disaggregation using a porcelain mortar and pestle after which it was sieved through 2000 µm aperture nylon mesh.

Determination of Physical properties

Determination of Swelling Power of the Clays

Swelling power was determined by the method described by Takash and Sieb (1988) and that of Hirsch and Kokini (2002). It involves weighing 1.00g of each clay sample from each of the hills and the processed clay from the river side into different 10.00 cm^3 centrifuge tube. Then 5.00cm^3 of Hanks solution was added to each set-up and mixed gently with a glass stirrer, the slurry was then heated in a water bath at a temperature of 100°C for 15 min. During heating, the slurry was continuously stirred gently using a glass stirrer in order to prevent clumping of the clay. After 15 min, the tube containing the paste was centrifuged at 3000 rpm for 10 min, and then the supernatant was decanted immediately following the centrifugation. The weight (gcm^{-3}) of the clay was then taken and recorded.

$$Swelling\ power = \frac{weight\ of\ wet\ mass\ of\ the\ clay}{Weight\ of\ the\ dry\ clay}$$

Determination of Dispersibility of the Clays

Dispersibility of the clay was determined by using the method described by Kulkarni *et al.*(1991). Five grammes of each of the clay samples (R1(HS), F1(HS), R2(HS), F2(HS), and FC(WS) was weighed into separate 100.00 cm^3 measuring cylinder, Hanks solution was then added to each 100.00 cm^3 cylinder to the mark. The set up was stirred vigorously using a glass stirrer and allowed to stand for 3 h. The volume of the settled particles in each set up was recorded and then subtracted from 100. The differences are reported as percentage dispersibility.

$$\%\ Dispersibility = 100 - volume\ of\ settled\ particle$$

Determination of Bulk Density of the Clays

The bulk density was determined by the method of AOAC, (1990). A 5.00 g amount of each of the clay samples was weighed into separate 50.00 cm^3 graduated measuring cylinder. The samples were packed by gently tapping the cylinder on the bench top 10 times from a height of 5.00 cm. The volume of each of the samples was then recorded.

$$Bulk\ density\ (g/ml) = \frac{weight\ of\ the\ sample}{volume\ of\ the\ sample\ after\ tapping}$$

Determination of Water Absorption Index of the Clay

Water absorption index was determined by using the method described by Solusulski (1962); Hirsch and KoKini (2002). Crucibles and centrifuge tubes were dried in an oven at 105°C for 20 min and then allowed to cool in a desiccator. After cooling the crucible, the centrifuge tubes were weighed and 1.00 g each of the clay samples was weighed into each of the tubes. Exactly 10.00 cm^3 of Hank's solution was added and then stirred gently with a stirring rod for 30 min. Each of the tube containing a clay type was centrifuged at 4000 rpm for 15 min. On completion of the 15min, the supernatant was decanted and discarded. The residue remaining in each of the tubes was weighed and recorded. Water absorption index was calculated as:

$$Water\ absorption\ index = \frac{weight\ of\ tube\ +\ residue\ after\ centrifuge - weight\ of\ empty\ tube}{Weight\ of\ sample} \times 100$$

Determination of pH of the Clays

An aliquot dispersion of 1.0 g of each of the clay sample was poured into a 10 cm^3 beaker and shaken in water for 5 min, the pH of the mixture was determined using a glass electrode coupled pH meter.

All the parameters were determined in triplicates and the mean and standard deviations recorded.

Determination of the Cation Exchange Capacity (CEC) of the Clay by the $BaCl_2$ Compulsive Exchange Method

The $BaCl_2$ compulsive exchange method was used to determine the CEC at the pH and ionic strength of the clay samples. The clay sample was slowly leached with 20 cm^3 0.1M $BaCl_2.2H_2O$ and 60 cm^3 of 2 mM $BaCl_2.2H_2O$ in 10 cm^3 portions at a time, allowing each addition to soak into the clay. The last 10 cm^3 of leachate was saved separately for pH determination. After leaching, the filter paper and the clay were carefully transferred to a pre-weighed 125 cm^3 flask and 10.0 cm^3 of 5mM $MgSO_4$ added. Occasional shaking of the volumetric flask was done for about 1 hr.

