Assessment of Heavy Metal Contamination from Municipal Solid Waste Open Dumping Sites in Bangladesh

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Abstract: *Co-disposal of the household originated hazardous materials with municipal solid waste (MSW) into the open dumping sites is the usual practice in Bangladesh. In this paper, characterization of heavy metals in MSW in the open dumping sites in Bangladesh is presented. MSW samples were collected from two open dumping sites at Matuail, Dhaka and Khulna and analyzed for total heavy metals content (Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn) and also heavy metal fraction (water extractable, exchangeable and bio-fraction). Moreover, Toxicity Characteristic Leaching Procedure (TCLP) extraction was done to evaluate pollution potential of heavy metals from the dumping sites. Leachate samples were also collected and analyzed for heavy metals content. The results of the analysis showed that the total metals content in MSW at the Matuail dumping site is higher than Khulna dumping site and the metals are predominantly associated with fine soil fraction. The total heavy metals content in MSW in the study sites are less than the total metals content in MSW at the dumping sites reported from Japan, India and Thailand. The study results showed that both sites contain high bio-available fraction of metals, which may easily be entered into a food chain and may cause health hazards. The result of TCLP extraction with the USEPA regulatory levels showed that the dumping sites are non-hazardous in nature in the context of heavy metal pollution. The runoff leachate also contains insignificant concentration of heavy metals. Under the present condition prevailing at the dumping sites, the dissolution of the acid soluble metal and the associated risk of heavy metal contamination are deemed very low. The findings may be useful as a first step in evaluating the heavy metals pollution potential from the open dumping sites in Bangladesh.*

Keywords: *Open dumping, municipal solid waste, heavy metal, leaching, leachate, Bangladesh.*

1. Introduction

In Bangladesh, urban population especially in city areas is increasing rapidly. This rapid increase in urban population causes a significant pressure on urban services like municipal solid waste (MSW) management. MSW management systems in all cities in Bangladesh are very much traditional and labor based and most of the solid wastes are disposed in the open dumping spaces due to lack of regulatory systems and effective management. Open dumping of municipal solid waste without source segregation is the usual practice in developing countries like Bangladesh. Co-disposal of household hazardous waste including batteries, paint residues, ash, treated woods and electronic wastes increases the heavy metal content in MSW dumping sites (Para et al., 1999; Esakku et al., 2008; Ahsan et al., 2013).

One of the major environmental impacts of municipal solid waste disposal is the influence of heavy metals in the dumping site. The effects of heavy metals are found to vary with the conditions prevailing in the dumpsites and its binding forms. The open dumpsite being exposed to the atmospheric condition undergoes different effects due to oxygen diffusion. Under high redox condition, the binding of metals to Mn and Fe oxide increases, whereas binding to carbonate, organic compound and sulfide tends to decrease (Prechthai et al., 2008). With more possibility of oxygen diffusion through the upper layer of the dumpsite and with sufficient moisture content, the degradation rate and the acid buffer capacity

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of the dumpsite is highly influenced. Under this condition, there is a drop in alkalinity, pH and sulfide oxidation, where heavy metals are easily available and released (Bozkurt et al., 2000; Prechthai et al., 2008).

Professionals in MSW management often require interpretation of the leachability of metals in order to assess the risk of dumping sites to human health and environment (Scott et al., 1990). Leaching tests are often applied in assessing worse case environmental scenario, where components of the samples become soluble and mobile. Various leaching methods have been cited in the literature. The mobility and toxicity of heavy metals present in dumping sites depend on the chemical form of the metals. Knowledge of heavy metal content, their species and leachability at various environmental conditions from the dumping site is a pre-requisite for assessing hazardous potential to the environment. Therefore, the hazardous potential of dumpsites can be better evaluated by fractionation of the metal content into bio-available, exchangeable, water soluble, reducible, oxidizable and residual fractions. The exchangeable and bio-available fractions are easily available for biological functions and can easily be entered into the food chain.

