

# Effect of methods of preparation on distribution of heavy metals in different size fractions of municipal solid waste composts

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**Abstract** The present study compares the distribution and nature of heavy metals in composts from 12 cities of India, prepared from different types of processed urban solid wastes, namely mixed wastes (MWC), partially segregated wastes (PSWC), and segregated bio-wastes (BWC). Compost samples were physically fractionated by wet sieving, followed by extraction of heavy metals by dilute HCl and NaOH. Bigger particles (>0.5 mm) constituted the major fraction in all three types of composts and had a relatively lower concentration of organic matter and heavy metals, the effect being more pronounced in MWC and PSWC in which a significant portion of the heavy metals was distributed in finer size fractions. Cd, Ni, Pb, and Zn were extracted to a greater extent by acid than by alkali, the difference being greater in MWC, which contained a higher amount of mineral matter. In contrast, Cu and Cr were extracted to a greater extent by dilute alkali, particularly from BWC containing a higher amount of organic matter. Water-soluble heavy metals were generally related to the water-soluble C or total C content as well as to pH, rather than to their

total contents. This study concludes that wet sieving with dilute acid can effectively reduce heavy metal load in MWC and PSWC.

**Keywords** Solid waste compost · Composting methods · Size fractions · Heavy metals · Extractability

## Introduction

Indian cities generate more than 70 million tonnes of solid waste every year, containing more than 40 % of nonbiodegradable materials, some of which are rich in heavy metals. Composts prepared from such waste have been found to contain high concentrations of heavy metals (Saha et al. 2010). When repeatedly applied to soil as a plant growth promoter, such composts can have negative effects like contamination of groundwater and the food chain by heavy metals, as well as inhibition of plant growth and activity of soil microorganisms (Chaney and Ryan 1994). However, the magnitudes of these negative effects are likely to depend upon the distribution of heavy metals in different physical fractions, as well their extractability.

During the collection of solid waste from cities, both bigger materials (paper, plastics, metals, biodegradable organic matter) and smaller materials (from construction activity, street sweepings, house cleaning, and sludge from sewage drains) enter the feedstock material for composting (Kumar et al. 2009). Due to the varying nature and composition of waste materials

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undergoing decomposition, the resultant composts contain various size fractions, ranging from fine dust to larger material. The source of metal-containing waste as well as the method of processing the waste during composting may determine the distribution of metals in different size fractions. Although the majority of MSW composts in India are prepared in an aerobic environment, feedstock is either of a mixed type so that it contains nonbiodegradable material or is of a segregated type so that it contains mostly organic wastes. Materials are either turned frequently as in mechanical compost plants or left unturned as in the case of worm composting (Saha et al. 2010). Different metal distribution trends have been reported in different size fractions of compost (Krauss et al. 1987; Petruzzelli et al. 1989; Zhao et al. 2012). All of these studies were conducted on a few compost samples, which were physically fractionated by using the dry sieving method. Fine materials (like dust) stick to putrescible materials and coat wet materials, and very small metallic compounds penetrate larger putrescible or other organic materials (Krauss et al. 1987).

Although considered very active due to their high surface-to-volume ratio and high mobility through soil pores, such fine particles cannot be separated completely by dry sieving of compost. Information on the effects of composting methods on the nature and distribution of particles and associated heavy metals in compost is practically absent. The present investigation was carried out to understand the effect of segregation of feedstock on the distribution of inorganic and organic matter, as well as of heavy metals in different size fractions of the resultant compost.

## Materials and methods

### Study material

Twelve municipal solid waste compost samples produced in different cities [Kolkata ( $S_1$ ), Solan ( $S_2$ ), Shimla ( $S_3$ ), Trivandrum ( $S_4$ ), Bangalore ( $S_5$ ), Nashik ( $S_6$ ), Mumbai ( $S_7$ ), Nagpur ( $S_8$ ), Bhopal ( $S_9$ ), Berhampore ( $S_{10}$ ), Suryapet ( $S_{11}$ ), and Vijaywada ( $S_{12}$ )] were used for this study. Of these, five samples ( $S_1$ ,  $S_3$ ,  $S_7$ ,  $S_9$ , and  $S_{10}$ ) were produced from mixed waste feedstock (MWC), four samples ( $S_2$ ,  $S_4$ ,  $S_5$ , and  $S_6$ ) were produced from partially segregated waste feedstock (PSWC), and three samples ( $S_8$ ,  $S_{11}$ , and  $S_{12}$ ) were