Conductivity of the 1.5 mM $MgSO_4$ solution was measured as approximately 300 µS or µmhos. Then an additional 0.100 cm^3 of 0.1 M $MgSO_4$ was poured whenever the conductivity of the sample solution was not 1.5 times this value (~300 µS); this was ceased when it was this value. The amount of 0.1M $MgSO_4$ added was then noted. After which the pH of the solution was determined.

A 0.05M H_2SO_4 solution was added drop-wisely to the solution if it was not within 0.1 units of the previously measured value of the last 10 cm^3 of sample leachate until the pH was within the appropriate range. Distilled water was added with mixing until the solution had conductivity that was that of the 1.5mM $MgSO_4$. The solution pH and conductivity was adjusted alternately until the end points were reached, then the outside of the flask was wiped, dried and then weighed for a final solution weight (W_f).

Measurement of the Radioactive elements in the Clay Samples

The concentrations of radioactive elements in the 'Nzu clay' samples were measured using Hiper Pure Gammanium detector with Resolution (FWHM): 2.3 Kev, ^{60}Co at 1.33Mev. P-type, model GC8023, Canberra. The determination was done in May 2014 at the Goechemistry Department of Obafemi Awolowo University, Ile-Ife, Nigeria. From the results obtained, the following radioactive hazard indices were measured: Absorbed dose rate, Radium equivalent activity (Ra_{eq}), Annual Gonadal Equivalent Dose (AGED), Representative gamma index (Iyr), External hazard index (Hex) and Internal hazard index (Hin).

X-ray Diffraction Analysis of the 'Nzu Clay' Samples

X-ray diffraction analysis of the clay samples was carried out at the Geological Survey Agency, Kaduna, Nigeria. The 'Nzu clay' samples were finely ground to pass through a 63 microns sieve. The powdered sample was then prepared using the sample preparation block and compressed in the flat sample holder to create a flat, smooth surface that was later mounted on the sample stage in the XRD cabinet. The sample was analyzed using the reflection-transmission spinner stage using the theta-theta settings on CuKα in the 2θ region,

glancing angle 15º - 75º with a two-theta step of 0.026 at 3.57 seconds per step. Tube current was 40 mA and the tension was 45 VA. Fixed divergent slit size of 1º was used and the goniometer radius was 240 mm. The intensity of diffracted X-rays was continuously recorded as the detector rotated through their respective angles. Peak intensity occurs when the mineral contains lattice planes with d-spacing appropriate to diffract X-ray at that value of 0 (Theo, (2002); Maslen *et al*., (2004).

Statistical Analysis

One-way ANOVA was employed in comparing the level of radioactive elements in the 'Nzu clay' by sites (HPGe values) at $P < 0.05$ using Duncan Multiple range test. Results are presented as mean ± standard deviation. Least Significant Difference (LSD) was used to determine which mean differs.

RESULTS AND DISCUSSION

The highest bulk density (g/cm^3) for the raw (R) and finished clay (F) samples was 0.72 ± 0.212 and 0.915 ± 0.120 respectively, showing that processing of the raw 'Nzu clay' resulted to increase in bulk density (Table 1). The finished clay sourced from riverside had the lowest value of bulk density (0.570±0.014). However, the highest dispersibility (%) value for the raw clay (R) and the finished (F) was 80.00 ± 1.414 and 77.250 ± 0.353 respectively, indicating decrease in dispersibility with processing of the clay (Table 1). For the water absorption index and swelling power of the clay, FC(WS) had the highest with values 2.230 and 2.070 respectively. The highest pH of the raw (R) and finished (F) 'Nzu clay' was 5.250±0.494 and 4.500±0.141 respectively, showing increased acidity with the processing of the clay.

