Assessment of the In-situ Concentrations of Some Heavy Metals in Surface Soil Dusts at the Katima Mulilo Urban Waste Dumpsite, Namibia

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ABSTRACT

The growing dominance of urban environment with heavy metals through natural and anthropogenic depositions and the potentially adverse health implications following environmental contaminations have focused attention on the disposal of urban and industrial wastes. This study employed analytical procedures to investigate the in-situ concentrations of lead, chromium, cadmium, arsenic, cobalt, nickel, selenium, copper, zinc, manganese, vanadium and uranium in the surface soil dusts at the Katima Mulilo urban waste dumpsite. Replicate surface soil dusts samples were randomly collected from twelve different points within the waste dumpsite, properly homogenized and three sub-samples were digested by EPA method 3050B. Then, the digestates were analyzed for the levels of the heavy metals using Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP: Perkin Elmer Optima 7000 DV). The results obtained varied widely with manganese recording the highest mean concentration of 73.23 mg/kg while selenium recorded the lowest level (0.27 mg/kg). The present concentrations of the heavy metals were generally lower than their respective guideline values for the protection of human and environmental health. Based on established guidelines for the contamination categories of heavy metals, the pollution indexes of the heavy metals generally revealed low contamination of the surface soil dusts but this does not preclude consideration for future effects due to accumulation and non-biodradability of heavy metals in environment. The results of soil enrichment factors however revealed significant to high enrichment (19.23 – 20.25) of the surface soil dusts by the heavy metals. These suggest that some of the waste materials disposed at the dumpsite may be rich sources of the heavy metals which upon decomposition released the elements onto the receiving surface soil. Therefore, we recommend that further research be carried out on the heavy metals concentration of the waste materials to identify those that are potential sources of soil contamination and suggest appropriate treatment and disposal methods. Furthermore, the urban wastes management department must provide machinery for wastes segregation prior to disposal and incineration.

Key words: Environmental contamination, heavy metals, wastes dumpsite, Katima Mulilo,

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1. INTRODUCTION

Municipal solid wastes normally termed as "garbage" or "trash" is an inevitable by-product of human urban settlements. The challenges posed by population explosion and urbanization have in most cases, increased the quantities and types of solid wastes produced, especially where the capacites for proper waste management and disposal are inadequate. Solid waste disposals (open dumps, landfills, sanitary landfills or incinerators) represent a significant source of metals released into the environment [1-5]. Depending on a city's level of wastes management, municipal wastes may be dumped in an uncontrolled manner, segregated for recycling purposes, or simply burnt. These practices pose great challenges to the well-being of city residents, particularly people living adjacent the dumpsites due to the potential of the wastes to release toxic pollutants e.g heavy metals that could threaten water supplies, food sources, land, air and vegetation.

Soil contamination by heavy metals from waste disposal sites is a serious problem in industrial and urban areas [6]. It has been reported that the concentrations of heavy metals in soil around waste dumps are influenced by the types of wastes, topography, run-off and level of scavenging [7].The global burden of diseases over the last few decades has generated attentions over the public health impacts attributed to environmental pollution resulting from improper wastes management and disposal. The World Health Organization (WHO) has reported that about a quarter of the diseases facing mankind today occur due to prolonged exposure to environmental pollution. More worrisome; most of these environment-related diseases are not easily detected and may be acquired during childhood, which manifest later in adulthood life stage.

Toxic metal elements such as lead, mercury, cadmium, arsenic, chromium, nickel and copper are important components of several household products that end up in waste dump. The disposal of materials contaminated with heavy metals, such as occurs with garbage dumps can create patchy point of contamination, which are of concern and pose dangers to people having contact with the contaminated soils [7]. This is particularly of great concern in the case of Katima Mulilo Urban wastes dumpsite where the unemployed citizens engaged in the practice of wastes scavenging for econmic purposes. Exposure to heavy metals is normally chronic (exposure over a longer period of time) since they are taken into the body through inhalation, ingestion and dermal contact. The International Occupational Safety and Health Information Centre (IOSHIC)'s report indicated that long-term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis. Allergies are not uncommon and repeated long-term contact with some metals or their compounds may even cause cancer [8]. It was also noted that most human load of toxic metals is acquired from the ambient concentrations of these metals through inhalation of dust and fumes, ingestion of food and drink and/or absorption through skin in extreme cases [9, 10]. If heavy metals enter and accumulate in body tissue faster than the body's detoxification pathways can dispose of them, a gradual build-up will occur.

