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ORIGINAL PAPER

The geochemistry of geophagic material consumed in Onangama Village, Northern Namibia: a potential health hazard for pregnant women in the area

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Abstract Ingestion of geophagic materials might affect human health and induce diseases by different ways. The purpose of this study is to determine the geochemical composition of geophagic material consumed especially by pregnant women in Onangama Village, Northern Namibia and to assess its possible health effects. X-ray fluorescence and inductively coupled plasma mass spectrometry were used in order to determine the major, and trace elements as well as anions concentrations of the consumed material. The geochemical analysis revealed high concentrations of aluminium (Al), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), potassium (K), sodium (Na), and silica (Si); and trace elements including arsenic (As), chromium (Cr), mercury (Hg), nickel (Ni) and vanadium (V) as well as sulphate (SO_4^{2-}), nitrate (NO_3^-), and nitrite (NO_2^-) anions comparing to the recommended daily allowance for pregnant women. The pH for some of the studied samples is alkaline, which might increase the gastrointestinal tract pH ($pH < 2$) and cause a decrease in the bioavailability of elements. The calculated health risk index ($HRI > 1$) revealed that Al and Mn might be a potential risk for human consumption. Based on the results obtained from the geochemical analysis, the consumption of the studied material might present a potential health risk to pregnant women including concomitant detrimental maternal and foetal effects.

Keywords Geophagy · Geochemistry · Termite mound soils · Pregnant women

Introduction

Geophagy is defined as the deliberate ingestion of earthy or soil-like materials such as clay (Lar et al. 2015; Ekosse and Jumbam 2010), chalk or coal (Crawford and Bodkin 2011). Historically, geophagy has been observed among humans (and animals) since ancient times and is spread worldwide (Ghorbani 2008). Nutritional deficiencies, plant toxins, or gastrointestinal sicknesses are the main physiological motivations for the practice of geophagy worldwide (Abrahams and Parsons 1996; Henry et al. 2013).

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Specific aims in the case of pregnant women include craving, and relief from morning sickness (Gomes and Silva 2007), foetal development as well as cultural beliefs (Agene et al. 2014; Ngole and Ekosse 2012).

Geophagic material may be directly ingested from the ground, however, in many situations there is a cultural preference for "special sources" such as local hills, mountains, gardens, riverbeds, termite mounds, as well as material used for huts construction (van Huis 2017). In the case of urban areas, the geophagic material is mainly purchased from street vendors and/or open markets (Ghorbani 2008; Ekosse et al. 2010). According to Foti (1994) and van Huis (2017), pregnant women frequently consume this material, in some cases up to 30 g three times a day. This practice can cause serious health complications in pregnant women and their unborn babies including risks of the concomitant detrimental maternal and foetal health effects (Mathee et al. 2014). Several researchers reported that the health effects caused by geophagy depend on the quantity of soil ingested as well as its physical properties, mineralogy, and geochemistry including excess or deficiency of major and trace elements, metals and metalloids, and their bioavailability, which are subjective to the soils pedogenetic development (e.g., Ngole and Ekosse 2012 and references therein).

In this paper, we present a case study of geophagic materials, which consist mostly of termite mound samples collected in the field in the Onangama Village, Northern Namibia. In addition to these, one sample of termite mound material and two of clay material were bought at Tukondjeni open market in Windhoek, which is a distance of 800km away, mainly for comparison purposes. Termite mounds are the frequent consumed material by pregnant women in this area due to their common occurrences. These mounds are a result of termites' activities using aggregates of soil material from different soil depths (generally from sub-soil), and organic materials gathered from the surrounding areas (Mujinya et al. 2013). The practice of geophagy from termite mound soils and its composition have been reported in some African countries including Ghana (van Huis 2017), South Africa (Walker et al. 1985), and Kenya (Luoba et al. 2004). In the case of Namibia, although the practice has been reported (Thomson 1997), there is no documentation on the geochemical composition of these soils to date. The study by Thomson (1997) focused mainly on the association of geophagy prevalence and anaemia.

The aim of this study is, therefore, to characterize for the first time the geochemical compositions of these geophagic materials commonly consumed by pregnant women in the study area. Furthermore, a brief literature survey on the health impacts of the revealed elements was conducted in order to assess and predict their possible health risks on these women.

Study area and geology

The present study was conducted in Onangama, a village situated in the Ohangwena Region, in northern part of Namibia, close to the Namibia-Angola borders (Fig. 1). Geologically, the study area falls within the upper part of Owambo Basin (Kalahari Sequence), which is covered entirely by reddish-brown to light greyish unconsolidated sands of the Andoni Formation (Miller 1983; Haddon 2006). The Kalahari Sequence is made up of the following formations, from the base upwards: a basal red fine-grained Ombalantu Formation, a conglomeratic Beiseb Formation, a red Olukonda Formation and an upper Andoni Formation (Miller 1992). The Kalahari Sequence sediments were deposited by rivers from Cretaceous to Recent (Haddon 2006) with Aeolian reworking of the uppermost unconsolidated sands occurring during the Pliocene and Quaternary (Haddon and McCarthy 2005). The latter was coupled with the weathering of the underlying calcareous sandstone (Haddon 2006). The deposition occurred under arid to semi-arid conditions and forms the final filling to the Owambo Basin (Haddon 2006), which formed during the breakup of Rodinia in the late Precambrian (Johnson et al. 1997).

Onangama village lies on sediments of silt, clay, limestone and sandstone and is dominated by colophospermum mopane shrubs and drainage patterns or *oshanas*. During the rainy season, the *oshanas* are filled up with seasonal waters while during the dry season they are vegetated with grass used for livestock grazing. The higher grounds between the drainage patterns are used for farming and are covered with various tree species.

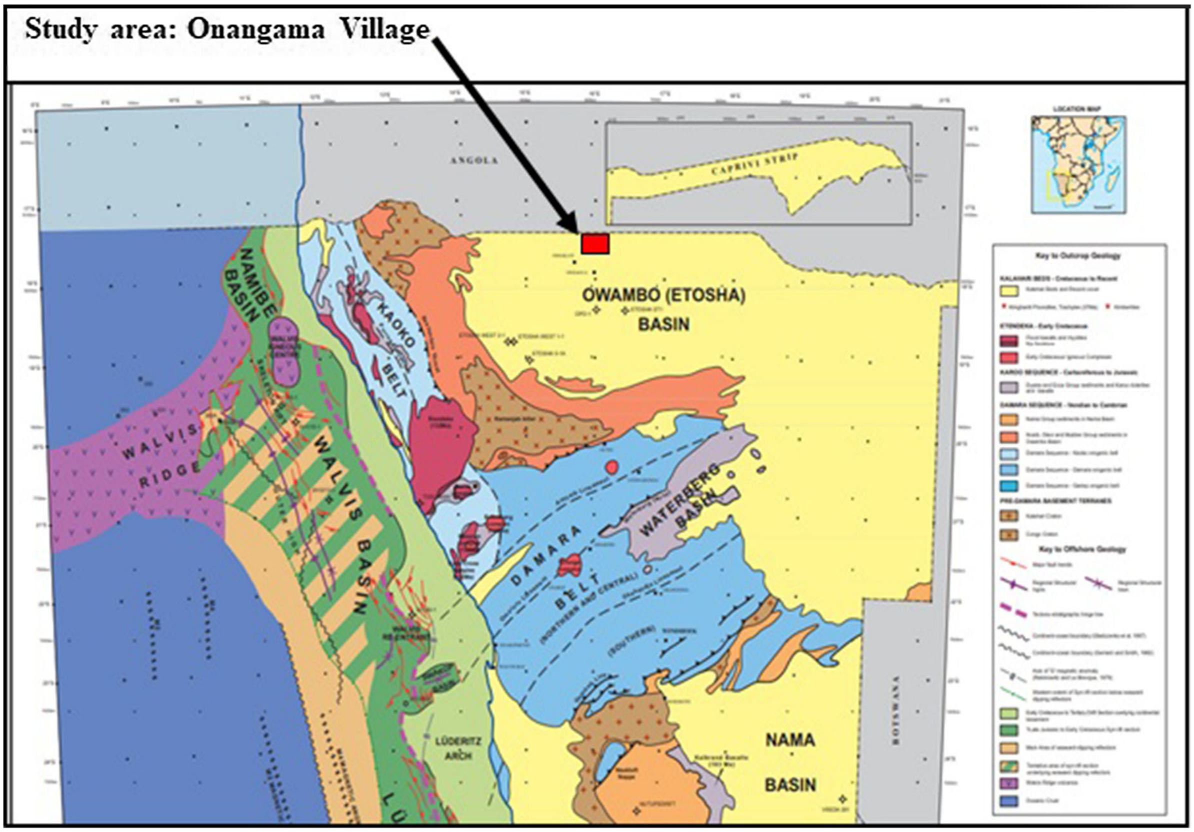

Fig. 1 Geological map of Namibia (NAMCOR 1998) showing study location

Materials and methods

Description of the studied materials

A total of fourteen samples in total were collected and prepared for this geochemical investigation. Eleven of the samples are termite mound soils (labelled ONC-1701 to ONC-1709, ONSC-1711, and ONC-1715) collected in the field in Onangama village. These samples weighing between 1 and 2 kg were collected using a stratified random sampling method. They were grouped according to their spatial occurrences and random sampling was used within each group. The study material occur in the field as light brown high termite mounds of up to five metres high and two metres wide (Fig. 2a). Using the Munsell soil colour chart, all the geophagic termite mound soil samples preserve a N 8/0 colour (grey). The termite mound soils in their environment (before sampling) display a compact, fine to coarse grained texture with vent holes, sometimes filled with black and/or brown organic materials (Fig. 2b).