From Table 1 the cation exchange capacity (CEC) of the raw and finished clay ranged from 9.725 ± 0.035 to 10.80 ± 0.424 meq/100g. Processing of the clay has no significant effect on the CEC ($P < 0.05$). As shown in Table 2, CEC of the clay samples is unaffected by the processing temperature, as the correlation coefficient r was 0.988 to 1.000. The standard CEC value for most edible clay minerals is 5 meq/100 g (James, 2001). The mean CEC value of 'Nzu Clay' in this study exceeds 5 meq/100g, this is an index of its high adsorptive capacity for cation and ability to enrich the host with cation when consumed.

Table 1: Physicochemical Parameters of Raw and Finished Clay Samples

Properties	Raw Samples		Finished Samples		
	R1(HS)	R2(HS)	F1(HS)	F2(HS)	FC(WS)
CEC (meq/100g)	10.800±0.424	10.200±0.989	10.250±1.202	9.870±0.671	9.725±0.035
Bulk density(g/cm^3)	0.725±0.212	0.710±0.000	0.915±0.120	0.880±0.169	0.570±0.014
Dispersibility (%)	80.00±1.414	80.00±0.000	77.250±0.353	74.750±3.880	76.500±0.707
Water absorption index	1.930±0.056	1.745±0.777	1.775±0.106	1.780±0.282	2.230±0.000
Swelling Power	1.680±0.028	1.685±0.049	1.555±0.636	1.590±0.424	2.070±0.000
pH	5.150±0.494	5.250±0.494	4.500±0.141	4.500±1.141	4.500±0.000

Table 2: Correlation of Physiochemical Properties of the Clay Samples

	R1(HS)	R2(HS)	F1(HS)	F2(HS)	FC(WS)
R1(HS)	1.000[a]	1.000[a]	1.000[a]	0.988[a]	1.000[a]
R2(HS)		1.000[b]	1.000[b]	0.999[b]	1.000[b]
F1(HS)			1.000[c]	0.999[c]	1.000[c]
F2(HS)				1.000[d]	0.999[e]
FC(WS)					1.000[f]

a: cation exchange capacity; b: bulk density; c: dispersibility; d: water absorption capacity; e: swelling power; f: pH

Table 3 Concentration (Bq/kg) of Radioactive Elements in the 'Nzu Clay' Samples

Samples	K-40	U-238	Th-232
R1(HS)	92.28±30.91	21.35±6.28	26.83±13.94
R2(HS)	54.45±32.45	29.08±18.22	30.84±22.2
F1(HS)	127.60±14.7	34.45±4.45	44.51±1.16
F2(HS)	125.90±2.77	26.72±13.31	28.38±14.53
FC(WS)	108.14±7.97	38.75±4.67	36.24±2.13
World mean and range	400(140- 850)	35(17-60)	30(11- 64)

(UNSCEAR, 2000)

[R1(HS)- raw clay from hill 1 of Azonogogo, F1(HS)- finished/processed clay from hill 1 of Azonogogo, R2(HS)- raw clay from hill 2 of Azonogogo, F2(HS)- finished/processed clay from hill 2 of Azonogogo, FC(WS)- finished/processed clay from riverside of Uzella river]

Table 4: Health Risk Hazard of Radioactive Elements in 'Nzu Clay' Samples

	Absorbed dose rate (nGy/h)	Radium equivalent activity(Raeq)	Annual Gonadal equivalent dose(AGED)	External hazard index(Hex)	Internal hazard index(Hin)	Representative Gamma index (1yr)
R1(HS)	30.36	66.83Bq/kg	207.1Sv/y	0.18eq	0.24eq	0.47
R2(HS)	34.84	77.37Bq/kg	234.64Sv/y	0.21eq	0.29eq	0.54
F1(HS)	48.86	107.9Bq/kg	330.79Sv/y	0.29eq	0.39eq	0.76
F2(HS)	35.17	76.99Bq/kg	239.58Sv/y	0.21eq	0.28eq	0.54
FC(WS)	44.88	98.89Bq/kg	303.68Sv/y	0.22eq	0.33eq	0.59
World mean (UNSCEAR, 2000)	60nGy/h	370Bq/kg	1.00mSv/y	1.00eq	1.00eq	1.00yr

