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GEOCHEMICAL CHARACTERIZATION, POTENTIAL HEALTH RISK ASSESSMENT AND INDIGENOUS KNOWLEDGE OF GEOPHAGIC SOILS OF BOTSWANA

by

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ABSTRACT

Geophagy, the deliberate consumption of earth materials including soils, has been widely reported across the globe at different periods of human history. Although widely practiced in Botswana, especially among pregnant women and children, the nature and potential human health risks of geophagy is poorly documented. The overarching aim of this research therefore is to characterize geophagic soils of Botswana, assess the potential human health risk of their consumption through multiple pathways and to evaluate consumers' traditional knowledge of geophagic soils. To achieve the research objectives, a mixed method of both qualitative and quantitative designs was used. The qualitative aspect focuses on evaluating the indigenous knowledge of geophagic soils in Botswana and their health impacts of consuming them while the quantitative aspect focuses on the characterization of these soils including mineralogical and geochemical properties. Using geochemical ratios of the United States Environmental Protection Agency (USEPA), human health risk indices such as carcinogenic risk (CR) and non-carcinogenic risks, hazard quotient (HQ), hazard Index (HI) were computed. The colours of the geophagic soils are dominantly various shades of brown ranging from reddish browns, yellowish browns, dark browns, pale browns and strong browns. The pH (H2O) ranges from 5.3 - 7.8 The electrical conductivity ranges from 43-1423.3 µS/cm. The soil organic matter is below 1.5 % for all the samples. Clay particles content ranges from 203g.kg^{-1} to 800g.kg^{-1}, silt particles range from 60 g.kg^{-1} to 320g.kg^{-1} and sand particles content ranges from 0g.kg^{-1} to 697 g.kg^{-1}. The clay-sized fractions contained kaolinite, illite, calcite, and muscovite. The essential elements order of concentration with respect to their means is: potassium (K) (14286 ppm) > calcium (Ca) (87723ppm) > magnesium (Mg) (4656 ppm) >phosphorus (P) (150 ppm). The order of mean concentrations for essential trace elements is iron (Fe) > copper (Cu) > chromium (Cr) > nickel (Ni) > zinc (Zn). For toxic elements (TEs), the order of concentration is: lead (Pb) > arsenic (As) > mercury (Hg) > cadmium (Cd) with Pb having a mean concentration of 15.2 mg/kg and As 1.9 mg/kg. The HIs of the potentially toxic elements (PTEs) for all the three exposure pathways are below 1 for both adults and children. Ni, Cr and As have the highest mean CR values which fall within the acceptable range of 1.00E-06 to 1.00E-04 for both adults and children for exposure through oral consumption and dermal contact while the mean CR values for exposure through inhalation are all below 1.00E-06. The most common reason for eating soil was cravings with 48% of the respondents followed by anti-stress effects (27%). Whereas 81% of the respondents reported that consume soil daily while 16% of the reported consuming soil weekly. The results demonstrate a good knowledge of the risks of geophagy by the study population. The most known and reported effect of soil consumption is constipation (46%) followed by worm transmission (39%). Implicitly, exposure to PTEs in the soils is less likely to have health risks, however, caution should be applied since aggregate exposure from other sources could cause a significant increase thereby resulting in negative health effects among practitioners.

Keywords: Iron supplements; Termite mounds; Oral ingestion; Potentially toxic elements; Health risk indices

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background

Geophagy, also referred to as Geophagia, is the ingestion of earth substances intentionally, including soil. Soil is made up of a combination of that comprises of mineral components (45%), air (20-30), water (20-30%), and organic materials. Soils act as a habitat for various organisms, are a medium for plant development, work as recycling system for carbon, water and nutrients, function as engineering resources and are reservoirs for water (Delgado-Baquerizo et al., 2020). The connection between soils and human health has been to some extent overlooked, in spite of the vital roles soils take part in in human life sustenance on Earth Soils can negatively impact human health without the appropriate monitoring in three ways: (i) human food supply can be exposed to disease-causing organisms or harmful levels of substances through the soil; (ii) pathogenic organisms can come into contact with individuals through direct interaction with the soil or breathing in dust particles from it and (iii) inadequate soils may cause malnutrition through food production that lacks the essential nutrients (Brevik and Burgess, 2013).

Geophagy as a practice has been globally observed for two millennia and primarily connected to tropical regions (Abrahams, 2002) and the African continent (Abu et al., 2017; Molale and Eze, 2023). Outside of Africa, soil eating has taken place in other regions such as North America, South America, Australia, Asia and Europe. A large population in China had resorted to eating clay during periods of intense food scarcity (Msibi, 2014). Geophagy is practiced by people of various ethnicities, socio-economic status, religious beliefs, and racial categories (Abrahams, 2002; Diko and Siewe, 2014; Msibi, 2014). In general, soil consumption is deemed as a negative habit including by those who practice the habit as shown by two studies in South Africa where most of the respondents said that it was not helpful (Msibi, 2014; S'khosana, 2017). Some people who practice geophagy have shown that they possess some knowledge on the effects of soil consumption. Most of the respondents from a study conducted in South Africa (60.6 % from a sample of 94) knew about the effects of geophagy which include stomach pains, worm infections, cancer, constipation, diarrhoea, bloody stools, painful defecation etc (Msibi, 2014). Geophagic substances are sold in open-air markets in Cameroon, these substances, referred to as 'Calabar chalk, are named after a city in Southeast Nigeria called Calabar. This city is known for mining and selling geophagic clays (Odangowei and Okiemute, 2019). In Botswana, the practice of geophagy is deep-rooted among different demographic groups, with children and women (particularly during pregnancy) being the leading participants.

Some reasons for soil ingestion include the relief of nausea during pregnancy, treatment of diarrhoea, fulfilment of cravings and the provision of essential nutrients. Geophagic clays known to have the ability to absorb dietary and bacterial toxins linked to gastrointestinal complications (Young et al., 2009; Hunter-Adama, 2016). Soil ingestion has been categorised as a psychiatric condition, a cultural phenomenon, or a result of hunger and poverty even though some of its benefits have been recognised (Woywodt and Kiss,2002). Some researchers suggest that nutritional deficiencies lead to a desire for non-food substances (Abrahams, 2002). Determining the presence of essential nutrients such as iron, calcium, magnesium and zinc in geophagic materials helps to test the theory that geophagic soils can complement the diets of consumers.

1.2 Statement of Problem

Excess consumption of geophagic materials has been reported to negatively affect human health. Common side effects associated with geophagy include colon blockage, metabolic and physiologic dysfunction resulting from potentially toxic element ingestion, cancer, and iron deficiency (Kawai et al., 2009; Nkansah et al., 2016). The accumulation of soil in the intestines can result in constipation, chronic abdominal pain and perforation of the colon due to the presence of large sandy particles in the soil (Abrahams, 2002). Medical practitioners in Botswana have also stated that tetanus as a result of soil consumption is a cause of concern due to the occurrence of micro-organisms in geophagic soils. Local news media outlets like Daily News and Pula 24 have reported on how popular soil eating is in Botswana with a number of the interviewees reiterating on how for them, they started the habit because they saw their peers and relatives indulge in soil eating. Hence, there is a timely need for this study to improve our knowledge of the properties of geophagic materials to determine why this is a commonly practiced culture throughout the country and the possible consequences.

1.3 Justification of the study

Although geophagy is widespread in Botswana, few studies have adopted a mixed analysis on the characterisation of geophagic materials from Botswana and the knowledge of geophagists on the habit. Even though the benefits of geophagy might be fulfilled, care should be taken, as they have been reported to contain potentially toxic elements such as lead, mercury and cadmium at in geophagic soils, which can be detrimental to human health (Hunter-Adams, 2016). This study identifies the elements (both essential and potentially toxic) present in geophagic soils of Botswana, furthermore the computation of human health risk indices (HRIs) in this study helps in determining the importance of the risk of consuming geophagic materials with certain concentrations of potentially toxic elements with respect to toxicity and carcinogenic risk.

1.4 Aim

The overarching aim of this study is to identify, characterise and analyse health risk possibilities associated with the voluntary ingestion of earth materials soils and to appraise the knowledge of indulgers on the practice.

1.5 Specific Objectives

The specific objectives include the following:

1. To characterise geophagic soils from Botswana using their morphological, physico-chemical properties.
2. To determine the concentrations of potentially toxic elements and essential nutrients in geophagic soils.
3. To assess the potential human health risk of consuming soil materials via multiple exposure pathways
4. Evaluate consumers' indigenous knowledge on geophagy.

CHAPTER TWO

REVIEW OF CONTEMPORARY AND RELEVANT LITERATURE

2.1 Introduction

Soil can be ingested intentionally and unintentionally, due to soil components entering the body in various ways (Young et al., 2009). Expecting mothers consume reduce nausea and vomiting and discomfort in the abdomen (Intiful et al., 2016) Soil cravings happen, most likely during the early phases of pregnancy (Garg and Sharma et al., 2009), meanwhile other forms of pica are commonly noticed in the third trimester (Young et al., 2009) Young children have a habit of putting things in their mouths which makes it a bit challenging to recognize geophagy in them (Gundacker et al.,2017). Reports have indicated that mothers who practiced geophagy during their pregnancies usually have children who eventually develop the same habit of soil ingestion (Kmiec et al.,2017) Although geophagy among teenage boys and men is seldomly acknowledged, especially in developed nations where it is often viewed as shameful and associated with lack of education, men in a village in Limpopo province, South Africa, were open about this behaviour, albeit it was reported in a very small percentage (1.95%) compared to women and girls (Malepe et al., 2023).

Geophagic products are marketed and sold to consumers without satisfactory information on the recommended dosage, duration of intake (including specifics about pregnancy trimesters, days/weeks/months) and patterns of consumption. These geophagic products are often mined/or sourced from urban or developing areas where there is a great possibility of contamination and high risks associated with both communicable and non-communicable diseases (Orish et al.,2020). The location where geophagists collect soil for consumption is important when evaluating the potential health impact because studies have shown that individuals ingesting soil from or near mining locations had higher levels of toxic metals such as lead and mercury in their blood compared to individuals who collected soil from non-mining areas The blood lead levels of pregnant women who consumed from mining area rose by 34%, meanwhile for those in non-mining areas had an increase of 33% (Thomas et al.,2024)

It is crucial to assess the quantity of soil consumed due to soils differing with time and location (Philips, 2017; Eze, 2022), assessment should not be based on previous studies carried out across different continents, periods and populations. Numerous geophagic soils remain unstudied (Abrahams,2002). The importance of soils to human health and well-being has been substantially overlooked until recently.

2.2 Prevalence of Geophagy in Africa

As previously stated, geophagy is a common practice in Africa (see fig 2.1). Some countries where geophagy has been documented frequently include Tanzania, Nigeria, Kenya, Cameroon, Ivory Coast, Malawi, Ghana, Guinea Sierra Leone, South Africa, Eswatini, Zimbabwe, Uganda, Zambia and Togo (Walker et al., 1997; Young et al., 2007; Ravuluvulu, 2018; Odangowei and Okiemute, 2019; Kambunga et al., 2019). In the West sub-region (Nigeria and other sub-Saharan nations like Ghana included), geophagic clays are important for the livelihoods/ economy of the community as they are sold in local markets (Orish et al., 2020). One town in Nigeria produces 500 tons of soil every year for consumption purposes and distributes it throughout West Africa (Roy et al., 2018), currently the marketing and selling of geophagic soils provides a source of income for many rural residents (Odangowei and Okiemute, 2019).

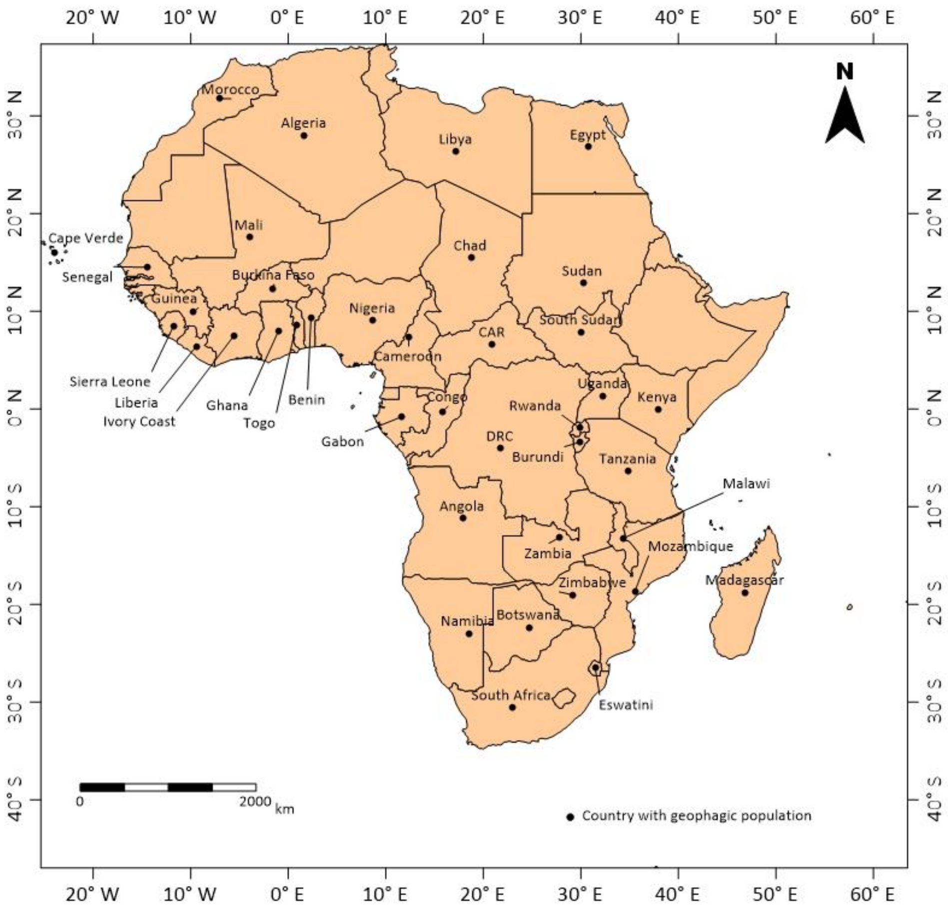

Fig. 2.1. African countries with reported cases of geophagy (adapted from Molale and Eze, 2023)

Geophagic soils are commonly collected by judging their appearance, taste and texture (Henry and Cring, 2012). Anthills, termite mounds and clay deposits are some of the sources of geophagic soils/materials (Eze et al., 2020). A study done in Nigeria with a population sample of 210 women found that 67 % of sample size practice geophagy while in Tanzania 155 pregnant women from a sample size of 340 (45 %) were reported to practice geophagy. Another study conducted in South Africa found that 54 % of pregnant women from a sample of 597 practice geophagy which shows how prevalent geophagy is among women, pregnant women included (Lar, Agene and Umar, 2015; Nyanza et al., 2014; Malepe et al, 2023). Overall, geophagy is more common in in Africans and individuals of African descent residing in the diaspora when compared to other demographics (Gorge and Ndip, 2011). In some African countries (e.g., Botswana), soil-eating is stigmatised, and as a consequence, geophagists are not open to the idea of sharing their experiences with the habit even though the topic is a cause for concern.

2.3 Processing methods

The processing of soil starts by cleaning/ removing sand and other course substances from the edible clay and afterwards wetting and kneading. Some geophagists and vendors process the soil by moulding and sun-drying before consuming it while some collect them directly from the source material and eat it without any kind of processing. Some of them scrap off the topsoil to collect from the sub-horizons (Msibi, 2014). Geophagic products are indirectly and directly marketed as nutraceuticals but there is diminutive to no information about these products (Orisakwe et al.,2020).

Other geophagists mix water with the soil, which is left to settle and thereafter drink the suspension. The aqueous suspension is called argillic water (Odangowei and Okiemute, 2019). In northern Vietnam, clays are cut into "thin tiles" and then dried in the sun. In central Mississippi, USA, some women season their geophagic clays with salt and vinegar, while some of them cook the clays in pans and oven to dry them (Henry and Cring, 2012). Heating the soil before eating has been reported to improve its taste and helps kill pathogens and microorganisms that may have dire effects on the human body when ingested (Msibi, 2014). Some practitioners prefer dry surface soil, whereas others dig 20 cm deep holes to source the geophagic soil (Geissler et al., 1997). In Sweden, mixing soil and flour to bake bread is a common practice. However, it is not known whether it was intended to improve taste or to combat the shortage of flour (Odangowei and Okiemute, 2019). Although processing methods such as heating are highly recommended to kill pathogens and micro-organisms, most geophagists (especially in Botswana) eat the soil directly from the source without any kind of processing which increases the chances of them experiencing adverse effects.

2.4 Properties of geophagic soils

2.4.1 Physico-chemical Properties

The properties of geophagic soils have incited concerns which led to research with the aim to understand and hypothesise the possible effects of consumption. Geophagists prioritize soil texture when selecting soils for geophagy, specifically the proportions of sand, silt, and clay. Fine-grained clays are preferred due to their desirable mouthfeel, while clay-rich soils are deemed chemically inactive and offer minimal toxic effects (Henry and Cring, 2012). These soils provide protective benefits to the gastrointestinal system, function as laxatives, and help alleviate diarrhoea due to their large surface area and absorption capabilities. Most geophagic soils in Cameroon and South Africa are classified as medium to high plasticity silt loam, whereas notable differences in the texture of geophagic soils have been observed in Tanzania (Young et al., 2009; Diko and Siewe, 2014).

The geophagic soils that are rich in clay are composed predominantly of weathered shale or clay material, more so, the quartz particles present in these geophagic clays are normally coarse and have an angular to very angular shape (Ekosse and Anyangwe, 2012). A study conducted in South Africa showed that geophagists preferred soils that are soft, powdery and have a silky texture The silt and fine particles from quartz and feldspars can have a negative impact on the dental enamel of consumers (Msibi, 2014).

Soil consumers typically evaluate the suitability of soil for consumption based on its colour, with preferences for white, dark greyish, or khaki hues linked to the presence of kaolin, smectite, and calcite (Ekosse and Anyangwe, 2012). In Tanzania, geophagic soils exhibit a range of colours from white to various shades of brown and red. The reddish tones, often associated with iron, are thought to enhance the visual appeal of these soils, which individuals consume as dietary supplements (Young et al, 2009). Research in South Africa's Limpopo and

Freestate provinces further indicates that white geophagic soils largely consist of kaolinite and smectite (Msibi, 2015).

On the other hand, the acidity of the soil and the presence of dissolved salts can have influence on the flavour as evidenced by geophagic soils in Moko, Cameroon being acidic and having a sour taste (Diko and Ekosse, 2014). In Tanzania, the pH of geophagic soils is widely varied, with diverse values and proportions of clay and non-clay contents. An area in Tanzania reported a pH range of 4.5 to 5.0 while in Cameroon and South Africa, the geophagic soils were reported to have pH values between 3.1 and 6.1 (Young et al., 2009; Diko and Siewe, 2014).