produced from segregated biodegradable waste feedstock (BWC). Nonsegregated wastes were heaped and left for several months with or without turning for decomposition of biodegradable wastes to produce MWC. During preparation of PSWC, nonbiodegradable wastes of big size, like plastics, rubber, metals etc., are manually removed prior to composting. For the preparation of BWC, segregated biodegradable wastes are collected separately from individual households, which are composted in pits or heaps using earthworms.

### Physical fractionation of composts

A portion of 100 g of oven-dried (at 70 °C) compost samples (termed hereafter “F<sub>o</sub>”) were equilibrated with 200 mL of double-distilled water in a 500-mL beaker with occasional slow stirring using a glass rod. The slurry was poured on the top of a vertically arranged, downward sequence of sieves (diameter of 20 cm) with pore sizes of 0.5, 0.25, 0.125, and 0.075 mm (along with a collector pan at the bottom of the column for collecting particles sieved through <0.075 mm in size). The compost suspension was poured slowly on the topmost sieve (0.5 mm pore size) in such a way that it was spread thinly with almost uniform thickness all over the sieve. Water was sprayed gently with a manually operated sprayer on the retained material on each sieve so as to wash downward any smaller particles that had been retained. The liquid containing smaller particles (<0.075 mm) that had been retained in the collector pan was centrifuged and subsequently filtered (through Whatman no. 42 filter paper). The filtrate was analyzed for heavy metal and organic C content. The particles retained on the 0.5-mm sieve (F<sub>0.5</sub>), 0.25 mm sieve (F<sub>0.25</sub>), 0.125-mm sieve (F<sub>0.125</sub>), and 0.075-mm sieve (F<sub>0.075</sub>), as well as the centrifuged particles (F<sub>cf</sub>) were dried in the oven at 70 °C for 24 h and pulverized. All the above processes were replicated thrice for each compost sample.

### Methods of analysis

Carbon content in the filtrates was determined with the help of a total organic carbon analyzer. Volatile solids (VS) in each size fraction were detected in terms of weight loss during dry combustion of 5 g of dried sample at 550 °C for 5 h in a furnace (Leege and Thompson 1997). Total Cd, Cr, Cu, Ni, Pb, and Zn content in materials from each size fraction and original compost samples were extracted by hot acid digestion using

HNO<sub>3</sub> and HClO<sub>4</sub> (3:1). Compost samples and their different size fractions were also extracted with dilute acid (0.1 N HCl) and dilute alkali (0.1 N NaOH) in the ratio of 1:100 by shaking for 4 h. Heavy metal levels in all the extracts were determined by using an inductively coupled plasma optical emission spectrophotometer.

Data were examined by two-way ANOVA followed by Duncan’s multiple range test using SPSS 10.0 statistical software.

**Results and discussion**

**Distribution of compost material in different size fractions**

In general, the major fraction (78 %) of the MSW compost belonged to the F<sub>0.5</sub> size fraction, and each of the other groups of smaller size comprised approximately 2 to 10 % of the total weight. BWC contained more material in the biggest size fraction (F<sub>0.5</sub>) than did PSWC or MWC (Table 1). The lowest weight was recorded for the F<sub>0.075</sub> size fraction in all the composts, irrespective of the method of preparation. Feedstock for MWC probably contained finer particles like dust (from street sweepings), soils, and ash particles (from burning of organic wastes). Furthermore, MWC is mostly prepared in aerobic windrows with frequent turning of composting materials, which might have broken bigger particles into finer ones. On the other hand, BWC is produced from segregated organic wastes by worm composting on static piles/pits with minimum or no turning, which might have resulted in the retention of more particles in the bigger size fraction at maturity.

