SOIL MATTERS

PROFESSORIAL INAUGURAL LECTURE

PRESENTED BY

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UNIVERSITY OF SOUTH AFRICA

JULY 27TH 2017

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1. Prelude

The Vice Principal Teaching, Learning, community engagement and student support, The Executive Dean, College of Agriculture and Environmental sciences, Directors of Schools and Chairs of Departments here present, colleagues, students, friends, Family, ladies and gentlemen. It is my distinct privilege to present my inaugural lecture titled "**Soil Matters**" here in University of South Africa, Africa's second best university.

When I graduated from university in the 90s, **The Environment** was the most fashionable word. With a background in Zoology, I was not sure whether to go into wildlife conservation or continue with parasitology, which formed the core of my undergraduate research. In 1998 a Common Wealth Fund for Technical Cooperation Bursary took me to Botswana to study Environmental Sciences at Master's level. There I met two enthusiastic scientists, Professor Totolo a soil scientist, and Prof Ekosse, a geologist/environmental scientist. I soon became infected with soil science and environmental science and so began my journey with environmental soil science.

2. Introduction

Soil matters could be considered as soil counts, soil is important, or soil is crucial. It could also mean the properties and characteristics of soils. It is assumed in this lecture that we all agree soil is crucial. Therefore, my lecture will focus on the latter which deals with the properties and characteristics of soils. My interest in soil properties and characteristics are centred on soil texture, pH, cation exchange capacity, electrical conductivity, total surface area, organic matter content, soil mineralogical composition, and heavy metal concentrations.

With regards to soil texture, I was intrigued by the statement that "**A clay content of 15 wt % in any soil has the same influence on the behaviour of the soil as a sand content of 70 wt %.** About 90% of all soil chemical reactions take place on the surface of clay particles. It is not just the amount of clay present in a soil that matters but the minerals that are contained in the clay because soil reactions take place on the surface of these minerals. I will at this stage explain what I mean by soil minerals because the term mineral means different things to different people.

- A farmer uses the term mineral to describe plant nutrients (calcium (Ca), magnesium (Mg), potassium (K), phosphates (PO_4^{3-}), nitrates (NO_3^-), sulphates (SO_4^{3-}) etc).
- Geologist, mineralogists and metallurgists, handle metals from which precious elements such as gold (Au), silver (Ag), platinum (Pt), Ni etc are obtained as minerals.
- If you have been to Nigeria, the term minerals in addition to the above also refers to what we call fizzes in South Africa, soda in the USA, and Top in Cameroon.
- I could also use the term mineral to refer to the inorganic components (sand, silt and clay) of soil.
- In addition, sometimes especially in West Africa, bottled still water is referred to as mineral water because of its high content of elements like Ca, Mg, and K.

In this presentation, the term mineral refers to the aluminosilicates, oxides, hydroxides, and carbonates which are crystalline, present in soil, and formed as a result of crystallization during the cooling of magma (primary minerals including quartz, feldspars, plagioclase, microcline, pyroxene, amphibolite) or from alteration of primary minerals (kaolinite, smectite, illite, talc). While the primary minerals are described as chemically inert, the secondary minerals usually present in the clay fraction of soils are usually negatively charged. The two main types of secondary minerals are the 1:1 type (made up of one aluminium octahedral sheet and one silicon tetrahedral sheet) and 2:1 type (made up of an octahedral sheet sandwiched between two tetrahedral sheets). In addition to these minerals, soil contains organic matter, which also has negatively charged sites. Hence **<u>most</u>** soils have a net negative charge and will attract cations. This explains why application of excess anions like nitrates and phosphates on soils would be a waste because they will simply leach through the soil particles except on soils that are rich in sesquioxides (oxides containing three atoms of oxygen with two atoms of another element e.g Fe, Al). Soil organic matter, clay content and mineralogical composition therefore determine the cation exchange capacity of the soil. Cation exchange capacity is a measure of how many cations soil particles can retain and it determines whether metals and plant nutrients are retained in or leached from the soil.

Another statement that intrigued me is a statement by Brady and Weil (2008), which says "**The total surface area of a teaspoon of clay is equivalent to the surface area of a soccer pitch**". Brady and Weil (2008) also said **if you would number the microorganisms contained in a handful of soil, they would number up to a million.** These two statements relate to the total surface area of soil. Soil surface area influences its surface charge density, and consequently cation exchange capcity.

Among soil pollutants, I have special interest in heavy metals and metalloids including arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), selenium (Se) and zinc (Zn) because of their occurrence in several products that we use in our everyday lives, and their potential to cause health complications. My research on heavy metals in soil has been guided by the statement that "**the total concentration of heavy metal in the soil only gives you an idea of the risk to which plants and animals may be exposed but it does not tell you that the plants and animals will be affected by the heavy metal** (Alloway, 2005)**.** Heavy metals in soils occur in five geochemical pools; exchangeable (soil solution), carbonate bound, reducible (Fe/Mn), oxidizeable (organic matter) and residual (silicate structure) pools. The concentrations of heavy metals in these different pools determine the level of impact they will have on the environment. These concentrations are determined by soil pH, organic matter content, mineralogy and redox conditions.

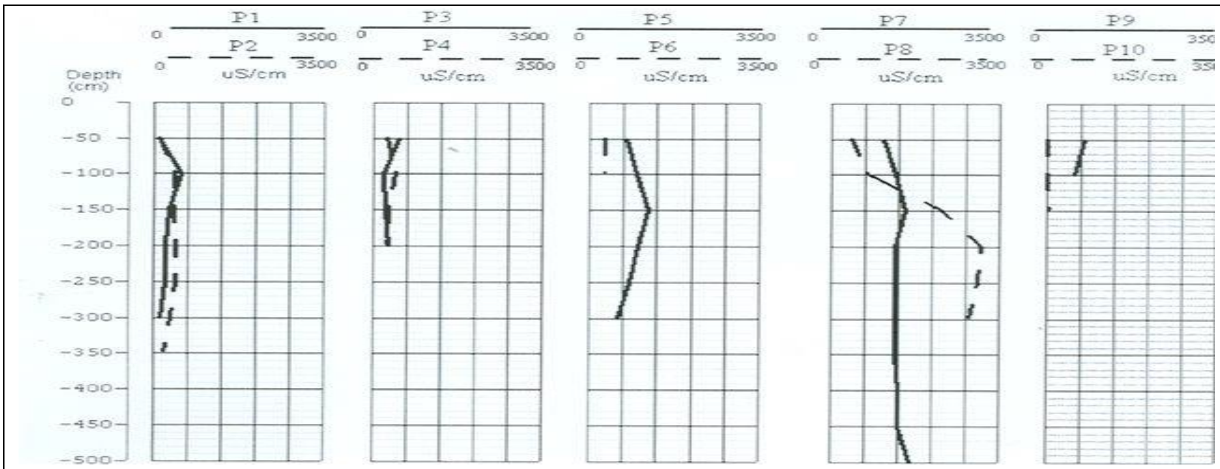
I have looked at the role of these soil properties and characteristics in different environments including landfills, landslide scars, untarred roads, and mining environments. I have also looked at them in soils that are ingested by man and those that are used for cosmetic purposes.

3. Soil matters in landfill environments

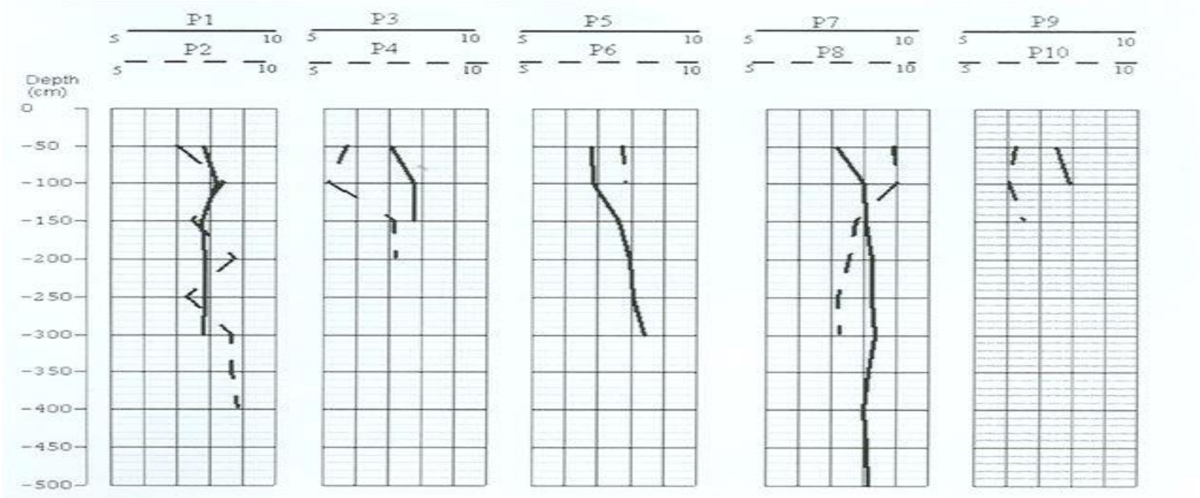
A landfill is a site where waste is buried. It is different from a dumpsite in that, it has a liner at the bottom to prevent leachate migration out of the landfill. Vents are installed to exhaust methane resulting from anaerobic decomposition processes, and the waste is compacted and covered with soil at the end of each day. Landfills are sources of organic and inorganic contaminants into surrounding soil and water resources. Soil properties of interest in any landfill environment include texture, mineralogical composition, cation exchange capacity, organic matter content and hydraulic properties because these determine the rate of contaminant plume migration and behaviour of contaminants in environments around the landfill. In-depth research into soil physico-chemistry and mineralogy in the subsurface environment of landfills with the Gaborone Landfill in Botswana as a case study was my first environmental soil science related research. I focused on variations in soil properties and understanding how these variations affect contaminant migration in the landfill environment. Soil physico-chemical properties around landfill environments tend to show huge variations and heterogeneities with depth because of inputs into the soil (Figure 1).

Inputs into soils around landfill environments include leachate migrating from the landfill. The characteristics of the leachate have a direct influence on the properties of surrounding soils including soil moisture content, pH, electrical conductivity, mineralogy, heavy metal concentration, and type of organic compounds. In the soils around the Gaborone landfill for example, the soil conductivity and pH were higher in areas around cells receiving metallic waste; salt content was generally higher in soils in the subsurface of cells receiving general waste; carbonate contents were exceptionally higher beneath cells receiving demolition waste. There is therefore a strong correlation between type of waste and the properties of soils where the leachate plume is moving. More details of these studies can be found in Ngole, Totolo and Ekosse (2002, and 2004).

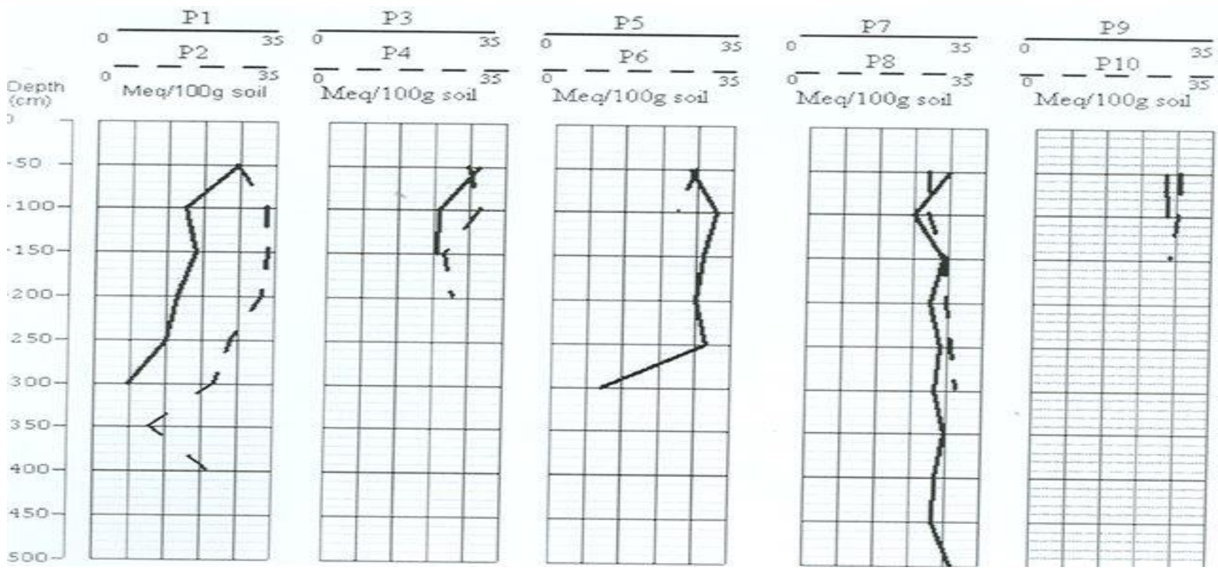
The parent material of soil determines its mineralogy but in landfill environments, movement of leachate into surrounding soils presents a chemical environment that influences weathering processes. Landfill leachate could be acidic or alkaline depending on the age of the landfill. Weathering processes of soils within a leachate plume could result in the occurrence of minerals which cannot be traced back to natural weathering products of the parent material of the soil. In the Gaborone landfill, albite (a Na-feldspar with chemical formula $NaAlSi_3O_8$) a high temperature mineral was identified. The presence of albite in this environment was attributed to high pH and concentration of Na in the leachate. Calcite ($CaCO_3$) occurrence was associated with soils around cells receiving demolition waste.