In addition to the above, three other samples (labelled WNCs-1716, WNC-1717, and WNC-1718) weighing about 100 g were purchased from Tukondjeni open market in Windhoek city. These samples were sold per piece, with the price varying according to the lamp and/or block sizes. Two types of samples were purchased and considered in this investigation:

- Two clay soil lumps (WNCs-1716 and WNC-1717), which look similar to each other in terms of texture and colour (Fig. 2c), but different from the termite mound samples collected in the field. They are fine-grained and N 7/0 (light grey) in colour based on Munsell soil colour chart. The vendor stated that these samples were imported from Angola.
- One termite mound soil sample (WNC-1718), which looks similar to the samples collected in the field in terms of colour and texture (Fig. 2d). The

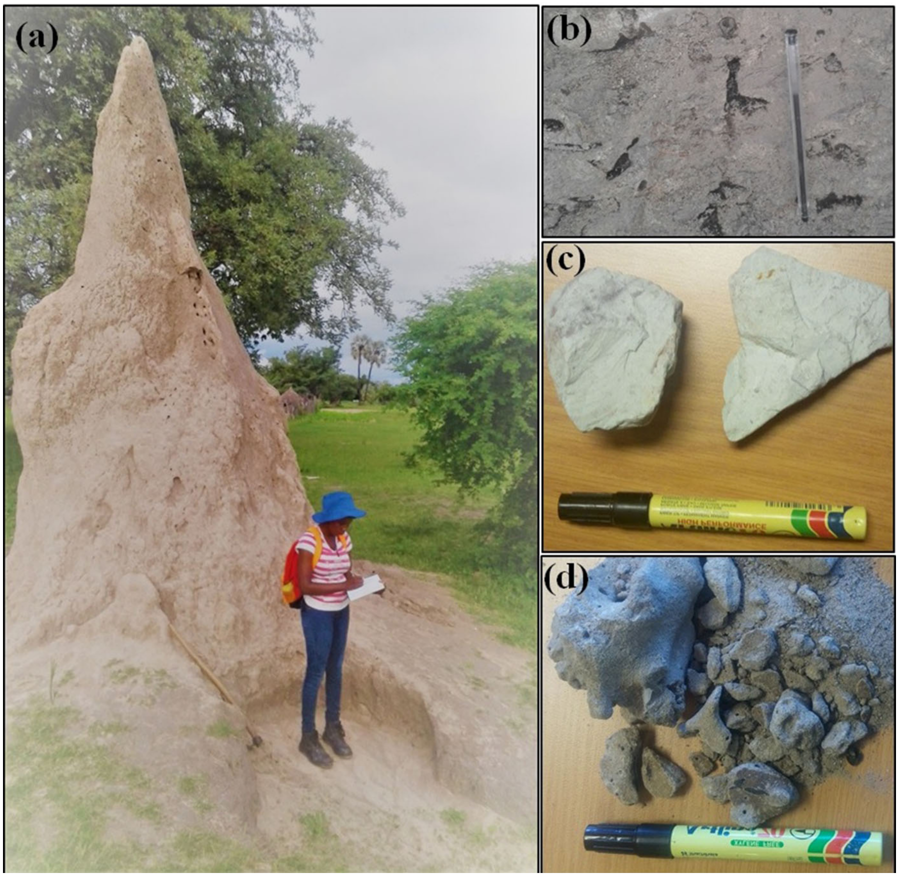

Fig. 2 **a–d** View of the termite mound in the field (**a**), close up of the termite mound soil collected in the field (**b**), clay soil purchased from the open market (**c**), and termite mound soil purchased from the open market (**d**)

vendor stated that this sample was collected from Onangama Village.

Methods of investigation

The following analytical methods and calculation were conducted during the course of this investigation:

(i) *X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) analytical methods* in order to effectively characterise the geochemistry of studied geophagic materials, XRF and ICP-MS analytical methods were used to determine the major elements (oxides), and trace elements and anions composition, respectively. The XRF analysis was conducted at Spectrum facility in the faculty of science at the University of Johannesburg while the trace elements analysis (ICP-MS) was performed at the Agricultural Research Council (ARC), in Pretoria using water soluble extra method and ion chromatography method for anions. For XRF chemical analysis, about 2.00 g of each sample were dried overnight in the drying oven at 105 °C and cooled to room temperature using a desiccator before starting with the borate fusion preparation. 0.7 g of the dried sample was mixed with 0.5 g of $LiNO_3$ and 5.90 g of 50/50 flux (49:75 mass% lithium tetraborate, 49:75 mass% lithium metaborate, 0:5 mass% lithium bromide) and placed into the fusion machine at 1050 °C. After the fusion was completed, the fusion discs were labelled on the top side with self-adhesive labels and stored in the desiccator in C1 Lab 330 until the chemical composition analysis was done.

For ICP-MS analysis, an USEPA 3051A procedure (USEPA 1995) was followed, where by the crushed samples were dissolved in concentrated nitric and hydrochloric acids using microwave heating, cooled, filtered, centrifuged, and diluted to a volume before analysis.

(ii) *pH estimation* in order to determine the soil pH, the procedures from ISO 10390 (2005) were adopted. A suspension of soil was made up in five times its volume of a 0.01 mol/L solution of calcium chloride ($CaCl_2$) in water. The pH was then measured using a calibrated SensoDirect 150 set PH/CON MultiMeter instrument.

(iii) *Health risk index (HRI) calculation* for the assessment of the potential health risk upon ingestion of the geophagic materials, a non-carcinogenic hazard characterized by a health risk index (HRI) (Nkansah et al. 2016) was calculated. A HRI less than 1 ($HRI < 1$) indicates that the exposed population is unlikely to experience obvious adverse effects; whereas a HRI above 1 ($HRI > 1$) suggests that there is a chance of non-carcinogenic effects, with an increasing probability as the value increases (Liu et al. 2013). In order to calculate the HRI, two parameters are required; the probable daily intake (PDI) and the permitted maximum tolerable daily intake (PMTDI) standards set up by World Health Organization (WHO), and Food and Agriculture Organization (FAO). The mathematical representation of the HRI is as follow:

$$\mathrm{HRI} = \mathrm{PDI} \div \mathrm{PMTDI}$$

The PDI is calculated by multiplying the maximum elemental concentrations (Conc. max) with the Mean Daily Consumption (MDC) (Arhin and Zango 2017).

$$\mathrm{PDI} = \mathrm{Conc.\,max} \times \mathrm{MDC}$$

The PMTDI, also known as the toxicity threshold value or chronic reference dose (RfD) for pregnant women in mg/kg-day of a specific heavy metal is obtained from the standard set value by WHO and FAO (Song et al. 2013). The average body weight of the women in the study area was 65 kg.

Results

The geochemical, soil pH, and the HRI results of the studied samples are described under the section below. Statistical analysis is also performed on the obtained results and summarized in Table 1.

Major elements composition

Major chemical compositions in mass% and re-calculated values in mg/kg of all the studied samples are presented in Table 2. Concentrations of elements in mg/kg including Al, Ca, Fe, K, Mg, Mn, Na and Si, in relation to their RDA are reported on simplified charts (Fig. 3). The samples collected in the field and those purchased from the open market are presented in different colours on same figures for comparison purpose.

Samples collected in the field

The results show that all eleven samples are characterized by a relatively homogenous composition in terms of Al_2O_3 (5.51–8.71%), FeO (1.22–2.77%), MgO (0.64–1.08%), K_2O (0.57–0.91%), MnO (0.06–0.11%), and Na_2O (0.51–1.07%). However, CaO and SiO_2 show relatively large variations ranging between 0.63–10.04 and 67.58–87.61%, respectively (Table 2).

