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Geophagy and its potential human health implications - A review of some cases from South Africa

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ABSTRACT

The complex human behaviour of eating earthy materials is known as geophagy. It is of worldwide concern because of its potential health implications associated with the practice. South Africa is one of the developing countries where geophagy is predominant with several motivations attributed to justify the practice. However, the aetiology and possible health risks of geophagy are poorly understood among the geophagic individuals. Some published articles of geophagy focuses on aspects of the source materials (.i.e., physicochemistry, mineralogy and geochemistry characteristics of the ingested earthy material) with reference to possible health impacts, whereas others focused on its prevalence and practices. Inadequate investigations are available for holistic interpretations focusing on the prevalence of geophagic practices, and characterising the source material with the related health risks when consumed. This review aims to fill the knowledge gap by detailing some findings on published works of geophagy and how human health can be affected by such practice conducted in five South African provinces (i.e., Limpopo, Kwazulu-Natal, Free State, Eastern Cape, and Gauteng) where it is prevalent. The present review also aims to minimise and promote health educative awareness about geophagy among consumers and general public, as well as the need for more holistic studies of the earthy material ingested (including all aspects of composition, biological, and physico-chemical properties as well as bioaccessibility and bioavailability of the consumed material) and its potential human health risks.

1. Introduction

Geophagy or geophagia is related to the voluntary and continuous ingestion of earthy materials, that include rocks, soils/sediments, and clays, both by humans and animals (Kambunga et al., 2019a and references therein). The practice has been reported as early as the fourth century among different communities around the globe (Ekosse et al., 2010, 2017), including developing countries (Brand et al., 2009; Ngole-Jeme and Ekosse, 2015) especially in Africa. Though commonly practiced among pregnant women (Macheka et al., 2016; Kambunga et al., 2019a), women of all ages, educational level, and social status equally engage in the habit (Songca et al., 2010; Malepe, 2022). The practice has been associated with a number of reasons which include an inbuilt response to malnutrition (nutrient supplementation), relieves gastrointestinal (GI) disorders such as nausea and diarrhoea, and creates a barrier effect against toxins and pathogens as recently summarized by Malepe (2022).

In some African countries, the Chaggas people of Tanzania consider geophagy sacred for women (Orisakwe et al., 2020); in Yorubas of Nigeria, earthy materials are used to cure different diseases such as dysentery and cholera highlighting their medicinal value (Momoh et al., 2015); in South Africa, it is common for women to associate soil ingestion with aesthetic benefits (Matike et al., 2011) as well as its therapeutic effects (Malepe, 2022); in Namibia, pregnant women consume soil because of its antinausea effects (Kambunga et al., 2019a). There are socio-economic and cultural groups that consider the practice of geophagy by pregnant women a promoting factor for the dark skin pigment in infants (Getachew et al., 2021; Bernardo et al., 2022).

The practice of geophagy can be detrimental to the health implicated with severe health threats such as damage to the dental enamel, nutrient deficiency, rupture and perforation of the sigmoid colon, impacts on a foetus in pregnant women (Kambunga et al., 2019a, 2019b; Malepe, 2022), and a possible source of potentially toxic elements and micro-organisms (Phakoago et al., 2019; Bonglaisin et al., 2022). The extent and severity of health effects, either positive and/or negative of geophagy cannot be based on theories or speculations when the nature

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of the consumed geophagic material is not known or studied. Therefore, it is important to assess and understand the nature and composition of the consumed materials by characterising them in terms of their physico-chemical properties, and compositions (mineralogical and geochemical).

South Africa is one of the developing countries where human geophagy is entrenched and commonly practiced in several provinces, including Limpopo, Kwazulu-Natal, Free State, Eastern Cape, and Gauteng. Its prevalence is cut across people of all ages, cultural and socio-economic backgrounds, ethnic groups, gender, and religious affinities (Abrahams, 2002). This review focused mainly on the published articles from the provinces mentioned above on (i) the human geophagy surveys focusing on the prevalence and practice of geophagy and their causative reasons for consumption; (ii) the nature and composition of the consumed materials; and (iii) associated health effects that might arise upon consumption.

2. History of human geophagy

Human geophagy has been around since prehistoric times and is practiced worldwide (Walker et al., 1997; Ghorbani, 2009). The practice has been reported since Roman and Greek times (Woywodt and Kiss, 2002). Hippocrates (460 – 377 BC) made the first known medical mention of geophagy about the desire of pregnant women to engage in the practice (Young et al., 2010). Other ancient authors also reported that geophagy had soothing effects, being used as a remedy for ulcers, easing stomach distresses (diarrhoea), and menstrual cramps (Woywodt and Kiss, 2002).