The Physico-chemical properties of geophagic soils vary with location due climatic conditions, geological set up, the biodiversity of the location and other factors of soil formation. Even though some soils have properties that may render them as somewhat "safe" for consumption, other factors such as the geochemistry which cannot be judged with the naked eye or by simple touch/feel play a vital role when evaluating the significances of geophagy.

2.4.2 Mineralogical Properties

Research on the minerology of geophagic soils has been carried out to expand insight on their health related and environmental effects. Ayidinulp (2014) defines a mineral as a naturally occurring homogenous solid that has a specific but generally variable chemical composition and an organised atomic structure The mineralogical content of geophagic soils has been understudied (Young et al., 2009), but studies have uncovered that kaolin ($Al_2Si_2O_5(OH)_4$) is the predominant mineral contained in geophagic soils across different countries (Mwangi and Ochieng, 2011).

The studies geophagic soils in Tanzania showed to have lower quantities of quartz (4-35%) and higher levels of kaolin (58-95%). Goethite is another common iron oxide found in

Geophagic soils, additionally clays consist of trace amounts of gibbsite, which is typical of soils that have experienced intense weathering. Kaolinite has shown to have different particle shapes (such as flat, platy forms versus tubular or spherical shapes). These properties can to a great extent, impact the ability to coat the intestinal wall, serving as barrier against harmful substances and microbes whilst stimulating the production of mucus (Young et al., 2009).

The geophagic clays of Botswana predominantly consist of quartz (SiO_2) which makes up about 70 wt%, followed by goethite and kaolinite with mean concentrations of 9 wt% and 8 wt% respectively. Mica ($KMgAlSi_4O_{10}(OH)_2$), feldspar ($KAlSi_{3)}$ and hematite ($F_e2O_{)}$ were also identified (Ekosse and Anyangwe, 2012). In Eswatini, quartz, and kaolinite, together with plagioclase, microline, muscovite, goethite, hematite and illite-smectite were largely composed in geophagic soils (Ekosse and Ngole, 2012). Studies have shown that geophagic soils from Nigeria and Cameroon contain primary minerals such as quartz), mica (likely muscovite) and also secondary minerals such as montmorillonite, smectite and goethite have also been noted in geophagic soils from Nigeria and Cameroon (Ekosse and Jumbam, 2010).

From the observed literature, quartz and kaolinite are seemingly the most dominant minerals in geophagic samples from Africa. Kaolinite as a clay mineral may be beneficial due to its absorptive qualities but the presence of quartz on the other hand risks the danger of intestinal discomfort due to rupturing and blockage to geophagists.

2.5 Biochemical functions of soil ingestion

2.5.1 Absorption of dietary and bacterial toxins

The consumption of geophagic clays has advantages, such as their ability to absorb dietary and bacterial toxins linked to gastrointestinal issues (Nkansah et al, 2016). Many studies have highlighted the role of probiotic microbes in preventing the proliferation of harmful bacteria, enhancing the immune system, and boosting resistance to infections (Msibi, 2015). Some individuals who practice geophagy have claimed that they consume soil to mitigate the harmful effects of plant chemicals or organisms by adsorbing pathogens and toxins within the intestinal lumen or by forming a coating on the intestinal endothelium, which reduces its permeability to toxins and pathogens (Young et al. 2009).

Adsorbent smectitic clays have been shown to potentially protect the intestine from harmful substances and alleviate conditions such as esophagitis, gastritis, and colitis (Odangowei and Okiemute, 2019). Clays are employed in the treatment of various types of poisoning, including cases of mercury exposure. The effectiveness of this treatment is attributed to the ion exchange capacity of clay, which indicates the mobility of its components (Ekosse and Jubman, 2010). These characteristics may play a significant role in determining the ability of clays to coat the gut lining, thus serving as a barrier against detrimental chemicals and pathogens, as well as stimulating mucus secretion (Young et al., 2009).

The ability of clays to absorb toxins is a beneficial property but the tendency of geophagists to overconsume soil might render it counterproductive since overaccumulation of kaolinite could lead to absorption of essential elements into the clay matrix instead of them being absorbed in the gut stream which could lead to malnutrition, moreover intestinal blockage.

2.5.2 Nutritional benefits

Exposure essential trace elements like iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), chromium (Cr), resulting from geophagy has not been extensively studied. Nevertheless, it may significantly influence the recommended dietary intake of various trace elements in human nutrition (Ngole-Jeme et al., 2016). Although trace elements are found in minimal quantities in the human body and other organisms, they are vital for sustaining health and wellness. For trace elements to be beneficial, they must exist in small and precisely regulated amounts. If their concentration exceeds the optimal level, they can become harmful (Hasan, 2021). Pregnant women who require extra calcium may be subject to geophagy as some clays have been confirmed to supplement calcium. Calcium is vital for the development of bones in particular for foetuses (Odangowei and Okiemute, 2019

Investigations into the effects of soil consumption on human mineral nutrition have been carried out, testing the idea that many mineral nutrients found in geophagic substances may be available for bodily absorption). Red soil is believed to contain properties that can hinder iron deficiency anaemia (IDA) (Ekosse and Jubman, 2010). Research conducted by Geissler et al. (1998) identified a notable negative relationship between geophagy and IDA. Despite the association of geophagy with anaemia, it has not been scientifically determined whether individuals consume soil due to iron deficiency or if iron deficiency arises from the practice of geophagy, given that the bioavailability of iron in ingested soils is not assured (Odongo, 2015).

Geophagists often have the belief that they crave soil because they lack Fe in their system, but ingesting soil would only worsen their IDA condition due to the above stated reasons. The incentive to consume geophagic materials with the objective to supplement Fe would otherwise be null and void. Soil characteristics vary by location, which would also affect the bio-accessibility and bioavailability of both essential and potentially harmful elements. Furthermore, the bioavailability and bio-accessibility of essential and trace elements in the soil are also influenced by additional factors such as soil pH. A lower pH increases the solubility of chemical elements in the gastrointestinal system (Kambunga et al; 2019).

2.6 Potential implications of geophagy to human health

2.6.1 Exposure to potentially toxic elements

Even though there may be recognised advantages and benefits of geophagy, it is necessary to take caution since these soils may contain harmful substances such as lead (Pb), mercury (Hg) and cadmium (Cd) as well as microbes that could have a negative effect on human health. Several factors such as age, sex, growth, body composition, genetics, pregnancy and lactation influence the uptake of potentially toxic elements (PTEs) (Freeland, 2015) Research has extensively documented soil contamination by heavy metals in Africa (e.g., Eze et al., 2010; Eze et al., 2016a; Eze et al., 2016b; Kebonye et al., 2017). PTEs have been currently deemed as some of the significant environmental pollutants as their release into the environment has increased over the last decade. Particular metals occur naturally in the Earth's crust and therefore present in geophagic materials that humans consume in varying amounts. Elevated levels of trace metals in soils are related to the increase in the prevalence of various health conditions (Owumi and Oyeleni, 2015)

Severe arsenic (As) poisoning has been associated with gastrointestinal issues, which symptomise as nausea, stomach pain and diarrhoea. Ingestion of arsenic overtime in small amounts or through dermal contact can cause chronic exposure in children (Egendorf et al.,2020). Children in Bangladesh who had arsenic levels below the determined limit of 50µg/L in their urine were reported to have weakened cognitive function (Nyanza et al., 2014). Other effects of arsenic exposure include skin disease (hyperkeratosis), acute kidney injury, severe hypertension and respiratory failure. Moreover, exposure to As in the first trimester of pregnancy has been linked to low birth weight. (Brusseau and Pepper, 2019; Egendorf et al., 2020). Cd is precarious to human health due to it resulting in damage to the lungs and kidneys. Exposure to Cd and Pb can lead to cancer in humans and disrupt the endocrine system and cause estrogenic effects according to the Agency for Toxic substances and Disease Registry (ATSDR, 2019) (Egendorf et al., 2020).

Ingested soil can be recognized as a significant source of PTEs in areas are geochemically unusual such mining area. In north-central Nigeria, high levels of uranium (U) and thorium (Th) in soils covering granite complexes have been reported. Radiation occurs in the above-mentioned area where geophagy is a prominent practice (Davies, 2013). Exposure to Pb, which as origins in smelting from many years ago, can result in several health issues such as anaemia, kidney failure, immune system damage, reproductive organ harm and foetal toxicity (Hildebrand, 2011; Owumi and Oyeleni, 2015; Egendorf et al., 2020).

Pb has impact on many organs, however the most critical effect of its exposure is observed in the developing brain and nervous system of children. In South Africa, a study uncovered that geophagists had high levels of Pb, however, this relationship was not found to not be statistically significant (Hunter-Adams, 2016). Recent studies, have though, revealed that the blood and urine samples from pregnant women who practice geophagy had higher concentrations of trace metals compare to those from non-consumers in south Africa (Orisakwe et al., 2020.) More so, some other effects of critical exposure to Pb include convulsions, coma and even death, while lingering effects can cause cognitive damages and behavioural issues (Mileke, 2020). In seven Asian countries, reports have established that children's IQ scored dropped after exposure to Pb a total of 169 locations with reductions ranging from 4.94 to 14.96, indicative of a significant effect on cognitive ability (Fowler et al., 2015).

Pb has been recognised by the World Health Organisation (WHO) as a cause for significant health concern. In pregnant women, when the body needs more calcium, Pb is released from the maternal bones into the bloodstream, furthermore, Pb also affects bone formation (Hildebrand, 2011). More research should be carried to study how geophagy together with the type of soil can have impact on Pb exposure, including factors such as maternal diet, and the levels of calcium and iron (Gundacker et al., 2017). The lack of food intake diaries and comprehensive dietary studies, makes the assessment of geophagy's contribution to the overall Pb and Cd exposure to individuals complicated (Orisakwe, 2020).

Pregnant women and young children are the demographics particularly vulnerable to Pb. They can absorb between 40% and 70% of the ingested Pb. Newborns being at more risk as the have blood levels that exceed those of their mothers due to simple diffusion and the unidirectional transfer of Pb across the placenta (Hildebrand, 2011). The consideration of the exposure of toxic metals to pregnant women is vital because these substances can pass through the placental barrier leading to problems in placental transport mechanisms (Orisakwe et al.,2020).

Considering soil ingestion in risk evaluation linked to Pb and other PTEs such as As and Hg is essential. Another unsafe element regularly found in geophagic substances is Hg. Hg primarily exits in the three chemical forms: Hg) (metallic), which is quickly inhaled and absorbed by all the major organs; 1-Hg(organic compounds), which primarily accumulates in the kidneys and can cause damage to the kidneys; and meHg(organic compounds, like methyl mercury).Hg can have long term effects on the development of the brain and nervous system foetuses including the endocrine systems of children (Egendorf et al.,2020)

As urbanisation and mining expands, soils are at risk of contamination by toxic elements including the ones that are picked for consumption. Therefore, it could be said the rate of soil contamination increases over a short period time due to the ever-growing industrialisation in or near settlements. Nevertheless, not only geophagists are affected by contamination of soils in urban and mining areas, communities at large breathe in contaminated dust particles which poses as a threat to their health as well.

2.6.2 Gastrointestinal disturbance

The buildup of soil in the intestines can lead to constipation, ongoing abdominal discomfort, and colon perforation (Abrahams, 2002). Woywodt and Kiss (1999) documented a case of sigmoid colon perforation and lethal peritonitis due to geophagy in a patient from South Africa, who also reported experiencing constipation and severe pain. Additionally, there have been accounts of soil accumulation in pregnant women resulting in maternal fatalities and complications during labour (Odangowei and Okiemute, 2015). The geophagic clays found in Botswana and Eswatini are primarily composed of quartz, which may result in negative consequences like intestinal blockage and irritation of the gut lining (Ekosse and Anyangwe, 2012; Ekosse and Ngole, 2011).

Soils that contain iron could worsen irritation of the intestinal lining, leading to gastrointestinal issues such as cramps and obstructions. Nevertheless, excess iron accumulation in the body is typically caused by genetic predispositions or prolonged intake of iron-rich foods or supplements (Nyanza et al., 2014). Geophagists who consume soil and/earth materials frequently (every day or several times a day) bear a greater risk of suffering from gastrointestinal disturbance. This would apply to most of them since the habit can be addictive.

2.6.3 Pathogenic organisms and microbe ingestion

Soil contains millions of microbes, which can be classified into five categories: bacteria, viruses, algae, fungi, and protozoa (Msibi, 2015; Mhete et al., 2020). These microbes have the potential to cause infections in the gastrointestinal system. In Africa, elevated levels of aerobic bacteria and fungi have been detected in geophagic soils (Gundacker et al., 2017). Geophagic soils can also harbour bacteria such as Clostridium perfringens, Clostridium tetani, and Clostridium botulinum, which are responsible for gas gangrene, tetanus, botulism, and other pathogenic infections in humans (Obi and Ekosse, 2010). Microbiological assessments of geophagic substances in Central, West, and East Africa indicated that certain samples would be deemed unsuitable for consumption due to high levels of microbial contamination in unheated materials (Kutalek et al., 2010).

Table 2. 1: Groups of bacteria and fungi found in geophagic samples from Central, West and East Africa, Europe and USA (Molale and Eze, 2023)

Groups of Bacteria	Groups of Fungi
Bacillus spp.	*Penicillium spp.*
Corynebacterium spp.	*Aspergillus spp.*
Coagulase negative staphylococci	*Cladosporium spp.*
Micrococsuss spp.	*Streptomyces spp.*
Acinetobacter spp.	*Acremonium spp.*
Enterobacteriaceae spp.	*Paecilomyces spp.*
Pseudomonas spp.	*Rhizopus spp*
	Nigrospora spp.
	Scedosporium spp.
	Candida spp.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Research Design

A convergent parallel mixed-method research design was applied for this study. While qualitative approach focused on the use of structured questionnaires to evaluate traditional knowledge of geophagic soils in Botswana and further identify the demographics of practitioners, quantitative approaches sought to characterise the soils based on their morphological, physical, (geo) chemical and mineralogical properties.

3.2. Geographical and environmental setting of the study area

Geophagic soil samples were collected from six towns/villages namely: Molapowabojang (South district), Gaborone (South–East district), Mochudi (Kgatleng district), Palapye (Central district), Tonota and Francistown (Northeast district). Geographically, they are located within latitudes 20° and 26° S and longitudes 24° and 30° E and fall within the eastern Hardveld of Botswana (Eze, 2022). The populations of the sampling locations are as follows; Molapowabojang has a population of 8722, while Gaborone has a 246 325 population. Mochudi has a population of 50 317, Palapye has a population of 52 636. Francistown and Tonota have populations of 103 417 and 23 296 respectively. 44.4% of the households in Botswana are female headed. The populations of the age ranges are as follows: ages 65 and older represent 6% of the total population while adults of ages 36-64 represent 28% of the total population. The youth of Botswana (ages 18-35) are 30% of the population while minors (0-17 years) are the most dominant age group with 36% (Statistics Botswana, 2022).

The country is divided into the Kalahari Desert Sandveld in the centre which covers two-thirds, the northeastern part (wet sandveld) which is categorised by green wetlands, the eastern part which is dominated by loamy clay soils. The climate of Botswana is arid to semi-arid consisting of warm winters and hot summers, the rainy season has low rainfalls and high rates of evapotranspiration. The rainfall ranges from 650mm in the northeast (Chobe) to 250mm in the southwest while the average rainfall countrywide is 450mm per year. Eastern Botswana has an average rainfall of more than 400 mm, and the vegetation type is grassland. The average monthly maximum temperatures can reach as high as 44°C in summer from October to March with an average of 35°C and 40°C during the day while the night temperatures occasionally reach below 26°C. Winters in Botswana are mostly dry, daytime temperatures go as high as 27°C dropping to about 7°C at night. July is the coldest month where temperatures can go as low as subzero (Zhou et al.; 2016).