The re-calculated concentrations of each element in mg/kg (Table 2) compared to the daily recommended guidelines for pregnant women as suggested by the World Health Organization (WHO 1996), Food and Agriculture Organization/World Health Organization (FAO/WHO 2003), Environmental Protection Agency (USEPA 1993), Bhaskarachary (2011), Johnson (2006), Pennington (1988), Ronnenberg et al. (2004), Castiglioni et al. (2013), Santamaria (2008), and Pennington (1991) (Table 3) revealed the following:

- All eleven samples show higher concentrations of Al, Ca, Fe, Si, and Mg (Fig. 3a–e),
- Ten samples with high K concentrations (Fig. 3f),
- Seven samples with high Mn (Fig. 3g) concentrations, and
- Four samples with high Na (Fig. 3h) concentrations.

Table 1 Statistic summary of all the results obtained

Component	*N*	Minimum	Maximum	Mean	SD	Variance
Soil pH	14	3.77	8.17	7.1343	1.42833	2.040
HRI	7	0.012	328,316	47,024.10143	124,038.4745	1.539E + 10
Major elements						
Al_2O_3	14	3.981	31.020	9.90950	7.861134	61.797
CaO	14	0.000	10.040	3.31857	3.185191	10.145
Fe_2O_3	14	1.094	2.767	2.05821	0.526403	0.277
K_2O	14	0.240	1.251	0.68864	0.281005	0.079
MgO	14	0.635	1.082	0.85200	0.172401	0.030
MnO	14	0.00	0.11	0.0393	0.04287	0.002
Na_2O	14	0.000	1.508	0.37014	0.435441	0.190
SiO_2	14	53.28	92.46	75.0421	10.71150	114.736
Trace elements						
As	14	0.01	0.08	0.0243	0.02209	0.000
Cr	14	0.01	0.75	0.0643	0.19740	0.039
Cu	14	0.01	0.46	0.0836	0.11359	0.013
Hg	14	0.00	0.10	0.0107	0.02895	0.001
Ni	14	0.00	0.49	0.1471	0.12591	0.016
V	14	0.05	2.45	0.6707	0.73928	0.547
Anions						
SO_4^{2-}	14	18.20	24917.00	5792.9214	8293.57111	68,783,321.819
NO_3^-	14	12.60	3710.00	521.3786	999.46384	998,927.974
NO_2^-	14	0.00	900.90	73.6143	238.21909	56,748.337

N is for number of parameters analysed, i.e., samples

HRI is for health risk index

SD is for standard deviation

Samples purchased from the open market

The results show that all samples have a relatively homogenous composition in terms of Fe_2O_3 (1.09–2.13%), K_2O (1.21–1.25%), and MgO (0.69–0.78%); however, Al_2O_3 (6.08–31.02%), SiO_2 (53.28–92.46%), CaO (0–1.02%), and Na_2O (0–1.51%) show relatively large variation in their compositions (Table 2).

The re-calculated concentrations of each element in mg/kg (Table 2) compared to the daily recommended allowance (RDA) for pregnant women as suggested by the World Health Organization (WHO 1996), Food and Agriculture Organization/World Health Organization (FAO/WHO 2003), Environmental Protection Agency (USEPA 1993), Bhaskarachary (2011), Johnson (2006), Pennington (1988), Ronnenberg et al. (2004), Castiglioni et al. (2013), Santamaria (2008) and Pennington (1991) (Table 3) revealed the following:

- All three samples are characterized by high concentrations of Al, Fe, Mg and Si (Fig. 3a, c–e) but no Mn is detected (Fig. 3g),
- Both clay soil samples (WNCs-1716 and WNC-1717) show high K concentrations (Fig. 3f); however, only sample WNCs-1716 shows high concentrations of Na (Fig. 3h), no Na is detected in sample WNC-1717, and
- The termite mound sample (WNCs-1718) is characterized by high Ca concentration, while K and Na concentrations are low.

It is worth noting that the termite mound sample purchased from the open market (WNC-1718) has the highest concentrations of Si (432,251 mg/kg) comparing to all other studied samples, whereas the clay soil samples (WNCs-1716 and WNC-1717) from Angola have the highest concentrations of Al and K as well as Na but only in one sample (WNCs-1716) (Fig. 3).

The average chemical composition for each element in all the studied samples (Table 2) was reported on the same simplified chart for comparison purpose

Table 2 Major elements concentrations of the studied samples

Elements	Samples collected in the field											
	ONC-1701	ONC-1702	ONC-1703	ONC-1704	ONC-1705	ONC-1706	ONC-1707	ONC-1708	ONC-1709	ONSC-1711	ONC-1715	Avg.
Composition in mass%												
Al_2O_3	5.51	8.18	8.71	6.86	6.47	7.06	8.04	7.14	8.45	3.98	6.24	6.97
CaO	10.04	1.35	5.15	6.70	5.83	2.97	3.58	0.63	0.94	0.89	7.30	4.13
Fe_2O_3	1.80	2.63	2.70	2.14	1.88	2.27	2.58	2.22	2.77	1.22	1.74	2.18
K_2O	0.57	0.50	0.74	0.54	0.58	0.91	0.66	0.82	0.57	0.60	0.45	0.63
MgO	1.05	0.80	1.08	0.73	0.83	1.08	1.06	1.05	0.74	0.64	0.67	0.88
MnO	0.10	–	0.11	0.07	0.06	0.07	0.08	–	–	–	0.06	0.05
Na_2O	0.51	0.28	0.16	0.22	0.38	0.08	0.10	0.57	–	1.07	0.24	0.33
SiO_2	67.58	80.08	71.58	73.21	74.25	79.02	76.72	83.34	81.36	87.61	73.19	77.09
Re-calculated chemical composition in mg/kg												
Al	29,159	43,289	46,093	36,303	34,239	37,362	42,548	37,785	44,717	21,062	33,022	36,870.82
Ca	71,756	9648	36,807	47,885	41,667	21,227	25,586	4503	6718	6361	52,173	29,484.64
Fe	12,589	18,394	18,884	14,967	13,149	15,876	18,045	15,527	19,373	8533	12,170	15,227.91
K	4732	4151	6143	4483	4815	7554	5479	6807	4732	4981	3736	5237.55
Mg	6334	4826	6515	4403	5007	6515	6394	6334	4464	3860	4041	5335.73
Mn	775	–	852	542	465	542	620	–	–	–	465	387.36
Na	3783	2077	1187	1632	2819	593	742	4229	–	7938	1780	2434.55
Si	315,937	374,374	334,637	342,257	347,119	369,419	358,666	389,615	380,358	409,577	342,163	360,374.72

Elements	Samples purchased from the open market				
	WNC_S-1716	WNC-1717	WNC-1718	Avg.	SD
Composition in mass%					
Al_2O_3	25.01	31.02	6.08	20.70	7.861134
CaO	–	0.07	1.02	0.36	3.185191
Fe_2O_3	1.09	1.66	2.13	1.63	0.526403
K_2O	1.21	1.25	0.24	0.90	0.281005
MgO	0.69	0.78	0.73	0.73	0.172401
MnO	–	–	–	–	0.04287
Na_2O	1.51	–	0.06	0.52	0.435441
SiO_2	56.91	53.28	92.46	76.90	10.71150
Re-calculated chemical composition in mg/kg					

Table 2 continued

Elements	Samples purchased from the open market				
	WNC_S-1716	WNC-1717	WNC-1718	Avg.	SD
Al	132,353	164,158	32,175	109,562	
Ca	–	500	7290	2596.67	
Fe	7623	11,610	14,897	11,376.67	
K	10,045	10,377	1992	7471.33	
Mg	4162	4705	4403	4423.33	
Mn	–	–	–	0	
Na	11,202	–	445	3882.33	
Si	266,054	249,084	432,251	315,796.33	

Avg. is for average

SD is for standard deviation

mg/kg is milligrams per kilograms

(Fig. 4). With the exception of Mg, Fe and Si concentrations, which are nearly the same in all the studied samples, Ca and Mn are higher in the samples collected in the field than those purchased from the open market, while K, Na, and Al show a reverse trend (Figs. 3, 4).

Trace elements

Trace elements' compositions in mg/kg and re-calculated values in µg/kg of all the studied geophagic material samples are presented in Table 4. Cu and Zn revealed low concentrations in all the studied samples (Table 4). As, Cr, Hg, Ni, and V concentrations in relation to their RDA are reported on simplified charts (Fig. 5). In the same manner as the major elements, the samples collected in the field and those purchased from the open market are presented in different colours on the same figures for comparison purpose.

Samples collected in the field

All samples show a heterogeneous composition in terms of concentrations of some elements including V (0.05–0.29 mg/kg), Cr (0.01–0.75 mg/kg), Hg (0–0.05 mg/kg), and Ni (0.09–0.49 mg/kg); however, As concentrations (0.01–0.08 mg/kg) are nearly the same in all samples (Table 4).

