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Chemical Composition of Clay Soil Analysis and Potential Health Risks: Experimental Study in Tshwane District, Gauteng Province

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Abstract: The practise of geophagy is common amongst women of childbearing age from different geographic locations, including South Africa, regardless of their social and economic status such as their level of education, race, marital status, income or occupation. This study aimed to examine the women of childbearing age in Tshwane District, Gauteng Province, South Africa. An experimental study was conducted at the laboratory to examine the chemical composition of clay soil ingested by geophagic women of childbearing age. Thirty-nine clay soil samples were collected from study participants attending antenatal care services and family planning at public healthcare facilities of Tshwane District, Gauteng Province, and subjected to geochemical analysis. The concentrations of vanadium, manganese, chromium, and barium were detected in quantities exceeding 100 mg/kg in almost all samples. Cadmium, mercury and silver were detected in low concentrations below 1 mg/kg in all samples. The practice of geophagy amongst women of childbearing age has been reported to be associated with detrimental health outcomes and risks such as iron deficiency anaemia, constipation, shortness of breath, maternal and childhood mortalities and morbidities, neurological and central nervous system disorder, death, appendicitis, cancers, teratogenic risks, and ulcers. The chemical composition of clay soil eaten by geophagic women of childbearing age contains potentially harmful substances, thus the practise of geophagy is toxic and should be discouraged to protect public health.

Keywords: chemicals; potential health risk; geophagy; soil addiction; clay soil; women of childbearing age; trace elements; Tshwane District

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1. Introduction

Geophagy (soil addiction) refers to the continuous craving and consumption of earth materials such as rocks, chalk, kaolin, clay, dirt, clay soil, sediments, sand and soft stones, particularly by women of childbearing age [1–5]. These earth materials that are consumed by geophagic women of childbearing age are mainly sourced from the fields, mountains, woods, walls, molehills, termite mounds, pits, wells, rivers, holes, trees, and market-places [3,6,7]. The characteristics of the clay soils that are often consumed by women of childbearing age are known to differ according to texture, colour, smell, taste, particle size, electrical conductivity, water content, mineralogy and chemical composition, and pH [8].

A study conducted in South Africa found that more than 80% of women practised clay soil ingestion during their gestation period [3], but the toxicological aspects and environmental health constituents of geophagy are mostly not understood by geophagic women [8]. Studies have reported that geophagic material such as clay soil is known to contain toxic chemicals and biological agents [1–5,8]. Mercury, chromium, arsenic, iron, copper, calcium, aluminium, potassium, lead, magnesium, cadmium, manganese, uranium, nickel, cobalt, tin, silica, palladium, and sodium are some of the common elements that are indirectly consumed by people who practice geophagy [1–3,9,10]. Other studies have reported that aluminium oxide, and metal oxide are the most common constituents of the clay soil consumed by women of childbearing age [2,9,11,12].

The toxicity of these elements when consumed in excessive amounts could lead to low birth rates, neonatal mortality, foetal abnormalities, miscarriages, stillbirths, and complications during pregnancy and childbirth [3,5,8,11,13–15]. Other studies further indicate that geophagy is associated with risks of mineral and nutrient deficiencies such as iron deficiency, zinc and manganese deficiency, low levels of haemoglobin, cardiac arrest, and shortness of breath depending on the dose, frequency, and period [1,2,8,15–18].

The provision of iron supplements, folic acid, and magnesium pills are some of the public health interventions that are presently used to assist geophagic women of childbearing age to prevent and control geophagy. However, geophagy is still a major public health concern because there are currently no environmental or bioremediation technologies to treat and remove the high concentrations of chemical elements detected in clay soil.

A gap has been identified in medical intervention in that the majority of women of childbearing age who practice geophagy are not aware of the chemical content of clay soil, as well as the dangers and health consequences that are linked to this practice [2,9,13]. Therefore, this study has examined the chemical composition of the clay soil consumed by women of childbearing age in Tshwane District. The potential health risks of clay soil chemical composition were also investigated.

2. Materials and Method

2.1. Study Setting

The analysis of the clay soil was conducted in the (C1 LAB 338C) Biochemistry laboratory at the University of Johannesburg, Auckland Park Campus, Gauteng Province. The biochemistry laboratory specialises in the analysis of chemical elements. The samples of clay soil were collected from participants residing in Tshwane District, Gauteng Province who were consulting in the antenatal care and family planning units. The chemical composition of clay soil differs from one geographical area to the next.

2.2. Study Design

An experimental study design was conducted to examine the chemical composition of the clay soil eaten by women of childbearing age in Tshwane District, Gauteng Province. The concentration levels of the chemical substances such as vanadium, chromium, lithium, beryllium, uranium, barium, mercury, lead, silver, zinc, copper, nickel, cobalt, manganese, cadmium, strontium, arsenic, and bismuth were analysed. These chemical elements were selected based on their capacity to pose potentially serious negative health effects that impact negatively on public health when consumed in excessive quantities, to inform the health education and promotion intervention program aimed at mitigating the practise of geophagy amongst women of childbearing age.

2.3. Data Collection

Data collection commenced after receiving ethics approval from Sefako Makgatho Health Sciences University Ethics Committee. Clay soil samples were collected from the participants in the study around Tshwane District (see Figure 1). Sealable plastic bags were used to store and package the samples of clay soil. The samples were then labelled. Post-collection, the clay soil samples were transported and submitted to the biochemistry laboratory where the chemical analysis was performed. ICP Mass Spectrometry was used to detect the chemical composition of the soil. The step-by-step procedures stipulated by the manufacturer of the ICP Mass Spectrometer were followed when performing the tests (see Table 1).

Figure 1. Clay soil samples.

Table 1. NexION 300X ICP-MS (PerkinElmer, Inc., Waltham, MA, USA) settings.

Parameter	Parameter Setting
Nebuliser flow (L/min)	0.62
Aux. Flow (L/min)	1.2
Plasma Flow (L/min)	18
Power (W)	1600
Cell Gas A (mL/min)	5
Discriminator Threshold (V)	12.5
Deflector Voltage (V)	−6.25
QRO (V)	−7.8
Cell Entrance (V)	−5.5
Cell Exit (V)	−19.2
CRO (V)	−9

2.4. Data Collection Procedure

The 39 clay soil samples (see Figure 1 above) were collected from participants attending antenatal care services and family planning in the four settings in Tshwane District in Gauteng Province. Simple random sampling was followed to include all soil samples collected from participants in the study. The soil samples were first collected and stored in sealed plastic bags for packaging, and then stored in storage bags from the data collection sites. The samples were taken for crushing in preparation for laboratory analysis. The samples were crushed into powder, then poured into 50 mL granular bio tubes.

