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Heavy Metal Concentrations in Soil and Green Vegetables (*Vigna unguiculata*) around Volcanic Mountain of Oldoinyo Lengai, Arusha, Tanzania

Khamis O. Amour[1*] and Najat K. Mohammed[2]

[1]Department of Physics, The State University of Zanzibar, P.O.Box 146, Zanzibar, Tanzania.
[2]Department of Physics, University of Dar es Salaam, P.O.Box 35063, Dar es Salaam, Tanzania.

Authors' contributions

This work was carried out in collaboration between both authors. Author KOA designed the study and performed the analysis including the statistical analysis of the study. Author NKM supervised the analysis of the samples and wrote the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The aim of this work was to assess heavy metal concentrations of samples collected from areas around a volcanic mountain in Tanzania. Fifty five soil samples and 10 samples of bean leaves were analysed using Energy Dispersive X- ray Fluorescence spectrometry (EDXRF). The concentrations of heavy metals in the samples are presented, statistical analysed and compared with control. The concentration in bean leaves are also compared with the maximum tolerable limits set by FAO/WHO to assess their safety for consumption. The results from this study show that high concentration of elements in both soils and bean leaves samples from Oldoinyo Lengai areas might be associated with frequently eruptions of the volcanic mountain of Oldoinyo Lengai. Hence, farming in Oldoinyo Lengai areas is introducing heavy metals in the food chain.

Keywords: Heavy metal; volcanic mountain; Oldoinyo Lengai; EDXRF; soil; bean leaves.

**Corresponding author: E-mail: Khamisamour97@yahoo.com, khamis.amour@suza.ac.tz;*

1. INTRODUCTION

The accumulation of heavy metals in soils is of increasing concern due to food safety threat and potential health risks as well as detrimental effects on soil ecosystems [1]. A number of studies have been carried out in various volcanic mountains in the world to analyze the levels of heavy metals in soil associated with volcanic eruption [2-4]. All of these studies have reported that, high concentration of heavy metals exists in the soils located close to the volcanic mountains. In Tanzania, Oldoinyo Lengai is the only active volcanic mountain. This mountain is situated at Ngorongoro District in Arusha Region North of Tanzania. Records have shown that in 1917, the mountain had an eruption which resulted in volcanic ash being deposited as far as about 48 km from the mountain. The mountain had small scale eruption in 1960's and then it was dormant until 1983 when ash and lavas were erupted from north crater of the mountain [5].

In 2007, the Oldoinyo Lengai had another major volcanic eruption, which was characterized by mixed ashes, dust and lava [6]. One of the villages which were severely affected by the volcanic eruption which took place in 2007 was Engare sero village. The eruption sent the plume of ash and steam up to 18 km down wind and cover north and west flank in fresh lava flow. The prevailing wind in the North -West direction was the main pathway of sending the volcanic ash from Mt. Oldoinyo Lengai to the surrounding villages including Engare sero.

The present study has assessed the concentration of heavy metal in soil and green vegetables (*Vigna unguiculata*) around mountain of Oldoinyo Lengai associated with volcanic eruption of the mountain.

2. MATERIALS AND METHODS

2.1 Study Area 1

The volcanic mountain of Oldoinyo Lengai is located between 02°30' and 02°45' southern latitude and 35°45' and 36°00' Eastern longitude. It is on the floor of the Great East African Rift Valley, approximately 16 km south of Lake Natron (Fig. 1).

Agriculture (mainly vegetable farming), pastoralism and tour guiding are the main activities of the people living in villages around the mountain. The main source of water for both cultivation and pastoralism is from Engare Sero River. This river receives its water from Engare sero water falls which is a few kilometres nearby the Oldoinyo Lengai Mountain. The local farmers make their own streams and drainage system along the river side to their vegetable farms. The cultivation of vegetables is without the use of any fertilizer.

2.2 Soil Sampling

Thirty five soil samples were collected from open areas in fields around Mt. Oldoinyo Lengai. Another 20 soil samples were collected from the vegetable farms situated at the centre of Engare sero village (14 km from the mountain) in which mixed fruit plants and vegetables are grown. Ten samples, which were used as control, were collected from Dar es Salaam Region. In each sampling point, 0.25 kg soil samples were taken at a depth of (0-5) cm.