All the samples collected in the field are characterized by high concentrations of As and V (Fig. 5a, e); however, only nine samples have high Cr and Ni concentrations (Fig. 5b, d), and one with high Hg concentration (Fig. 5c) as compared to the daily recommended guidelines for pregnant women suggested by the WHO (1996), Trumbo et al. (2001), Solomons (1985), FAO/WHO (2003), USEPA (1993) Gunderson (1988) and Lucian et al. (2010) (Table 3).

Samples purchased from the open market

Except for As (0.01 mg/kg), which has a similar composition in all the samples, the compositions of V (0.06–0.29 mg/kg), Cr (0–0.02 mg/kg), Hg (0–0.05 mg/kg), and Ni (0–0.19 mg/kg) show large variation ranges (Table 4).

The results show that all samples are characterized by high concentrations of As and V (Fig. 5a, e); however, only two samples showed high Cr concentrations (Fig. 5b). High concentration of Hg is only

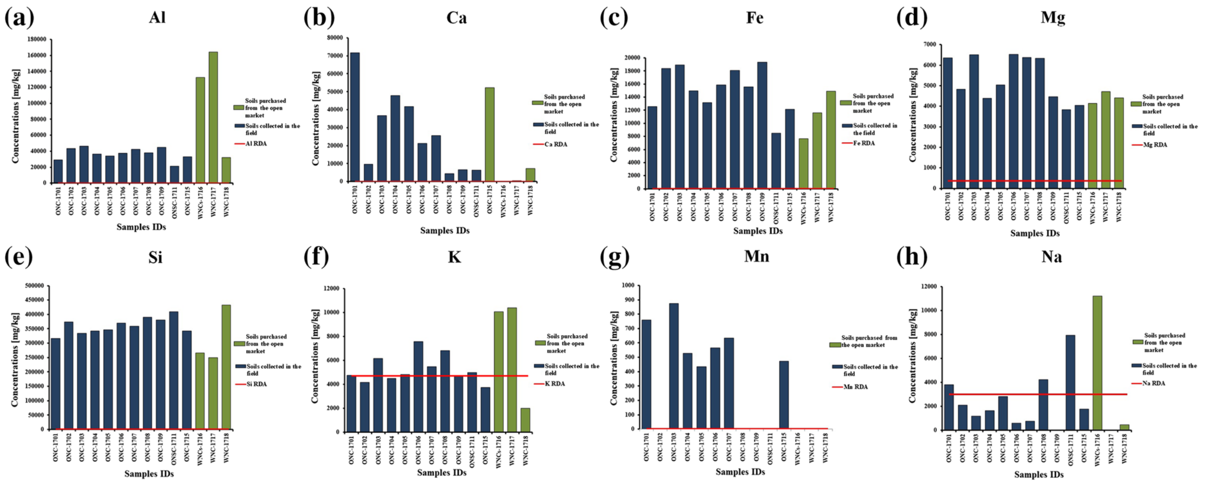

Fig. 3 **a–h** Major elements concentrations of all studied geophagic material in relation to their RDA for pregnant women

Table 3 The recommended daily allowance/intake for pregnant women

Elements	RDA (mg/kg)	References
Aluminium (Al)	1	Pennington (1988)
Arsenic (As)	0.0021	Trumbo et al. (2001)
Calcium (Ca)	1000	WHO (1996)
Chromium (Cr)	0.005	WHO (1996)
Copper (Cu)	1.8	Solomons (1985)
Iron (Fe)	27	Ronnenberg et al. (2004)
Magnesium (Mg)	350–360	Castiglioni et al. (2013)
Manganese (Mn)	2	Santamaria (2008)
Mercury (Hg)	0.001–0.002	FAO/WHO (2003) and EPA (1993)
Nickel (Ni)	0.07–0.08	Gunderson (1988)
Nitrate (NO_3^-)	45	NRC (1995)
Nitrite (NO_2^-)	3.3	NRC (1995)
Potassium (K)	4700	Bhaskarachary (2011)
Silicon (Si)	19	Pennington (1991)
Sodium (Na)	2980	Johnson (2006)
Sulphate (SO_4^{2-})	850	NRC (2005)
Vanadium (V)	0.0065–0.018	WHO (1996)
Zinc (Zn)	11	Lucian et al. (2010)

RDA is recommended daily allowance

observed in the termite mound sample (WNC-1718) while high Ni concentration is only observed in one of the clay sample (WNCs-1716) (Fig. 5c, d), respectively.

In general, the termite mound samples collected in the field show higher concentrations of As (average = 0.03 mg/kg), V (average = 0.81 mg/kg), Cr (average = 0.08 mg/kg), and Ni (average = 0.17 mg/kg) comparing to the samples purchased from the open market (averages in mg/kg: 0.01 As, 0.16 V, 0.01 Cr and 0.06 Ni). In contrast, Hg concentrations are higher in the termite mound sample purchased from the open market (0.02 mg/kg average) than in the samples collected in the field (0.00091 mg/kg average) (Fig. 6).

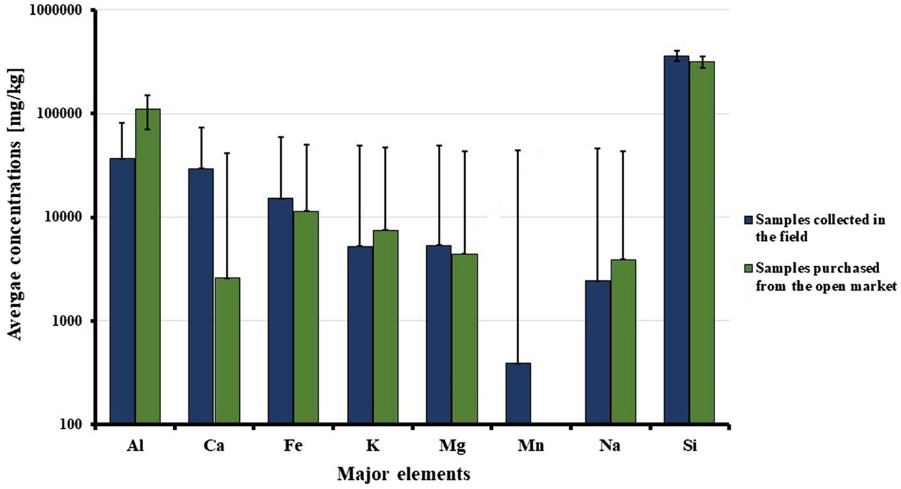

Fig. 4 Comparison of major element concentrations between the samples from the field (blue) and open market (green)

Anions

Anions' compositions in mg/kg of all the studied soil samples are presented in Table 4. Concentrations of NO_3^-, NO_2^-, and SO_4^{2-}, in relation to their RDA are reported on simplified charts (Fig. 7). The samples collected in the field and those purchased from the open market are presented in different colours on the same figures for comparison purpose.

Samples collected in the field

The results show that all samples are characterized by heterogeneous compositions in terms of NO_3^- (66.3–1256.4 mg/kg), SO_4^{2-} (1360–24,917 mg/kg) and NO_2^- (6.9–25.5 mg/kg) (Table 4).

All the samples collected in the field showed high concentrations of NO_3^- except sample ONC-1706 (Fig. 7a); however, only nine samples have high SO_4^{2-} (Fig. 7b) and eight with high NO_2^- concentrations (Fig. 7c) as compared to the daily recommended guidelines for pregnant women suggested by NRC (1995, 2005) (Table 3).

Samples purchased from the open market

Similar to the samples collected in the field, the results show that all samples purchased from the open market have heterogeneous compositions with regards to NO_2^- (8–900.9 mg/kg), NO_3^- concentration (0–70 mg/kg), and SO_4^{2-} (0–1080 mg/kg).

The results revealed high concentrations of NO_2^- in all samples (Fig. 7c); however, only one sample has high NO_3^- and SO_4^{2-} concentrations (Fig. 7a, b) compared to the RDA for pregnant women.

In general, the samples collected in the field show higher concentrations of SO_4^{2-} (average = 7270.32 mg/kg), and NO_3^- (average = 654.79 mg/kg) comparing to the samples purchased from the open market (averages in mg/kg: 375.8 SO_4^{2-} and 32.2 NO_3^-). In contrast, NO_2^- concentrations are higher in the samples purchased from the open market (306.97 mg/kg average) than the samples collected in the field (9.97 mg/kg average) (Fig. 8).

Soil pH

The pH values of studied samples collected in the field ranged from 7.26 to 8.17 while those purchased in the open market were between 3.77 and 7.92 as indicated in Table 5. Based on the pH values, all the studied samples are alkaline except for the two samples from the open market, which are slightly acidic.