The ICP Mass Spectrometer instrument (refer to Figure 2) was used to measure the quantity and detect the chemical content of the clay soil samples collected from the participants in the study. The chemical composition tests were performed by a qualified laboratory and instrument technician at the University of Johannesburg, Gauteng Province, whereby the step-by-step procedures stipulated by the ICP Mass Spectrometer manufacturer were followed to ensure the accuracy of the results. The analysed data for the clay soil samples gave good recoveries, which confirmed the accuracy of the results. The digestion process took place in 2023, followed by the analysis, and the extraction of data.

Figure 2. NexION 300X ICP-MS instrument.

A Metter ToledoXP205 (Mettler Toledo, Columbus, OH, USA) analytic balance (refer to Figure 3) was used to weigh approximately 0.2 g samples to the nearest 1 mg. The samples were transferred to microwave vessels along with 9 mL Suprapure HNO_3 (Merck, Germany) and 3 mL HCl (Merck, Darmstadt, Germany). The samples were centrifuged for 10 min at 6000 rpm. A quick visual inspection was conducted to ensure there are no solid matter suspended during the transfer of samples using pipette. The samples were digested according to a modified method based on United State EPA 3051protocol. The samples were then heated from a room temperature to 200 °C for 15 min and kept at 200 °C for another 10 min. After digestion, the samples were quantitatively transferred and diluted to the 50 mL mark. The samples were diluted an additional 20 times by pipetting 500 micro litres and diluting 10 mL with 1% nitric acid to matrix match with calibration standards. Calibration standards that ranged from 0.1 to 10 μg/L were prepared from NIST traceable RMs and diluted with 1% nitric acid as well. The ICP Mass Spectrometer was warmed up for a minimum of 30 min to ensure instrument stability and robustness during the analysis. The instrument was tuned according to the specification to acquire the required sensitivity and low oxides. Calibration curves with $R^2 > 0.9950$ are considered sufficiently linear and indicate that the instrument is performing well. The clay soil samples were then analysed. All elements were measured in the Kinetic Energy Discrimination (KED) mode. AMIS0373 was analysed as a quality control. The laboratory results for the chemical analysis of the clay soil composition were captured using an Ms Excel spreadsheet. The test results confirmed the presence of chemical parameters found in the clay soil collected from the participants, who were women of childbearing age attending antenatal care services and family planning in the healthcare facilities of Tshwane District, Gauteng Province. The chemical elements found in the clay soil samples were detected in different quantities. The results derived from the biochemistry laboratory tests were used to inform the development of a health education and promotion intervention program.

Figure 3. Metter ToledoXP205 analytic balance.

2.5. Study Population (Inclusion and Exclusion Criteria)

Clay soil samples were collected from women of childbearing age attending antenatal care services and family planning in the healthcare facilities of Tshwane District, Gauteng Province, who constituted the study population. Earth materials such dirt, rocks, sand, soil, kaolin, chalk, and sediments were excluded in the study. Only clay soil samples were included in the study as the most consumed and preferred earth material by geophagic women of childbearing age due to its perceived cleanness and taste, and accessibility from street vendors and open markets. Clay soil was defined as a common solid clay purchased from street vendors and open markets that is consumed by women of childbearing age who practise geophagy (refer to Figure 1).

2.6. Sample Size and Sample Selection

39 clay soil samples were collected from participants residing in the geographic locations shown on the map above (see Figure 4) for Tshwane District. Random sampling was followed when including clay soil samples in the study.

2.7. Data Analysis

The descriptive statistics, parameter concentrations, tables, and graphs were developed using Ms Excel 2021 and Stata 17. Quantitative data from the laboratory were processed using STATA 17 software.

2.8. Validity and Reliability

The chemical composition tests of clay soil eaten by geophagic women of childbearing age were performed in an accredited laboratory with a valid licence to perform the tests. AMIS0373 was analysed which is used to ensure quality control. The ICP Mass Spectrometer instrument was used, following the step-by-step procedure outlined by the manufacturer. The procedure was followed as outlined on the specification to determine the quantity and content of the chemical elements in clay soil. The ICP Mass Spectrometer equipment used in the laboratory was prepared, calibrated, and tested, so that the researcher was able to follow the step-by-step procedures outlined by the device manufacturer to improve the reliability and validity of the results for the chemical analysis of the clay soil. After centrifuge, 500 µL sample is transferred and diluted to 10 mL for a 20× dilution.

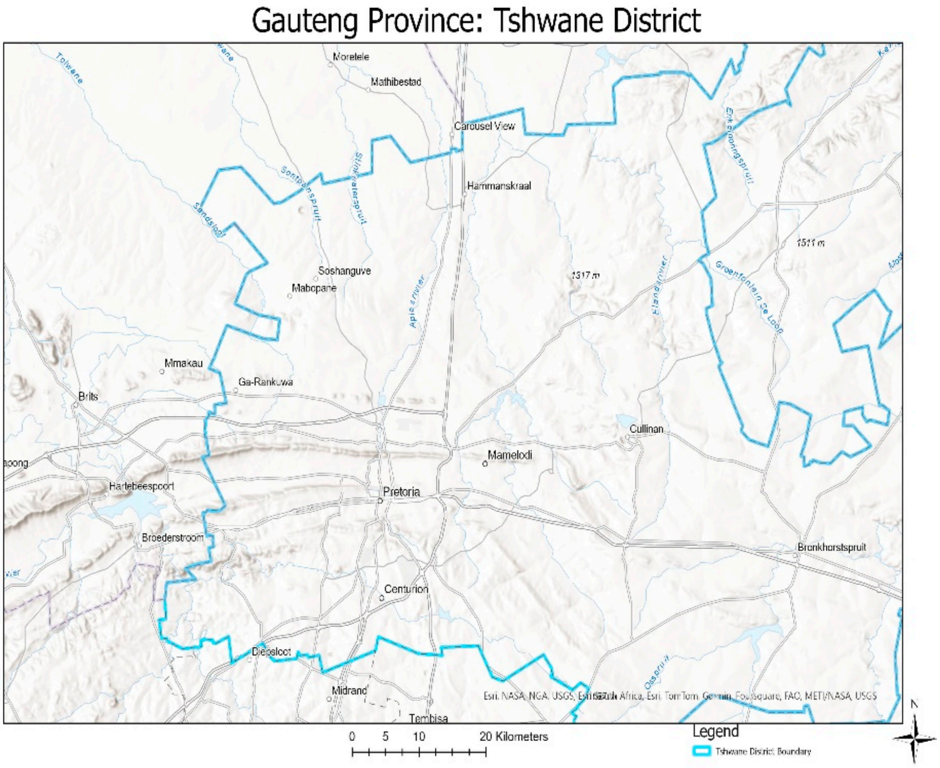

Figure 4. Geographic locations where clay soil samples were collected.