Distribution of electrical conductivity at different depths along Profiles



Distribution of pH at different depths along Profiles



Distribution of cation exchange capacity at different depths along profiles

Figure 1: Distribution of Soil Physicochemical properties with depth around the Gaborone Landfill (Ngole et al 2002)

Secondary clay minerals including montmorillonite ($Na_{0.2}Ca_{0.1}Al_2Si_4O_{10}(OH)_2(H_2O)_{10}$), kaolinite ($Al_2Si_2O_5(OH)_4$) and illite ($K_{0.65}Al_{2.0}[Al_{0.65}Si_{3.35}O_{10}]\ (OH)_2$) were identified in the soils from the southern corner of the landfill which was poorly drained and flooded with leachate (Figure 2).

Figure 2: Leachate migrating from the Gaborone landfill

Concentration patterns of heavy metals in soils around landfills are influenced by the direction of flow of leachate whose composition is determined by the type of waste deposited in the landfill. Where a landfill receives waste rich in heavy metals whether of industrial or domestic origin, there will be enrichment of heavy metals in the soil. Values for geo-accumulation index and contamination factors of various heavy metals in soils in the surrounding of Gaborone landfill indicate significant enrichment of the soils with heavy metals, especially Cu, Ni and Zn (Figures 3 & 4). Soil profiles with monmorillonitic clays had higher concentrations of heavy metals than those with 1:1 type clay minerals kaolinite and illite, highlighting the role of soil minerlogy in heavy metal sorption in the soil environment.

Variations of heavy metal concentrations around the landfill environment showed a high positive correlation with cation exchange capcity, clay content and kaolinite/illite/smectite presence. Details of heavy metals in soils around landfill environments are contained in Ngole et al (2006) and Ngole and Ekosse (2012). In my assessment of the effects of landfills on soils, it is apparent that not only the hydraulic properties which include permeability and infiltration rates should be considered as is most often the case but soil clay content and mineralogical composition should also be taken into consideration. This is because, even when leachate happens to seep through the soil layers, the soil could sorp cationic contaminants from migrating leachate reducing the potential negative impact on ground water.

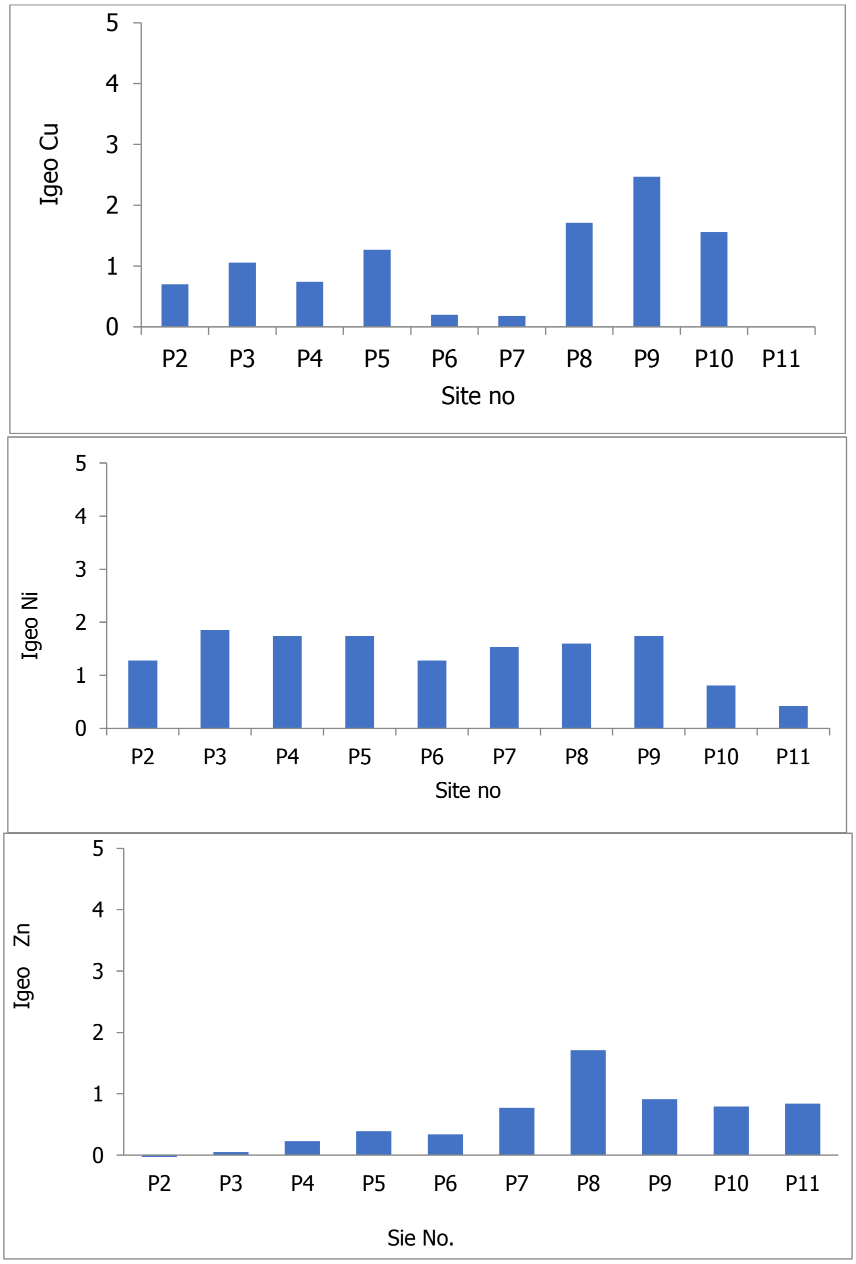


Figure 3: Geoaccumulation indices of copper (a), nickel (b) and zinc (c) in soils within the landfilling environments

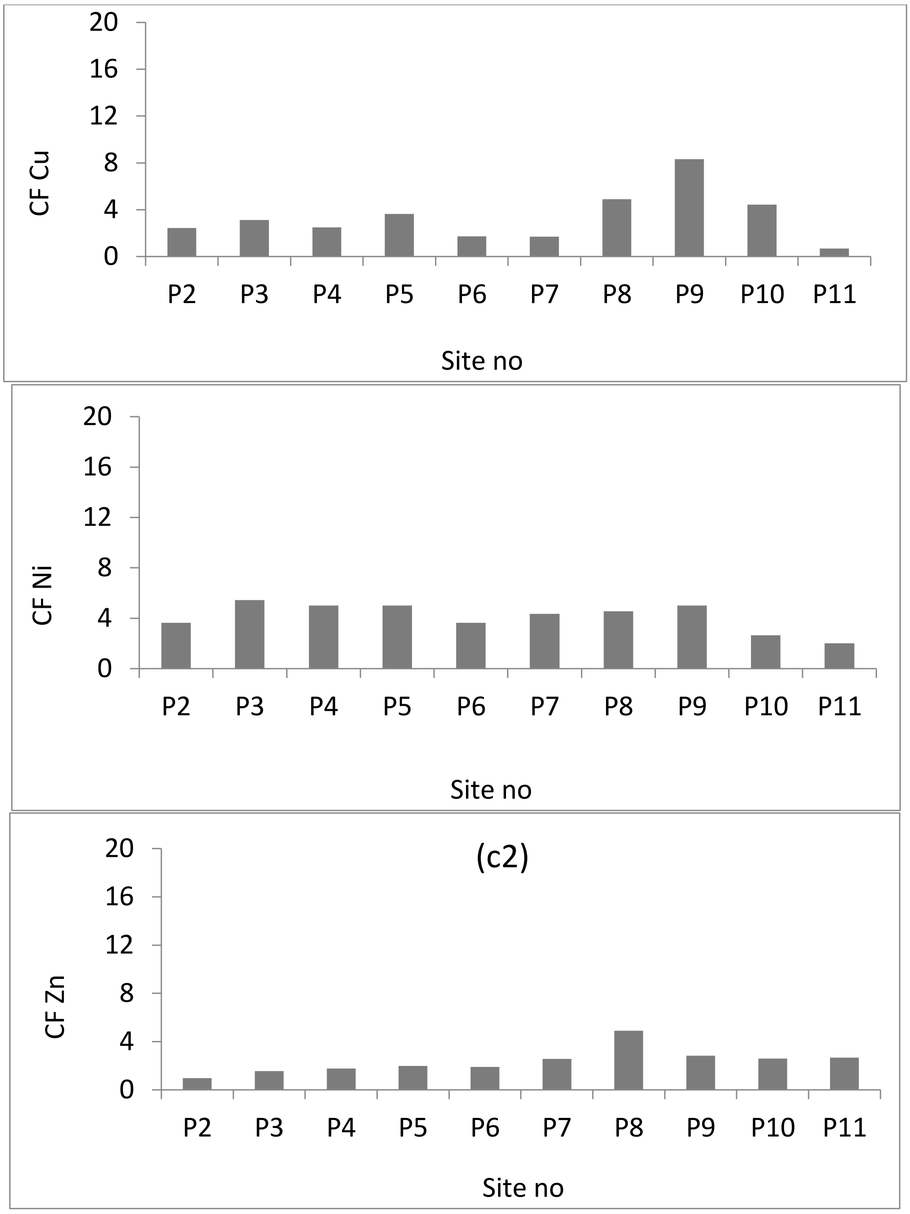


Figure 4: Contamination factors of copper (a), nickel (b) and zinc (c) in soils within the landfilling environments

4. Soil matters in landslide events

I have also been involved in some research on soils in landslide scars specifically in Cameroon. Soil texture, water retention capacity, mineralogy and Atterberg limits, especially plasticity index play a significant role in the occurrence of landslides. Landslides would typically occur at the permeability barrier between the soil and bedrock but in the series of landslide events which took place in Cameroon in 2004, the bedrock was more than 15 m below the slip surface of the slide. We found out that soil texture on three different slip surfaces sampled was highly clayey with a high water retention capacity and low plasticity limit (Table 1).

Table 1: Physico-chemical properties of samples of unconsolidated sediments of the 2001 landslides at the Mabeta New Layout area in Limbe Cameroon

Properties	**Site A**	**Site B**	**Site C**
Fine sand + silt+ clay wt. %	53.6	67.0	54.3
Medium + coarse sand wt. %	27	31	44.7
Bulk density (g/cm^3)	1.08	0.97	0.89
Loss-on-ignition (%)	24.1	19.4	25.7
Water absorption (%)	24.5	29.1	23.4
Linear shrinkage (%)	5.4	8.3	7.7
Volume shrinkage (%)	4.8	8.5	7.0
Plasticity index (%)	13.5	20.75	19.25

Source: Ngole et al (2007)

High water retention capacity of the clayey soils reduces the matric potential and plasticity limit of the soil, causing it to behave like pure water. The slip surfaces of the landslides were characterised by extensively weathered soils as reflected by the mineralogy of the soils and values for Chemical Index of Alteration (CIA) (74.5 – 91.4). Minerals identified in soil samples from this surface included anatase (TiO2), annite ($KFe_3AlSiO_{10}(OH,F)_2$), augite ($Ca_2(Al\text{-}Fe)_4(Mg\text{-}Fe)_4Si_6O_{24}$), goethite ($FeO(OH)$), hematite ($Fe_2O_3$) and kaolinite minerals ($Al_2Si_2O_5(OH)_4$) which must have occurred as a result of excessive leaching of Mg, Ca, K, and Na from the soils. This excessive chemical weathering results in heterogeneities in the soil, which together with a high bulk density caused by excessive water retention and clayey texture would contribute to instability of slopes in the event of excessive rainfall. These in addition to the disturbance of the angle of repose of the slopes caused by infrastructural developments would render any slope highly unstable, consequently increasing the likelihood of landslides. We have documented the influence of soil properties on the occurrence of landslides in Ekosse et al (2005), Ngole et al. (2007), and Motake et al (2012).

5. Soils matters in Agriculture

One of the main ecological functions of soil is that it serves as a medium for plant growth. My research activities in this area have focused more on monitoring and assessing the quality of soil as a medium for plant growth rather than looking at soil fertility, and has been grounded in the principle of waste recycling. The specific waste I dealt with being sewage sludge.

Organic amendments have been proven to not only improve the nutrient content of soils, but also the physical condition of the soil. My research in this area has looked at soil physicochemical properties, mineralogical composition and how they affect and are affected by application of sewage sludge. Environmental and health concerns associated with the use of sewage sludge for agricultural purposes were also looked at. The research was carried out using soils form Padamatenga (vertisol), Mmamabula (arenosol), Barolong farms (luvisol) and Tuli Block (luvisol) all areas in Botswana. Seventy percent (70%) of the soil cover in Botswana is arenosol which is characteristically sandy with a massive structure. Improving the productivity of arenosol will contribute positively toward food security in Botswana hence the investigations related to the use of sludge to improve soil quality for agricultural purposes.