Non-carcinogenic health risk index

According to the survey conducted in the study area, about 88.2% of reproductive aged women practicing geophagy consume a daily average of 150 g of termite mound soil. The latter has been used in the determination of the Probable Daily Intake (PDI) for the samples in this study (Table 6) since there is no set

Table 4 Trace elements and anions concentration of the studied samples

Trace elements	Samples collected in the field												Samples purchased from the open market				
	ONC-1701	ONC-1702	ONC-1703	ONC-1704	ONC-1705	ONC-1706	ONC-1707	ONC-1708	0NC-1709	ONSC-1711	ONC-1715	Avg.	WNC$_S$-1716	WNC-1717	WNC-1718	Avg.	SD
Chemical composition in mg/kg																	
As	0.01	0.02	0.02	0.02	0.02	0.07	0.02	0.02	0.01	0.08	0.02	0.03	0.01	0.01	0.01	0.01	0.02209
Cu	0.04	0.05	0.07	0.06	0.14	0.07	0.05	0.46	0.02	0.10	0.05	0.10	0.02	0.01	0.03	0.02	0.11359
Cr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.75	–	0.01	–	0.08	0.02	–	0.02	0.01	0.19740
Hg	–	0.01	–	–	–	–	–	–	–	–	–	9.1 × 10-4	–	–	0.05	0.01	0.02895
Ni	0.26	0.19	0.23	0.13	0.11	0.09	0.14	0.49	0.04	0.12	0.06	0.17	0.19	–	–	0.06	0.12591
V	0.32	0.20	0.19	1.24	0.35	1.91	0.45	2.45	0.05	1.05	0.71	0.81	0.29	0.06	0.12	0.16	0.73928
Zn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.00
Re-calculated chemical composition in μg/kg																	
As	10	20	20	20	20	70	20	20	10	80	20	30	10	10	10	10	
Cu	40	50	70	60	140	70	50	460	20	10	50	100	20	10	30	20	
Cr	10	10	10	10	10	10	10	750	–	10	–	80	20	–	20	13	
Hg	–	10	–	–	–	–	–	–	–	–	–	0.91	–	–	50	17	
Ni	260	190	230	130	110	90	140	490	40	120	60	170	190	–	–	63	
V	320	200	190	1240	350	1910	450	2450	50	1050	710	810	290	60	120	160	
Zn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Anions	*Chemical composition in mg/kg*																
NO_3^-	87.9	3710	134.3	241.5	1111.9	29.4	230.7	66.3	234.6	99.7	1256.4	654.79	12.6	14	70	32.2	999.46384
SO_4^{2-}	24,917	1360	18,083	2720	4454	32.5	2120	1585	557	18,671	5474	7270.32	29.2	18.2	1080	375.8	8293.57111
NO_2^-	9.3	0	15.3	10	0	6.9	9.1	25.5	16.2	0	17.4	9.97	900.9	12	8	306.97	238.21909

mg/kg is milligrams per kilograms

μg/kg is micrograms per kilograms

Avg. is for average

SD is for standard deviation

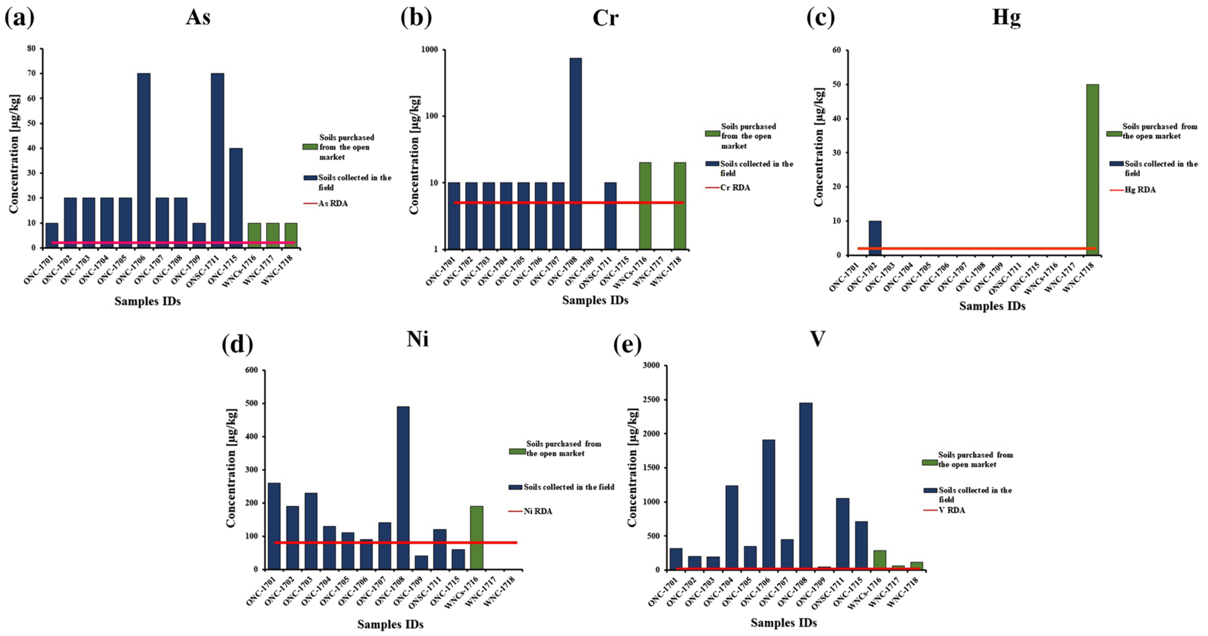

Fig. 5 **a–e** Trace elements concentration of geophagic material in relation to the RDA for pregnant women

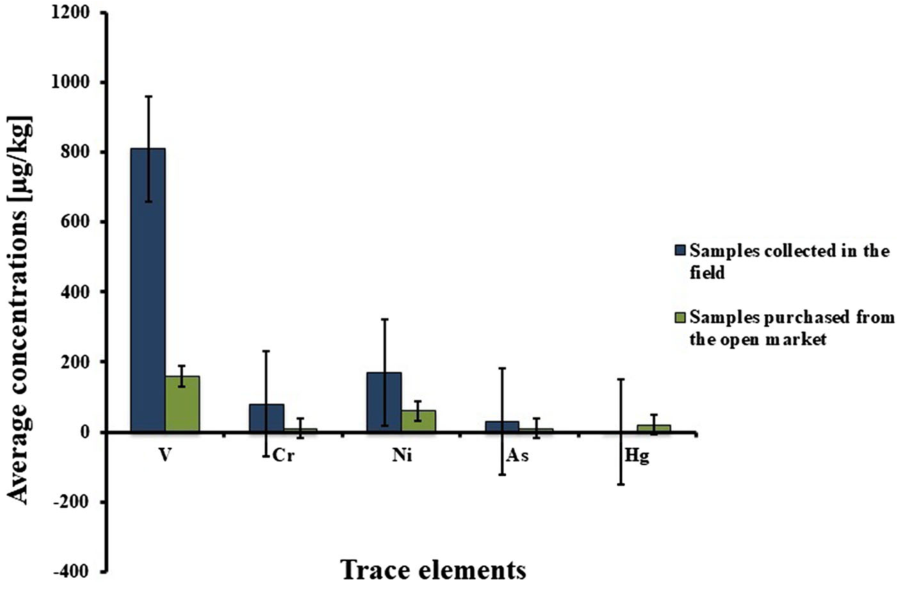

Fig. 6 Comparison of trace element concentrations between the samples from the field (blue) and open market (green)

amount for standard permitted maximum tolerable daily intake (PMTDI) of geophagic materials in Namibia. The standard PMTDI (µg/kg BW/day) estimated by WHO and FAO and the health risk index (HRI) results are also shown in Table 6 and are used to calculate the PMTDI for 65 kg BW (µg/day). Based on the HRI results, Al and Mn are classified with a very high potential risk of non-carcinogenic effects (HRI > 1) by the consumption of 150 g of the geophagic material/day.