2.9. *Ethical Considerations*

The study protocol was approved by Sefako Makgatho Health Sciences University. Clearance and approval were obtained from the Sefako Makgatho Health Sciences University Research Ethics Committee (SMUREC/H/290/2023: PG).

3. Results

This analysis was conducted using Stata 17 software at 95% ci and 5% significance level.

Descriptives statistics of chemical elements detected in clay soil that is consumed by women of childbearing age in Tshwane District, Gauteng Province were also described (see Table 2 below). In all the 39 clay soil samples analysed, lithium ranged from 12 to 38 mg/kg vanadium ranged from 77 to 864 mg/kg, manganese ranged from 33 to 742 mg/kg, cobalt ranged from 7 to 20 mg/kg, copper ranged from 21 to 58 mg/kg, uranium ranged from 3 to 10 mg/kg, beryllium ranged from 0.2 to 5 mg/kg, chromium ranged from 125 to 320 mg/kg, lead ranged from 13 to 29 mg/kg, nickel ranged from 26 to 67 mg/kg, barium ranged from 85 to 291 mg/kg, bismuth ranged from 0.2 to 1.8 mg/kg, strontium ranged from 18 to 113 mg/kg, arsenic ranged from 4.7 to 14 mg/kg, and zinc ranged from 33 to 122 mg/kg. Cadmium was detected in only six out of 39 clay soil samples analysed, with the range between 0.1 mg/kg and 0.2 mg/kg, but the remaining 33 samples contained cadmium at quantities below 0.1 mg/kg. Mercury and silver concentrations detected in the clay soil samples were found to be below 0.1 mg/kg in all 39 samples that were analysed (refer to Table 2 below).

Chemical composition of clay soil consumed by women of childbearing age in Tshwane District.

The average values for each chemical parameter were calculated. The concentrations of chemical elements detected in the clay soil commercialised in Marabastad, distributed in all areas of Tshwane, and eaten by women of childbearing age and pregnant women, contained vanadium as the trace element with the highest chemical content with an average concentration of 575 mg/kg, followed by manganese with an average concentration of 396 mg/kg and chromium with an average concentration of 249 mg/kg. The remaining trace elements were reported at levels below 100 mg/kg, starting with zinc with an average concentration of 72 mg/kg. Strontium, nickel and copper were detected at quantities above 50 to 40 mg/kg. Lead and lithium were detected in the samples at levels above 20 mg/kg, followed by cobalt, with an average concentration of 13 mg/kg. Barium and uranium were reported at concentrations below 10 mg/kg. Bismuth was the lowest detected trace element with a concentration lower than 1 mg/kg (see Figure 5).

Table 2. Descriptive statistics of chemicals analysed in clay soil.

Chemical Elements	Mean	Std Dev	Min	Max
Li	23	6	12	38
Be	2	1	0.1	5
V	575	207	77	864
Cr	249	52	125	320
Mn	396	178	33	742
Co	14	3	7	20
Ni	47	10	26	67
Cu	42	9	21	58
Zn	72	30	33	122
As	8	3	5	14
Sr	55	28	18	113
Ba	189	56	85	291
Pb	23	3	13	29
Hg	0.1	6	0.1	0.1
Ag	0.1	6	0.1	0.1
Cd	0.11	0.04	0.1	0.3
Bi	0.3	0.3	0.2	2
U	7	2	3	10

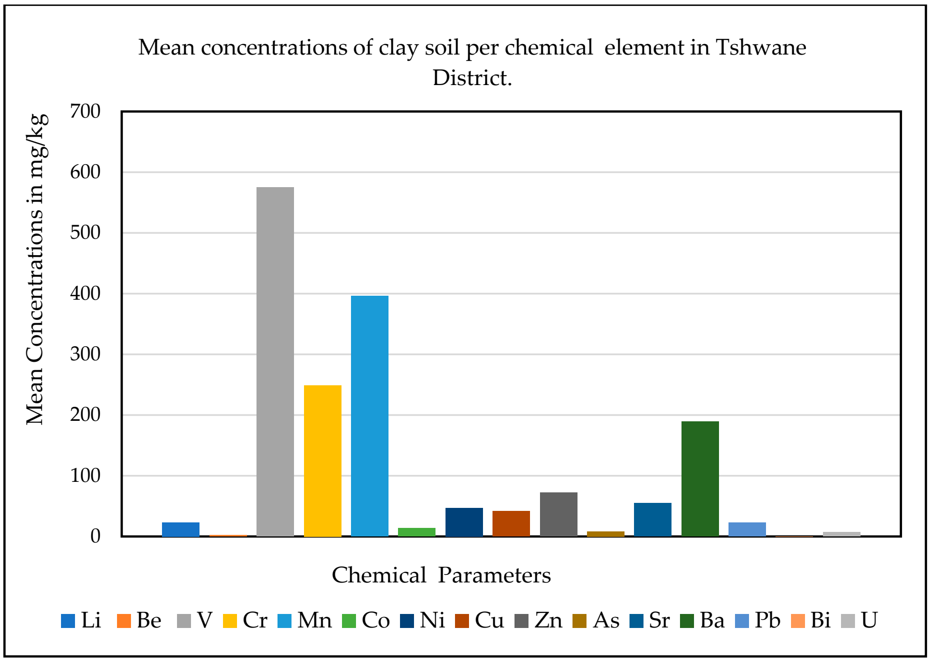

Figure 5. Mean concentrations per trace element detected in clay soil.

The recommended standards for trace elements intakes were consulted to determine the potential health risks linked with ingestion of clay soil amongst women of childbearing age (refer to Table 3) adopted from a published study [19].

Table 3. Recommended standards for trace elements intake (adopted from a published study by [19].

Recommended Standards	Trace Elements. (Variables)	Adults	Pregnant	Reference
Recommended daily allowance (RDA).	Aluminium	0.10–0.12	–	ATSDR (2000) [20]
	Calcium	1200–1300	1000–1300	IOM (1999) [21]
	Mag	240–420	350–400	
	Copper	0.9	1	IOM (2002) [22]
	Iron	8—18	27	
	Silica	12	19	
	Zinc	8–11	11	
Adequate intake (AI)	Chloride	100	100	IOM (2005) [23]
	Nitrate	3.7	3.7	
	Nitrite	0.06	0.06	
	Potassium	2300–3400	2600–2900	
	Sodium	1200–1500	1500	
	Chromium	0.025–0.035	0.029–0.030	IOM (2002) [22]
	Manganese	1.8–2.3	2	
	Cobalt	0.003–0.008	0.003–0.008	ATSDR (2000) [20]
	Sulphate	14	14	IOM (2005) [23]
Tolerable upper intake level (UL)	Arsenic			
	Nickel			
	Lead			

Chemical composition of clay soil in Tshwane District, Gauteng Province.

