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REVIEW PAPER

Review of the nature of some geophagic materials and their potential health effects on pregnant women: some examples from Africa

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Abstract The voluntary human consumption of soil known as geophagy is a global practice and deep-rooted in many African cultures. The nature of geophagic material varies widely from the types to the composition. Generally, clay and termite mound soils are the main materials consumed by geophagists. Several studies revealed that gestating women across the world consume more soil than other groups for numerous motives. These motivations are related to medicinal, cultural and nutrients supplementation. Although geophagy in pregnancy (GiP) is a universal dynamic habit, the highest prevalence has been reported in African countries such as Kenya, Ghana, Rwanda, Nigeria, Tanzania, and South Africa. Geophagy can be both beneficial and detrimental. Its health effects depend on the amount and composition of the ingested soils, which is subjective to the geology and soil formation processes. In most cases, the negative health effects concomitant with the practice of geophagy eclipse the positive effects. Therefore, knowledge about the nature of geophagic material and the health effects that might arise from their consumption is important.

Keywords Geophagy · Soil material consumed · Pregnant women · Health implications · Africa

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Introduction

Geophagy is defined as the purposive ingestion of soil-like materials such as clay, and chalk, or coal (Crawford and Bodkin 2011). Geophagy can be related to pica, which is an ingestion disorder usually defined as the continuous ingestion of non-food substances (Swamy and Dewang 2011). Historically, geophagy has been reported in humans and also animals worldwide since ancient times, e.g. 40 BC and 100 AD in Lemnos (Greece) (Abrahams 2013). The practice of geophagy is not bound to socio-economic status, age, religion or racial origin. According to Njiru et al. (2011), geophagy occurs mainly in childhood (Rose et al. 2004), during pregnancy, persons suffering from malnutrition, in colour than Caucasian people, and in rural than urban areas (Simpson et al. 2000).

Different soil materials have been reported for the practice of geophagy depending on their inorganic characteristics such as physico-chemistry, mineralogy and geochemistry (Ngole and Ekosse 2012). The consumed soil materials include clays, termite mounds, mountains/hills, gardens and riverbeds soils (Ekosse et al. 2010). Generally, clay-rich soil materials are the most ingested due to their soft nature and the presence of aggregate of minerals and elements (Kootbodien et al. 2012). The geochemistry and mineralogy of geophagic material, mainly clay, have been studied by different authors (Wilson 2003; Mashao 2018; Kambunga et al. 2019), among others. The chemical elements in the geophagic material have also been identified. The geochemistry of geophagic material is considered significant for the assessment of the possible health effects that can arise from the consumption of such materials.

It is known that geophagy is spread globally and people all over the world ingest soil for various reasons (Ghorbani 2008). For example, in Australia, some aborigines consume white clay mainly for medicinal purposes (Rowland 2002). In Africa, geophagy is common in several countries, such as South Africa, Malawi, Kenya, Ghana, Cape Verde, Zambia, Zimbabwe and Swaziland, especially among pregnant women (Walker et al. 1997). Cultural beliefs, nutrients supplementation and medications are the main historical and intuitive basis for geophagy in Africa (Young et al. 2010a, b).

Although geophagic material is believed to act as a medicine and also to alleviate hunger (Reinbacher 2003), the negative effects of soil consumption might overshadow the positive effects (Saathoff et al. 2002, Kambunga et al. 2019). Therefore, the evaluation of geophagic material as traditional remedies by scientific methods to determine their effectiveness and assure safety standards is required. The present paper updates information in the field of geophagy complementing the comprehensive review by Njiru et al. (2011). The main focus of the present paper is on the nature of geophagic material and its potential health effects on pregnant women in Africa as they are mostly known to practice geophagy. The term geophagy in pregnancy (GiP) will be used throughout this review.

Nature of some geophagic material

Most studies focus mainly on clay soil as the most common geophagic material being consumed. However, very few studies were conducted on termite mound soil and other geophagic materials. Although numerous soil materials are known for the practice of geophagy (Ekosse et al. 2010), the section below will focus on clay and termite mound soils, which are the most and least commonly studied. These types are commonly consumed because of their clay composition dominant nature.

Clay soils

The term “clay” is generally defined as a “naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when fired or dried” (Guggenheim 1993). Velde (1995) used the term “clay” to refer to all materials falling under the particle size < 0.002 mm, composed by a group of minerals sharing a homogenous chemical composition and crystal structure. In terms of occurrence, clay minerals occur in soils and sediments (Heine and Völkel 2010) and form major constituents of shale rocks (Buol et al. 2011).

Structure and formation of clay minerals

Clay minerals display a platy or flaky habit and have tetrahedral SiO_4 parallel sheets Barton (2002). The formation of these minerals depends on environmental and chemical conditions. According to Heine and Völkel (2010), they are formed by two main processes, which are (i) physical breakdown of parent rocks with zero effects on the chemical composition and (ii) production by chemical weathering, with alteration of chemical composition.

These authors underlined that the characteristics of parent rocks, climate, water and organisms are the main factors that affect weathering. Processes such as erosion, transportation and deposition of clay minerals by water or wind can occur after weathering. Flora, Animalia, lithostratigraphy, landscape, water flow, time and human activities also play a significant role in the development of soil and clay minerals.

Physico-chemical properties of clay soil and minerals

Ghadiri et al. (2015) identified some of the clay minerals properties such as cation exchange capability, catalytic abilities, swelling behaviour; some minerals expand when exposed to water and low permeability. In Foley (1999), an explanation on cation exchange capabilities revealed that it is the result of the charged surface of the clay minerals, which gives space for the ions attraction and repulsion of the clay mineral surfaces. Several types of ions can be fixed on these surfaces including organic molecules, such as pesticides (Shahidi et al. 2015). Large surface areas associated with clay minerals enable the adsorption of cations and microorganisms (Ekosse and Anyangwe 2012). Ekosse et al. (2010) also highlighted the isomorphic substitution within clay minerals, where atoms replacement takes place (e.g. Al^{3+} can replace Si^{4+} in the tetrahedron).

Geophagic clay soils differ in mineralogy, chemical composition, taste, smell and other physical properties. Ngole and Ekosse (2012) and Henry et al. (2013) among others concluded that the behaviour and interactions of ingested soil in the gastrointestinal tract of an individual practicing geophagy depend on the physico-chemistry and mineralogical compositions of the clays and other soil constituents. Ngole and Ekosse (2012) emphasized that correlations between soil geochemical, physico-chemical and mineralogical properties and the health of geophagists can be drawn. Soil properties play a major role in satisfying geophagist's preferences (Ngole and Ekosse 2012). Geophagic clays' characteristics include the colour, texture, particles size, chemical and mineralogical composition, pH, electricity conductivity (EC) and water content. According to Okereafor et al. (2016), most geophagic clay soils are highly retentive, which give them the ability to absorb metal ions.

(a) Colour

Clay colour may give indications of the mineralogical composition and soil processes. Geophagists usually use colour and texture of clay soils to identify their soil preferences (Reilly and Henry 2000). Abrahams and Parsons (1996) concluded that white clay is mostly composed of kaolinite while yellow and red clays contain iron (Ngole et al. 2010). This evidence was supplemented by Fernández-Caliani and Cantano (2010) who found that kaolin mineralogy can be white cream, red (with haematite, Fe_2O_3), yellow brown (with goethite, FeO(OH) and grey green (with a mineral of the chlorite group). Colours such as grey and yellow–brown can be related to the presence of organic matter and iron oxides (Okereafor et al. 2018).

