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Mineral composition and heavy metal risk assesment of selected geophagic soils from Tanzania

Consolata E. Rukondo [a,*], Clarence A. Mgina [b], Harishchandra B. Pratap [c]

[a] Department of Biochemistry, Muhimbili University of Health and Allied Sciences, P.O. Box 65001, Dar es salaam, Tanzania
[b] Department of Chemistry, College of Natural and Applied Sciences, University of Dar es Salaam, P.O. Box 35064, Dar es Salaam, Tanzania
[c] Department of Zoology and Wildlife Conservation, College of Natural and Applied Sciences, University of Dar es Salaam, P.O. Box 35064, Dar es Salaam, Tanzania

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ABSTRACT

Geophagy or Pica is the unintentional traditional behavior of eating soil by indigenous people in different countries. practiced in many countries due to nausea among pregnant women and mineral deficiencies without knowing the associated health risks. In this study the mineral composition of geophagic soil and its associated health risk among consumers was determined. Dry soil sticks consumed by women were obtained from open markets in Morogoro, Njombe and Mwanza regions in Tanzania. The elemental concentration of geophagic soil was analyzed using Flame Atomic Absorption spectrophotometer. Health risk assessment methods were used to obtain health information after chronic exposure to geophagic soils. The tests used were Target Hazard Quotients (THQ), Total Target Hazard Quotients (TTHQ) and Cancer Risks (CR). The concentration range of metals in samples obtained from three different regions were 16,335.7–47,773.7 mg/kg for Fe, 46.2–1073.5 mg/kg for Ca, 155.3–514.9 mg/kg for K, 44.5–112.4 mg/kg for Zn, 40.7–95.1 mg/kg for Na, 2.4–66.7 mg/kg for Cu, 109.5–572.6 mg/kg for Mn, 3.8–6.85 mg/kg for Pb, 3.1–93 mg/kg for Ni, 62.7–638.6 mg/kg for Cr and 0.4 mg/kg for Cd. The Provisional Daily Intake (PDI), THQ, TTHQ and CR ranged between 3.0×10^{-3} –34.12 mg/kg/day bw, 0.043–48.75, 34.52–77.36 and 2.55×10^{-5}- 0.23 respectively. The TTHQ>1 was evident for metals in all sampling sites which is indicative of non-carcinogenic health effects. Prolonged exposure to Pb at low concentrations in samples from all the sites can cause pathological effects. The cancer risk values for Pb, Ni, Cr and Cd were <1 in which the consumer is likely not to develop cancer in a life time. Essential minerals – Fe, Ca, Zn, Na, K and toxic metals Pb, Cr, Ni and Cu were detected in all the samples. Cd occurred only in samples from Mwanza region that was below the tolerable daily intake. According to WHO/FAO expert's joint committee any amount of Pb consumption is not permitted. Given the presence of essential minerals in the geophagic soils which are however accompanied by toxic minerals in some cases which might have carcinogenic effects, prolonged consumption should be discouraged to avoid risks of serious adverse effects to the health of the general population.

1. Introduction

Pica is the practice of eating non-nutrient substances, the habit has been practiced in various parts of the world [43]. Geophagy is one among of the many forms of Pica which is the practice of consuming clay or soil. The history of geophagy has been traced back to 460–377 BC when the habit was compiled in the medical textbooks by the Romans and Greeks. The habit continued to exist in the middle-ages 23–79 AD where geophagy was first associated with anemia. Between 16th and 17th centuries, geophagy was still practiced, however at this time it was mentioned to cause chlorosis. In parts of Europe, geophagy was reported between 18th and 19th century where this habit was again associated with chlorosis in young children [51]. Geophagy has been practiced in Africa and Asia where it has played different roles in medicine, spiritual, religious rituals, psychological, nutritional and in cosmetics [13,19,51]. In Africa, geophagy has been reported in many countries including Nigeria, Sierra-Leone (Hunter 1993), Zambia [46],Tanzania [53], Ghana [38] South Africa [19,32], Chad [27] and others. Geophagic soils have been consumed in Tanzania and areas near Kalambo falls at the border between Tanzania and Zambia [31]. The soil is commonly known as "komo" in Zanzibar Island, "madongo" and "pemba" in Tanzania mainland. The soil might contain both, toxic as well as essential minerals

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* Corresponding author.
E-mail address: rukondoconsolata@gmail.com (C.E. Rukondo).

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[53]. In Tanzania, studies have shown that 50 g of soil was ingested daily by women of a reproductive age above 20 years [39,52]. Likewise, 90 g of clay soil have been reported to be ingested per day by women in Namibia and 70 g by women in Ghana [29]. This means the practice may cause undesirable effects to both, mother and fetus during pregnancy [6]. It has been also reported that the soil affect the weigth of newborn [41]. The effects of toxic metals have been reported to cause damage to the liver and kidneys [16], intestine, vital organs such as heart and may cause cancer [38]. Despite of the soil toxicity, it contributed about 17–55% essential minerals required during pregnancy [18]. Health risk assessment studies helps to explore the potentiality of geophagy to induce health hazards to consumers. In Tanzania, Nyanza et al. [39] and Young et al. [53] reported the presence of toxic heavy metals such as lead, mercury and arsenic in their respective areas of study. Such studies and report have also been done by other researchers including Molale and Eze (2023) [36], Davies [13], Orisakwe [40] and others, hence making the assessment of health hazards of great importance. Therefore, this study focuses on identifying mineral constituents of the geophagic soil collected from different parts in Tanzania (Morogoro, Njombe and Mwanza regions) in 2019 and assessing the associated health risks to the consumers.The analysis was done in 2019–2020 at the University of Dar es Salaam and Ardhi University.