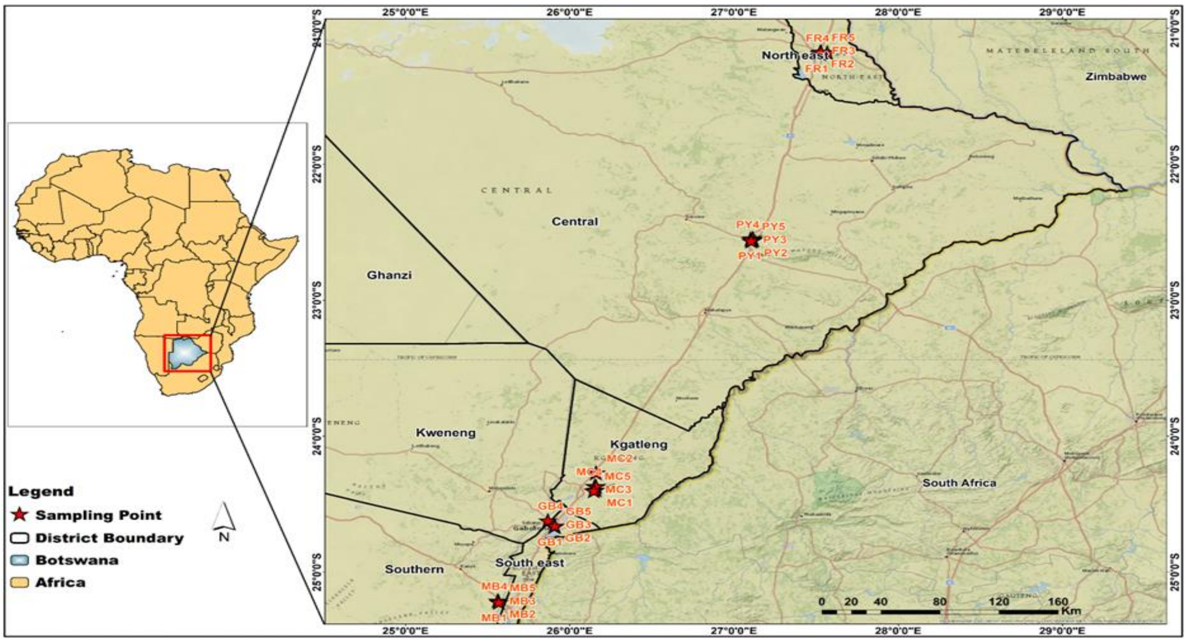

Figure 3.1: Map showing the sampling sites for the geophagic soil samples

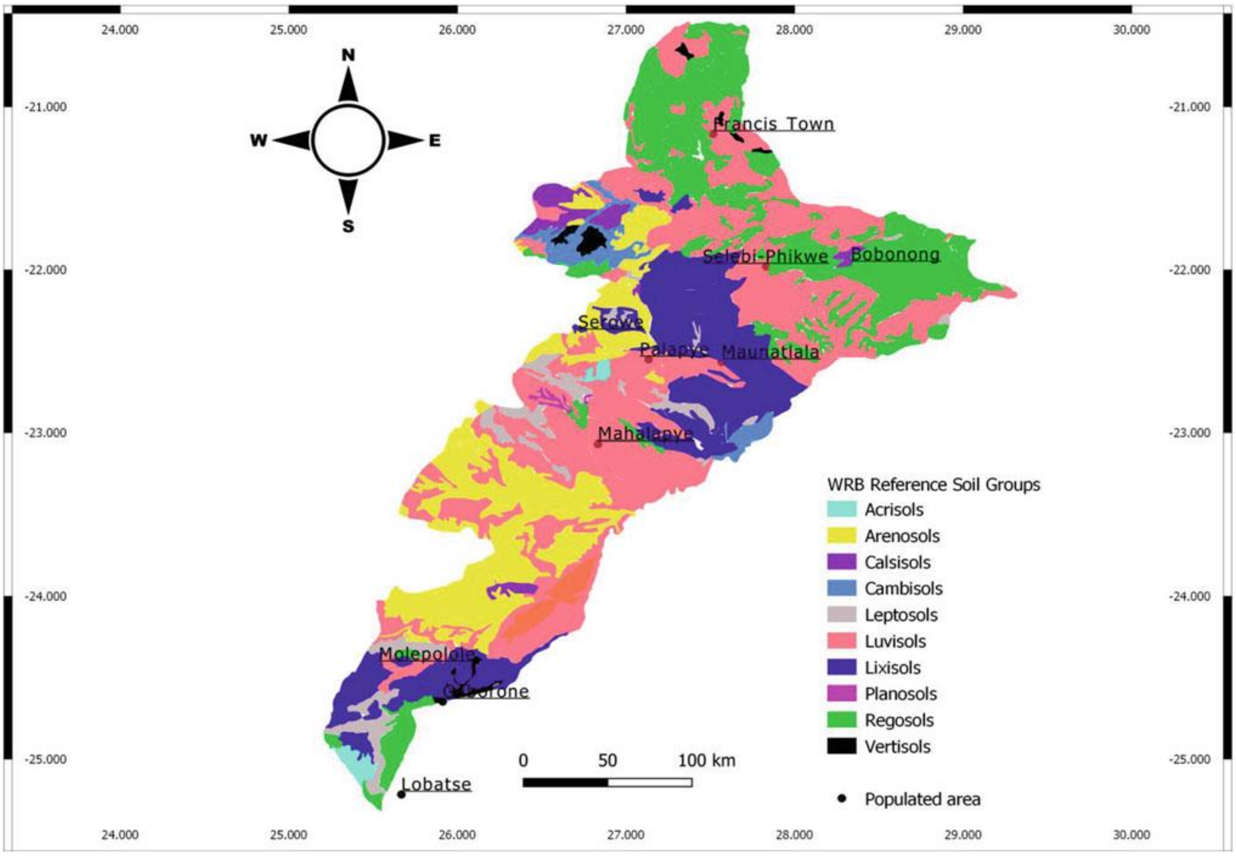

Figure 3.2: Map showing soil groups along the eastern Hardveld of Botswana (Eze, 2022)

According to the World Reference Base (WRB) classification system, the identified soil groups in the sampling locations were as follows (Fig. 3.2): Gaborone has Lixisols, Molapowabojang has Regosols, Mochudi and Palapye have Luvisols, and Francistown and Tonota both have Luvisols. Luvisols are the most dominant soil group in Botswana, covering approximately 29 000 km^2, whereas Lixisols cover approximately 13 000 km^{2,} respectively (Eze, 2022). Luvisols are formed from the pedogenic process of the translocation of clay minerals from the topsoil to the Bt horizon. Lixisols are believed to have evolved from intense chemical weathering when the climate is wetter than the current climate is. Luvisols are quite fertile due to the presence of high-CEC clays and therefore are conducive to arable farming, which is their limiting factor; however, they have poor physical properties, resulting in low water retention. Iron-rich horizons in Lixisols result from wet climatic conditions during development (Eze, 2022).

3.3. Field study and soil sample collection

Systematic random sampling was carried out with the help of the locals to identify the most common sources of geophagic materials in their communities (Figures 3.3 – 3.8). Five samples were collected from each town/village, resulting in a total sample size of thirty. The samples were collected via an uncontaminated trowel and a knife and stored in polythene sampling bags. For quality control purposes, the surface of the termite mound from the point of sampling was scrapped off before collecting the sample. This was done to get a true representative of the soil and to avoid the parts that have been exposed to environmental factors on the surface. The sampling tools were washed with deionised water and wiped with clean paper towels before collecting a new sample to prevent cross contamination.

Figure 3.3: A termite mound in Francistown

Figure 3.4: A market stall in Gaborone selling geophagic clays

Figure 3.5: Termite mound in Mochudi

Figure 3.6: Termite mound in Molapowabojang

Figure 3.7: Termite mound in Palapye

Figure 3.8: Termite mound in Tonota

3.4 Laboratory analyses

3.4.1 Sample Preparation

The soil samples were air dried at room temperature by spreading them in drying trays. After drying, the samples were gently crushed with a mortar and pestle and passed through a 2 mm sieve to remove large roots and coarse fragments. The samples were then put into uncontaminated polythene sampling bags.

3.4.2 Soil colour

The colour descriptions of the samples, which comprised the hue, value/chroma and colour, were obtained via comparison with those of standard soils recorded in the Munsell Soil Colour Book. Its chart was interpreted as follows: hue = colour, value = lightness of colour, and chroma = purity of colour (Munsell, 2010).

3.4.3 Particle size analysis

The Bouyoucos hydrometer method was used to determine the particle size distribution of the soil samples. Fifty grams of each soil sample was mixed with Calgon solution and stirred with a mixer for 3 minutes. After stirring, the contents of the mixing cup were quantitatively transferred into a 100 mL graduated cylinder and filled with water to the mark. The contents of the graduated cylinder were then gently mixed until a uniform suspension was obtained. Hydrometer readings were recorded 40 seconds after the hydrometer was inserted for silt + clay readings and after 2 hours for clay readings. The percentages of sand, silt and clay were then calculated (Bouyoucos, 2016).

3.4.4 Soil moisture content

The gravimetric method was used to determine moisture content. The soil was weighed and put into the oven to dry at 105°C for 24 hours, allowed to cool for 30 minutes and weighed again to compute the total moisture lost (Shukla et al. 2014).

3.4.5 Soil organic matter

The loss-on-ignition method was used to determine the soil organic matter content. After all the moisture was removed, the samples were weighed in crucibles and placed in a furnace at 550°C for 2 hours to burn all the organic matter. The samples were then allowed to cool for 12 hours in a desiccator and finally weighed. The organic matter content was calculated via the following formula:

$$\text{Loss on ignition (LOI)} = (\,[(\text{weight of crucible} + \text{sample}) - (\text{weight of crucible} + \text{sample weight after drying})])/([(\text{weight of crucible} + \text{sample}\,) - (\text{weight of crucible}))$$

$\%\ \text{Organic Matter} = (\%\ \text{LOI} * 0.7) - 0.23$ (Konare et al., 2014)

3.4.6 pH and Electric Conductivity (EC)

First, a multiparameter (pH and EC) instrument was calibrated with buffer solutions (pH 4 and 7). The electrode was rinsed with deionised water prior to analysis of other samples to avoid cross contamination. Triplicate readings for each parameter were recorded, and the average values were calculated. For pH (H_2O), 10 g of soil was weighed in 100 mL polyethylene bottles, and 25 mL of water was added (soil to water ratio of 1:2.5 w/v). The mixture was shaken thoroughly for 60 minutes with a shaking machine. The mixture was carefully stirred with a glass stirring rod until homogenised and allowed to stand for 60 minutes. The electrode was placed in the supernatant, and the pH value was recorded when the value on the electrode was stable (FAO, 2021). For pH ($CaCl_2$), 10 g of each soil sample was weighed into 100 mL polyethylene bottles containing 25 mL of calcium chloride solution (soil to 0.01 M $CaCl_2$ ratio of 1:2.5 w/v). The soil-$Cacl_2$ mixture was thoroughly shaken for 60 minutes with a shaking machine. The mixture was then carefully stirred with a glass stirring rod until homogenisation was achieved, and the mixture was allowed to stand for 60 minutes. The readings were taken in triplicate by placing the electrode in the supernatant (FAO, 2021).

The EC was measured with a pH/EC meter calibrated with a potassium chloride (KCl) solution (NIST traceable) and was 0.147 dS/m. Ten grams of the soil sample was weighed in 100 mL polyethylene bottles, and 50 mL of distilled water was then added to the container. The bottles were then shaken with an electronic shaker for 60 minutes. The mixture was allowed to stand for 30 minutes. The reading was then taken by dipping the electron probe in the supernatant when the value on the probe was stable. The electrode was rinsed with deionised water prior to analysis of other samples to avoid cross contamination. Triplicate readings for each parameter were recorded, and the average value was calculated (FAO, 2021).

3.4.7 Determination of clay sized minerology of geophagic soil samples

To prepare the soil samples for clay sized minerology analysis, the clay particles were extracted. Approximately 50 g of soil was poured into a graduated cylinder and filled with water. The contents were shaken and left for 8 hours to settle 10 cm below the brim. A pipette was then used to extract water with clay szied particles, which were subsequently transferred into a centrifuge tube. The mixture was subsequently centrifuged at 2500 rpm for 3 minutes to separate the water and clay sized particles. The supernatant was discarded while the clay sized particles (sediments) were thinly smeared on a microscope slide, dried and thereafter ready for clay minerology analysis. The mineral species in the geophagic soils were detected via an X-ray diffractometer operated at 40 kV and 30 mA. The data were collected with a scan speed of 2°/min-1 and scan angles ranging from 10 to 80°C via Cu–Ka radiation (Moore and Reynolds (1989)

3.4.8 Chemical Element composition determination

Geophagic soil samples were sent to the geochemistry laboratory of Standard Global Services (SGS) South Africa to test for essential elements (calcium, potassium, magnesium), essential trace elements (zinc, copper, chromium, iron and nickel) and potentially toxic elements (mercury, cadmium, arsenic and lead) via an Agilent Inductively Coupled Plasma

Optical Emission Spectrometry I(CP–OES) mass spectrometer. The aqua regia digestion method with a mixture of 3:1 hydrochloric acid (HCl) and nitric acid (HNO_3) was utilised. Samples consisting of aqua regia were then heated until a low boiling point was reached to oxidise acid-soluble elements. After the reaction was completed, the samples were then diluted to volume, allowed to settle and analysed. To check the accuracy of the results, the certified in-house reference materials LKSD2 and Oreas 906 were used for quality control. All of the values measured in the analytical blanks were below the corresponding detection limits, and they were also included to control for any contamination. In order to evaluate precision, duplicate samples were analyzed; for most of components whose concentrations were over their detection limits, the relative percentages of difference were typically less than 5%.

3.5 Human health risk assessment via the use of health risk indices (HRIs)

The human health risks of soil consumption were determined for three exposure pathways, namely, oral consumption, dermal contact and exposure through inhalation, via indices provided by the United States Environmental Protection Agency (USEPA) (Table 3.1 and Table 3.2). The health risks were computed for both children and adults since they have varying parameters, such as body weight, adherence factor, exposure duration and ingestion rate.

3.5.1 Noncarcinogenic health risk analysis

3.5.1.1 Hazard quotient

The Hazard Quotient (HQ), mainly utilized by the USEPA (1989) to evaluate health risks from air pollutants, is the ratio of exposure to harmful substances compared to the chronic reference dose (RFD) of a toxic substance (mg kg/day). An HQ of less than 1 ($HQ < 1$) indicates that the exposure is unlikely to lead to noticeable adverse effects, while an HQ greater than 1 ($HQ > 1$) suggests a significant risk of non-carcinogenic effects for individuals exposed (USEPA, 1989; Nkansah, 2016; Lučić and Onjia, 2023).

$$\mathrm{HQ} = \mathrm{EDI/RFD} \qquad \textit{eq 3.1}$$

where HQ is the hazard quotient, EDI is the estimated daily intake in mg/kg/day, and RFD is the chronic reference dose. The values for RfD for the different elements were obtained from the USEPA.

The estimated daily intake (EDI) may be determined as follows:

$$\mathrm{EDIoral} = \frac{\mathrm{Cs} \times \mathrm{IR} \times \mathrm{ED} \times \mathrm{EF} \times \mathrm{FI}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \qquad \mathrm{eq3.2}$$

$$\mathrm{EDIdermal} = \frac{\mathrm{Cs} \times \mathrm{SA} \times \mathrm{AF} \times \mathrm{ABS} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \qquad \mathrm{eq3.3}$$

$$\mathrm{EDIinh} = \frac{\mathrm{Cs} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{ET}}{\mathrm{PEF} \times \mathrm{BW} \times \mathrm{AT}} \qquad \mathrm{eq3.4}$$

where EDI oral is the daily exposure amount of PTEs through oral ingestion (mg/kg/day), EDI dermal is the daily exposure amount of PTEs through dermal contact (mg/kg/day), and EDI inh is the daily exposure amount of PTEs through inhalation (mg/kg/day). The exposure factors and variables for these models are shown in Table 3.2 with reference to the USEPA.

3.5.1.2 Hazard index (HI)

The hazard index (HI), developed by the USEPA, is the sum of hazard quotients that affect the same target organ or organ system. An HI ≥ 1 means that exposure to contaminants is most likely to cause adverse effects, whereas an HI<1 means that exposure is unlikely to cause adverse effects in subjects (Nkansah, 2016; Miletić, Lučić and Onjia, 2023).

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{RFD}} \qquad \text{eq 3.5}$$

3.5.2 Carcinogenic risk (CR)

Cancer risk (CR) is the likelihood of an individual's risk of suffering from cancer in a lifetime due to exposure to carcinogens. A cancer risk between $1*10^{-4}$ and $1*10^{-6}$ is considered acceptable. The total cancer risk is the sum of the carcinogenic risk for each carcinogenic element through all three exposure pathways, which are calculated via equation (3.6) below (Miletić, Lučić and Onjia, 2023):

$$\mathrm{CR} = \mathrm{EDI} * \mathrm{SF} \qquad \text{eq3.6}$$

Table 3.1 Reference doses (RfD) and slope factors of PTEs for health risk assessment

Element	Oral RfD	Dermal RfD	Inhalation Rfd	Oral Sf	Dermal SF	Inhalation SF	Reference
As	3.0E-04	3.0E-04	3.0E-04	1.5	1.5	1.5E+01	Kamunda, Mathuthu & Madhuku (2016)
Cd	5.0E-04	5.0E-04	5.7E-05	5.0E-01	6.1	6.3	Kamunda, Mathuthu & Madhuku (2016)
Cr	3.0E-03	6.0E-05	2.86E-05	5.0E-01	20	42	Kouadio et al. (2024)
Cu	4.0E-02	1.2E0-1	4.02E-1	1.7	42.5	8.4E-01	Kouadio et al. (2024)
Fe	7.0E-01	-	-	-	-	-	Nkansah et al. (2016)
Ni	2.0E-02	5.4E-03	9.0E-05	1.7	42.5	8.4E-01	Kouadio et al. (2024)
Pb	2.0E-02	5.25E-04	3.52E-03	8.5E-03	8.5E-03	4.2E-02	Kouadio et al. (2024)
Hg	3.0E-04	3.0E-04	8.6E-05	-	-	-	Kamunda, Mathuthu & Madhuku (2016)
Zn	3.0E-01	6.0E-02	3.0E-01	-	-	-	Kouadio et al. (2024)

Table 3.2 Variables used for health risk assessment (Kouadio et al. 2024)

	Value	Units
IR (Rate of soil ingestion)	100 adults 200 adults	Mg/day
ED (Exposure duration)	24 adults 6 children	Year
EF (Exposure duration)	350	Days/year
BW (Body weight)	63 adults 29 children	kg
AT (Average exposure time)	ED * 365 (noncarcinogens) 76.6*365 (carcinogens)	Days
SA (Surface area of exposed skin)	5700	cm^2
AF (Adherence factor)	0.07 adults 0.2 children	$mg/cm^2/h$
ABS (dermal absorption factor)	0.001	-
ET (Exposure time)	8	m^3/kg
PET (Emission factor)	1.36E09	Hours/day
FI (Factor ingested)	1	

3.6 Administration of Questionnaires

The questionnaires were prepared to be administered to locals who currently consume soil and to those who have left the habit. The goal was to administer as many questionnaires as possible to respondents since there are no available data on the population of geophagy practitioners. The questionnaires were administered to respondents from ages 12 and above as that is the age when most geophagy practitioners intentionally start the habit as evidenced by a study done by Geissler et al. (1997) where 80% of children aged 11-12 years old in Western Kenya. Some of the information sought from practitioners and former practitioners includes personal details (age, gender residence, highest level of education attained), their awareness of geophagy, the frequency of consumption and whether they have notified their health workers.

3.7 Data visualisation and Statistical Analysis

Data were analysed using R software and Microsoft Excel. R software was used to analyse data from questionnaires while excel was used to create tables and charts for morphological, physical, chemical and geochemical data.

CHAPTER FOUR

RESULTS

4.1 Physico-chemical properties of the geophagic soil samples

4.1.1 Soil colours

The geophagic soils vary in colour with brown and its shades being the most dominant followed by yellowish red (Table 4.1). The soils from Francistown are mostly dark brown, with the exception of FR1, which has a dark reddish brown colour, whereas the soil colours from Gaborone vary widely, ranging from pale browns to olive browns and yellowish browns. The soils from Molapowabojang and Mochudi are mostly various shades of olive brown, with some being yellowish brown. The soils from Palapye are predominantly various shades of yellowish browns, with two exceptions: yellowish red (PY3 and PY4). The soils from Tonota had various shades of brown from yellowish brown, strong brown and grayish brown (Fig 4.1, Table 4.1).