2.3 Vegetable Sampling

Ten bean leave (*Vigna unguiculata*) samples were collected from the farmlands of Engare sero village. They were then put into labelled plastic bags and transported to the Physics Laboratory in the University of Dar es salaam for further preparation.

2.4 Sample Preparation

In the laboratory, at room temperature, the soil samples were first air dried for 72 hours and then were oven dried for 24 hours at 40°C to obtain constant weight. The dried soil samples were then ground using electric grinder and sieved through 0.4 mm polystyrene sieve and kept in well labelled plastic bags ready for further analysis. The bean leaves samples (*Vigna unguiculata*) were washed by distilled water and subsequently rinsed to eliminate all contaminants including air-borne pollutants. All washed bean leave samples were chopped into small pieces and then dried using electric oven at the temperature range between (40-50)°C for 24 hours. The dried samples of vegetables were then ground using electric grinder in order to obtain fine powder. The obtained powder were sieved through 0.4 mm polystyrene sieve and kept in well labelled plastic bags ready for measurements.

At Tanzania Atomic Energy Commission (TAEC) laboratory, the soil and bean leave samples were weighed by using a digital balance to obtain 12.0 g and 6 g samples, respectively. The samples were then mixed with cellulose binder in the ratio of 4:0.9 for proper binding. In order to get the exact weight of the mixtures, the binder weights were 2.7 g for soil sample and 1.35 g for bean leaves sample to make the analytes of approximately 14.7 g and 7.5 g respectively. The mixed powders were then put into a pulverizer for mixing and homogenising purposes. By using manual hydraulic press machine, the pellets of soil and bean leaves samples were made through application of pressure of 15 tonnes and 10 tonnes, respectively. Pellets of intermediate thickness with outer diameter of 32 mm were produced. The pellets were finally kept into the labelled sample holders and then placed in the EDXRF machine for analysis. Quality control was carried out using Montana II for soil and Tomato leaves for vegetable samples both from National Institute of Standards and Technology (NIST).

Table 1 and Table 2 show that the analyzed elements were within the range of standard reference materials.

Table 1. The comparison between the experimental values (mgkg^{-1}) of (SRM 2711 a Montana II soil) with reference values

Elements	Experimental values	Reference values
Mg	8780	10700
Al	67528	67200
K	23056	25300
Ca	26056	24200
Cr	55	52.30
Mn	607	675
Fe	29043	28200
Cu	4.17	4.70
Zn	412	414
Rb	118	120
Sr	231	242
Cd	59.60	54.10
Pb	1439	1400

3. RESULTS AND DISCUSSION

3.1 Elemental Concentrations in Soil

The statistical presentation of the data from soil samples are shown in Table 3. Elements that are normally distributed are reported using arithmetic mean (±SEM) whereas elements that follow non normal distribution are reported using geometric mean (×/÷SD).

Table 2. The comparison between the experimental values (mgkg^{-1}) of (SRM 1573a tomato leaves) and reference values

Elements	Experimental values	Reference values
Mg	11550	12000
Al	549	598
K	25086	27000
Ca	49351	50500
Cr	1.44	1.99
Mn	275	246
Fe	309	368
Cu	4.17	4.7
Zn	28	30.9
Rb	16.60	14.89
Sr	77	85

The t-test from SPSS Version 20 was used to statistically compare the mean concentrations of elements in mountain soil and farm soil. The t-test showed that the farm soil had significantly ($p \leq 0.05$) higher concentration of Mg, Al, K, and Cu than the mountain soil. The mountain soil had significantly ($p \leq 0.05$) higher concentration of Ca, Zn, Pb, Cd and Th than the farm soil. The concentrations of Cr and Mn were higher in mountain soil than in farm soil and Fe was higher in farm soil than in mountain soil although the difference were not statistical significance. Although the differences between the majorities of the elements in the two types of soil samples were statistical significance, their variation was minor. The biggest difference was found in Zn in which the mean value in soil samples from the mountain was 1.5 times higher than the value in the farm soil.

