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Heavy metal contamination in soils from a municipal landfill, surrounded by banana plantation in the eastern flank of Mount Cameroon

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Municipal solid waste generated in our cities, with an unprecedented population growth, has resulted in degrading environmental quality, thus a major problem for policy makers. The extent of Pb, Cu, Zn, Cd, Hg and Zn contamination in soils of the studied area, where vegetables were grown, using metal contamination factor (CF) and pollution load index were assessed. The concentrations of heavy metals studied were in the order Cu > Zn > Cd > Hg > Pb > Ni, with the highest value (in mg/kg) for Zn (14.15±0.73), Cu (14.15±1.59), Cd (6.57±1.71) and Hg (6.29±0.97) recorded in site SS1. The geo-accumulation index (*Igeo*) indicated that sites SS3, SS4 and SS5 were uncontaminated, moderately contaminated (1< *Igeo*<3) for Zn, landfill was moderately to heavily contaminated (1< *Igeo*<3) for Cu, Cd and for swamp only Hg. Contamination factor (CF) for soils indicated that site SS1 had a very high degree of contamination (CF > 6) for Cu and Cd while the swamp, old dumpsite and downstream had a low contamination (CF<1). The landfill area is moderately contaminated and considering the age and other anthropogenic factors, this environment may become highly polluted in future. This present work could serve as a landmark for contemporary research in eco-toxicology.

Key words: Heavy metals, contamination, soils, agriculture, landfill, Buea.

INTRODUCTION

Once released into the environment, heavy metals are often considered as a problematic environmental pollutant because of their well-known effects on living organisms. The term “heavy metal” is generally used to describe a group of metals and metalloids with an atomic density greater than 5.0 g/cm^3 and is toxic or poisonous even at low concentration (Duffus, 2002; Lenntech, 2004). Their effects on living organisms generally results from contamination of either abiotic systems (soil, water and air) and subsequent uptake and bio-accumulation/

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magnification by living organisms. The effects of heavy metals on the health of living organisms can be felt even when in small amounts. Heavy metals are among the leading health concerns all over the world because of their resulting long-term cumulative health effects (Huton and Symon, 1986). Heavy metals have been reported to produce mutagenic, teratogenic, neurotoxic and carcinogenic effects even at very low concentrations (Das et al., 1990; Al Saleh et al., 1996; Waalkes et al., 1999; Ngole and Ekosse, (2012; Ngole, 2015). The agency for toxic substances and disease registry (ATSDR, 2015), reported that cadmium and lead are carcinogenic, and that prolonged exposure to low concentrations of cadmium could lead to kidney disease, lung damage, fragile bones, and of Lead, nervous disorder. Heavy metals possess certain chemical and physical properties for which their use in certain products is almost unavoidable though some of such uses have been on a decline, as in the case for mercury (Aucott, 2006). When heavy metals are incorporated into products and these products are subsequently disposed of in landfills at their end-of-life or -use, there is a high possibility that with time, they will be released into the surrounding ecosystems mainly soil and water.

Increased concern on soil contamination by heavy metals has been shown in recent years. Soils are sources of substrate nutrients and are the basis of sustenance to livelihood (Abdullah et al., 2009; Asongwe et al., 2014). Thus, soils play an important role in ecological stability. Nevertheless, their quality with regards to the concentrations of heavy metals may be compromised. The origin of heavy metals in the environment could be both from natural or anthropogenic sources which include: atmospheric deposition, vehicular emission, sewage, irrigation, mining activities, industrial activities, waste disposal and agricultural applications (Asaah et al., 2006; Zhang et al., 2011; Ngole and Ekosse, 2012). They are notorious when they bio-accumulate in soil and due to their long persistence time in the course of interaction with soil component, they consequently enter food chain through plants or animals (Dosumu et al., 2003). Thus, plants grown on contaminated soils bio-accumulate these heavy metal contaminants which pose high risk to human health.