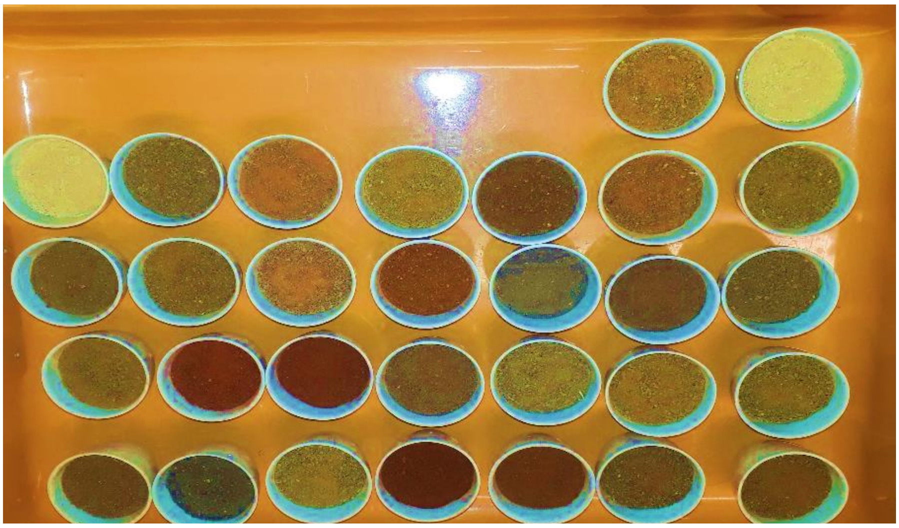

Figure 4.1 Soil colours of geophagic soils

Table 4.1: Soil colours of geophagic soils

	DRY		**MOIST**	
Sample ID	**Hue, Value & Chroma**	**Colour**	**Hue, Value & Chroma**	**Colour**
FR1	5YR 3/4	dark reddish brown	2.5YR 3/3	dark reddish brown
FR2	7.5YR 4/6	strong brown	7.5YR 2.5/3	very dark brown
FR3	10YR 3/4	dark yellowish brown	10YR 3/3	dark brown
FR4	10 YR 4/4	dark yellowish brown	10YR 3/3	dark brown
FR5	7.5YR 4/1	dark gray	7.5YR 3/1	very dark gray
GB1	10YR 8/2	very pale brown	2.5Y 5/4	light olive brown
GB2	10YR 8/2	very pale brown	10YR 8/4	very pale brown
GB3	10YR 4/6	dark yellowish brown	2.5Y 4/4	brown
GB4	2.5Y 5/4	light olive brown	2.5Y 4/4	olive brown
GB5	10YR 5/4	Yellowish brown	10YR 3/6	dark yellowish brown
MB1	2.5Y 5/4	light olive brown	2.5Y 4/3	olive brown
MB2	2.5Y 5/4	light olive brown	2.5Y 4/4	olive brown
MB3	2.5Y 5/4	light olive brown	2.5Y 4/3	olive brown
MB4	10YR 5/4	Yellowish brown	2.5Y 5/4	light olive brown
MB5	2.5Y 5/6	olive brown	2.5YR 5/3	light olive brown
MC1	10YR 4/6	dark yellowish brown	10YR 3/6	dark yellowish brown
MC2	2.5Y 4/3	olive brown	2.5Y 4/2	dark grayish brown
MC3	2.5Y 5/4	light olive brown	10YR 4/4	dark yellowish
MC4	2.5Y 5/4	light olive brown	2.5Y 4/4	olive brown
MC5	10YR 4/6	dark yellowish brown	10YR 3/6	dark yellowish brown
PY1	10YR 3/4	dark yellowish brown	10YR 3/3	dark brown
PY2	10YR 4/6	dark yellowish brown	10YR 3/3	dark brown
PY3	5YR 4/6	yellowish red	5YR 3/4	dark reddish brown
PY4	5YR 4/6	yellowish red	5YR 3/4	dark reddish brown
PY5	10YR 5/8	yellowish brown	10YR 3/6	dark yellowish brown
TN1	10YR 4/4	dark yellowish brown	10YR 3/2	very dark grayish brown
TN2	10YR 4/3	brown	10YR 3/2	very dark grayish brown
TN3	2.5Y 4/2	dark grayish brown	2.5Y 3/3	dark olive brown
TN4	7.5YR 4/6	strong brown	7.5YR 4/4	strong brown
TN5	10YR 4/3	brown	10YR 3/2	very dark grayish brown

FR= Francistown, GB= Gaborone, MB=Molapowabojang, MC= Mochudi, PY= Palapye, TN= Tonota

4.1.2 Soil texture

Sandy clay loam is the most dominant soil texture (13 samples) followed by clay texture with 8 samples (Table 4.2). 5 samples are sandy clay textured, and 4 samples are clay loam textured. The two samples bought from the Gaborone market (GB1 and GB2) are both clay textured.

4.1.3 Particle size distribution

The clay content (Table 4.2) ranged from 130g/kg to 800g/kg from TN5 and GB1, respectively, whereas the silt content ranged from 60g/kg to 587g/kg from PY4 and TN5 and for sand, the content ranged from 0g/kg to 697g/kg from GB1 and GB2 (from the market) and GB3, respectively. Sand particles were the most dominant with an average percentage of 466g/kg and a standard deviation of 155, whereas clay and silt had average percentages of 373g/kg and 160g/kg, and standard deviations of 123 and 98 respectively.

4.1.4 Soil moisture content

The moisture content (Table 4.2) of the soil samples ranged from 0.11% to 2.06%, the soil with the lowest soil moisture content being GB5 and the highest being GB4. The average soil moisture content was 0.73% and a standard deviation of 0.46%.

4.1.5 Soil organic matter

The soil organic matter content (Table 4.2) for all the samples was less than 1.5%. MC4 and GB5 have the highest SOM content of 1.4%, and GB3 has the lowest SOM content, with 0.2% SOM. The average SOM is 0.9% across all the sampling points, and the standard deviation is 0.3%.

4.1.6 pH and electrical conductivity

The pH (H_2O) (Table 4.2) soil samples ranged from 5.3-7.8, with the highest pH being from the MC4 sample and the lowest being from GB2. Only 12 of the 30 samples had pH values below 7, with an average pH of 7 across all the soil samples and a standard deviation of

0.7. The soils bought from the market in Gaborone (GB1 and GB2) and GB3 had the lowest pH values of 5.8, 5.3 and 5.6 (extremely and moderately acidic), respectively, while the other 10 acidic soils were slightly acidic.

The pH ($CaCl_2$) ranged from 5.2 (GB2) to 7.6 (MC4). Sixteen of the 30 soil samples had a pH lower than 7 compared with the pH tested in water, of which only 12 samples had a pH lower than 7. Owing to the high H^+ content in water, the pH tested in water is higher than the pH tested in 0.01 M calcium chloride solution. The average pH across all the soil samples was 6.7, with a standard deviation of 0.6. In terms of pH (H_2O), the lowest pH was detected in the soil samples purchased from the Gaborone market (GB1 and GB2) and GB3, with pH values of 5.7, 5.2 and 5.6, respectively.

The electrical conductivity ranged from 43 μS/cm to 1423 μS/cm from sampling points GB1 and GB4, respectively, with a total average EC of 354 μS/cm across all the sampling points (Table 4.2). The GB4 soil had the highest soil moisture content. The standard deviation of the EC was 312 μS/cm.

Table 4.2: Physicochemical properties of geophagic soils

Sample ID	**Soil texture**	**Clay**	**Silt**	**Sand**	**W**	**SOM**	**pH**	**pH**	**EC**
			-----------(g kg-1) -----------		**---------(%) ---------**		**(H_2O)**	**($CaCl_2$)**	**(µS/cm)**
FR1	Clay loam	363	240	397	0.4	0.9	7.2	6.2	87
FR2	Clay loam	283	240	477	1.3	1.1	6.4	6.6	160
FR3	Sandy clay loam	343	140	517	1.1	1.3	7.1	6.8	210
FR4	Sandy clay loam	323	200	477	0.8	1.2	6.5	6.4	183
FR5	Clay loam	383	180	437	1.3	1.1	7.3	7.0	173
GB1	Clay	800	200	0	0.6	1.2	5.8	5.7	43
GB2	Clay	680	320	00	0.3	1.1	5.3	5.2	100
GB3	Sandy clay loam	203	100	697	0.1	0.2	5.5	5.6	863
GB4	Clay loam	383	180	437	2.1	1.0	6.1	6.6	1423
GB5	Sandy clay loam	253	130	617	0.1	1.4	6.5	6.4	527
MB1	Sandy clay loam	303	120	577	1.0	0.9	6.6	6.4	313
MB2	Clay	422	160	418	0.6	1.1	6.4	6.0	273
MB3	Clay	422	140	438	1.2	1.1	6.5	6.2	260
MB4	Clay	422	240	338	0.6	1.2	6.8	6.2	80
MB5	Clay	442	100	458	0.9	1.0	6.6	6.1	370
MC1	Sandy clay loam	322	140	538	0.4	0.7	7.2	6.9	443
MC2	Sandy clay	362	80	558	0.3	0.5	7.5	7.0	263
MC3	Sandy clay	362	100	538	1.0	0.9	7.5	7.3	440
MC4	Clay	482	140	378	0.7	1.4	7.8	7.6	977
MC5	Sandy clay loam	312	110	578	0.7	0.7	7.6	7.4	160
PY1	Sandy clay loam	342	80	578	0.4	0.8	7.4	7.0	327
PY2	Sandy clay loam	322	120	558	1.5	0.7	7.4	7.1	247
PY3	Sandy clay	362	100	538	0.8	0.8	7.5	7.2	123
PY4	Sandy clay loam	282	60	658	0.4	0.3	7.1	6.9	183
PY5	Clay	482	180	338	0.6	1.0	7.5	7.2	247
TN1	Sandy clay	363	80	557	0.4	0.8	7.1	7.2	237
TN2	Sandy clay loam	323	150	527	0.3	1.0	7.4	7.5	1010
TN3	Sandy clay	363	140	497	0.4	1.2	7.7	7.4	347
TN4	Sandy clay loam	343	90	567	0.5	0.7	7.5	7.3	387
TN5	Sandy clay loam	130	587	293	1.1	0.9	7.7	7.6	173
	Minimum	**130**	**60**	**00**	**0.1**	**0.2**	**5.3**	**5.2**	**43**
	Maximum	**800**	**587**	**697**	**1.4**	**28.3**	**7.8**	**7.6**	**1423**
	Average	**373**	**160**	**466**	**0.9**	**1.9**	**7.0**	**6.7**	**354**
	SD	**123**	**98**	**155**	**0.3**	**4.9**	**0.7**	**0.6**	**312**

FR= Francistown, GB= Gaborone, MB=Molapowabojang, MC= Mochudi, PY= Palapye, TN= Tonota

4.1.7 Minerology of clay-sized fractions

Kaolinite ($Al_2Si_2O_5(OH)_4$ and quartz (SiO_2) are the main clay minerals in geophagic soils from Botswana. Kaolinite is present in all the samples except for one (TN3), and quartz minerals are also found in all the samples except for TN3 and FR4. The other predominant minerals are muscovite ($KAl_2(Si_3Al)O_{10}(OH)_2$) (33 % of the samples) and goethite ($FeO(OH)$) (40% of the samples) (Table 4.3). The samples bought from the Gaborone market (GB1 and GB2) and one sample from Molapowabojang (MB1) are the only samples containing illite ($K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$ whereas halloysite ($Al_2Si_2O_5(OH)_4$) was found in the Palapye and Tonota samples (PY5 and TN1). Calcite ($CaCO_3$) and montmorillonite($(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_{2n}(H_2O)$) was found in TN4 and TN5 respectively.

Table 4.3: Qualitative Minerology of the clay-sized fractions

Sample ID	Kaolinite	Quartz	Muscovite	Goethite	Illite	Halloysite	Montmorillonite	Calcite
Francistown								
FR1	+	+	+					
FR2	+	+						
FR3	+	+	+					
FR4	+							
FR5	+	+						
Gaborone								
GB1	+	+			+			
GB2	+	+			+			
GB3	+	+		+				
GB4	+	+		+				
GB5	+	+		+				
Molapowabojang								
MB1	+	+			+			
MB2	+	+		+				
MB3	+	+		+				
MB4	+	+						
MB5	+	+						
Mochudi								
MC1	+	+	+					
MC2	+	+		+				
MC3	+	+						
MC4	+	+	+	+				
MC5	+	+	+	+				
Palapye								
PY1	+	+	+					
PY2	+	+						
PY3	+	+						
PY4	+	+	+					
PY5	+	+		+		+		
Tonota								
TN1	+	+	+	+		+		
TN2	+		+					
TN3			+	+				
TN4	+	+					+	
TN5	+	+		+				+

FR= Francistown, GB= Gaborone, MB=Molapowabojang, MC= Mochudi, PY= Palapye, TN= Tonota

4.2 Geo-chemistry of geophagic soils

4.2.1 Essential elements

Tonota and Francistown geophagic soils presented the highest calcium concentration, with a means of 19584 ppm and 15768 ppm respectively. Palapye and Molapowabojang have a close range in mean concentrations of 5504 ppm and 4960ppm respectively. Gaborone and Mochudi presented the lowest mean concentrations of calcium at 3742 ppm and 3076 ppm (Table 3). All the samples have concentrations higher than the recommended daily dosage (RDD) of 1200 ppm (Figure 4.2a; Table 4.4).

Francistown and Tonota presented the highest magnesium contents, with close ranges of mean concentrations of 8396 ppm and 7720 ppm respectively. Palapye, Molapowabojang, Gaborone and Mochudi have mean concentration 3604 ppm, 3024ppm, 2778 ppm and 2414 ppm respectively (Table 4.5). All the samples had concentrations higher than the RDD of 360 ppm (Figure 4.2b; Table 4.4).

Phosphorus is the least concentrated essential element in geophagic soils of Botswana. Francistown had the highest mean concentration of 232 ppm. Tonota, Molapowabojang Gaborone, and Palapye closely followed, with mean concentrations of 220ppm, 144 ppm and 130ppm and 112ppm, respectively. Mochudi geophagic soils had the lowest phosphorus content, with a mean concentration of 62 ppm (Table 4.5). All the samples are below RDD of 700 ppm for P (Figure 4.2 c; Table 4).

Gaborone has the highest mean concentration of potassium (22680 ppm), while Tonota, Molapowabojang, Palapye have mean concentrations 20920 ppm, 17660 ppm and 11760 ppm respectively. Francistown and Mochudi geophagic soils have lower potassium contents of 6920 ppm and 5780ppm, respectively (Table 4.5). All the samples have a concentration above the

RDD of 5000 ppm except samples from FR1, GB2 ,GB3, MC3, and MC4, (Figure 4.2d); Table 4).

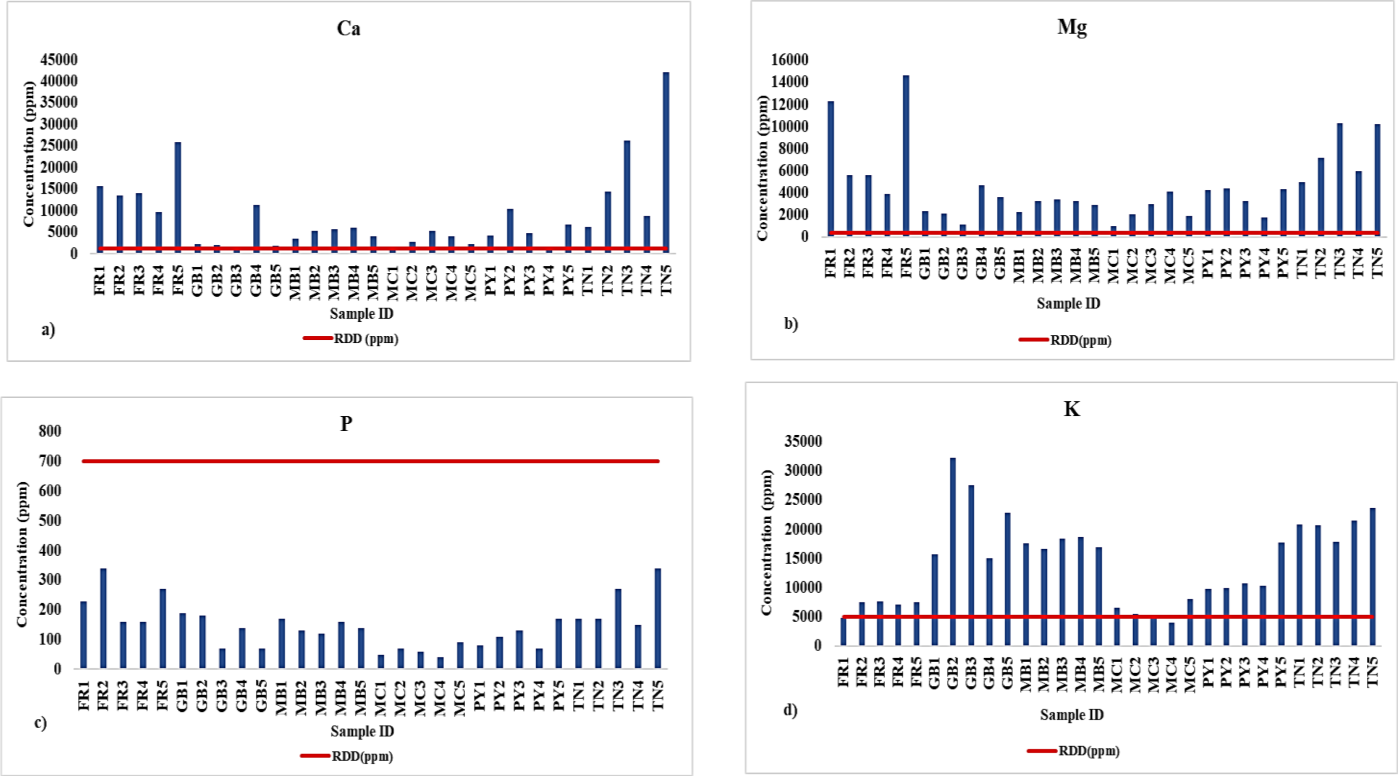

Figure 4.2 a-d: Essential elements compared to their Recommended Daily Dosage (RDDs)

4.2.2 Essential trace elements

Francistown had the highest zinc content, with a concentration of 51.4 mg/kg, closely followed by Tonota, Gaborone and Molapowabojang, with mean concentrations of 53.6 mg/kg, 45.6 mg/kg and 43.2 mg/kg, respectively. The remaining sampling locations presented lower zinc contents, with concentrations of 29.8 mg/kg and 26.4 mg/kg for Mochudi and Palapye, respectively (Table 4.5). 15 samples from FR1, FR2, FR5, GB1, GB2, GB5, MB2, MB3, MB4, MB5,TN1, TN2, TN3, TN4, TN5 have concentrations higher than the RDD of 40mg/kg for Zn (Figure 3a); Table 4).

Iron is the most dominant essential trace element found in geophagic soils from Botswana. Francistown and Tonota had the highest iron contents, with mean concentrations of 55460 ppm and 44340 ppm, respectively. Molapowabojang soil also has a high Fe content of 38680 ppm, which is within a close range of mean concentrations of iron from Mochudi, Palapye and Gaborone 36980 ppm, 34940 ppm and, 30020 ppm respectively (Table 4.5). All the samples have concentrations above the RDD of 60 ppm for Fe (Figure 4.3b); Table 4.4).