The thirty-nine clay 39 samples received from the participants differed in colour, texture, taste, and particle size Some samples were extremely hard; some were soft, dusty, and rock-like; and some were brittle. The concentrations of chemical elements detected in the samples were recorded independently per sample in mg/kg (refer to Figures 6–13 below).

Figures 6 and 7 above indicate that vanadium was detected in high quantities for all samples except samples 21, 24, and 39—in other words, in 36 out of 39 samples. Manganese was the trace element second most frequently detected, not being detected in samples 21, 24, 25, 30, and 39, and exceeding all comparable parameters in samples 14, 19, and 28. The concentrations of chromium were close to those of manganese for this set of comparisons. Barium concentrations were lower than those of vanadium, chromium, and manganese in similar samples. Although these samples were taken from Marabastad in Tshwane, the concentrations of the trace elements detected differed from one sample to the next.

The second set of comparisons between trace elements of lithium, cobalt, nickel, copper, zinc, and strontium indicated that zinc had the highest concentrations in 16 out of 39 samples, followed by strontium and nickel. Cobalt was detected in the lowest concentrations for this set of comparison. A constant variation in the concentrations was observed in the samples (see Figures 8 and 9).

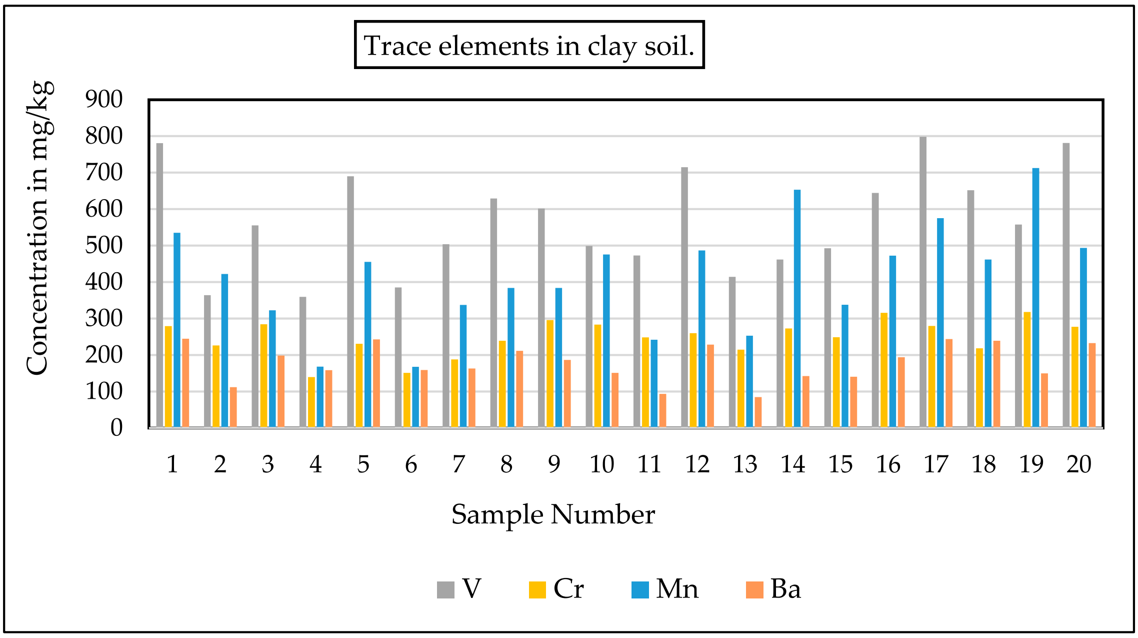

Figure 6. Trace elements detected in clay soil for samples number 1–20.

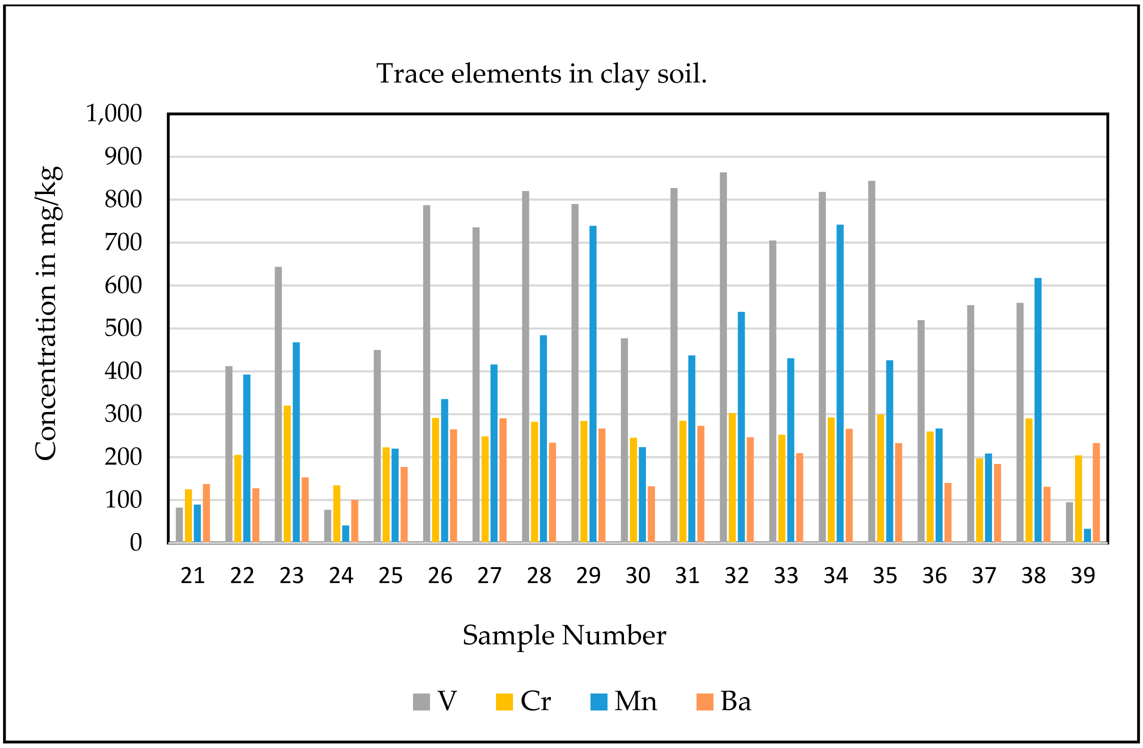

Figure 7. Trace elements detected in clay soil for samples number 21–39.