Due to the heterogeneity and complexities of the wastes at dumpsite, a variety of contaminants might affect the immediate and long-term use of the open dumpsite soil for other purposes [11], especially in a city such as Katima Mulilo undergoing rapid infrastructural development. For example, where the peripheral soil is intended for use in road construction and foundation to structures; there could be high organic matter content which has the tendency to decompose and develop voids, thus affecting the use of the soil for construction purposes [12]. The same loss of utility value would affect any surrounding soil that is comparatively contaminated by its proximity to waste dumpsite since the adverse impact in the surrounding soil may capture, to a lower or the same level, the effect at the dumpsite depending on the spreading distance from the dumpsite or any point of pollution [13].

Baseline data for the occurrence of heavy metals as contaminants are critical component of the criteria for assessment of key pollutants in soils, especially where human activities are evident. Such data are particularly, important to Namibia's Vision 2030 focal area of population and environmental health. Thus, this study provides the baseline data of in-situ soil heavy metals concentration at the Katima Mulilo urban waste dumpsite.

2. MATERIALS AND METHOD

2.1 Study area

The study focused on Katima Mulilo urban waste dumpsite. It is located on latitude 17^{o}50′S and longitude 24^{o}25′E based on the Global Positioning System (GPS) geographical information recorded at the site on 28 May 2015. The dumpsite has an estimated longest land dimension of 346.78m and widest land dimension, 296.64m. According to Namibia 2011 population and housing census preliminary result, Katima Mulilo urban has a population of 28,200 and a total land area of 32 Sq.Km [14]. The city has witnessed tremendous population growth and urbanization in recent times and these have contributed to enormous amounts of solid wastes generated by the populace. In Katima Mulilo urban, solid wastes collection and disposal are handled by the Town Council's department of environment. However, the town council has no capacity for waste treatment and hence, proper management and disposal of the solid wastes remains a big challenge in the city. Solid wastes disposal in Katima Mulilo is based on the open dumping and incineration at the dumpsite and these practices have the potential to release toxic metal elements into the environment. Most worrisome, the unemployment problem has forced some city residents into waste scavenging at the dumpsite (Figure 1); some of whom are vulnerable children whose frequent contacts with contaminant-bearing soil such as the dumpsite soil put them at risk of chronic exposure to toxic metal elements. This portends great challenge to Namibia's Vision 2030 focal area of population and environmental health which must be tackled through relevant research such as the in-situ determination of the soil levels of heavy metals contamination at the waste dumpsite and suggests useful mitigation strategies.

2.2 Sample collection and pretreatment

Six replicate surface dusts samples were collected on bi-weekly basis between August-October, 2014 during dry season period in Katima Mulilo. On each sampling day, surface dusts were randomly collected from twelve points 20m apart within the dumpsite area and pooled together. Surface dust samples were swept with plastic brush into plastic waste packer and transferred into pre-labelled polyethene bags. Samples were collect during the still morning weather, often between 6:00 and 8:00 in the area, to allow dust emitted into the atmosphere during the day to settle. The soil dusts samples consisted of a variety of dust particle sizes ranging from large grit to aerosol particles. All unwanted materials like pieces of papers, broken bottles, cigarette ends, dry leaves, pebbles, textile materials etc were first carefully hand-picked and then, samples collected at each point were thoroughly mixed to ensure homogeneity and filtered through 75 μm stainless steel sieve. This sieve fraction was selected because it has been reported that dust particles ranging from 75-125 μm contain high levels of heavy metals and are known to be the very harmful to humans if inhaled [15, 16]. Four sub-samples were taken from the large sieved samples and transferred into clean, pre-labelled polyethylene bags and then conveyed to Analytical Laboratory Services, Windhoek Namibia, for further processing and analyses. All materials used for holding samples, homogenization and sieving were pre-cleaned to minimize the potential of cross contamination.