Waste disposal and agriculture are two of the anthropogenic activities that have contributed to increased levels of heavy metals in soils (Modaihsh et al., 2004; Ngole and Ekosse, 2012; Bitondo et al., 2013). Until the 1980s, the problem of municipal solid waste management (MSWM) for many communities was viewed from the cost perspective hence little attention was paid to it (Bhide and Sundersand, 1983). More so, in developing countries, MSWM was partly paralyzed by the problem of insufficient public and private funds to sustain existing schemes and corrupt management systems (Gupta et al., 1998; Buenstro et al., 2001a) and also mainly due to the fact that municipal solid waste management is influenced by a complex interrelationship of political, legal, socio-cultural, environmental and economic factors as well as available resources (Kumar et al., 2005). MSW, however, constitutes a serious environmental problem with varying degrees of direct as well as indirect negative effects on the environment and its ecosystems. Its handling across the different functional elements requires greater attention as it raises concerns not only about cost but also about environmental health and pollution. Within the EU for example, the presence of heavy metals in waste as a result of their uses in modern society is a matter of ever-growing concern to both politicians, authorities and the public (European Commission, 2002). Such concerns are slowing receiving widespread attention in developing countries like Cameroon where the fate of most MSW is disposal on open dumps and landfills. This widespread attention constitutes fall outs from the Cameroonian government's commitment to handling environmental related issues with the councils playing a very significant role in waste management. In developing countries, municipal solid waste management has most often been the responsibility of the government and/or municipalities. In Cameroon, it is the sole responsibility of municipal councils to manage MSW within the council areas, which may be through a contracted agent. Change in lifestyle and consumption habits are of particular significance to the type and quantity of municipal solid waste generated. With the usage of electrical and electronic devices on the rise (UNEP, 2009), the amount of electrical and electronic waste (e-waste) incorporated each day among the municipal solid waste (MSW) is equally growing enormously around the world. A majority of this alongside the MSW ends up in landfills and open dumps with resulting environmental and human consequences. Most noxious components including toxic substances such as heavy metals found in MSW often times leached into soil and subsequently pollute ground water at varying degrees.

Of recent, the government of Cameroon has equally given considerable attention to food insecurity with a need to boost agricultural productivity, so as to meet up with food demand of an ever increasing population. The application of pesticides and fertilizers are important inputs for agricultural production (Zhang et al., 2011), most of which may contain some amount of heavy metal in the formulae. Surrounding the Mussaka landfill is a banana plantation where there is the regular application of some pesticides and fertilizers in order to control pests/diseases as well as enhance production. The landfill receives unsorted and untreated municipal waste mainly from the following sources: Residential, commercial, institutional, medical and construction sources. The hydrogeological setting of the landfill is not the best. More so, the landfill lacks all side-sealing systems. Thus, the effects of agricultural activities and landfill operations and reactions represent a potential source of heavy metal contamination around the Mussaka area.

There is still a dearth of studies on heavy metal pollution in Cameroon, particularly those related to soil pollution by landfills and the subsequent management of such pollution. There are a number of previous research works on municipal solid waste management in Cameroon including aspects of: generation, characterization (Achankeng, 2003; Manga et al., 2011); options of recycling and recovery (Asong, 2010). Also, some preliminary studies have been carried out on soil pollution from industries in Cameroon, mainly around Douala by Asaah et al. (2006). However, there is the need to fully investigate the impacts of waste in landfills and agricultural inputs on the surrounding soil. In Cameroon, there is no guideline for management and control of soil pollution drawn for the country but guidelines drawn from international treaties are applied. It is for this reason that baseline data has to be collected to enhance policy and to build up soil pollution guidelines.

The Mussaka landfill, that has just been operational for about five years, and located in a very moist and hot climatic setting, continues to receive huge amounts of unsorted and non-pretreated waste from Buea and its environs. The surrounding land use practices (like plantation agriculture, vegetable production and car wash unit) and the presence of sensitive ecosystems (a flowing stream, used for drinking and irrigation and a wetland) further renders this area very important as a production sites for agriculture. However these changes in land use practice have degraded the surrounding ecosystem with likely negative impacts on environment. The risk of contaminants accumulating in soil, environment and crops due to leachate from the landfill, fertilizer and pollutants is of serious concern. Given the above situation, it is very essential that the concentration of heavy metals and their potential health risk is assessed in-order to formulate policies and prevent health risk in this agricultural bread basket region. The main objectives of the current study were: (1) to determine the concentration of Pb, Cu, Zn, Cd, Hg and Zn in soils around the Mussaka landfill surrounded by plantation agriculture, and (2) delineate the extents of heavy metal contamination and their potential health risk.

MATERIALS AND METHODS

Study area description

Mussaka is located between latitude 04°08.036′ and 04°12.627′ North and Longitude 009°13.104′ and 009°18.675′ East, in the outskirt of Buea. Buea is the headquarters of South West Region and covers an area of 870 km^2, with a population of approximately 200,000 inhabitants (BUCREP, 2005), it is located on the eastern slopes of Mount Cameroon (Figure 1). The Mussaka landfill spans an area of about 13240 m^2 (1.3 ha) and is surrounded mainly by the Cameroon Development Cooperation (CDC) banana plantation. The landfill is the only current and official landfill that serves the entire Buea municipality. It receives about 104 tonnes of waste daily and has been used by HYSACAM Company for five years.