The presence of toxic heavy metals in the dumping sites in Dhaka and other cities in Bangladesh may create an acute pollution of soil and water and also may pose health hazards to the city people. However, no study has yet been conducted to assess the heavy metal content of the MSW and its pollution potential to the environment in Bangladesh. The pollutants may spread with high monsoon rain in and around the dumping sites. Leachate from dumping sites may also pose an important hazard for the environment. Several cases of groundwater pollution from landfill leachate were reported (Arneth et al., 1989). This study was conducted on the samples collected from two open dumping sites (one is Matuail, Dhaka and another is Khulna) in Bangladesh. The purpose of the present research work is to characterize the heavy metals content in the solid wastes disposed of to the dumping sites and its mobility potential in different forms under various conditions. The concentration of the heavy metals in the runoff leachate from the dumping sites was also analyzed in this study.

2. Materials and Methods

2.1 Description of the selected dumpsites

More than 3500 tons of MSW are generated per day by 12 million populations in Dhaka City, of which about 1200 tons of wastes are disposed into the Matuail dumping site by Dhaka City Corporation (Yousuf, 2009). The total area of the Matuail landfill is about 40 ha, half of which is a 15-year old dumping site. Before 2007, the site was an open dumping site receiving about 1800 tons of MSW daily. The site is now converted into sanitary landfill having well managed daily operation, leachate and gas collection system. On the other hand, the daily generation of MSW in Khulna City is about 520 tons, of which about 50% of the MSW is collected and dumped by Khulna City Corporation (KCC) from 1977 into the open dumping site at Khulna, located about 8 km away from the city center. The total area of this dumping site is 20 acres. Recently, KCC has started a new dumping site and thus dumping to this old site is closed for the last few years. The site is unprotected and uncontrolled with no leachate or gas collection system.

2.2 Basic characteristics of MSW in Bangladesh

The general nature of MSW in the urban areas of Bangladesh is almost the same and very much similar to that of the cities of least developed Asian countries. The waste generation rate varies from 0.325 to 0.50 kg/cap/day (Alamgir, 2009; Rahman and Al-Muyeed, 2010), of which major source of MSW are generated from residential (75-85%), commercial (11-22%), institutional (1.0-1.5%), municipal services (0.5-1.25%) and other sources (0.4-2.5%). The typical composition of MSW is 68-81% food and vegetable waste, 7-11% paper and paper products, 3-5% polythene and plastics, 1-7% textiles and 7-19% inert materials like glass, metals, ceramic and construction materials. Another study by Alamgir and Ahsan (2007) reported an average composition of MSW in the cities of Bangladesh was about 74.4% organic matter, 9.1% paper, 3.5% plastic, 1.9% textile and wood, 0.8% leather and rubber, 1.5% metal, 0.8% glass and 8% other waste. The MSW contains high volatile solids (43-71%), while ash residue from 29-57% and high moisture (56-70%). The average value of pH are in the range 7.7-8.7, with average carbon, nitrogen, potassium and phosphorus contents of 11.50%, 0.91%, 0.76% and 0.33%, respectively (Alamgir, 2009).

2.3 Solid waste sampling and analysis

Four MSW samples from the dumping site at Khulna and seven MSW samples from the dumping site at Matuail, Dhaka were collected during August 2008. Partially decomposed MSW samples of about 4.0 kg from each sampling location from the two dumping sites were taken at a depth of about 0.3 m by manual excavation. All the MSW samples were then air dried and the composition of each sample was determined. Each air dried sample was then sieved through 2.0 mm sieve and about 100 gm of each samples passing through 2.0 mm sieve (fine fraction) was collected into plastic containers for subsequent heavy metal analysis. The fraction over 2.0 mm of each sample was then thoroughly mixed, grinded and sieved through 2.0 mm sieve and about 100 gm of each samples passing through the sieve (grinding fraction) was collected into plastic containers for subsequent laboratory analysis.

2.4 Extractions

Acid extraction, water extraction, Ethylenediaminetetraacetic acid (EDTA) extraction and KNO_3 extraction were done to assess the total heavy metals content, water extractable, exchangeable and bio-available fractions of heavy metals, respectively in both of the fine and grinding fraction of the collected samples. For the determination of total heavy metal content, aqua regia extract of both fractions of MSW samples were done using HNO_3 and H_2O_2 according to the standard method by USEPA (1996). The digests were filtered through 0.10 μm membrane filter and then filled to 50 mL with ultra pure water for element analyses. For water extraction, 5.0 gms of each fraction were mixed with 50 mL ultra-pure water (L/S ratio is 10) and shaken for 4-hr using a mechanical shaker. Then, samples were filtered through 0.10 μm filter paper and acidified to pH 2.0 and stored at 4^0C for later analysis for heavy metals.