During the middle age (980 – 1037 AD), imprisonment to cure geophagy in young boys was recommended (Roselle, 1970), but more gentle treatment was recommended during pregnancy (Kipel, 1993). Reports indicated that the practice was often observed as a chlorosis symptom and spread widely throughout Europe during the 16th century (Woywodt and Kiss, 2002). According to Parry-Jones and Parry-Jones (1992), chlorosis, also known as *febris alba* is a malnutritional disorder or green sickness mainly affecting teenage girls.

During the 17th century, "terra sigillata" was commonly used, a sacred earth that facilitates childbirth and alleviates menstruation disorders (Woywodt and Kiss, 2002). Geophagy remained common in Europe during the 18th and 19th centuries and is still observed among young girls with chlorosis (Woywodt and Kiss, 2002). Geophagic customs in natives of South America dried earth and piled up in heaps to be consumed during periods of famine (Parry-Jones and Parry-Jones, 1992). In Africa, "safura," a disease of earth-eating among the slaves of Zanzibar, was found (Woywodt and Kiss, 2002). Poverty was thought to be the possible explanation for the behaviour, but this theory was rejected after observing that wealthy people were also affected.

3. Prevalence and practice of geophagy in South Africa

Several authors have documented the prevalence of geophagy in different provinces of South Africa (George and Abiodun, 2012; De Jager et al., 2013; Msibi, 2014; Momoh et al., 2015; Macheka et al., 2016), namely, Limpopo, Gauteng, Kwazulu-Natal, Free State and Eastern Cape (Fig. 1). The practice of geophagy has been reported, mainly in the eastern and central parts of South Africa. Table 1 summarizes the reported case studies on human geophagy in South Africa with reference to their province and region.

Table 1
Summary of studies conducted on human geophagy in South Africa.

Province	Region	References
Limpopo	Sekhukhune District, Polokwane, Vhembe District, Siloam village, Mashau village	Nwafor (2008); Ekosse et al. (2010); Momoh et al. (2015); Phakoago et al. (2019); Mashao (2018); Ravuluvulu (2018)
Free State	Thabo Mofutsanyane District (QwaQwa), Mangaung	Perridge et al. (2011); De Jager et al. (2013); van Onselen (2013); Raphuthing (2015)
Kwazulu-Natal	Durban, Mkhanyakude District, uMzinyathi, and uMgungundlovu Districts	Rajcoomar, 2011; Msibi, 2014; S'khosana, 2017
Gauteng	Pretoria, Johannesburg	Mathee et al. (2014); Macheka et al. (2016)
Eastern Cape	Oliver Reginald (OR) Tambo District Municipality, Transkei, King Sabatta Dalyndyebo Municipal area	George and Ndip (2011); George and Abiodun (2012)

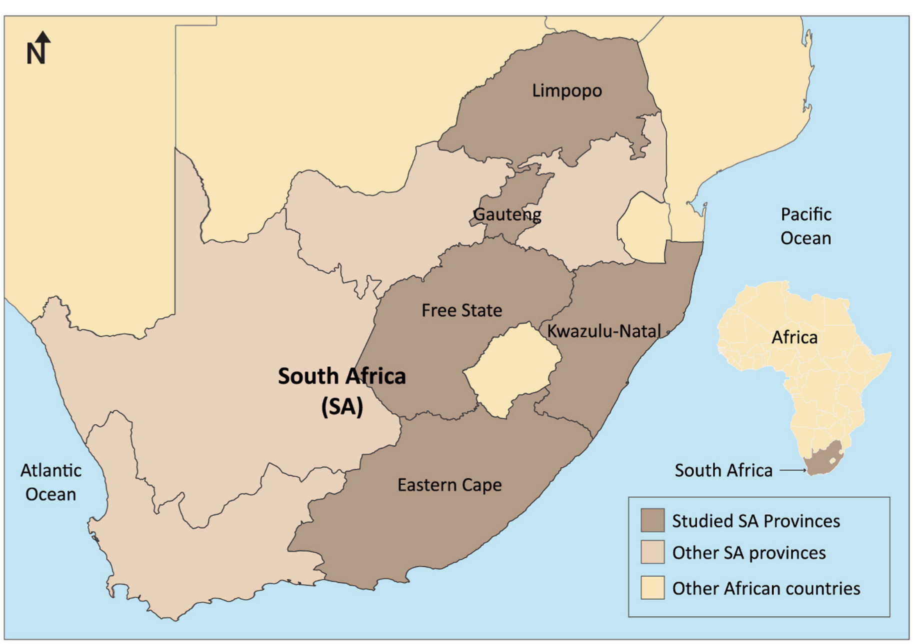

Fig. 1. A map showing the provinces of South Africa where geophagy is commonly practiced and reported.