One of the major health and ethical concern with regards to the use of sewage sludge for agricultural purposes is the possibility of the transfer of enteric pathogens contained in the sludge to food crops, and their eventual ingestion by man/livestock. Sewage sludge contains a huge load of enteric pathogens (Figure 5) which could be transferred to food crops grown on soils amended with the sludge. Reducing the pathogen load in sludge-amended soil would enable the sludge to be used safely for the growth of food crops. This could be done if we know the factors that affect the survival of these pathogens in the soil environment.

Figure 5: Indicator organisms (*E. coli*) in sewage sludge

I investigated the soil factors that affected the survival of indicator organisms in the soil environment. Survival of indicator organisms tends to be highest in clayey (27%

clay) and lowest in the sandy soils (90 % sand). This is attributed to the fact that fine textured soils shield soil microbes from environmental stress and provide protection from predators (protozoans) through pore size exclusion. Microbes could however easily migrate to subsurface layers in sand textured soils where they can survive for longer periods compared to when they are on the surface horizons. This may explain why despite the low survival rate of *E. coli* in sandy soils, they were identified in spinach grown on arenosol with a high sludge application rate (Figure 6).

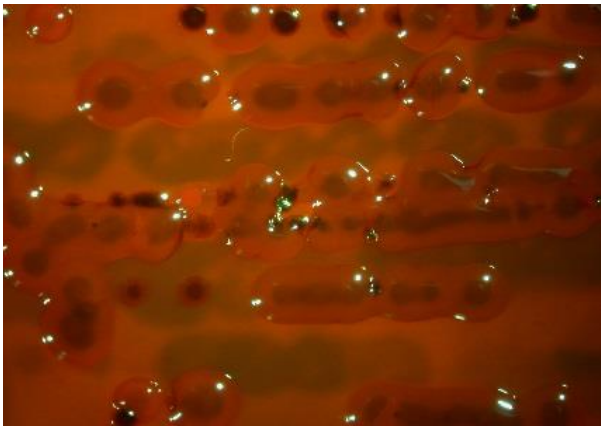
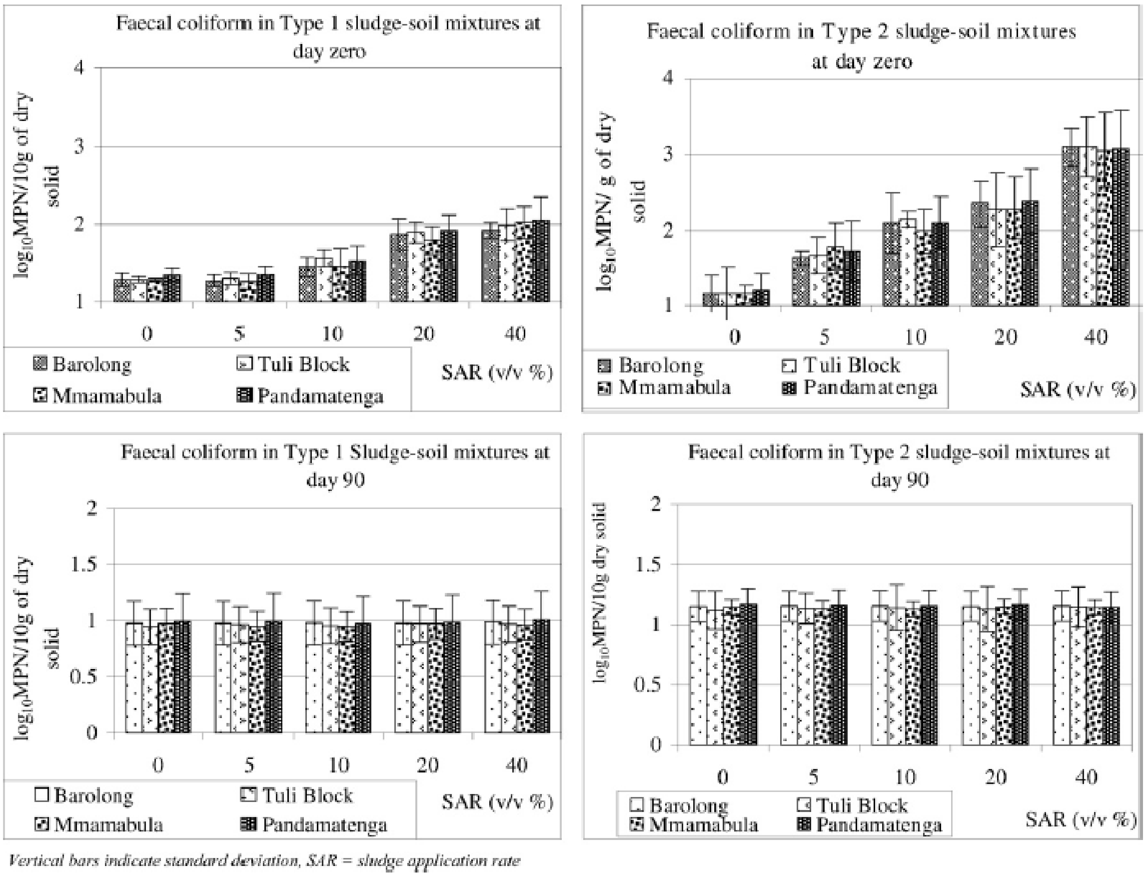


Figure 6: Vegetable sample showing presence of *E coli* 120 days after sludge application

Survival of microorganisms in the soil is also significantly affected by the mineralogy with microbes surviving better in soils with 2:1 type clays than in the 1:1 type clays. 2:1 type clays form organo-mineral complexes with applied organic compounds making them inaccessible to microbes responsible for decomposition. In addition aromatic organic compounds which are more recalcitrant than the aliphatic compounds are more often than not bound to the 2:1 clays whereas aliphatic compounds are bound mostly by 1:1 type clays. Organic matter turnover in 2:1 type soils is low providing a sustained source of nutrients for microbes. The mineral composition of a soil should therefore be one of the soil factors considered in the design of sludge or any organic matter application program. In order to guarantee sanitary condition of the sludge amended soil, it is advisable to allow a period between when sludge is applied to the soil and when food crops are sown. This period varies with environment and soil properties. In my research, I found that under arid conditions, a sludge application-to-planting interval of 90 days (3 months) reduces the health risk associated with growing food crops on sewage sludge-amended soil but an interval of 120 days is better for older sludge and an even longer period when fine textured soils are under consideration (Figure 7). Details of these research results are contained in Ngole, Totolo and Mpuchane (2006a, 2006b and 2007) and Ngole (2007).



Source: Ngole Totolo and Mpuchane (2006)

Figure 7: Faecal coliforms in soil/sludge mixtures at day 0 and day 90

Another area of concern in the use of sludge for agriculture is the ability of sludge to enrich soils with heavy metals. Application of heavy metal rich sludge onto soil would significantly increase the concentrations of heavy metals in the soil and one would expect this to translate into high metal uptake by plants grown on such soils. Not the whole amount of metals in the sludge are leachable and hence may not contribute to the available fraction of heavy metals in the sludge-amended soil (Ngole 2005). The rate of organic amendment application and the age of amendment used individually have no effect on accumulation of heavy metals in plants grown on sludge-amended soils but paired interactions between soil type and these two would influence the rate of heavy metal uptake (Ngole and Ekosse 2009). Ngole (2007) found no relationship between metal mobility factor in the soil and bioconcentration factors of heavy metals in vegetables grown on the soil (Figure 8).

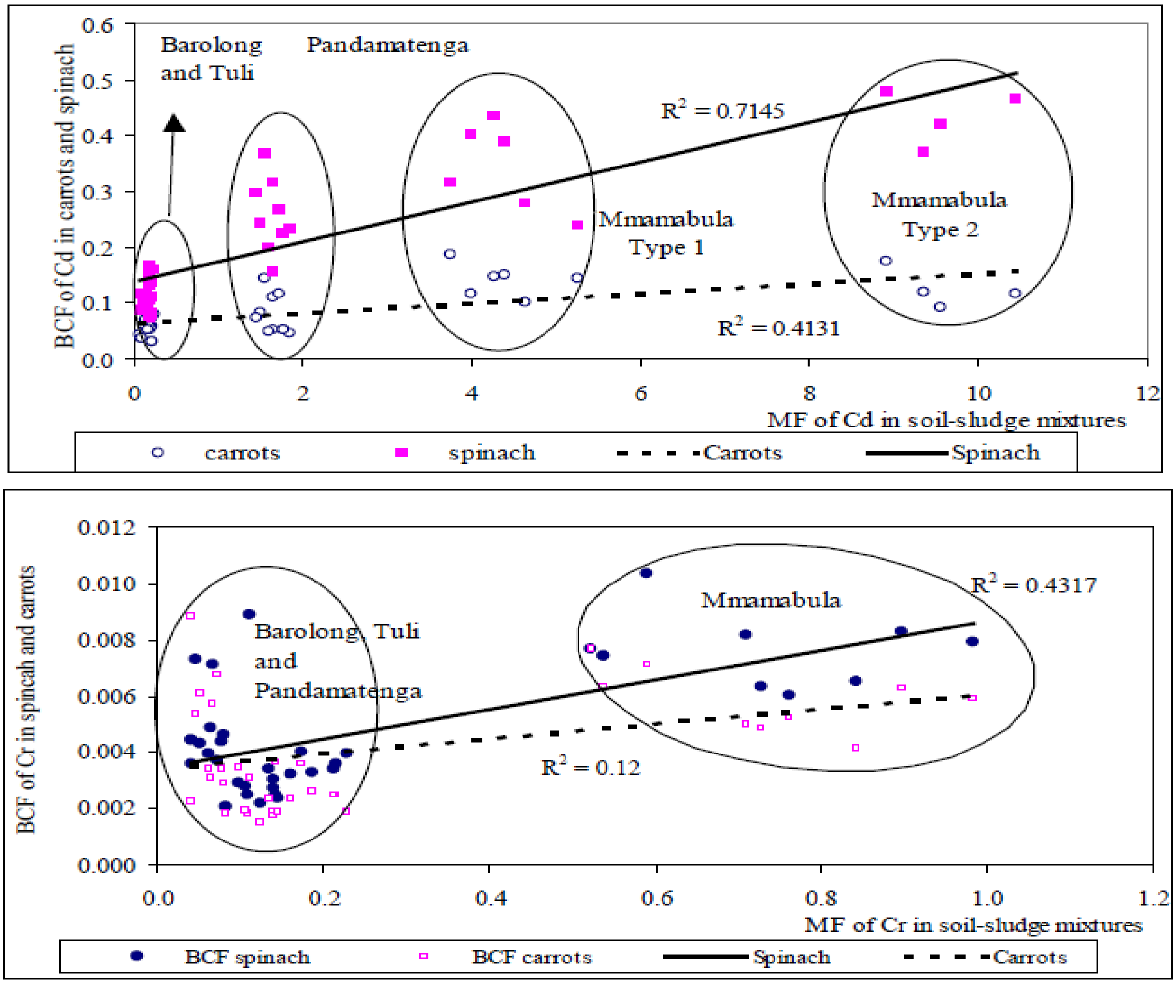


Figure 8: Relationship between mobility factor of heavy metal and bio concentration factor of heavy metals in vegetables grown on sludge-amended soils

Changes in soil properties caused by organic amendments affect heavy metal partitioning into the various geochemical pools in the soils and therefore affect their mobility and bioavailability. Application of sewage sludge or any other organic amendment would shift the heavy metal concentration from the exchangeable to the organic matter or oxidizeable pool, decreasing their bioavailability (Table 2). Heavy metals form complexes and chelates with the added organic matter that more often than not decrease the mobility of heavy metals in sludge-amended soils. The decrease in bioavailability as a result of sludge application is more obvious in sandy soils (e.g arenosol) compared to the silty, loamy or clayey soils (e.g luvisols and vertisols) (Table 2). It also varies with heavy metal as some metals have a stronger affinity for organic matter than others. The ability of organic amendments to immobilize heavy metals is currently being exploited as a means of attenuating heavy metals in soil. These results indicate that using sewage sludge to improve the productivity of soils including arenosols can be profitable provided the necessary precautions are taken to ensure a reduction in enteric pathogen loads and heavy metal bioavailability (Ngole 2007b).