R1(HS)- raw clay from hill 1 of Azonogogo, F1(HS)- finished/processed clay from hill 1 of Azonogogo, R2(HS)- raw clay from hill 2 of Azonogogo, F2(HS)- finished/processed clay from hill 2 of Azonogogo, FC(WS)- finished/processed clay from riverside of Uzella river

The activity concentration of ^{40}K ranged from 54.45 ± 32.45 to 127.60 ± 14.7 Bq/kg with R2(HS) having the lowest activity concentration and F1(HS) having the highest activity concentration of ^{40}K (127.60 ± 14.7 Bq/kg). The reported values are below the permissible limit of ^{40}K which is mean and range 400 and (140 – 850) Bq/kg respectively recommended by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000). However, it is of note that processing of the 'Nzu clay' causes significant increase in the activity concentration of ^{40}K (Duncan multiple range test at $P < 0.05$).

Activity concentration of ^{238}U in 'Nzu clay' studied ranged from 21.35 ± 6.28 to 38.75 ± 4.67 Bq/kg, with R1(HS) having the lowest activity concentration while FC(WS) had the highest activity concentration of 38.75 ± 4.67 Bq/kg. All the values of ^{238}U are within the allowable limit for ^{238}U in standard soil, mean 35 and range 17- 60 Bq/kg, according to UNSCEAR (2000).

The study indicated that the activity concentration of ^{232}Th in 'Nzu clay' ranged from 26.83 ± 13.94 to 44.51 ± 1.16 Bq/kg, with R1(HS) having the lowest concentration of ^{232}Th (26.83±13.94 Bq/kg), while F1(HS) contained the highest concentration of ^{232}Th (44.51±1.16 Bq/kg). This indicates that processing temperature increased the activity concentration of ^{232}Th; except for F2(HS) in which the raw clay counterpart had 28.38 ± 14.53 Bq/kg ^{232}Th compared to 30.84 ± 22.2 Bq/kg in F2(HS). Though, the justification for this increase could not be explained yet. The activity concentration of ^{232}Th in all the 'Nzu clay' samples are within the allowable world mean of 30 Bq/kg and range 11- 64 Bq/kg according to UNSCEAR (2000). Though there is dearth information on the composition of radioactive elements in edible clay. This study compares well with the work carried out by Agbalagba *et al.* (2011) on the analysis of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil samples collected from oil and gas field environment of Delta State. The activity concentration reported by Agbalagba *et al.* (2011) ranged from 19.2 ± 5.6 $Bqkg^{-1}$ to 94.2 ± 7.7 $Bqkg^{-1}$ with mean value of 41.0 ± 5.0 $Bqkg^{-1}$ for ^{226}Ra, 17.1 ± 3.0 $Bqkg^{-1}$ to 47.5 ± 5.3 $Bqkg^{-1}$ with mean value of 29.7 ± 4 $Bqkg^{-1}$ for ^{232}Th, and 107.0 ± 10.2 $Bqkg^{-1}$ to 712.4 ± 38.9 $Bqkg^{-1}$ with a mean value of 412.5 ± 20.0 $Bqkg^{-1}$ for ^{40}K. The values obtained are in good agreement with the world range values reported in other countries.

The mean absorbed dose rate by the 'Nzu Clay' was calculated to be 48.86 nGy/h. This is within the world average which is 60 nGy/h according to UNSCEAR (2000). The mean value of the Annual Gonadal Equivalent Dose (AGED) in the 'Nzu Clay' was 207.1 Sv/y, which is relatively high and could pose risk to the activity of the bone marrow and the bone surface cells (Table 4). The values of the radium equivalent activity index, representative Gamma Index (Iyr), external hazard index (Hex) and internal hazard index (Hin) of the 'Nzu clay' samples were less than unity, indicating that there is a negligible health hazard in consuming 'Nzu Clay'.