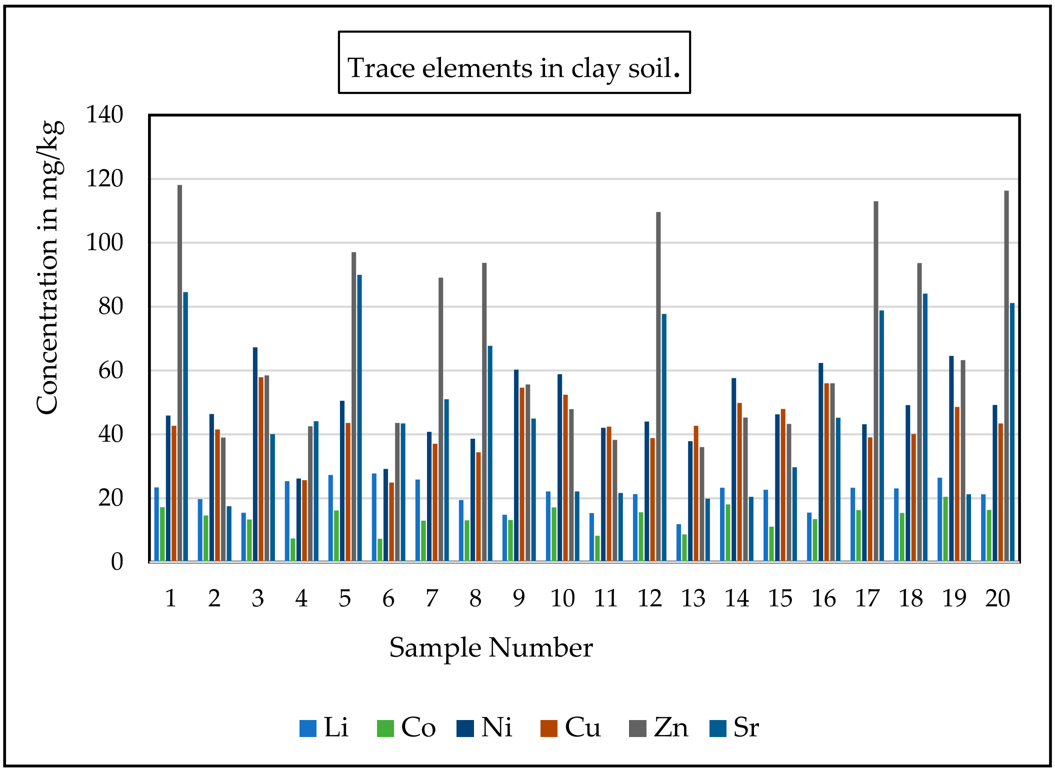

Figure 8. Trace elements detected in clay soil for samples number 1–20.

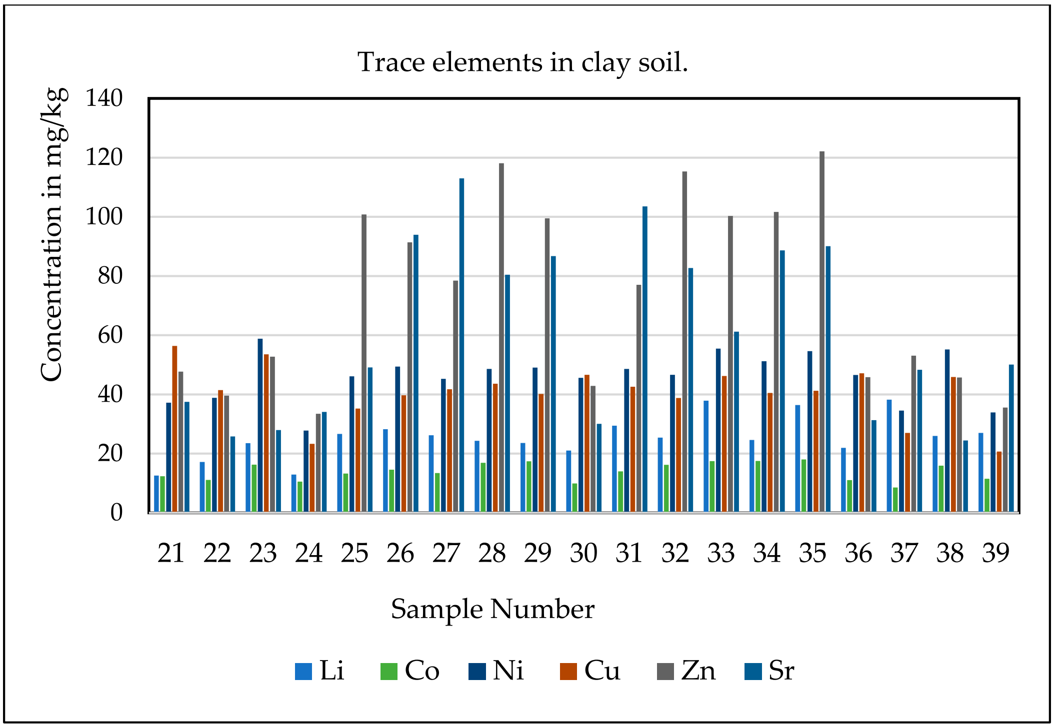

Figure 9. Trace elements detected in clay soil for samples number 21–39.