Fig 1: Scavanging activities at the Katima Mulilo Urban wastes dumpsite

2.3 Sample Digestion

The dust samples were digested according to the reported EPA method 3050B for Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-OES) analysis [17]. A known amount (1.00g) of each sieved dusts was transferred into a digestion vessel and 10mL of 1:1 nitric acid (HNO3) was added, mixed thoroughly and covered with a watch glass. Then, the samples were heated to 90^{o}C and refluxed at this temperature for 10 minutes after which they were allowed to cool for 5 minutes under room temperature. Thereafter, 5mL of concentrated HNO3 was added to each, covered and refluxed again at 90^{o}C for 30 minutes. Then, the solutions were allowed to evaporate without boiling to approximately 5 mL each and cooled again for 5 minutes. This was followed by the addition of 2 mL of deionised water plus 3mL of 30% hydrogen peroxide (H_2O_2) to each. The vessels were covered and heated just enough to warm the solutions for the peroxide reaction to start [18]. This was continued until effervescence subsided and the solutions were cooled. The acid-peroxide digestates were covered with watch glasses and heated until the volume reduced to approximately 5 mL again. Then, 10 mL of concentrated hydrochloric acid (HCl) was added to each, covered and heated on a heating mantle, then refluxed at 90^{o}C for 15 minutes. After cooling, each digestate was filtered through

Whatman No. 41 filter paper into a 100 mL volumetric flask and the volume made up to the mark with deionised water [18].

2.4 Sample Analysis

Ten (10) mL of each digestate was taken and mixed with equal volume of matrix modifier [18], and then analyzed using ICP-OES (ICP: Perkin Elmer Optima 7000 DV) for the levels of lead, chromium, cadmium, arsenic, cobalt, nickel, copper, zinc, selenium, vanadium, manganese, uranium, .

2.5 Data Analysis

Data generated from quadruplicate analyses were expressed as mean concentration of each element and inter-elemental correlation was calculated to determine the degree of association between the heavy metals.

2.6 Assessment of Site Contamination

The topsoil geochemical quality in urban environment depends not only on the concentration of pollution sources, but also on time-span of urbanization and density of the population [17]. Thus, it is expedient to compare heavy metal concentrations in the topsoil with their guideline limit values upon which informed decision about the site quality could be made. In this study, site contamination was assessed using the criteria of Single Element Pollution Index (SEPI), Combined Pollution Index (CPI) [19], and soil Enrichment Factor (EF), [20]. Each of these assessment criteria was calculated using the following equations;

$$\text{SEPI} = \frac{\text{Soil metal concentration}}{\text{Soil permissible limit of the metal}} \quad (1).$$

$$\text{CPI} = \frac{\text{Soil metal concentration /Its Soil PMC}}{\text{Number of the metals investigated}} \quad (2).$$

$$\text{EF} = \frac{\text{C/Fe(sample)}}{\text{C/Fe(earth crust)}} \quad (3).$$

Where PMC is the metal's permissible maximum concentration used [21], C/Fe(sample) is the ratio of the metal to Fe concentration of the sample and C/Fe(earth crust) is the ratio of the metal to Fe concentration of the earth crust. The earth crust Fe concentration used in this study was the value reported in iron- Encyclopedia of earth [22].

3. RESULTS AND DISCUSSION

3.1 In-situ concentrations of the heavy metals in surface soil dusts at the waste dumpsite

The results presented in Figure 2 show the in-situ concentrations (mg/kg) of lead (Pb), chromium (Cr) cadmium (Cd), Arsenic (As), cobalt (Co), nickel (Ni), selenium (Se), copper (Cu), zinc (Zn), manganese (Mn), vanadium (V) and uranium investigated in the surface soil dusts at the Katima Mulilo urban waste dumpsite.