**Table 1** Average distribution of mass in size fractions of composts prepared from different types of feedstock

	MWC	PSWC	BWC
	% of total dry matter		
F <sub>0.5</sub>	73.5 a	74.7 a	87.2 a
F <sub>0.25</sub>	8.0 b	5.1 b	3.1 b
F <sub>0.125</sub>	7.1 b	6.6 b	4.1 b
F <sub>0.075</sub>	3.8 b	3.7 b	2.3 b
F <sub>cf</sub>	7.7 b	9.9 b	3.5 b

Column means followed by the same lowercase letter are not significantly different among themselves at 0.05 probability level

**Volatile solids**

The levels of volatile solids, a measure of organic matter content, varied significantly among different size fractions. Prior segregation also had a significant effect on its distribution in different size fractions. The volatile solid content increased significantly with decrease in size fractions of MWC and PSWC but decreased with decreasing size fractions of BWC (Table 2). This indicates that there were higher amounts of mineral matter in the coarse fraction (>500 μm) of MWC and PSWC, and relatively lower amounts in the same fraction of BWC. Debris from building/construction materials and weathered fragments from metallic waste present in the mixed waste might have contaminated the larger fractions of MWC and PSWC and reduced VS. On the other hand, less mechanically invasive processes (being earthworm-assisted turning decomposition) might have retained larger amounts of organic material in the bigger size fraction of BWC. However, in contrast to our results, Zhao et al. (2012) observed that organic matter content decreased with decreasing particle size in compost produced from mixed waste in an aerobic composting system in China. As they fractionated the compost into different and bigger size ranges, such observation in these two studies could not be compared.

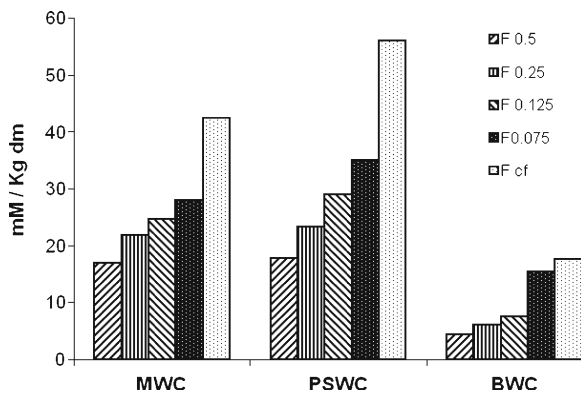
**Heavy metal content**

Mean total heavy metal concentration was the lowest in the biggest size fraction (F<sub>0.5</sub>) of compost, and it increased with decreasing size fractions (Fig. 1). Solubilization of metals in waste (by organic acid produced during the decomposition of organic matter) and their subsequent adsorption on finer particles (due to higher surface area) might have caused their enrichment in the finest fraction during composting. Petruzzelli et al.

**Table 2** Content of volatile solids (in percentage) in size fractions of composts prepared from different types of feedstock

	MWC	PSWC	BWC
F <sub>0.5</sub>	11.1 b	22.6 b	31.0 a
F <sub>0.25</sub>	13.3 b	23.5 b	25.3 b
F <sub>0.125</sub>	14.8 ab	30.6 a	23.8 b
F <sub>0.075</sub>	17.2 a	30.5 a	23.3 b
F <sub>cf</sub>	18.8 a	31.3 a	27.0 ab

Column means followed by the same lowercase letters are not significantly different among themselves at 0.05 probability level



**Fig. 1** Effect of segregation of feedstock on total heavy metal concentration in different size fractions of composts

(1989) also reported the highest concentration of heavy metals in the finest fraction. The total metal concentration in all the size fractions of BWC was considerably lower than that in the respective fractions of MWC and PSWC (Fig. 1), probably due to very low amounts of metal-rich wastes in the feedstock for composting in the case of BWC. The finest fraction ( $F_{cf}$ ) of MWC and PSWC had considerably higher amounts of heavy metals than other fractions. The ratios between the concentrations in the finest fraction ( $F_{cf}$ ) and those in the largest fraction ( $F_{0.5}$ ) indicated that Cu showed overall maximum enrichment in the finer fractions, followed by  $Zn = Pb > Ni > Cr > Cd$  (Table 3).