The area has a gentle to undulating relief, with a swamp and a nearby stream. The geologic setting of the landfill is volcanic, with the rock type being mainly a basaltic tuff. In vertical sections of approximately 1.5 m on some side cutting within the landfill, one finds some form of layering. The layers are marked by basalts of pebbles to cobble sizes in a mud matric being intercalated with a thin dominantly mud layer. It is because of the nature of the matrix materials and the mud that the landfill operators make use of the basaltic tuff as top sealing material. In other to meet up quantity of top sealing material, weathered tephra tuff is transported from a nearby locality and used on the landfill.

The nearby stream, flowing through the northern and eastern parts of the landfill is being used upstream for car washing and downstream for drinking and irrigation of banana, tomato and vegetable farms by the CDC Company and the locals around the area. The stream is separated from the active waste disposal front by a wetland thus rendering the area ecologically sensitive. The currently used method of disposal is a fairly controlled one characterized by: Weighing of truck load upon arrival, partitioning of landfill area into active and passive disposal spaces, spread of waste over broader areas, volume reduction by compaction with heavy duty machinery, spreading of sealing materials. These actions, although playing a role in the daily management of the landfill, fall short of appropriate measures to be taken to prevent waste in the landfill from interacting with the environment. For example, cover sealing material is placed in an extensive horizontal pattern which may create opportunity to wider migration of leachates and interaction of materials unlike in the case of creating cells of smaller sizes and concave surfaces. In terms of quantity, about a 104 tonnes of unsorted waste come into the landfill daily.

Sampling of soils

Soil samples for analyses were collected from the landfill and its surrounding area (Figure 2). Using an auger, soil samples were collected at different locations in the landfill at depths between 0 and 30 cm. The sampling sites were chosen based on the different anthropogenic activities along the landfill zone. A total of five sampling sites were identified in this study. From each site, three soil samples (in replicates) weighing an average of 900 g were collected and making a total of 15 samples analysed. Each sample was air-dried, sieved through a 2 mm sieve, and used for subsequent. The soil pH was determined using a 1:2.5 soil solution ratio with the help of the PD 300 series pH meter. The electrical conductivity was measured using the 1:5 soil solutions, where 10 g of soil was put into a beaker followed by the addition of 50 ml distilled water. The mixture was agitated for 1 h and filtered after 16 h. The value of electrical conductivity was read from a conductivity meter calibrated with 0.01 N KCl. The soil texture was determined using the hydrometer method. Soil particle size was determined using the Pipette method. The weight percent (wt %) of sand, silt, and clay was plotted in a textural triangle to determine the texture of the samples.

The following parameters were determined based on Pauwels et al. (1992): Organic carbon (OC) by the Walkley and Black method using acidified potassium dichromate; soil bases and cation exchange capacity (CEC); total nitrogen content by Kjeldahl method (TKN); concentration of exchanged aluminium is determined by calorimetry; available phosphorus was determined by the Bray II method. Heavy metals concentrations in the soil samples were