For EDTA extraction, 4.0 gm of samples of each fraction was added with 40 mL of 0.05 M DTPA, 0.01 M $CaCl_2$, 0.1 M TEA (triethanolamine) buffered at pH 7.3 and mechanically shaken for 2-hr. Samples were then filtered and stored for later analysis for heavy metals. For KNO_3 extraction, samples were mixed with 0.5 M KNO_3 at L/S ratio of 1:4 and mixed using a mechanical shaker for 16 hrs. Samples were filtered and stored for subsequent heavy metals analysis. Moreover, TCLP extraction according to USEPA (1992) was done to evaluate pollution potential of heavy metals from the dumping sites. The extract solution with a pH of 4.93 ± 0.05 was used for the test. All the extractions were done twice for accuracy and the concentrations of Cd, Cr, Pb, Cu, Ni, Zn, Fe, Mn and Mg were measured by using ICP-AES. The moisture content of solid waste was analyzed by drying at 105^0C, whereas the volatile content was determined by the method of ignition at 550^0C. The pH and electrical conductivity (EC) of the samples were measured by adding 2.0gm of samples into 20 mL ultra-pure water (L/S ratio is 10) and shaken for 2-hr (Prechthai et al., 2008). Samples were then filtered with 0.45 μm filter paper after stabilizing for 20-30 minutes. The pH and EC of the samples were then measured using pH and EC probes.

2.5 Leachate sampling and analysis

There is no leachate collection system in the Khulna dumping site. Therefore, four leachate samples were collected at the time of solid waste sampling from the accumulated leachate into the depressions inside the dumping site. The Matuail dumping site has pipe and surface drain networks for runoff leachate collection. The collected leachate is treated by the stabilization pond system (consists of four ponds) located nearby the site. Two leachate samples were collected from the surface drains and three samples from three ponds. Each sample was collected into plastic sampling bottle of 250 mL capacity. All the samples were acidified with 1.0 mL concentrated HCl, labeled properly and preserved well for subsequent laboratory analysis.

The leachate analysis was done in duplicates following the standard methods for water and wastewater analysis (APHA 1998). The pH and EC of the leachate samples were measured using pH and EC probes and total organic carbon (TOC) by TOC analyzer. For heavy metal analysis, 100 mL of the leachate sample was digested with 65% HNO_3, then filtered and analyzed for metal contents (Cd, Cr, Pb, Cu, Ni, Zn, Fe, Mn and Mg) using ICP-AES.

3. Results and Discussion

3.1 Basic characteristics of solid waste at the dump sites

Table.1 shows the average result of physical and chemical characteristics of the MSW samples tested. The composition of waste is presented in Figure 1. The pH of the waste at both sites is within the neutral range indicating the possibility of waste to neutralize the organic acid that can be generated from the anaerobic degradation of organic matter. The moisture content and the total solids in both sites are not varied significantly; however, a significant variation in volatile solids is observed. In Matuail dumping site, every day fresh wastes are dumped containing higher organic matter and plastic than the wastes at Khulna dumping site, the wastes are partially decomposed. The wastes at Khulna dumping site are more stable as the last dumping was done only five years ago. The major identifiable components of the wastes were soil, plastic, noncombustible and combustible matters (Figure 1). The composition of the samples varied significantly, indicating the heterogeneous nature of the sites.