2. Materials and methods

2.1. Sample collection sites

Geophagic soils were purchased from Manzese (Mz) (6°48′S, 39°14′E) and Mawenzi (Mw)(6°49′S, 37°39′E) markets in Morogoro region,the region has a Tropical wet and dry or Savanna climate with yearly average temperature of 24.77 °C and precipitation of about 269.12 mm annually; Njombe (Nj) (9°20′S, 34°46′E) and Mlangali (Ml) (9°45′S, 34°32′E) markets in Njombe region, Njombe region has a Temperate highland and tropical climate with yearly temperature ranging between 19,69°C-26.19 °C and annual precipitation of 123.99 mm: Mkuyuni (Mk) (2°33′S, 32°54′E) and Kirumba (Kr) (2°30′S, 32°53′E) markets in Mwanza region, this region has a tropical climate with average temperature of 23.1°CTanzania (Fig. 1). The geophagic soils are obtained by digging 5 m deep pits to reach the clay soil with desired texture and aroma. This soil is then sun dried for one or two days, homogenized, sieved and molded into sticks shapes for sale at different markets. The geophagic soil sticks collected for analysis from local markets were stored in labeled polyethylene bags. The samples were transferred to the laboratory where they were stored in a dry place at room temperature.

2.2. Sample digestion and analysis

Sample digestion was done at the Chemistry department, University of Dar es Salaam where the geophagic samples were first oven dried at

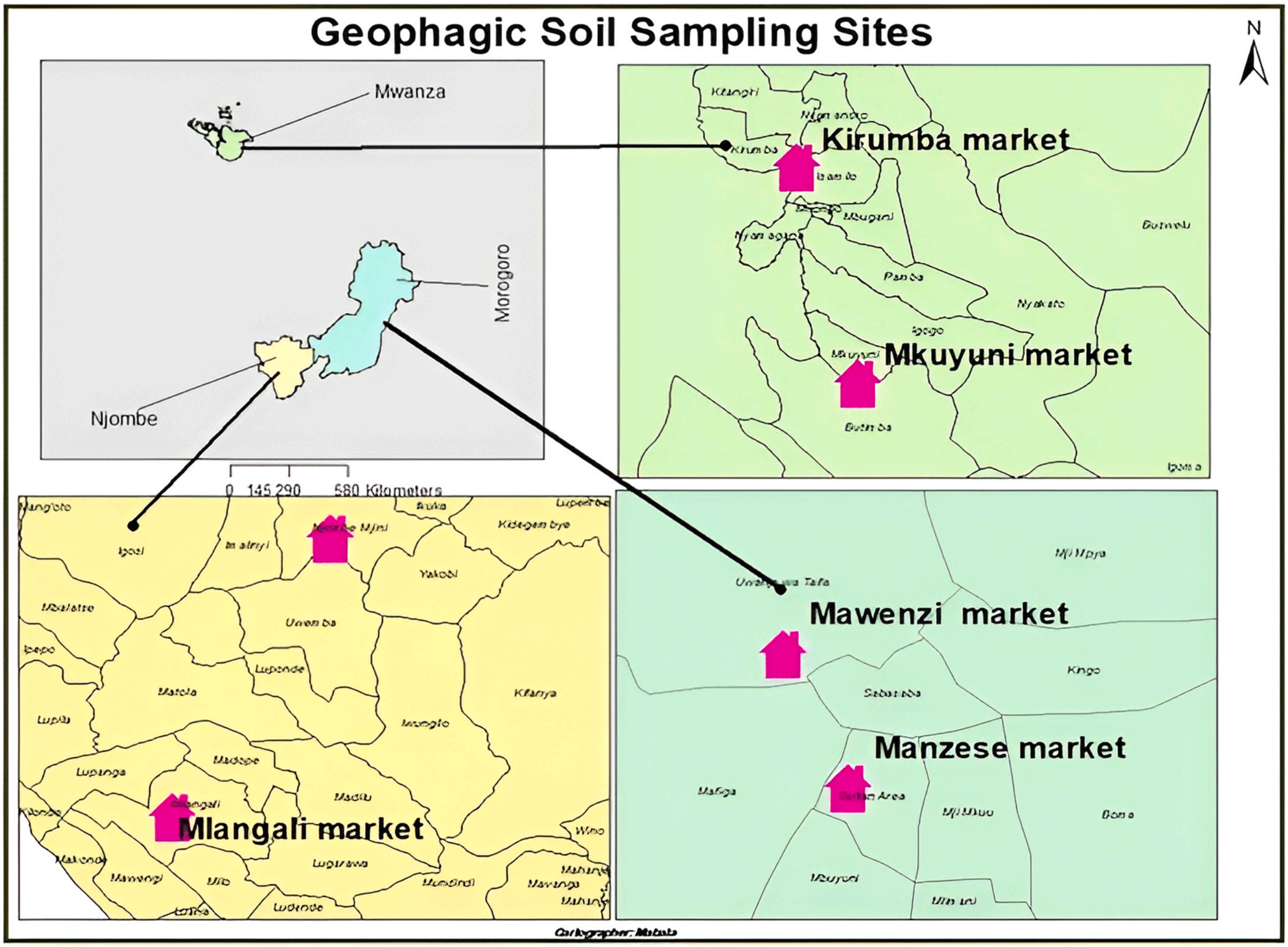

Fig. 1. Geophagic soil sampling sites in different parts of Tanzania".

110 °C for about two hours and cooled in a desiccator for 15 minutes. After cooling the samples were homogenized by using motor and pestle and sieved in a 75 μm sieve to achieve the uniform size. The sample digestion was done using a freshly prepared aqua regia by mixing HNO_3 69% w/v and HCl 37% w/v (Loba Chemie Ltd, India) in a ratio of 1:3 [33,47,48]. 2.5 g of the sieved soil samples were weighed using Mettler analytical balance and transferred to 100 ml beakers followed by 20 ml of freshly prepared aqua regia. The mixture was heated on a hot plate to 100 °C for 1 hour [26] and allowed to cool for 20 min. Thereafter, 10 ml of $HClO_3$ was added in the mixture to enhance reaction and complete digestion. The mixture was heated to 100 °C for 5 minutes and allowed to cool for 20 minutes.

