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Heavy metal contamination at dumpsites at Eldoret, Kenya, in the Lake Victoria Basin

SANDRA KHATIEBI[1*], DONALD SIAMBA[2], ZEDEKIAH ONYANDO[1], CHRISPINUS MULMBALA[3]AND MARTHA KONJE[2]

[1]*Department of Biological Sciences, Masinde Muliro University of Science and Technology, P.O. Box, 190-50100, Kakamega, Kenya*
[2]*Department of Biological and Environmental Sciences, Kibabii University, P.O. Box, 1699-50200, Bungoma, Kenya*
[3]*School of Health Sciences, Moi University, P.O. Box, 3900-30100, Eldoret, Kenya*

*****Corresponding author: skhatiebi@mmust.ac.ke

Abstract
This study assessed the heavy metals concentrations in municipal solid wastes at Eldoret Mwenderi dumpsites located at the shores of river Sosiani within the Lake Victoria Basin, Kenya. Concentrations of the three heavy metals analysed (lead, arsenic and cadmium) in water and leachate were higher than the WHO acceptable standards. Lead concentrations in solid wastes were slightly above East African acceptable standards but well above the US EPA compost standards. The wastes dumped in this site are not sorted and the dumpsite lacks a leachate collection and removal system. Lack of composite liners at the bottom and side of the dumpsite allow leachates to move into the ground water around the dumpsite. These metals are a potential threat to Lake Victoria and regular monitoring of ground and surface water of the surrounding area should be done to detect any heavy metals escaping the dumpsite.
Keywords: Heavy metals; Leachate; Management; Pollution; Wastes

Introduction
Solid waste management is driven by the desire to protect environmental quality and public health and management programmes require an understanding of the physical, chemical and biological attributes of the waste material which influence its behaviour in the natural environment. These physico-chemical and biological characteristics serve as indicators of which waste management options would be suitable for integrated municipal solid waste programmes. The open dumping of solid waste is prevalent in developing countries like Kenya and it degrades the environment in a number of ways. For instance, accumulations of copper, lead, iron, and zinc were found within the disposal site and in surface soil samples up to 75 m away from a disposal site in Zimbabwe (Chifamba, 2007). Leachates collected from Ibadan and Lagos dumpsites in Nigeria had appreciable levels of dissolved solids, chloride, ammonia, chemical oxygen demand (COD), lead, iron, copper and manganese, most likely a result dumping lead acid car batteries and metal scraps at these sites (Ikem *et al.*, 2002).

At the Dandora dumpsite in Nairobi, cadmium levels in soil samples were six times higher than the critical levels mentioned by the Dutch and Taiwanese authorities (Kimani, 2007). High levels of cadmium in surface soil levels relative to those of subsurface samples were attributed to a recent increase in the deposition of cadmium-containing waste at the dumpsite. Leachates contaminate both ground and surface water and during floods, water mixed with leachate may flow out of the dumpsites into nearby ponds, streams, and rivers. The Nairobi River, for example, passes through the Dandora Municipal Dumping site and in most cases an earth mover is used to spread the wastes to create more space, thus pushing some wastes into the river. This potentially endangers the health of communities living downstream who could be depending on the river's water for domestic or agricultural uses (Kimani, 2007).

Heavy metals, i.e. with a density > 5 gcm^{-3}, have been used in different parts of the world for thousands of years (Lars, 2003) and are known to have various health effects due to their toxicity (Jaishankar *et al*., 2014). These metals are unaffected during degradation of organic waste and are toxic to living organisms when exceeding a certain concentration. Compost made from solid waste and used as manure may therefore contain heavy metals (Smith, 2009; Jafari *et al.*, 2014) and bioaccumulation can pose a threat to human health if they enter the food chain. Exposure of heavy metals through various routes (Hu, 2002) including inhalation, ingestion and skin absorption may cause blood and bone disorders, kidney damage, and decreased mental capacity and neurological damage. Excessive exposure causes nausea, anorexia, vomiting, gastrointestinal abnormalities, dermatitis, and other cumulative effects on the various parts of the body depending on the type of heavy metal involved (Mahoney and Moy, 2005).

Wastes and sludges from municipal dump sites are frequently applied to agricultural lands owing to their high content of organic matter, biogenic compounds and nutrients (nitrogen, phosphorus, magnesium, calcium, and sulphur) required for plant growth (Wierzbowska *et al*., 2016).However, the occurrence of cadmium, cobalt, manganese, nickel, lead and zinc has been reported in compost made from such wastes (Goen and Liang, 1998; Zufiaurre *et al*., 1998; Ciba *et al*., 1999; Staelens *et al*., 2000; Hong *et al*., 2002; Smith, 2009; Kanmani and Gandhimathi, 2013) and leachate from unlined landfills create environmental hazards. Heavy metals therefore need serious assessment before compost made from solid wastes is used by farmers (Yuskel, 2015) since, in certain cases, the levels exceed the specified limits (Vyas, 2007).