The highest concentrations of copper were detected in the Francistown and Tonota geophagic soils, with mean concentrations of 172 mg/kg and 103.5 mg/kg, respectively, followed closely by the Molapowabojang geophagic soils, with a mean concentration of 92.48 mg/kg, and the Gaborone soils, with a mean concentration of 73.56 mg/kg. Mochudi and Palapye had the lowest copper contents, with means of 69.94 mg/kg and 56.56 mg/kg, respectively (Table 4.5). All the samples have concentrations above the RDD of 10mg/kg for Cu (Figure 4.3c); Table 4.4).

The Cr content was the highest in Tonota and Mochudi with means of 88 mg/kg and 85.4 mg/kg, respectively. Palapye and Francistown presented mean concentrations of 80.2 mg/kg and 74.2 g/kg, respectively, whereas the Molapowabojang and Gaborone geophagic soils presented mean concentrations of 70 mg/kg/kg and 67.2 mg/kg chromium, respectively Table 4.5). The observed geophagic soil samples all have concentrations higher than the RDD of 0.035mg/kg for Cr (Figure 4.3d); Table 4.4).

Mochudi, Francistown and Tonota geophagic soils have mean concentrations of 60.6 mg/kg, 59.6 mg/kg and 53.6 mg/kg of Ni, respectively. Molapowabojang, Palapye and Gaborone have lower concentrations of nickel, with means of 41.6 mg/kg, 35.4 mg/kg and 35.2 mg/kg, respectively (Table 4.5). All of the 30 samples have concentrations higher than the RDD of 1.1mg/kg of Ni (Figure 4.3e); Table 4.4).

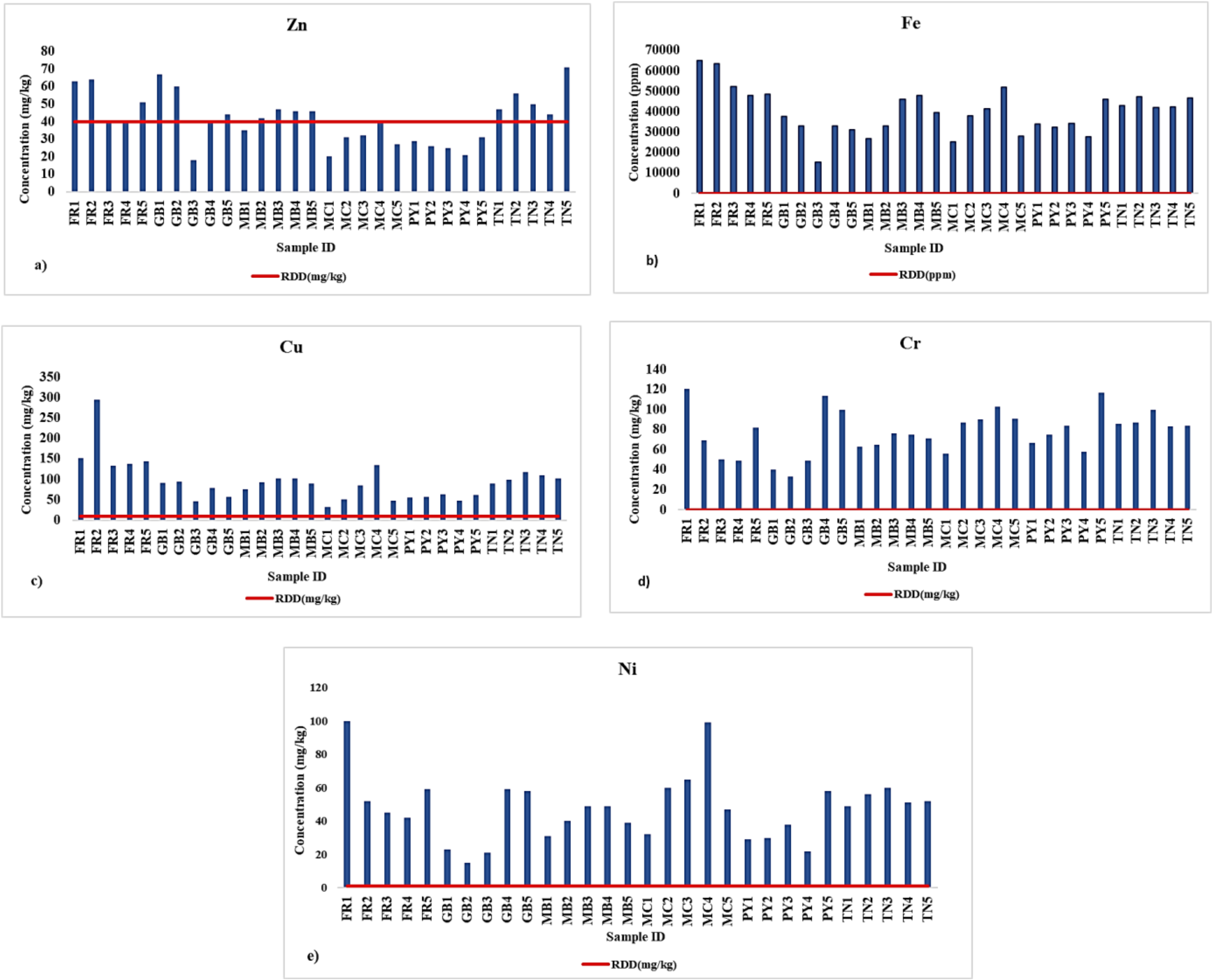

Figure 4.3a-e: Essential trace elements compared to their RDDs

4.2.3 Toxic elements

Compared with essential elements and essential trace elements, toxic metals are present at lower concentrations in the geophagic soils of Botswana. Molapowabojang geophagic soils have the highest As content, with a mean concentration of 2.4 mg/kg, closely followed by Mochudi and Gaborone geophagic soils, with means of 2.2 mg/kg and 2.0 mg/kg, respectively. Palapye, Tonota and Francistown geophagic soils presented relatively low As contents, with mean concentrations of 1.75 mg/kg, 1.6 mg/kg and 1 mg/kg, respectively (Table 4.5). The samples all have concentrations higher than the TIL of 0.0000081mg/kg for As (Figure 4.4a); Table 4.4).

Francistown, Tonota and Gaborone had higher cadmium contents than did the other sampling locations, with mean concentrations of 0.07 mg/kg, 0.06 mg/kg and 0.035 mg/kg, respectively. Molapowabojang, Mochudi and Palapye all had relatively low cadmium contents, with mean concentrations of 0.03 mg/kg (Table 4.5). All 30 samples except 2 from FR2 and TN5 were found to have concentrations below TIL of 0.071 mg/kg for Cd (Figure 4.4b; Table 4.4).

For Pb, Gaborone geophagic soils presented the highest lead mean concentration of 29.76 mg/kg, followed by Tonota geophagic soils, with a mean concentration of 18.06 mg/kg, and Palapye geophagic soils, with a mean concentration of 12.26 mg/kg. The Mochudi and Molapowabojang geophagic soils had mean concentrations of 11.86 mg/kg and 11.66 mg/kg, respectively. Francistown geophagic soils had the lowest lead concentrations (mean of 7.36 mg/kg) (Table 3). All the samples have concentrations higher than the tolerable intake level (TIL) of 0.01mg/kg (Figure 4.4c; Table 4.4)

Mochudi and Tonota geophagic soils had the highest mercury contents at mean concentrations of 0.46 mg/kg and 0.33mg/kg, closely followed by Palapye geophagic soils, with a mean concentration of 0.22 mg/kg. Gaborone geophagic soils have mean concentration of 0.17 mg/kg and while whereas Molapowabojang and Francistown both have a mean concentration of 0.16 mg/kg (Table 4.5). All samples have concentrations higher than TIL of 0.005mg/kg for Hg (Figure 4.4 d); Table 4.4).

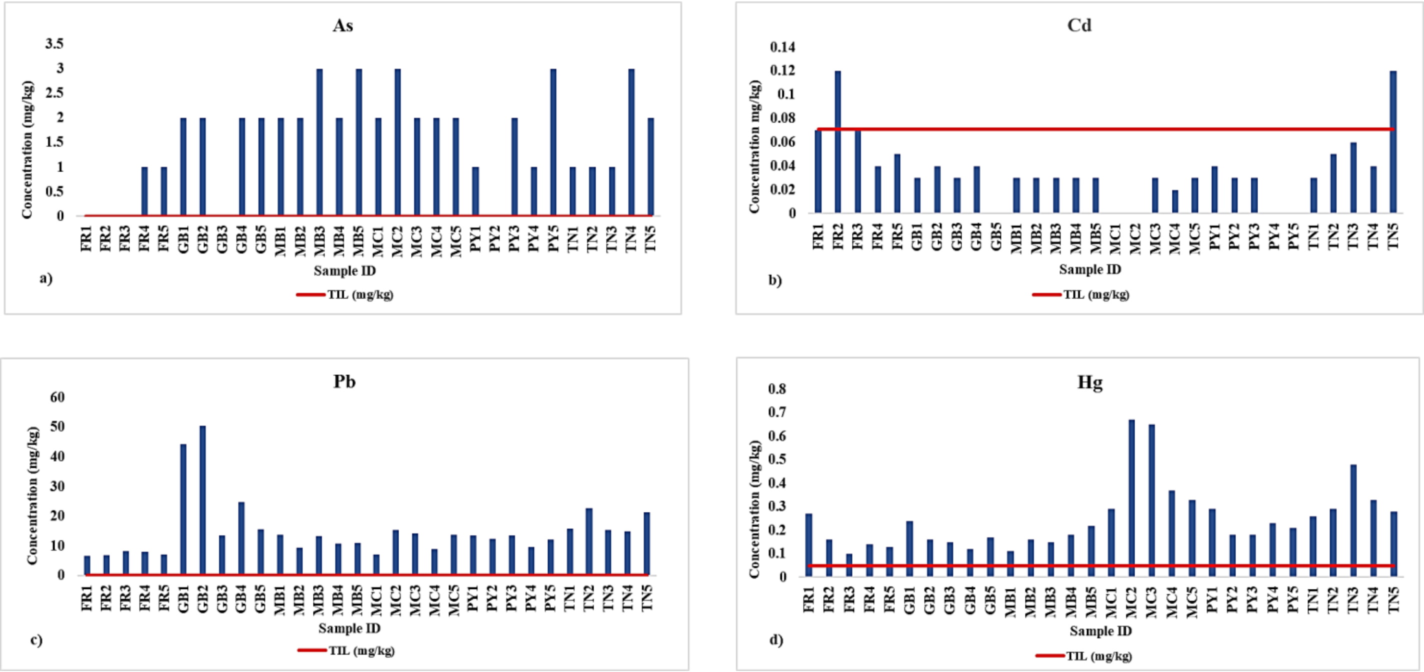

Figure 4.4a-d: Toxic elements compared to their Tolerable Intake levels (TILs)

Table 4.4: Chemical elements and their Recommended Daily Dosage (RDD) and Tolerable Intake Levels (TILs*)*

Element	RDD/TIL (mg/kg)	Reference
Ca	1200	Mouri et al., 2023
Mg	360	Bernado et al., 2022
P	700	Panel and Nda, 2015
K	5000	Bernado et al., 2022
Zn	40	Bernado et al., 2022
Fe	30-60	Bernado et al., 2022
Cu	10	Bernado et al., 2022
Ni	1.1	Mouri et al., 2023
Pb	0.01	Mouri et al., 2023
As	0.000081	Mouri et al., 2023
Cr	0.035	Mouri et al., 2023
Cd	0.071	Rachmayani, 2015
Hg	0.005	Freely et al., 2011

Table 4.5: Mean concentrations of the elements found in geophagic soils

	Location	Francistown	Gaborone	Molapowabojang	Mochudi	Palapye	Tonota	**Total Mean**
Essential Elements (ppm)	Ca	15768	3742	4960	3076	5504	19584	8772.3
	Mg	8396	27748	3024	2414	3604	7720	4656
	P	232	130	144	62	112	220	150
	K	6920	22680	17660	5780	11760	20920	14286
Essential Trace Elements (mg/kg)	Zn	51.4	45.6	43.2	29.8	26.4	53.6	41.7
	Fe	55460	30020	38680	36980	34940	44340	40070
	Cu	172	73.56	92.48	69.94	56.56	103.5	94.7
	Cr	74.2	67.2	70	85.4	80.2	88	77.5
	Ni	59.6	35.2	41.6	60.6	35.4	53.6	47.7
Toxic elements (mg/kg)	As	1	2	2.4	2.2	1.75	1.6	1.9
	Cd	0.07	0.035	0.03	0.03	0.03	0.06	0.04
	Pb	7.36	29.76	11.66	11.86	12.26	18.06	15.2
	Hg	0.16	0.168	0.164	0.462	0.218	0.328	0.25

4.3 Health risk analysis of geophagic soils

4.3.1 Hazard Indices of PTEs for adults and children

Exposure of potentially toxic elements through oral consumption has the highest means of hazard quotients and hazard indices, followed by exposure through dermal contact and lastly inhalation. For health risk analysis in adults as shown in Table 4.6, Francistown and Tonota have the highest oral mean HI values (7.31 E-02 and 6.08 E-02 respectively). Molapowabojang, Mochudi and Palapye geophagic soils closely follow with oral mean HI's of 5.28 E-02 and 5.25 E-02 respectively while Palapye and Gaborone have the lowest mean oral His of 4.81 E-02 and 4.28 E-02 respectively. For HI through dermal contact Tonota, Mochudi and Palapye geophagic soils have HI's of 1.45 E-03, 1.40 E-03 and 1.31 E-03 respectively while Francistown and Molapowabojang and Gaborone have lower mean HI's of 1.21 E-03, 1.15 E-03 and 1.13 E0-3 respectively. For HI's of exposure through inhalation, Tonota and Mochudi have the highest mean HI's of 5.17 E-05 and 5.16 E-05 followed by Francistown with a mean HI of 4.58 E-05 while Palapye, Molapowabojang and Gaborone have lower mean HI's of 4.50 E-5, 4.10 E-05 and 3.87 E-05 respectively. The mean HI's for adults were all below 1, which means that exposure to potentially toxic elements in geophagic soils is less likely to cause adverse effects in geophagists.

For health risk analysis in children, exposure of PTEs through oral consumption has the highest mean HI values, as observed in adults as well (Table 4.7). Francistown and Tonota geophagic soils have the highest oral mean HI's (2.86 E-01 and 2.31 E-01 respectively) followed by Molapowabojang geophagic soil (2.00 E-01). Mochudi, Palapye and Gaborone samples have lower mean HI values of 1.94 E-01, 1.80 E-01 and 1.57 E-01 respectively. Tonota, Mochudi and Palapye have mean dermal contact HI's of 2.44 E-03, 2.29 E-03 and 2.13 E-03 respectively, while Francistown, Molapowabojang and Gaborone geophagic soils have lower HI values of 2.06 E-03, 1.94 E-03 and 1.92 E-03 respectively. For exposure of PTEs through inhalation, Tonota, Mochudi and Francistown have higher mean HIs (2.83 E-05, 2.85 E-05 and 2.51 E-05) while Palapye and Molapowabojang and Gaborone have mean HI's of 2.47 E-05, 2.25 E-05 and 2.12 E-05 The mean HI's for children were all below 1, as observed in adults as well, which means exposure of PTEs to geophagists is less likely to cause adverse effects to them. Children have higher mean HI's as compared to adults, which puts them at a higher risk from exposure to PTEs in geophagic soils.

Table 4.6: Mean HIs for adults

Location	HI Oral	HI dermal contact	HI Inhalation
Francistown	7.13E-02	1.21E-03	4.58E-05
Gaborone	4.28E-02	1.13E-03	3.87E-05
Molapowabojang	5.28E-02	1.15E-03	4.10E-05
Mochudi	5.25E-02	1.40E-03	5.16E-05
Palapye	4.81E-02	1.31E-03	4.50E-05
Tonota	6.08E-02	1.45E-03	5.17E-05

Table 4.7: Mean HIs for children

Location	HI Oral	HI dermal contact	HI Inhalation
Francistown	2.86E-01	2.06E-03	2.51E-05
Gaborone	1.57E-01	1.92E-03	2.12E-05
Molapowabojang	2.00E-01	1.94E-03	2.25E-05
Mochudi	1.94E-01	2.29E-03	2.85E-05
Palapye	1.80E-01	2.13E-03	2.47E-05
Tonota	2.31E-01	2.44E-03	2.85E-05

4.3.2: Contributions of the exposure pathways and PTEs to the HI

Exposure to PTEs by oral ingestion is the greatest contributor to the Hazard Index (HI) for adults in all locations with percentages ranging from 98% to 97% (Figure 4.5a-f). The second greatest exposure pathway contributor to HI is dermal contact with percentages ranging from 2% to 3%. Exposure to PTEs by inhalation is least contributor to HI with 0% in all the locations. Fe contributes the most to the HI of adults with percentages ranging from 74% to 83% followed by Cr (10% to 16%). As is the third largest contributor in Gaborone, Molapowabojang and Mochudi with percentage range of 2% to 4% while Cu contributes 3%

to 5% in Molapowabojang, Mochudi Tonota, Francistown and Gaborone. Pb contributes 3% in Gaborone and only 1% in Molapowabojang, Mochudi, Palapye and Tonota. Nickel contributes a low percentage of 1% in all the locations while Hg contributes 1% to 2% in all the locations. Cd contributes 4% in Tonota and 0% in the rest of the locations while Zn contributes 0% to the HI in all the sampling locations (Figure 4.6 a-f).