After cooling the samples were filtered into the beakers to obtain a clear solution. Acid insoluble particles left in the conical flask were washed with distilled water. The original filtrate and the washings were transferred to a 50 ml volumetric flask and distilled water was added to the mark. Determination of metal composition was done at the School of Engineering and Environmental Studies, Ardhi University, by using Flame Atomic Absorption Spectrophotometer (AAS, Analyst-100, Perkin Elmer). The AAS standard solutions with high purity for Fe, Zn, Ca, K, Na, Cr, Pb, Cd, Ni, Mn and Cu were obtained from Chem-Lab NV (Germany). The metal concentration of aqua regia blanks were below the detection limit. For analytical quality assurance the Standard Reference Material (SRM), the marine sediment IAEA-356 was used. The percentage recoveries for SRM IAEA-356 were within the accepted range of 96.8–116% as reported by the Department of Environmental Protection approved quality assurance [10].

2.3. *Physical properties of geophagic soils*

For pH and conductivity determination,10 g of the sieved geophagic soil samples were added to 20 ml of distilled water in 50 ml beakers and stirred using a magnetic stirrer for 10 min. The samples were left to stand for 10 minutes and the pH and TDS was measured using a pH and TDS meter. The moisture content of 30 g sieved geophagic soil samples were measured. The weight of crucibles and wet samples were recorded. The samples were oven dried for 24 hours at 105 °C. Moisture content was determined as the difference between moist and dry soil.

2.4. *Health risk assessment*

The potentialities of assessing health effects caused by consuming geophagic soils from the selected markets cannot be attained from the concentrations alone. Health risk assessment tests were used to estimate the probability in which people can be affected after exposure for a certain period of time. Target hazard quotient (THQ), total target hazard quotient (TTHQ) and cancer risk (CR) were determined as proposed by United States Environmental Protection Agency (USEPA 2003) [38,42] and Ain et al. [2]. Provisional maximum tolerable daily (PMTDI) intake per average body weight of adults were calculated to estimate the number of metals ingested daily [29,38].

2.5. *Target hazard quotient (THQ)*

Target hazard quotient was formed by United State Environmental Protection Agency to establish the potential health effects after exposure to toxic substances. To determine the threat to human health stemming from the intake of carcinogenic and non-carcinogenic elements. The U.S. Environmental Protection Agency (USEPA) introduced the target hazard quotient (THQ) and hazard index (HI) Pokorska-Niewiada et al. [42] and Ain et al. [2]. It is the ratio between the estimated daily intakes to the reference dose which when consumed do not accelerate any potential health effect estimated by length, weight, frequency of exposure, body weight (70 kg for an adult) and the amount consumed per day in grams Nkansah et al. [38], and Kortei et al. [29]. THQ was calculated by the following equation

$$THQ = \frac{EFR \times \mathrm{EDtot} \times \mathrm{IngR} \times \mathrm{C}}{\mathrm{RfDo} \times Bw \times \mathrm{ATn}} \times 0.001$$

While; EFr = Exposure frequency, EDtot = Exposure duration, IngR = Soil ingestion rate, C = Heavy metal concentration (mg/kg), RfDo=Reference dose, Bw = Average adult body weight and ATn = Average exposure for non-carcinogens 365 days/year x Number of exposure years (70 years) Kortei et al. [29], Pokorska-Niewiada et al. [42], Ain et al. [2]

2.6. *Total target hazard quotient (TTHQ)*

This is the effect estimated upon exposure to more than one hazardous substance [38,42] and Ain et al. [2]. Total target hazard quotient of geophagic soils collected from selected local markets was obtained by adding target hazard quotient of each hazardous substance. The later was calculated according to Nkansah et al. [38], Chien et al. [11] and Kortei et al. [29], Pokorska-Niewiada et al. [42], de Almeida et al. [14] and Ain et al. [2]. Total hazard quotient value greater than 1 indicates that potential health risk may occur upon exposure and when it is less than 1 indicates no substantial health effects that may arise upon exposure.

$$TTHQ = THQ\ Toxicant1 + THQ\ Toxicant2 \quad + THQ\ Toxicant3$$

2.7. *Cancer risk*

Assessing the probability of consumers developing cancer after exposure to the soil is of great concern. According to International Agency for Research in Cancer (IARC 2012), cadmium, chromium and lead are carcinogenic. Cancer slope factor (CanSF) is an estimated upper bound (95% confidence level) of the probability that a person will develop cancer (Table 1.). In this study cancer slope factors for carcinogenic trace elements was used to calculate cancer risks. Cancer risk was achieved by summing the risks of each carcinogenic metal.

$$\mathrm{CR} = \frac{\mathrm{C} \times \mathrm{IngR} \times \mathrm{EFr} \times \mathrm{EDtot}}{\mathrm{Bw} \times \mathrm{ATn}} \times \mathrm{CanSF}$$

where;CR=Cancer risk, EFr = Exposure frequency, EDtot = Exposure duration, IngR = Soil ingestion rate, C = Heavy metal concentration (mg/kg), Bw = Average adult body weight, CanSF = Cancer slope factor of hazardous substances (mg/kg/day), ATn = Average exposure for non-carcinogens 365 days/year x Number of exposure years (70 years) Kortei et al. [29], (Pokorska-Niewiada et al. [42], de Almeida et al. [14] and Ain et al. [2] Table 2.

2.8. *Provisional daily intake of nutrients from geophagic soils*

Provisional daily intake (PDI), the amount taken with a normal weight of an individual that is considered as safe for human health was

Table 1
Oral reference doses (RfDo) of metals in mg/kg/day and cancer slope factor (CanSF) for toxic heavy metals as derived from literature.