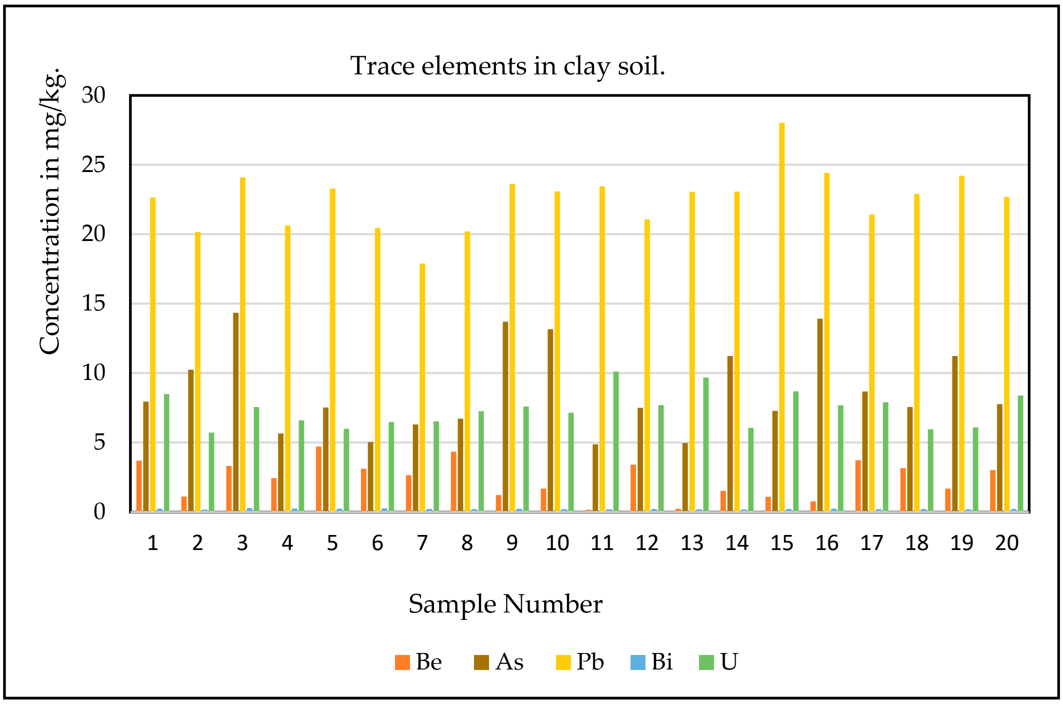

Figure 10. Trace elements detected in clay soil for samples number 1–20.

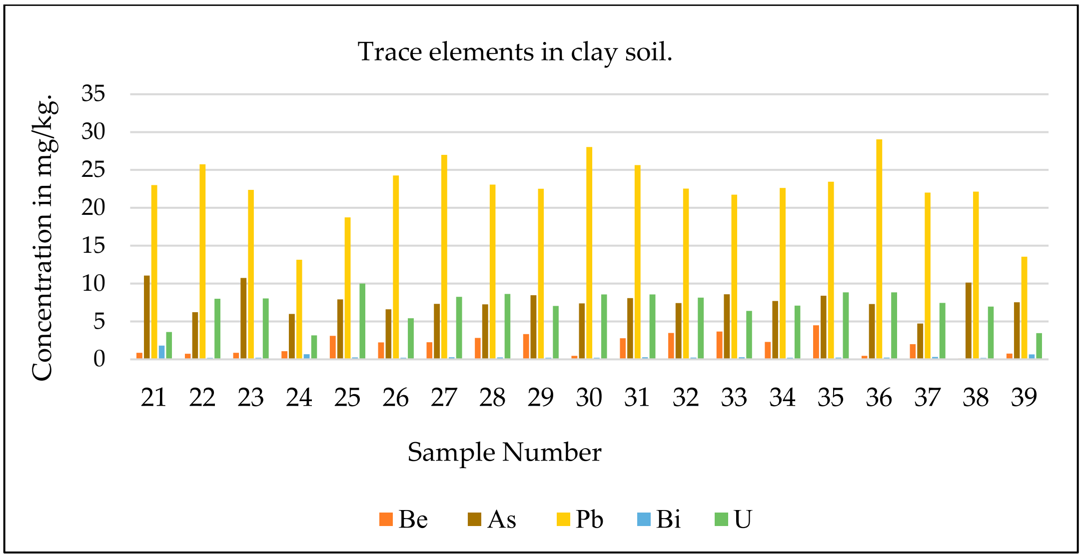

Figure 11. Trace elements detected in clay soil for samples number 21–39.

Figures 10 and 11 compared the concentrations of beryllium, arsenic, lead, bismuth, and uranium that were detected in the clay soil samples. Lead concentrations were higher for this set of comparison, followed by almost similar concentrations of arsenic and uranium. The lowest detected parameter for this set of trace elements was bismuth.

Figures 12 and 13 indicate the concentrations of lead, cadmium, and mercury detected in the samples. These chemicals are listed as the most toxic trace elements. Most of these parameters were reported to be detected at levels that were below 0.1 mg/kg in the almost all samples. Cadmium was detected at quantities of 0.17, 0.24, 0.13, and 0.22 for samples 4, 5, 8, and 12, respectively. An assumption of 0.09 mg/kg was made for all the concentrations of lead, cadmium, and mercury that were reported to be below 0.1 mg/kg.

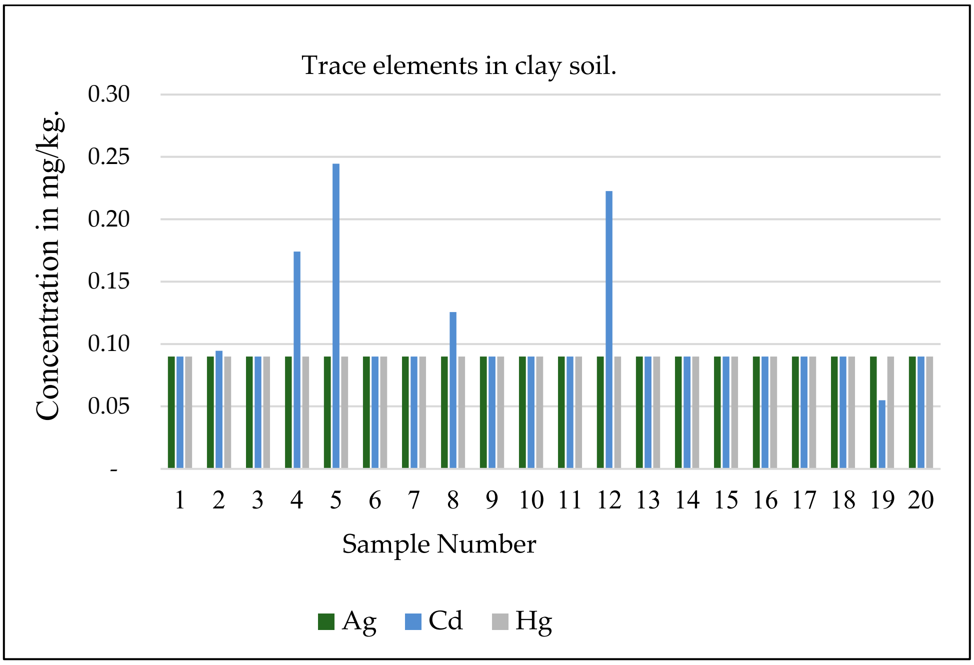

Figure 12. Trace elements detected in clay soil for samples number 1–20.

