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RESEARCH ARTICLE

Environmental implications of high metal content in soils of a titanium mining zone in Kenya

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Abstract Mining activities contribute to an increase of specific metal contaminants in soils. This may adversely affect plant life and consequently impact on animal and human health. The objective of this study was to obtain the background metal concentrations in soils around the titanium mining in Kwale County for monitoring its environmental impacts. Forty samples were obtained with half from topsoils and the other from subsoils. X-ray fluorescence spectrometry was used to determine the metal content of the soil samples. High concentrations of Ti, Mn, Fe, and Zr were observed where Ti concentrations ranged from 0.47 to 2.8 %; Mn 0.02 to 3.1 %; Fe 0.89 to 3.1 %; and Zr 0.05 to 0.85 %. Using ratios of elemental concentrations in topsoil to subsoil method and enrichment factors concept, the metals were observed to be of geogenic origin with no anthropogenic input. The high concentrations of Mn and Fe may increase their concentration levels in the surrounding agricultural lands through deposition, thereby causing contamination on the land and the cultivated food crops. The latter can cause adverse human health effects. In addition, titanium mining will produce tailings containing low-level titanium concentrations, which will require proper disposal to avoid increasing titanium concentrations in the soils of the region since it has been observed to be phytotoxic to plants at high concentrations. The results of this study will serve as reference while monitoring the environmental impact by the titanium mining activities.

Keywords Topsoil · Subsoil · Metal contaminants · Environmental impacts · Enrichment factors · Human health

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Introduction

Metals have unique properties that make them indispensable in our everyday life. Some of these properties include the following: strength, durability, and conductivity of heat and electricity (Chen 2012; Hudson et al. 1999). The properties make metals ideal for use in communications, infrastructure development, and in the built environment (Pokhrel and Dubey 2013; Van der Voet et al., 2013). Consequently, the demand for minerals and metals continues to increase due to population growth, rapid urbanization, new infrastructure growth in developing countries, widespread use of electronic gadgets worldwide (Greenfield and Graedel 2013), and transition to new energy technologies (Van der Voet et al. 2013). Globally, it is projected that the demand for minerals and metals will increase from 9,722 million tonnes in 2013 to11,238 by 2018, a compounded annual growth of 2.9 % (Market Line 2015). Over time, the metal and mineral reserves in the developed countries have declined, and this has caused huge investments in exploration and mining sectors in the developing countries mainly in Latin America, Africa, and parts of Asia (Market Line 2015). Kenya has benefited from this shift of international interest and has recently started titanium mining in Nguluku and Maumba areas which are located in the coastal region (Base Resources 2015). While the mining will improve the economy and increase employment in the

country, there are environmental impact concerns due to mining activity.

Though metals have contributed immensely to the development of infrastructure, economic growth and improvement of the general welfare of our present society, they have also contributed to the contamination of our environment (Allan 1997; Dudka and Adriano 1997; Salomons 1995; Van der Voet et al. 2013). Mining involves extraction of the ore and beneficiation processes which produce large quantities of waste that in most cases contain waste rock dumps and tailings (Salomons 1995) and other metals that are simply by-products of the process but not of interest (Dudka and Adriano 1997). Initially, the wastes are close to the plant, but in time they spread out to the surrounding environment and inevitably contaminate the air, water, and soils in the region (Pokhrel and Dubey 2013). In particular, the soil system is directly affected by deposition of metals whose concentrations are directly influenced by the scope of the mining activities.

Soil is an important natural resource that supports life for plants, animals, and human beings and should therefore be protected against all forms of contaminants. The capacity of the soil to perform this function involves, among others, having adequate quantities of macro and micronutrients. Many of the micronutrients are metals, and their main sources include the parent material (White and Zasoski 1991) and human activities (He et al. 2005; Loska et al. 2004; Senesi et al. 1999). Furthermore, metal levels in soils are governed by geological and physicochemical properties of the soils (Bini et al. 2011; Kabata-Pendis 2011), soil organisms, topography of the region, vegetation, time, and lithology (Sucharova et al. 2012). Due to these complex factors, the distribution of metals in soils varies widely (Kabata-Pendis 2011). Any metal increase in soils will elevate the amounts for plant uptake and consequently, through the food chain, expose human beings to harmful concentration levels resulting in possible adverse health effects. Globally, many studies are being done on environmental contamination with a significant portion being on soil metal contamination (Guo et al. 2014).