3.1. Prevalence

In general, pregnant women are the group with higher geophagic prevalence in South African Provinces (Olowoyo and Macheka, 2013). Geophagy in pregnancy (GiP) is considered a cultural phenomenon embedded in indigenous knowledge (Njiru et al., 2011). A higher prevalence of GiP was observed in women from South Africa (80.5% prevalent rate) than in immigrant women (Mathee et al., 2014). A quantitative survey carried out in an antenatal clinic in Pretoria (Gauteng Province) revealed that up to 54.0% of females confirmed practicing geophagy, from a total sample of 597 pregnant women (Macheka et al., 2016). Another study by George and Abiodun (2012) conducted in three primary health care antenatal clinics in Eastern Cape Province reported a lower percentage (36.7%) of GiP than non-pregnant women (63.3%) from a total of 210 women. Studies conducted in Free State Province showed that the practice is more common in females, with a prevalence rate of 60.9% and 56.6%, as reported by van Onselen (2013) and Raphuthing (2015), respectively. In Kwazulu-Natal Province, Msibi (2014) reported a 100% prevalence of geophagists among females (n = 94), with only 3.2% pregnant. A more recent work by S'khosana (2017) indicated that up to 51.6% of females from the uMgungundlovu and uMzinyathi districts (Kwazulu-Natal Province) reported practising geophagy.

Geophagy in children is considered a normal behaviour among toddlers between 18 and 24 months and young children aged 2–6 years (Bisi-Johnson et al., 2010; Ravuluvulu, 2018). Nwafor (2008) and Phakoago et al. (2019) further explained that children accidently consume geophagic materials because of curiosity or as a way to explore their surroundings by putting their hands or any objects in their mouths (hand-to-mouth behaviour). There is little literature documenting on children involved in the practice in South Africa. In the case of the Kwazulu-Natal Province, the prevalence of geophagic practices in rural school children was less frequent in boys (39.0%), decreasing with age (Saathoff et al., 2002). These authors concluded that the practice was more common in children from families of higher socio-economic status. In addition, Rajcoomar (2011) reported a higher prevalence of geophagy in children (50.0%) in comparison to adults (46.7%) in this province, with only 3.3% not consuming geophagic materials. This is concomitant with the findings by Simpson et al. (2000), that geophagy appears to be more common in children than in adults.

According to Geissler et al. (1999), the practice of geophagy in teenage and adult males from developed countries has rarely been documented. This is because they possibly feel ashamed and very secretive about this practice (Luoba et al., 2004). The study findings carried out by Phakoago et al. (2019) contrasted with the statement made above, where men, especially those from the Mphanama village in the Limpopo Province, were neither secretive nor ashamed to reveal their practice. The percentage of male consumers of geophagic materials is very small (1.5%) compared to that of females (98.5%), on the study by Mashao (2018), conducted in the Limpopo Province.

3.2. Aetiology

According to a study conducted by Phakoago et al. (2019), geophagy appeared to be a normal daily practice in the Ga-Nchabeleng and Mphanama villages (Limpopo Province), with numerous motivations put forward to explain its practice. Geophagy is emanated from children having seen their mothers or close relatives consuming geophagic materials (Msibi, 2014). The practice is passed from generation to generation due to cultural and traditional beliefs, medicinal and physiological values, and psychological behaviour (Geissler et al., 1999).

Geophagy is considered a culturally sanctioned practice in many communities (George and Ndip, 2011), observed mainly during pregnancy (Bisi-Johnson et al., 2010). Research conducted in South Africa found that pregnant women tend to believe that soil eating protects the foetus from harmful substances (Nwafor, 2008) and prevents prolonged childbirth (Mathee et al., 2014). Geophagy during pregnancy is also believed to soothe "morning sicknesses" - a feeling of discomfort, nausea, and vomiting usually during the first trimester (George and Abiodun, 2012; Msibi, 2014) and makes the foetus look beautiful (Mashao, 2018). South African geophagic women from urban areas believe that consuming soil enhances their beauty by softening and lightning their skin (Songca et al., 2010).

Geophagy is usually associated with a physiological response to mineral nutrient deficiencies (George and Ndip, 2011). In most cases, cravings for earthy materials usually occur when the demand for nutrients is higher, especially during pregnancy. For example, a research work carried out by George and Abiodun (2012) in the Eastern Cape Province, revealed that 80.0% of pregnant women indulge in geophagy as they believe that earthy materials provide essential nutrients required during pregnancy. Geophagic soils obtained from the termitaria are usually enriched in calcium and iron (Ekosse et al., 2010). In the Vhembe District (Limpopo Province), reddish-brown soils are believed to prevent Fe deficiency (Momoh et al., 2015).

Geophagic materials are commonly ingested as a possible remedy to cure various diseases (Moagi, 2010; Msibi, 2014). In the Limpopo Province, geophagic individuals from the Sekhukhune area believed that eating soil eliminates diarrhoea (Phakoago et al., 2019). Studies in certain areas in this province reported that geophagic women seek traditional doctors to administer earthy materials during pregnancy (Ravuluvulu, 2018; Phakoago, 2017). This trend is also observed in the Gauteng Province, where 3.9% of pregnant women used traditional African medicines to facilitate prolonged childbirth and promote good and healthy pregnancy (Mathee et al., 2014). In addition, a study by De Jager and Ekosse et al. (2011) observed that traditional healers suggest using geophagic clays in wet or dry forms, along with other medicinal herbs.