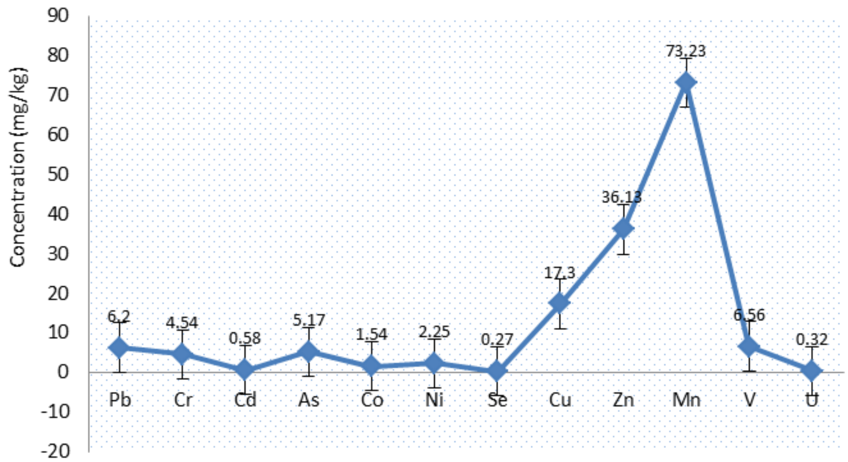

Fig 2: In-situ concentrations (mg/kg) of the heavy metals in surface soil dusts at Katima Mulilo urban waste dumpsite

The levels of the heavy metals varied widely with manganese recording the highest mean concentration of 73.23 mg/kg while selenium recorded the lowest level (0.27 mg/kg). Appreciably higher levels were recorded for Zn (36.13 mg/kg) and Cu (17.30 mg/kg). The result also showed appreciable concentrations of V, Pb, As and Cr with mean levels of 6.56 mg/kg, 6.20 mg/kg, 5.17 mg/kg and 4.54 mg/kg respectively. The other results obtained were; Ni 2.25 mg/kg, Co 1.54 mg/kg, Cd 0.58 mg/kg and U 0.32mg/kg. Generally, the present concentrations of the heavy metals were well below their regulatory guideline values for the protection of humans and environmental health (Appendix 1). However, this does not preclude the consideration for future concern due to the heavy metals' non-biodegradability and accumulative effects which could gradually build up to environmental toxic levels. As they are elements, heavy metals cannot be broken down and will therefore persist in the environment [24]. In a recent study, the presence of heavy metals: Fe, Zn, Pb, Cu, Cd, Co, Cr , As, Ba, and Ni was reported in the dumpsite soils of two refuse dumpsites in Akure Nigeria which the authors attributed to wastes as the major sources of the heavy metals [23]. Heavy metals contamination of soils and vegetation around solid waste dumps in Port Harcourt Nigeria was also reported and attributed to solid wastes as the main source [7]. The accumulative effect of most heavy metals is particularly due to the fact their amounts released into the human ecosystem from anthropogenic sources far exceeded the depositions from their natural background sources. Research has indicated that some of the oldest cases of environmental pollution in the world were caused by heavy metal extraction and use, for example; copper, mercury and lead mining, smelting and utilisation by the Romans [24].

Thus, human beings, especially vulnerable children scavenging daily at the Katima Mulilo waste dumpsite are at risk of chronic exposure to heavy metals contaminant-bearing dusts via inhalation, dermal contact and absorption. It is also noteworthy that since the waste dumpsite is an open land where the incineration of wastes also takes place, toxic metal particulates released during burning may also deposit and contaminate the surrounding graze lands. This has implication for the possible transfer of ingested heavy metals into human food chain by the animals grazing extensively within vicinity of the dumpsite.

