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Leaching characteristics of solid waste at an urban solid waste dumping site

Rowshan Mamtaz [1], Md. Hasan Chowdhury[2]

[1] *Department of Civil Engineering*
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh
[2] *Chittagong Port Authority, Chittagong, Bangladesh*

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Abstract

Rapid urbanization of Dhaka city, the capital of Bangladesh, and its fast increasing population over the last few decades have created immense pressure on its urban services including solid waste management. DCC disposes off the city's solid waste in open low lying areas without any segregation and any soil cover. Matuail, located approximately 5 km southwest from the city centre, is one of the major landfill sites of DCC and has been selected as the study area in the present research. In order to assess the pollution level and the leaching behaviour of wastes, solid waste, leachate and soil samples were collected from the study area. The presence of significant concentration of toxic heavy metals in solid waste found in the present study shows that there is a potential for contamination of soil and groundwater by leaching. The concentration of heavy metals in converted soil is much higher than that of natural soil in the dumping site. This finding further confirms that contamination by leaching is actually occurring. The high concentration of Fe, Cu, Mn and Zn in TCLP extracts indicates that there is a great possibility of soil and ground water contamination due to leaching of solid waste. The average concentration of heavy metals in TCLP extracts ranges from 135 mg/kg for Zinc (Zn) to 0.20 mg/kg for Cadmium (Cd). Among the heavy metals tested in TCLP extract, manganese shows the maximum leaching tendency (about 33%) whereas iron shows minimum leaching behavior (about 1%).

Keywords: Leaching, Solid Waste, Dumping Site, Leachate, Groundwater

1. Introduction

Rapid urbanization of Dhaka city and its fast increasing population over the last few decades have created much pressure on its urban services. The existing services are far too inadequate to serve the inhabitants and solid waste management is one of the major problems faced by the authorities and the inhabitants alike. Dhaka City Corporation (DCC) is executing the solid waste disposal as its task. DCC does not have any sanitary landfill for ultimate disposal of waste. Present landfills operated by DCC are not properly designed to protect the environment and the neighbourhood from adverse impacts of landfill gas and leachate. Besides, potential health hazards as well as vegetation damage, unpleasant odours, soil pollution and water pollution are also major concerns. DCC disposes off the city's solid waste in open low lying areas without any segregation and any soil cover. Leaching from the solid waste (municipal, industrial and clinical) is a growing concern for the surrounding environment and public health. The waste disposed off at the dumping site is usually highly polluted with toxic metals. Disposal of waste on land may lead to leaching (aggravated by rainfall) and subsequent contamination of soil and groundwater aquifers and hence may pose a potential threat to environment.

Matuail, located approximately 5 km southwest from the city centre is one of the major landfill sites of DCC (having an area of 52 acres) and it has been selected as the study area in the present research (Figure 1).

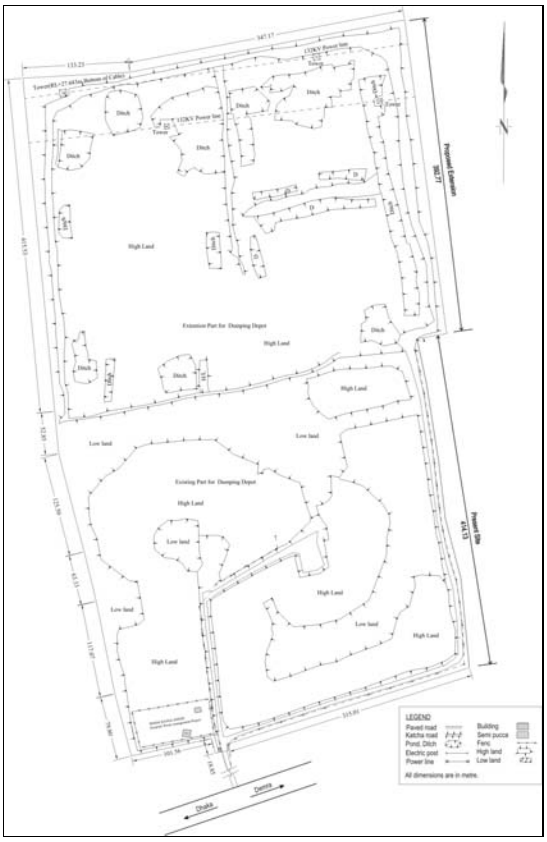

Fig. 1. Project location

The major objectives of the study are:

1. To determine the heavy metal concentration in solid waste,
2. To assess the contamination of natural soil and converted soil at the dumping site,
3. To analyse the composition of leachate, and
4. To study the leaching behaviour of waste

2. Materials and methods

Four types of samples were collected in the present study to determine the concentration of heavy metals and to understand their leaching behaviour (Figure 2). These are (1) solid waste samples, (2) soil samples that have been formed from solid waste (converted soil), (3) existing natural soil, and (4) leachate.

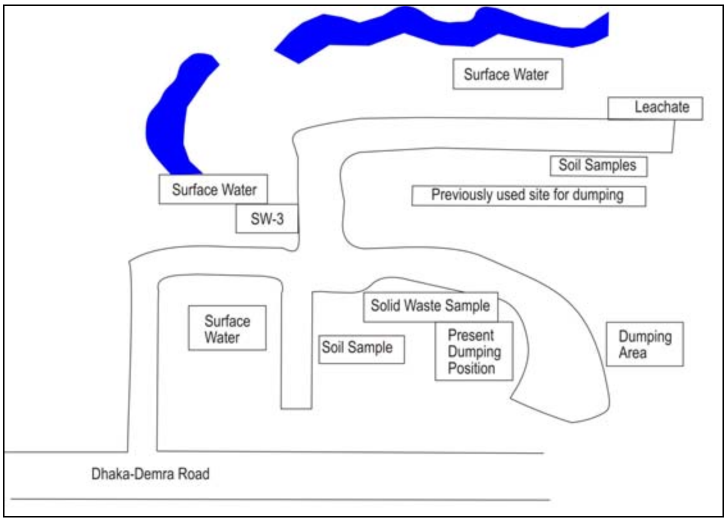

Fig. 2. Sampling locations

Solid waste that is being dumped at Matuail consists of municipal, industrial and clinical waste and hence is rich in toxic and hazardous substances. To study the concentration of toxic heavy metals in waste, five solid waste samples were collected randomly from different locations approximately 5 to 6 m apart within the study site. The solid waste samples were digested to determine the total concentration of Fe, Pb, Cu, Zn, Mn, Cd and Ni. The digestion was performed following Aqua-Regia digestion method. Testing of above mentioned parameters was performed using flame emission atomic absorption spectrophotometer (AAS) (Shimadzu AAS 6800).

Matuail disposal site has been used as dumping site for more than ten years. In this site solid waste that was dumped long ago has been converted to soil and local people use a portion of this site for agriculture. Four converted soil samples were collected along the periphery of the site. At each location, samples have been collected from three different depths i.e., 0, 0.5 and 1 m. Altogether 12 (twelve) converted soil samples were collected. Natural soil samples were also collected from one location from the above mentioned depths. To determine the concentration of heavy metals such as Fe, Pb, Cu, Zn, Mn, Cd and Ni, both converted soil and natural soil were digested and subsequently analyzed using AAS.

Leachate is the liquid that percolate through solid waste and has extracted dissolved and suspended materials from it. The liquid portion of leachate is produced from decomposition of waste and also comes from external sources such as rainfall, ground water, etc. The generation of leachate is a long term process and leachate is usually collected by drilling borehole in the vicinity of the dumping site. In the present study leachate could not be collected following the standard practice. Instead, the liquid secreted from the solid waste was considered as leachate and was collected from four points as it spread out into natural drains along the periphery of the dumping site (Plate 1). Therefore, the term leachate used in the present study does not represent the ideal leachate. To analyze the composition of leachate, pH, colour, TS, TDS, TSS, Fe, Pb, Cu, Zn, Mn, Cd and Ni were determined following the standard methods (APHA, AWWA and WEF, 1998).