Many studies have reported high metal concentrations in soils and rivers near and far from mining areas. As expected, the metal contaminants in soils corresponded to the nature of the mine: As and Cu from a tin and tungsten mine (Ngoc et al. 2009); As, Cd, and Cu from copper mines (Bech et al. 1997; Pourret et al. 2015); As, Cd, Hg, Pb, and Sb from gold mines (Abdul-Wahab and Marikar 2012; Rafiei et al. 2010); Cr, Ni, and Co from chromite mines (Kien et al. 2010; Krishna et al. 2013); and Zn and Pb in lead-zinc mines (Jing et al. 2005; Monterroso et al. 2014; Oyarzun et al. 2011). Mine wastes have also been reported to be serious sources of soil and water contamination. In South Morocco, tailings were observed to contaminate streams (Khalil et al. 2008); in Spain high Zn and Pb were reported in native plant species in Cartagena-La Union (Conesa et al. 2006). The environmental effects of titanium mining depend on the methods used to obtain TiO_2 and pure titanium metal. The two main methods used are the sulphate and chloride processes (Zhang et al. 2011), and they produce acidic waste which causes environmental problems whether the waste is dumped on land or discharged into waterways (Lane 1991). The disposal of titanium tailings into the sea has been observed to cause changes and diversity in the fauna composition (Olsgard and Hasle 1993). Recently, the state of metal pollution from mines in China has been reviewed (Li et al. 2014), and studies on soils surrounding the mining areas are reported to be heavily polluted with heavy metals originating from the mines (Ma et al. 2015; Zhuang et al. 2009).

Metal concentration profiles in the soils vary both vertically and horizontally (Deschenes et al. 2013), and the information on vertical profile can be used to determine whether the source of the metals is from mainly the parent material or from anthropogenic sources. Anthropogenic sources normally deposit on the surface and hence accumulate in the topsoil while the concentrations of metals of geogenic origin will increase with depth (Borûvka et al. 2005). The concept of enrichment factor is used to estimate whether the metal concentrations in the soils are contributed by either of the two mechanisms (Blaser et al. 2000; Reimann and Caritat 2005). Enrichment at the surface is assumed to be due to human activities whereas at lower depths it is caused by translocation of the element within the soil profile. However, there is always the possibility of naturally occurring enrichment at the soil surface due to nutrient cycling (Bourennane et al. 2010; Steinnes and Njästad 1995).

Most studies on environmental effects of mining have been done after the operations have started or years after the mining plant is closed. Ideally, it may be more appropriate to determine the baseline levels of the metals before the mining activity commences and thereafter perform periodical audits to determine the environmental impacts. There is an assumption that the background levels of the area of interest have not been contaminated by with metal from other human activities. The objective of this study was to measure the metal concentrations in the soils before the commencement of the titanium mining, especially metal contaminants that would be produced by titanium mining. The results will be used in follow-up studies during the operations of the titanium mines.

Materials and methods

Study area

The study area is located in Kwale district, in the coastal region of Kenya, and lies between longitudes 38° 31′ and 39° 31E and latitudes 3° 30′ and 4° 45S. The region borders the Taita—Taveta County to the northwest, Kilifi County to the north, Mombasa County to the northeast, Indian Ocean to

the southeast, and Tanzania to the south (Fig. 1). This region is generally characterized by sediments of Triassic to Jurassic ages, igneous rocks of Cretaceous age, and the unconsolidated sediments of Tertiary to Quaternary ages (Horkel et al. 1984).