Table 5: Mineral Compositions of the 'Nzu Clay' Samples

Sample	Mineral name	Compound name	Chemical formula	Crystal system
R1(HS)	Kaolinite	Aluminium silicate hydroxide	$Al_2Si_2O_5(OH)_4$	Monoclinic
F1(HS)	Quartz /Kaolinite	Silicon Oxide/ Aluminium silicate hydroxide	SiO_2 / $Al_2Si_2O_5(OH)_4$	Hexagonal/Monoclinic
R2(HS)	Kaolinite	Aluminium silicate hydroxide	$Al_2Si_2O_5(OH)_4$	Monoclinic
F2(HS)	Quartz/Kaolinite	Silicon Oxide/ Aluminium silicate hydroxide	SiO_2 / $Al_2Si_2O_5(OH)_4$	Hexagonal/Monoclinic
FC(WS)	Quartz /Kaolinite	Silicon Oxide/ Aluminium silicate hydroxide	SiO_2 / $Al_2Si_2O_5(OH)_4$	Hexagonal/Anorthic

R1(HS)- raw clay from hill 1 of Azonogogo, F1(HS)- finished/processed clay from hill 1 of Azonogogo, R2(HS)- raw clay from hill 2 of Azonogogo, F2(HS)- finished/processed clay from hill 2 of Azonogogo, FC(WS)- finished/processed clay from riverside of Uzella river

Mineral Composition of the Clay Samples

Table 5 and Figure 4a-d present the mineral composition of the 'Nzu clay' samples. The characterization of the clay by X-ray diffraction patterns as provided by the XRD result showed peaks that indicate the presence of pure kaolinite (aluminium silicate hydroxide) with the chemical formula $Al_2Si_2O_5(OH)_4$ in the raw 'Nzu clay' in R1(HS) and R2(HS), having monoclinic crystal system (Eigbike *et al.,*2013). Kaolin minerals have long been used in pharmaceutical formulations to treat both the causes and the symptoms of gastrointestinal distress. The beneficial role of the kaolin minerals inherent in 'Nzu clay' accounts for its ability to coat and adhere to the gastric and intestinal mucus membrane, thus protecting the body against toxins, bacteria, viruses, and adsorbing excess water in faeces (Eigbike *et al.,*2013).

The processed 'Nzu clay' samples obtained from the hill (F1(HS) and F2(HS)) are dominantly composed of the mineral quartz with chemical formula SiO_2 having hexagonal crystal system.

X-ray diffraction of 'Nzu Clay' sample on CuKα in the 2θ region, glancing angle 15º – 75º Stick Pattern

Mineral name: Kaolinite; Compound name: Aluminium Silicate Hydrate; Crystal system: Monoclinic