(b) Texture and particle size

According to Diko and Ekosse (2014), geophagists are attracted by the texture of consumed material, with a partiality given to the softer (Van Onselen et al. 2015), silky or powdery. USDA classified particle size diameter as medium to very coarse sand (0.25–2 mm), very fine to fine sand (0.05–0.25 mm), silt (0.002–0.05 mm) and clay (< 0.002 mm) (Velde 1995; King et al. 1999).

The most commonly noted textures of geophagic clays are clay, silty clay or silty clay loam or loam with clay always dominating (Ngole et al. 2010). Important information on nutrition, protective and other health issues can be inferred using the fractions of geophagic clays. Geophagic soils with a high percentage of clay-sized particles exhibit high cation exchange surface areas, which promote high adsorption abilities. Diarrhoeas curtail and gastrointestinal ailments are hypothesized to this property (Okereafor et al. 2016). However, coarse-textured soils are linked with dental damages (Young et al. 2008). According to King et al. (1999), most of geophagic materials contain < 20% clay content.

(c) pH

Most of the studied geophagic clays are found to be acidic, which generally induce the sourness of the soil (Diko and Ekosse 2014). These soils are the ones most selected by pregnant women, for example, in Kenya, Malawi, South Africa and Nigeria. Acidic clay is traditionally accepted as capable of preventing excessive saliva secretion and reducing nausea during pregnancy (Lakudzala and Khonje 2011; Diko and Diko 2014).

Most chemical reactions depend on the pH balance in the soil. Therefore, knowledge of the pH can be used to access the degree and rate of the chemical reactions (Candeias et al. 2014; Kambunga et al. 2019). According to Oomen et al. (2000), the possibility of chemical reactions in geophagic clay material is higher in environments with low pH (≤ 2), e.g. gastric stomach juice. Therefore, metals in these soils are more soluble (Alloway 1990) and their bioavailability for incorporation in biological processes increases as the pH decreases (Young et al. 2008). According to Sherwood (1995), geophagic soils with high pH (alkaline) may not have a noticeable impact on elements and nutrients released in the GIT. However, in the duodenal, alkalinity with pH ≥ 8 can cause chemical reactions if the geophagic material is of clay size (Oomen et al. 2000).

(d) Electrical conductivity

Ngole et al. (2006) suggested that electrical conductivity can be used to deduce the amount of dissolved salts in the geophagic clays. Okereafor et al. (2016) among other studies confirmed notable high values of EC in geophagic clays in some parts of South Africa ranging from 122 to 1029 µS/cm. Higher EC values usually occur in clays supposed to absorb diarrhoea-causing enterotoxins and protect the gastrointestinal epithelium (Okereafor et al. 2016). In a study conducted by Goldberg and Forster (1990), an association between aggregation of soil particles, soil pH and dissolved salts was found. Mahaney et al. (1999) confirmed that the flocculation of soil consumed might stimulate coating in the enteric barrier, therefore shielding the intestines from the acidic stomach juice.

(e) Organic matter content and water retention capacity

Soil organic matter (SOM) can be referred to any decomposed material, which is originated from living organisms (plant or animal) and returned to the soil (Cotrufo et al. 2015). Ngole et al. (2010) highlighted that soil organic matter is a source of nitrogen and possible pathogenic bacteria are likely to harbour in organic matter (OM)-rich soils. The SOM content in some geophagic clays from South Africa, Swaziland, Zaire and Uganda ranges from 0.2 to 1.5% (Abrahams and Parsons 1996; Ngole et al. 2010).

Brady and Weil (1999) defined water retention as the ability of soils to process and hold different amounts of water. Geophagic clay soils have variable water retention capacities (WRC). Different authors suggest a linear relationship between the amount of clay content and WRC (Ngole et al. 2010). Like the pH of geophagic clay soil, WRC is being used in traditional medicine and pharmaceuticals for diarrhoea and GI illnesses prevention (Ngole et al. 2010). This can be related to the fact that geophagists ingest clay soils to curb diarrhoea (Ngole et al. 2010). However, studies performed on geophagic soils with higher percentage of clay contents point out the possible existence of numerous micropores in which some potentially pathogenic bacteria could be lodged (Ngole et al. 2010).

(f) Mineral phases and chemical elements

Geophagic clay mineral phases and chemical elements vary depending on source rocks, pedogenic conditions, environment, and climate, among other factors. Chandrajith et al. (2009), Gichumbi et al. (2012), Mwangi and Ochieng (2011), Diko and Ekosse (2014), and Ngole-Jeme and Ekosse (2015) identified mineral phases such as alunite, anatase, calcite, chlorite, dolomite, gibbsite, goethite, gypsum, halite, halloysite, haematite, illite, kaolinite, microcline, muscovite, orthoclase, quartz, rutile, sanidine, siderite, smectite and vermiculite in geophagic clays. Common chemical elements found in geophagic clay material included aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), calcium (Ca), chlorine (Cl), chromium (Cr), cobalt (Co), copper (Cu), fluoride (F), iodine (I), iron (Fe), lead (Pb), lithium (Li), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), phosphorus (P), potassium (K), rubidium (Rb), selenium (Se), silver (Ag), sodium (Na) and zinc (Zn) (Mahaney et al. 1999; Ekosse and Jumbam 2010; Dhembare 2013).

Termite mounds/hills material

Termite mounds also known as "ant"-bed, "ant"-hill or termite hill are built using aggregates of soil and rock material from numerous metres in depth, and organic material gathered from the surrounding area (Holt and Lepage 2000; Korb 2003). Termite mounds have been described in many places in Africa including Ghana, Zimbabwe and Namibia, and examples are presented in Fig. 1 (Dowuona et al. 2012; Seymour et al. 2014; Kambunga et al. 2019).

The practice of geophagy with termite mounds sources has been reported in several countries. For example, in Ghana, termite mound soils are mainly consumed by women (34–68%), mostly from rural

Fig. 1 Examples of termite mounds from some African countries including **a** Namibia (sourced from Kambunga et al. 2019), **b** Zimbabwe (sourced from Seymour et al. 2014) and **c** Ghana (sourced from Dowuona et al. 2012)

areas (van Huis 2017). In South Africa, Walker et al. (1985) observed that the practice of the termite mounds soil consumption is common among rural women mainly during pregnancy (44%). In western Kenya, about 50% of women consume soil and half of them preferred termite material (Luoba et al. 2004).

Van Huis (2017) identified that pregnant women frequently consume these soils, sometimes even up to 30 grams three times a day (Francoise 1994). The termite mound soil does not always have to come from the source; in some cases, women consume the one used to construct huts (van Huis 2017). Some women interviewed in Francoise's (1994) study described that the simplest process of termite mound soil consumption is breaking off small pieces from the mound, crumbling it to a powder and eating it.