The distribution of a heavy metal in a given size fraction was computed by multiplying the concentration of that metal with the weight of the material present in the respective size fraction and expressing the result as a percentage of the metal present in the original compost ( $F_0$ ). The maximal proportion (53–75 %) of the total heavy metal content was present in the biggest size fraction  $F_{0.5}$ , followed by the smallest size fraction  $F_{cf}$  (12–24 %), whereas contributions by other size fractions were lower (5–11 %). This indicates that a considerable portion of metals can be removed only by washing through the finest sieve, particularly in the case of MWC (14 %) and PSWC (24 %). In contrast, in spite of the low metal content in BWC, most of it (approximately 75 %) was present in the  $F_{0.5}$  fraction.

#### Water-soluble fraction of heavy metals

Contents of water-soluble heavy metals (except Cr) were generally lower in BWC than either in MWC or PSWC or both (Table 4). However, the proportion of

**Table 3** Total heavy metal contents (in milligram per kilogram dm) in size fractions of composts prepared from different types of feedstock

		Cd	Cr	Cu	Ni	Pb	Zn
$F_{0.5}$	MWC	2.5	90.3	378.5	30.0	150.9	536.2
	PSWC	1.5	68.0	426.7	61.6	107.5	542.3
	BWC	0.3	22.8	80.6	8.5	45.1	163.3
$F_{0.25}$	MWC	3.4	107.7	492.3	32.7	250.9	673.8
	PSWC	1.5	93.6	528.6	70.4	351.6	678.3
	BWC	0.2	12.3	112.3	7.4	132.2	223.0
$F_{0.125}$	MWC	4.2	102.6	572.1	39.8	260.8	775.4
	PSWC	1.8	114.8	732.1	103.5	227.8	815.8
	BWC	0.4	7.9	167.1	9.1	187.0	249.3
$F_{0.075}$	MWC	4.3	141.3	630.8	42.4	297.5	864.2
	PSWC	1.9	137.0	891.2	125.3	219.0	1,005.0
	BWC	0.4	33.7	323.0	13.9	200.5	558.7
$F_{cf}$	MWC	4.8	176.4	992.0	47.0	369.0	1,370.4
	PSWC	2.6	157.7	1,557.0	159.9	297.8	1,596.0
	BWC	0.5	21.1	414.7	13.6	199.0	628.0
$LSD_{0.05}$		0.8	16.3	12.8	14.7	21.6	18.2

soluble metals (sum of all the metals expressed as percentage of total content) in compost ranged from 0.25 and 2.13 and was higher in BWC than in either MWC or in both MWC and PSWC. A simple correlation analysis revealed a significant correlation between water-soluble carbon (WSC) and the soluble forms of Cd ( $r = +0.593^*$ ), Cu ( $r = +0.956^{**}$ ), Ni ( $r = +0.876^{**}$ ), Pb ( $r = +0.637^*$ ), and Zn ( $r = +0.942^{**}$ ). However, a significant correlation was seen between water-soluble Cr and VS ( $r = +0.678^*$ ). This indicates that mineralization of organic matter (as indicated by VS) in conjunction with complexation by soluble humic matter might be the

**Table 4** Average water-soluble carbon and heavy metal contents in composts prepared from different types of feedstock

	Cu	Cd	Pb	Cr	Ni	Zn	C (%)
	mg/kg dm						
MWC	3.24 b (0.60)	0.02 a (0.37)	0.30 ab (0.16)	0.27 b (0.22)	0.31 ab (0.85)	2.51 b (0.40)	0.26 (2.76)
PSWC	4.77 a (0.93)	0.02 a (1.10)	0.41 a (0.31)	0.24 b (0.28)	0.79 a (1.13)	3.95 a (0.62)	0.30 (2.28)
BWC	0.79 c (0.94)	0.01 b (2.78)	0.08 b (0.14)	0.45 a (1.71)	0.20 b (2.24)	1.04 c (0.57)	0.24 (1.45)

Column means followed by the same lowercase letters are not significantly different among themselves at 0.05 probability level. Figures in parenthesis indicate percentage of total content

major controlling factor for the concentrations in the water-soluble fractions for all heavy metals. Stepwise regression analysis (involving pH, WSC, TOC, and total

heavy metal content) indicated that water-soluble Cd, Ni, and Pb were also significantly related to multiple factors as follows:

$$\text{Water - soluble Cd} = -0.134 + 0.0265 * \text{WSC} + 0.019 * \text{pH} (R^2 = 0.631^*)$$

$$\text{Water - soluble Pb} = -2.743 + 0.634 * \text{WSC} + 0.383 * \text{pH} (R^2 = 0.662^*)$$

$$\text{Water - soluble Ni} = -0.289 + 1.853 * \text{WSC} + 0.0006 * \text{Total Ni} (R^2 = 0.902^{**})$$

This also demonstrates a significant role of pH in the case of Cd and Pb and of total content in the case of Ni in terms of controlling their solubility.