Table 1 Physical and chemical characteristics of the solid waste (mean and SD)

Location	pH	EC (mS/cm)	Moisture (%)	Volatile Solids (%)	Total Solids (%)
Matuail, Dhaka	7.76 ± 0.57	1.107 ± 0.68	46.51 ± 6.25	46.04 ± 6.25	52.35 ± 6.25
Khulna	7.95 ± 0.26	2.64 ± 2.12	40.76 ± 5.03	18.94 ± 1.40	59.24 ± 5.03

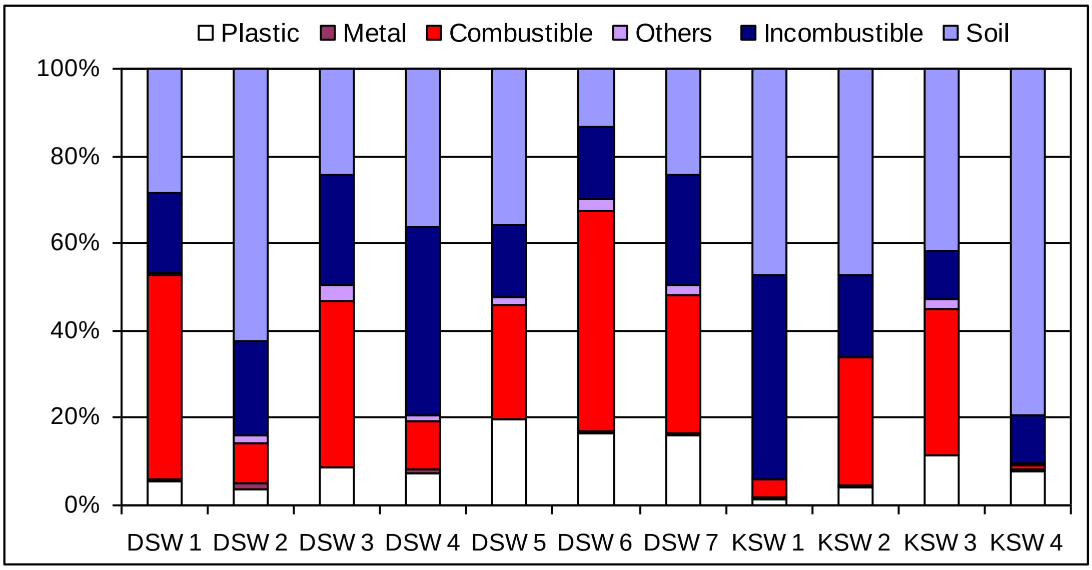

Figure 1 Composition of solid waste in the dumpsites. DSW and KSW mean the waste from Matuail, Dhaka dumping site and Khulna dumping site, respectively

3.2 Heavy metal content

The mean concentration of heavy metals and its range (minimum and maximum values) in solid waste samples of both Matuail and Khulna dumping sites are shown in Table 2. The average metal contents in both sites are also shown in Figure 2. In Matuail, heavy metals are predominantly associated with the fine fraction; whereas in Khulna, heavy metals are predominated in grinding fraction. The presence of Cd and Co in both sites is very insignificant, much Cr, Cu, Mn, Ni and Zn are present in Matuail than Khulna. However, in Khulna, the concentration of Pb is higher than Matuail. In Bangladesh, co-disposal of household hazardous wastes, paint residues, ash, electronic wastes, biomedical, plastic and non-ferrous metals with kitchen wastes are practiced. Moreover, a significant portion of the industrial wastes is also disposed to the dumping sites with the MSW. These two factors mostly contribute to the presence of heavy metals in the MSW at the dumping sites. Based on the average concentration, the heavy metal components in the MSW were found in the following order: Zn > Cu > Mn > Cr > Pb > Ni > Co > Cd in Matuail, Dhaka dumping site and Pb > Zn > Mn > Cu > Cr > Ni > Co > Cd in Khulna dumping site. The result shows contamination levels at Matuail dumpsite with Zn, Cu, Mn, Cr and Pb are at a higher level, whereas Pb, Zn, Mn and Cu are at a higher level at the Khulna dumping site.

The heavy metal contents in the MSW in the study sites were compared with reported level of heavy metals content in the dumping sites in Japan, India (Esakku et al., 2003; Esakku et al., 2008) and Thailand (Prechthai et al., 2008) as shown in Figure 3. It reveals that the heavy metals content in MSW at the two study dumping sites is less than other dumping sites. In Bangladesh, domestic wastes are mostly disposed to the dumping sites and the resource recycling from the MSW both at the secondary and the final disposal sites is the main factor behind the lower content of heavy metals in the wastes at both the dumping sites examined here.