4. Geophagic materials in South Africa

Studies in South Africa revealed that the majority of geophagic individuals from rural areas mostly obtain their earthy materials from, e.g., hills or mountains, garden and yard soils, termitaria or riverbeds, and excavation sites, whereas those in urban areas mainly purchase materials from street vendors or local markets (Ekosse et al., 2010; George and Ndip, 2011; Mogongoa et al., 2011; Olowoyo and Macheka, 2013; van Onselen, 2013; Mathee et al., 2014; Momoh et al., 2015). However, in the case of rural areas of Sekhukhune (Limpopo Province), 84.2% of consumers preferred soils purchased from the local markets (Phakoago, 2017). In the Kwazulu-Natal Province, geophagists preferred dry soils as they occur naturally and can be obtained free (S'khosana, 2017).

The most common geophagic materials preferred by consumers appear to be clays, mud, termite mounds, soils, and soft or white crushed stones. These materials are known by their local or native names, differing with locality and tribe (Table 2). Geophagic soils from the Free State Province are traditionally named *mobu*, *sweets*, *dipompong*, or *rama*

Table 2
Some of the native names of geophagic materials documented in South Africa.

Province	Tribe	Native Name	Geophagic Material	Reference
Limpopo	Pedi	Mohlwa	Termite mound	Nwafor (2008)
		Mataga	White stones	
		Mobu	Soil	Ekosse et al. (2010);
		Letsopa	Clay	Phakoago et al. (2019)
		Leraga	Mud	
	Venda	Vumba	Clay	Momoh et al. (2015);
		Munyaka	Soil	Mashao (2018)
Free State	Sotho	Mobu	Soil	Perridge et al. (2011)
Kwazulu-Natal	Zulu	Isidulu	Termite mound	Msibi, 2014
		Ibumba	Clay	S'khosana (2017)

(Perridge et al., 2011). In the Kwazulu-Natal Province, are known as *Isidulu, umuhlwa, and ibumba* (S'khosana, 2017). In other areas of the Limpopo Province, earthy materials are called *munyaka* and *vumba* from the Venda tribe (Momoh et al., 2015), whereas *mobu* and *letsopa* from the Pedi tribe (Phakoago et al., 2019).

The physical and chemical properties of geophagic materials play a significant role in the accessibility of nutrients (Ngole and Ekosse, 2012), which may help interpret physiological and nutritional aspects of geophagy (Ngole et al., 2010). According to a study conducted by Mashao (2018), colour is the first property that appeals to consumers, which indicates mineralogy or the presence of organic matter. In the Free State Province, freshly mined topsoil and excavated soils in the Thabo Mofutsanyane District, generally present a brownish colour (Perridge et al., 2011). The study concluded that this might be attributed to the absence of processing and/or heat treatment. Most of the studied geophagic clayey soils from South Africa were greyish to yellowish, corresponding to the colour of hematite and goethite (Ngole et al., 2010). Clayey soils with yellowish-brown colour, suggest the presence of organic matter (Okereafor et al., 2016). In the Mashau village of the Limpopo Province, the most preferred soils were brown to reddish (Mashao, 2018).

The texture is another important property for geophagic individuals, usually with a preference for soft, silky, and powdery materials (Diko and Ekosse, 2013). Okereafor et al. (2016) conducted a study in selected informal open markets in South Africa and found that geophagic clayey soils were dominated by clay-sized particles with some silt and very fine sand particles. Research by Mashao (2018) in the Limpopo Province, found that geophagic clayey soils were sandier, especially those from Doli village. George and Ndip (2011) revealed that clay texture influenced the cation exchange capacity (CEC), being higher than in loam sands, sandy loam, sandy clay loam, and sandy clay in the Eastern Cape Province. Ngole et al. (2010) found that geophagic clayey soils were texturally dominated by silty clay.

According to Diko and Ekosse (2013), the taste of geophagic materials is influenced mainly by their pH and the dissolved salt content. A study by Olowoyo and Macheka (2013) revealed that the pH of the geophagic soil samples was mostly acidic. Geophagic soil samples obtained from traditional mine sites in South Africa showed that the soil samples were generally acidic, with pH ranging from 3.1 to 6.1 (Diko and Diko, 2014). Similar findings by Msibi (2014) and Okereafor et al. (2016).

Electrical conductivity (EC) is indicative of the amount of dissolved salts present in clays and soils (Ngole et al., 2010). Diko and Diko (2014) and Mashao (2018) found that most of the studied geophagic materials exhibited low EC values, suggesting low dissolved salts content. The findings of a study by Okereafor et al. (2016) were in contrast with the study findings conducted by Diko and Diko (2014) and Mashao (2018), where the geophagic soil samples exhibited a very high EC.