Table 2: Changes in mobility factors of heavy metals in different sludge-amended soils 90 days after sludge application

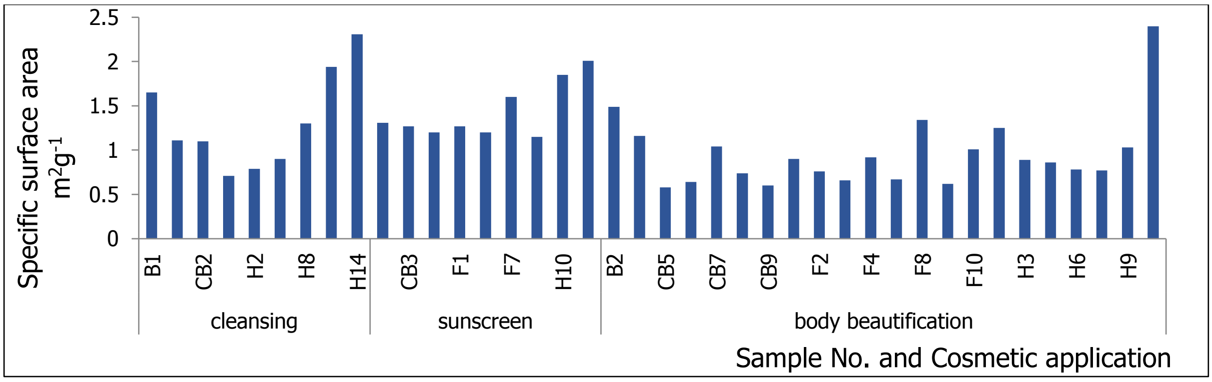
Metal	SAR (v/v %)	Luvisol 1	Luvisol 2	arenosol	Vertisol
Cr	0	-0.03	0.11	0.06	0.08
	5	-0.04	0.09	-0.15	0.14
	10	-0.04	0.04	-0.28	0.11
	20	-0.01	-0.05	-0.21	0.14
	40	-0.08	-0.01	-0.28	0.10
Co	0	0.23	2.05	24.63	-0.03
	5	0.45	0.80	-6.49	-0.02
	10	0.65	0.60	-4.33	-0.01
	20	0.80	-0.15	2.23	0.01
	40	0.53	0.29	0.87	0.01
Cu	0	-0.16	0.08	0.43	-0.02
	5	0.06	-0.04	0.25	0.02
	10	-0.01	-0.02	-0.14	0.00
	20	-0.02	-0.07	-0.21	0.01
	40	-0.05	0.08	-0.10	0.02
Pb	0	-0.43	1.28	1.30	-0.81
	5	0.60	1.16	2.33	-0.31
	10	0.03	0.07	-1.00	-0.40
	20	0.41	-0.07	-0.64	-0.14
	40	-0.06	-0.08	-0.76	0.06
Mn	0	0.42	0.05	-0.74	-0.07
	5	-0.06	-0.01	-0.42	-0.07
	10	0.01	-0.02	-0.52	-0.03
	20	-0.05	-0.14	-0.50	-0.03
	40	-0.12	-0.02	-0.92	-0.07
Ni	0	0.05	0.10	0.11	0.00
	5	-0.14	0.27	-0.31	-0.01
	10	-0.03	0.18	-1.00	-0.02
	20	0.06	0.23	-1.20	0.02
	40	-0.11	0.31	-0.24	0.00
Zn	0	0.10	-0.04	-0.21	-0.04
	5	0.10	0.03	0.44	0.13
	10	0.19	0.38	-0.90	-0.04
	20	0.07	0.01	-0.04	-0.04
	40	-0.12	0.15	0.23	-0.05

Source: Ngole 2007

6. Soil matters and cosmetics

Soils are also widely used for cosmetic purposes. Clays form an important component of many cosmetic products because of their chemical, physical and mineralogical properties. Indigenous communities in Africa have been exploiting these properties for a variety of purposes. The desire to correlate the indigenous knowledge that governs the use of clays for various cosmetic purposes in our local communities with scientific principles and theories led to investigations on clays used by various communities in Eastern Cape Province in South Africa. Soil properties of significance in the cosmetic industry include particle size, refractive index, mineralogy, surface area, pH, and sorption properties. A variety of soil types are used for purposes that include sun screening, beautification and cleansing.

Soils used for sunscreen are expected to have the ability to reduce absorption of radiant energy and ultra violet (UV) light. This is related to the refractive index and the specific surface area of the soils. Soils used for cleansing should have the ability to absorb toxins from the skin. Soil absorption is associated with soil texture, cation exchange capacity and mineralogy. Soil colour, pH and mineral content are the main properties determining its use for beautification. In some instances, we found that the physicochemical properties of the soil have a relationship with their uses. For example; Soils used as sun screen in the Eastern Cape Province were clayey with a hue of 2.5 YR corresponding to the colour of hematite (Fe_2O_3) and goethite (FeO(OH), which have high refractive indices (n_w=3.15 and n_α=2.39, respectively). Consequently, these soils have low UV transmission. These samples also had a higher specific surface area than those used for cleansing and body beautification (Figure 9).



Source: Matike et al (2011)

Figure 9: Specific surface area of soil samples used for cleansing, sun screening and body beautification

Soils with high specific surface area have the ability to refract radiant energy reducing the amount of UV light absorbed by the skin on a sunny day. Finer particles and high hue (bright colours) were characteristic of soils generally used for beautification. Soil pH is also significant in soils used for beautification. Studies have shown that the growth of *Propionibacterium acnes,* which causes acnes is much lower at a pH of 5.5 and below. Soils used for beautification are expected to have low pH values because continuous application of soil with pH values > 5.5 would encourage the development of acne. The pH of the cosmetic soil samples analysed ranged from 4.53 to 9.57 with majority of the samples being acidic. The samples used for body beautification had mean pH values of 6.43. Samples of soils used for cleansing recorded the highest mean CEC (22.9 meq/100 g), than those used for body beautification and sunscreen. With a relatively high CEC, soils used for cleansing had a high potential to adsorb toxins from the skin. Details of these studies can be found in Matike, Ekosse and Ngole (2010; 2011); and Mpako, Matike, Ekosse, and Ngole (2011). These results highlight some scientific justification that the soils used by these communities could serve the purpose for which they are used.

7. Soils matters and geophagia

Geophagia is the deliberate ingestion of soils previously reported mainly among pregnant women, but now highly prevalent among women who are not pregnant and even some men. Those indulging in the practice have used very interesting reasons to justify the eating of soil. Reasons such as pregnancy, craving, nutrient supplementation, medicinal value and hunger have been proven and documented in other studies and were highlighted in our studies. However, many more reasons including relieving stress, improving female fertility, reducing insomnia, increasing immunity, prevention of STDs, just to name a few are some of the reasons that ladies in Limpopo, Free State, Eastern Cape, and Gauteng Provinces have used to justify the habit (Songca et al., 2010). Studies carried out by de Jager, Ngole and Ekosse (2013) revealed a lack of knowledge on the health implications of geophagia on humans. Considering that the practice of geophagia cannot be eradicated, the mission of the research group on African clay and Clay minerals has been to make the soils ingested safer for those indulging in the practice.

We have characterised soil materials eaten by women in different countries including South Africa, Botswana, Democratic Republic of Congo, Togo Swaziland, Cameroon, and Nigeria in an endeavour to correlate the reasons given to justify the habit with the properties of the soil and to suggest possible beneficiation processes where necessary. These materials are highly varied in colour (Figure 9) and granulometric properties (Figure 10).

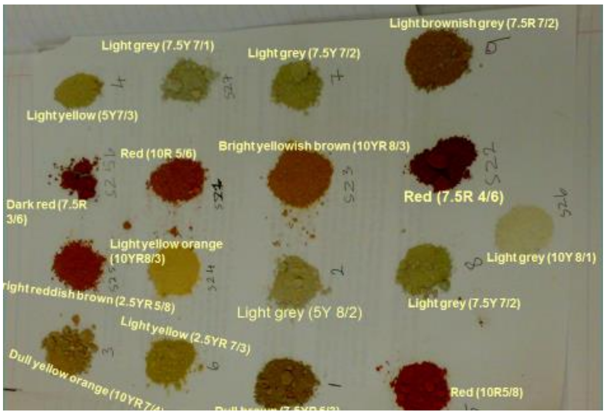


Figure 9: colours of geophagic soils

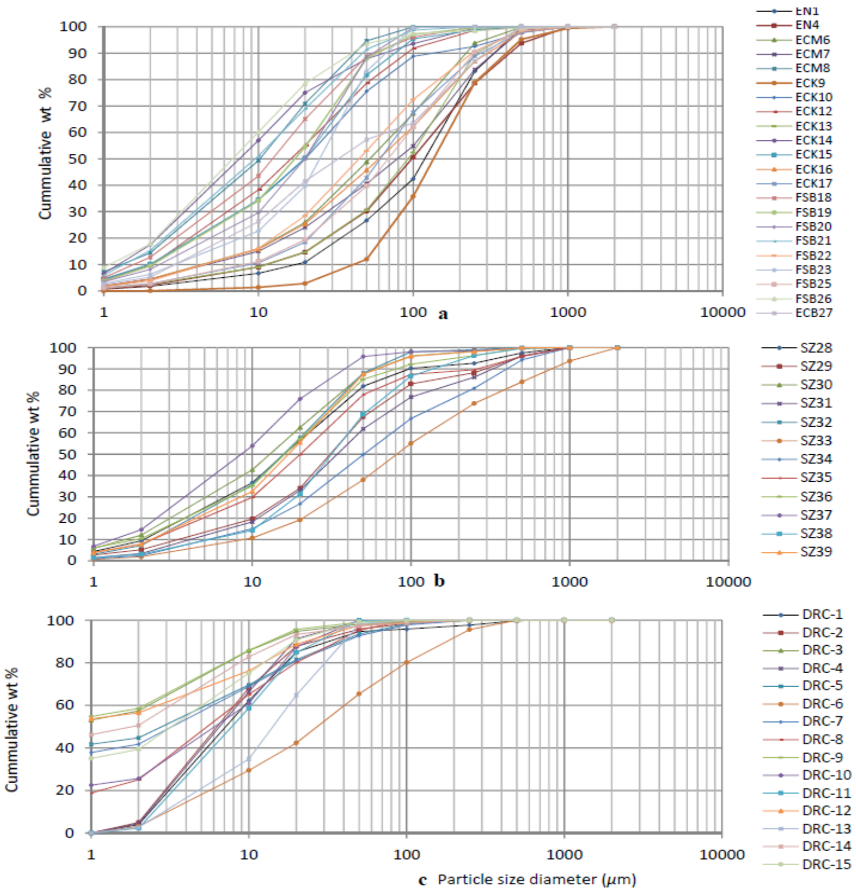


Figure 10: Particle size distribution curve of geophagic samples from South Africa (a) Swaziland (b) and DRC (c).

Contrary to people's belief, our results indicate that soils deliberately ingested are not always clayey in texture. Geophagic soils from South Africa contained more sand particles (mean = 31.14% ± 2.8) than those from Swaziland (mean = 25.76% ± 3.8) and DRC (mean = 5.0% ± 3.4). (Ekosse, Ngole and de Jager 2010; Ngole et al 2010; Ekosse, Ngole, and Longo-Mbenza 2011, and Ekosse and Ngole 2012; Ekosse, Ngole-Jeme and Diko 2017).

Minerals that we identified in geophagic soils include quartz (SiO_2) kaolinite ($Al_2Si_2O_5(OH)_4$), halite (NaCl), microcline ($KAl_3Si_3O_{10}(OH)_2$), muscovite ($KAlSi_3O_8$), goethite (FeO.OH) and/or haematite (Fe_2O_3), siderite ($FeCO_3$), gibbsite ($Al(OH)_3$), anatase (TiO_2), talc ($Mg_3(OH)_2Si_4O_{10}$) and smectite ($Na0.3(Al,Mg)_2Si_4O_{10}$-$(OH)_2.xH_2O$) with kaolin being the most dominant secondary mineral in most of the samples studied (Figure 11).

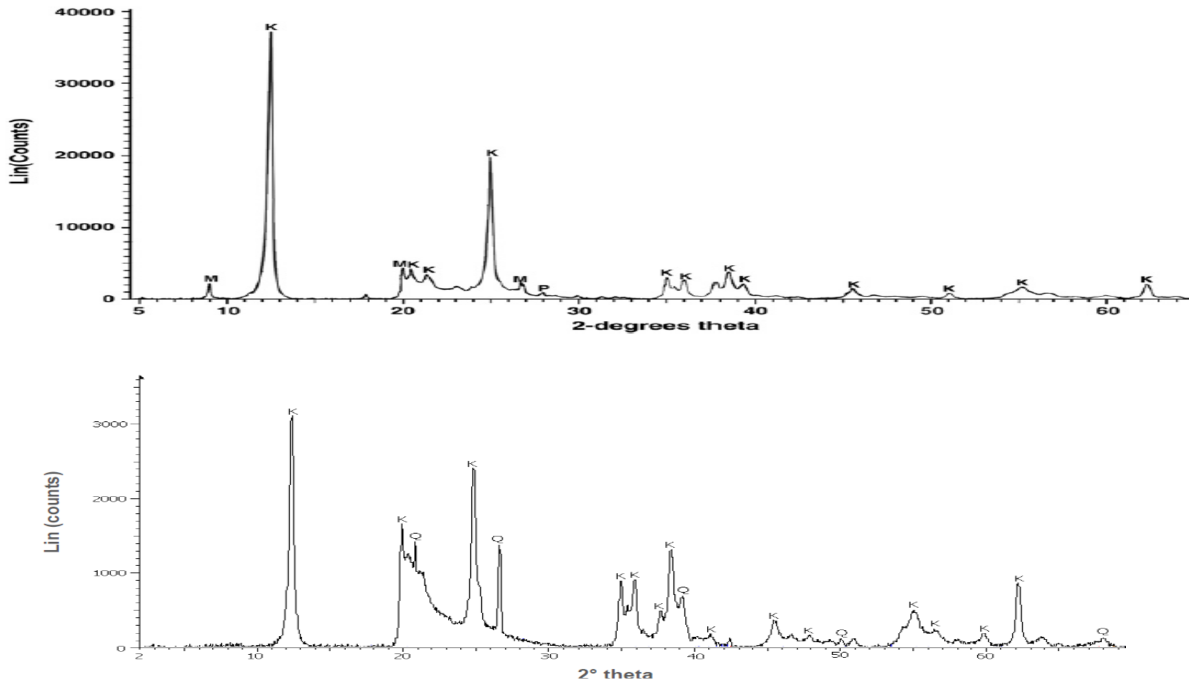


Figure 11: Representative Diffractograms of geophagic soils

The implication of the mineralogy and textural properties of the soils ingested on the geophagic individual is the possibility of damage of the dental enamel. This is because quartz which dominates the mineral assemblage of these soils has a hardness of seven (7) on the Mohr hardness scale compared to hydroxyapatite (5 on the Mohr hardness scale) which makes up dental enamel. This risk was identified in soils from

South Africa, Swaziland, DRC and Togo (Ngole-Jeme and Ekosse 2015). Beneficiation processes that would increase the fineness of these soils while reducing the quartz content are recommended to reduce the possibility of dental enamel destruction. Alleviation of gastrointestinal disorders such as diarrhoea is also a reason that has been used to justify geophagia. The use of kaopectate (a kaolin-derived medication) in the treatment of diarrhoea is well documented. The assumption by geophagists that they ingest soil to alleviate symptoms of diarrhoea can be justified by the occurrence of kaolinite in most of the soil samples analysed. Kaolinite in the soil is an absorbent able to absorb moisture from the gastrointestinal tract (GIT) reducing the occurrence of diarrhoea. Ingesting kaolin rich soils (like the calabar chalk), could cause constipation. These highlights the significance of soil texture and mineralogical composition in the consequences of geophagia.