The t - test was also used to statistically compare the mean concentrations of elements in volcanic soils with their concentrations in control soil samples. Both mountain and farm soils have significantly ($p \leq 0.05$) higher concentrations of Mg, K, Ca, Cr, Mn, Fe, Cu, Zn, Pb and Th than the control soil samples. Zn had the highest difference of about 12 times higher levels in mountain soil than in control. Cu was in concentration of about 5 times higher in both soil types than in control samples. The mean concentrations of Mg, Ca and Mn were 2.3, 3.9 and 4.8 times higher in mountain soil than in control soil. Fe, Cu and Zn were also higher in mean concentrations in mountain soil than in control soil by 2.2, 4.7 and 11.8 times, whereas the concentrations of Pb and Th were 1.9 and 4.4 times, respectively higher in mountain soil than their concentrations in control soil.

Table 3. The average and range concentrations (mgkg^{-1}) in soils samples, arithmetic means (A. mean ± SEM) and geometric means (G. mean ×/÷ SD)

Elements	Mountain soil (N= 35)	Farm soil (N= 20)	Control soil (N= 10)
Mg	4129±465(2675–19647)	5750±136 (4668–6835)	1745±271(940–3224)
Al	20733×/÷1861(13783–24437)	26897×/÷7433(6886–33675)	45106±271(21822–59854)
K	19085±3780(12451–147498)	19627±159(1844–21281)	15287±432(1327.8–16785)
Ca	122141±831(109208–136371)	113480±2316(9072–126149)	31293±1543(6275–127325)
Cr	57.45×/÷11.02(38.17–97.1)	57.08×/÷5.83(51.26–76.55)	53.11±2.33(46.03–70.09)
Mn	3865.43×/÷1292.16(2468–79951)	3134×/÷764(2070–4219)	797.47±9.99(407.9–2602.9)
Fe	66233±304(61635–71569)	66454±492(6024–68721)	29907±7738(1139–66487)
Cu	61.16±0.67(52.48–72.43)	70.71±1.78(54.48–83.12)	12.83±1.17(4.26–63.79)
Zn	888.57×/÷86.98(310.20–1138.44)	629.89×/÷ 5.72(325.69–933.21)	50.15±3.6(22.42–55.01)
Cd	11.08±0.48(4.28–16.24)	9.93±0.68(3.78–16.19)	20.49±2.27(9.55–34.09)
Pb	49.63± 0.44(43.77–54.23)	45.65±1.90(22.9–56.37)	25.49±4.10(17.01–52.09)
Th	46.69×/÷5.89(22–52.40)	43.75×/÷5.74(31.20–50.80)	10.44±0.48(7.93–13.33)

Several studies [3,4,7,8] reported elevated concentrations of Mn, Cu, Fe, Zn, Cr, and Pb in volcanic soils of Italy, Portugal, Turkey and Malaysia, respectively. Hence, higher concentration of heavy metals in the soils analysed in this study may also be associated with the eruption of Mt. Oldoinyo Lengai. Table 4 compares the average concentrations of elements determined in Oldoinyo Lengai soil samples with the concentration in volcanic soil reported elsewhere. Mn, Fe, Zn and Cd are higher in sample from this study than in all the literature reviewed in this work.

3.2 Elemental Concentrations in Bean Leaves

The concentrations of elements found in samples of bean leaves (*Vigna unguiculata*) are reported in Table 5. All elements, except Cd, which were found in soil samples were also found in the vegetable samples. Cd in vegetable samples was found below the MDL (2.4 $mgkg^{-1}$) of the system used in this study.

The mean concentration of elements in bean leaves (*Vigna unguiculata)* grown at Engare sero village were compared with the Maximum Tolerable Limits (MTLs) set by WHO and FAO. Fig. 2 shows the comparison between the concentrations of *Vigna unguiculata* grown at Engare sero with those of MTLs.

In comparisons with studies conducted in green vegetable grown in contaminated areas of Tanzania, the concentrations of toxic element Pb in Engare sero bean leaves was 1.6 times higher than the concentration of Pb in green vegetables grown along the sites of Sinza and Msimbazi Dar es salaam [9]. However, [10] reported the mean concentration of Pb as 7.97 $mgkg^{-1}$ in green vegetable from Dar es Salaam, which is 1.3 times higher than that found in this study. The mean concentration of Pb reported by [11] was 0.90 $mgkg^{-1}$ in the *amaranth* grown in Zanzibar. This value is much lower than the mean concentration of Pb in Engare sero bean leaves.