Formation

Termites generally select fine-grained material during their building process (Jouquet et al. 2002; Abe et al. 2009). Mujinya et al. (2013) articulated that particles deposited in mounds come from different soil depths. Deke et al. (2016) reported that the soil used by termites for mound building usually originates from subsoil. A noticeable enhancement of organic carbon, clay content and nutrients, which is a function of depth where termites gather the soil material, has been studied (Sarcinelli et al. 2009). Jouquet et al. (2007) pointed out that this process plays a major role in the dynamics of clays and SOM in several tropical environments. Specific activities involve soil transportation, particle size arrangement, nutrients concentration, organic matter turnover, porosity, erosion and organo-mineral microaggregation (Sarcinelli et al. 2009). Dowuona et al. (2012) revealed a positive correlation between the abundance of termite mounds and the availability of water; for example, most termite mounds are found near a water source.

Physico-chemical properties of termite mound material

(a) Colour

The colour of the mounds is mostly influenced by the subsoil composition, but factors such as weathering might have an influence too (Dowuona et al. 2012). Sarcinelli et al. (2009) addressed the reddish brown and yellowish-brown mounds, as some of the termite mound's colour noted in arid to semi-arid environments.

(b) Shape and size

Dowuona et al. (2012) reported conical and "cathedral" shapes for most termite mounds. Other researchers name termite mound shapes as "umbrella" shaped (Jouquet et al. 2015). Further findings were the compacted and sealed surface with some internal macropores for ventilation and regulation of temperature (Korb 2003).

Adekayode and Ogunkoya (2009) concluded that the elevation of termite mounds can go up to 7 metres. The massive network of galleries in termite mounds can reach 15–20 m in depth (Leonard and Rajot 2001). The bases of termite mounds are recorded to reach a diameter of up to 4.50 m (Dowuona et al. 2012). Comparatively lower termite mound sizes have been reported in Northern Namibia (Turner 2000).

(c) pH

The pH inconsistence in termite mounds and nearby surface has been identified. In some studies, pH and microbial population are higher in termite mounds in comparison with adjacent soils (Ohkuma 2003), whereas in others, the pH values in termite mounds are lower in relation to adjacent soil areas (Kaschuk et al. 2006). The high pH observed in the mounds can be linked to high Ca and Mg concentrations (Sarcinelli et al. 2009). The average pH in termite mounds is found to range from 4.2 to 6.9 (Kaschuk et al. 2006).

(d) Organic matter content and water retention capacity

Termites decompose organic matter, which accelerate the increase in aggregate stability and soil porosity and can enhance water retention (Sarcinelli et al. 2009). In addition, the network of galleries found in termite mounds increases soil porosity and water infiltration (Leonard and Rajot 2001).

(e) Mineral phases and chemical composition

The clay fraction of termite mounds is an important component as it acts as a binding material and a holder of moisture (Donovan et al. 2001). Kaolinite and illite are the main clay mineral constituents that have been reported in termite mound studies (Mujinya et al. 2013). These minerals can attain up to 60–100% of termite mound mineral composition (Mujinya et al. 2013; Abe 2016). According to Boyer (1971), African termite mounds records have shown a high percentage of kaolin (70–85%) compared to other termite mounds in the world. According to Mujinya et al. (2011), the high clay content (mainly kaolinite) in termite mounds when compared to that of the surrounding area could be related to particles selection (Jouquet et al. 2002) and physical alteration of soil through the termites' gut.

Factors influencing minerals' accumulation in termite mounds when compared to adjacent soils have been outlined as follows:

(i) soil particles selection and the use of a richer subsoil by termites (Jouquet et al. 2002; Abe et al. 2012) and
(ii) the combination of flora, saliva, excreta and pedological alterations (Erpenbach and Wittig 2016). Additional suggested factors could be the mounds microflora activities (Erens et al. 2015) and termite mound "umbrella effect", which flakes rainfall and leach retardation in low to medium rainfall zones (Watson 1976).

Different processes such as clay particles selection and alterations as well as mineralization of plant biomass influence the availability of major and trace elements or cations in termite mound soils (Erpenbach and Wittig 2016). Higher concentrations of chemical elements have been found in termite mound soil than in the adjacent soil (Mills et al. 2009; Seymour et al. 2014). Several studies identified high content of Ca, Mg, K, P, Fe, K, and organic carbon than in the adjacent surface soil (Kaschuk et al. 2006; Ackerman et al. 2007; Mujinya et al. 2011; Joseph et al. 2013; van Huis 2017).

Certain factors have been reported to affect the chemical composition of the mounds, which include: the termite species (Erpenbach and Wittig 2016), the stage of the mound, the sampled part and the type of soil (Mujinya et al. 2010). Kandasami et al. (2016) outlined that the chemical composition also depends on the redistribution of material throughout the mound during the wet seasons and the content of organic matter.

Review on some selected elements commonly found in geophagic material and their possible reproduction-related health effects

Price (2000) outlined the fourteen naturally occurring chemical elements needed by the human body for an efficient metabolism function, known as essential elements (EE): calcium (Ca), chromium (Cr), copper (Cu), fluoride (F), iodine (I), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), phosphorus (F), potassium (K), selenium (Se), sodium (Na) and zinc (Zn). Based on emerging information, boron (B), nickel (Ni), silicon (Si) and vanadium (V) are also considered now beneficial to human bodies (Aras and Ataman 2006). Gordon (1977) articulated that excess or deficiency of any EE can lead to health problems in diverse ways. Potential toxic elements (PTE) include lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), aluminium (Al) and tin (Sn) (Patterson 1980; WHO

1996); however, some studies have found some benefits among some of these elements such as Li (Kabata-Pendias and Mukherjee 2007). The selection of elements for discussion under this section was based on the known geochemistry of various geophagic materials that are believed to be consumed by pregnant women.

Aluminium

Aluminium (Al) is the third most abundant element in the earth's crust ∼ 8% and the most abundant metal (Barabasz et al. 2002). Al is found in aluminosilicates, clay minerals such as kaolinite, montmorillonite and illite (Barabasz et al. 2002), cryolite and bauxite rocks (Krewski et al. 2007). The bioavailability of Al through ingestion consumption is 0.1–0.4% for Al^{3+} and ≤ 0.1% for Al $(OH)_3$ (Krewski et al. 2007). Citrate (Landry 2014), acidic pH (Kabata-pendias 1993) and the presence of elements such Zn, Fe and Cu increase the absorption and accumulation of Al (Kuroda and Kawahara 1994). Al accumulation is decreased by Si-containing compounds during oral exposure (Krewski et al. 2007). Al reduces the absorption of Sr, P and F and also nullifies Mg, Ca and Fe (WHO 1996). Babies can obtain Al from their mothers through breast feeding; however, the transmission is minimal (ATSDR 2000).

There are no set biological functions of Al in humans (Landry 2014); however, for adults, an intake of 1 mg/kg a day is required (Pennington 1988). Although 95% of Al is removed by kidneys (Krewski et al. 2007), the accumulation of Al can lead to toxicity, which has been linked to bone and neurological disorder such as epilepsy, inhibition of long term potentiation, learning disorder and impaired spatial working memories (Kerr et al. 1992), low birth rate, (Paternain et al. 1988), growth retardation and foetal abnormalities (Domingo et al. 2000; Kawahara et al. 2007).