Research work conducted by Perridge et al. (2011) in the Free State Province showed that 32.7% of the soil samples yielded a fungal structure, indicating that the consumed material was rich in organic matter (OM). Another recent work by Okereafor et al. (2016) revealed that the degree of OM content in the geophagic clays was low. This may infer a low pathogen load in the samples, and the danger of bacterial infection when consuming these samples is also slim.

4.1. Mineralogical composition

According to Young et al. (2008), mineralogy is relevant to geophagy's nutritional and protective hypotheses. It may indicate whether clay will bind with dietary micronutrients like Fe or Zn or if it can absorb toxic chemicals, viruses, or bacteria. Ekosse et al. (2010) analysed the mineral content of 40 geophagic clay samples from the Limpopo and Free State Provinces. The mineral phases identified in the clay samples were kaolinite, illite, mica, quartz, and feldspars, which represent the genesis of the mineral of the species. Mineral phases identified in the geophagic soils from a research work carried out by Ngole and Ekosse (2012), included quartz (dominant), kaolinite, plagioclase (albite and anorthite), hematite, microcline, muscovite, illite, and smectite.

Okereafor et al. (2016) revealed that kaolinite was the main clay mineral, alongside muscovite, andesite, and fayalite in the studied geophagic clayey soils sold in selected South African informal markets. In contrast, quartz was the only non-clay mineral identified. Ekosse et al. (2017) analysed the mineralogical constituents of geophagic material samples from the Free State Province. Results showed an abundance of quartz and smectite. Ngole-Jeme and Ekosse (2015) found that quartz content was higher in samples from South Africa than those collected in other countries (Swaziland and the Demographic Republic of Congo), which may influence the sorption capacity. The study further showed that the content of Fe-bearing minerals, like hematite, goethite, and siderite, was relatively low, suggesting that soil samples might be low in Fe.

4.2. Geochemical composition

The total chemical analyses provide useful information about nutritional relevant element content in the geophagic materials, significant in the context of hypotheses relating geophagy to micronutrient deficiency (Young et al., 2008; Bonglaisin et al., 2022). Geochemical composition is considered significant for assessing the possible health effects of consuming geophagic materials.

A study by Mashao (2018) revealed the presence of Ca, Cr, Fe, K, Mg, Mn, Na, and P in geophagic soils from the Mashau village. Ekosse et al. (2017) characterised the geophagic soils consumed in the Free State Province to understand their elemental composition and weathering intensity. Outcomes of the study showed that the major dominant oxides were SiO_2 and Al_2O_3, whereas very high chemical index alteration (CIA) and chemical index weathering (CIW), suggesting an extreme and intense silicate weathering environment.

The intake of each chemical element in the human diet should be within the accepted or recommended daily allowance (RDA) standards for body function (Brevik and Burgess, 2015). However, deviation from daily consumption (either an increase or decrease) can result in element deficiency or toxicity in the human system. Paracelsus (1493–1541 AC) stated that "all substances are poisons; there is none which is not a poison; the right dose differentiates a poison and a remedy."

Msibi (2014) studied Zn content in soil samples from Somkhele (15.00 mg/kg), Ibomvu (1.94 mg/kg), Tin town (1.57 mg/kg), and Mbhodla (1.20 mg/kg), while samples from Bhambanana (0.08 mg/kg) had low Zn concentration, being concluded that these soils did not meet the RDA standards. Research carried out by Olowoyo and Macheka (2013) reported concentrations of Al (60.04–169.3 mg/g) and Pb (21.8–36.7 μg/g) higher than the RDA. Moreover, in a study conducted in the Gauteng Province by Fosso-Kankeu et al. (2015) reported that the amount of leached metals such as Pb (0.06–3 mg/L), Ni (0.06–1.5 mg/L), and Co (0.001–0.60 mg/L), exceeded the adequate daily intake standard limit for body functions of 20 μg/L, 0.025–0.03 mg/kg, and 0.002–0.1 mg/kg, respectively.

Health risk assessment estimates possible adverse health effects that may occur over a specified period upon ingesting the geophagic materials (Nkansah et al., 2016). Hazard quotient (HQ) and total chronic hazard index (HI), when >1 indicate a potential health risk of non-carcinogenic diseases associated with overexposure, whereas HQ and HI < 1 suggest no health risks upon ingestion (Candeias et al., 2020). Olowoyo and Macheka (2013) suggested that geophagic individuals might be at risk of health outcomes when consuming studied soil samples with HQ > 1, mostly due to Mn, Pb, and Fe content. A study carried out by Ngole-Jeme et al. (2016) in South Africa reported non-carcinogenic hazard >1 related to Pb concentration. Carcinogenic risk was also estimated, and As and Ni content were above the unacceptable value of 1×10^{-4}. The study concluded that adults and children ingesting these geophagic materials are at risk of developing cancer in their lifetime.