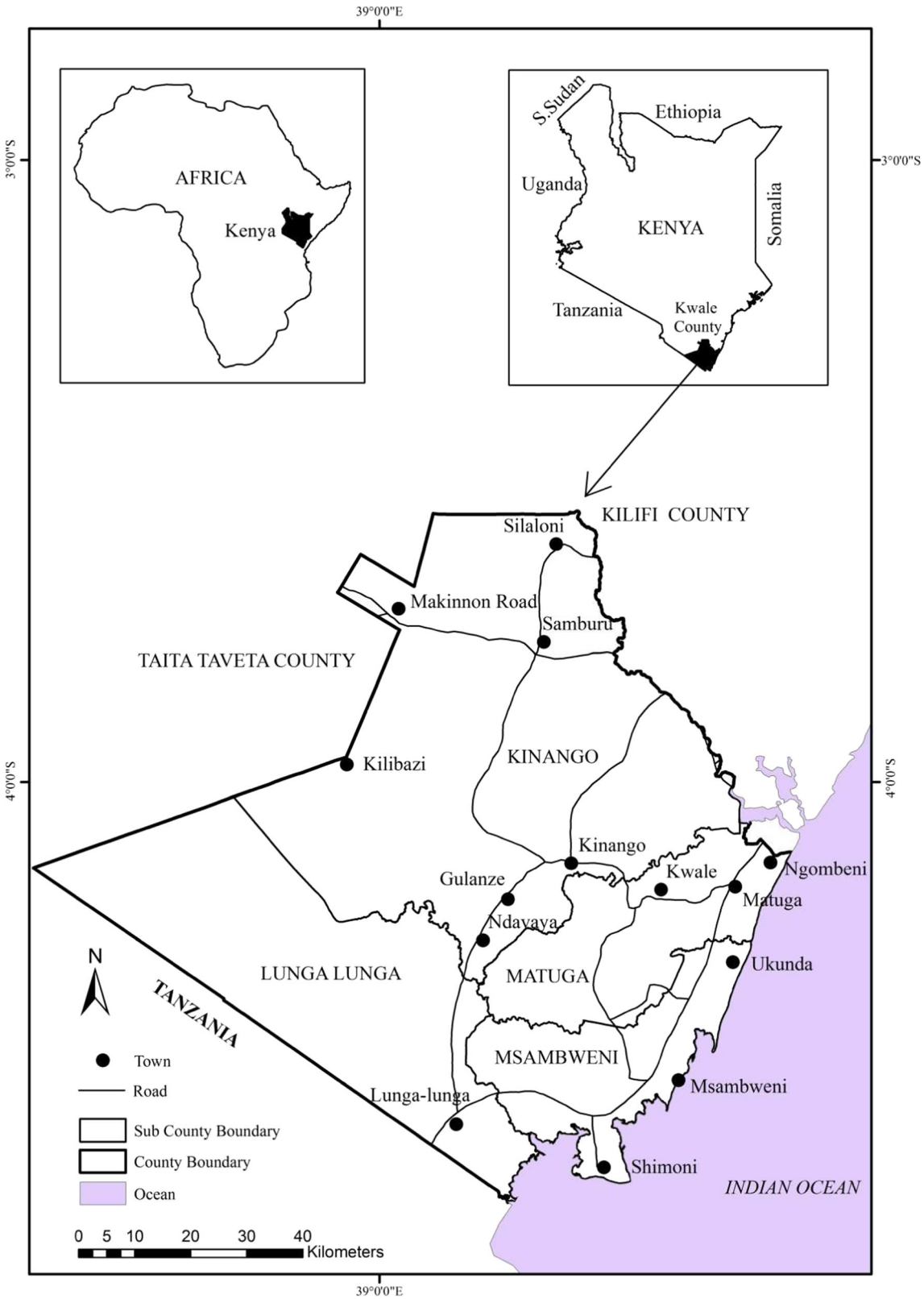

Fig. 1 Map showing the location of Kwale County

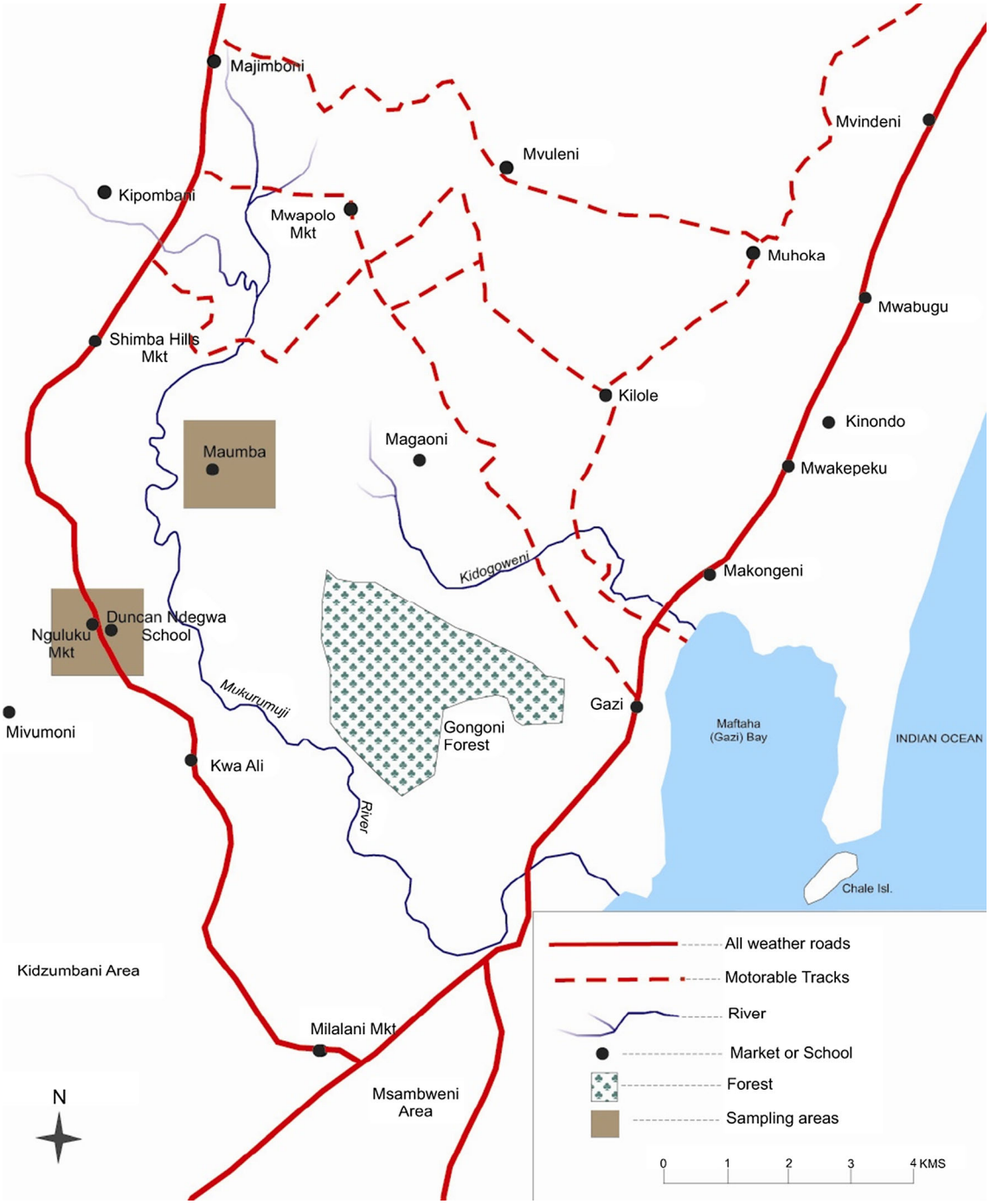

Fig. 2 Map showing the sampling site (Maumba) in Kwale County

Sampling

Soil samples were taken from two agricultural areas; Miembeni and Maumba Central, both sampling areas are in the larger Maumba region (Fig. 2). These are the areas where mining is scheduled to start. At each site, samples were collected from ten different locations, at two different depths; up to 30 cm (topsoil) and below 30 cm (subsoil). Samples weighing between 500 and 1000 g each were collected and were considered representative of soils in the respective region. The large mass of a sample was necessary for in addition to metal contaminant evaluation; radioactivity levels were also to be measured.

Enrichment factors

The enrichment factor is calculated (Reimann and Garrett 2005) as follows:

$$EF_{(El)\ \text{crust}} = \frac{[El]_{\text{sample}}}{[X]_{\text{sample}}} \Big/ \frac{[El]_{\text{crust}}}{[X]_{\text{crust}}}$$

where "*El*" is the element of interest; "*X*" is the chosen reference element; and the subscripts "sample" and "crust" indicate the medium that the concentration refers to. In case the values of the element of interest and the reference in the crust are not available, then the values from a deep soil horizon have been used (Bourennane et al. 2010; Hernandez et al. 2003; Sucharova et al. 2012). The reference element is selected based on the assumption that it does not have anthropogenic enrichment and is also hardly affected by weathering (Blaser et al. 2000), or its concentration in the earth's crust is so abundant that any anthropogenic addition hardly influences its concentration (Galuska and Migaszewski 2011). Elements that fall into first category are Sc, Ti, and Zr (Bourennane et al. 2010; Sucharova et al. 2012), and those that fall into the second category include Al, Mn, and Fe (Galuska and Migaszewski 2011; Loska et al. 2004).