3.2 Pollution Indexes

The levels of the Single Element Pollution Index (SEPI) of the heavy metals recorded in surface soil dusts at the Katima Mulilo waste dumpsite (Figure 3) varied between 0.014 to 0.52. Arsenic recorded the highest SEPI of 0.52 while U recorded the least (0.014). The highest SEPI recorded for arsenic suggests that the human population, especially those scavanging at the dumpsite who are constantly in direct contact with the surface soil dusts are at risk of both acute and chronic exposures to the element. Arsenic toxicity has been linked to increased chances of cancer development, especially cancers of the skin, lung, liver, kidney and bladder [10]. The toxicity of arsenic and its inorganic compounds were classified as: acute toxicity, sub-chronic toxicity, genetic toxicity, developmental and reproductive toxicity [25], immunotoxicity [26], biochemical and cellular toxicity [27]. Report also indicated that arsenic-induced oxidative stress causes DNA strand breaks; an alkali-labile site which eventually results into DNA adducts [28].
Results of the other SEPIs were Pb 0.062, Cr 0.045, Cd 0.19, Co 0.051, Ni 0.03, Se 0.27, Cu 0.17, Zn 0.18, Mn 0.069, and V 0.044. Based on the established guideline for contamination categories of heavy metals pollution index, [19], (Appendix 2) these results generally revealed

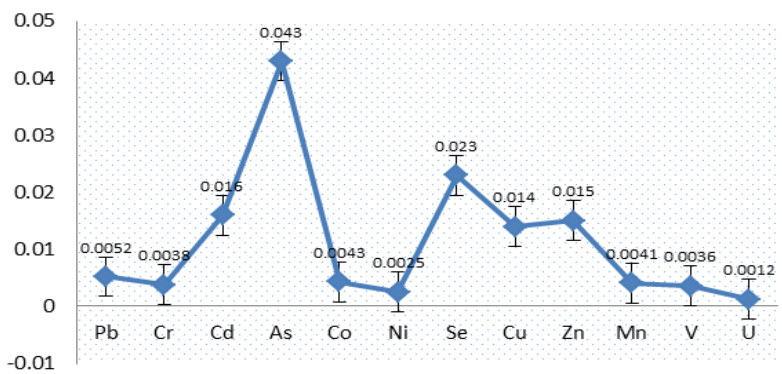

Fig 3: Single Element Pollution Index of the heavy metals in surface soil dusts at the dumpsite

low contamination of the surface soil dusts in terms of the metal elements investigated. However, some of the heavy metals (e.g Pb, Cr, Cd) have been identified among the toxic elements that will continue to accumulate in urban environment due to their non-biodegradability and long residence time [17]. Furtherrmore, human exposures to heavy metal elements have been noted with great concern, particularly because of the classification of some (e.g As, Cd, Cr, Ni) as potential carcinogens [17]. Carcinogenic substances are those that induce tumors (benign or malignant), increase their incidence or malignancy or shorten the time of tumor occurrence when they get into the body through inhalation, injection, dermal application or ingestion [29].

The Combined Pollution Index (CPI) of the heavy metals in surface soil dusts at the dumpsite (Figure 4) indicated that each of the present level was less than one (1) and this suggests that the average concentrations of the heavy metals were below the selected standards. However, this does not necessarily indicate that there are no anthropogenic sources of enrichment over background level, but suggested single metal contamination [30]. The trend of the results of CPI of the heavy metals was similar to that of the SEPI with As (0.043) recording the highest level while U (0.0017) was the least.

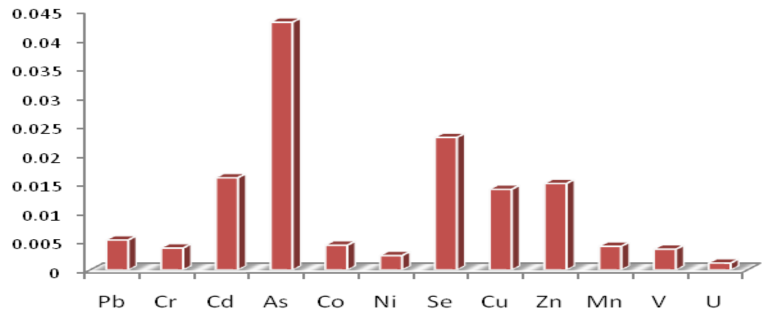

Fig 4: Combined Element Pollution Index of the heavy metals in surface soil dusts at the dumpsite