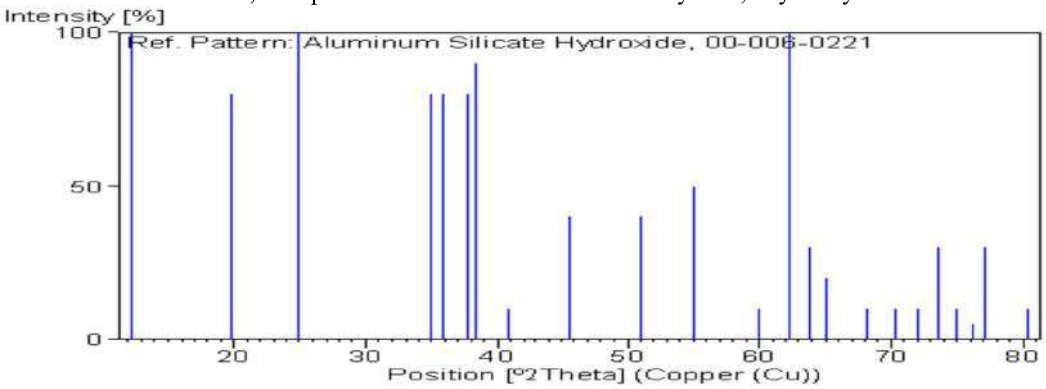

Figure 4a: XRD diffractogram for 'Nzu clay' from Site1 R1

Mineral name: Quartz; Compound name: Silicon Oxide; Crystal system: Hexagonal

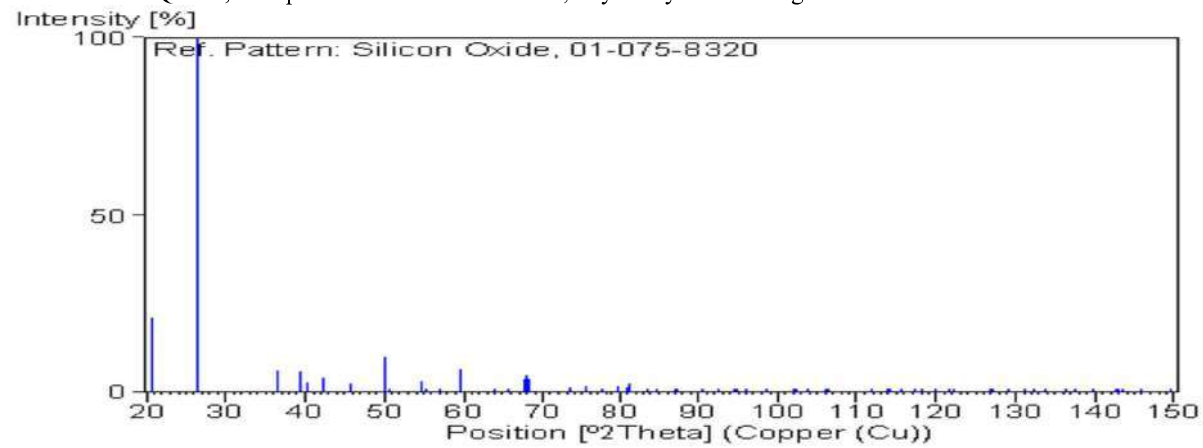

Figure 4b: XRD diffractogram for 'Nzu clay' from Site 2 F1

Mineral name: Kaolinite; Compound name: Aluminium Silicate Hydrate; Cystal system: monoclinc

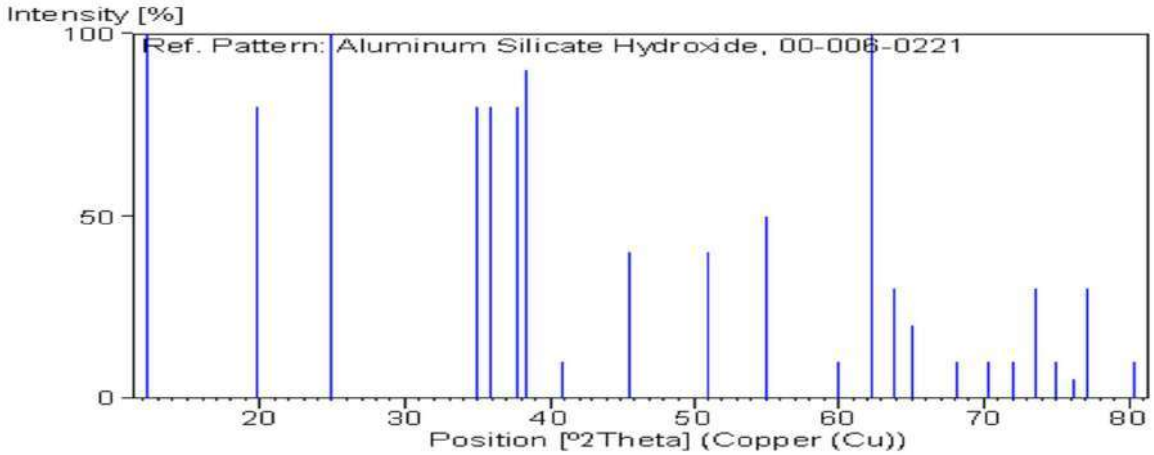

Figure 4c: XRD diffractogram for 'Nzu clay' from Site2 R1

Mineral name: Kaolinite; Compound name: Aluminium Silicate Hydrate; Crystal system: Anorthic