This paper reports the results of an investigation of heavy metal concentrations in leachates and soils discharged from degradable municipal solid wastes at the Mwenderi dumpsite, near the Sosiani River, Eldoret, Kenya.

Methods

This study was carried out in Eldoret, a city in Western Kenya located at 0˚31'N, 35˚16'E at an elevation varying from about 2100 to more than 2700 m. The population grew from around 194,000 in 1999 to 290,000 in 2009 (Government of Kenya, 2010). The Eldoret municipal dumpsite is located to the south west, approximately 4 km from the Central Business Centre and next to a residential estate (Figure 1). The residential areas were categorised in three classes depending on the amount of monthly rent paid by the tenants i.e. high income (> USD 200), middle income (USD 100-200) and low income (USD 100 and below).

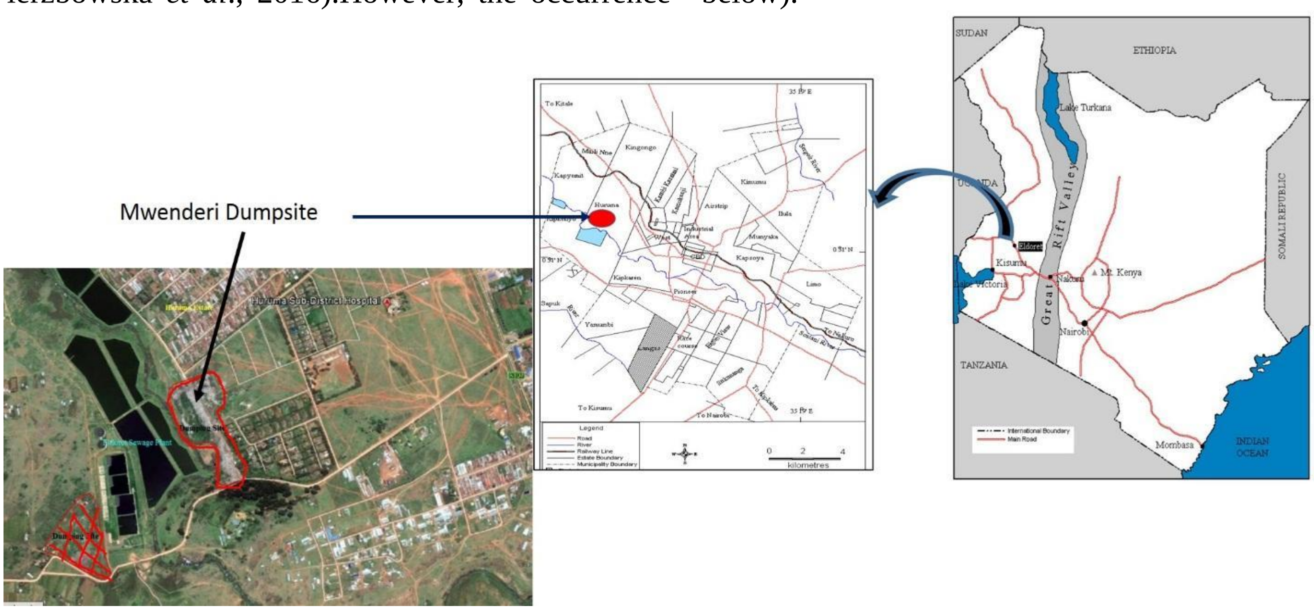

Figure 1. The dumpsite and its location in Eldoret and Kenya. Map of Kenya, Eldoret town showing the estates, the central business district, and the location of the dumpsite.

Wastes were sampled by taking the first of every three bags unloaded at the dumpsite and categorised on the house hold status at least six bags were selected and the mixed waste was immediately placed into 20-litre plastic buckets. The waste samples were then mixed and a 100-kg subsample weighed out and segregated into eight classes: putrescible organic waste (kitchen waste, fruit and vegetable peels, yard waste), textile/clothes, paper, plastic/polythene bags, glass, metal, ash and clinical (hazardous) wastes.

About 2 kg each of organic, degradable paper and textiles, were then taken, thoroughly mixed and collected in polythene bags for heavy metals analysis. Samples from stagnant pools and flowing leachate from the dumpsite were collected into plastic bottles that had been pre-cleaned with concentrated nitric acid and the rinsed with distilled water. They were kept in an ice box with ice-bags, transported to the laboratory and refrigerated at 4^{o}C until analysed.

The leachates, wastes and water were analysed for lead, arsenic and cadmium by flame atomic absorption spectrophotometry (PerkinElmer, Analyst™ 200, Waltham, MA 02451 USA) with operating conditions as in Table 1 (USEPA, 2006). All reagents were of analytical grade, purified water was used for all dilutions and all glassware was cleaned by soaking in a 10% nitric acid solution and then rinsing them with purified water prior to use to prevent contamination. The element stock solutions (1000 μgml^{-1}) were provided by Inorganic Ventures (Madrid, Spain).