Table 2 Heavy metal contents in the MSW at the dumping sites (mean and range)

Parameters in mg/kg dm	Matuail Dumping Site		Khulna Dumping Site	
	Grinding Fraction	Fine Fraction	Grinding Fraction	Fine Fraction
Cadmium (Cd)	ND	ND	ND	ND
Cobalt (Co)	0.0457	ND	ND	ND
	(0.088 - 0.23)			
Chromium (Cr)	12.06	25.23	2.66	2.28
	(5.03 - 19.66)	(10.10 - 81.19)	(2.12-3.62)	(1.72-2.96)
Copper (Cu)	18.95	41.53	12.31	8.95
	(4.58 - 30.30)	(14.41-137.70)	(5.66-17.70)	(4.72-14.66)
Manganese (Mn)	13.84	30.16	23.2	19.72
	(8.54 - 22.20)	(9.66-82.89)	(20.00-25.20)	(16.28-24.20)
Nickel (Ni)	1.54	3.02	0.875	0.70
	(0.78 - 2.86)	(0.84-9.89)	(0.68-1.22)	(0.42-0.90)
Lead (Pb)	8.36	21.14	43.49	31.55
	(2.24 - 17.75)	(5.66-87.79)	(18.74-69.60)	(11.18-69.6)
Zink (Zn)	23.42	62.24	29.85	20.94
	(18.05 - 32.14)	(19.41-163.80)	(15.98-45.80)	(12.46-29.4)

ND = Not Detected. Values into the parenthesis indicate the range (minimum and maximum value)

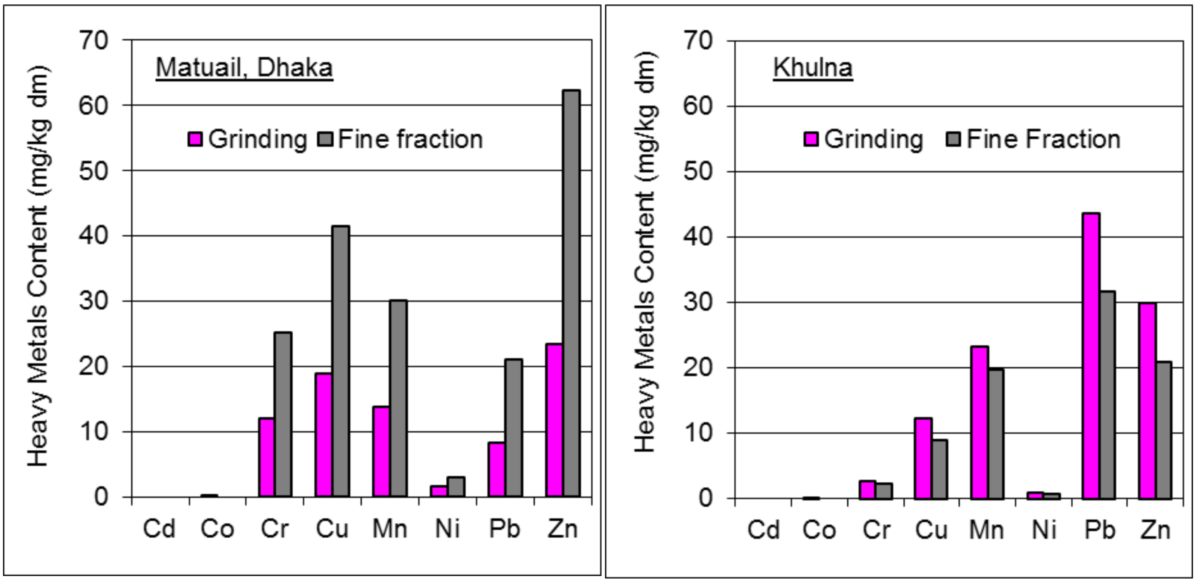

Figure 2 Average concentration of heavy metals in the MSW samples at the dumping sites