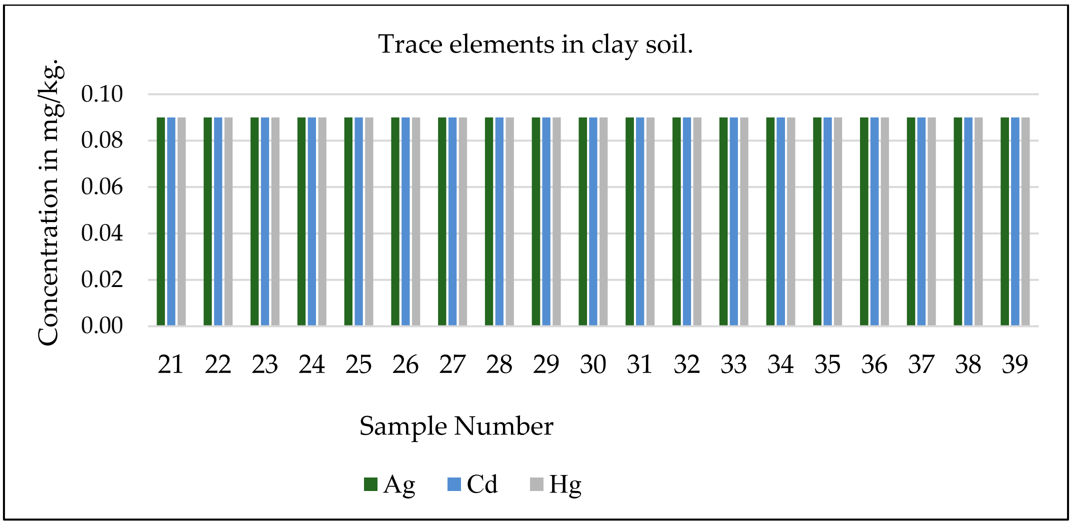

Figure 13. Trace elements detected in clay soil for samples number 21–39.

4. Discussion

The harmful chemical substances contained in clay soil eaten by geophagic women of childbearing age through the practise of geophagy are often not known and understood by consumers [1,2,9,21]. The bulk of geophagic women of childbearing age lack proper knowledge and understanding when it comes to the dangers and detrimental health effects associated with the practice of geophagy [2,3,6,9,13], which served as the gap in their knowledge that necessitated the performance of this study.

The test analysis found that indeed there are chemical parameters detected in clay eaten by women of childbearing age. Similar studies conducted in Namibia and in Limpopo [22,23] also detected chemical elements in the clay soil consumed by geophagic women. Chemical substances were detected in varying quantities in the 39 clay soil samples. The chemical elements assessed in clay soil ingested by geophagic women of childbearing age in Tshwane District comprise zinc, copper, manganese, chromium, cobalt, vanadium, lithium, nickel, arsenic, silver, barium, beryllium, bismuth, strontium, uranium, cadmium, mercury, and lead. Studies conducted across different locations in Africa found similar elements in increased concentrations in clay soil samples [1–3,9,16].

Vanadium was detected in a high quantity, ranging from 77.28 to 863.80 mg/kg, with an average concentration of 574. 92 mg/kg in a bio-test tube containing 50 mL clay soil. Although vanadium has been reported to be more harmful when inhaled as compared to when it is ingested orally, it is nevertheless known to pose a risk of respiratory diseases and a carcinogenic risk due to its toxicity [24].Vanadium is known to play no specific important role in the human body, but its ability to cause distress in iodine intake has been reported [24]. Death, fatigue, hypertension, anaemia, diarrhoea, green tongue, depressed food intake and growth, and foetal malformations have been reported as some of the potential health risks associated with vanadium ingestion from geophagic materials such as clay soil [2,8,24].

Manganese is one of the non-essential trace elements that was detected in high quantity levels in the clay soil eaten by pregnant women and women of childbearing age in Tshwane District, with concentrations ranging from 33.02 to 741.93 mg/kg and an average of 396.16 mg/kg for all the samples that were analysed. Manganese performs functions such as protein and energy metabolism, but the potential health risk linked with manganese is that if it is consumed in excessive quantities, it can lead to the development of neurological disorders such as manganism, which is normally presented as Parkinson's disease [3,8,17,19]. Adverse health caused by the ingestion of clay soil high in manganese content include reproductive and cognitive effects [3,17,19,24]. The recommended adequate intake of manganese is reported to be between 1.8 and 2.3 mg/kg for adults, and for pregnant women, it is 2 mg/kg.

Chromium is one of the chemical elements that was detected in large quantities in the samples, ranging from 125.26 to 320.03 mg/kg, with an average of 249.15 mg/kg. The excessive intake of chromium can be detrimental to human health, leading to potential risks to the digestion system, the eyes, and the respiratory tract, as well as irritation of the skin [8,17]. Other potential health risks experienced by pregnant women who have ingested chromium include back pain, malformations, mortality, skeletal defects, hypertension, and complications during pregnancy and childbirth [8,19]. Having developmentally delayed babies with damaged blood cells, nervous systems, livers, kidneys, and gastrointestinal disorders [8,19] are some of the potential health risks linked with the consumption of chromium amongst pregnant women. The suggested adequate intake of chromium is 0.0025–0.035 mg/kg for adults and 0.029–0.030 mg/kg for pregnant women.

Zinc is one of the trace elements that was detected at a noticeable quantity in the clay soil samples collected from study participants. When zinc intake is excessive, this can lead to possible health complications to the gastrointestinal system, which could hamper the availability of other elements such as copper, resulting in deficiencies. Abdominal cramps are some of the potential outcomes associated with the ingestion of clay soil with high concentrations of zinc [8,9,19]. The recommended daily allowance of zinc is 8–11 mg/kg for adults, and for pregnant women, it is 11 mg/kg.

Strontium, copper, and nickel were detected at reasonable quantities ranging from 40 to 50 mg/kg in the clay soil consumed by pregnant women and women of childbearing age. These elements have a direct impact on human health when consumed in quantities exceeding the recommended daily intake levels. The potential health risks associated with a high intake of nickel may include uterine problems amongst pregnant women, which could lead to miscarriages, and musculoskeletal defects during the childhood or infancy stages. The excess ingestion of nickel through geophagy amongst women of childbearing age and pregnant women is associated with adverse health risks such as diarrhoea, vomiting, nausea, shortness of breath, an increased red blood cell count, and heart failure leading to death. Other health effects of the ingestion of clay soil with an excessive concentration of nickel amongst pregnant women and women of childbearing age include musculoskeletal defects such as deformities of the feet and abortions [1,2,9,17,19]. The tolerable upper intake level of nickel for adults is 1 mg/kg, and for pregnant women, it is also 1 mg/kg [19]. When copper is consumed in high concentrations, this can lead to both short- and long-term health risks such as fatigue, liver damage, loss of concentration, and learning disabilities. Other health risks linked with the consumption of clay soil include vomiting, diarrhoea, anaemia, nausea, and death [8,9,19,24]. The recommended daily allowance of copper is 0.9 mg/kg for adults and 1 mg/kg for pregnant women [19]. The ingestion of strontium through the practice of geophagy is linked to potential health risks such as bone and kidney damage. Another trace element that was found in the clay soil ingested by women of childbearing age was cobalt. This element is known to cause potential risks to the endocrine system and cardiovascular and neurological disorders when consumed in excessive quantities [1,8,12,19,24]. The suggested adequate intake of cobalt is 0.003–0.008 mg/kg for adults, whether pregnant or not [19].