Metal	RfDo (mg/kg/day)	CanSF	Reference
Fe	0.7	-	[38],
Ca	1000	-	Office of dietary supplements (NIH).
K	3500	-	WHO [49]
Zn	0.3	-	[11,38]
Na	1500	-	WHO [49]
Cu	0.04	-	[29]
Mn	0.14	-	[29]
Pb	0.0035	0.0085	JEFCA 2003 and [29]
Ni	0.02	1.2	[29]
Cr	0.003	0.5	[25],
Cd	0.001	0.38	JEFCA 2003, [38]

Table 2
Exposure parameters used for health risk assessment on geophagic soil consumption as per United States Environment Protection Agency (USEPA 2003).

Exposure parameters	Unit	Value
Body weight	Kg	70
Exposure frequency	Days	365
Exposure duration	Years	30
Ingestion rate (IR)	mg/day	100
Average time (AT)	Days/Years	
For carcinogenic		366 × 70
For non-carcinogenic		365 × ED*

* Exposure dluration

calculated [38]. The amount of geophagic soil consumed was 50 g day^{-1} equivalent to 0.05 kg was multiplied by the concentration of metal and divided by the average body weight of an adult individual 70 kg [50]), Ain et al. [2]which gave the daily intake in mg/kg/day/body weight.

$$\mathrm{PDI} = \frac{\text{Concentration of metal in food} \times \text{Food consumption}}{\text{Body weight(kg)}}$$

3. Results

3.1. Physical properties of geophagic soils

Geophagic soil sticks from different regions varied in color from pale golden, light grey and reddish brown. The moisture content of soil ranged from 2.17% to 7.62% as they were dried in the sun for three days before being packed for consumption thus causing low moisture content. The pH of the soil from Morogoro region were more acidic ranging from 5.1 to 5.5 while those from Mwanza and Njombe were less acidic with pH ranging from 6.4 and 6.7 (Table 3).

3.2. Mineral composition of geophagic soils

The concentrations of minerals of soil sticks are given in Table 4. The highest concentration of Fe occurred in Morogoro samples from Mw was 47,773.7 mg/kg followed by Mz with 45,556.9 mg/kg. Iron concentrations among different sites were 47,773.7 > 45,556.9 > 40,368.2> 39,592.2 >16,391.6 > 16.335.7 mg/kg for samples from Mw, Mz, Kr, Mk, Ml and Nj markets respectively. Samples from Mwanza region had the highest calcium levels with 1073.5 and 1051.3 mg/kg from Kr and Mk respectively. The descending order of calcium between the sites was 1073.5>1051.3 >389.3 >351.3>46.2>44.5 mg/kg samples from Kr, Mk, Mw, Mz, Nj and Ml respectively. For potassium, Ml and Nj sites had the highest concentration. The potassium concentrations were 514.9>468.4> 289.1>286.5>188.3>155.3 mg/kg in samples from Ml, Nj, Mk, Kr, Mz and Mw, respectively. The composition of Zn was higher in Mk and Kr samples with 112.4 and 96.2 mg/kg followed by Ml 73.7 mg/kg, Nj 72 mg/kg, Mw 45.6 mg/kg and Mz 44.5 mg/kg. The sodium concentrations were 95.1>90.5>60.3>53.3>46.40>40.7 mg/kg for Kr, Mk, Ml, Nj, Mw and Mz, respectively. Other metals analyzed were Cu, Cr, Ni, Pb, Mn and Cd. The highest concentrations of chromium were 638.6 and 552.7 for Mz and Mw followed by manganese with 572.6 and 500.2 mg/kg for Mk and Kr samples. The concentration of Ni was greater in Mk and Kr samples with 93.0 and 78.8 mg/kg while the concentration of Cu was 66.7 and 58.6 mg/kg in Kr and Mk samples. High amount of Pb ranging from 3.8 to 6.9 mg/kg was detected in samples from all sites. Cd concentrations in samples from Mk and Kr were of 0.4 mg/kg while in other sites it was below the detection limit. The overall order of mineral concentration was Fe > Ca > Cr>Mn>K>Zn>Ni>Na>Cu>Pb>Cd.

Table 3
Physical properties of geophagic soils.

Region	Sampling Site	Color	Weight per stick (g)	Moisture %	pH	TDS µs/cm
Mwanza	Mkuyuni (Mk)	Pale golden	25.79	2.81	6.6	34.9
	Kirumba (Kr)	Pale golden	25.81	2.17	6.7	34.8
Njombe	Njombe (Nj)	Light grey	55.42	6.52	6.5	14.8
	Mlangali (Ml)	Light grey	57.85	7.62	6.4	14.8
Morogoro	Mawenzi (Mw)	Reddish brown	9.38	5.17	5.5	49.1
	Manzese (Mz)	Reddish brown	9.07	3.56	5.1	49.2

TDS = Total dissolved solids

3.3. Provisional daily intake (PDI)

Provisional daily intake of metals from geophagic soils from different sites with the recommended values has been summarized in Table 5. These are concentrations of some essential minerals needed by the body daily to maintain growth of an individual without contributing health effects. When food is ingested above the recommended value it may contribute to health effects. However, health effects are also likely to occur when intake is below the recommended value. For essential elements (Fe, Ca, K, Zn and Na), PDI was compared against the maximum daily dietary reference intake set forth by the World Health Organization (2012), the National Institute of Health and European food safety authority (EFSA 2013) [17]. For potential toxic metals (Pb, Cd, Mn, Ni, Cr and Cu), the PDI was compared against standards established by the Joint FAO/WHO Committee on Food Additives (JECFA) [24], European food safety authority and National institute of health (NIH). JECFA considers each metal’s metabolism by the body and effect on human health.