Sample preparation

The samples were crushed using a pestle and a mortar to reduce the particle sizes and ensure homogeneity. This was followed by sieving through a 75 μm mesh to fine particles samples. The fine samples were then dried in an oven at 100° C for 48 h to constant weight. The coning and quartering procedure was repeated on the dried samples to obtain a 25 g representative aliquot of each sample which was then stored in a petri dish.

The 25 g aliquot was further ground in an agate mortar to reduce the particle sizes. Then, cellulose was added and the mixture was homogenized. Cellulose was added in order to reduce matrix effects in the analysis and improve pellet formation. Due to the sandy nature of mineralised soils, cellulose in the sample increased the cohesiveness of the soil particles that is needed in pelletizing. Small amounts of the homogenized mixture were pressed into pellets of 2.5 cm diameter using a hydraulic press at pressure of 2–3 kPa. Two pellets were made from each sample and the pellets were weighed before analysis. The mass of the pellets was used in the determination of elemental concentrations. Each sample was analysed three times giving a total of six analysis results from each soil type at each sample location.

Quality assurance

The accuracy of the analytical method was evaluated by analyzing an International Atomic Energy Agency reference sample; soil seven. The samples were prepared following the same procedure used for soil samples.

Sample analysis

X-ray fluorescence (XRF) analysis method was used to analyse the samples. The analysis instrumentation setup used consisted of a Canberra Si(Li) detector crystal model 2008 with 6 mm active diameter, 5 mm sensitive depth, and a beryllium window thickness of 0.025 mm. The spectrometer resolution was 180–190 eV at the Manganese K_α spectral line of 5.9 KeV at a time-shaping-constant of 10 μs. The detector bias voltage was −1500 V supplied by an Ortec model 456 high voltage supply. The electronics included a Canberra model 2026 signal-shaping amplifier with a pile-up rejector (PUR) and an interface analogue digital converter, Canberra model 8075 ADC. The ADC was connected to a personal computer facilitated with a multichannel analyzer (MCA) software, Canberra S-100, for spectral data acquisition, storage, and analysis.

The pellets of the prepared samples were irradiated for a period of 1500 s using a Cd-109 excitation source and the data deconvolution was carried out using the fundamental parameter method of the Analysis of X-rays using Iterative Least square (AXIL) software. AXIL is a key component of the International Atomic Energy Agency (IAEA) software, Quantitative X-Ray Analysis System (QXAS) that allows the analysis of the XRF spectra for the elements of interest.

Three measurements of each pellet were carried out as follows: the sample was analysed for 1500 s to acquire the spectrum of interest; the sample with multielement target on top of it for 500 s and finally the target alone for 500 s for the purpose of absorption correction. The multielement target was a thick pellet of pure cellulose mixed with titanium, manganese, zinc, bromine, and niobium compounds of high purity. The energies of characteristic x-rays of these elements covered the calibrated energy range of the multichannel analyzer.

Table 1 Certified and experimental mean metal concentration values in IAEA Soil 7 (mg kg^{-1})

Element	Certified values	Experimental values	95 % Confidence range
Ti (%)	0.30	0.28	0.26–0.37
Mn (μg g^{-1})	631	558	604–650
Fe (%)	2.57	2.28	2.52–2.65
Zr (μg g^{-1})	185	193	180–201
Nb (μg g^{-1})	12	17.3	7–17

Results and discussions

Quality assurance

The measured values of most of the elements of interest are within the certified limits (Table 1), but minor deviations are observed for manganese, iron, and niobium. However, using *t* test, the differences between the measured mean from the certified mean is not significant at 95 % confidence limit.