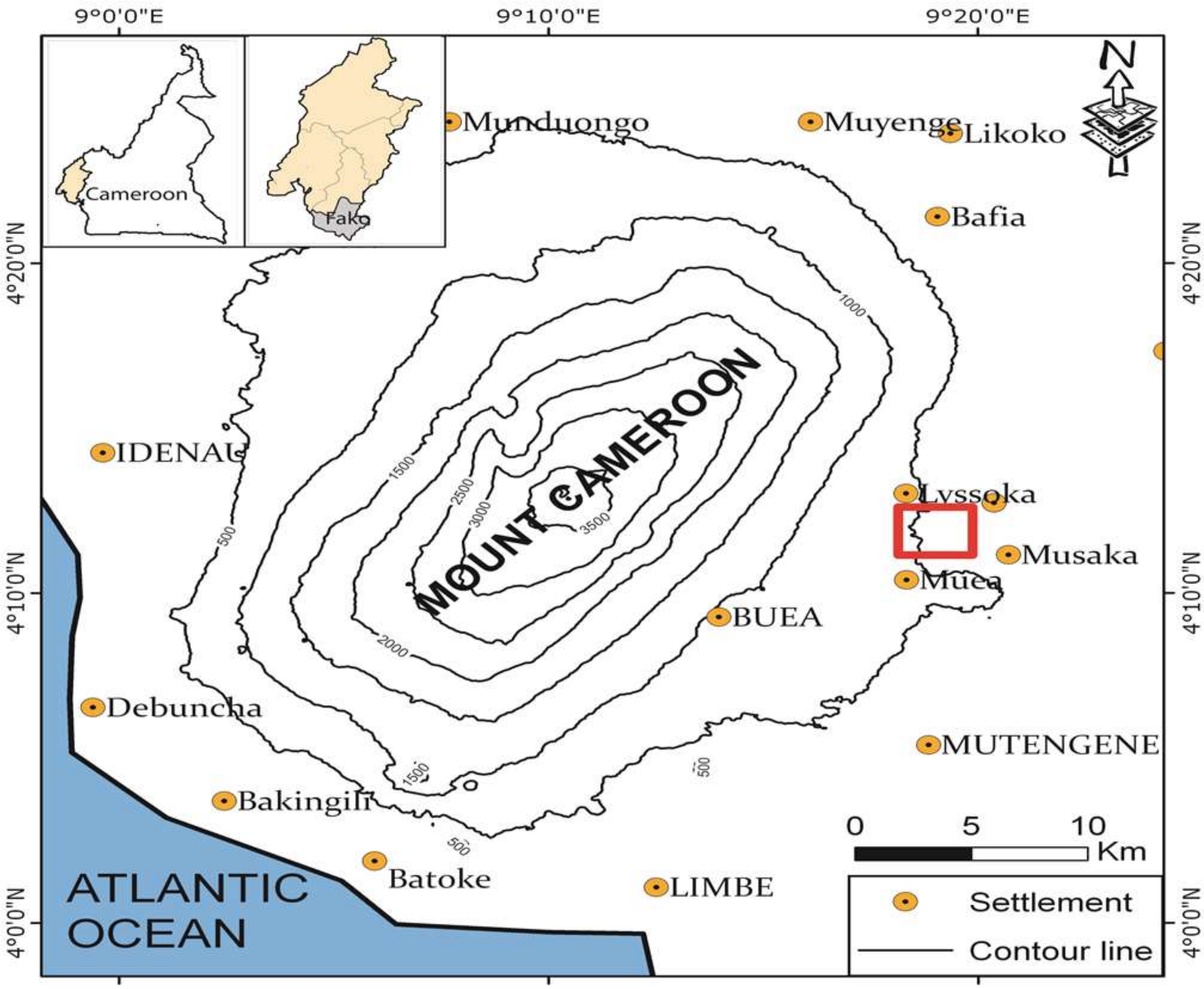

Figure 1. Location of the Mussaka landfill.

determined using atomic absorption spectrometer (Perkin Elmer). The concentrations of Zn, Cu, Ni, Pb, Cd and Hg were analyzed after acid digestion. All samples were analyzed in duplicate and the mean value reported as the concentration value for the metal.

Data interpretation

The extent of Zn, Cu, Ni, Pb, Cd and Hg contamination in soils within the Mussaka landfill vicinity was assessed using: The geo-accumulation index (I_{geo}) and the contamination factor (CF) proposed by Muller (1969) and Hakanson (1980). Some recent studies (Ngole and Ekosse, 2012) have used I_{geo} and CF to evaluate heavy metal contamination in terrestrial environment. The I_{geo} and CF were determined using the mathematical formulae as indicated in Equations 1 and 2 respectively.

Equation 1: Geo-accumulation index:

$$I_{geo} = log_2(C_n / 1.5xB_n)$$

Where, C_n = average concentration of heavy metal measured in the soil; B_n = average geochemical background concentration of the same heavy metal; 1.5 = background matrix correction factor due to lithogenic and anthropogenic influences.

Equation 2: Contamination factor:

$$CF = C_m/B_m$$

Where, C_m = measured concentration of heavy metal in the soil and B_m = local background concentration value of the heavy metal.

The concentrations of the heavy metals in the control samples (Site SS_5, control) were used as the background concentration values to calculate the heavy metal contamination factor (I_{geo} and CF) in this study. Interpretation of I_{geo} and CF were explained according to the classes as described by Ngole and Ekosse (2012).

The pollution load index (PLI) was also employed to assess the extent of heavy metal pollution in the soils. This was done with the formula used by Ngole and Ekosse (2012) as indicated in Equation 3.