The leaching tests of five solid waste samples were carried out following the USEPA Method 1311 (USEPA, 1992) known as Toxicity Characteristics Leaching Procedure or TCLP to assess the leaching behavior of solid wastes. Among the five samples collected, two TCLP tests were performed for each sample. The concentration of heavy metals in TCLP extract was determined following standard method using AAS.

3. Results and discussion

The result of analysis of heavy metals in solid waste samples is presented in Figure 3. The average concentrations of Fe, Zn, Cu and Pb were found to be about 9600, 1541, 886 and 328 mg/kg respectively. Concentrations of Ni (23 mg/kg) and Cd (0.8 mg/kg) are much less than these four parameters. Therefore, it could be said that the potential of significant leaching was present in Fe, Zn, Cu and Pb.

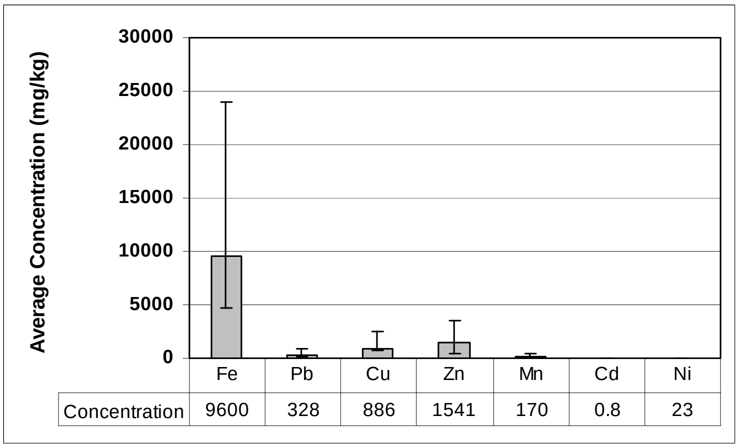

Fig. 3. Average heavy metal concentration in solid waste samples

Natural soil and converted soil (soils formed from solid wastes due to dumping over a long time) were analyzed to investigate the possible contamination of heavy metals. The presence of heavy metals such as Pb, Cu, Zn, Fe, Mn, Cd and Ni was determined at varying depth (0, 0.5 and 1 m). Since the concentrations of these parameters do not follow any regular trend with depth, no correlation between the concentration and depth can be established. For this reason average concentration is shown as the representative concentration for a particular metal in both the natural and converted soils (Table 1).

It has been observed from the data that heavy metal concentration in converted soil is significantly higher than that of natural soil for all the parameters (Pb, Cu, Zn, Mn, Cd, and Ni) except Fe. This finding shows that the converted soil, which formed due to dumping of wastes over the years, is highly contaminated with toxic metals. The concentration of Fe is higher in natural soil than converted soil. Further investigation is necessary to determine whether this is due to higher concentration of naturally occurring iron in that area. The high concentration of heavy metals in converted soil may in future lead to groundwater contamination. According to Chilton and Kinniburgh (2003), the baseline concentration of the heavy metals in soils is usually in the range of 0.1-200 mg/kg. Heavy metals such as Zn, Cd, Cu, Pb, Ni and Cr are present in all natural soils but are usually found at low concentration (Table 2). Higher concentration usually occurs in soils below or near landfills and agricultural lands that have been irrigated with contaminated water. This is supported by the findings of present study. Table 3 shows an indication of probable soil contamination with respect to maximum allowable limits for heavy metals in soil in different countries.

Table 3 shows that the concentration of Cd and Ni found in present study is less than the maximum allowable limit whereas concentration of Cu, Pb and Zn found in present study are much higher than the maximum allowable limit used in different countries.

The result of analysis of leachate samples collected from dumping sites shows that these is a potential for the soil and groundwater to be contaminated (Table 4). The test result shows that leachates have high concentrations of Fe, Zn, Ni, Pb and Cu.