Reduction of salivation and the feeling of nausea during pregnancy is also another reason that women use to justify geophagia. This is related to the electrical conductivity and pH of geophagic soils which are associated with the organoleptic properties of the soils ingested. Acidic soils have a sour taste whereas soils with high electrical conductivity are salty. These tastes have been reported to contribute to the reduction of salivation and nausea during pregnancy.

Another health issue associated with geophagia is its potential to contribute to the prevalence of geohelminth (worm) infections. Geohelminths are helminthic parasites in which at least one developmental stage (most commonly the ova) requires a period of incubation in the soil prior to being infective. Survival of the ova of these parasites in the soil is determined by soil texture, pH moisture and organic matter contents. Occurrence of human mortality due directly to geohelminth infection is low but chronic worm infestation results in sustained immune activation which is a major enhancing factor in the pathogenesis of several diseases including AIDS. We therefore looked at the role of geophagia in the occurrence of geohelminth infection by evaluating the presence of geohelminth ova in samples of geophagic soils. The ova of *Ascaris lumbricoides (roundworm), Trichuris trichuria (whipworm)*, *Ancylostoma duodenale (Hookworm)* and *Strongyloides stercoralis (thread worm)* were identified in some samples with *A. lumbricoides* being the most prevalent (Table 4).

Table 3: Geohelminths identified in some geophagic soil samples

Sample Id	*Ascaris lumbricoides*	*Trichuris trichuria*	*Hook worm*	*Strongyloides stercoralis*
EN1	+			
EN2	+		+	
EN4	+			+
EN5	+++	+++		
ECM7	+		+	
ECK9	+			+
ECK17	+			

Source: Sumbele Ngole and Ekosse 2014

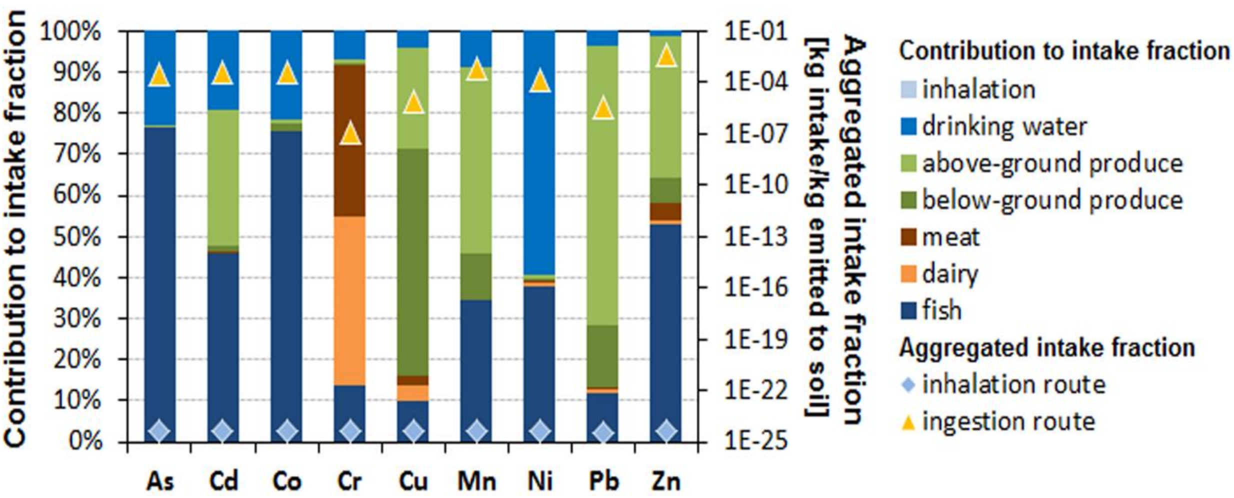
Soils showing positive results for geohelminths were sandy and silty in texture with low concentrations of sesquioxoides. These oxides serve as cementing agents in the soil. Low concentrations of these will allow free movement of these infective stages in the soil environment and possibly away from harsh environmental conditions. The geophagic materials we have characterised so far have a silty texrture, a water retention capacity of 30 – 75%, pH values between 5 – 7.5, EC values ranging from 10 - 200 µS/cm, and organic matter content of between 0.1 – 1.5% (Ngole et al, 2010; Ekosse, Ngole, and Longo-Mbenza 2011; and Ekosse and Ngole 2012). These properties favour the survival of geohelminths in the soils. Geophagic materials should not be collected from open fields or from topsoil to reduce the intake of helminth ova as a result of geophagia. These results have been presented in Sumbele, Ngole and Ekosse (2014).

We tested the hypothesis that soils are ingested to supplement for nutrient deficiencies. In many areas, the reddish soil is preferred and the general belief is that reddish soils are rich in iron. Whereas colour could be used to determine the presence or absence of Fe oxides in soils, it should be noted that there is some variability in mineral colours. This variability in the colour of minerals that are commonly found in soils and clays that are ingested may result in the soil or clay having a colour which is not indicative of its mineral content. Using colour alone to determine the Fe content of geophagic soils may therefore be deceitful. Supplementation of iron has been used to justify geophagia but geophagia could in some cases result in anaemia because the minerals contained in the soil as well as the soil CEC would cause the soil to bind Fe in the GIT, reducing its bioaccessibility. This would rather result in Fe absorption from the GIT instead of its supplementation. The consequence will be anaemia. Our studies indicate CEC values of between 5 -19 meq/100g soil which is relatively low and could imply low absorption of Fe from the GIT by these soils. Supplementation of Ca among lactating mothers is another assumption made by geopagists.

We carried out simulation studies using the physiologically based Extraction technique (PBET). This technique uses gastric juice (prepared from 2.5 g pepsin, 1 g tri-sodium citrate, 1 g DL Malic acid, 840 µl lactic acid syrup, and HCl distilled deionised water), and pancreatic juice (500 mg of pancreatin and 175 mg of bile salts per litre of gastric juice solution neutralized to pH 7 with solid sodium hydrogen carbonate ($NaHCO_3$)), to determine the bioaccessibility of nutrients in materials ingested by humans. With up to 50% bioaccessibility of some supplements (Ca, Co, Cu, Fe, K, Mg, Mn, Na, P and Zn), < 1% of the Recommended dietary allowance (RDA) of a 65kg adult is met by ingesting 30 g of soil daily (Ngole and Ekosse 2012). Our Investigations on geophagia is still going on.

8. Soil heavy metal contamination and associated Health risk

Heavy metal occurrence in soils could be from natural and anthropogenic sources and have received attention because of their potential negative effects on various environmental sectors. In the computation of human recommended dietary allowance of heavy metals, the food ingested is what is usually taken into consideration (Figure 12).



Source: Ngole-Jeme and Fantke 2017

Figure 12: Distribution of pathways contributing to potential human exposure following an assumed emission of different heavy metals and metalloids

There is exposure to heavy metals through incidental ingestion of, dermal contact with, or inhalation of soil particles that are contaminated with heavy metals. Exposure of humans to heavy metals through these routes is a hidden source of heavy metals that is not factored into the RDA but that could be making significant contributions to the heavy metal intake of individuals. My research on soil heavy metal contamination and assessment of health risk associated with exposure to heavy metals in soils have focused on three different soil types; soils in the subsurface on landfills, geophagic soils, soils along unpaved roads, and soils in the vicinity of mine tailings.

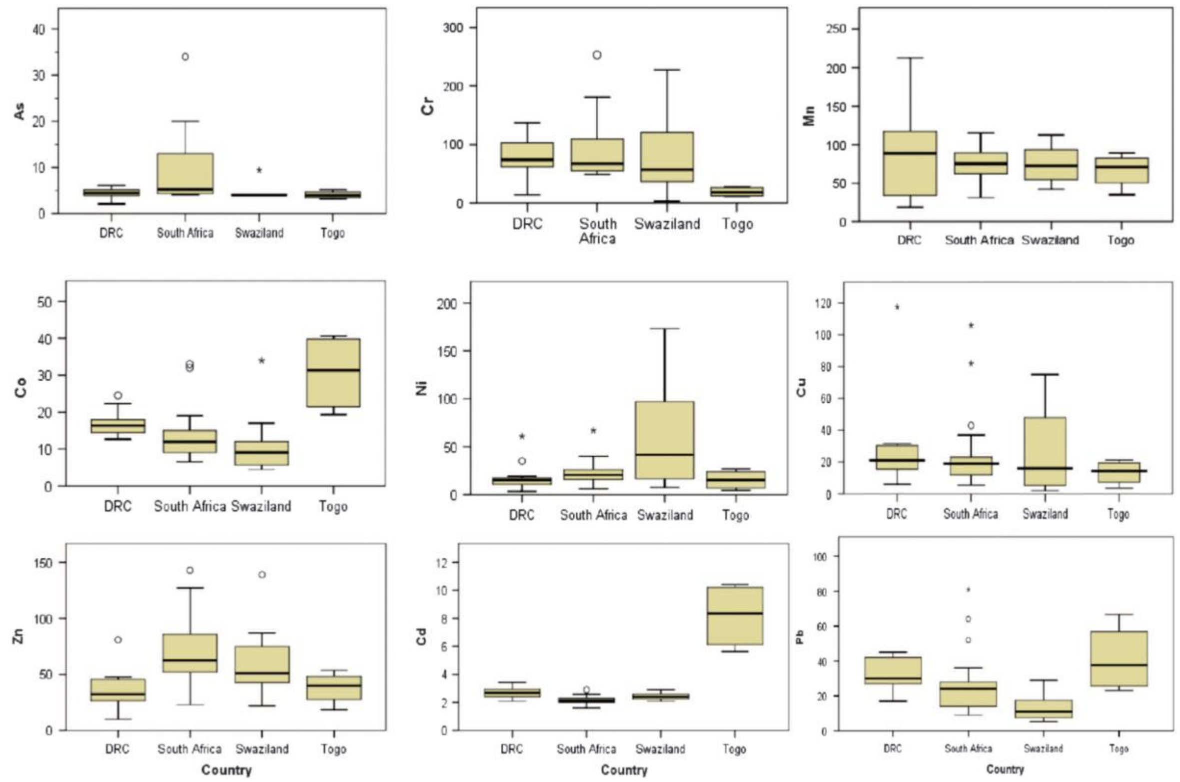
8.1 Heavy metal exposure as a result of Geophagia

The concentrations of heavy metals in geophagic materials vary depending on the parent material from which the soil was formed, natural processes of weathering, and anthropogenic activities which might have reduced or increased this background concentration. Geophagic soils are usually mined from non-industrialised areas and are expected to have low concentrations of heavy metals. However, the background concentrations of heavy metals in some soils could be high enough to present an environmental and human health risk. Differences were observed in concentrations of heavy metals in the geophagic samples we have studied (Figure 13). Using PBET, we were able to determine the percent bioaccessibility of heavy metals in ingested soil in the stomach and the intestines using Equation 1.

$$\%\ bioaccessibility = \frac{SPH + IPH}{SPH + IPH + RPH}$$

Where SPH is the concentration of trace element in the stomach phase; IPH is the concentration of trace element in the intestinal phase; and RPH is the concentration of trace element in the residual phase.

Bioaccessibility of heavy metals is higher in the stomach than the intestines. This is not unexpected given that the pH of gastric juice could be as low as 2. In the geophagic soils, Zn was found to be the most bioaccessible whereas Cd is the least bioaccessible heavy metal in human GIT. We also found that eating up to 30 g of soil /day could supply a 65 kg adult with more than the RDA for Cr and Co, up to 2% of RDA for Cu and 0.4% of the RDA for Zn (Ngole and Ekosse 2012; Ngole-Jeme Ekosse and Songca, 2017). We calculated the non-carcinogenic and carcinogenic risk associated with exposure to heavy metals in these soils as a result of their ingestion using the parameters in Table 4.