There are various in vitro and in vivo methods that have been developed and used to assess the oral bioavailability and bioaccessibility of elements from the consumed geophagic materials. Bioavailability is defined as the proportion of an ingested nutrient absorbed and consequently distributed throughout the body (Young et al., 2008), whereas bioaccessibility is the fraction of the element that is mobilised from their matrix in the GI tract and becomes potentially available for intestinal absorption (Momoh et al., 2013; Candeias et al., 2021). These may depend largely on factors, such as, the pH, forms or chemical nature of the elements, and body weight of the geophagic individuals (Olowoyo and Macheka, 2013).

Research by Fosso-Kankeu et al. (2015) simulated the metal mobility and availability of geophagic clays, As, Cr, Cd, Zn, Pb, Ni, Se, Cu, and Mg, exhibited different mobility during leaching. Extraction using simulated gastric fluid, suggested that ingesting geophagic clays represented a potential risk. The two-stage physiologically based extraction test (PBET) simulate the human stomach and intestine to estimate elements bioaccessibility. Momoh et al. (2013) conducted a study in Limpopo Province, finding that Mn bioaccessibility fractions were similar in both the stomach and intestine. In contrast, Fe and Zn were higher in the stomach condition, and Cu was bioaccessible only in the intestine conditions. The study concluded that geophagic materials might provide a significant source of Cu and Mn. In contrast, the studied samples could contribute to Fe and Zn's daily recommended nutrient intake (RNI). Ngole-Jeme et al. (2016) showed that, with the exception of Co in studied geophagic soil samples, the bioaccessibility of all trace elements, including As, Cd, Cr, Mn, Ni, Pb, and Zn, was higher in the stomach phase than in the intestinal phase. These observed differences could be attributed to the compositions of the sources of these soil samples (host rocks) as well as the soil properties such as pH, texture and total organic carbon content.

5. Health outcomes

According to Gevera and Mouri (2021), the practice of geophagy may have harmful or beneficial effects on human health depending on the nature and composition of the consumed materials. The latter may also depend on the element of interest, how much material is consumed (dose), how often (frequency), and the bioavailability (Mashao, 2018; Malepe, 2022). Geophagy has been traditionally associated with medicinal treatment and remedy for certain diseases as well as supplementation of mineral nutrients (Van Wyk, 2013). Despite the beneficial aspects of geophagy, this practice may expose geophagic individuals to various health implications.

5.1. Potential health benefits

According to Johns and Duquette (1991), human geophagy maintains homeostasis by correcting mineral nutrient imbalance because geophagic soils contain large quantities of both macro and micro mineral nutrients. In addition, Msibi (2014) emphasised that if a significant amount of the mineral elements found in the soils are bioavailable after consumption, they will contribute to mineral nutrition and alleviate mineral deficiencies.

Soils that are mainly used for geophagy contain much-needed mineral elements such as Fe, Zn, Cu, Mg, and Mn (Ngole et al., 2010). For instance, the presence of Ca, Cr, Fe, K, Mg, Mn, Na, and P in geophagic soils from the Mashau village might be a potential source of mineral nutrients (Mashao, 2018). Of these nutrients, Na, K, Mg, Ca, and P are classified as macronutrients required in amounts of >100 mg/d, whereas Fe, Mn, and Cr are micronutrients required in amounts of <100 mg/d (Soetan et al., 2010). Fosso-Kankeu et al. (2015) study reported that geophagic clays could serve as a nutritional supplement by providing Fe from goethite [FeO(OH)], Ca, and Mg from smectite minerals $[(Na,Ca)(Al,Mg)_6(Si_4O_{10})_3(OH)_{6-n}(H_2O)]$.

Moreover, soils have been associated with healing common GI tract illnesses because they possess medicinal properties (Msibi, 2014). Ngole et al. (2010) and Ekosse et al. (2011) showed yellowish soils (enriched in goethite and hematite) and white clays (enriched in kaolin and smectite). Kaolinitic and smectitic clays have been used by pharmaceuticals to prevent nausea and vomiting (Young, 2007) and alleviate GI discomfort related to diarrhoea (Slamova et al., 2011; Ngole and Ekosse, 2012). These clay minerals have the aptitude to bind with mucus in the intestinal mucosa, causing intestinal linings to be impermeable to toxins, pathogens, and other harmful substances, thus creating a protective coat on the intestines (Young et al., 2010; Gevera and Mouri, 2021). This coating further protects the intestines from acidic gastric juice and prevents stomach ulcerations (Ngole et al., 2010).

Okereafor et al. (2016) study from chosen casual markets in South found that geophagic clayey samples were dominated by clay-sized particles with some silt and very fine sand particles. The study suggested that these geophagic samples possess a high surface area that allows them to absorb much more water, supporting the medicinal hypotheses that geophagic soils tend to curtain diarrhoea and other GI ailments. Clays can also play a role in reducing heartburn because of their alkaline properties (Myaruhucha, 2009).