Discussion

An element concentration above the RDA is considered of serious concerns as it could be potentially

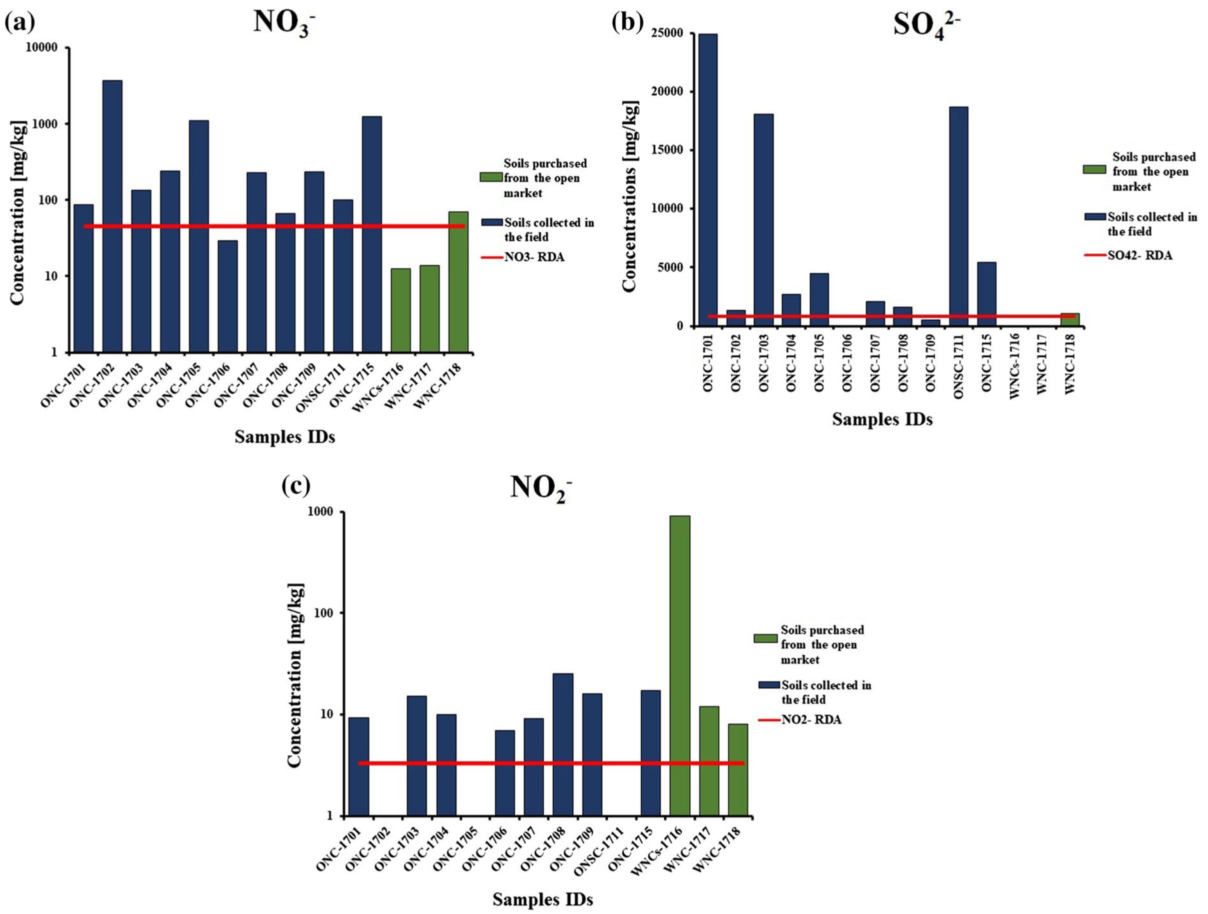

Fig. 7 **a–c** Anion concentration of geophagic material in relation to the RDA for pregnant women

harmful to human health. The potentially toxic elements' induced health effects (toxicity intensity) depend on various physical, biological and behavioural factors. This includes the element's concentration, dose, bioavailability and absorption rate within the human body, element's oxidation state, age, weight, gender, gestation state, soil pH, gastrointestinal pH of the human being, intake route, period of geophagic materials ingestion, elements interaction with other elements, as well as anions and diet of each individual (Ngole et al. 2010; Buck et al. 2016 and references therein). Further information on these aspects is presented in a more detailed literature review study by Kambunga et al. (submitted 2018). The sections below discuss the geochemical composition of the studied materials in terms of major and trace elements as well as anions, compare their concentrations to the RDA, and advance on the possible health effects based on some known examples from literature. In addition, soil pH and HRI results are also presented and discussed.

Potential health effects of the chemical elements present in the studied material

Potential positive health effects of the essential elements

Pregnancy is always accompanied by physiologic alterations that result in increased plasma volume and red blood cells, amplified energy demand and decreased concentrations of circulating nutrient-binding proteins and micronutrients (Picciano 1996; Ladipo 2000). These changes are responsible for many micronutrients deficiencies and micronutrients demands or supplements. The presence of essential

Fig. 8 Comparison of anion concentrations between the samples from the field (blue) and open market (green)

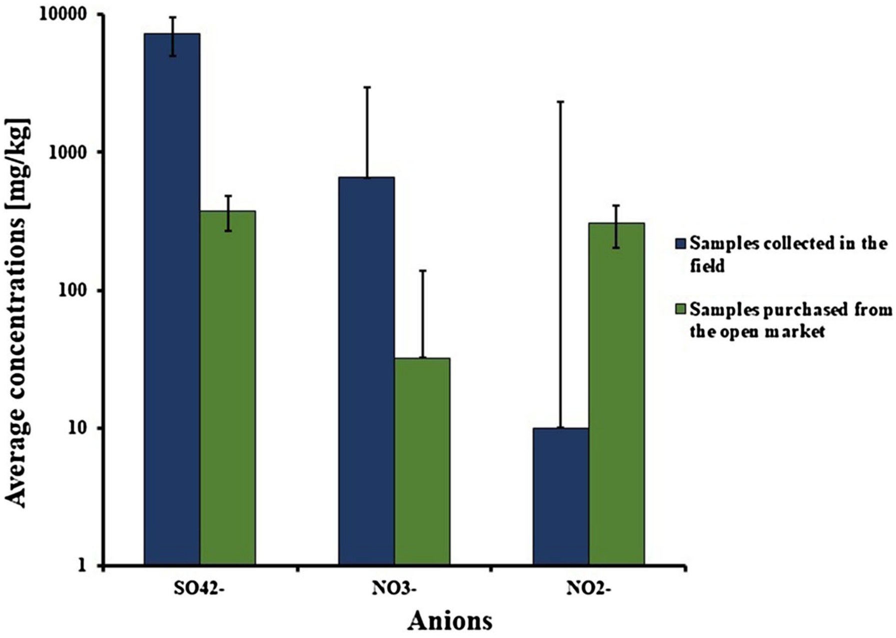

Table 5 Soil pH of the studied soil samples

Sample IDs	Soil pH
Samples collected in the field	
ONC-1701	7.45
ONC-1702	7.26
ONC-1703	7.49
ONC-1704	7.76
ONC-1705	7.57
ONC-1706	7.61
ONC-1707	7.64
ONC-1708	7.98
ONC-1709	7.54
ONSC-1711	8.17
ONC-1715	7.87
Samples purchased from the open market	
WNC$_S$-1716	3.85
WNC-1717	3.77
WNC-1718	7.92

Standard deviation is 1.42833

elements (Ca, Fe, Mg, Mn, K, Na, Cr and Ni) in the studied soils might supply nutrients to pregnant women depending on their availability and accessibility to the body.

Potential negative health effects

Major elements Aluminium (Al) is considered non-essential with no physiological function in the human body (WHO 1996). Reports relate its toxicity with bone and neurological disorders such as learning disorder and impaired spatial working memories (Kerr et al. 1992), external visceral, skeletal malformations and low birth rates (Paternain et al. 1988), growth retardation, foetal abnormalities, epilepsy, and inhibition of long term potentiation (Domingo et al. 2000; Kawahara et al. 2007). Al concentrations in the studied samples, especially the clay soil lumps (WNCs-1716 and WNC-1717) from the open market, are very high (up to 164,158 mg/kg) comparing to the RDA (Table 3, Fig. 3a). Although not all Al is absorbed by the human body, its bioaccumulation over time might, however, cause adverse health effects in pregnant women and their foetuses (WHO 1996). The result suggests that women consuming the samples purchased from the open market have a potentially higher health risk than those consuming the soil collected in the study area.