Lead (Pb) is non- essential element as it is toxic even in trace amount [12]. The presence of high concentrations of lead in food and vegetables has been reported to cause a number of diseases, including cardiovascular and renal failure [13]. In this study, mean concentration of Pb in bean leaves was 6.36 $mgkg^{-1}$, which is 21 times higher than the maximum permissible limit of 0.3 $mgkg^{-1}$ set by [14].

The mean concentration of Cu found in bean leaves grown in Engare sero farm was 23.94 $mgkg^{-1}$. This value is significantly higher than its value reported in all studies reviewed in this work. Mohammed and Khamis [11] and Behemuka and Mubofu [9], reported 10.10 and 7.95 $mgkg^{-1}$, respectively in green vegetables which are 2.3 and 3 times lower than the concentration obtained in Engare sero farm.

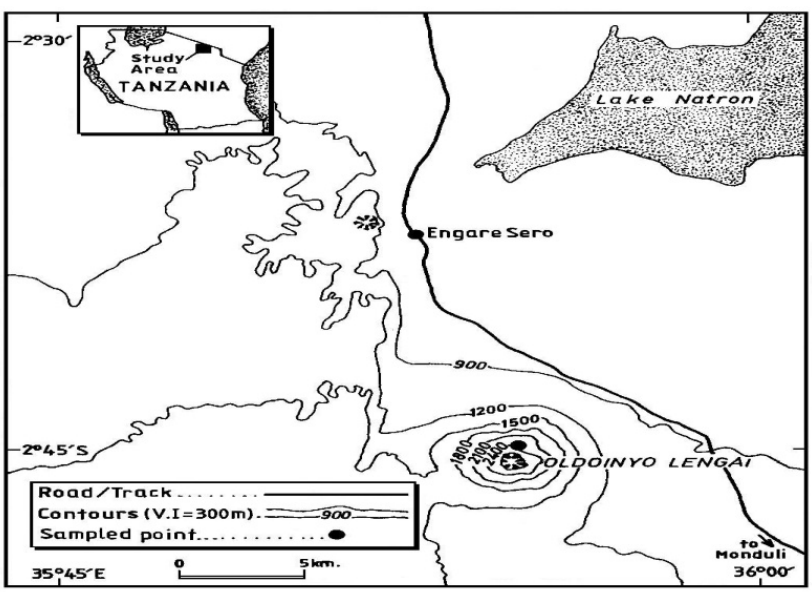

Fig. 1. Oldoinyo Lengai areas showing sampling points

Table 4. Comparison of the mean concentrations of heavy metals (mgkg^{-1}) in Oldoinyo Lengai soil with other values from elsewhere

	Cu	Mn	Pb	Fe	Zn	Cr	Cd	Ref
Mountain soil of Oldoinyo Lengai	61.16	3865.43	49.63	66233	888.57	44	11.08	
Farm soil of Oldoinyo Lengai	70.71	3134	45.65	66454	629.89	44	9.93	
	44.50	1075	25	-	252	48	0.23	[17]
	49	1066	31	39.60	93	106	-	Adamo, et al. 2003. [18]
	20	171	80	-	12	-	5.90	Türkdoğan, et al. 2002. [2]
	58	-	BDL	-	162	300	0.19	Amir, et al. 2014. [19]
	31.38	285.48	25.95	9929	52.88	12.28	0.25	WHO, 2001 [14]
	25	-	17	-	198	ND	ND	Amaral, et al. 2006a. [7]
	68	-	8	-	124	121	-	Baba, et al. 2008. [3]
	12.98	174.09	36	3.96	56.72	-	0.84	Amir, et al. 2014. [19]

ND = Not Detected; BDL = Below Detection Limit

Table 5. Average and range concentrations of elements analyzed in bean leaves samples from Engare sero village