A study conducted by Diko and Diko (2014) assessed the ability of geophagic soils obtained from traditional mine sites in Cameroon and South Africa, to relieve morning sickness (nausea and vomiting during pregnancy), and found that studied samples were suitable for use as a remedy. The findings suggested that soil samples from South Africa were generally acidic, with pH ranging 3.1–6.1, while human saliva varies between 5 and 8. Thus, consuming these soil samples could reduce pH in the mouth and thereby increase acidity in the oral cavity, which may decrease salivation. In case of other provinces in South Africa, Msibi (2014) and Okereafor et al. (2016) found that the pH of geophagic samples was acidic and thus, would impart a sour taste. These studies further suggested that sour taste might be beneficial to prevent excessive secretion of saliva and reducing nausea during pregnancy.

5.2. Potential health threats

Despite the beneficial aspects of geophagy, most geophagic individuals are unaware of the detrimental health effects resulting from this practice. Soil may influence on the bioavailability of elements resulting in element deficiencies, heavy metal contamination or toxicity, geohelminths infections, and damage to the dentition and gastrointestinal lining (Saathoff et al., 2002; Ekosse et al., 2017).

According to Young (2007), dentists can identify geophagic individuals by excessive tooth abrasion, cracks, decay, and a rare damage pattern to the tooth surface. Ngole et al. (2010) found that geophagic clayey soils were texturally dominated by silty clay, and a considerable amount of sand may present some health risks. The study further emphasised that sand particles may impart an undesirable gritty feeling during ingestion because fine sand particles of quartz and feldspars, may negatively affect the teeth. Ekosse et al. (2017) analysed the mineralogical constituents of geophagic samples from Free State Province. Results indicated that geophagic soils have abundant quartz and smectite content. Quartz has a hardness of 7 on the Mohs scale, higher than the dental enamel; hydroxylapatite $[Ca_5(PO_4)_3(OH)]$ - a calcium phosphate mineral with a Mohs hardness scale of 5. During mastication, these could damage and/or destroy the dental enamel through grinding, cracking, splitting, and breakage.

According to Ngole and Ekosse (2012), the morphology of coarse quartz particles varying from angular to very angular coarse particles, is another potential health risk associated with geophagy. Ekosse et al. (2010, 2017) highlighted that angular coarse silica particles present in the geophagic materials, might be abrasive to the gastrointestinal tract. When consumed, they pass through the GI tract unaltered and are deposited into the colon. Then occurs erosion of the colon's GI lining, leading to rupturing and eventually perforating the sigmoid colon

(Okereafor et al., 2016; Ekosse et al., 2017). These may form a knot that tightens and forms a double-loop obstruction (Lohn et al., 2000). Moreover, the consumption of soil enriched in kaolin may result in constipation, which leads to abdominal obstruction and pain due to the soil accumulation in the colon (Ngole-Jeme, 2017).

Geophagy has been suggested to provide nutrient supplementation to geophagic individuals (Mashao, 2018; Malepe, 2022). However, in a study by Msibi (2014) emphasised that geophagic clays have the aptitude to bind with nutrients, reducing their bioavailability and eventually leading to a lack of nutrients in the diet. For instance, Ca in the gut decreases Fe absorption, which causes irritation of the gut lining and results in gastrointestinal disorders such as stomach cramps and constipation (Nyanza et al., 2014). According to Ngole et al. (2010) and Okereafor et al. (2016), acidic geophagic samples tend to prevent the stomach pH from dropping to favourable levels that will allow the dissolution of Fe and thereby reducing its bioavailability in the human system, even when Fe concentration is high in the consumed material. Geophagic soils may become harmful when soils and clays of high potassium or high cation exchange capacities (CECs) are ingested (George and Ndip, 2011). Soils with high K content have been associated with hyperkalemia, cardiac arrythmia, and cardiac arrest (Gefland et al., 1975), whereas those with high CECs with Fe deficiency anaemia decrease absorption and bioavailability of Fe and hypokalemic myopathy by gastrointestinal K depletion (Chaushev et al., 2003). Hypokalemic myopathy has been reported in South Africa associated to geophagy (Moagi, 2010).

Despite the advantages of geophagy as a mineral nutrients supplement, the practice also constitutes a health threat because earthy materials can be contaminated with potentially toxic heavy elements (Fosso-Kankeu et al., 2015). Ekosse et al. (2017) studied geophagic soils from the Free State Province and found that samples presented an excess content of As, Pb, Cr, Ni, and Zn. The study concluded that such soils represented significant health risks to consumers. As, Cd and Pb in geophagic clays are considered toxic even in trace amounts (Fosso-Kankeu et al., 2015) and associated with adverse neurological disorders, reproductive effects, and impaired cognitive development in children (Nyanza et al., 2014).