Arsenic

Naturally, arsenic (As) is part of the earth's crust with high concentrations occurring in soils covering As-rich geological units, e.g. sulphides (Abernathy and Morgan 2001; Paikaray 2015). Arsenic can be in the form of organic compounds (monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA)) or inorganic (arsenate (As^{5+}) and arsenite (As^{3+}) (Mishra et al. 2017). Trace amounts of As are found in air, water, soils/sediments and biota (Abernathy and Morgan 2001) occurring either as −3 in the arsenides, +3 in the arsenites and +5 in the arsenates (Uher 2001). Inorganic As taken in through ingestion can be absorbed relatively rapidly and extensively (WHO 2001). However, certain factors such as the solubility of the compound, valence state, GIT constituents and the matrix in which it is ingested may affect the absorption (ATSDR 2000). Subsequently, extra phosphate can reduce arsenate's (As^{5+}) intestinal absorption and renal tubular reabsorption (Gonzalez et al. 1995). Studies have reported that breast feeding provides 0.31–2 µg/day of As (Carignan et al. 2015).

There is no set biological function of As in a human body, and its traceable amount in the body for pregnant women is 2.1 µg (Trumbo et al. 2001). Although 45% and 75% of arsenate (As^{5+}) and arsenite (As^{3+}), respectively, are excreted in urine, if greater amounts are absorbed than the body can detoxify and eliminate, an increase in the burden of arsenic may develop (WHO 2001). Arsenite (As^{3+}) and arsenate (AS^{5+}) are the utmost toxic form and are assumed to be carcinogenic (WHO 2010; Saha et al. 2012; Sarkar and Paul 2016). As toxicity can either cause acute or chronic effects depending on the amount of As taken in as well as the method of ingestion. Some studies demonstrated that arsenite freely crosses the placenta and can cause health risks to foetuses (Milton et al. 2017). Reproduction-related effects of As include gastrointestinal symptoms (Civantos et al. 1995), increased risk of miscarriage, low birth weight (Senguta et al. 2014), foetal mortality, (Hood and Harrison 1982), skeletal malformed foetuses (Senguta et al. 2014), retarded mental growth and low IQ level (Kapoor and Prakash 2013).

Calcium

Calcium (Ca) is fifth in abundance in the earth's crust and mostly found in limestone ($CaCO_3$), gypsum ($CaSO_4{\cdot}2H_2O$) and fluorite (CaF_2). Calcium absorption is directly proportional to its need; the greater the need, the more efficient the absorption; however, the efficiency of absorption decreases with an increase in Ca intake (Del Valle et al. 2011). The absorption of calcium depends on intestinal pH, age and life stage (NIH; calcium 2009). Net Ca absorption is reported to be high in babies and children (up to 60%), which decreases with age increase and increases during pregnancy.

The main function of Ca is being a primary structural constituent of the skeleton (WHO 1996; Brown 2000). Pregnant women are recommended the intake of 800–1000 mg/day (WHO 1996). Calcium deficiency can lead to weaker bone structure, increased risk of bone fractures (Wood 2000), osteoporosis, limited body height, preeclampsia and preterm delivery (Hacker et al. 2012). High Ca in the blood can cause renal failure, tissue calcification, hypercalciuria, prostate cancer and heart disease (NIH 2009).

Chromium

Chromium (Cr) naturally is found in rocks and soil and in volcanic dust and gases primarily as trivalent chromium (Cr^{3+}) and hexavalent chromium (Cr^{6+}) (Krejpcio 2001). Absorption from Cr ingestion is $<$ 10% (ATSDR 2012b). Generally, the absorption of Cr is decreased by the presence of Zn, V and Fe supplementation (Chen et al. 1973). Ingestion absorption rate depends on the daily dose (Anderson et al. 1983) and the solubility of Cr compounds (Guertin 2004).

Cr^{6+} is classified as carcinogenic to humans (Fuentes-Gandara et al. 2018), whereas Cr^{3+} is considered essential for good health but may still cause some health effects when extremely high amounts are taken (Krejpcio 2001). Cr^{3+} is required for the release of energy from glucose (Goldhaber 2003) and maintenance of the RNA molecule configuration (Eastmond et al. 2008). The minimum mean intake for Cr is $\sim$ 0.005 mg/day (WHO 1996). The toxicity effects of Cr depend mainly on the oxidation state and compounds' solubility (ATSDR 2012b). Although most of the absorbed Cr is excreted through urine, residual Cr^{6+} absorbed can lead to gastrointestinal and neurological effects, complications during pregnancy and childbirth (ATSDR 1998; EPA 1998; Krejpcio 2001; Nickens et al. 2010).

Copper

Copper (Cu) is a common trace element found in different rocks and minerals, and its compounds have oxidation states of Cu^{+} and Cu^{2+} (ATSDR 1990; Lajçi et al. 2017). Cu oral absorption ranges from 24 to 60% in adults (Bost et al. 2016). Factors such as Cu concentrations in the diet (Bost et al. 2016) together with the presence of other metals (Ralph and McArdle 2001) and age (Varada et al. 1993) may affect Cu absorption. In infants, high intake of Fe has been associated with a decrease in copper absorption (Choi et al. 2016).

According to Goldhaber (2003), Cu is involved in the formation of connective tissue and in the normal functioning of muscles (Uauy et al. 1998), immune and nervous systems (Olivares and Uauy 2005). The recommended daily allowance/intake (RDA/RDI) of copper for pregnant women is 1.8 mg (Smith and Hsu 2018). Cu deficiency is rare, but if it occurs, its symptoms include impaired growth, mental retardation, connective tissue abnormalities, altered immunity and even foetal death (Keen et al. 1998; Ralph and McArdle 2001). Cu toxicity can lead to nausea, vomiting, diarrhoea, anaemia and death (Cordano 1998; Bost et al. 2016).

Iron

Iron (Fe) is the fourth most abundant element and is mostly found in minerals such as pyrite (FeS_2), haematite (Fe_2O_3), magnetite (Fe_3O_4) and siderite ($FeCO_3$) (Abbaspour et al. 2014). The common oxidation states of Fe are Fe^{2+} (ferrous) and Fe^{3+} (ferric) (Phippen et al. 2008). Generally, Fe^{2+} is more easily absorbed by the body than Fe^{3+}, with optimum uptake taking place in the small intestine (Heming et al. 2011).

Fe is an essential component of haemoglobin (Abbaspour et al. 2014) and is responsible for oxygen transportation, growth development, normal cellular functioning, and synthesis of some hormones and connective tissue (NIH 2009; Valko et al. 2005). The recommended daily allowance/intake for pregnant women is 27 mg (Ronnenberg et al. 2004). Deficiency in Fe can lead to anaemia, impaired mental and motor development, amplified risk of preterm infants, low birth weight and growth retardation, augmented neonatal mortality and minimized iron transmission to the foetus (Ramakrishnan 2000; Wood 2009). Fe deficit can lead to anaemia during pregnancy (Allen and Casterline-Sabel 2001).

Magnesium

Magnesium (Mg) is the eighth most abundant element and occurs in rocky minerals such as dolomite, magnetite, olivine and serpentine (Fife 1999). It has one main oxidation state (Mn^{2+}) (De Baaij et al. 2015). Mg is essential for the mineralization and development of the skeleton (Olivares and Uauy 2005; Larsson and Wolk 2007). For pregnant women, the recommended daily intake is 350–360 mg/day (Castiglioni et al. 2013).

Magnesium deficiency persuades increased neuromuscular excitability (Saris et al. 2000), premenstrual syndrome (PMS) and infertility (Castiglioni et al. 2013). Toxicity effects can result in nausea, vomiting, diarrhoea, confusion, lowered blood pressure and low heart rate (Castiglioni et al. 2013). Nevertheless, adverse health effects of Mg depend on the dose amount, method and duration of exposure, form of the chemical compound and the presence of other chemicals during exposure (Jokinen 1990).