**Dilute acid (0.1 N HCl)-extractable heavy metal content**

On an average, approximately 42 % (on a molar basis) of the total heavy metal content was extracted by 0.1 N HCl from the F<sub>0</sub> fraction (Table 5). Among the heavy metals, the average extraction values were approximately 76 % for total Cd, 58 % for total Zn, 47 for total Pb, 32 % for total Cu, 26 % for total Ni, and 8 % for total Cr. Extractability of the sum of all the metal contents (on a molar basis) was higher for MWC (47 %) than for PSWC (37 %) and BWC (33 %). Dilute acid extracted a higher proportion of Cu, Ni, Pb, and Zn but a lower proportion of Cd from unsieved (F<sub>0</sub>) MWC than from BWC (Table 6).

Extraction of total metal content by dilute HCl was higher from finer fractions than from the F<sub>0.5</sub> size fraction; the difference being more pronounced in BWC (Table 5). While comparing different types of composts, extractability of Cd and Zn was found to be

higher in finer fractions than in coarse fractions (such as F<sub>0.5</sub>) in MWC and PSWC but did not follow any particular trend across the size fractions of BWC (Table 6). In contrast, an increase in the extractability of Cu, Ni, and Pb with reducing size fractions was observed prominently only for BWC. There was either no specific trend or no significant difference in the extractability of Cr among the size fractions of compost prepared by different methods.

Dilute acid is expected to extract mainly mineral forms of heavy metals—almost all of the water-soluble, exchangeable, and carbonate forms as well as some of the oxide forms of heavy metals—although extraction from the organic-bound fraction is also possible (Filgueiras et al. 2002; Kashem et al. 2007). Davies et al. (1997) also reported that most of the metals bound by humic acid are removed by washing with 0.1 M HCl, revealing the acidic functional groups of humic acid as the principal metal-binding sites. Due to its lower ash content, there might be fewer mineral forms of heavy metals in BWC. However, high cation exchange capacity of humic acid and fulvic acid in BWC may provide more sites for electrostatic retention of the metals (particularly Cd and Zn), which

**Table 5** Concentration of 0.1 N HCl and 0.1 N NaOH extractable heavy metals (in millimole per kilogram dm) in size fractions of composts prepared from different types of feedstock

	MWC		PSWC		BWC		Mean	
	HCl	NaOH	HCl	NaOH	HCl	NaOH	HCl	NaOH
F <sub>0.5</sub>	43.7 b	13.6 a	45.4 a	21.2 a	37.0 bc	16.4 bc	43.9 b	17.0 a
F <sub>0.25</sub>	48.3 ab	13.7 a	53.7 a	20.8 a	51.0 b	18.2 b	50.8 a	17.1 a
F <sub>0.125</sub>	52.1 ab	16.0 a	48.3 a	21.9 a	47.7 b	22.1 ab	50.0 a	19.2 a
F <sub>0.075</sub>	54.6 a	17.9 a	50.0 a	20.8 a	35.9 c	12.2 c	50.0 a	18.4 a
F <sub>cf</sub>	55.5 a	17.7 a	50.6 a	22.2 a	65.5 a	34.4 a	54.3 a	21.6 a

Column means followed by the same lowercase letter are not significantly different among themselves at 0.05 probability level

**Table 6** Dilute acid (0.1 N HCl) and alkali (0.1 N NaOH) extractable heavy metals (percentage of total content) in different size fractions of composts