3.4. Reference doses, slope factors, target hazard quotients, total target hazard quotients and cancer risks

Reference dose (RfD) values for heavy metals which were used to calculate THQ (Target Hazard Quotients) ranged between 0.001 and 0.7 mg/kg/day and slope factors used to calculate cancer risk ranged from 0.0085 to 1.2 mg/kg/day as shown in Table 1. (USEPA 2003). Target Hazard Quotient (THQ) values ranged from 0.27 to 40.40 and Total Target Hazard Quotient (TTHQ) was 72.32% for Mk. THQ ranged from 0.23 to 41.19 and TTHQ of 77.36% for Kr. THQ ranged from 0.043 to 16.67 and TTHQ value of 34.52% for Nj. THQ ranged from 0.091 to 20.42 and TTHQ of 40.47% for Ml. THQ ranged from 0.11 to 48.75 and TTHQ of 65.07% for Mw. THQ ranged from 0.11 to 46.49 and TTHQ of 64.19% for Mz, respectively Table 6. Cancer Slope Factor (CanSF) values for carcinogenic metals such as cadmium, chromium, nickel and lead were 0.38, 0.5, 1.2 and 0.0085 mg/kg/day, respectively. Cancer risk values were 0.064 for Mk, 0.048 for Kr, 0.025 for Nj, 0.033 for Ml, 0.19 for Mw and 0.24 for Mz Table 6.

4. Discussion

4.1. Essential minerals in geophagic soils

4.1.1. Iron

The provisional maximum tolerable daily intake (PTDMI) for iron was 34.12 and 32.54 mg/kg/day/bw for Mw and Mz, 28.28 mg/kg/day/bw for Mk, 28.83 mg/kg/day/bw for Kr, 11.67 mg/kg/day/bw for Nj and 11.71 mg/kg/day/bw for Ml. The iron intake was high in Mw and Mz sites because of high levels of kaolinite and Fe-oxyhydroxides making the soil to appear reddish in color (Yanai et al., 2014). The provisional intake for iron was high compared to the recommended PMTDI due to high concentration of iron in geophagic soils compared to other metals. High iron contents in Tanzanian geophagic soils collected

Table 4
Concentration of metals in geophagic soils from Mwanza, Njombe and Morogoro regions in Tanzania values are expressed as mean (mg.kg^{-1}) ± SD.

Region	Mwanza		Njombe		Morogoro		
Site	Mkuyuni	Kirumba	Njombe	Mlangali	Mawenzi	Manzese	P-Value
Fe	39592.2 ± 382.55	40368.2 ± 461.13	16335.71 ± 244.67	16391.6± 315.23	47773.7 ± 235.80	45556.9 ± 211.27	$p < 0.05$
Ca	1051.3 ± 22.54	1073.5 ± 54.59	46.2 ± 0.26	44.6 ± 0.26	389.3 ± 0.26	351.3± 0.26	$p < 0.05$
K	289.1 ± 11.77	286.5 ± 10.69	468.4± 12.65	514.9 ± 22.91	155.3 ± 0.14	188.3 ± 0.17	$P > 0.05$
Zn	112.4 ± 0.27	96.2 ± 0.23	72 ± 0.4	73.7 ± 0.41	45.6 ± 0.042	44.5 ± 0.041	$p < 0.05$
Na	90.5 ± 2.22	95.1 ± 1.23	53.3 ± 0.3	60.3 ± 0.34	46.40 ± 0.04	40.7 ± 0.03	$p < 0.05$
Cu	58.6 ± 0.14	66.7 ± 0.16	2.4 ± 0.01	5.1 ± 0.02	15.1 ± 0.013	15.9 ± 0.014	$p < 0.05$
Mn	572.6 ± 6.38	500.2 ± 6.2	361.8 ± 9.05	384.1 ± 8.17	170.2 ± 4.15	109.5± 2.1	$p < 0.05$
Pb	4.6 ± 0.01	5.98 ± 0.01	3.8 ± 0.014	4.58 ± 0.02	6.85 ± 0.006	5.9 ± 0.005	$P > 0.05$
Ni	93.1 ± 0.22	78.8 ± 0.19	3.1 ± 0.017	4.5 ± 0.025	14.5 ± 0.013	10.2 ± 0.009	$P < 0.05$
Cr	96.7 ± 0.23	116.6 ± 0.19	62.7 ± 0.35	85.8 ± 0.48	552.7 ± 7.51	638.6 ± 6.58	$p < 0.05$
Cd	0.4 ± 0.00	0.4 ± 0.00	ND	ND	ND	ND	NS

ND = Not detected

Table 5
Average daily intake of metals from geophagic soils in mg/kg/day/bwt from different sites compared to the recommended PMTDI.

Sites	Mk	Kr	Nj	Ml	Mw	Mz	Recommended PMTDI mg/kg/day/bwt	References
Fe	28.28	28.83	11.66	11.71	34.12	32.54	0.8	[24]
Ca	0.75	0.77	0.03	0.03	0.28	0.25	18.57	[37]
K	0.21	0.20	0.33	0.37	0.11	0.13	50.14	[49]
Zn	0.08	0.07	0.05	0.05	0.03	0.03	0.14	[49]
Na	0.06	0.07	0.038	0.04	0.03	0.03	28	[49]
Cu	0.04	0.05	0.002	0.004	0.01	0.01	0.012	[37]
Mn	0.41	0.36	0.258	0.27	0.12	0.08	0.04	[17]
Pb	0.004	0.004	0.003	0.003	0.005	0.004	-	[24]
Ni	0.07	0.06	0.002	0.003	0.01	0.007	0.002	[20]
Cr	0.07	0.08	0.045	0.06	0.39	0.46	0.0005	[17]
Cd	0.0003	0.0003	ND	ND	ND	ND	0.001	[24]

Table 6
Target hazard quotients (THQ), total target hazard quotients (TTHQ) and cancer risk (CR) of metals in geophagic soils from different sampling sites in Tanzania.