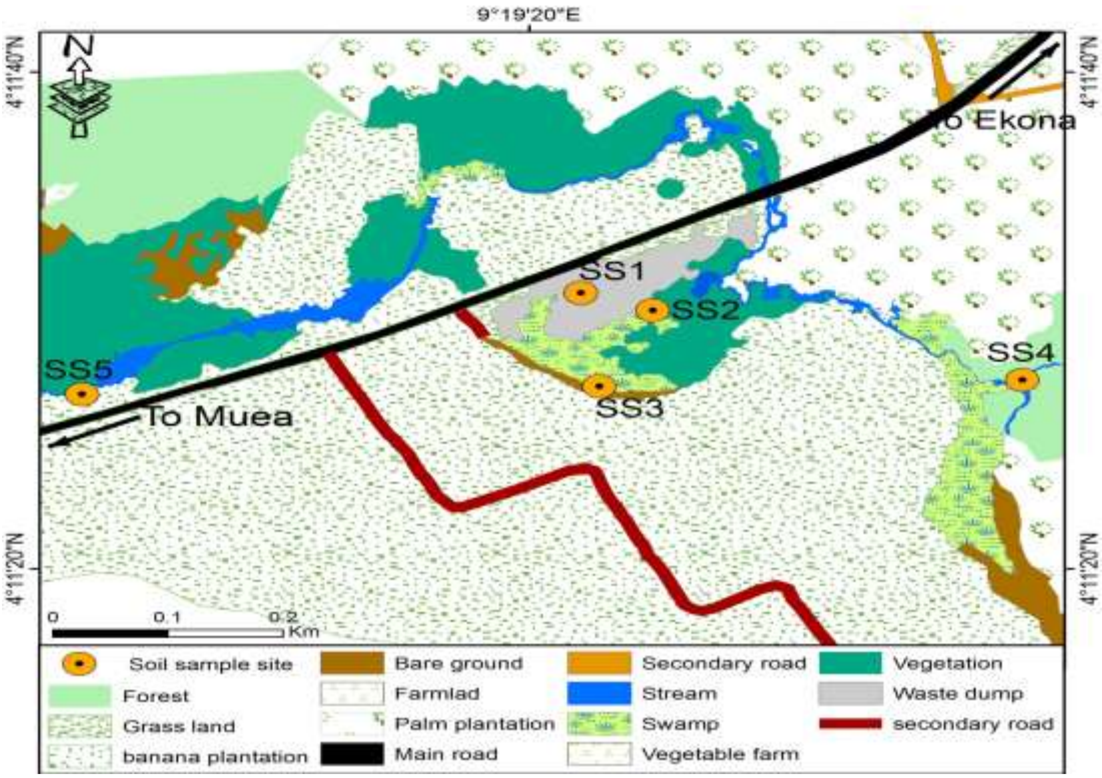

Figure 2. Study area showing sample collection points and different land use forms around the study area.

Equation 3: Pollution load index:

PLI = $\sqrt[n]{(CF1 \times CF2 \times CF3 \times \ldots \ldots \times CFn)}$

Where, CF is contamination factor and N is the number of elements. PLI values <1 indicate no pollution whereas values >1 indicate pollution.

RESULTS AND DISCUSSION

Soil physico-chemical properties

A number of physico-chemical properties of soils in this study were determined (Table 1). With respect to texture, the percentage of clay ranged from 1.33 to 17.67%; silt 16.67 to 29.33%; sand 53.33 to 82.00%. The percentage composition of these three components revealed that the soils in the study area could be texturally classified as sandy loam to loamy sand. This indicated a higher sand content than silt and clay. The soil physico-chemical parameters show varied correlations with heavy metals. Soil textural parameters show a slightly positive correlation with heavy metals. Soils of this nature are reported by Dube et al. (2001), to cause less dispersion of contaminants because of their high porosity and permeability.

The pH of the area ranged from moderately acidic (5.90) to slightly acidic (6.97). Heavy metals are generally more mobile at pH < 7 than at pH > 7. This can therefore be hazardous for agricultural purposes since crops are known to take up and accumulate heavy metal from contaminated soils in their edible portions (Wei et al., 2005). Such weak acidic pH in the study area can be attributed the landfill activity and agricultural inputs such as pesticides, fungicides and fertilizers. This finding is consistent with those of Srivastava (2012), who attributed acidic pH of soils to the presence of metal scrap, waste materials in the dumpsites and other anthropogenic activities at Allahabad, India.

Total nitrogen ranged from 3.5 to 4.4 gkg^{-1}. The organic carbon as well as the organic matter in soils did not vary significantly (P>0.05) among the sites, and could be due to agricultural activities in the entire study site. However, higher values of organic carbon and organic matter were recorded within the landfill sites than the control site upstream. This could be due to high organic waste input into the landfill undergoing decomposition. The organic matter plays an important role in soil structure, water retention, cation exchange and in the formation of complexes (Alloway and Ayres, 1997). The mean concentrations of Ca, Mg, K, and Na across the sites (Table 2) showed no significant differences (P > 0.05).

Table 1. Soil physico-chemical parameters for studied area.