Manganese

Manganese (Mn) forms ~ 0.1% of the earth's crust (Howe et al. 2004) and is mainly found in minerals such as pyrolusite, rhodocrosite, rhodonite and hausmannite (HSDB 1998; Johnson et al. 2016). Mn^{2+} and Mn^{4+} are the common valence states (Howe et al. 2004) with Mn^{2+} being the most bioavailable (Santos-Burgoa et al. 2001). Mn absorption is affected by previous manganese, phosphorus and calcium intake (EPA 2003). Calcium, for example, may prevent the absorption of Mn (Parmalee and Aschner 2016). Finley (1999) demonstrated that iron status may also affect manganese absorption and retention.

Mn plays a role in reproduction; bone growth; and mental function (EPA 2003; Avila et al. 2013). Pregnant women need 2 mg/day of Mn (Santamaria 2008). Mn adverse health effects depend on the dose, the duration, nature of exposure, presence of other chemical elements, age, sex, and diet, among other factors (ATSDR 2012a). Mn deficiency is associated with impaired growth, skeletal defects and reduced reproductive function (Wood 2009). Excess Mn can cause manganism and adverse reproductive, neurological and cognitive effects (Aschner et al. 2005; Boudissa et al. 2006; Aschner et al. 2007).

Mercury

Mercury (Hg) is the only liquid heavy metal, which naturally occurs in the environment (Jaishankar el al. 2014) as metallic or elemental mercury, mercuric sulphide, mercuric chloride or methylmercury (Silva et al. 2005). It is found in sulphides minerals (Silva et al. 2005), cinnabar, metacinnabar and hypercinnabar (Mudgal et al. 2010). The oxidation states of Hg are Hg^{2+}, Hg^{+} and 0 (Silva et al. 2005). From oral ingestion, absorption rates of organic and inorganic Hg from the GTI are 10% and ~ 95%, respectively (Neeti and Prakash 2013). Furthermore, absorption of inorganic Hg from parenteral exposure is 100% (Clarkson et al. 2003).

There are no functions of Hg in a human body; hence, it is classified as carcinogenic to human beings (ATSDR 2003). The traceable amount of Hg in the body is 0.1–0.23 µg/kg (US EPA 1997; FAO/WHO 2003). The toxicity intensity of Hg depends on its chemical form with the order as: ionic < metallic < organic (Clarkson and Magos 2006). Methyl mercury (Hg^{2+}) is the most common organic specie and is toxic to human health (Silva et al. 2005), whereas when it comes to pregnant women, elemental and organic Hg is the most dangerous (Neeti and Prakash 2013). Hg can cause stillbirths (Sikorski et al. 1987), infertility, miscarriage and prematurity, low libido (sex drive) and premenstrual syndrome (PMS) in women (Neeti and Prakash 2013). Neurotoxic effects on foetuses/and babies often lead to reduced performance in tests and neuromotor disabilities, congenital malformations (Jaishankar et al. 2014) and spatial cognition (Bose-O'Reilly et al. 2010).

Nickel

Nickel (Ni) forms ~ 0.008% of the earth's crust (WHO 2000) and can be found in air, water and soil (Duda-Chodak and Blaszczyk 2008). The absorption rate of Ni is < 15% from the gastrointestinal tract (Nordberg et al. 2014). Factors that may affect the absorption rate include the chemical form and the deposition site (Nordberg et al. 2014).

Ni plays a role in the absorption of Fe by the human body and is considered vital for strong skeletal frames building (Petzold and Al-Hashimi 2011; Chivers 2015). The daily recommended intake of nickel for pregnant women is 70–80 µg/day (Gunderson 1988).

Ni deficiency can lead to growth retardation (Kumar and Trivedi 2016). Toxicity can lead to abortions and musculoskeletal defects such as feet deformities (Vaktskjold et al. 2008).

Potassium

Potassium (K) is the seventh abundant element in the earth's crust, which occurs naturally in minerals such as feldspars and micas (Bhaskarachary 2011). K only has one oxidation state (K^{+}) (Turck et al. 2016). According to Bailey et al. (2014), ~ 90% of K is absorbed in the small intestine.

K plays an important role in the maintenance of cellular fluid trans-membrane gradients and movement of nerve impulses and muscles (Rose et al. 2004; Sheng 2000). The recommendation daily intake for pregnant women is 4.7 g/day (Bhaskarachary 2011). K deficiency can result in a condition called hypokalaemia (Crook et al. 2001). K toxicity can cause a rare disease called hyperkalaemia (Lehnhardt and Kemper 2011).

Silicon

Silicon (Si) is the second most abundant element on the earth's crust (Kurakevych et al. 2017). It has three main oxidation states (Si^{4-}, Si^{2+} and Si^{4+}), with Si^{4+} being the most common in nature. Primarily, Si occurs in silica or silicate forms, with plagioclase feldspar [$NaAlSi_3O_8$–$CaAl_2Si_2O_8$] and quartz [SiO_2] being the main source (Poitrasson 2017). Si absorption is a function of exercise (Nielsen 1999), age and oestrogen levels (Pérez-Granados and Vaquero 2002).

Si plays roles in the calcification of bone (Dashnyam et al. 2017), glycosaminoglycan metabolism in cartilage and connective tissue (Murray et al. 2000) and Al homeostasis (Birchall et al. 1996). The daily recommended allowance for Si during pregnancy is 19 mg/day (Pennington 1991). Si deficiency can cause impairment of normal growth while toxicity results in silicosis (Pennington 1991).

Sodium

Sodium (Na) is a naturally occurring element mainly found in silicates such as feldspars and Na-mica; however, trace amounts can be found in phosphate, halide, carbonate, nitrate, borate and sulphate minerals (Rudnick and Gao 2004). Studies reported that ~ 98% Na is absorbed in the intestine (Pohl et al. 2013).

Na is the main cation in the extracellular fluid, and its functions are similar to those of K (Sheng 2000; Doyle and Glass 2010). The recommended daily allowance for Na for pregnant women is 2.98 g/day (Johnson 2006). Na deficiency results in an electrolyte disorder called hyponatremia (Liamis et al. 2008). Its manifestations include cerebral oedema and neuromuscular hyper excitability (Olivares and Uauy 2005). Na toxicity can lead to permanent neurological damage in infants (Pohl et al. 2013).

Titanium

Titanium (Ti) is the fourth most abundant metallic element in the earth's crust and has three main oxidation states (Ti^{2+}, Ti^{3+} and Ti^{4+}), of which Ti^{4+} is the most common (Zierden and Valentine 2016). It is found mainly in minerals such as rutile, brookite, anatase (all titanium dioxide), ilmeite (titanium-iron oxide) and sphene [$CaTiSiO_5$] (Patone et al. 2006) with trace amounts occurring in pyroxene, amphibole, mica and garnet (Jovanović 2015). According to Jovanović (2015), Ti absorption from oral consumption is minimal (~ 3%). TiO_2 absorption depends mainly on its concentration and the size of TiO_2 particle (Tassinari et al. 2014).