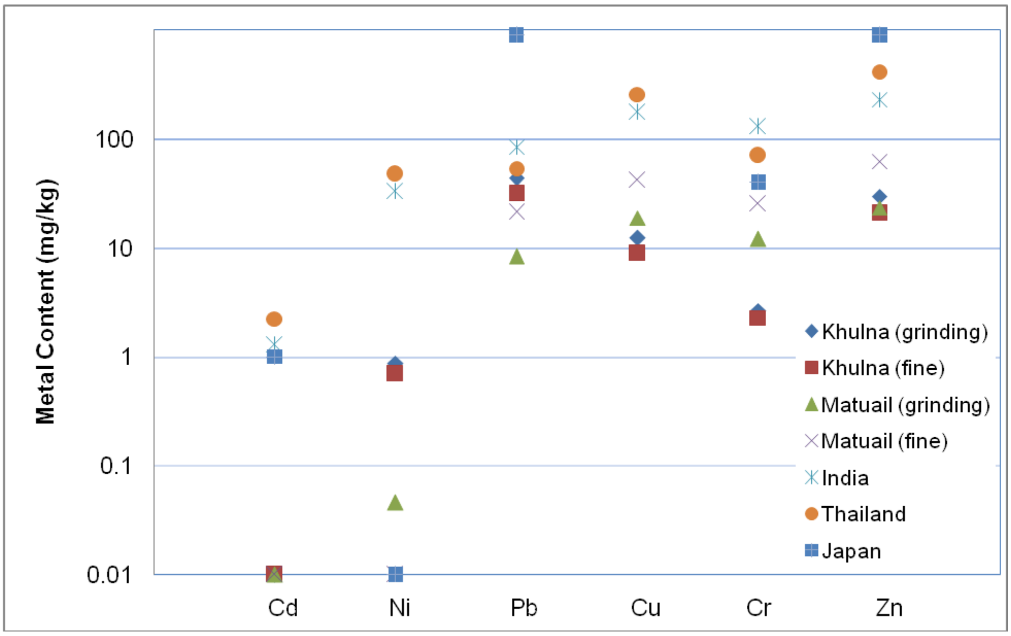

Figure 3 Comparison of heavy metals content in MSW at several dumping sites in Asia

3.3 Heavy metal leaching test

The mobility and thus toxicity of heavy metals in wastes depends largely on their binding forms. The water soluble, bio-available and exchangeable fraction of heavy metals in the two dumping sites are presented in Table 3. For Matuail, these values are associated with the fine fraction and for Khulna, these are associated with grinding fraction. The test results showed that the leaching of the metals with rainwater is very low, mostly insoluble in water and metals are not expected to be released with rainwater under the conditions prevailing in the dumping sites. However, bio-available fractions of the metals like Pb, Mn and Cu are significant and may easily be entered into the food chain. This high bio-available fraction of the heavy metals in the dumping sites may cause significant health hazard and the sites must be restricted for vegetable growing and other agricultural activities. Bio-availability of the metals has the following order: Pb > Mn > Cu > Ni > Zn > Cr in Matuail and

Pb > Cu > Mn > Zn > Ni > Cr in Khulna. The exchangeable fraction is mobile fraction that is also easily available for biological functions. The test results indicated that an exchangeable fraction of the metals is less available for biological functions.

Table 3 Result of leaching tests (mean and SD)

Heavy Metals	Matuail Dumping Site			Khulna Dumping Site		
	Water Soluble (%)	Bio-available (%)	Exchangeable (%)	Water Soluble (%)	Bio-available (%)	Exchangeable (%)
Cd	0	0	0	0	0	0
Co	0	0	0	0	0	0
Cr	0	3.77±2.72	0	0	0	0
Cu	0.032±0.085	33.11±24.80	0.11±0.194	0.826±1.185	45.52±9.09	0.70±0.58
Mn	0	39.16±24.96	0.082±0.16	0	39.06±7.32	0.074±0.15
Ni	0	24.75±18.64	0.29±0.71	0	22.65±11.24	0
Pb	0	54.11±36.45	0.07±0.18	0.25±0.05	62.47±33.96	0.103±0.207
Zn	0	24.07±15.54	0.114±0.16	0	34.95±8.82	0.058±0.115

The result of TCLP extraction with USEPA regulatory levels is shown in Table 4. The concentration of Zn, Mn and Cu analyzed in the TCLP leachate were high. However, all the heavy metals especially Cd, Cr and Pb concentration in TCLP test were well below the regulatory levels. Thus the degree of leaching and the risk of metal contamination and the environmental hazard associated with the dumpsites are very low with respect to Cd, Cr and Pb contents (< 1, 5, 5 mg/L, respectively). However, more sampling and analysis should be done to confirm this hypothesis.