Table 1
Representative average concentration of metal in natural soil and converted soil

Parameter	Converted soil (mg/kg) n = 12 (average±SD)	Natural soil (mg/kg) n = 3 (average±SD)
Fe	16533±351	30667±8327
Pb	1449±1307	91.17±18.3
Cu	519±29	44±6.8
Zn	2108±127	914±455
Mn	218±27	128±57.4
Cd	1.61±0.11	<MDL
Ni	37.25±5.7	24.67±2.7

Note: MDL stands for Minimum Detection Limit. For Cd, MDL is 0.001 ppm

Table 2
Normal content intervals and maximum allowable limits
of heavy metals in soils (Kloke 1980)

Chemical Element	Normal content interval (mg/kg)	Maximum allowable limits (MAL) (mg/kg)
Cd	0.1-1.0	3
Co	1-10	50
Cr	2-50	100
Cu	1-20	100
Ni	2-5	50
Pb	0.1-20	100
Zn	3-50	300

Plate 1. Leachate at Matuail dumping site

Table 3
Values of maximum allowable limits (M.A.L) for heavy metals in soil (mg/kg) used in different countries (in Kabata-Pendias 1995; USEPA 1983)

Chemical element	Austria	Canada	Poland	Japan	UK	Germany	U.S.A (1983)	Concentration found in converted soil in present study
Cd	5	8	3	-	3	-	0.7	1.61
Co	50	25	50	50	-	-	40	-
Cr	100	75	100	-	50	200	1000	-
Cu	100	100	100	125	100	50	100	519
Ni	100	100	100	100	50	100	500	37.25
Pb	100	200	100	400	100	500	200	1449
Zn	300	400	300	250	300	300	300	2108

The concentration of heavy metals in leachate found in the present study is less than the range of concentration normally found in leachate from municipal solid waste (Pohland et al, 1983; BUET, 2000). The reason for this may be that concentration of the leachate was diluted by rainwater since the samples were collected during monsoon. Moreover, the leachate samples under this study were collected from the periphery of the dumping site instead of drilling boreholes within the site. The generation of leachate is a long term process. Long term monitoring of groundwater quality and tracking of the movement of leachate are needed in order to determine any possible contamination of groundwater. Although the concentration of leachate under this study is different from those reported in other literatures, the finding of this study (Table 4) suggests that the leachate generated from the disposed solid waste is contaminated and proper attention should be given in the design of the landfill site in order to protect soil and groundwater.

TCLP tests were carried out to study the leaching behaviour of solid waste and the concentration of heavy metals in TCLP extract is presented in Table 5.

Using average heavy metal concentration in solid waste (Figure 3) and average heavy metal concentration in TCLP extract (Table 5), percentage of leaching of heavy metals are calculated and is presented in Table 6. From Table 6 it is observed that there is a high potential of leaching of heavy metals from solid waste especially for Mn, Cd, Ni and Zn. Dumping of solid waste at Matuail started more than 10 years ago and the degree of leaching depends on the time since disposal. There is no segregation of the different types of waste especially industrial and clinical wastes. The site was not designed as sanitary landfill site. For all these reasons mentioned above, the actual degree of leaching may be different from that calculated in the present study.

USEPA (1997) sets guideline values of heavy metal in TCLP extract for land disposal. Table 7 shows a comparison between the concentration in TCLP extract found in the present study and USEPA limit.

Concentration of only two parameters (Pb and Cd) could be compared with USEPA (1997) standard as shown in Table 7. For the other toxic heavy metals (Cu, Zn, Mn, Ni, Fe and Mn), there is no limit specified in USEPA guideline and therefore could not be compared. The compared data (Pb and Cd) indicates that the concentration in TCLP extract found in the present study is within the standard limit set by the USEPA (1997). However, it could not be confirmed within the scope of this study whether this finding is representative of the whole site. Therefore, it is suggested to carry out more extensive field sampling and testing program to assess the extent of contamination of groundwater aquifer by leaching.