Sites	Mk		Kr		Nj		Ml		Mw		Mz	
	THQ	CR	THQ	CR	THQ	CR	THQ	CR	THQ	CR	THQ	CR
Fe	40.40		41.19		16.67		16.73		48.75		46.49	
Ca	N/A		N/A		N/A		N/A		N/A		N/A	
K	N/A		N/A		N/A		N/A		N/A		N/A	
Zn	0.27		0.23		0.17		0.17		0.11		0.11	
Na	N/A		N/A		N/A		N/A		N/A		N/A	
Cu	1.05		1.19		0.043		0.091		0.27		0.28	
Mn	2.92		2.55		1.84		1.96		0.87		0.56	
Pb	0.94	3.3×10^{-5}	1.22	3.4×10^{-5}	0.76	2.55×10^{-5}	0.93	2.55×10^{-5}	1.39	4.25×10^{-4}	1.20	3.4×10^{-5}
Ni	3.32	0.059	2.81	0.005	0.11	1.98×10^{-3}	0.16	2.7×10^{-3}	0.52	9.1×10^{-3}	0.36	6.37×10^{-3}
Cr	23.02	0.034	27.76	0.042	14.92	0.023	20.42	0.031	13.16	0.19	15.20	0.23
Cd	0.41	1.89×10^{-3}	0.41	1.8×10^{-3}	ND	ND	ND	ND	ND	ND	ND	ND
TTHQ CR	72.32	0.064	77.36	0.048	34.52	0.025	40.47	0.033	65.07	0.19	64.19	0.24

ND = Not detected, N/A = Not available;

from Kigoma region had 87,754 mg/kg, which was equal to PMTDI of 62.68 mg/kg/day/bw [39]. These values exceeded the results of this study. Likewise, geophagic soils collected from Kakamega county in Kenya showed high concentration of iron which was harmful to health [35]. However, the essentiality of iron in the body is due to its functions in oxygen transport, DNA synthesis and electron transport [12]. Concentration of iron in samples from this study exceeded the provisional daily intake of 0.8 mg/kg/day/bw proposed by WHO/FAO (2019). Boveris et al. [7] reported that iron intake greater than 18 mg per day caused hematochromatis. Iron is a transition metal and its resulting redox properties have been used during evolution in the development of oxidative energy generation. Despite this known essentiality, it contributes to the production of radical oxygen species including superoxide, hydrogen peroxide, hydroxyl radicals, and singlet oxygen, which damage cellular and subcellular structures resulting in accelerated aging and liver damage [8].

4.1.2. *Calcium*

The amounts of calcium in geophagic soils from selected sites ranged between 44.6 and 1051 mg/kg, which gave the PDI of about 0.75 mg/kg/day/bw for Mk 0.77 mg/kg/day/bw for Kr, 0.033 mg/kg/day/bw for Nj, 0.03 mg/kg/day/bw for Ml 0.28 mg/kg/day/bw for Mw and 0.25 mg/kg/day/bw for Mz. Both, Mk and Kr sites had geophagic soils rich in calcium compared to other sites which could be due to high clay content. According to Abrams [1] and National Institute of Health NIH [37] about 18.57 mg/kg/day/bw is needed daily by the body however, the results from this study were below the required daily intake of calcium established by National Institute of Health NIH [37]. Thus, consuming an average of 50 g of geophagic soil each day, it contributes a small percentage of the total calcium needed daily for the body's growth and metabolism.

4.1.3. Potassium

Results shows that the provisional daily intake of potassium after ingesting 50 g of geophagic soil were 0.21 mg/kg/day/bw for Mk, 0.20 mg/kg/day/bw for Kr, 0.34 mg/kg/day/bw for Nj, 0.37 mg/kg/day/bw for Ml, 0.11 mg/kg/day/bw for Mw and 0.13 mg/kg/day/bw for Mz. The amount of potassium recommended to be consumed per day should not exceed the recommended value of 50.14 mg/kg/day/bw established by WHO [49]. The amount beyond the recommended levels contributes to heart disorders and hyperkalemia. From the analysis the concentrations of potassium were high in Nj and Ml sites with 468.4 and 514.9 mg/kg. However, the daily intake of potassium from all sites was below the recommended levels, that does not lead to any health effects but the little amount is needed daily for body growth, strengthening muscles and promotes heart functions.

4.1.4. Sodium

Consumption of 50 g of geophagic soil per day contributes to sodium intake of about 0.06 mg/kg/day/bw for Mk, 0.07 mg/kg/day/bw for Kr, 0.04 mg/kg/day/bw for Nj and Ml, and 0.03 mg/kg/day/bw for Mw and Mz respectively. The recommended daily intake of sodium is 28 mg/kg/day/bw [49]. When compared, the results obtained in this study were below the recommended daily intake of sodium and only contributes little amount to the total sodium needed per day for body's functions. According to WHO [49], sodium intake within the recommended levels decrease the risks of cardiovascular diseases and elevated blood pressure.

4.1.5. Zinc

Intake of average amount of geophagic soil of about 50 g per day contributes to 0.08 mg/kg/day/bw for Mk, 0.07 mg/kg/day/bw for Kr, 0.05 mg/kg/day/bw for Nj and Ml and 0.03 mg/kg/day/bw for Mw and Mz. Thus, there are no potential risks posed by zinc because the concentration present in geophagic soils was below the permissible level of 0.14 mg/kg/bw/day proposed by FAO/WHO (2019) joint expert committee. The amount of zinc in ingested geophagic soil enhances growth, enzymes functions in metabolism and elimination of toxic metals such as cadmium (Ray et al., 2009) [44]. However, zinc intake above the recommended levels has been reported to interfere with the intake of other important elements such as iron and copper in the body [22].