The same samples (WNCs-1716 and WNC-1717) as above contain the highest concentrations of K (up to 10,377 mg/kg) (Table 3, Fig. 3f). This element plays an important role in the maintenance of cellular fluid trans-membrane gradients, and movement of nerve

Table 6 Health risk indices of potential toxic elements in the studied soil

Element	Concentration$_{max}$ (mg/kg)	Mean consumption daily average (day^{-1})	PDI (mg/kg/day)	PMTDI (mg/kg/day)	HRI	Remarks
Al	164,158	0.002	328,316	1	328,316	Not safe
As	0.08	0.002	0.00016	0.0021	0.076	Safe
Cr	0.75	0.002	0.0015	0.005	0.3	Safe
Hg	0.05	0.002	0.0001	0.002	0.05	Safe
Mn	852	0.002	1704	2	852	Not safe
Ni	0.49	0.002	0.00098	0.08	0.012	Safe
V	2.45	0.002	0.0049	0.018	0.272	Safe

PDI is probable daily intake

PMTDI is permitted maximum tolerable daily intake

HRI is health risk index

The mean consumption daily is 150 g

Standard deviation is 124,038.4745

impulses and muscles (Rose et al. 2004; Sheng 2000). Despite its importance in the human body, excessive amount of K can result in a rare disease called Hyperkalaemia (Lehnhardt and Kemper 2011). This condition is associated with tissue damaging, rupture of blood cells, kidney damage, and heart arrhythmia (Lehnhardt and Kemper 2011). Other signs of K toxicity include drop in blood sugar level, which leads to sweating, headaches, weakness, trembling, and nervousness (Bhaskarachary 2011). Although the consumption of these geophagic materials might supply K to pregnant women, there is still a potential risk of K toxicity due to higher concentrations than RDA.

Sodium (Na) has important physiological roles as K, which involves the maintenance of cellular fluid trans-membrane gradients, and movement of nerve impulses and muscles (Sheng 2000; Doyle and Glass 2010). Na toxicity has been reported to increase the risk of heart failure (WHO 1979), permanent neurological damage in infants (Pohl et al. 2013), and to cause nausea, vomiting, convulsions, muscular twitching and rigidity, as well as cerebral and pulmonary oedema (DNHW 1992). Although pregnant women might obtain Na supplementation through the consumption of these soils, the high concentrations of Na (up to 11,202 mg/kg) observed especially in one of the clay soil lump samples (WNCs-1716) purchased from the open market (Table 3, Fig. 3h) might cause Na toxicity.

Silica (Si) is an essential component of the connective tissues in the human body (Murray et al. 2000). Its toxicity can lead to an erosive gastritis (the erosion of gastrointestinal (GI) lining), which may lead into internal bleeding and ulcers in the lining of the stomach (Barker 2005). The studied samples are all characterized by high concentrations of Si (up to 432,251 mg/kg) compared to the RDA (Table 3, Fig. 3e) especially in the termite mound purchased from the market (WNC-1718) suggesting a possible serious health hazard when consumed.

Calcium (Ca) is required during pregnancy in high content, as it is needed for foetuses' developmental functions such as skeletal formations (WHO 1996). Despite the fact that Ca is vital during foetuses' development, excess intake can cause renal insufficiency, vascular and soft tissue calcification for foetuses, Hypercalciuria, heart disease, kidney stones (NIH 2018), and constipation (Sizer and Whitney 1997). Although these geophagic materials may provide Ca upon digestion, the excessively high Ca concentrations (up to 71,756 mg/kg) in some of the samples collected in the field compared to the RDA for pregnant women (Table 3, Fig. 3b) might render them harmful. The low concentrations and absence of Ca in the open market samples suggest a lower Ca toxicity risk.

The need of iron (Fe) intake increases during pregnancy to accommodate foetal and placental growth, and cover for blood loss at delivery (Grieger and Clifton 2014). Fe supplementation is one of the most known motivations for pregnant women to practice geophagy (Haron et al. 2011). The studied samples contain high Fe (up to 19,373 mg/kg) comparing to the RDA during pregnancy (Table 3, Fig. 3c). The consumption of these samples in moderation might act as supplements of Fe to pregnant women. However, the practice of geophagy during pregnancy has been outlined as a major risk factor for anaemia during pregnancy. Although the studied soil samples contain high amount of Fe (up to 19,373 mg/kg), the bioavailability, which might lead to Fe toxicity is controlled by some mechanisms according to Young (2007) and Toker et al. (2009), which are:

1. The interference of Al and Hg with red blood cells production;
2. The reduction in Fe bioavailability due to the attraction and binding of nutrients by charged ions found in the geophagic materials;
3. Inhibition of Fe absorption due to damaged intestinal linings by tough geophagic materials;
4. The severe blood loss due to hookworm infection found in geophagic materials; and
5. Change in pH in the GI tract, which can either inhibit absorption of Fe if the pH raises or favours proliferation of microbes if the pH becomes alkaline.

Magnesium (Mg) is vital for the mineralization and development of the skeleton (Olivares and Uauy 2005). Despite its importance, Mg toxicity can cause confusion, low blood pressure and heart rate (Castiglioni et al. (2013). Although the studied samples may supply Mg to pregnant women upon ingestion, their higher concentrations (up to 6515 mg/kg) than the RDA (Table 3, Fig. 3d) suggest a potential health hazard depending on the amount consumed.

Manganese (Mn) is considered a trace element, which is required in small amounts for the function of human bodies. This element plays a role in the reproductive system, bone growth, and mental functions (USEPA 2003). Even though Mn is essential for the human body, its excess may lead to reproductive and respiratory problems (Aschner et al. 2005), and foetal neurological complications such as memory impairment, reduced learning capacity, decreased mental flexibility, cognitive slowing, and difficulty with processing visuo-motor and visuo-spatial information (Aschner et al. 2007). Therefore, the higher concentrations of Mn (up to 852 mg/kg) than the RDA (Table 3, Fig. 3g) in the samples collected in the field might lead to its toxicity.

Trace elements In this study, trace elements Cu, Ni, and Zn are selected for the discussion due to their importance during pregnancy for the development of the foetus (Ladipo 2000) and As, Cr, Hg, and V due to their potential toxic nature and high concentrations in the studied samples.

Studies have shown no evidence of arsenic (As) biological function and it is classified as carcinogenic to humans (IARC 2012). Several health issues were reported as a result of acute and chronic exposure to As toxicity specifically arsenite (As^{3+}) and arsenate (AS^{5+}), the most toxic forms of this element (WHO 2010; Saha et al. 2012). Commonly, As^{3+} is prevalent in anoxic conditions, while As^{5+} is in oxic soils; also in soils As^{3+} can occur as $As(OH)_3$ in acidic conditions and as an anion [$AsO_3{}^{3-}$] in alkaline ones; As^{5+} exists as an anion [$H_2AsO_4{}^{-}$ or $HAsO_4{}^{2-}$] in soils with normal pH (4–8) (Ruby et al. 1999). Among the most relevant health effects due to As toxicity to pregnant women are increased risks of gastrointestinal related issues (Civantos et al. 1995; WHO 2010), miscarriages (Sengupta et al. 2014), foetal mortality (Hood and Harrison 1982), low birth weight and skeletal malformed foetuses (Sengupta et al. 2014), mental growth retardation and low IQ level (Neeti and Prakash 2013). All the studied samples show over four times higher As concentrations (up to 0.08 mg/kg) than the RDA for pregnant women (Table 3, Fig. 5a). Therefore, the consumption of these materials especially the termite mound samples collected in the field, which contain the highest amount of As, can cause serious health issues to pregnant women and their foetuses over time.

The dominant oxidation forms of Cr in the environment are the trivalent (Cr^{3+}) and the hexavalent (Cr^{6+}) ones (Bartlett and James 1988). Cr toxicity is dependent on the oxidation state being Cr^{6+} classified as carcinogenic to humans and highly toxic to all forms of life (Megharaj et al. 2003). Cr^{6+} toxicity in humans has been linked to growth retarded babies with damaged blood cells, livers, nervous systems, and kidneys (MacKenzie et al. 1958; Waldron 1980). Cr^{3+} is considered an essential micronutrient for several organisms being fairly insoluble in water in opposition to Cr^{6+} that is very soluble and easily transported from soils to groundwaters (Megharaj et al. 2003). Cr^{3+} is required for the release of energy from glucose (Goldhaber 2003) and maintenance of the ribonucleic acid (RNA) molecule configuration (Eastmond et al. 2008). Although Cr concentrations are not high in all geophagic samples as compared to the RDA (Table 3, Fig. 5b), some samples contain high values than RDA (up to 0.75 mg/kg), which might lead to its toxicity when consumed over a long period of time. The samples collected in the field contain over seven times more Cr than the samples purchased from the open market. The latter indicates a lower Cr toxicity risk in the samples purchased from the open market.

There are no recognized functions of mercury (Hg) in the human body and is classified as carcinogenic to humans (ATSDR 1999). Methyl mercury (Hg^{2+}) is the most organic common species and toxic to human health (Silva et al. 2005) whereas when it comes to pregnant women, elemental and organic Hg are the most dangerous (Neeti and Prakash 2013). The most relevant possible health issues to pregnant that can be caused by Hg toxicity for pregnant women include infertility, miscarriage and prematurity, low libido and premenstrual syndrome (PMS) (Neeti and Prakash 2013), neurocognitive deficits such as reduced performance in tests and neuromotor disabilities, congenital malformations (Sikorski et al. 1987), and spatial cognition impairment in foetuses (Bose-O'Reilly et al. 2010). Among the studied geophagic materials, sample ONC-1702 collected in the field and the termite mound sample purchased from the open market show higher Hg concentrations (0.02 and 0.05 mg/kg, respectively) than the RDA for pregnant women (Table 3, Fig. 5c). Such high Hg concentrations might constitute a potential health risk to the consumers in the area.