The pH of the ingested earthy material may also affect the behaviour of chemical elements during consumption. For instance, Olowoyo and Macheka (2013) revealed that the pH of the geophagic soil samples were acidic, which may facilitate the release of toxic trace elements into the human system when consumed. Excess content of leached metals, such as Pb, Ni, Co, and Fe, above their adequate daily intake standard in the geophagic clay samples, may not be safe for human consumption, especially Pb (Fosso-Kankeu et al., 2015). The accumulation of this element in the body may cause Pb poisoning, and is associated with damage to the central nervous system and kidneys in adults (Ekosse et al., 2015), anaemia, high blood pressure in old and middle-aged people, reduces fertility in men, and cause miscarriages in pregnant women (Herselman, 2007).

In the northern part of the Kwazulu-Natal Province, geohelminth infections were reported among children from rural areas, resulting in a major health risk (Saathoff et al., 2002). In addition, children were infected with *Ascaris lumbricoides* and *Trichuris trichiura* (Rajcoomar, 2011). A research work carried out by Sumbele et al. (2014) in the Eastern Cape Province reported that ingesting sandy soils with a high load of *Ascaris* increased the risk of intestinal perforation. The high sand and silt content of geophagic soils favour the survival of geohelminths. These authors further emphasised that consuming soils contaminated with geohelminths may increase symptoms of Fe deficiency anemia, once up to 0.15 mL of blood could be lost in a day because of geohelminth infections.

In the case of the Limpopo and Free State Provinces study by Ekosse et al. (2010), emphasised that geophagic clays collected at the river beds are usually loaded with water borne bacteria and pathogens. And such materials may increase the gastrointestinal pH, binds toxins and pathogens when consumed (Ekosse et al., 2010; Msibi, 2014). Phakoago (2017) also emphasised that the presence of plant remains such as stems, leaves and roots in the ingested earthy materials may result in diarrhoea, nausea and irritates the digestive system.

6. Prevention of geophagy practices

Despite the detrimental health effects associated with geophagy, it is clear that the practice is endemic in South Africa. There is a need for intervention regarding its detrimental health consequences. This could be done through geophagy health care awareness programs in the geophagic communities.

Geophagy health education can be conducted through community engagement projects such as collaborative works with community groups and/or leaders to create geophagy awareness through meetings and gatherings as well as antenatal education for pregnant women to inform them about the risk of developing Fe deficiency anemia and other health risks associated with geophagy. Schools, religious congregations, and public health care centres can be used as venues for such programs. However, it is important to note that the practice cannot be eradicated, given its long term use by geophagic individuals. The educational process needs time for the consumers to understand the possible detrimental health issues.

Implementation of measures that reduce the health risks associated with the practice can be proposed to the local communities during the educational awareness programs. These include the understanding of following certain processing and treatment methods of the geophagic materials before consumption, as summarized by Ekosse et al. (2010), e.g., pounding, sieving, grinding, and slurring. Additionally, geophagic materials should not be obtained from the riverbeds and open fields or topsoil to reduce the intake of helminth ovaries causing bacterial infections. If obtained, the use of heat treatment, such as baking or boiling the geophagic materials before ingestion should be mandatory. The practice may help reduce the presence of some microbes, bacteria, and pathogens in earthy materials. Heating geophagic materials also improve the palatability of the geophagic soils, reduce the moisture content of the soils, and enhance desirable colours to be richer and brighter (Ekosse et al., 2010).

7. Concluding remarks

This review is inferred from some published research works on human geophagy conducted in five provinces of South Africa, the following can be concluded.

- The fact that a high number of people in South Africa, most commonly females practice geophagy, means that there are surely many sites or sources where the geophagic individuals collect their material, which are still not studied for their composition and potential health risks.
- Several studies have revealed that geophagic individuales practice geophagy consume for many reasons including medicinal, cultural and nutrients supplementation purposes. While ingesting earthy material may be beneficial for such purposes, the practice might cause several (short and/or long term) health complications such as dental and intestinal abrasions, elements toxicity (As, Cd and Pb), impact on the absorption of some essential elements such as iron, leading to some health issues such as anaemia, GI disorders such as stomach cramps and constipation and geohelminths infections, amongst many others.
- Most studies focused solely on some aspects related to the source materials such as the physico-chemical properties, mineralogy, and geochemistry, and with reference to some potential health implications. Whereas, only few studies attempted to further correlate the source material with their geological occurrences, which might have an influence on the observed composition of the geophagic materials.

Furthermore, only few studies documented the health risk assessment as well as the bioaccessibility tests of the consumed material.

- Therefore, it is important to (i) consider a more holistic studies of the geophagic material ingested (including geochemical and mineralogical nature of the consumed material and its biological, and physico-chemical properties) and (ii) implementation of health educational programs to sensitize and inform geophagic individuals as well as the general public on the potential hidden short and/or term health implications of the practice. This will result in the promotion of good quality health and well-being among the population of South Africa as well as other countries, especially in rural areas where people rely mostly on their natural environment for their nutrition.

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

The authors do not have permission to share data.

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