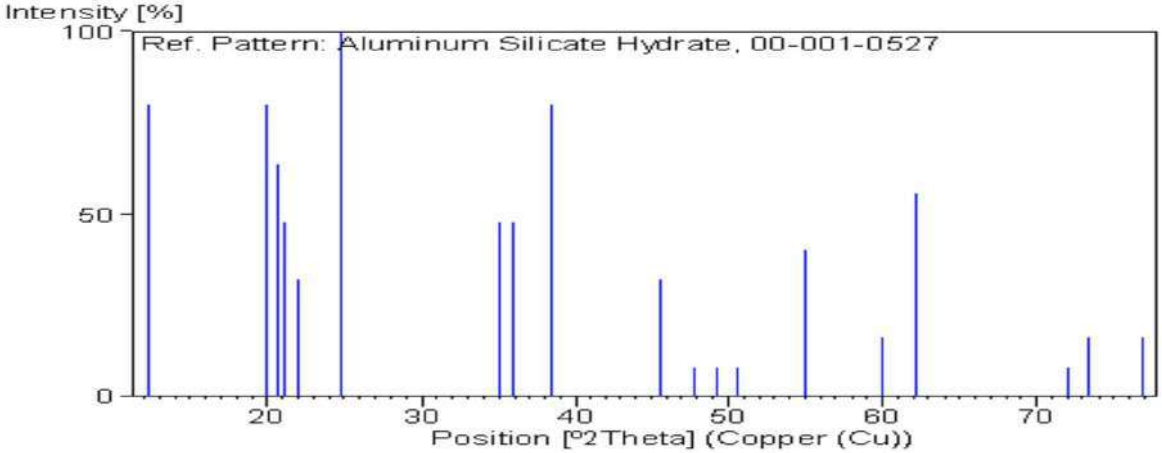

Figure 4d: XRD diffractogram for 'Nzu clay' from Site 3 FC

The mineral, quartz having hexagonal crystal system is also dominant in the processed/finished 'Nzu clay' FC(WS) obtained from the river side of Uzella river. The mineral (kaolinite) that is also present in FC(WS) has crystal system (anorthic) that is different from the crystal system in kaolinite contained in the 'Nzu clay' from the hill side of Azonogogo (Table 5). This difference could be attributed to the difference in their source.

CONCLUSION

The study indicated that the 'Nzu clay' samples were slightly acidity, making the inherent sour taste to appeal to the consumers of the clay. The clay has good dispersibility. The high swelling power and water absorption index of the clay may account for good ability for absorption of water from the gastrointestinal tract. The cation exchange capacity of the clay was high, so the clay has capacity to exchange its cation with the minerals in the body. Most of the clay samples obtained from the three sites were predominantly a mixture of the mineral kaolinite and quartz (SiO_2 and $Al_2Si_2O_5(OH)_4$). The presence of the minerals kaolinite and quartz may account for the reason why 'Nzu clay' have a unique flavour and taste which appeals more to consumers than the other clays with minerals such as halloysite, illite, mica, and feldspar that are not ingested by man. However, long-term exposure to kaolin and quartz may lead to a relatively benign pneumoconiosis, known as kaolinosis, silicosis and lung cancer.

The radioactive elements ^{40}K, ^{238}U and ^{232}Th in the 'Nzu clay' studied are within the world mean range by UNSCEAR (2000). The calculated mean value of health hazard indexes; absorbed dose rate, Annual Gonadal Equivalent Dose (AGED), radium equivalent activity index, representative Gamma Index (Iyr), external hazard index (Hex) and internal hazard index (Hin) are all within the world mean range; however, continuous consumption of the clay over years could portray a

different scenario about the stated hazard indices in addicts of the clay. This study shows that consumption of 'Nzu clay' should be continually banned as the presumed benefits not withstanding is outweighed by the health hazard that could occur in people who ingest the clay habitually.

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