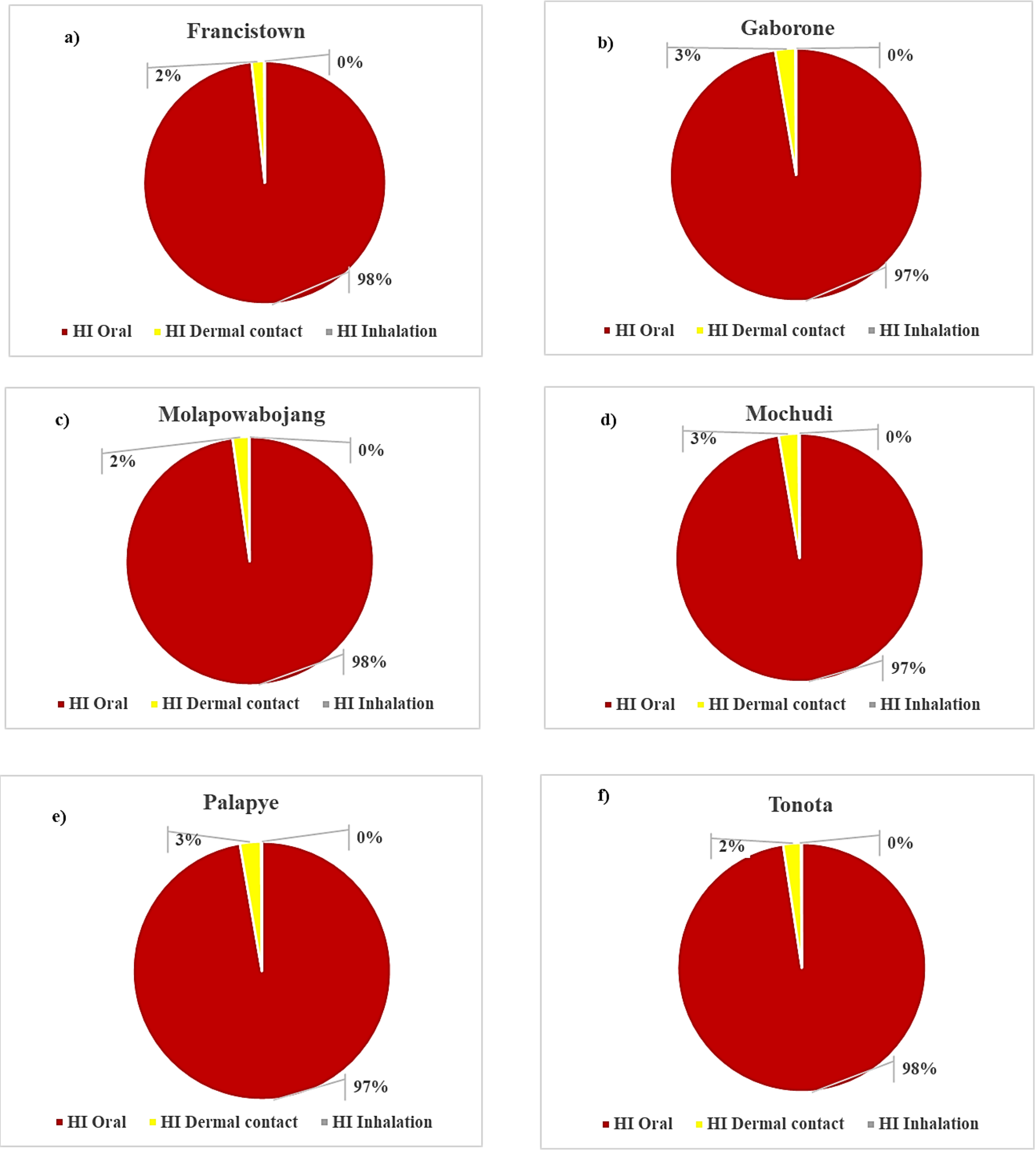

Figure 4.5a-f: Contributions of the three exposure pathways to the hazard index (HI) in adults

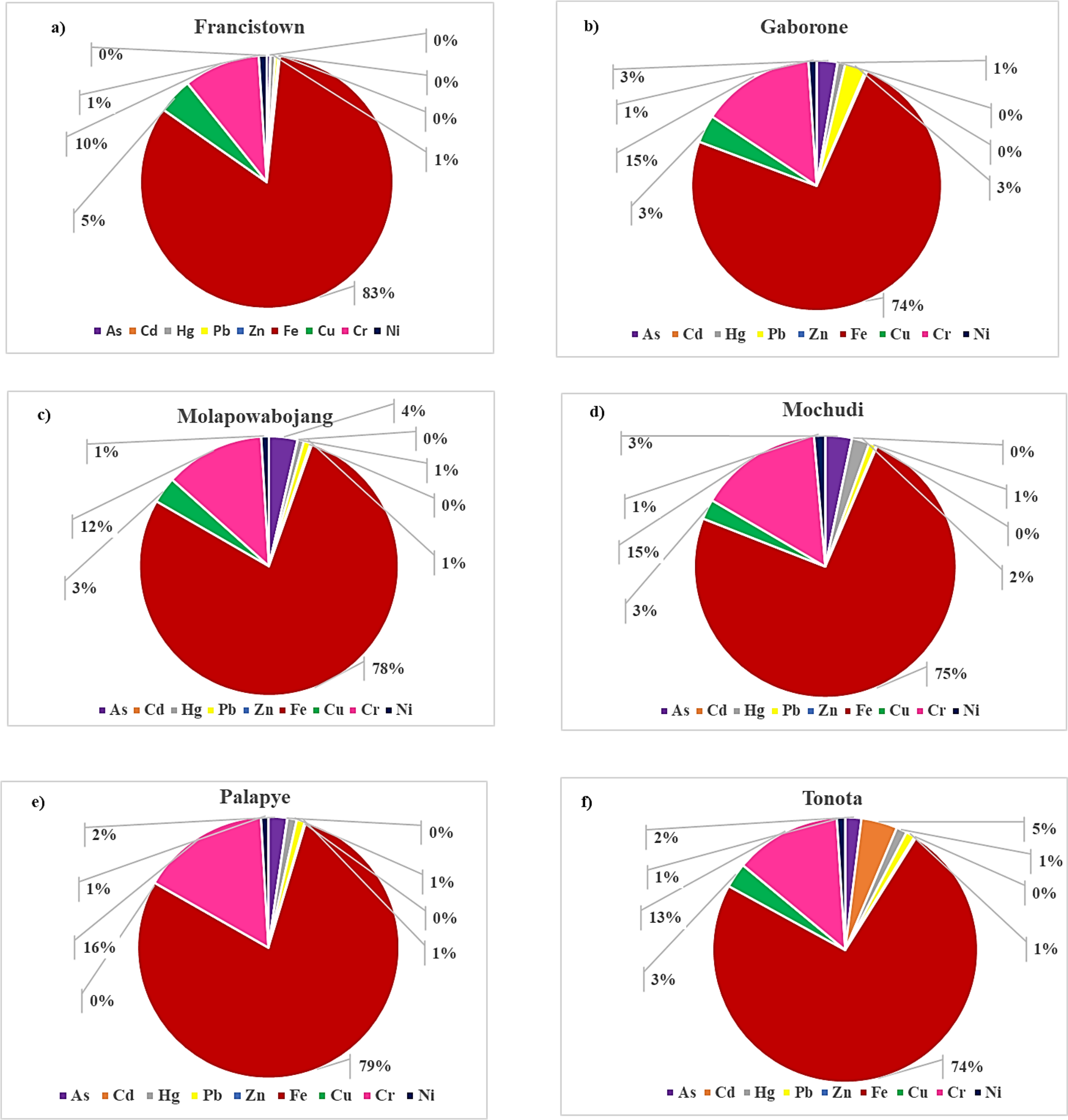

Figure 4.6a-f: Contributions of PTEs to the hazard index (HI) in adults

Exposure by oral ingestion is also the greatest contributor to HI in children in all the locations with 99% in all the locations (figure 4.7a-f). Oral ingestion is followed by exposure through dermal contact with a percentage of 1% in all the locations. Exposure through inhalation is also the least contributor to the HI in children with a percentage of 0% in all the locations. Fe contributes the most to the HI in children with a percentage range of 89% to 91% in all the sampling locations followed by Cr with a percentage range of 5% to 3% in all the locations except Francistown where it only contributes 3%. Cu contributes 3% to 5% in all the locations while Hg contributes 1% in Francistown, Molapowabojang and Palapye; 2% in Tonota and 3% in Mochudi. Ni only contributes to the geophagic soil of Gaborone with 3%. The rest of the PTEs do not contribute to the HI in all the locations(figure 4.8a-f).

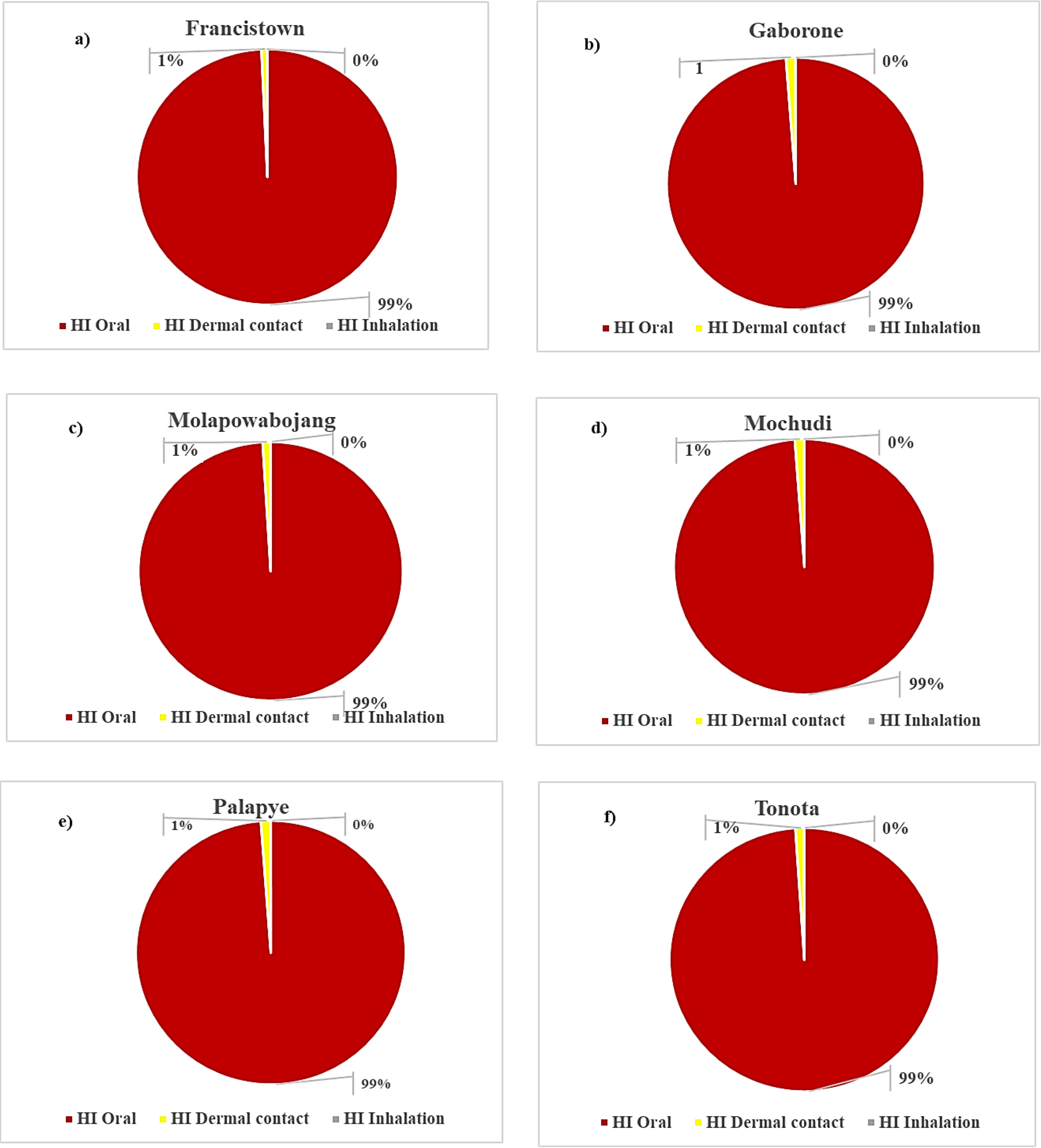

Figure 4.7 a-f: Contributions of the three exposure pathways to the hazard index (HI) in children

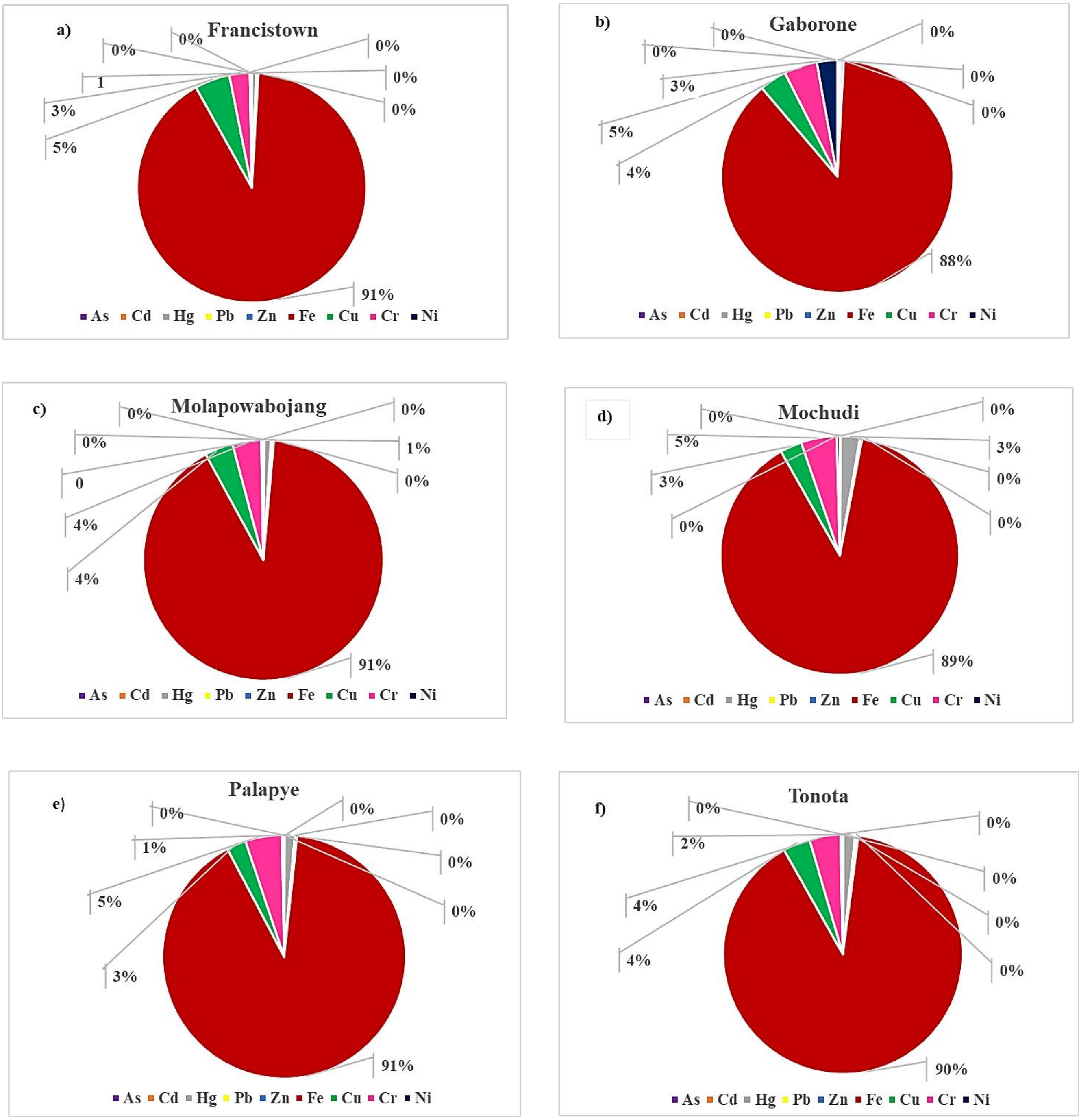

Figure 4.8a-f: Contributions of PTEs to the hazard index (HI) in children

4.3.3 Carcinogenic health risk analysis/cancer risk (CR)

The cancer risk (CR) associated with oral consumption is greater than that associated with exposure through dermal contact and inhalation for both adults and children. The mean oral CRs for adults are the highest for arsenic, nickel and chromium at all the sampling locations (figure 4.9a-f). The mean CR values for these carcinogenic elements are all within the acceptable range of 1.00E-06 to 1.00E-0. For CR resulting from exposure through dermal contact, the mean CR values for nickel are quite high compared with those of the other carcinogens throughout all the sampling locations, but they fall within the acceptable range. The mean CR values for exposure by inhalation are all less than 1.00 E-06. However, Chromium had the highest means of CR values for inhalation at all the sampling locations.

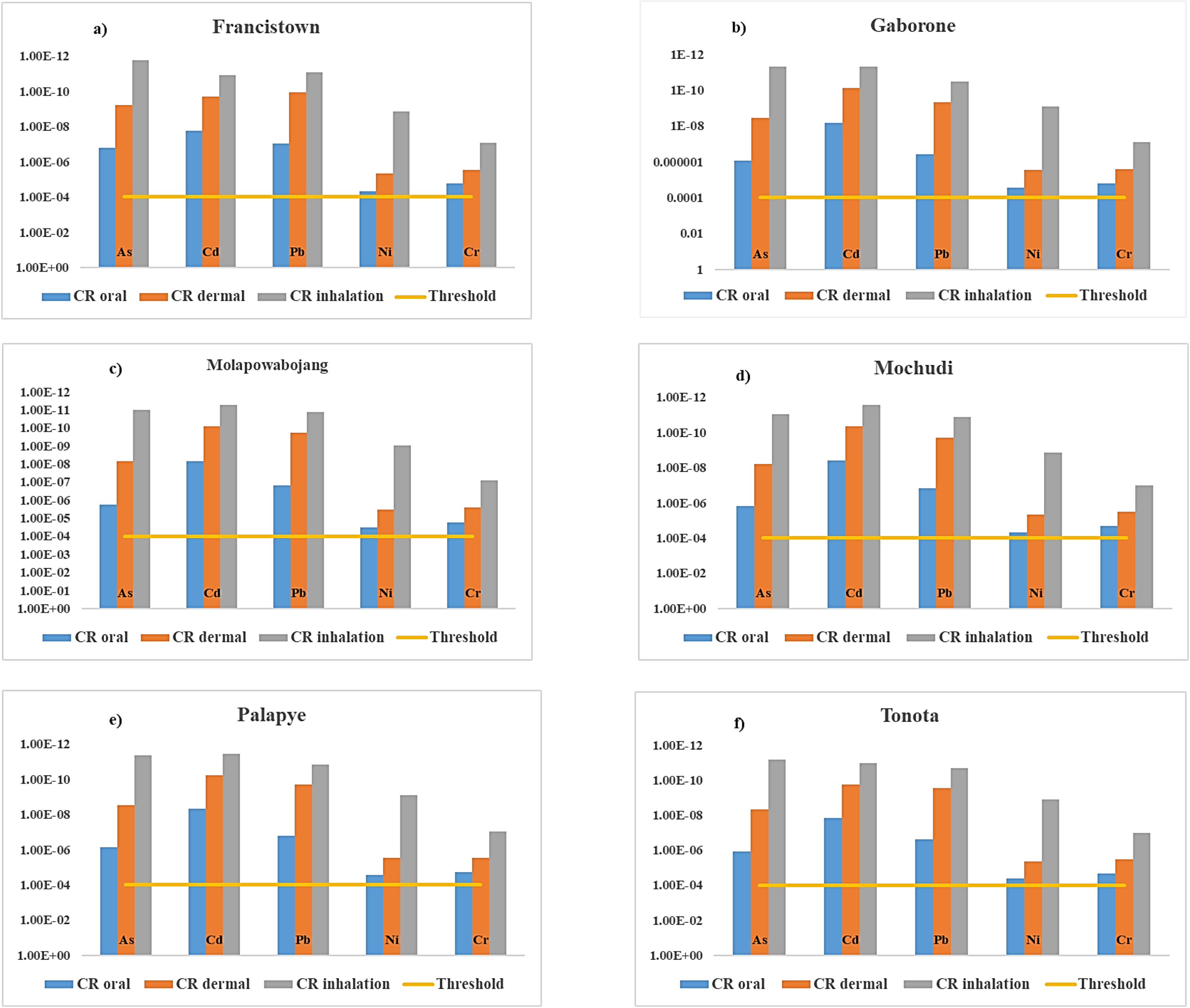

Figure 4.9a-f: Cancer Risks (CRs) for adults

As observed in the CR values for adults, the mean oral CR values for children are also the highest compared with those of the other exposure pathways (figure 4.10a-f). Nickel and chromium had the highest mean oral CR values across all the sampling locations, falling within the acceptable range (1.00 E-06 to 1.00 E-04), followed by As and Pb. The mean CR values are relatively high for nickel and chromium for exposure through dermal contact at all the sampling locations, and the mean CR values for these carcinogens also fall within the acceptable range. The mean CR values for exposure via inhalation are all less than 1.00 E-06 for children.