Though Ti is regarded as non-carcinogenic to humans, there are still no set of biological functions of it in the human body (Nordberg et al. 2014). The estimated maximum tolerable Ti amount in the human body is 0.80 mg/kg (WHO 1996). The toxic effects of TiO_2 depend on the presence of high fluoride concentrations and low pH (Noguti et al. 2012), the amount of the dose and the size of nanoparticles (Jia et al. 2017). Possible health effects that can result from Ti/TiO_2 toxicity include disturbed developing nervous system (Rollerova et al. 2015), foetuses' mortality and intrauterine growth retardation (Delgado and Paumgartten 2013).

Vanadium

Vanadium (V) is the 22nd most abundant element in the earth's crust (ATSDR 1992) and has three natural common oxidation states (V^{3+}, V^{4+} and V^{5+}) (Crans et al. 1998). The most reported toxic V compounds are vanadium pentoxide (V_2O_5), sodium metavanadate ($NaVO_3$) and sodium orthovanadate (Na_3VO_4) (Mateos-Nava et al. 2017; Marques et al. 2017). The absorption of V from the GIT is ~ 10% (Nriagu 1998). Absorption of V depends on the species V^{5+} which is more easily absorbed when compared to V^{4+} (WHO 1996).

V has no specified role in the human body (WHO 2001) but can distress iodine intake. The daily recommended intake for pregnant women is 10 µg/day (WHO 1996). The toxicity of V compounds is directly proportional to the increase in valances states (Barceloux, and Barceloux 1999) and is reduced by the presence of Cr, Fe, Cl and $Al(OH)_3$ (Al hydroxide) (Nielsen 1987; Vincent 2018). Toxicity of V can result in depressed growth and foetal malformations (Altamirano-Lozano et al. 2014).

Zinc

Zinc (Zn) is the 25th most abundant element (Irwin et al. 1997) and has one main oxidation state (Zn^{2+}) (Roney 2005). Zn is found in minerals such as sphalerite, smithsonite and zincite (EPA 2005). The absorption of Zn from ingestion normally ranges from < 15 to 55%, and it is affected by zinc excretion and absorption rates (Johnson et al. 1993), existing zinc levels in the body, and age (EPA 2005).

Zn is required for growth, maturation and normal development (Hambidge 2000; Olivares and Uauy 2005). The recommended daily allowance for pregnant women is 20 mg/day (Lucian et al. 2010). Manifestations of Zn deficiency include growth retardation, LBW, extended labour, prematurity, and delayed sexual and skeletal maturation, (Black 2003; Walker et al. 2009). Acute adverse effects of Zn toxicity include abdominal cramps among others (Chasapis et al. 2012).

Geophagy in pregnancy (GiP)

According to Ladipo (2000), pregnancy is commonly accompanied by physiologic changes that result in increased blood plasma volume, energy demand (Picciano 1996) and decreased concentrations of nutrients. These changes are responsible for many micronutrient deficiencies and demands. As a result, sickness and other health-related problems might arise, which can lead to geophagy. Hergüner et al. (2008) and Callahan (2003) stated that physiological and psychological factors are the main motivations for geophagy during pregnancy. Young (2010) highlighted that factors influencing GiP also have cultural and socio-economic motives.

Prevalence of geophagy practice in pregnancy and some examples from Africa

Although pregnant women globally consume soil (e.g. Mcloughlin 1987; Simpson et al. 2000), the prevalence in Africa is more significant (Geissler et al. 1999; Kawai et al. 2009) (Figs. 2, 3). According to Geissler et al. (1999), approximately 50% of pregnant women in Africa are reported to practice geophagy with the most prevalent cases being Namibia, Uganda, Malawi, Kenya, Tanzania and South Africa (Luoba et al. 2004; Mikkelsen et al. 2006; Ngozi 2008; Dissanayake and Chandrajith 2009; Lakudzala and Khonje 2011; Macheka et al. 2016; Kambunga et al. 2019) (Fig. 3). Examples of GiP in some African countries are briefly discussed in the section below, and the corresponding data are presented in Fig. 3 based on the amount of literature available.

Namibia, Malawi and Uganda

The prevalence of GiP in these countries is apparently the highest in Africa based on available data as shown in Fig. 3. According to recent studies, GiP prevalence can reach up to 88% in Namibia (Kambunga et al. 2019), 84% in Uganda (Dissanayake and Chandrajith 2009) and 82% in Malawi (Lakudzala and Khonje 2011). These studies reported that the main types of soils consumed by pregnant women in these countries are:

(i) Clay and termite mound soils are the main types of material consumed in Namibia, with the average daily consumption of 150 g (Kambunga et al. 2019);
(ii) Alfisol, oxisol and vertisol types of soils in Malawi, with a frequency ranging from two to several times per day (Dissanayake and Chandrajith 2009);
(iii) Clay (*bumba*), termite mound soil and well/river soil in Uganda (Abrahams 1997; Geissler et al. 1997), with a mean average

Fig. 2 A map of Africa showing some examples of countries where GiP is practiced

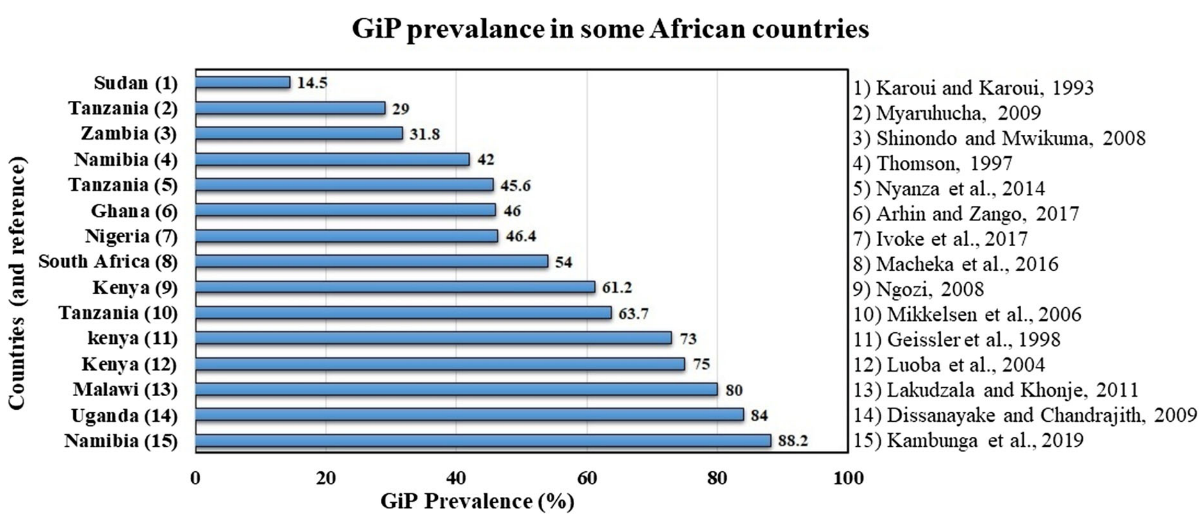

Fig. 3 Prevalence of geophagy during pregnancy in some African countries

daily intake of 53–62.5 g (Young et al. 2010a, b; Nyanza et al. 2014).

Huebl et al. (2016) reported that persistent craving, appetite booster, vomiting, heartburn and salivation alleviation, taste and soil aroma are some of the main motivations for the practice among pregnant women in Uganda. According to these authors, factors such as age group, education level and occupation could also influence the practice. In the case of Malawi, pregnant women claimed that the taste of clay diminishes nausea, discomfort and vomiting in "morning sickness" (Dickinson et al. 2009). It is also used to determine if a woman is truly pregnant (Hunter 1993).