Property	Site				
	SS_1	SS_2	SS_3	SS_4	SS_7
Clay (%)	10.36[b]	10.00[b]	17.67[ab]	1.33[a]	1.33[a]
Sand (%)	60.30[a]	65.00[a]	53.33[a]	82.00[a]	81.67[a]
Silt (%)	29.33[a]	25.00[a]	29.00[a]	16.67[a]	17.00[a]
OC (%)	3.84[a]	4.60[a]	2.33[a]	2.21[a]	1.46[a]
OM (%)	6.63[a]	7.94[a]	4.02[a]	3.81[a]	2.51[a]
Soil textural class	SL	SL	SL	LS	LS
Total nitrogen (gkg^{-1})	4.2[a]	4.4[a]	3.9[a]	3.7[a]	3.5[a]
BD (g/cm^3)	0.86[a]	ND	0.97[a]	0.97[a]	0.57[a]
C/N ratio	8.99[a]	10.45[a]	6.06[a]	5.52[a]	4.06[a]
pH_{KCl}	4.43[a]	6.40[a]	5.47[a]	5.43[a]	5.97[a]
pH_{Water}	6.97[a]	6.90[a]	6.43[a]	5.90[a]	6.57[a]
EC (mS/cm)	0.03[a]	0.04[a]	0.04[a]	0.04[a]	0.03[a]
CEC (cmol(+)/Kg)	15.17[a]	16.20[a]	10.97[a]	11.73[a]	9.61[a]
Available Bray 2-P (mg/kg)	124.36[a]	19.68[c]	28.33[b]	9.88d	26.32[b]

Means that do not share a letter within the column are statistically different.

Table 2. Mean concentrations of exchangeable cations across the sampling sites.

Site	Exchangeable cations ($cmol_+/kg$)			
	Ca^{2+}	Mg^{2+}	K^+	Na^+
SS_1	**1.47±1.11[a]**	**0.53±0.30[a]**	0.04±0.00[a]	0.03±0.00[a]
SS_2	0.24±0.00[a]	0.20±0.00[a]	0.04±0.00[a]	0.030±0.00[a]
SS_3	0.43±0.05[a]	0.24±0.05[a]	0.40±0.00[a]	0.03±0.00[a]
SS_4	0.37±0.03[a]	0.19±0.05[a]	0.40±0.00[a]	**0.02±0.00[a]**
SS_7	0.32±0.00[a]	0.03±0.03[a]	0.40±0.00[a]	0.030±0.00[a]

SS_1, Dumpsite; SS_2, Swamp below the dump; SS_3, old dumpsite; SS_4, downstream; SS_7, control site. Kruskal Wallis test was used to test for significance and the means were separated using Turkey method at α = 0.05; Means that do not share a letter within the column are statistically different.

The mean concentrations of soil nutrients compared to critical values were as follows: Calcium was very low, magnesium was generally very low, potassium was very low and sodium was very low.

Though the concentrations of exchangeable Ca and Mg in the soils did not show any significant difference among the sites, the values within landfill were slightly higher than those of the control site. This may be connected to the heterogeneous nature of wastes received by the landfill, which is expected to impact differently on soil properties (Adjia et al., 2008).

Heavy metal concentrations in soils and risk assessment indices in study area

Heavy metals concentrations in the soils

The mean concentrations of heavy metal (in mg/kg) in soil samples collected from the study area are presented in Table 3. Within the currently active landfill zone, measured concentrations of heavy metals were in the order Zn > Cu > Cd > Hg > Ni > Pb. The concentration of zinc reveals a decreasing trend from the active landfill to the peripheries. The concentrations of the other metals do not show any trends in variations across sample sites. Compared to the EU and WHO values, most of the heavy metal values in the soil were below the permissible limits. This may be ascribed to their continuous removal by vegetables and other plants growing in the studied area. However, copper and cadmium recorded some values that were higher than WHO permissible limits. This could be attributed to leachate migration from the decomposing waste within active landfill, and accumulation from agricultural inputs from the plantation. Adjia et al. (2008) reported similar results on heavy metals content in soil of sites around landfill used for periurban agriculture in

Table 3. Mean heavy metal concentrations in soils at the Mussaka landfill vicinity compared to the European Union and WHO permissible limits.