4.1.6. Copper

The daily intake of copper in geophagic soil was 0.04 mg/kg/day/bw for Mk, 0.05 mg/kg/day/bw for Kr, 0.002 mg/kg/day/bw for Nj, 0.004 mg/kg/day/bw for Ml, 0.01 mg/kg/day/bw for Mw and Mz. The concentration of samples from Kr and Mk was above the recommended value of 0.012 mg/kg/day/bw (NIH 2019) while those of Nj, Ml, Mw and Mz samples were below the recommended daily intake respectively. High amounts of copper rarely occur naturally in the soil and the contamination in Mk and Kr geophagic soil sticks can be due to contaminated water used during making the sticks which is usually collected from the nearby surrounding Lake Victoria. The contamination of the lake water may be caused by industrial activities and sewage effluents surrounding the area and from fertilizers due to farming activities. Ingesting recommended amounts of copper is vital for the body function. However, the excess causes several effects including cardiac diseases, carcinogenic effects and liver damage (Boveris 2012). Like iron, excess copper causes production of harmful free radicals in the body [8].

4.1.7. Manganese

From the analysis, all samples from Mk, Kr, Nj, Ml, Mw and Mz showed higher Mn concentrations of 0.41, 0.36, 0.26, 0.27, 0.12 and 0.08 mg/kg/day/bw respectively, which was above the recommended value of 0.04 mg/kg/day/bw [17]. The presence of higher manganese concentrations of about 40–900 mg/kg in soil has been reported to be caused by erosion of crustal rock [34]. However, the soil near industrialized and mining areas can be more contaminated. The results obtained in this study shows that geophagic soils sold in Kr and Mk area in Mwanza region have manganese amount that is above Minimal Risk Levels (MRLs) similar to soil composition reported in Benin [4]. The soils sticks distributed in Mwanza region are made in an area near the industries and polluted lake water is being used, this might also contribute to manganese exposure. Mw and Mz sites in Morogoro on the other hand are populated areas with many activities and hence concentration above the MRLs was expected from these sites. Long time exposure can lead to health effects such as neurological damages, reproductive effects, skeleton impairment and Parkinson's disease [30].

4.2. Toxic metals in geophagic soils

4.2.1. Lead

Lead is toxic non-biodegradable metal making its long stay within the environment.(Flora et al., 2012) [21]. For women ingesting the soil per day the intake of lead is 0.004, 0.004, 0.003, 0.003, 0.005 and 0.004 mg/kg/day/bw in Mk, Kr, Nj, Ml and Mz, respectively. According to FAO/WHO joint expert committee (2019), there is no any recommended amount of lead intake that can be tolerable by the body. This indicates that Pb is very toxic. Presence of Pb in geophagic soil sticks collected from Kr and Mk sites may be due to water used to make the sticks [28] and possible contamination in markets where they are sold. Higher amounts of Pb in selected geophagic soil sticks corresponds with those reported by Nyanza et al. [39], Miller et al. [35] and Kortei et al. [29] and [4]. Chronic exposure to Pb from the soil daily may affect different body organs such as kidney [3,35], liver, brain and blood [23]. For lactating mothers Pb can be transferred to the baby through milk and effect the baby's growth (Miller 2018)

4.2.2. Cadmium

It is known for its severe toxicological effects. Daily cadmium intake was 0.0003 mg/kg/day/bw in both samples from Kr and Mk. The amount was below the tolerable maximum daily intake of cadmium proposed by joint experts committee (WHO/FAO 2019) which is 0.001 mg/kg/day/bw, these results correspond to a study on geophagic soil composition reported in Benin [4]. However, cadmium was not detected in samples from other sites. This is similar to that reported by Nyanza et al. [39] on concentration of geophagic soils in Tanzania. When the amounts of Cd ingested were higher than the permissible levels caused renal effects [9] and damage of the liver and kidney [44].

4.2.3. Chromium

The geophagic soil samples from Mw and Mz had high chromium of 0.39 and 0.46 mg/kg/day/bw compared to recommended PMTDI. The remaining samples had 0.07 mg/kg/day/bw, 0.08 mg/kg/day/bw, 0.05 mg/kg/day/bw and 0.06 mg/kg/day/bw for Mk, Kr, Nj and Ml which were below the maximum tolerable daily intake of 0.3 mg/kg/day/bw. Presence of high levels of chromium in geophagic soil sticks from Mw and Mz can be due to natural composition of rocks and sediments that compose them and anthropogenic deposition [5] Chromium is beneficial as it helps the body in metabolism of different macromolecules such as glucose and lipids. Chromium can be stored in the liver, kidney, plasma, RBC's, lungs and bone marrow and its level should be balanced in the body because chronic and sub chronic excess exposures causes respiratory effects, death of fetus and neural malfunctions (Ray et al., 2009).

4.2.4. Nickel

It is important in the body when it is present within the recommended levels. The recommended daily intake of nickel is 0.002 mg/kg/day/bw [20]. Nickel concentration from the analyzed geophagic soil samples was higher than recommended value in Mk, Kr, Mw, Mz and Ml with 0.07, 0.06, 0.01, 0.007and 0.003 mg/kg/day/bw, respectively these results correspond to a study on geophagic soil composition reported in Benin [4]. while that of Nj had lower concentration of 0.002 mg/kg/day/bw which was within the recommended values. Presence of nickel in geophagic soil sticks can be of natural occurrence and anthropogenic inputs such as depositions from burning fossil fuels [45]. The results were similar to those reported by Nyanza et al. [39] on geophagic soil composition in Tanzania, except those from Ml and Nj which had a very low concentration of nickel. Physiologically nickel acts as a co-factor that helps in iron absorption in the body from diet (Das et al., 2008). The toxic effects of nickel include hepatotoxicity and reduced hemoglobin after exposure to 25 mg/kg/day for six weeks (Das et al., 2008). Kidney toxicity and respiratory effects have been reported by Denkhaus and Salnikow [15]

4.3. Comparison between metal concentrations in different sites

One way analysis of variance shows that there are significant differences in concentrations between metals since $p < 0.05$ except the concentration of lead and potassium in which no difference was observed $p > 0.05$ as shown in Table 2.14. However, there was a significant difference in mineral composition between sites $p = 0.0044$. The Table 2.14 shows that there is no significant difference in the metal concentration between samples collected in the markets sites from the same region of the country. Significant difference was observed between samples which were collected from different regions.