Table 4
Concentration of different parameter in leachate sample

Parameter	Range of concentration in present study	Average Concentration
PH	7.75 - 8.5	7.96
Colour (Pt-Co)	5340 -15600	9130
TS (mg/l)	6315 -14387	9607
TDS (mg/l)	5226 - 7620	6133
TSS (mg/l)	1033 - 6767	3474
Fe (mg/l)	4 -16	10.5
Pb (mg/l)	0.33 -1.30	0.67
Cu (mg/l)	0.16 – 0.53	0.27
Zn (mg/l)	0.69 - 2.53	1.36
Mn (mg/l)	0.39 - 0.80	0.5
Cd (mg/l)	< M.D.L – 0.005	0
Ni (mg/l)	0.21 - 0.25	0.23

Note:

Minimum Detection Limit (M.D.L) for Cd: 0.001 ppm. Leachate sample have been collected from drainage channel along the periphery of the site without drilling boreholes.

Table 5
Average value of heavy metal concentration in TCLP extract

Parameter	Unit	MDL	Concentration Present in TCLP Extract					Average
			Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	
Fe	mg/l	0.04	2.3	1.3	6	3.2	4.55	3.47
	mg/kg		46	26	120	64	91	69.40
Pb	mg/l	0.001	0.33	0.29	0.29	0.57	0.58	0.41
	mg/kg		6.57	5.84	5.80	11.31	13.68	8.64
Cu	mg/l	0.014	0.12	0.16	0.02	0.53	3.75	0.92
	mg/kg		2.40	3.16	0.47	10.57	75.09	18.34
Zn	mg/l	0.004	2.49	3.30	2.35	4.81	20.76	6.74
	mg/kg		49.88	65.90	47.00	96.18	415	135
Mn	mg/l	0.02	2.15	2.52	3.59	3.02	2.86	2.83
	mg/kg		43.05	50.40	71.85	60.45	57.20	56.59
Cd	mg/l	0.001	0.010	0.010	0.006	0.012	0.013	0.010
	mg/kg		0.20	0.20	0.12	0.25	0.26	0.20
Ni	mg/l	0.001	0.15	0.09	0.08	0.16	0.41	0.18
	mg/kg		2.96	1.84	1.51	3.28	8.11	3.54

Table 6
Percentage of leaching of heavy metals with respect to average heavy metal concentration in solid waste

Parameter	Average Concentration in solid waste (mg/kg)	Average concentration in TCLP extract		% of leaching
		mg/l	mg/kg	
Fe	9600	3.47	69.20	0.72
Pb	328.26	0.41	8.64	2.63
Cu	886	0.92	18.33	2.06
Zn	1541	6.74	135	8.75
Mn	170	2.83	56.60	33.28
Cd	0.80	0.01	0.20	25.09
Ni	23.33	0.18	3.54	15.16

4. Conclusions

The presence of significant concentration of toxic heavy metals in solid waste found in the present study shows that there is a potential for contamination of soil and groundwater by leaching. The concentration of heavy metals in converted soil is much higher than the natural soil in the dumping site. This finding further confirms that contamination by leaching is actually occurring. Analysis of the leachates indicates high concentration of colour, TS, TDS, Pb, Zn, Cu and Ni. The high concentrations of Fe, Cu, Mn and Zn in TCLP extracts indicate that there is a great possibility of soil and ground water contamination due to leaching of solid waste. The average concentration of heavy metals in TCLP extracts ranges from 135 mg/kg for Zinc (Zn) to 0.20 mg/kg for

Cadmium (Cd). Among the heavy metals tested in TCLP extract, manganese shows the maximum leaching tendency (about 33%) whereas iron shows minimum leaching behavior (about 1%).

Table 7
Land disposal restriction-Universal treatment standards set forth by the USEPA (USEPA 1997)

Heavy metal	Concentration in TCLP Leachate (USEPA,1997) (mg/l)	Concentration in TCLP Leachate found in the present study (mg/l)
Pb	0.75	0.41
Cr	0.60	-
Cd	0.11	0.01
Hg	0.20	-
Fe	--	3.47
Cu	--	0.92
Mn	--	2.83
Zn	--	6.74
Ni	--	0.18

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