Nickel (Ni) plays a role in the absorption of Fe by the human body, and is considered vital for strong skeletal frames building by strengthening bones and assisting in the breakdown of glucose (Nielsen 1985). Despite the vital biological function of Ni, toxicity exposures either in utero, during infancy, or childhood can result in miscarriages and musculoskeletal defects such as feet deformities (Vaktskjold et al. 2008). The high concentrations of Ni (up to 0.49 mg/kg) (Table 3, Fig. 5d) in some of the studied soils suggest a risk of Ni toxicity over time through the process of bioaccumulation.

Vanadium (V) has no specific role in the human body; instead it can cause distress to iodine intake (WHO 2001). The toxicity of V compounds is directly proportional to the increase in valances states; for example, V^{5+} is the most toxic (Barceloux and Barceloux 1999). The most known V toxicity results from airborne rather than from oral ingestion (Mukherjee et al. 2004). Nevertheless, its toxicity can cause depressed growth, diarrhoea, depressed food intake, death (Somerville and Davies 1962), anaemia (Hogan 1990), high blood pressure (Carmignani et al. 1991), fatigue (Barceloux and Barceloux 1999), and green tongue (Dimond et al. 1963). In all the studied samples, V is more than two times higher (up to 2.45 mg/kg) than the RDA (Table 3, Fig. 5e). These high concentrations in the geophagic materials collected in the field than those purchased from the open market; make them much more hazardous to the health of the consumers in the area.

Anions NO_3^- and NO_2^- play a physiological role in the vascular and immune function in the human body (Lundberg et al. 2009). NO_3^- and NO_2^- toxicity can result in a blood disorder in infants called methemoglobinemia, also known as a "blue baby syndrome", which if left unattended can cause brain damage and eventually death (ATSDR 2000). Other toxicity effects include gastric cancer, premature birth, low birth weight infants, birth defects, sterility, intrauterine growth restriction, and complications of pregnancy (Manassaram et al. 2007). The high concentrations of NO_3^- and NO_2^- (up to 1256.4 and 999.9 mg/kg, respectively) compared to their RDA (Table 3, Fig. 7a, c) in some of the studied samples present a high risk of their toxicity. The samples collected in the field suggest a higher NO_3^- toxicity risk than the open market ones. Conversely, the samples purchased from the open market unveil higher NO_2^- toxicity risk than those collected in the field.

Sulphate (SO_4^{2-}) is known for being essential in numerous cellular and metabolic processes in foetal development (Dawson et al. 2015). Regardless of its importance for healthy growth and development, excess SO_4^{2-} can cause foetuses abnormalities such as bone fractures and osteopenia conditions (Duffy et al. 2012; Mechcatie 2013), and hypocalcaemia in pregnant women (Duffy et al. 2012). The high concentrations of SO_4^{2-} (up to 24,917 mg/kg) compared to the RDA (Table 3, Fig. 7b) found in some of the studied samples present a risk of SO_4^{2-} toxicity. The samples collected in the field present a higher risk of SO_4^{2-} toxicity compared to the samples purchased from the open market.

Generally, the differences observed in the geochemistry of the samples collected in the field and those purchased from the open market suggest a greater health risk in the samples collected in the field. The geochemical differences indicate that the clay lumps from the open market and the soil collected in the field have different geogenic conditions. However, the geochemical composition of the termite mound soil sample (WNC-1718) purchased from the same market is nearly the same with those collected in the field. The latter might suggest the same source.

Soil pH

Soil pH measures the acidity or alkalinity of the soil. Many chemical reactions are pH dependent; hence, knowledge of the pH can be used to access the likelihood of the extent and speed of chemical reactions (Candeias et al. 2014; Van Reeuwijk 2002).

In acidic conditions, metals and contaminants in soils matrix are more soluble (Oomen et al. 2002; Gibson et al. 2015) and their bioavailability and bioaccesibility for incorporation in biological processes increases as pH decreases (John and Leventhal 1995). In the GI tract, the solubility of chemical elements increases with a decrease in pH (Young et al. 2007). The ingestion of materials causes the increase in the GI tract pH up to 6, which can lead to a potential decrease in the bioaccessibility of compounds. However, the GI tract pH normal values are attained back even with some ingested materials still in the GI tract (Oomen et al. 2002). In vitro digestion models experiments indicate that the main parameter affecting bioaccessibility of ingested materials in a soil matrix is the gastric pH and the presence of dietary elements (Oomen et al. 2002; Ljung et al. 2007). According to Sherwood (1995), geophagic soils with high pH values (mostly alkaline) may not have a noticeable impact on elements and nutrient release in the GI tract.

Furthermore, dissolved salts and pH are responsible for the taste of the geophagic materials, which can be sour in the case of acidic soil (Diko and Ekosse 2014). These sour soils are most commonly selected by pregnant women in Kenya and Nigeria, being purported to be capable of preventing excessive saliva secretion and reducing nausea during pregnancy (Ibeanu et al. 1997; Diko and Diko 2014). Although the current studied samples are not acidic, the preference of sour soil might be given to those with a weak alkalinity such as some of the termite mounds samples collected in the field (sample ONC-1701: pH of 7.45, ONC-1702: pH of 7.26, ONC-1705: pH of 7.57, and ONC-1709: pH of 7.54).

Non-carcinogenic health risk indices

Although most of the HRI for individual elements is less than 1, the cumulative effects of these elements are significant. Additionally, the HRI depends on the body weight, the unique GI characteristics of each individual, and the quantity of soil consumed per day. Individuals have different body weights and responses and the quantity of soil consumed per day varies depending on the soil consumption motivations. Therefore, the HRI might underestimate the health risk.

Concluding remarks

The present study, which focuses on a detailed geochemical analysis of geophagic material from Onangama village, northern Namibia, revealed important compositional characteristics, which can induce serious health implications to the consumers in the area, especially pregnant women. These are:

- The studied geophagic material might supply essential elements such as Ca, Fe, Mg, K, Na, Mn, Ni, S, and Si to pregnant women and their foetuses upon ingestion. However, the presence of high concentrations of elements such as As, Cr, Hg, V, and Al in these materials can cause potential health risks due to their toxicity.
- Except for K, Mn and Na, which are present in high concentrations only in some samples, all other major elements including Mg, Fe, Si, Mn and Ca are present in high concentrations in all the studied samples comparing to their RDA.
- V, Cr, Ni, As, Mn, SiO_4^{2-}, NO_3^-, and Ca, are significantly higher (especially V and SiO_4^{2-}) in the termite mounds samples collected in the field comparing to those purchased from the market.

- Al, Hg, K, Na, and NO_2^-, are significantly higher in the open market samples comparing to the samples collected in the field.
- Fe, Mg and Si are nearly the same in all the studied samples.
- The two clay samples (WNCs-1716 and WNC-1717), purchased from Tukondjeni open market in Windhoek, which were imported from Angola according to the vendor, show a significant difference in their chemical composition mainly in terms of Al, Ca, K, and SO_4^{2-} comparing to the rest of the samples. This might confirm the statement of the vendor that they do not come from the same locality as the rest of the studied samples. However, the termite mound sample (WNC-1718) purchased from the same open market has nearly the same composition as those collected from the field, suggesting that it might have been sourced from the study area.
- The geochemical composition of the samples collected in the field suggests that a potential health risk to the consumers in the area might be more substantial than that of the purchased samples from the open market. This poses a greater health risk because samples in the field (which show high risk) are readily (more) available than those in the open market.
- The soil pH of all the studied geophagic materials is higher than the GIT pH, which might increase the GIT pH upon ingestion leading to a temporary reduction in the bioaccessibility of chemical elements present in the geophagic materials.
- Although only Al and Mn showed a potential health risk based on the HRI calculations, this latter (HRI) might underestimate the health risks associated with the other potential toxic elements due to its influence based on the body weight, individual GI tract characteristics and dose rates.

Based on the present geochemical investigation, it can be concluded so far that the frequent consumption of the studied geophagic materials might constitute a potential health hazard for pregnant women in the area. However, in order to verify the possible health issues that are known from literature, the type and magnitude of these issues, which might result from the consumption of such material, a thorough health investigation on pregnant women in the area is necessary. Additionally, experiments need to be performed with these geophagic materials for a better understanding of elements bioavailability and bioaccessibility to pregnant women.

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