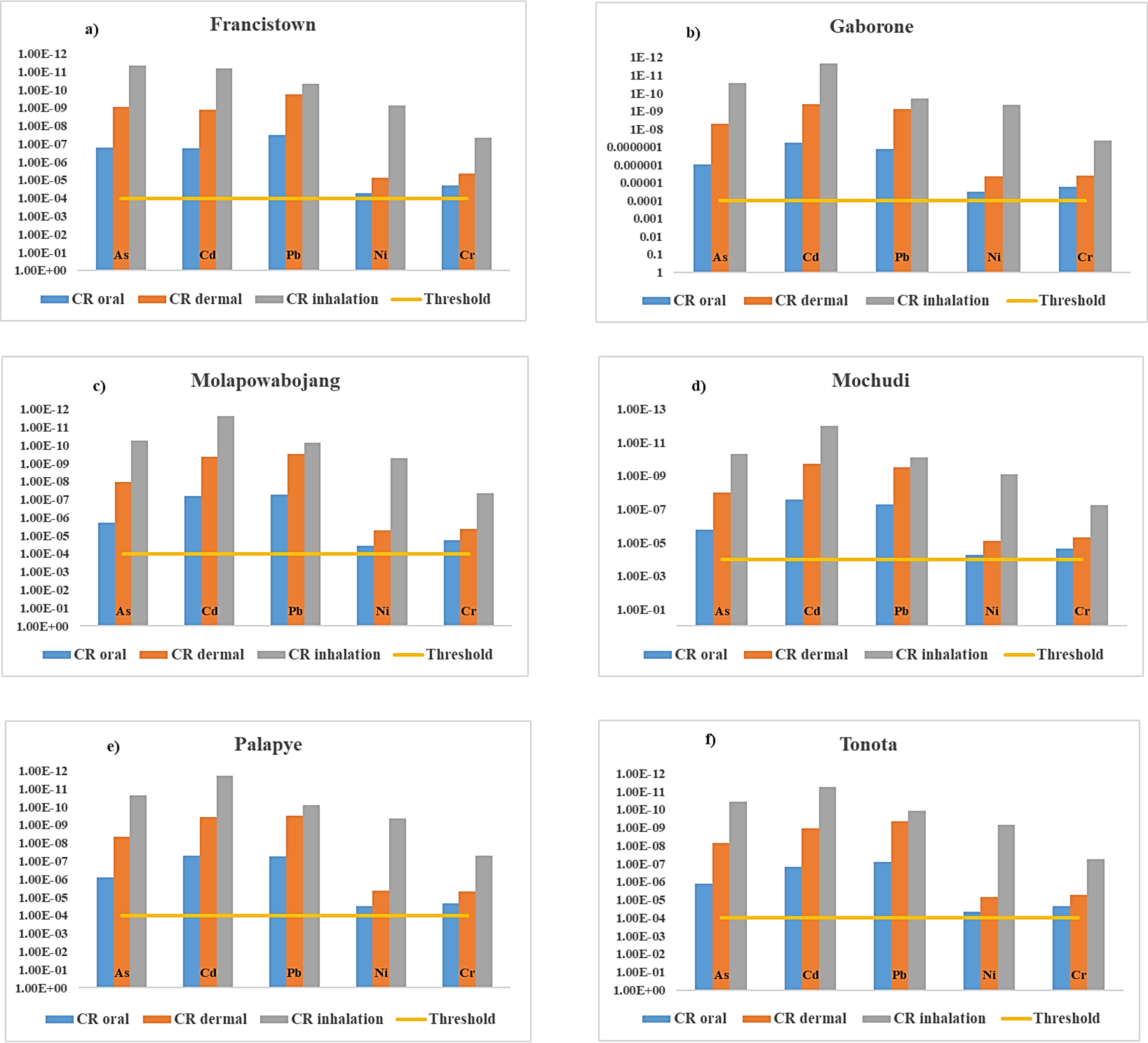

Figure 4.10 a-f: Cancer risk (CR) for children

4.4 Questionnaire responses

4.4.1 socio-demographics

Among the 66 participants in the questionnaires, 98.48% of the respondents were female, whereas only 1.52% were male as observed in Table 4.8. These findings suggest that geophagy is more common among females. 59.09% of the respondents were over the age of 30, 24% were in the 20--30 years age group, and only 16.67% of the respondents were aged 12-19 years. These findings suggest that geophagy is more common in older people. Forty-one percent of the participants had a junior secondary level of education, 36.36% had a tertiary level of education, 16.67% had a senior secondary level of education, and only 6.06% had a primary school level of education.

Table 4.8: Socio-demographics of the questionnaire participants

Variables	Observations	Frequencies (N=66)	Percentage (%)
Age	12-19 years	11	16.67
	20-30 Years	16	24.24
	>30 years	39	59.09
Gender	Female	65	98.48
	Male	1	1.52
Education	Primary	4	6.06
	Junior secondary	27	40.91
	Senior secondary	11	16.67
	Tertiary	24	36.36

4.4.2 Prevalence of Geophagy

Eighty-two percent of the respondents reported that they consumed soil daily; 17% said that they only consumed soil weekly, while only 1% of them consumed soil occasionally (Table 4.9). Thirty-two percent of the respondents said that they know fewer than 5 people who consume soil, whereas 68% said that they know more than 5 people who consume soil. Eighty-two percent of the respondents said that they were initiated into the habit by friends/family, whereas 16% of them were self-initiated. Sixty-eight percent of the respondents reported that they had been consuming soil for 1--5 years, 15% said that they had consumed soil for 6--10 years, and 9% of the respondents had been accustomed to it for more than 10 years. 5% said they recently started the habit (1> year), whereas 3% were not sure how long they had been consuming soil. One hundred percent of the respondents reported that they did not pretreat the soil (baking/heating) before ingesting.

Table 4.9: Prevalence of geophagy in Botswana

Variables	Observations	Frequencies (N=66)	Percentage (%)
Frequency of consumption	Daily	53	82
	Weekly	11	17
	Occasionally	1	1
How many people do you know that eat soil	<5 people	21	32
	≥5 people	44	68
Initiated into practice by..	Friends/Family	54	82
	Self	12	16
Duration of consumption of soil	<1 year	3	5
	1 to 5 years	45	68
	6 to 10 years	10	15
	More than 10 years	6	9
	Not sure	2	3
Pre-treatment of soil (baking/heating)	Yes	0	0
	No	66	100

4.4.3 Knowledge of geophagy

Constipation, soil-transmitted helminths and digestion abnormalities are the commonly known effects at frequencies of 46, 39 and 26, respectively. Intestinal blockage and anaemia have frequencies of 21 and 20, respectively, and only 1 respondent reported that they had no knowledge of the effects of geophagy.

The participants were also asked about their reasons for consuming soil. Cravings are the most common reason for soil ingestion, with a frequency of 56; the second most common reason is anti-stress effects (32 frequency). The consumption of soil simply as a habit has a frequency of 24, while the least common reasons for geophagy are peer pressure and positive health effects.

Friends/family and health care workers, as sources of knowledge on the effects of geophagy, are the most common among respondents (45 and 43 frequencies). Personal experience is one of the sources of knowledge for some of the respondents, as they experience it first (frequency 13). Media is the least common source of knowledge among the respondents.

The participants were asked why they thought pregnant women consumed soil, and the most common answer was cravings with a frequency of 61, followed by 'to reduce/stop morning sicknesses with a frequency of 36'. Some respondents believed that pregnant women practice geophagy so that they can have beautiful/smooth babies and prevent prolonged labour during birth.

Among the respondents who stopped the habit of geophagy, 14 (63%) of the 22 said they stopped ingesting soil for health-related reasons, 3 (14%) said they stopped when they became pregnant, and the remaining said they simply made the decision to stop the habit (14%), with some no longer craving soil (9%).

Table 4.10: Participants' knowledge of geophagy

Variables	Observations	Frequencies	Percentage (%)
Awareness on effects of geophagy	Anaemia	20	13.07
	Constipation	46	30.07
	Soil transmitted helminths	39	25.49
	Intestinal blockage	21	13.73
	Abnormality in digestion	26	16.99
	No knowledge	1	0.65
Reasons for eating soil	Anti-stress effects	32	27.35
	Cravings	56	47.86
	Peer pressure	1	0.85
	Habit	24	20.51
	Health positive effects	4	3.42
Source of knowledge on effects	Friends and/or family	45	42.06
	Health care workers	43	40.19
	Personal experience	13	12.15
	Media	6	5.61
Why they think pregnant women ingest soil	To reduce/stop morning sickness	36	31.58
	To have a healthy pregnancy	8	7.02
	To prevent prolonged labour	4	3.51
	Cravings	61	53.51
	To have smooth/beautiful baby	5	4.39
Why some participants stopped ingesting soil	Pregnancy	3	13.64
	Health reasons	14	63.64
	Personal decision	3	13.64
	No cravings	2	9.09

4.4.4 Relationships between variables

Table 4.11 shows the relationship between the level of education of respondents and those who stopped consuming soil. All 4 of the respondents with a primary school level of education reported that they had stopped the habit of geophagy, whereas of the 27 with junior secondary level education, 12 said that they had stopped the habit. Only 1 out of 11 of the respondents with senior secondary-level education said that they had quit consuming soil. For the respondents with tertiary-level education, only 5 of the 24 reported having stopped the habit.

Table 4.11: Education vs those who stopped consuming soil

Education	Have you stopped consuming		
	No	Yes	Total
Primary	0	4	4
Junior Secondary	15	12	27
Senior Secondary	10	1	11
Tertiary	19	5	24
Total	44	22	66

Table 4.12 shows the relationships between the variables “Age” and “Frequency of consumption”. Among the 11 respondents in the 12–19-year age group, 8 reported consuming soil daily, and 3 said they consumed soil weekly. For respondents in the 20–30-year age group, 12 out of the 16 respondents said that they consumed soil daily, whereas 3 reported that they consumed soil weekly, and only 1 said that they consumed soil occasionally. Thirty-three of the 39 respondents in the > 30 years age group said that they consumed soil daily, 5 said that they consumed geophagic soils weekly, and only 4 said that they consumed geophagic soils occasionally.

Table 4.12: Age vs. frequency of consumption

	Frequency of consumption			
Age	Daily	Weekly	Occasionally	Total
12-19	8	3	0	11
20-30	12	3	1	16
>30	33	5	1	39
Total	53	11	2	66

CHAPTER FIVE

DISCUSSION

5.1: Disturbance and absorption of toxins in the intestines

The geophagic soils from Botswana have higher sand particles content compared to clay and silt. The presence of sandy coarse particles can have adverse effects on consumers such as intestinal blockage, rupturing of the intestinal wall, abdominal pains and constipation as evidenced by a case study done by Woywodt and Kiss (1999) where a patient who consumed soil had intestinal blockage due to accumulation of soil particles and perforation of the intestines. Moreso, coarse sandy particles can harm teeth (dental enamel) (Ngole, 2012). However, a study done by Diko and Ekosse (2014) found that geophagic soil in Moko, Cameroon is mostly silty, with the sand particles averaging 22.7%, clay particles with 15.2% and silt particles averaging 62.1%. Silt size particles were found to also be dominant in geophagic samples in South Africa, Congo and Democratic Republic of Congo (Diko and Diko, 2014; Ekosse, Ngole and Longo-Mbenza, 2011). But according to Kambunga et al. (2019), geophagic soils are usually determined to be clay, silty clay or silty clay loam, the clays being the dominant particles.

The mineralogy of clay-sized particles (Table 4.3) of the samples in this study mainly consists of kaolinite and quartz minerals as shown in table 4.3. Muscovite and goethite are the other predominant minerals found in this study. Clays have been used to treat poisoning due to their iron-exchange capacity (Ekosse and Jumbam, 2010). Due to its capability to absorb liquids in the digestive system, kaolinite has been used anti-diarrhoeal medicine has been said to be ease illnesses such as esophagitis and gastriris (Ekosse and Anyangwe, 2012; Odangowei and Okiemute,2019). Nevertheless, the ability of clays to absorb can be said to be harmful because it may absorb essential nutrients from gastrointestinal juices after it absorbs toxic compounds (Tateo et al., 2006). Quartz particles can cause abrasion in the intestinal lining in consumers which in turn results in stomach pain and discomfort. Kaolinite has been found to be abundant in African termite mounds (70-85%) in comparison to other termite mounds around the world (Kambunga et al.,2019). A study done in Tanzania found that kaolin had higher contents as compared to quartz minerals, and the prevalent iron oxide contained in the geophagic samples was goethite which is also reflected in this study (Young et al., 2010). However, in another study done in Botswana, quartz was found to be the most dominant mineral (70 wt%) followed by goethite and kaolinite with 9wt% and 8wt% respectively (Ekosse and Anyangwe, 2012).

5.2: Exposure to parasites and micro-organisms

The average moisture content of the geophagic soils was found to be 0.73%. The soil samples were collected during the dry season (June and July). Geohelminth eggs which have been found in geophagic soils need a certain amount of soil moisture to thrive and embryonate therefore soils with high moisture content are most likely to contain parasitic worms and their eggs in them (Shinondo and Mwikuma, (2009). The soil organic matter ranged from 0.22% to 1.39% with an average of 0.94%, also presented in Table 4.2. Organic matter influences the soil moisture content, The higher the SOM, the higher the soils' ability to retain moisture. This is in close range to the SOM values of geophagic samples from South Africa, Swaziland, Zaire and Uganda (range 0.2% to 1.5%) (Kambunga, Cadeias and Haseela., 2019). As previously stated, soils with higher moisture content harbour the risk of bearing a suitable environment for geohelminth ova and thus being risky to consumers (Shinondo and Mwikuma, 2009). According to Ekosse (2010) and Ngole-Jeme et al. (2010); Soils with high SOM consist of elevated levels of micro-organisms such as bacteria and fungi which poses as a risk to soil consumers. These microbes could lead to infections in the gastrointestinal tract. Bacteria such as Clostridium perfringens, *Clostridium tetani, and Clostridium botulinum* which may be found in geophagic soils are causative agents of gas gangrene, tetanus and botulism and other human pathogens (Obi & Ekosse, 2010).

5.3: Taste and preference

Some geophagists have reported to consume soil to reduce nausea and excess salivation, acidic nature of geophagic soils may help with that (Diko and Siewe, 2014). Overall, the pH of geophagic soils from Botswana is moderately acidic, slightly alkaline and neutral (Table 4.2). This is in accordance with research done by Ekosse and Anyangwe (2012) which found that the pH of geophagic soils sold in Gaborone market were acidic. Geophagic samples from Moko, Cameroon has a pH ranging from 4.8 to 5 with an average of 4.9 (Diko and Ekosse, 2014), while the pH of geophagic soils from Eastern Cape, South Africa ranged from 4.9 to 8.3 (Ngole and Ekosse, 2012). The samples bought from the Gaborone market for this study, are acidic which proves that geophagists prefer to consume soils with a sour taste because acidity can have effect on the taste (Diko and Ekosse, 2014). The EC of geophagic soils for this study ranged from 1423µS/cm to 43µS/cm and a total average of 354µS/cm. A study done in South Africa found the EC values of geophagic clays sold in Johannesburg markets to be ranging from 121µS/cm to 1028.50µS/cm with an average of 671.1µS/cm which is in close range to the EC values of geophagic soils of Botswana (Okereafor et al., 2018). The dissolved salts in geophagic soils from Botswana are high, of which could influence the taste.

Soil colour is one of the properties that geophagists observe when they choose their preferred soils of consumption (Msibi, 2015 Young et al., 2010). Geophagic soil samples collected for this study were mostly brown (various shades of brown) with a few red, khaki and grey soil samples Table 4.1, figure 4.1). This is in agreement with a study done in Botswana which found that geophagic soils sold by vendors are white, dark greyish and khaki (Ekosse and Anyangwe, 2012). Another study done in Democratic Republic of Congo found that the geophagic soils have various colours, these being black, white, red, pink shades of grey and shades of brown (Ekosse, Ngole and Mbenza, 2011). The notion that red soils have high iron content is quite common among geophagists while cream/khaki soils are believed to have some calcium content. Even though some of the geophagic soils from Botswana are red and khaki, this could indicate that they contain calcium and iron, but their bioavailability is not definite.

5.4: Essential Elements

Potassium, calcium, magnesium, and phosphorus have been found in the geophagic soils of Botswana; these elements are classified as macro-nutrients and thus needed in significant quantities (more than 100 mg/day) (Hooda et al., 2004). One possible explanation for the consumption of soil is that it is a reaction to nutritional deficiencies, suggesting that the vital elements found in geophagic soils might help to improve the diets of those who engage in geophagy (Abrahams, 2002). Nevertheless, excessive exposure to these essential elements could lead to adverse effects for consumers. All the samples exceeded the recommended daily allowance (RDA) of calcium at 1200ppm (Figure 4.2a; Table 4.4). Calcium absorption varies based on intestinal pH, age, and life stage, with higher absorption rates during periods of increased demand, particularly in infants and pregnant women, while decreasing with age (Kambunga et al.,2019). Calcium, a key element in the earth's crust, is primarily found in minerals such as limestone ($CaCO_3$), gypsum ($CaSO_4 \cdot 2H_2O$, and fluorite (CaF_2) (Kambunga et al.,2019). It is essential for bone and tooth development, which may drive pregnant women to consume soil as a calcium supplement (Odangowei and Okiemute, 2019). However, excessive intake can lead to cardiovascular complications (Reid et al., 2015).