Metal concentration in the topsoil and subsoil

In both regions, the mean metal concentrations of Ti and Fe were higher than those of Mn and Zr by an order of magnitude (Table 2). While the mean metal concentrations of Ti and Fe in topsoil were similar in the two regions, those of Mn and Zr were higher in Miembeni region by 57 to 36 %, respectively. However, concentrations of the four metals were higher in the subsoil of Miembeni than in Maumba: Ti and Fe by 33 and 14 %, respectively, and Mn and Zr by 33 and 62 %, respectively. In both regions, the species' concentration distributions were positively skewed for Zr in Miembeni in both top and subsoils, and Nb in Maumba topsoil were negatively skewed. The relative standard deviations varied from 0.28 to 0.79 showing that the variability in the individual metal concentrations was high. In particular, the relative standard deviations for Zr (subsoil) in Miembeni region and Nb (topsoil) in Maumba region are 0.79 and 0.68, respectively. This is possibly due to the wide sampling area and possible differences in degree of weathering. According to Kabata-Pendis and Mukherjee (2007), the global concentrations of Ti, Mn, Fe, Zn, Zr, and Nb in soils are: Ti, 0.02 to 2.4 %; Mn, 10 to 9000 mg kg^{-1}; Fe, 0.5 to 10 %; Zn, 10 to 300 mg kg^{-1}; Zr, 30 to 850 mg $kg^{-1,}$ and Nb, < 4 to 44 mg kg^{-1}. Based on this data, the concentrations of Mn and Fe are in the lower end while the concentrations of Zr and Nb are on the higher end. Although the mean concentrations of titanium and iron were similar, overall, the concentrations follow the following trend: Fe > Ti > Zr > Mn > Nb.

Recently, Towett et al. (2015) have reported data on elemental content of Sub-Saharan Africa soils where they observed a wide variation in total element concentrations suggesting that this could be due to differences in the parent materials. The concentrations of Ti, Mn, and Fe varied as

Table 2 Summarized statistics of Ti, Mn, Fe, Zr, an Nb concentrations measured in topsoil and subsoil in Miembeni and Maumba Central regions

Miembeni					
Topsoil	Mean ± 1 SD	Median	Minimum	Maximum	RSD
Ti (%)	1.4 ± 0.7	1.3	0.6	2.8	0.50
Mn (%)	0.11 ± 0.06	0.09	0.06	0.25	0.55
Fe (%)	1.8 ± 0.73	1.9	0.89	3.0	0.41
Zr (%)	0.15 ± 0.08	0.13	0.06	0.33	0.53
Nb (μg g^{-1})	23 ± 12	17	14	52	0.52
Subsoil	Mean ± 1 SD	Median	Minimum	Maximum	RSD
Ti (%)	1.6 ± 0.69	1.5	0.47	2.8	0.43
Mn (%)	0.09 ± 0.04	0.09	0.02	0.17	0.44
Fe (%)	2.1 ± 0.71	2.1	1.2	3.1	0.34
Zr (%)	0.29 ± 0.23	0.19	0.12	0.85	0.79
Nb (μg g^{-1})	30 ± 15	27	14	57	0.50
Maumba Central					
Topsoil	Mean ± 1 SD	Median	Minimum	Maximum	RSD
Ti (%)	1.4 ± 0.53	1.2	0.55	2.5	0.38
Mn (%)	0.07 ± 0.04	0.06	0.04	0.15	0.57
Fe (%)	1.7 ± 0.53	1.6	0.97	2.9	0.31
Zr (%)	0.11 ± 0.04	0.11	0.05	0.18	0.36
Nb (μg g^{-1})	34 ± 23	27	17	93	0.68
Subsoil	Mean ± 1 SD	Median	Minimum	Maximum	RSD
Ti (%)	1.2 ± 0.49	1.0	0.71	2.2	0.41
Mn (%)	0.06 ± 0.03	0.05	0.03	0.10	0.50
Fe (%)	1.8 ± 0.50	1.6	1.4	2.7	0.28
Zr (%)	0.11 ± 0.04	0.10	0.07	0.18	0.36
Nb (μg g^{-1})	29 ± 15	28	14	64	0.52

RSD Relative standard deviation

follows: Ti, 2.6 μg g^{-1} to 2.56 %, Mn, 1.6 to 6575 μg g^{-1} and Fe, 20 μg g^{-1} to 2.08 %. A comparison with this study shows data that the Ti and Mn are in the same range but the Fe values are slightly higher.