4.4. Health risk assessment

Consuming geophagic soils enhance the possibility of toxic heavy metals to enter the human food chain and this effect should be eliminated [29]. This is because it is hard to detect the acute effect as most of the effects occur at later stages of life. In this study cadmium was not detected in samples from Nj, Ml, Mw and Mz. This is similar to results on geophagy in artisanal gold mine communities reported by Nyanza et al. [39] which showed that cadmium content was < 0.01 mg/kg. However, cadmium was detected in samples from Mk and Kr and the amount taken daily was below the tolerable daily intake, the target hazard quotient of cadmium THQ was <1 which implies that the amount of cadmium in the samples cannot pose any effect. WHO/FAO joint expert committee (2019) recommends that any amount of Pb is not beneficial to human health. From the analysis Pb was detected in each of the samples and the THQ of Pb was >1 for Mz, Mw and Kr samples, whereas the amount was <1in samples from Nj, Ml and Mk. Non-carcinogenic effects can be seen in iron and chromium, which are the heavy metals with the highest THQ values exceeding 1 from both samples. Since THQ for zinc was <1 in all samples so there are no any health risks posed by the metal. In Kr and Mk samples the THQ for copper, manganese and nickel was >1 and in the remaining sites Nj, Ml, Mw and Mz had <1 THQ values. The Total Target Hazard Quotient (TTHQ) in both sampling sites, Kr and Mk was >1 which means that there are possibilities of developing non-carcinogenic effects in a lifetime. In assessment of cancer risks the International Agency for Research on Cancer (IARC) classify heavy metals Ni, Cr, Cd as group 1 carcinogens. Ni and Cr were dominant in all samples but Cd was only found in Kr and Mk samples. Cancer risks for chromium, nickel and cadmium in all sampling sites exceeded the safety limit of 10^{-6} (the acceptable level of carcinogenic risk for humans). This makes the possibility for geophagic soil consumers to develop cancer in lifetime. These results correlate with those reported in Volta region of Ghana by Kortei et al. [29].

Table 7
Statistical table comparing the sites with their metal concentration.

Sites in comparison	Mean rank difference	Significant/Not significant	P-value
Mk vs Kr	-4.627	ns	$p > 0.05$
Mk vs Nj	9.573	s	$p < 0.05$
Mk vs Ml	7.073	ns	$p > 0.05$
Mk vs Mw	1.173	ns	$p > 0.05$
Mk vs Mz	2.673	ns	$p > 0.05$
Kr vs Nj	14.2	s	$p < 0.05$
Kr vs Ml	11.7	ns	$p > 0.05$
Kr vs Mw	5.8	ns	$p > 0.05$
Kr vs Mz	7.3	ns	$p > 0.05$
Nj vs Ml	-2.5	ns	$p > 0.05$
Nj vs Mw	-8.4	ns	$p > 0.05$
Nj vs Mz	-6.9	ns	$p > 0.05$
Ml vs Mw	-5.9	ns	$p > 0.05$
Ml vs Mz	-4.4	ns	$p > 0.05$
Mw vs Mz	1.5	ns	$p > 0.05$

5. Conclusion

From the analysis of geophagic soils essential minerals Fe, Ca, Zn, Na and K and toxic metals Pb, Cr, Ni and Cu were detected in all the samples. Cd was detected in samples from Kr and Mk only which was 0.0003 mg/kg/day/bw in both samples but not in samples from other sites. Fe reported from all sites was above the recommended daily intake ranging from 11.67 to 34.54 mg/kg/day/bw in both sampling sites while zinc, sodium and calcium from all sites were below the tolerable daily intakes. Chromium was high in samples from Mw and Mz with 0.36 and 0.46 mg/kg/day/bw respectively while from other sites the concentration was below the recommended daily intake ranging from 0.05 to 0.08 mg/kg/day/bw. On the other hand, Mk and Kr had high levels of Manganese, however the level of manganese in all sampling sites was above the recommended level of 0.04 mg/kg/day/bw with levels ranging from 0.08 to 0.41 mg/kg/day/bw. Nickel was within the tolerable daily intake in Nj sample with 0.002 mg/kg/day/bw while other samples from Ml, Mk, Kr, Mw and Mzwere above daily tolerable intake with 0.007–0.07 mg/kg/day/bw. According to WHO/FAO joint expert's committee, lead should be avoided and any amount of lead is not permitted for the body. However, in all sampling sites lead was detected and the daily intake ranged from 0.003 to 0.005 mg/kg/day/bw this means that the soil is not suitable for use despite of the presence of essential minerals. Due to presence of lead, prolonged consumption of the soil can lead to damages of the liver and kidney. Cadmium was detected in samples from Kr and Mk but the concentration was below the tolerable daily intake of 0.0003 mg/kg/day/bw thus it does not induce any effects. The Hazard index was greater than 1 in all samples which means that chronic bioaccumulation of the metals from geophagic soils may result to non-carcinogenic effects in women especially pregnant mothers in lifetime. Cancer risk was less than 1 in samples from all sites which means no carcinogenic effect are likely to occur during lifetime.

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CRediT authorship contribution statement

Harishchandra B. Pratap: Conceptualization, Formal analysis, Resources, Supervision, Validation, Visualization, Writing – review & editing. **Clarence A. Mgina:** Conceptualization, Data curation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing. **Consolata Elias Rukondo:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data have been shared alongside the article

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