Element	Concentrations (mgkg^{-1})	Element	Concentrations (mgkg^{-1})
Mg	6247.99±184(5335-7975)	Fe	4856±46.22(3634–7967)
Al	476.72±65.25(192-962)	Cu	23.94±1.50(17.99–32.83)
K	28941±592(26173-31736)	Zn	44.65±1.51(38.34–56.38)
Ca	32217±559(29884-35943)	Cd	BDL
Cr	4.8±1.12(0.76–13.73)	Pb	6.36±0.48(4.70–8.60)
Mn	275.89±10.19(231.98–334.91)	Th	5.66±0.11(3.50–6.23)

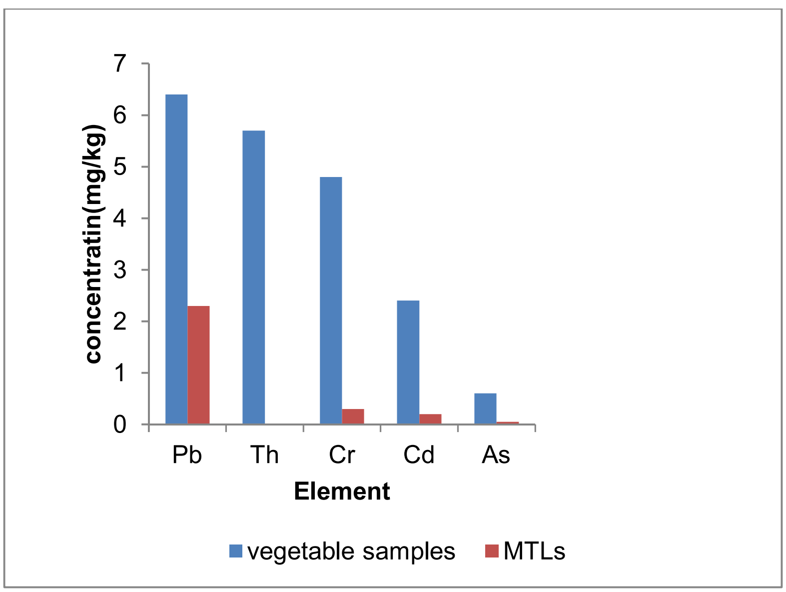

Fig. 2. Comparison between elemental concentrations in vegetable samples grown at Engare sero with the MTLs

Cr in samples of bean leave grown at Engare sero was found to be 4.8 mgkg^{-1}. The mean concentration of Cr reported by Mohammed and Khamis [11] was 2.55 mgkg^{-1}, which is 1.9 times lower than the value obtained in this work. However, Kihampa et al. [10] reported higher concentration of Cr (71.93 $mgkg^{-1}$) in green vegetables grown in contaminated areas in Dar es Salaam, which is 14.9 times higher than that obtained in samples from Engare sero. The mean concentration of Cr (4.80 $mgkg^{-1}$) in this study was found to be higher than the FAO/WHO permissible limit (2.3 $mgkg^{-1}$) for Cr in vegetables [15].

Thorium (Th) is toxic and radioactive element. Th in a body has been reported to accumulate in the nervous system and bones leading to cancer and mutation [16]. The average concentration of Th determined in this study was 5.66 $mgkg^{-1}$. However the permissible limit set by WHO in vegetables is 0.005 $mgkg^{-1}$, which is 113 times lower than the Th value obtained in this study [15].

4. CONCLUSION

This study determined the concentrations of essential and toxic elements in soils and bean leaves (*Vigna unguiculata*) grown in Oldoinyo Lengai volcanic areas using EDXRF spectrometry. The concentration of Mg, K, Ca, Cr, Mn, Fe, Cu, Zn, Pb and Th in both mountain and farm soils were found to be significantly ($p<0.05$) higher than their concentrations in control soil samples. The mean concentrations of heavy metals Al, K, Ca, Cr, Mn, Fe, Zn, Pb and Th in bean leaves were found to be above the permissible limits set by FAO/WHO. The concentrations of toxic element Cd in bean leaves samples were detected below the BDL of 2.4 $mgkg^{-1}$. However, this value is 12 times higher than the WHO permissible limits of 0.2 $mgkg^{-1}$. The results from this study show that farming at areas close to the Oldoinyo Lengai Mountain is introducing high levels of heavy metals in the food chain.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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