	Cd		Cr		Cu		Ni		Pb		Zn	
	HCl	NaOH	HCl	NaOH	HCl	NaOH	HCl	NaOH	HCl	NaOH	HCl	NaOH
MWC												
F <sub>0.5</sub>	68.3 b	7.9 a	8.9 b	6.9 a	44.3 b	30.7 a	35.4 a	14.5 a	45.3 b	3.6 a	50.9 b	3.5 a
F <sub>0.25</sub>	77.3 b	8.7 a	15.2 a	8.3 a	45.8 ab	28.3 a	32.7 a	16.6 a	53.3 ab	3.2 a	57.1 ab	5.0 a
F <sub>0.125</sub>	80.3 ab	11.5 a	15.8 a	16.8 a	43.8 b	32.6 a	31.8 a	19.1 a	60.4 a	4.7 a	64.6 a	4.3 a
F <sub>0.075</sub>	90.2 a	15.4 a	19.1 a	16.1 a	44.8 b	36.9 a	34.8 a	20.0 a	61.0 a	4.6 a	69.6 a	5.3 a
F <sub>cf</sub>	93.4 a	10.7 a	9.2 b	9.3 a	52.7 a	39.9 a	34.4 a	20.7 a	62.1 a	3.5 a	65.2 a	3.7 a
F <sub>o</sub>	74.4	9.1	8.8	7.0	35.9	25.0	46.7	15.6	52.6	4.5 b	65.3	3.5
PSWC												
F <sub>0.5</sub>	70.7 b	12.1 b	8.6 a	11.2 a	43.9 b	43.7 a	34.7 b	14.2 a	58.9 a	7.4 a	52.9 b	6.2 a
F <sub>0.25</sub>	88.3 a	18.3 ab	6.9 a	9.0 a	57.0 a	44.5 a	46.1 a	14.0 a	36.0 b	4.0 a	62.8 ab	7.3 a
F <sub>0.125</sub>	80.0 ab	21.4 ab	6.6 a	10.2 a	42.0 b	42.5 a	32.4 b	12.3 a	57.8 a	9.6 a	62.9 ab	7.5 a
F <sub>0.075</sub>	85.5 a	22.4 a	6.0 a	9.1 a	42.7 b	40.1 a	32.7 b	11.7 a	55.7 a	8.2 a	66.1 a	7.4 a
F <sub>cf</sub>	89.4 a	18.3 ab	7.3 a	8.9 a	46.5 ab	41.4 a	28.1 b	10.1 a	58.7 a	7.4 a	62.1 ab	6.8 a
F <sub>o</sub>	78.1	17.8	7.2	21.2	27.5	42.4	13.7	15.2	46.5	6.9	52.0	7.0
BWC												
F <sub>0.5</sub>	87.5 a	25.0 b	1.8 b	8.8 c	29.7 c	40.9 bc	9.5 b	7.1 a	30.4 b	3.7 a	49.1 ab	7.0 a
F <sub>0.25</sub>	85.7 a	28.6 b	16.5 a	22.2 c	47.9 b	47.0 b	19.3 a	10.8 a	56.9 a	6.0 a	55.0 a	5.6 a
F <sub>0.125</sub>	83.3 a	50.0 a	9.7 ab	60.5 a	38.1 bc	49.4 b	17.6 a	8.8 a	62.3 a	8.7 a	53.6 ab	5.5 a
F <sub>0.075</sub>	92.3 a	38.5 b	9.0 ab	20.1 c	30.2 c	28.1 c	13.6 ab	6.2 a	52.0 a	3.8 a	40.1 b	3.2 a
F <sub>cf</sub>	86.7 a	60.0 a	8.8 ab	39.4 b	97.3 a	79.8 a	18.2 a	11.1 a	58.6 a	3.7 a	48.0 ab	7.1 a
F <sub>o</sub>	88.9	33.3	5.1	23.9	20.7	52.9	19.5	8.5	19.5	6.6	45.6	23.6

Column means for particular compost type followed by the same lowercase letters are not significantly different among themselves at 0.05 probability level

might also have been exchanged and extracted by acid.