Table 4 Heavy metal concentrations in the extracted leachate from TCLP test in mg/L (mean and range)

Heavy Metals	Matuail Dumping Site	Khulna Dumping Site	USEPA Regulatory Level
Cd	0	0	1.0
Co	3.04 (2.95-3.25)	2.93 (2.9-2.95)	NA
Cr	3.24 (3.2-3.3)	3.29 (3.2-3.4)	5.0
Cu	4.66 (3.3-6.4)	4.20 (4.1-4.4)	NA
Mn	69.87 (46.35-111.0)	59.71 (30.35-77.5)	NA
Ni	2.54 (0-7.20)	0	NA
Pb	2.06 (1.8-2.43)	3.35 (3.1-3.8)	5.0
Zn	70.23 (19.05-170.50)	11.88 (8.55-17.0)	NA

3.4 Characteristics of Leachate

The characteristics of the leachate collected from the study dumping sites are presented in Table 5. It reveals that pH of the leachate samples is within the neutral range and there is no significant variation. The EC and TOC levels of the leachate from Matuail dumping site are much higher than Khulna; leachate in Matuail dumping site contains much organic matter, as the major portion of the MSW are partially decomposed. Significant variations of these parameters are observed in both sites as a result of the influence of solid waste age heterogeneity on the degradation rate.

Table 5 Characteristics of leachate from the dumpsites (average and range)

Parameter	Khulna Dumping Site	Matuail Dumping Site
pH	7.23 (7.03-7.54)	7.71 (7.35-8.09)
EC (mS/cm)	3.14 (1.57-5.89)	10.45 (3.77-16.16)
TOC (mg/L)	219.7 (74.3-420.0)	2351.0 (202.0-4390.0)
Cd (mg/L)	0	0
Co (mg/L)	0	0
Cr (mg/L)	0	0.02 (0.013-0.039)
Cu (mg/L)	0	0
Mn (mg/L)	0	0.01 (0-0.026)
Ni (mg/L)	0	0.01 (0.06-0.023)
Pb (mg/L)	0	0
Zn (mg/L)	0	0.01 (0-0.032)

The metal contents in the leachate samples from both dumping sites are insignificant. The concentration of the metals in the runoff leachate is very much similar to water exchangeable fraction as presented in Table 3. Absent or very low level of Mn in the runoff leachate indicates very high redox potential prevailing at the dumpsites. Under such condition, the binding of metals to Mn and Fe oxide increases, Mn precipitates with carbonate and sulfide and retains at the dumpsite (Prechthai et al., 2008). Therefore, the dissolution of the acid soluble metal is probably low under the condition that presently prevailing at the dumpsites.

4. Conclusions

The municipal solid waste (MSW) at the Matuail dumping site at Dhaka is relatively fresh and is less decomposed than the waste at Khulna dumping site. The heavy metals content in MSW at Matuail site is higher than Khulna, which is mainly associated with fine soil fraction. The high bio-available fraction of the metals especially Pb, Mn and Cu in both the dumping sites may easily be entered into the food chain and may cause health hazards. The TCLP extractable metal contents were well below the USEPA regulatory levels; thus the dumping sites are non-hazardous in nature in the context of heavy metal pollution. The runoff leachate also contains insignificant concentration of heavy metals. Under the present condition prevailing at the dumping sites, the dissolution of the acid soluble metals and the associated risk of environmental pollution by heavy metals are very low. However, there may be other organo-chemicals that may contaminate the soil and water in and around the dumping sites. This research work was based on limited samples. More sampling and also depth wise sampling and analysis as well as sequential extraction of metals are thus suggested in order to obtain a firm conclusion regarding the binding of heavy metals and their pollution potential from the dumping sites in Bangladesh.

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