Kenya

The prevalence of GiP is about 61.2–75% in Kenya (Geissler et al. 1998a, b; Luoba et al. 2004; Ngozi 2008). The mostly consumed soils are from the walls of houses and gullies, termite mounds and salt licks (Geissler et al. 1997; Luoba et al. 2005). The daily consumption is about 30–41.5 g (Geissler et al. 1999; Mwangi and Ochieng 2011), with a frequency of at least once a day (Luoba et al. 2005). Soil taste and smell as well as pregnancy cravings have been reported as the main motives for the practice of geophagy (Geissler et al. 1999; Njoki and Kiprono 2009). Age, education level, marital status, occupation are also the main factors associated with GiP in Kenya (Luoba et al. 2004).

Tanzania

Mikkelsen et al. (2006), Myaruhucha (2009) and Nyanza et al. (2014) reported that 29–63.7% of pregnant women in Tanzania tend to practice geophagy. Soil sticks, called "pemba", termite mound soil, and ground soil have been reported to be consumed by pregnant women (Mahaney et al. 1996; Yanai et al. 2009). According to Young et al. (2010a, b) and Nyanza et al. (2014), the mean average daily intake is between 53 and 62.5 g. Motivations are mainly linked to culture, the persistent desire to consume soil, reduction in morning sickness, attraction by the soil's scent and enjoyment of its taste (Knudsen 2002; Myaruhucha 2009). Factors such as marital status, occupation, anaemia and gestation age have also been reported to influence the practice of geophagy during pregnancy (Kawai et al. 2009; Young et al. 2010a, b).

South Africa

Macheka et al. (2016) reported that GiP prevalence is about 54% in South Africa. Pregnant women consume mainly clay, and termite mound soils, with the estimated daily intake of about 24–30 g, which can vary depending on the consumption motives (Ekosse et al. 2010; S'khosana 2017). According to Macheka et al. (2016), the reason for the consumption is related to the satisfaction from the soil's taste and relief of heartburn. Other reasons include cravings, taste texture, and smell of the geophagic material and salivating during pregnancy (George and Ndip 2011). Factors such as age, employment status and family guidance influence the geophagic habits during pregnancy (Mathee et al. 2014).

Nigeria

The prevalence of GiP in Nigeria is about 46.4% (Ivoke et al. 2017). Clay (*Nzu*), soil from cooking mounds (*Aja Ekwu*), termite mounds (*Ozuru Akika*), walls of huts and soil from gullies (*Aja Ulo*), and path edges (*Ajauzo*) are the most consumed soils (Izugbara 2003; Ivoke et al. 2017). The study of Izugbara (2003) revealed that the frequency of soil consumption in pregnant women is at least once a day. A high percentage of pregnant women in Nigeria believe that geophagy is good for foetal development (Doe et al. 2012). Motivations for GiP in Nigeria include craving, reduction in vomiting, salivating, infections and complications during and after birth, appetite stimulation, qualitative and quantitative breast milk guarantee, unborn and newly born health safeguard, prevention of miscarriage and stomach purification (Olatunji et al. 2014; Lar et al. 2015). Sociodemographic factors such as education level, marital status and occupation once again influence the practice of geophagy (Izugbara 2003; Agene et al. 2014; Ivoke et al. 2017).

Ghana

In Ghana, GiP prevalence is reported to be approximately 46% (Arhin and Zango 2017). Creamy white loamy clay soil is the most consumed material by pregnant women (Stokes 2006) with a daily intake of about 70 g (Twenefour 1999). Traditionally, pregnant women practice geophagy in some regions of Ghana (Mensah et al. 2010). However, there are other reasons linked to such practice, which include cravings, soil smell and taste (Tano-Debrah and Bruce-Baiden 2010; Norman et al. 2015). It is also believed to cure morning sickness (Mensah et al. 2010), reduce vomiting and spitting, prevent heartburn and treat nausea and diarrhoea (Norman et al. 2015). In Ghana, factors such as age group, marital status and occupation were also reported to influence the practice of geophagy among pregnant women (Norman et al. 2015).

Zambia, Sudan and Cape Verde

Very little data were found on GiP in these countries, which indicate low prevalence with 14% in Sudan (Karoui and Karoui 1993) and 31% in Zambia (Shinondo and Mwikuma 2008). Clay, termite mound, hut bricks and stones have been reported as the main types of soil consumed in Zambia (Nchito et al. 2004), with a frequency of approximately 50–150 g/day (Young et al. 2011). Cravings, soil taste and alleviation of morning sickness were the main motives for the practice of geophagy among pregnant women in Zambia (Shinondo and Mwikuma 2008).

Ghorbani (2008) and Gomes et al. (2012) reported the consumption of clay soil among pregnant women in Cape Verde. The main motivations of such practice are related to gastrointestinal illnesses, skin healing and morning sicknesses (Gomes 2017).

Motivations for geophagy in pregnancy (GiP)

Under this section, the motivation factors for geophagy in pregnancy with reference to some examples in Africa are discussed in more detail.

Medical motivations

Several studies have shown that pregnant women consume soil for many reasons. Changes during pregnancy cause sickness symptoms and other health-related problems, which might lead to geophagy. For instance, GiP in sub-Saharan Africa has been used for the relief of symptoms like nausea, vomiting, heartburn (possibly due to gastrointestinal alterations), menstrual pains, and pregnancy stress (Gomes and Silva 2007; van Huis 2017). Similar motivations have been reported in pregnant women from Malawi who appealed that the taste of soil diminishes the nausea, discomfort and vomiting in "morning sickness" (Hunter 1993). According to George and Ndip (2011), Woywodt and Kiss (2002) and Khare et al. (2017), in some African countries including South Africa and Botswana, the majority of pregnant women consume soil due to cravings, enjoyment of the palate, texture or smell of the soil material and also excess salivating during pregnancy.

Traditional believes

Doe et al. (2012) stated that many pregnant women in Africa believe that geophagy is good for foetal development, with emphasis in Nigeria. A study on African pregnant women revealed that soil consumption facilitates smooth delivery, perceived enhancement of personal appearance, which includes dark skin pigment enrichment for babies (Bengt and Lagercrantz 1958). Furthermore, reports from Malawi have shown that the practice of geophagy among pregnant woman is normal and it is used to recognize if the woman is really pregnant (Hunter 1993).

Nutrient supplements and immunity booster

Nutrients' demand increases during pregnancy leading to micronutrient deficiencies. According to Njiru et al. (2011) and Khare et al. (2017), craving for soils by pregnant women is linked to dietary supplement for micronutrient intake. These include essential elements such as Ca, Zn and Fe. However, the bioavailability of K, Fe and Zn can be reduced by the consumption of non-food substances such as soil, chalk and soap, which in the end lead to micronutrient deficiencies (Young et al. 2010a, b). Doe et al. (2012) added that in most cases where pregnant women are unable to get adequate and proper medical services, there is a tendency to practice geophagy to derive the essential elements for the development of their foetus. The immune system gets suppressed during pregnancy, but the need to protect the foetus from harmful substances is still vital (Njiru et al. 2011).