Source: Ngole-Jeme, Ekosse and Songca 2017

Figure 13: Box plot showing distribution of pseudo-total concentrations of trace elements in geophagic soil samples from the four different countries.

Among all the 57 geophagic samples studied, seven presented a potential risk of trace element exposure to both children and adults because these samples had Chronic Hazard Index (CHI) values >1. Twenty-two geophagic soil samples had CHI values between 0.7 and 1.4, implying that frequent consumption of these soils could present human health risk related to trace element exposure. Mean values for CHI followed the order Togo > DRC > South Africa > Swaziland with values of 0.87, 0.65, 0.52, and 0.32, respectively with Pb having the highest HQ. Heavy metal related non-carcinogenic risk (hazard quotient) associated with ingesting soils from SA, DRC, Swaziland and Togo, generally followed the order Pb > Cr > As > Co > Mn > Ni > Cu = Zn = Cd. Carcinogenic risk (> $1x10^{-4}$) associated with oral intake of Ni rich soils by adults and children were observed in some geophagic soil samples (Ngole-Jeme, Ekosse and Songca 2017) as indicated in Table 5. Geophagia therefore presents a hidden yet an unacknowledged source of heavy metal intake in humans indulging in geophagia.

Table 4: Parameters and values used

Parameters	Unit	Definition	Values used	
			Children	Adults
CDI	mg/kg/d	Chemical Daily Intake of heavy metal		
IR	mg/d	Ingestion rate	200	100
EF	d/year	Exposure frequency	350	350
ED	years	Exposure duration	6	30
PEF	----------	Particle emission factor	1.36×10^9	1.36×10^9
InhR	m^3/d	Inhalation rate	7.6	20
BW	kg	Body weight	15	70
CF	kg/mg	Units correction factor	10^{-6}	10^{-6}
FI	--------	The fraction of soil or dust contacted that is presumed to be contaminated	1	1
AT	d	Average time over which exposure is averaged	EDx365	EDx365

Source: Ngole-Jeme, Ekosse and Songca 2017

Table 5: Carcinogenic risk associated with ingesting geophagic soils samples from the four different countries

	AS		Ni	
	Adult	Child	Adult	Child
DRC1	1.07E-05	4.58E-07	2.56E-06	2.39E-06
DRC2	8.12E-06	4.09E-07	5.34E-06	4.99E-06
DRC3	1.31E-05	6.20E-07	5.34E-06	4.99E-06
DRC4	1.47E-05	6.87E-07	1.34E-05	1.25E-05
DRC5	2.17E-06	4.55E-06	3.01E-06	2.81E-06
DRC7	4.39E-06	1.84E-07	1.04E-05	9.73E-06
DRC8	1.13E-06	4.65E-07	4.17E-06	3.89E-06
DRC9	1.15E-05	5.50E-07	4.87E-06	4.55E-06
DRC10	2.88E-06	5.92E-07	3.10E-06	2.89E-06
DRC11	1.59E-05	5.73E-07	6.26E-06	5.84E-06
DRC12	2.03E-05	7.01E-07	5.17E-06	4.83E-06
DRC13	4.47E-06	6.53E-07	6.92E-06	6.46E-06
DRC14	6.81E-06	2.75E-07	2.00E-05	1.87E-05
DRC15	7.75E-06	3.09E-07	5.34E-06	4.99E-06
EN1	4.50E-05	9.16E-07	1.09E-05	1.02E-05
EN2	7.78E-05	2.11E-06	2.89E-05	2.70E-05
EN3	4.79E-05	1.78E-06	2.07E-05	1.93E-05
EN4	6.45E-05	1.36E-06	1.09E-05	1.02E-05
EN5	3.61E-05	1.34E-06	1.54E-05	1.44E-05
ECM6	2.94E-05	1.19E-06	5.17E-06	4.83E-06
ECM7	2.06E-05	3.01E-07	3.39E-06	3.16E-06
ECM8	2.29E-05	6.49E-07	2.67E-05	2.49E-05
ECM9	2.63E-05	6.11E-07	6.84E-05	6.38E-05
ECK10	2.52E-05	7.56E-07	4.65E-05	4.34E-05
ECK11	1.55E-04	5.93E-06	1.54E-05	1.44E-05
ECK12	2.31E-04	6.17E-06	1.71E-05	1.60E-05
ECK13	1.83E-05	4.58E-07	1.59E-06	1.48E-06
ECK14	5.24E-05	2.14E-06	1.09E-05	1.02E-05
ECK15	1.89E-05	4.87E-07	1.88E-05	1.76E-05

	AS		Ni	
Sample	Adult	Child	Adult	Child
ECK16	3.06E-05	4.02E-07	2.89E-05	2.70E-05
ECK17	2.26E-05	3.77E-07	3.31E-06	3.09E-06
FSB18	7.42E-05	1.48E-06	2.67E-06	2.49E-06
FSB19	2.77E-05	9.27E-07	1.38E-05	1.29E-05
FSB20	1.61E-05	7.33E-07	2.26E-05	2.11E-05
FSB21	2.28E-05	5.23E-07	2.07E-05	1.93E-05
FSB22	3.19E-05	5.65E-07	3.35E-05	3.13E-05
FSB23	2.77E-05	1.16E-06	1.88E-05	1.76E-05
FSB24	9.20E-05	1.90E-06	7.22E-06	6.74E-06
FSB25	8.85E-05	2.44E-06	1.38E-05	1.29E-05
FSB26	2.56E-05	1.21E-05	1.92E-04	1.79E-04
ECB27	1.19E-04	5.64E-05	5.54E-05	5.17E-05
SZ28	2.08E-05	1.39E-05	1.11E-04	1.04E-04
SZ29	9.77E-06	7.24E-06	1.88E-05	1.76E-05
SZ30	5.89E-05	1.20E-05	7.91E-04	7.38E-04
SZ31	2.44E-06	6.39E-06	2.47E-06	2.30E-06
SZ32	1.68E-05	1.64E-05	6.15E-06	5.74E-06
SZ33	4.49E-05	9.27E-06	4.38E-05	4.08E-05
SZ34	1.07E-06	9.11E-06	3.31E-06	3.09E-06
SZ35	2.87E-05	1.06E-05	1.28E-03	1.19E-03
SZ36	1.63E-04	2.50E-05	5.75E-04	5.37E-04
SZ37	1.25E-05	8.02E-06	1.49E-04	1.39E-04
SZ38	1.28E-05	1.36E-05	2.60E-04	2.43E-04
SZ39	1.80E-05	2.58E-05	4.38E-05	4.08E-05
TG1	2.83E-06	3.71E-06	4.12E-06	3.84E-06
TG2	8.74E-06	3.39E-06	3.04E-05	2.84E-05
TG3	9.87E-06	8.55E-06	1.88E-05	1.76E-05
TG4	3.53E-06	6.41E-06	8.03E-07	7.49E-07

8.2 Heavy metal contamination and exposure along unpaved roads

Heavy metal exposure studies were also carried out in soil samples from unpaved roads in Cameroon. Unpaved roads are characteristic of most sub-Saharan countries. Soil particles along unpaved roads are enriched with heavy metals derived from vehicular emissions and other anthropogenic activities that are taking place along these roads. Lead Cu, Zn, Fe and Cd are some of the heavy metals originating from the wear and tear of tires, alloys, wires and brake parts. The extent of heavy metal contamination in roadside soil varies with several factors including poor roads, driving patterns, passenger and goods overloads, and engine revving because these influence vehicular emissions. Emissions increase by a factor of 10 during traffic congestion compared to smooth driving conditions. Several indices are used to determine heavy metal contamination of soils. Here I used contamination factor (ratio of the concentration of a given metal in soil to the background concentration of the given metal in the specific environment) and pollution load index to determine the extent of heavy metal contamination in dust particles from unpaved roads. There is significant heavy metal contamination in the soils along the roads (Table 5). The extent of contamination of the soils with heavy metals increases with Average Daily Traffic volume and the kinds and density of anthropogenic activities along the roadside.

Table 6: Contamination factors (CF) and Pollution load index (PLI) of metals in soils along the highway

Sample site	Contamination Factor							PLI
	Cr	**Cu**	**Cd**	**Co**	**Ni**	**Pb**	**Zn**	
KA1	4.2	3.2	0.9	1.1	1.1	1.0	1.9	1.6
KA2	4.9	2.9	1.0	1.3	2.4	1.5	1.9	2.0
KA3	4.4	2.5	1.0	1.4	2.3	2.4	2.2	2.1
KA4	3.2	2.5	1.0	1.2	5.9	3.5	2.0	2.3
KA5	3.7	6.7	1.0	1.1	1.4	2.4	12.2	2.7
KA6	3.4	2.0	1.0	1.2	1.6	2.0	2.3	1.8
KA7	2.8	3.1	1.2	1.4	2.0	5.5	2.7	2.4
KA8	3.7	2.6	1.1	1.4	2.4	4.2	2.4	2.3
KA10	1.7	1.3	1.1	1.2	2.0	1.4	1.5	1.4
KA11	1.6	0.9	1.1	1.0	0.7	3.4	1.2	1.2
KA12	1.8	1.6	1.2	1.6	2.8	1.2	1.1	1.5

CF<1 = low contamination, 1<CF<3 = moderate contamination, 3<CF<6 = considerable contamination; CF>6 = very high contamination; PLI values < 1 indicate no pollution whereas values > 1 indicate pollution.

Source (Ngole-Jeme, 2016)

Individuals residing along such roads are exposed to dust generated by vehicular traffic through inhalation, dermal contact and incidental ingestion. Using similar parameters as shown in Table 4 to determine exposure, the health risk associated with heavy metal exposure from soil was calculated. Dermal exposure took into consideration the skin surface area available for exposure for the head, arms, hands, legs and feet which is different for adults and children. The soil adherence factor and dermal absorption factors on the skin of adults and children also differs. These were all taken into consideration in the determination of exposure risk. Heavy metal exposure risks along these roads are higher for children than for adults and vary with the specific heavy metal. Hazzard Quotients values for Cr, Cd and Pb exceeded the reference dose (RfD) for these metals (Table 7).

Table: 7 Daily intake of heavy metals by adult and children and hazard quotients (HQ)

		Daily intake		*RfD (mg/kg/day)	Hazard Quotient	
Heavy metal	Descriptive statistics	Child	Adult		Child	Adult
	minimum	1,90E-04	1,10E-04	3E-3	0,06	0,035
	Maximum	7,60E-04	4,90E-04		0,25	0,16
Cr	Mean (n = 12)	5,20E-04	3,10E-04		0,17	0,10
	minimum	5,00E-05	2,10E-05	4E-2	1.3E-3	5.2E-4
	Maximum	1,90E-04	1,70E-04		4.7E-3	4.2E-3
Cu	Mean (n = 12)	1,10E-04	6,50E-05		2.6E-3	1.6E-3
	minimum	4,60E-06	4,70E-06	1E-3	4.5E-3	4.8E-3
	Maximum	5,90E-06	6,70E-06		5.9E-3	6.7E-3
Cd	Mean (n = 12)	5,20E-06	5,70E-06		5.2E-3	5.7E-3
	minimum	1,20E-04	5,40E-05		**	**
	Maximum	2,00E-04	8,60E-05		**	**
Co	Mean (n = 12)	1,60E-04	6,60E-05		**	**
	minimum	1,50E-05	9,40E-06	2E-2	7.5E-4	4.7E-4
	Maximum	7,10E-05	6,20E-05		3.6E-4	3.1E-3
Ni	Mean (n = 12)	3,10E-05	2,30E-05		1.6E-4	1.2E-3
	minimum	5,90E-05	6,00E-05	1.4E-4	**0,42**	**0,43**
	Maximum	5,10E-04	3,30E-04		3,62	2,38
Pb	Mean (n = 12)	2,30E-04	1,50E-04		1,63	1,06
	minimum	1,40E-04	9,40E-04	3E-1	4.7E-4	3.1E-4
	Maximum	1,10E-03	1,10E-03		3.8E-3	3.6E-3
Zn	Mean (n = 12)	4,00E-04	2,50E-04		1.3E-3	8.5E-4

Mean values for both dermal and oral intake of heavy metals indicated that dermal intake was higher than oral intake for Cd, Co, Ni, Pb and Zn in adults whereas for children, oral intake was higher for Cr, Co, Pb, and Zn (Ngole-Jeme 2015). Heavy metal related non-carcinogenic risk associated with ingestion and inhalation of roadside dust should be a major concern in areas with untarred roads (Figure 14)

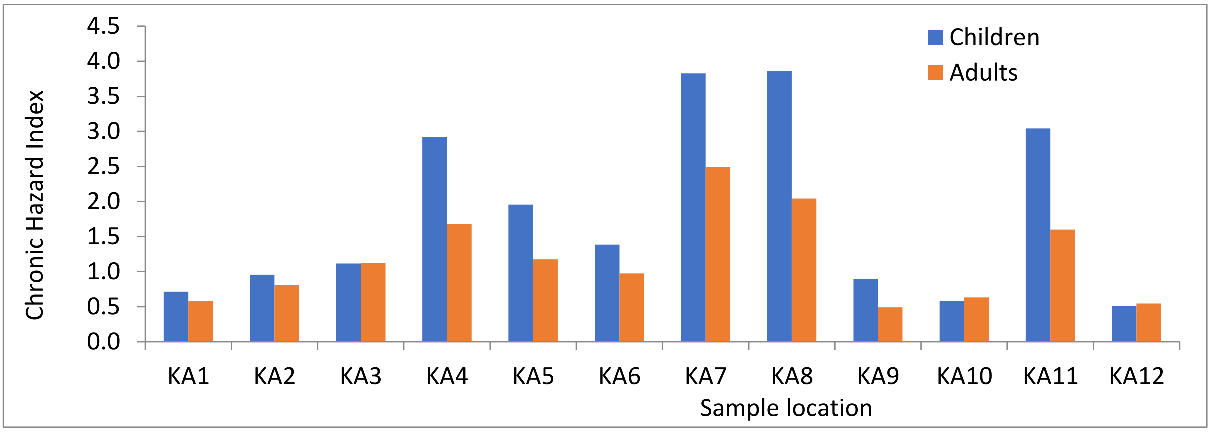


Figure 14: Total chronic hazard index of soils along unpaved roads for children and adults *(source: Ngole-Jeme 2015).*

8.3 Soil heavy metal contamination and exposure around mine tailings

Mining environments are some of the most contaminated with heavy metals. The pathway of heavy metals in mine tailings varies depending on several environmental factors (Figure 15).