Site	pH_{Water}	Heavy metals concentrations (mg/kg)					
		Zn	Cu	Ni	Pb	Cd	Hg
SS_1	6.97[a]	14.15±0.73[a]	14.15±1.59[a]	1.85±0.17[ab]	[BD]L	6.57±1.71[a]	6.29±0.97[a]
SS_2	6.90[a]	11.18±0.00[a]	0.76±0.00[bcd]	1.75±0.00[a]	0.49±0.00[a]	0.41±0.00[b]	3.55±0.00[a]
SS_3	6.43[a]	7.80±0.20[ab]	0.54±0.04[bcd]	2.12±0.03[b]	1.29±0.09[a]	0.73±0.06[b]	0.85±0.29[a]
SS_4	5.90[a]	8.73±0.45[ab]	1.04±0.22[abcd]	2.03±0.02[ab]	1.23±0.03[a]	0.90±0.06[ab]	1.45±0.42[a]
SS_7	6.57[a]	6.29±0.03[b]	1.68±0.23[acd]	2.15±0.01[b]	1.21±0.12[a]	0.92±0.06[ab]	1.10±0.03[a]
EU*	5<pH<6	60	20	15	70	0.5	NA
	6<pH<7	150	50	50	70	1.0	
WHO	NA	50	4	68	20	0.3	NA

SS_1, Dumpsite; SS_2, swamp below the dump; SS_3, old dumpsite; SS_4, downstream; SS_7, control site; BDL, below detectable limit; NA = not available. *Maximum permissible levels according to the EU Directive (European Union, 2002).

Table 4. Geo-accumilation index for studied heavy metals in soils around the Mussaka landfill.

Site	I_{geo}-Zn	I_{geo}-Cu	I_{geo}-Ni	I_{geo}-Pb	I_{geo}-Cd	I_{geo}-Hg
SS1	0.58	2.49	-0.81	BDL	2.25	1.93
SS2	0.24	-1.74	-0.89	-1.89	-1.74	1.10
SS3	-0.27	-2.25	-0.58	-0.49	-0.92	-0.94
SS4	-0.11	-1.29	-0.67	-0.56	-0.62	-0.18
SS7	-0.59	-0.58	-0.58	-0.60	-0.58	-0.58

SS_1, Dumpsite; SS_2, swamp below the dump; SS_3, old dumpsite; SS_4, Downstream; SS_7, control site; BDL, below detectable limit; NA = not available. $I_{geo}< 0$=uncontaminated, $0 < I_{geo}< 1$=moderately contaminated, $1 < I_{geo}<3$=moderately to heavily contaminated, $3 < I_{geo}< 4$=heavily contaminated, $4 < I_{geo}< 5$=heavily to extremely contaminated.

Ngaoundere. Also, similar results have been obtained by Ngole and Ekosse (2012) who reported higher concentration levels of heavy metals at sites where leachate plumes were found within the Gaborone landfill environment. Modaihsh et al. (2004), equally reported high cadmium concentrations in soils due to application of inorganic fertilizers. Cadmium is one of the most eco-toxic metals, with highly undesirable effects on soil health, plant metabolism, humans and animal health (Kabata-Pendias, 2000). At very low concentrations, chronic exposure to cadmium can result to anemia, anosmia, cardiovascular diseases and renal problems (Sharma et al., 2006).

Geo-accumulation indices heavy metals in the soils

The geo-accumulation index (*Igeo*) for the quantification of heavy metal accumulation in the soils showed that safe for the active landfill site that is moderately to heavily contaminated for most of the analysed heavy metals, all other sites were uncontaminated (Table 4). The active landfill was moderately to heavily contaminated for copper, cadmium, mercury, and zinc but uncontaminated for nickel.

This is likely influenced by leachate from the landfill, which suggests a very stern anthropogenic influence which is not unconnected with the landfill receiving all kinds of mixed wastes ranging from domestic, electronic, commercial and medical wastes (Aboyade, 2004). Zinc for instance, is a component of paint pigments, steel products, metal, automotive parts, roofings, and packaging materials (Alloway, 1995) which were components of the municipal waste deposited on the site.

Contamination factor of heavy metals in the soils

Values of the contamination factor (CF) for soils in the study area indicated that active landfill site had a high to very high degree of contamination (CF > 5) with regards to mercury, cadmium and copper. The contamination factor for heavy metals for all other sampling sites was generally less than 3 implying low to uncontaminated sites. It was also observed that CF values for copper in sampling sites other than active landfill are very low. The