Magnesium, being the eighth most abundant element in the earth's crust and found in minerals such as dolomite magnetite and serpentine, plays a crucial role in bone development and influences bone-forming cells (Kambunga et al., 2019). All samples exceeded the regulatory detection limit of 360 mg/kg of magnesium in this study (Figure 4.3b; Table 4.4). Additionally, it is acknowledged for its mood-enhancing properties; research indicates that individuals engaging in geophagy, particularly pregnant women, consume soil for stress relief, demonstrating a connection between soil intake and psychological benefits (Yamamoto et al., 2019). However, excessive magnesium consumption can result in adverse effects such as fatigue, nausea, and respiratory failure (Seo and Park, 2008). Phosphorus is identified as the least abundant macro-element in geophagic soils from All samples are below the permissible RDD for phosphorus, which is 700 mg/kg (Figure 4.3 c; Table 4.4). Phosphorus plays a crucial role in the growth and repair of tissues and cells (Bird and Eskin, 2021). However, elevated phosphorus levels may compromise bone health (Takeda et al., 2012).

Potassium is the primary macro element in the geophagic soils of Botswana based on the findings of this study. As the seventh most abundant element in the Earth's crust, potassium primarily exists in minerals like feldspars and micas and is absorbed mainly through the small intestine, playing a crucial role in nutrient and waste circulation (Kambunga et al.,2019). All Botswana samples are above the recommended daily limit of 5000 ppm (Figure 4.2d; Table 4.4). This indicates a high likelihood of adverse effects, such as hyperkalaemia, from the consumption of potassium-rich geophagic soils. Hyperkalaemia is a condition caused by high potassium consumption, as demonstrated in a study by Gelfand et al. (1975) due to potassium absorption from potassium-rich soils. Compared to a study in Ghana carried out by Nkansah et al. (2016), which reported a mean potassium concentration of 27661.83ppm in geophagic clays

5.5: Essential Trace Elements

Trace elements are essential to the diet and needed in minute amounts. Trace or micro elements can harm consumers if ingested in excess of the recommended daily dose (Frazzolli et al., 2016; Ngole-Jeme, 2010). 2012). 50% of the samples exceed the RDD of 40mg/kg for zinc (Figure 4.3a; Table 4.4). Zinc, the least prevalent essential trace element in this study, is required for protein synthesis, enzymatic processes, and element metabolism (Mosallaei et al., 2023; Odongo, 2015). The accumulation of soil particles may reduce zinc absorption, putting individuals who suffer from zinc deficiency and attempt to supplement through geophagy at risk (Hood and Henry, 2002; Abrahams, 2002). Moreover, zinc excretion, body zinc levels, and age affect zinc absorption in the human body (Kambunga et al., 2019). Olajide-Kayode (2023) found high zinc concentrations in southern Nigeria, unlike Botswana's geophagic soils

This study identified iron, the fourth most abundant metal in the Earth's crust (Kambunga et al., 2019), to be the most abundant necessary trace element in Botswana's geophagic soils. Fe is essential, excessive intake can result in tissue damage, heart disease, and hormone problems (Mosallaei et al., 2023). Ingested soils usually provide ferric iron in the form of insoluble complexes, which animals cannot absorb. However, acidic environments like the gastrointestinal tract can convert ferric iron into ferrous iron (Abrahams, 2002). In red geophagic soils in the Persian Gulf, iron (Fe) was shown to be the most common metal (Mosallaei et al., 2023). Another Kenyan study found high iron concentrations in geophagic soils at 87754, 49771, and 34833 ppm (Nyanza et al., 2016).

Cu levels exceeded the RDD of 10 mg/kg (Figure 4.3c; Table 4.4). Cu is critical for oestrogen metabolism and neurotransmitter and dopamine production (Mosallaei et al., 2023). Cu intake over recommended levels can cause nausea, vomiting, and liver enzyme dysfunction (Taylor et al., 2020). Additionally, elevated Fe levels in babies have been linked to lowered Cu absorption (Kambunga et al., 2019). All samples in this study surpass the RDD of 0.0035 mg/kg for Cr (Figure 4.3d; Table 4.4). Cr is essential for insulin function and lipid and carbohydrate metabolism, but high ingestion can cause lung cancer (Mosallaei et al., 2023). In addition, Zn, Vanadium (V,) and Fe supplements can limit Cr absorption (Kambunga et al., 2019).

All samples had Nickel levels higher than the RDD (1.1 mg/kg) (Figure 4.3e; Table 4.4). Nickel is found in water, air, and soil and makes up 0.008% of the crust (Kambunga et al., 2019). Nickel is important in protein function and DNA and RNA structure, but acute exposure can harm the kidneys, liver, brain, nasal cancer, and dermatitis; furthermore, it also enhances Fe absorption (Mosallaei et al., 2023; Ekosse and Jumbam, 2010; Kambunga et al., 2019). The mean Ni concentration in geophagic soils in Cameroon and Nigeria was 42 pmg/kg (Ekosse and Jumbam, 2010), which is in close range to the findings of this study.

5.6: Toxic elements

Lead (Pb), cadmium (Cd), and mercury (Hg) have been identified as the most dangerous elements by the United States Global Monitoring (Mosallaei et al., 2023). In addition, As, Cd, Hg, and Pb have been found in soils where geophagy is practiced (Frazzoli et al., 2016). All samples exhibit concentrations that exceed the tolerable intake levels (TIL) for As, Pb and Hg (Figure 4 a, c, d; Table 4.4), while only two samples show concentrations above the reference dose (RDD) for Cd (Figure 4b;Table 4.4). Exposure to Pb can result in behavioural issues, damage to the nervous system (particularly in children), as well as damage to the renal and cardiovascular systems (Egendorf et al., 2020; Hildebrand, 2011). In a study by Kortei et al. (2020), a mean concentration of 0.53 mg/kg for Pb was found in geophagic soils in Ghana, whereas another research conducted by Nkansah et al. (2016) in Ghana as well, reported a mean concentration of 25.06 mg/kg in geophagic clays, which is similar to the mean concentration observed for geophagic soils in Botswana.

Cd is recognized as a carcinogen affecting the endocrine system according to Egendorf et al. (2020). Previous research conducted by Kutelek et al. (2020) indicated mean concentrations of 0.097 mg/kg in Central Africa and 0.051 mg/kg in West Africa of Cd. Exposure to as may lead to health issues such as nausea, abdominal pain, and diarrhoea (Egendorf et al., 2020). The mean concentrations of As in geophagic soil samples from South Africa, the Democratic Republic of Congo, Swaziland, and Togo was 2.19 mg/kg, while in

Ghana, was 1.63 µg/kg which shows the vast difference of Pb content in soils from various geophagic material sources across the continent of Africa (Ngole-Jeme et al., 2018; Kortei et al., 2020). Mercury is the only heavy metal that naturally occurs in the environment in various forms, including metallic or elementary mercury, mercury sulfide, or methyl mercury (Kambunga et al., 2019). Exposure to mercury can lead to detrimental effects on children's brain and nervous system development, as well as issues such as premenstrual syndrome in women, miscarriages, and infertility (Kambunga et al., 2019). A study by Nkansah et al. (2016) found the mean concentration of mercury in geophagic clays in Ghana to be 0.81 mg/kg, while a study by Nyanza et al. (2014) reported it as 0.046 mg/kg in Kenya.

5.7: Non-carcinogenic health risks

The oral intake of potentially toxic elements (PTEs) contributes the most to hazard quotients (HQ) and hazard indices (HI) for both adults and children, with lower values associated with dermal contact and inhalation (Figure 4.5a-f; Figure 4.7a-f). The mean HI remained below 1, indicating a lower likelihood of adverse effects for geophagists (Table 4.6; Table 4.7). In Ghana, the HI for dermal exposure was significantly lower (0.0006) than for oral ingestion (0.64) (Nkansah et al.,2016). However, another study reported concerning total hazard quotients (THQ) for arsenic (As) and nickel (Ni) at 2.62 and 10.34, respectively, in Ghana highlighting potential health risks associated with exposure to these elements (Kortei et al.,2020).

Fe was identified as the main contributor to the Hazard Index (HI) for adults, followed by Cr (Figure 4.6a-f). Fe was also the predominant contributor to the HI for children, with significant inputs from Cr and Cu, while other potentially toxic elements (PTEs) contributed less than 3% and below to the HI in children (Figures 4.8a-f). Despite lead (Pb) being the most common toxic metal found in geophagic soils in Botswana, its impact on the HI is negligible, accounting for only 8% in adults and less than 3% in children. Pb is prevalent in a number of geophagic soils across Africa, posing serious health risks, especially to children, which raises concerns about its presence in consumed soils (Olajide-Kayode et al., 2023). Conversely, studies from Southern Nigeria and South Africa reported that Pb levels exceeded guideline values for both demographic groups (Orisakwe et al.,2020).

5.8: Carcinogenic health risks

The risk of cancer from oral exposure is higher than from dermal contact and inhalation for both adults and children. Among all the sampling sites, nickel, chromium, and arsenic exhibit the highest mean cancer risk values, all within the acceptable range of 1.00 E-06 to 1.00 E-04 (Figure 4.9 a-f; Figure 4.10a-f). This suggests a low likelihood of adverse effects from carcinogenic elements in Botswana's soils for geophagists. Therefore, the presence of As, Ni, and chromium (Cr) in geophagic soils of Botswana, raises significant concerns, even though some of the CR values obtained for these soils fall within acceptable limits, considering the cumulative exposure to these carcinogenic elements from other sources beyond just geophagic clays/soils. In contrast, the cancer risk (CR) values for arsenic and nickel in South Africa exceed acceptable levels for both demographics (Ngole-Jeme et al.,2016). In the geophagic clays from Ghana's Volta region, the CR values for As and Ni were identified as 2.82 and 19.38, respectively. For arsenic in the Kumasi metropolis, calculated CR values were 2.26 E-05 for ingestion and 2.69 E-06 for dermal exposure (Kortei et al., 2020; Nkansah et al., 2016).

5.9: Knowledge from Questionnaire respondents

5.9.1 Socio-demographic information of geophagists

98% of the questionnaire respondents are female and only 2% of them are male which suggests that geophagy is more prominent within the female sex. This was also reflected in other studies done by Msibi (2015), Kutalek et al. (2010) and Ekosse et al. (2010) Another study done by Nyanza et al. (2014) is common among mothers and pregnant women. The majority of the respondents are over the age of 30 years (59%) therefore, geophagy is more common in older people in Botswana. This is also reflected in a study carried out in Tanzania where it was discovered that only 15.3% of interviewees are 33-40 years while the age group that practised geophagy the most are aged 21-26 years (31.2%). Most of the interviewees have a junior secondary level education (41%) followed by interviewees with tertiary level education (36%), 17% of them have senior secondary education and only 6% of the respondents have primary school level education. The result of this study suggests that practice of geophagy may be a dying habit among people in Botswana as it is mostly practiced by older people. This could be due to it being regarded as a shameful act. This is in contrast with studies done by S'Khosana (2017), Iron-Segev et al. (2018) and Nyanza et al. (2014) which discovered that geophagists with lower levels of education (mostly primary level) are more likely to consume soil.

5.9.2 Prevalence of geophagy

Most of the respondents reported (82%) that they consume soil daily (Table 4.9). Ingesting soil daily puts consumers at a higher risk of experiencing adverse effects such as accumulation of coarse particles in the stomach which can cause intestinal blockage and rupturing if the intestinal wall, which may lead to abdominal pains This is reflected in other studies carried out in various parts of Africa, for e.g. geophagists in Tanzania (83% of respondents), Nigeria (85%) and Kenya (71%) reported to be ingesting soil more than once a day (Nyanzah et al., 2014; Lar, A gene, Umar, 2015; Iron-Segev et al., 2018).

A majority of the respondents (68%) reported to know more than 5 people who consume soil. When asked if they had external influence on how they commenced the habit, most of the respondents said they were initiated into the practice by friends and/or family. This shows how rampant and prevalent geophagy is in Botswana in general. This is mirrored by a study performed by Msibi (2015) in South Africa where a majority (60%) of geophagists also reported that their household members also consume soil

5.9.3 Knowledge of the effects of geophagy

The questionnaire respondents have shown to have a good knowledge on the effects of geophagy. Only 1 respondent said they have no knowledge on the effects of soil ingestion (Table 4.10). From these responses, it can be said that even though geophagists are aware of the negative effects of soil ingestion, it is a tough habit to break out of due to addiction. Some other known effects of geophagy reported by geophagists in South Africa include acute stomach pains, worm infections, cancer, constipation, diarrhoea, blood stools, womb blockage, fibroids, painful defecation, appendicitis, gallstones, acute bladder pains and heavy bleeding (Msibi, 2015). Friends/family are the most common source of knowledge on the effects of geophagy. The second most common source of knowledge is health care workers according to the responses. Some geophagists said they experienced the effects themselves. In south Africa a few geophagists reported to have undergone surgery due to having a gall stone problem (S'khosana, 2017).

Cravings are the most common reason for soil ingestion followed by anti-stress effects in this study which suggests that most Batswana could have an addiction. This is in agreement with a study done in South Africa where 62% of interviewees said their reason for soil ingestion is cravings, 18% said they didn't know why perhaps it being a force of habit and only 6.2% said they consumed soil because they were pregnant (S'khosana, 2017).

Due to pregnancy being a sensitive issue, instead of asking participants if they are pregnant, they were asked generally why they think pregnant women ingest soil. The most common answer is "cravings" followed by "to reduce morning sickness. This is also reflected in a study performed by Nyanzah et al. (2014) and by Lar, Agene, Umar (2015) where a majority of the pregnant women ingested soil due to cravings and were of the belief that soil ingesting stopped/prevented morning sickness while some said it reduces complications during birth and salivation.

From the 66 participants of the questionnaire, only 33 % of them reported to have stopped the habit of geophagy (Table 4.10). A majority of the participants (63 %) who stopped the habit said they stopped due to health-related reasons. The most common source of knowledge of the effects of soil eating where from health workers according to the responses which could be a contributing factor to them stopping the habit. This is in contrast with a study carried out in Kenya where a whopping 77% of interviewees reported to want to leave the habit of soil consumption and therefore reduced the intake of soil (Iron-Segev, 2018).

5.9.4 Relationship between variables

Table 4.11 shows the relationship between the level of education of the participants VS the those who stopped ingesting soil. All of the participants with primary school level education have left the habit of soil ingestion, while 44.44% with Junior secondary level education. This study only has 66 participants which is not an accurate representation of the population of geophagists (and their demographic in some cases) in Botswana. Although the practice of geophagy is prevalent in Botswana, people were hesitant to take part in the questionnaire interview for various reasons one of them being that geophagy is viewed as a peculiar and shameful act.

Table 4.12 shows the relationship between variables "Age" and "Frequency of consumption". A majority of the participants in all the all groups said they consume soil daily. Geophagists have said they have a strong and repeated desire to consume soil because of the "good smell" which could be the reason for this frequent consumption which puts them at a higher risk of being affected by the adversative effects of geophagy (Nyanzah et al., 2014).

5.10 Major Limitations and Strengths

Due to lack of resources, the identification of soil transmitted helminths in geophagic soil samples was not able to be determined. The soils were observed under a microscope and there were some worms and eggs present in the samples but because of the lack of a microscope with a camera, the researcher could not take clear images for accurate identification. Another limitation of the study is that the extraction of metals with gastric and digestive juices using the simulated gastrointestinal tract in vitro would have given a more accurate representation of the accessible concentrations of PTEs and essential elements in the soil. One strength of this study is that it included the social aspect from the people who practice geophagy as most studies concentrate on studying the geophagic material only.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The notion that geophagic soils can supplement nutrients to geophagists may be flawed because their bioavailability is not guaranteed moreover, the average hazard indices (HI) for adults and children were found to be below 1 for all the exposure pathways therefore exposure to the potentially toxic chemical elements is less likely to cause adverse effects in consumers. The cancer risk (CR) values were mostly below the acceptable range with the exception of Ni, Cr and As whose CR values fell within the acceptable range in all the exposure pathways. However, the presence of these carcinogenic elements may be detrimental due to aggregate exposure. Exposure by oral ingestion has the highest HI and CR values compared to exposure by dermal contact and inhalation. According to the responses from the questionnaires, geophagy is more common in women and people aged above 30 years. Most of the interviewees said consume soil every day and also know more than 5 people who practice the habit as well. This shows how prevalent geophagy is in Botswana. The respondents are quite aware of the effects of soil consumption, which include, exposure to parasitic worms, constipation and abnormality in digestion, however they still consume soil which could be a sign of addiction.

6.2 Recommendations

Geophagists should be more educated on the habit of soil eating as it has proved to reduce intake by a significant rate in other countries. For those with a severe addiction, it is recommended that they at least bake/treat the soil before eating it to kill the microbes and parasitic worms in the soil and consume soil moderately instead of daily.

CHAPTER SEVEN

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APPENDIX

Appendix A

I, Tsholofelo L. K Molale from Botswana International University of Technology and Science (BIUST), am conducting a research on the potential harmful effects on geophagy. Geophagy is the habitual ingestion of soil. Your response from this questionnaire will help in finding out how widespread geophagy is In Botswana and the knowledge people who eat soil possess on this topic. Your responses will be anonymous. Thank you for participating in this research.

Please tick/circle the relevant option on the questions below.

1. Age
    a. 13-19
    b. 20-30
    c. ≥30

2. How long have you been eating soils

____

3. Residence

____

4. Highest Education Level attained
   a. Primary
   b. Junior Secondary
   c. Senior Secondary
   d. Tertiary

5. Gender
   a. Male
   b. Female
   c. Other

6. Awareness of Geophagia

   [Below are the potential harmful effects of geophagia, please tick/circle the effects you know or have heard of.]

   a. Iron deficiency anaemia
   b. Constipation
   c. Soil transmitted intestinal parasites
   d. Abnormality in digestion
   e. Intestinal blockage
   f. Any other ....?

7. Source of knowledge on the harmful effects

   [if you have more than one source, tick/circle the relevant ones]

   a. Friends/family
   b. Media (radio, television, newspapers, magazines, internet)
   c. Health care workers (Doctors and/or Nurses)
   d. Others ....

8. Frequency of consumption of soil

____

9. Initiated into geophagy by:
   - a. Friends
   - b. Family
   - c. Other: ____________________________

10. Reason for eating soil
    - a. cravings
    - b. habit
    - c. health positive effects
    - d. peer pressure
    - e. anti-stress effects
    - f. Other……

11. Have you stopped eating soil? If yes, what are the reasons? Please circle/tick the relevant option/s
    - a. pregnancy
    - b. health reasons
    - c. other: _______________________________________

12. Do you cook/heat the soil before eating/
    - a. yes
    - b. no

13. Have you told your doctor/nurse that you eat soil?
    - a. Yes
    - b. no

14. How many people do you know who eat soil? How common do you think soil ingestion is in your community?

a. Less than 5

b. ≥5

15. Why do you think pregnant women ingest soil?

a. To reduce or stop morning sickness

b. To have a healthy pregnancy

c. Soil prevents prolonged labour

d. Cravings

e. To have a smooth/beautiful baby

General comments --