Lead, arsenic, cadmium, and magnesium are known to be the most toxic trace elements that have detrimental effects on public health. They are listed as such and are known to be elements of concern. In our study, Pb was detected at concentrations ranging from 13.14 to 29.05 mg/kg, with an average of 22.59 mg/kg for all 39 samples which were collected and analysed. The potential health effects related to the ingestion of clay soil that contains high quantities of Pb, As, Cd, and Mg include premature deaths, low-birth-weight babies, anaemia, nervous system disorder, and at times, the occurrence of death for both the mother and the child [2,8,19,25,26]. It must be noted that lead (Pb) is one of the toxic trace elements that is listed as a carcinogen. The suggested tolerable upper intake level of Pb is 0.01 mg/kg for adults and pregnant women [19].

Arsenic was also detected in quantities ranging between 4.71–14.32 mg/kg, with an average of 8.32 mg/kg, posing serious health risks to geophagic women of childbearing age. It can have both acute and long-term effects. The consumption of clay soil with a high arsenic content could lead to the development of abdominal pains, numbness, vomiting, diarrhoea, headaches, and muscular pains. Chronic exposure to the ingestion of clay soil amongst pregnant women could lead to premature childbirth and miscarriages. The consumption of clay soil with a high arsenic content during the gestation period is associated with an increased risk of foetal mortality, retarded mental growth and low IQ level of the foetus, skeletal malformation, and a low birth weight [8,26]. The suggested tolerable upper intake level of nickel is 0.0005 mg/kg for adults and pregnant women [19].

Trace elements such as cadmium, mercury, and silver were detected in this study at low concentrations below 0.1 mg/kg, and this a serious source of relief bearing in mind the potential health risks associated with these elements based on their toxicity and harmful properties. The low concentrations of mercury, cadmium, and silver in clay soil minimise the risks of miscarriage and prematurity, low libido, congenital malformations [8], infertility, and premenstrual syndrome amongst pregnant women, followed by neurocognitive deficits such as neuromotor disabilities [8], reduced performance in tests, and spatial cognition impairment for the foetuses [9,16,18,27,28].It is difficult to link or compare the chemical content of the above-mentioned substances, since the geographic locations where these clay soils are sourced from are unknown. Furthermore, we unable to confirm whether the clay soils received from the participants were processed materials or naturally found.

It was also noted that some of the trace elements detected in the clay soil are essential to performing crucial biological life processes in the human body, offering great health benefits when consumed at levels within the stipulated limits for recommended daily intake. Zinc, for instance, is essential for normal development, maturation, and growth. Cobalt is crucial due to its metal constituent of vitamin B12, and manganese is known to play an important role in bone growth, reproduction, and mental functioning [8].

The texture, smell, flavour, taste, colour, shape, and size differ from one supplier to the next. Although clay soil is eaten by women of childbearing age and pregnant women across the globe, particularly in African countries such as South Africa, Ghana, Zimbabwe, Tanzania, Kenya, and Malawi, the source of the clay soil is not usually reported. The street vendors commercialising this product have no clear idea where it comes from. Many assume that this is mountain soil and that the clay comes from caves. Some participants indicated the clay soil that is eaten by pregnant women and women of childbearing age in their district is naturally found on the ground, in the mountains, or in termite mounds [8], while most people are of the view that the clay soil is more of a processed product than a natural element. Although the participants reported that the street vendors stock clay soil from Marabastad in Tshwane as the common open market that supplies street vendors with clay soil, the concentrations of the chemical elements detected in this study differed from one sample to the next.

The chemical content of geophagic materials impact negatively on the overall health status of consumers which leads to many complications during pregnancy, childbirth defects, teratogenic risks, and possible interruptions in the development and growth of the foetus [2,7,9,16]. The possibility of giving birth to a pre-contaminated child with defects resulting from the toxic elements found in clay soil has been reported by other studies. Geophagy negatively impacts the overall health status of consumers, leading to compromised maternal and child health for pregnant women and contributing to increased numbers of maternal, neonatal, and child mortalities and morbidities [2,3,7,17,27,29]. Other health effects linked with the practice of geophagy amongst women of childbearing age and pregnant women include constant constipation, ulcers, infestations of worms, damage of the dental enamel, shortness of breath, fatigue, dizziness, appendicitis, fertility problems, and anaemia [9,13,19,24,29,30]. The creation of education awareness programs aimed at mitigating geophagy amongst such women is of paramount importance, particularly in South Africa, where the practice is very common, even being popularised on social media platforms. The greatest weapon that could be used to put an end to the practice of geophagy would be to empower women with the correct information. This would give them the capacity to take informed decisions. Therefore, the government of South Africa must prioritise geophagy health education and promotion programs to create awareness in the hope of curbing the practice in our communities, which indirectly exposes consumers to various harmful chemical substances.

Geophagic women of childbearing age and pregnant women must be taught about the importance of starting small vegetable gardens in their homes and planting vegetables that have a high iron content, such as beetroot and spinach, to assist in curbing their zeal to eat clay. Dietitians could also assist geophagic women with food plans. Various interventions to mitigate geophagy amongst women of childbearing age and pregnant women are obtainable; however, it is entirely up to individuals to make decisions on their own to quit geophagy. Bioremediation and pre-treatment of clay soil before commercialisation and consumption could assist in reducing the chemical content concentrations of clay soil eaten by geophagic women of childbearing age.

5. Conclusions

The chemical composition of the clay soil eaten by women of childbearing age contains harmful substances. Amongst the chemical elements examined in clay soil, vanadium, manganese, chromium, and barium were recorded in high quantities. The lowest chemical concentrations were detected for silver, cadmium, and mercury in clay soil eaten by geophagic women of childbearing age in Tshwane District, Gauteng Province. The trace elements detected in clay soil had high concentrations, exceeding the recommended allowable levels, and this poses serious health risks. The practice of geophagy contributes to the incidence of maternal, neonatal, and child mortalities and morbidities due to the chemical composition and structure of the substances eaten.

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