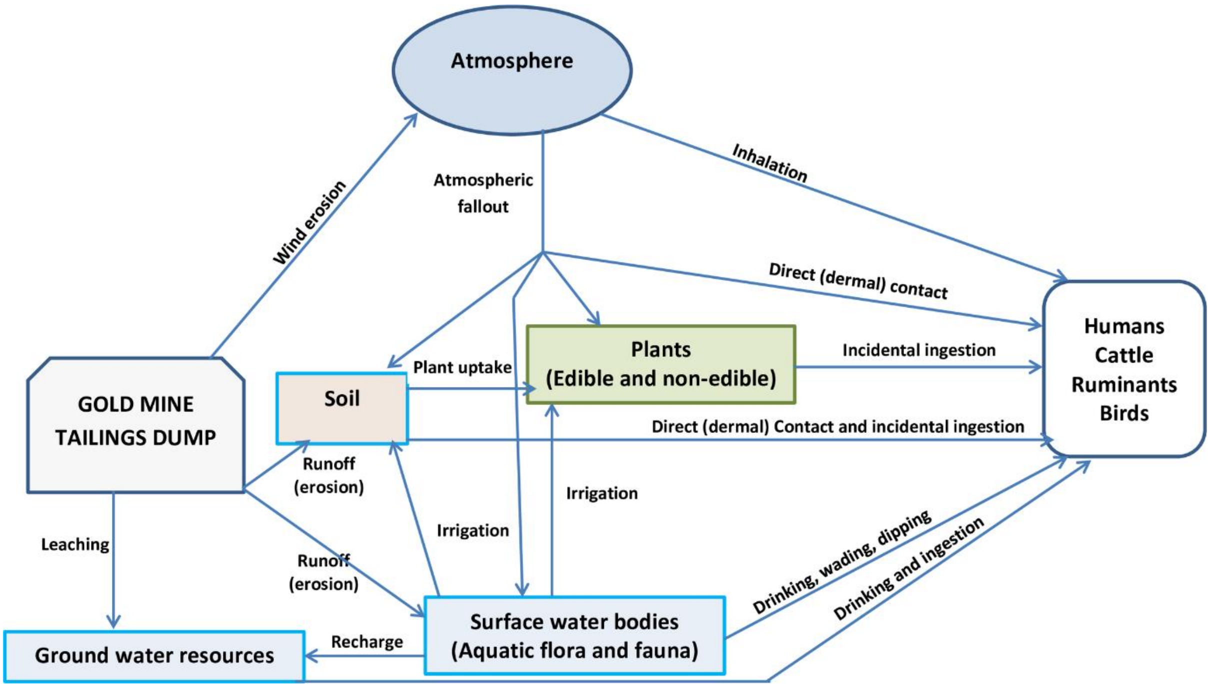


Figure 15: Conceptual illustration of the fate pathways of mining-related emissions of heavy metals and metalloids in the environment potentially leading to exposures for human and ecological receptors *(Ngole-Jeme and Fantke 2017).*

Soils around tailings are characterized by a low pH, low organic matter content, low CEC and a mineralogy that is reflective of the orebody from which the mineral element is extracted. The particle sizes of mine tailings can be described as well graded with a coefficient of uniformity > 6.0 because of the crushing that takes place. These key properties again play a significant role in determining the effect of mine tailings on ecosystem and human health as far as heavy metals are concerned. Type and quantity of heavy metals in mining environments show huge variations with type of mine and processing methods used for extracting the minerals from the orebodies. Even within the same type of mining environment, concentrations may vary depending on local geological characteristics. In Krugersdorp for example, we found that heavy metal concentrations in three different Au mines had significantly different levels of contamination (Ngole-Jeme and Fantke 2017) as indicated in Figure 16.

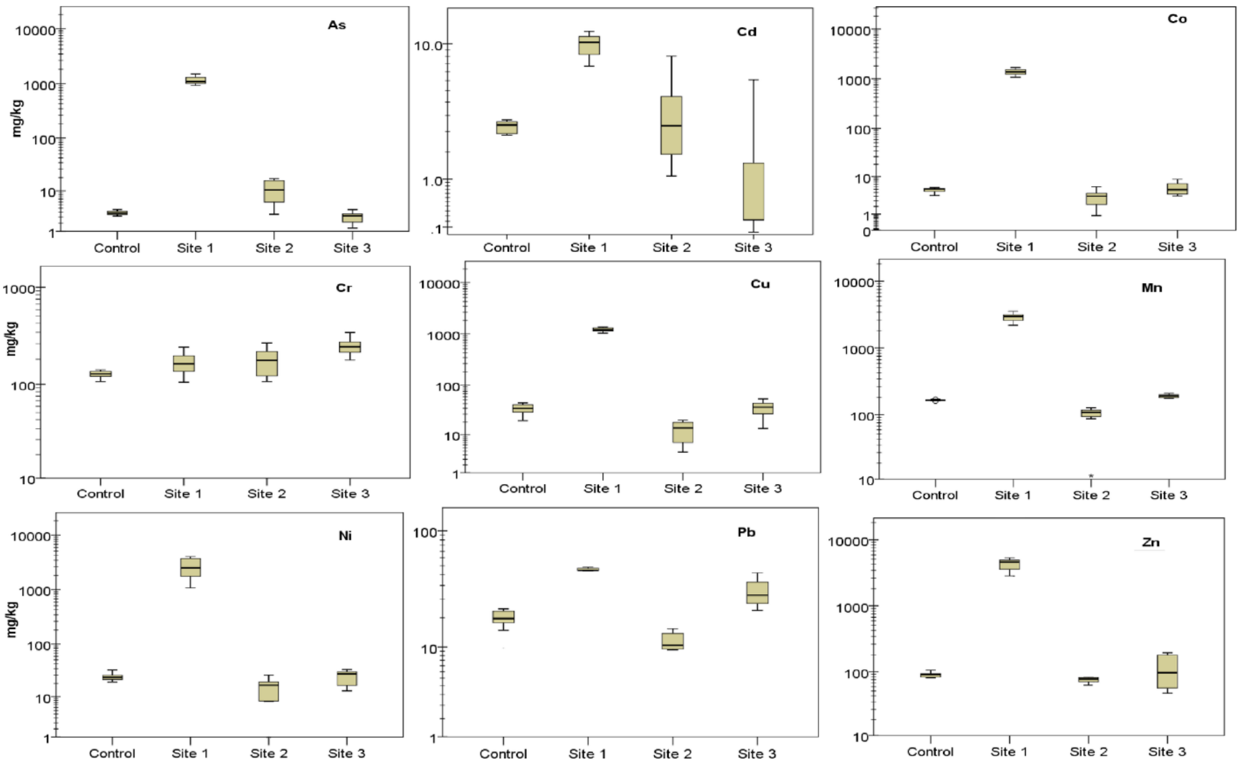


Figure 16: Concentrations of heavy metals and metalloids in samples of tailings contaminated soils.

Results indicate significant enrichments of soils with heavy metals and metalloids as indicated by the values for heavy metal and metalloid contamination factors (Figure 17). Heavy metal contaminated soils also present an ecological risk (Table 7). Ecosystem response of different heavy metals vary (As = 10, Cd = 30, Co = 5, Cr = 2, Cu = 5, Mn = 1, Ni = 5, Pb = 5) with As and Cd being the most ecologically toxic and Mn the least.

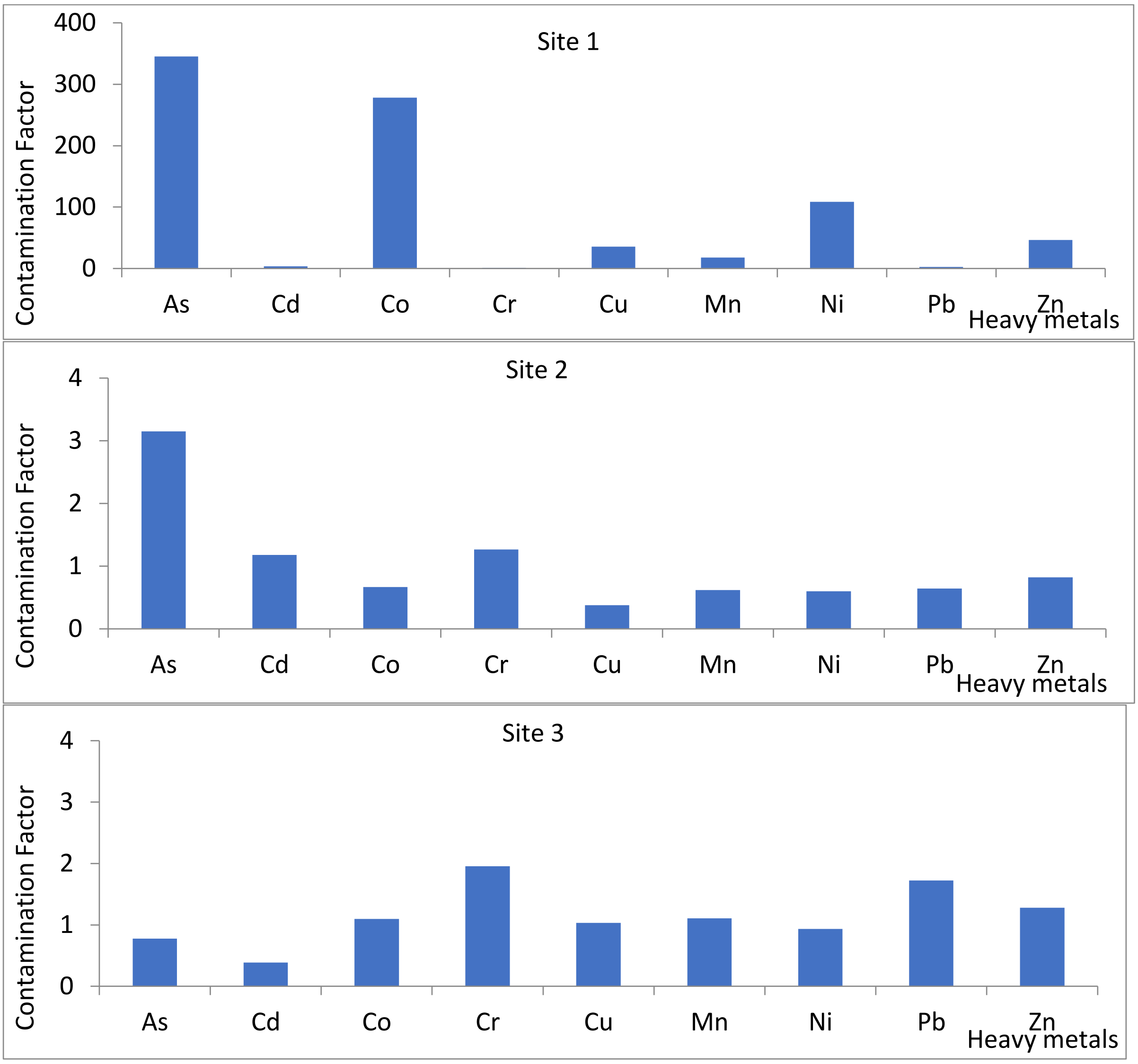


Figure 17: Heavy metal contamination factors at the three tailings sites

Table 7: Ecological risk of heavy metals in mining environments

Heavy metal	Site 1	Site 2	Site 3
As	3452,29	31,52	7,77
Cd	103,09	35,38	11,59
Co	1391,99	3,33	5,49
Cr	2,58	2,53	3,91
Cu	177,03	1,89	5,16
Mn	17,57	0,62	1,11
Ni	542,90	3,00	4,67
Pb	13,60	3,22	8,61
Zn	46,45	0,82	1,28

(Er) ≤ 40 = low risk; 40 < Er ≤ 80 = moderate risk; 80 < Er ≤160 = considerable risk; 160 < Er ≤ 320= high risk; Er > 320 = very high risk

In mining environments, high concentrations of As, Cd, Co, and Ni in mine tailings may present unacceptable risks to human populations as well as to ecosystems in the vicinity of mining areas (Figure 18).