Titanium mining will produce waste that contains high concentrations of Mn, Fe, Zr, and Nb, and this may spread to areas far off from the point source (Dudka and Adriano 1997; Pokhrel and Dubey 2013). The implications of the observed metal concentrations are their high enrichment beyond global concentrations once titanium mining operations start. In addition, the mining will also produce tailings, which contain low amounts of titanium, and the method used for disposal of this waste may increase the titanium levels in the surrounding environment thereby compounding the problem of soil contamination. A major concern is the metal content in mining dust, which will be mobilized into the lower troposphere and transported by the wind system. The dust will be deposited on soils and water bodies in widely spread distances from the mines and also becoming part of the regional atmospheric pollutants. Studies have shown that dispersal of waste through air can be a major pathway of contaminating the environment and affecting human health (Qu et al. 2012) besides mineral dust impact on climate change (Bian and Zender 2003). Both Ti and Zr are not known to play any role in plant and human, but there is evidence that they can be phytotoxic to plants at high concentrations (Kabata-Pendis and Mukherjee 2007). On the other hand, though Mn and Fe are essential metals, when their concentrations are high, they may become contaminants in the surrounding soils and consequently become a health issue (Chen 2012).

Transportation of the dust from the mining plant will increase the Fe and Mn concentrations in the surrounding agricultural lands, rivers, and streams. The concentrations may reach toxic levels, and consequently the contaminated soil and waters will be unable to support soil organisms (Šalamún et al. 2015), plants, algae, freshwater molluscs, and crustaceans (WHO 2004). A reduction of microorganisms lowers the soil fertility through the disruption of carbon and nitrogen biogeochemical cycles while plants will be contaminated by assimilating the metals from the soils and deposition of metals on the leaves (Bech et al. 1997; Dudka and Adriano 1997). As a result, the vegetation in the environment around the mining plant may be lost, and this may contribute to an increase in soil erosion exposing the area to further environment degradation and consequently poor food supply to animals and human beings.

Depth profile

The mean topsoil to subsoil ratios (Table 3) were observed to be similar for all elements, but Nb showed a wider spread by a factor of two in Maumba while Ti spread was highest in Miembeni. According to Facchinelli et al. (2001) a ratio greater than 2 implies influence of anthropogenic contribution. Bini et al. (2011) observed that ratios were useful only when chemical composition of the soil did not vary significantly with depth in the absence of contaminants migration within the soils. In this study the ratios were below 2 in both regions and therefore the evaluated elements were all geogenic contaminants.

Table 3 Topsoil to subsoil concentration ratios of measured elements in Miembeni and Maumba Central regions

Element	Miembeni region Concentration (mean ± 1 SD)	Maumba Central region
Ti (%)	1.0 ± 0.55	1.2 ± 0.40
Mn (%)	1.2 ± 0.47	1.2 ± 0.39
Fe (%)	0.9 ± 0.27	0.9 ± 0.26
Zr (%)	1.0 ± 0.50	1.0 ± 0.39
Nb (μg g^{-1})	0.8 ± 0.32	1.3 ± 0.76

Enrichment factors

Ti, Mn, Fe, and Zr elements were used in the calculation of enrichment factors since all qualified as reference elements (Galuska and Migaszewski 2011; Sucharova et al. 2012) during this study. The enrichment factors were tabulated (Table 4)

Table 4 Enrichment factors of the evaluated elements in samples from Miembeni and Maumba regions

	Miembeni	Maumba Central
	Reference element = Ti	
Element	Enrichment factors (mean ± 1 SD)	
Mn (%)	1.3 ± 0.51	1.2 ± 0.59
Fe (%)	1.0 ± 0.28	0.9 ± 0.22
Zr (%)	1.0 ± 0.42	0.9 ± 0.12
Nb μg g^{-1}	0.9 ± 0.36	1.4 ± 1.53
	Reference element = Zr	
Ti (%)	1.1 ± 0.30	1.1 ± 0.19
Mn (%)	1.3 ± 0.48	1.1 ± 0.36
Fe (%)	1.0 ± 0.25	0.8 ± 0.27
Nb μg g^{-1}	0.9 ± 0.42	1.2 ± 0.77
	Reference element = Mn	
Ti (%)	0.9 ± 0.50	1.0 ± 0.40
Fe (%)	0.8 ± 0.21	0.8 ± 0.29
Zr (%)	0.9 ± 0.37	1.0 ± 0.32
Nb μg g^{-1}	0.8 ± 0.31	1.2 ± 0.97
	Reference element = Fe	
Ti (%)	1.1 ± 0.42	1.2 ± 0.23
Mn (%)	1.3 ± 0.30	1.4 ± 0.45
Zr (%)	1.1 ± 0.31	1.3 ± 0.54
Nb μg g^{-1}	1.0 ± 0.37	1.4 ± 1.03