3.3 Soil enrichment factor

The results of the surface soil dusts enrichment factor (EF) of the heavy metals (Figure 5) investigated at the Katima Mulilo waste dumpsite ranged from 19.23 to 20.25. Manganese recorded the highest EF while Co recorded the least. The other results of the surface soil dusts EF were: Pb 19.55, Cr 19.85, Cd 20.00, As 19.46, Ni 19.67, Se 19.84, Cu 19.65, Zn 19.29, V 19.67 and U 19.34. Based on the established guideline for contamination categories of heavy metals soil enrichment factor [19], (Appendix 2), these results revealed significant (5 < EF < 20) to high (20 < EF < 40) enrichment of the surface soil dusts by the heavy metals. These suggest that most of the waste materials disposed at the dumpsite might be rich sources of the heavy metals which upon decomposition release the elements onto the receiving surface soil. Research finding has shown that decomposition or oxidation process releases heavy metal elements contained in waste materials into dumpsite soil thereby contaminating the soil [31]. Apart from the natural background concentrations of these heavy metals, several household and industrial wastes such as electronic parts, electro-plated materials, paint containers, used batteries, plastics, rubbers, stationery, textiles, carcases, waste foods especially from mega shops etc which are common dumped items at the Katima Mulilo urban wastes dumpsite could degrade to enrich the soil with their component metal elements.

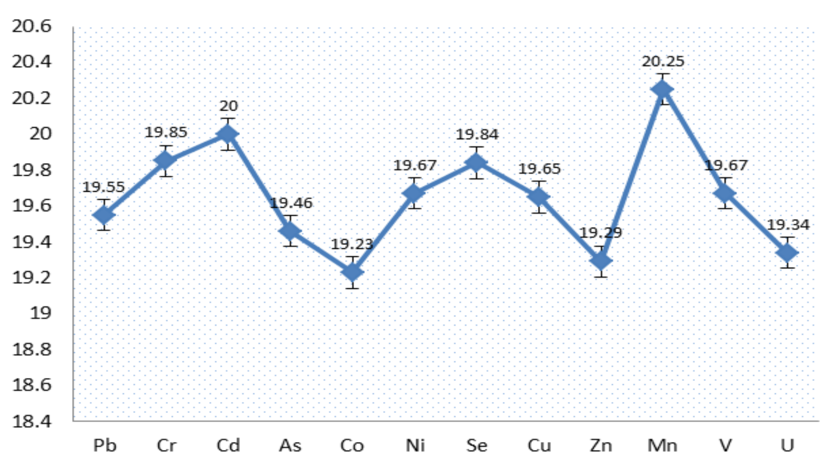

Fig 5: Enrichment factors of the heavy metals in surface soil dusts at the dumpsite

3.4 Inter-elemental correlation analysis of the heavy metals

The result of inter-elemental correlation coefficient (r) of the heavy metals (Table 1) investigated in the surface soil dusts of the waste dumpsite indicated extremely weak (r < 0.1), weak (r = 0.1 to 0.5), strong (r > 0.5 to 0.9), extremely strong (r > 0.9) and perfect (r = 1.000) correlations between the metals. The correlation coefficients of Cd and Cr (r = 0.010), Mn and Se (r = -0.058) as well as V and Se (r = 0.017) which showed extremely weak correlation suggests that the sources of these metals in the dumpsite surface soil dusts are virtually independent of each other and could come from different sources of wastes. The correlation coefficients of As and Cr (-0.989), Se and Cd (-0.990), Ni and Cr (-0.995) showed extremely strong negative correlation while those of Co and Pb (0.995), Ni and As (0.999), V and Ni (0.969) showed extremely positive correlation. The results for U and Ni as well as U and As showed perfect positive correlation (1.000). Generally, the negative correlations between some of the heavy metals suggest that as one of the metal increases in the surface soil dusts, the other one decreases. Conversely, the positive correlations suggest that all heavy metals concerned could accumulate simultaneously in the surface soil dusts at the dumpsite.