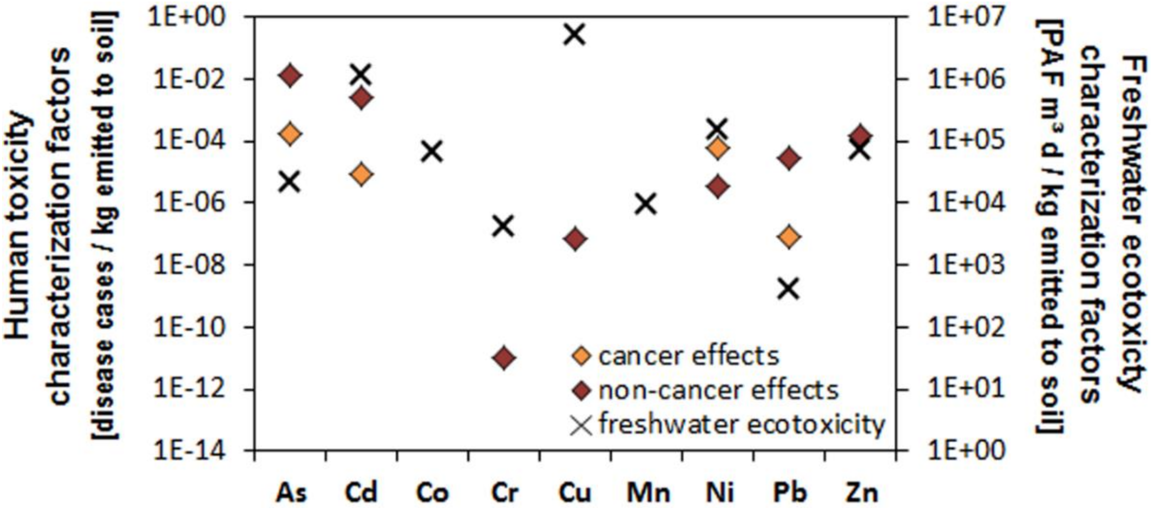


Figure 18: Distribution of potential human toxicity (left y-axis) and freshwater ecotoxicity (right y-axis) effects following an assumed emission of different heavy metals and metalloids of 1 kg per day to natural soil (Ngole and Fantke 2017).

Humans in the vicinity of mine tailings are at risk of developing cancer and non-cancer health complications associated with exposure to heavy metals via several ingestion- and dermal-related pathways and via inhalation. Significant exposure risk exists at the site where values for HQ and CHI for As, Cd, Co, Cr, Ni, and Mn in children and As and Cr for adults were > 1 (Fig 19). Cancer-related risks associated with metal and metalloid exposure among children are usually higher than in adults (values of 3×10^{-2} and 4×10^{-2} for As and Ni, respectively among children, and 5×10^{-3} and 4×10^{-3} for As and Ni respectively among adults). The accepted threshold for cancer related risk is 1 x 10^{-4}. The exposure-related risks are higher among children than adults, mainly via ingestion and dermal exposure (Ngole-Jeme and Fantke 2017). These results indicate that contaminated soils may pose a direct heavy metal exposure risk in mining areas.

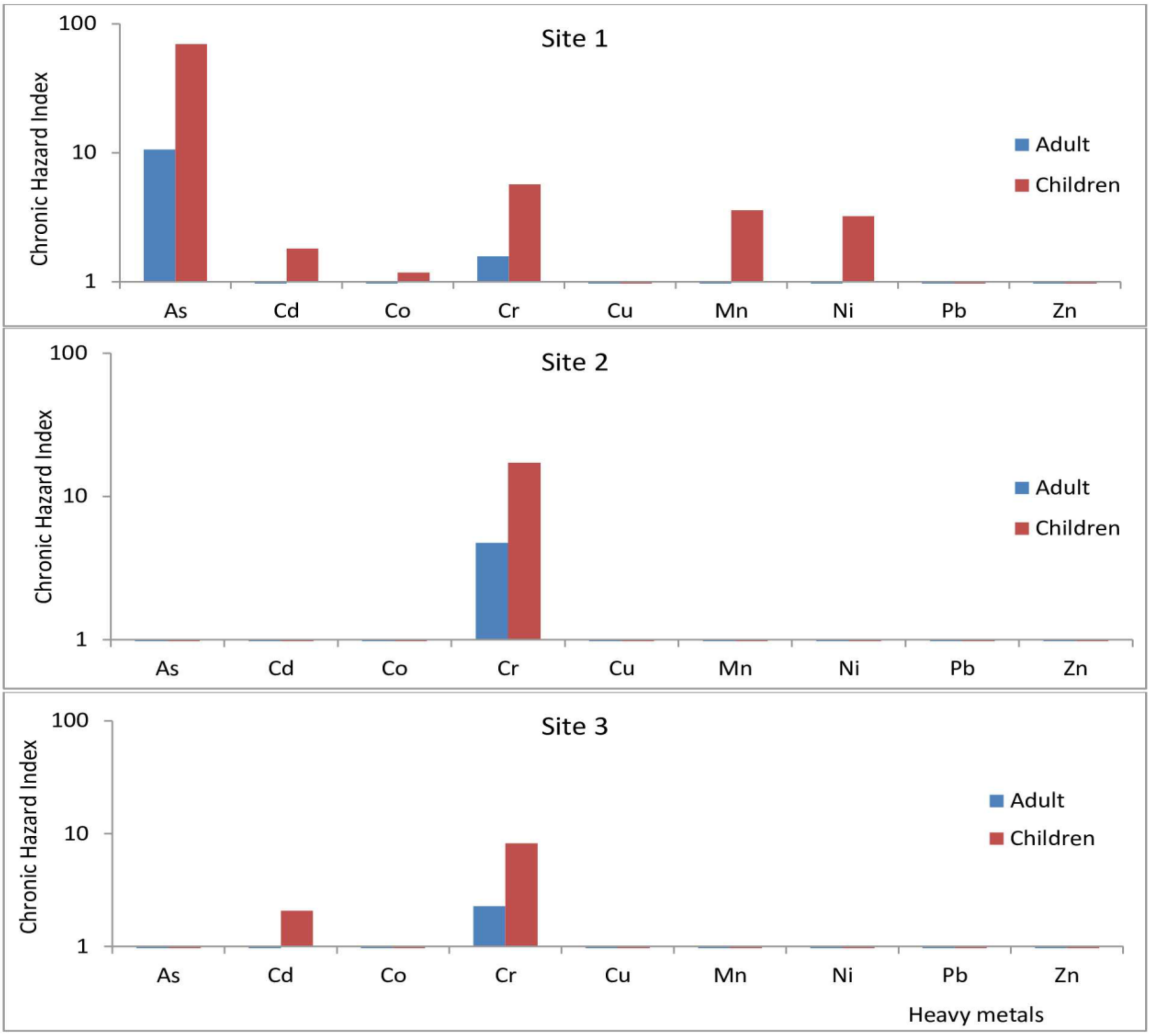


Figure 19: Chronic hazard index (CHI) for each metal and metalloid at the three study sites.

9 Ongoing research

My ongoing research focuses on the remediation of heavy metals contaminated soil. We are trying to identify heavy metal resistant bacteria which can be utilized as a microbial inoculant in the treatment of heavy metal contaminated environments. The heterogeneity of the soil environments presents a serious challenge for bioremediation because well adapted bacteria are required to bio remediate in specific environments. We have documented the diversity and roles of bacteria and archaea in bioremediation in Fashola, Ngole-Jeme and Babalola (2015) and the environmental effects and bacterial strategies for resistance in Fashola, Ngole-Jeme and Babalola (2016). So far, we have identified 12 strains with heavy metal resistance and are currently assessing their efficiency as possible inoculants in the treatment of heavy metal contaminated soil.

Another ongoing study is looking at the implications of temperature intensity and duration on the sorption properties of mine tailings contaminated soil and the implication of this on using organic amendments to remediate fire affected heavy metal polluted soil.

With regards to Geophagia, under the leadership of Prof Songca, we are looking at various aspects of Geophagia in Lesotho.

10 Future research

Future research interest will concentrate on the role of organo-mineral interactions in the behaviour of heavy metals in soils. Organic carbon inputs into soils are stabilized onto mineral surfaces through various organo-mineral bonding reactions depending on the composition of the organic inputs, soil mineralogy, and environmental factors. Focus will be on root exudates of different plants growing in heavy metal contaminated environments to understand how this could contribute to the amount of heavy metals assimilated by the plants from the soil and how these plants could be exploited as phytoremediators. I also intend to look at heavy metal uptake by plants grown in environments affected by both waste disposal and mining and to identify technologies that could be effective in attenuating heavy metals mobility in such environments

11 Conclusions:

Soils form a significant component of the biogeochemical cycles. Ecologically, they serve as a medium of plant growth, water purification, recycler of nutrients, a habitat for organisms, and an engineering medium supporting structures and as a modifier of the atmosphere. The function of soil at any given time and in any given environment is strongly influenced by its properties and characteristics as has been highlighted in its use for cosmetic purposes, as a medium that could retard contaminant migration in the environment (landfills) and a medium that could retard uptake of contaminants by food crops from the soil (agriculture). Soil properties could also contribute to the occurrence of landslide events and increase health complications by destroying dental enamel (geophagia) increasing the likelihood that an individual may suffer from heavy metal associated non-cancer related health complications (including kidney disease, lung damage, fragile bones, nervous disorder, gastrointestinal, nasal and lung irritation, ulceration of stomach and small intestines, dermatitis, and decreased sperm counts) and cancer in their lifetime. These studies have highlighted how soil properties could either positively or negatively affect any environmental sector. It also highlights the fact that no soil is useless because a soil that is unsuitable for one purpose because of its properties or characteristics will be important in another land-use.

Hence, Soil matters therefore determine the extent to which soil matters.

12 Acknowledgements

The Almighty

I Thank God for His Grace. I am where I am today because of Who He has been in my life. To Him be Honour, Glory and Praise.

My Supervisor

Prof O Totolo, Professor of soil science and Vice Chancellor BIUST, Botswana who was my MSc and PhD supervisor. Professor Totolo actually launched my academic career in 2003. Thank you Sir for the mentorship and guidance over the years.

My Line Managers

Prof Linington, The executive dean of CAES
Prof Nicolau, Director of the school of Ecological and Human sustainability
Prof W Nel, COD, Department of Environmental Sciences
UNISA has been a wonderful place to be because of your leadership.

Mentors

- Prof GE Ekosse, Professor of applied clay mineralogy, University of Venda, South Africa
- Prof SP Songca, Professor of organic chemistry, Deputy Vice Chancellor Research, University of Zulu Land, South Africa.

- Prof L de Jager: Professor environmental Health and Epidemiology, Former Dean of Environmental Science CUT
- Prof Sesai Mpuchane Professor of medical Microbiology

Thank you for smoothening all the rough edges in my research skills, writing skills, and ability to critique a manuscript

Collaborators

- Prof Elvis Fosso-Kankeu, North West University, South Africa
- Prof Ngole-sumbele, University of Buea, Cameroon
- Prof P Fantke, Department of Management Engineering, Technical University of Denmark
- Prof B Fonge, University of Buea, Cameroon
- Prof S Ayonghe, University of Buea, Cameroon

It has been a wonderful journey because of your unwavering commitment to our course

Colleagues

- Department Environmental Science, University of Botswana
- Department of Geography and Environmental sciences and Planning, University of Swaziland.
- Faculty of Science, Engineering and Technology at Walter Sisulu University, South Africa
- Department of Crop Science, North west University, South Africa
- College of Agriculture and Environmental sciences UNISA
- The entire staff of the Department of Environmental Sciences, UNISA. You are an amazing team,

Students

- Matike Emily
- Johanna Molepo
- Omotola Fashola
- Tresor Mbaya
- Nkateko Msimango

- Whitmore Masomera
- Babalwa Xalipi

You would have some of these names. You have been wonderful students.

Friends

Dr Lateefat Aderonke Archer

Dr and Mrs Ramachela

Prof and Prof Fombad

The Cameroonian community. I may not be able to list all names but your support over the years have kept me afloat.

Family

- Mr and Mrs Cathy Mbapeh, and Mr and Mrs Eric Njie. You have always been there for me
- My sisters Florence Ngole, Evelyn Ngole, Irene Ngole-Sumbele and Joshua Sumbele and Faith Ngole-Bate and John Bate. Your love, support and encouragement throughout this journey has been second to no other.
- My son, Emmanuel Etonde Ngole who has been my inspiration and source of strength. Thanks also for being my research photographer
- My Husband; Gustav Lyonga Jeme, you are the wind beneath my wings.
- My father Mr FN Ngole of Blessed memory and my mother Bertha B Ngole for all the sacrifices made to ensure that I completed my education. I will forever be grateful

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