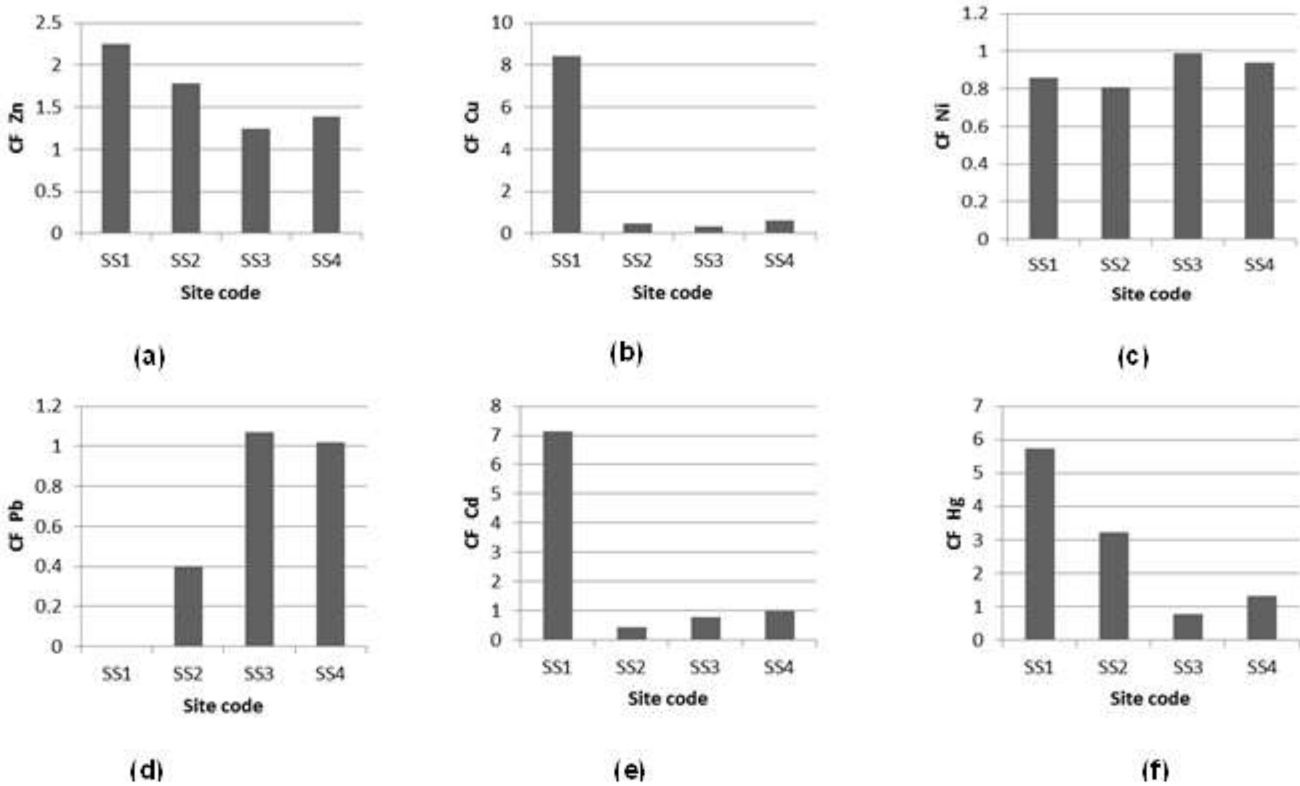

Figure 3. Contamination factor of (a) Zinc, (b) Copper, (c) Nickel, (d) Lead, (e) Cadmium and (f) Mercury in the soils within the landfill environment. (CF < 1 = low contamination; 1 < CF < 3 = moderate contaminated; 3 < CF < 6 = considerable contaminated; CF > 6 = very high contaminated).

presence of these metals could be explained as resulting from Leachate derived from landfill and agricultural origin, which are likely to contain high concentrations of heavy metals like Cu, Cd, Hg, Ni and Zn. These metals are used in manufacturing several commodities and products commonly used in homes as well as fertilizers, pesticides, herbicides and fungicides.

Pollution load index in the soils

Pollution load index (PLI) indicates the extent and infiltration of heavy metal in soil sample (Ahiamadjie et al., 2011). The pollution load index (PLI) for soils in this study took into account the combined polluting contributions of Zn, Cu, Pb, Ni, Hg and Cd (Figure 3). The values obtained for pollution index of the sampled sites within the study area indicated that Site SS_2 and SS_3 were not polluted (PLI < 1) while site SS_1 and SS_4 were polluted (PLI > 1). This can be explained by the high concentrations of Cu, Zn, Cd and Hg, which could have resulted from the decomposition of assorted waste in the landfill (site SS_1) and intense fertilizer and pesticide inputs at site SS_4.

Conclusion

In this study, an evaluation of the concentration of some heavy metal (Zn, Cu, Cd, Pb and Hg) as well as risk assessment indices was done for soils within the Musaka municipal solid waste landfill surrounded by a banana plantation. Although, most of the heavy metal concentrations in the soil were below internationally permissible limits, elevated levels of Cu and Cd in the soils at certain sites suggests possible need for concern with respect to future pollution as the landfill maturation progresses. The geo-accumulation and pollution indices of soil further reveal that with the current state of activity, the landfill is contaminated with heavy metals. Given that this landfill is relatively young, there is a need to develop monitoring program so as to enable subsequent decisions on water, land, and habitat use at the periphery of the landfill as well as downstream of water bodies to be made.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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