Table 1. Inter-elemental correlation coefficients of the heavy metals concentration of the waste dumpsite surface soil dusts

Heavy metal	Pb	Cr	Cd	As	Co	Ni	Se	Cu	Zn	Mn	V	U
Pb	1.000											
Cr	0.893	1.000										
Cd	0.459	0.010	1.000									
As	-0.817	-0.989	0.137	1.000								
Co	0.995	0.841	0.549	-0.752	1.000							
Ni	-0.844	-0.995	0.090	0.999	-0.783	1.000						
Se	-0.327	0.133	-0.990	-0.277	-0.424	-0.231	1.000					
Cu	-0.189	-0.611	0.786	0.721	-0.085	0.687	-0.866	1.000				
Zn	0.866	0.548	0.842	-0.419	0.913	-0.462	-0.756	0.327	1.000			
Mn	0.962	0.982	0.200	-0.943	0.929	-0.958	-0.058	-0.449	0.697	1.000		
V	-0.950	-0.989	-0.160	0.956	-0.913	0.969	0.017	0.485	-0.667	-0.999	1.000	
U	-0.827	-0.992	0.120	1.000	-0.764	1.000	-0.260	0.708	-0.435	-0.949	0.961	1.000

4. CONCLUSION

The result of this study revealed the presence of lead, chromium, cadmium, arsenic, cobalt, nickel, selenium, copper, zinc, manganese, vanadium and uranium in the surface soil dusts at the Katima Mulilo urban waste dumpsite. Although, manganese, zinc, copper, lead, arsenic and vanadium recorded appreciably high levels in the surface soil dusts, the present concentrations of the heavy metals were generally lower than their respective guideline values for the protection of human and environmental health. Based on the established guidelines for contamination categories of heavy metals, the present pollution indexes of the heavy metals investigated generally revealed low contamination of the surface soil dusts at the waste dumpsite. However, results of the soil enrichment factors revealed significant to high enrichment of the surface soil dusts by the heavy metals. These suggest that most of the waste materials disposed at the dumpsite might be rich sources of the heavy metals which upon decomposition release the elements onto the receiving surface soil. Therefore, we recommend that further research be carried out on the compositions of the waste materials to identify those that are potential sources of heavy metals contamination of soil and suggest appropriate disposal methods. Furthermore, the urban wastes management department must provide machinery for wastes segregation prior to disposal and incineration. In this way, waste materials which are potential sources of heavy metals contamination of soil might be separated and considered for alternative disposal other the present open dumping and incineration practices.

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Appendix 1

Maximum Permissible Concentrations (MPC) of the heavy metals in soil (Chen et al., 2005)

Heavy metal	CAS No	MPC (mg/kg)
Pb	7439-92-1	100
Cr	7440-47-3	100
Cd	7440-43-9	3
As	7440-38-2	10
Co	7440-48-4	30
Ni	7440-02-0	75
Se	7782-49-2	1
Cu	7470-50-8	100
Zn	7440-66-6	200
Mn	7439-92-1	1500
V	7440-62-2	150
U	7440-61-1	23

Appendix 2

Contamination categories based on Single Element Pollution Index (SEPI) (Chen et al., 2005) and soil Enrichment Factor (EF) (Foley et al., 2011)

Single Element Pollution Index		Enrichment Factor	
Classification	**Degree of contamination**	**Classification**	**Degree of enrichment**
SEPI ≤ 1	Low	EF < 2	Deficient to minimal
1 < SEPI ≤ 3	Moderate	2 < EF < 5	Moderate
SEPI > 3	High	5 < EF < 20	Significant
		20 < EF < 40	Very high
		EF > 40	Extremely high