Health effects associated with GiP

Several researchers concluded that the health effects of geophagy depend on the composition of the ingested soils, which is subjective to the soils formation and the amount of soil consumed. Types of soils consumed vary widely depending on the soils' intrinsic characteristics (Ngole and Ekosse 2012).

Possible positive health effects

(a) Immunity booster

Ingested soil during pregnancy may increase the digestive efficacy and decrease foetal exposure to pollutants consumed by the mother (Profet 1992). According to Abrahams (2005), the immunity of the mother and the foetus can be conferred by the disclosure to microbes in the soil during the production of immunoglobulin A antibody. The function of Immunoglobulin A is to prevent the attachment of pathogens on mucosa directly shielding the foetus from infections.

Consistent ingestion of soil might improve the mother's secretory immune system (Callahan 2003). For this hypothesis, Al salts mainly found in clays have been used as adjuvants (substances that amplify the body's immune response to antigens) in human vaccines. These salts are capable of absorbing numerous organic molecules and histiocyte (Gupta 1998), making the clay to act as inoculations. The antibodies produced by this process may also appear in breast milk, leading to the enhancement of the foetal immunity (Smith 1999).

(b) Protection

Most geophagious clays have high cation exchange capacity, which enable them to adsorb plant toxins (e.g. phytotoxins), decontaminating them and reducing their potential toxicity in humans (Abrahams 2005). Kaolinite–montmorillonite clay, diatomaceous and termite earth have the potential to bind microorganisms, offering protection to the individual (Njiru et al. 2011). Furthermore, smectite clays when bound with the intestinal mucus make the intestinal linings less porous to pollutants and pathogens, therefore protecting the body organs particularly during times of rapid cell division (Young 2010).

(c) Relief from gastrointestinal distress and other pregnancy-related diseases

According to Myaruhucha (2009), heartburns are caused by the hydrochloric acid in the stomach (pH = 2), and the ingestion of alkaline or kaolinite-rich clays can reduce heartburn and other gastrointestinal upsets (Rodríguez 2003; Limpitlaw 2010). Njiru et al. (2011) made reference to studies that suggest the relevance of geophagy during various trimesters of pregnancy. The properties of clay-rich soil such as soil plasticity and its composition make them effective at suppressing common symptoms of pregnancy-related illnesses (nausea, vomiting and salivating), the supply of essential nutrients, and softening of the pelvic bones makes parturition easier (Tayie et al. 2013; Njiru et al. 2011; Diko and Diko 2014; Diko and Ekosse 2014). Geophagic termite mound soils are enriched with calcium, which might help to reduce the risk of pregnancy-induced hypertension (Eiley and Katz 1998).

Possible negative health effects

The act of geophagy 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). These health problems are the result of excess or deficiency of major and trace elements, metals and metalloids consumed during geophagy, and also their bioavailability.

(a) Association and binding of geophagic soil with toxicants

Several studies have found high levels of PTEs in different geophagic materials (Scherz and Kirchhoff 2006; Agene et al. 2014; Kambunga et al. 2019 among others). The toxicity of PTEs might interfere with the health of foetus and mothers as discussed in section 3. In industrialized urban areas, GiP may be a trail for the ingestion of anthropogenic ecological soil pollutants and PTEs, especially in areas with high levels of heavy metals (Njiru et al. 2011). It is alerted that both maternal and foetus deaths can result from soils contaminated with herbicides/insecticides (Abrahams et al. 2006).

Clays have the nature of adsorption due to their cation exchange capacity. Clays may bind to pharmaceuticals (e.g. chloroquine, aspirin and others) making them less effective and posturing more risks to pregnancy, especially in malaria endemic areas where gestating women are put on malaria treatments.

(b) Anaemia and other diseases

GiP has been associated with *Ascaris lumbricoides* infection. Most studies have reported geophagy as one of the main risk factors for Fe deficiency. According to Young et al. (2007) and Toker et al. (2009), there are approximately eight mechanisms through which GiP can cause anaemia. The mechanisms include the reduction in Fe uptake when Zn and Pb are present in the soil; the interference of Al and Hg with red blood cells production; the reduction in Fe bioavailability due to the attraction and binding of nutrients by charged ions found in the geophagic material; and inhibition of Fe absorption due to damaged intestinal linings by tough geophagic material. Other mechanisms are the severe blood loss due to hookworm infection found in geophagic material; 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; and the interaction with feeding due to damaged teeth by hard geophagic material.

Adam et al. (2005) reported the probabilities of anaemia in Sudan, Pakistan and Tunisia among geophagious women. In addition, anaemia has also been identified as a major risk of stillbirths in Eastern Sudan (Ali and Adam 2010). Geissler et al. (1998a, b) reported that in Kenya, the low iron status and high anaemia prevalence were present among pregnant women (56%) and were linked to regular soil intake. Other case studies from South Africa have reported hypokalaemia and iron deficiency among pregnant women practicing geophagy (McKenna 2006). Furthermore, despite normal birth weights of infants of anaemic mothers, they have a high risk of becoming anaemic in life (de Pee et al. 2002).

(c) Reproduction-related problems and foetal development interactions

Geophagy has also been associated with maternal injury, constipation and dysfunctional labour (Simpson et al. 2000). The exposure of pregnant women to high concentrations of chemical elements, especially PTEs, can cause adverse health effects to foetus. Njiru et al. (2011) discussed that growth retardation is associated with LBW and premature births. Saunders et al. (2009) confirmed that the link between decreased foetal head perimeter, LBW, premature birth and GiP has been documented.

Mitigations of geophagy in pregnant women

Mandatory fortification of flour

Njiru et al. (2011) proposed methods to prevent geophagy during pregnancy. A suggestion is that since most African countries staple food consists of flour from maize, millet, cassava, wheat, barley and/or oats, the fortification of flour with essential elements required during pregnancy could be an option. One of the advantages is that it will reach all the community members including pregnant women and hence minimal soil craving.

Implementing of geophagy education in communities and during antenatal care

Although the practice of geophagy dates back in time and is deep-rooted in many countries, most people lack information on the possible harmful impacts that can result from this practice. The majority of geophagious women is more concerned about the benefits and neglects the hazards. The latter could be from the lack of geophagy education and cultural heritage as most women who consume soil are uneducated and live in rural areas. It is the duty of knowledgeable people to educate communities. This can be simply attained by incorporating geophagy classes under the antenatal care and through consistent community awareness meetings/gatherings. The subject can also be added as part of primary and secondary education to create more awareness during the basic life training. This is important as the practice of geophagy starts at early age and most of its health effects might be a product of elements accumulation over a long period of time.

Conclusions

Despite the negative effects associated with geophagy, the practice is still prevalent, especially in African countries. The nature and composition of geophagic material differ and determine the types and intensity of detrimental health effects to pregnant women and foetuses that might arise from their consumption. Dietary/nutritional mineral supplements, pregnancy-related sicknesses and cultural believes are the main motivations that drive pregnant women to consume soil material. Several studies concluded the possible advantages of geophagy and also predicted its peril. However, the negative effects of GiP have a high potential of overshadowing the health benefits. It is noted that the perceived health effects of GiP are mostly derived from assumptions rather than experimental data; hence, there is a need for experimental studies of the health effects in order to ascertain the link between the geophagic material and their possible health impacts. Systematic and scientific evaluation of geophagic material is therefore required in order to ascertain their health benefits and to maintain safety standards for consumption.

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