Table 1. Operating conditions for flame atomic absorption spectrometry.

	Cadmium	Lead	Arsenic
Wavelength (nm)	228.8018	217.0005	189.0
Flame length burner (mm)	100	100	100
Flame	Air-acetylene	Air-acetylene	Air-acetylene
Gas mixture flow (L h^{-1})	50	65	80

Waste samples were separately air-dried for 5 to 6 days and mixed thoroughly to achieve homogeneity, and then ground to reduce the particle size and sieved through a 2-mm mesh (Brigden *et al.*, 2008) after which a 1-g sample was taken from the sieved sample and weighed into a boiling tube. Then 15 ml of a ternary mixture, consisting of 20 ml concentrated. Hydrochloric acid, 500 ml concentrated nitric acid and 50 ml concentrated Sulphuric acid was added to the boiling tube. The samples were then digested in a block digester under a fume hood for 24 minutes and then allowed to cool. Distilled water was then added to each and filtered through a9-cm diameter Whatman No 42 filter. It was then made up to the mark with distilled water and the solutions were then stored for heavy metal determination.

The raw water and leachate samples (100 ml) were filtered through 9-cm diameter Whatman No 42 filter paper, and 15 ml of concentrated nitric acid and 10 ml of 50% concentrated solution was added to hydrochloric acid the filtrate The content was evaporated almost to dryness on a hot plate, after which a further 7 ml of 50% concentrated sulphuric acid was added and heated for 10 minutes. The solutions were allowed to cool, and then distilled water added to each and filtered into a 100 ml Pyrex volumetric flask through a 9-cm Whatman No 42 filter. This was then made up to the100ml mark with distilled water and heavy metals determined using a Perkin Elmer 200 Atomic Absorption Spectrophotometer.

Results

In general, the concentrations of heavy metals in household waste did not vary according to its source (Table 2). The average concentration of lead was 306.2 mg kg^{-1} with a lower concentration being recorded from the CBD (the average in household waste was 321.0 mg kg^{-1}). Arsenic concentrations (mean = 36.2 mg kg^{-1}) varied only slightly while cadmium (mean = 26.8 mg kg^{-1}) was rather above average in wastes from high income households. The concentrations of lead exceeded acceptable standard for East African wastes in all household waste but was slightly below in waste from the CBD. Arsenic concentrations exceeded these standards in all but the waste from high-income households while cadmium exceeded these standards in the waste from all sources. The concentrations of these heavy metals all exceeded the standards recommended by the US Environmental Protection Agency by factors of three to five.

Table 2: The concentrations (mg kg^{-1}) of heavy metals in solid waste from the Mwenderi dumpsite. CBD = central business district.

Household status	Lead	Arsenic	Cadmium
High income	308.4	33.1	29.7
Middle income	319.0	37.2	25.1
Low income	335.7	38.6	25.6
CBD	255.5	36.1	25.7
East African Standards	297.6	35.6	23.9
US EPA Standards	100.0	10.0	5.0

Heavy metal concentrations in the water and leachate exceeded the WHO standards (Table 3) and may therefore have some toxic impacts in the environment. The concentrations in water were lower than in the leachate; probably because of dilution but the levels in the river still pose an environmental risk.

Table 3. The concentrations (mg l^{-1}) of heavy metals in water from the Sosiani River and leachate from the Mwenderi dumpsite, compared with WHO acceptable levels.

Metal	Water	Leachate	WHO standard
Arsenic	0.060	0.137	0.001-0.002
Cadmium	0.009	0.012	0.005
Lead	0.078	0.297	0.010

Discussion

The waste dumped in this site is not sorted and the dumpsite lacks a leachate collection and removal system which removes leachates for treatment before they leave the landfill. There is also lack of composite liners at the bottom and side of the dumpsite thus allowing leachates to move into the ground water around the dumpsite. The lack of ground water monitoring programmes and prescribed procedures makes it difficult to determine how much waste material escapes from the landfill to contaminate the surroundings.

There is no procedure currently at the dumpsite for assessment of heavy metals. There is an urgent need to install systems that prevent the escape of heavy metals and reduce the risk of environmental contamination.

This is particularly important because the Sosiani River ultimately flows into Lake Victoria, which supplies water to many towns and villages and also supports a highly productive fishery. The bioaccumulation of metals from the lake, either directly from the water or through the consumption of fish, could therefore be a potential threat to human health. Studies has shown presence of elevated lead and cadmium in some of the rivers draining into Lake Victoria, which serve as the sink to excess untreated effluent of both industrial and municipal origin from major towns (Mutuku *et al*., 2014). Adverse health effects and resistance to decay make heavy metals particularly hazardous pollutants. Although heavy metal toxicity is well-documented, managing its exposure and related risks is a challenge around the world (World Health Organization, 2011). Bioremediation can be used to clean up the dangerous wastes, because the procedure can be easily carried out on site without initiating a major disruption of normal actions and threats to human and environment (Gupta *et al*., 2016).

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