and all were similar under the for different reference elements; however, Nb variability remained high in Maumba soils. These observations implied a close relationship in the soils from the two regions and it is possible they originated from the same parent material. According to Hernandez et al. (2003), enrichment factors between 0.5 and 2 indicated the soils had no anthropogenic inputs therefore the soils from the studied region had not been influenced by anthropogenic activities. The observation was in agreement with the criteria of ratios' assessment, thus confirming geogenic origin.

Correlation analysis

Correlation of a data set helps to determine if there are any associations among the variables. Table 5 shows the correlation coefficient of the evaluated metals in all samples from every main soil sample. Correlation analysis for the Miembeni region showed strong correlations among all the elements in the topsoil, while in the subsoil, it was only strong between Ti, Fe, and Nb. Similar results were obtained in the Maumba region where strong correlations were observed between Ti, Mn, Fe, and Zr in the topsoils, but Nb did not correlate with any of the other elements. In the subsoils, strong correlations were observed between Ti, Fe, Zr, and Nb while Mn correlated poorly with the other metals. In both regions, Mn had poor correlations with the other metals. In general, correlations were observed to be stronger in the subsoil, an observation also reported by Candeias et al. (2014). According to White and Zasoski (1991), some elements associate in the parent material and may persist into the soils. The strong topsoil correlations may be due to the soils being from one region with possible same soils formation factors other than the odd case of Nb in Maumba topsoil where it could have been reduced by leaching effects. However, the subsoil seemed to have suffered interference in formation since Mn and Zr in Miembeni and Mn in Maumba exhibited no correlation to other elements. These results may be interpreted to mean that this group of elements were originally correlated in their original formation, but over time the Mn levels have been affected by soil formation processes.

Table 5 Correlation matrix of the elemental concentration in topsoil and subsoil in Miembeni and Maumba regions

Miembeni region					
Topsoil	Element				
	Ti	Mn	Fe	Zr	Nb
Ti	1.00	–	–	–	–
Mn	0.80	1.00	–	–	–
Fe	0.94	0.88	1.00	–	–
Zr	0.98	0.81	0.91	1.00	
Nb	0.91	0.72	0.76	0.93	1.00
Subsoil	Element				
	Ti	Mn	Fe	Zr	Nb
Ti	1.00	–	–	–	–
Mn	0.14	1.00	–	–	–
Fe	0.95	0.30	1.00	–	–
Zr	−0.49	−0.07	−0.47	1.00	–
Nb	0.71	0.32	0.75	−0.42	1.00
Maumba Central region					
Topsoil	Element				
	Ti	Mn	Fe	Zr	Nb
Ti	1.00	–	–	–	–
Mn	0.90	1.00	–	–	–
Fe	0.97	0.92	1.00	–	–
Zr	0.97	0.82	0.90	1.00	
Nb	0.02	0.24	0.16	−0.23	1.00
Subsoil	Element				
	Ti	Mn	Fe	Zr	Nb
Ti	1.00	–	–	–	–
Mn	0.30	1.00	–	–	–
Fe	0.91	0.28	1.00	–	–
Zr	0.85	0.01	0.95	1.00	–
Nb	0.69	−0.12	0.65	0.64	1.00

Conclusion

The soils contain high concentrations of Ti, Mn, Fe, and Zr. The soils do not have any anthropogenic contributions of these metals, and currently their contributions are mainly from geogenic origin. However, mining of titanium may increase the concentrations in the top soils of the neighbouring agricultural lands through environmental deposition. Since it was possible to carry out this study before commencement of the titanium mining, a follow-up study is necessary during the titanium mining to audit the environmental impacts.

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