#### Dilute alkali (0.1 N NaOH)-extractable heavy metal content

On an average, dilute alkali extracted about 17.6 % (on a molar basis) of the total heavy metal content present in the F<sub>o</sub> samples, and extractability was higher in BWC (30 %) than in PSWC (21.9 %) or MWC (12.5 %). Average extractability of different heavy metals followed the order Cu (40.3 %)>Cd (22.2 %)=Cr (21.0 %)=Ni (18.5 %)>Zn (9.9 %)>Pb (6.1 %). For the original (F<sub>o</sub>) compost samples, considerably higher extraction was observed in BWC (as compared to MWC or both MWC and PSWC) for Cd, Cr, Cu, and Zn (Table 6). Alkali extracts mainly humic and fulvic acid fractions of organic matter and, therefore, is expected to

extract metals complexed by these soluble and insoluble organic compounds. These forms of the metals are tightly bound by mixed ligands inside the helix-like structures of humic acid molecules through the formation of coordinated complexes (Davies et al. 1997). Kaschl et al. (2002) also demonstrated the association of Cd with humified and less soluble organic materials like humic and fulvic acids. As the organic matter content of BWC was considerably higher than that of the other two types of composts (Saha et al. 2010), a higher level of metal extraction by dilute alkali is expected for BWC. Extractability of heavy metals was similar for all the size fractions of MWC and PSWC (Table 6). In the case of BWC, extractability of Cd and Cu increased with decreasing size fractions; whereas extractability of the other metals was similar for the different size fractions.

Cd, Ni, Pb, and Zn were extracted to a greater extent by acid than by alkali, the magnitude of difference being

greater for MWC containing higher amounts of mineral matter. In contrast, Cu and Cr were extracted to a greater extent by dilute alkali, particularly in BWC, which contain higher amounts of organic matter. This observation suggests that Cu and Cr were probably bound more to the organic matter through inner sphere complexes of humic acids.

## Conclusion

Our previous study (Saha et al. 2010) showed that composts manufactured in India from mixed wastes and partially segregated wastes were unsuitable for land application due to low organic matter and high heavy metal content (being greater than the quality control limits as specified by Fertilizer Control Order, 1985 of India). The present investigation shows that though finer size (<0.5 mm) particles constituted only a minor fraction in MWC and PSWC; they contained higher concentrations of organic matter as well as of heavy metals. In this fraction, heavy metals were largely present as inorganic forms or were electrostatically held on the surfaces of organic and inorganic particles. On the other hand, heavy metals were present in smaller quantities in BWC and were largely adsorbed and complexed in all the size fractions by organic matter. Composts prepared from mixed wastes and partially segregated wastes contained significant amounts (6–20 %) of the finest fraction (<0.075 mm) with the highest concentration of heavy metals, which, once applied in agricultural land, can travel down through macropores of soil profiles along with irrigation water. Mineralized and solubilized metals from bigger organic particles in compost material might have limited mobility due to strong interactions with soil constituents. On the other hand, heavy metal-loaded fine particles from MWC and PSWC have the potential to contaminate deeper layers of the soil profile and, thus, can pollute greater volumes of soil in the rhizosphere.

Although sieving of MWC and PSWC through a 0.5-mm sieve reduced heavy metal content by 22 and 16 %, respectively, in the retained material, it also decreased organic matter content by about 35 and 5 %, respectively, thus lowering its fertilizing value. This shows that only removal of finer size fractions after composting may not be a viable technology for improving the quality of composts prepared from urban solid wastes.

However, 0.1 N HCl could extract about 44–45 % of the total heavy metal content from the biggest size fraction, suggesting that wet sieving with dilute acid may be a viable technology for making mixed waste composts and partially segregated waste composts suitable for land application.

## References

- Chaney, R.L., & Ryan, J.A. (1994). *Risk based standards for As, Pb, and Cd in urban soils*. Frankfurt: DECHEMA.
- Davies, G., Fataftah, A., Cherkasskiy, A., Ghabbour, E.A., Radwan, A., Jansen, S.A., Kolla, S., Paciolla, M.D., Sein, L.T., Buermann, W., Balasubramanian, M., Budnick, J., & Xing, B. (1997). Tight metal binding by humic acids and its role in biomineralization. *Journal of the Chemical Society, Dalton Transactions*, 4047–4060.
- Filgueiras, A. V., Lavilla, I., & Bendicho, C. (2002). Chemical sequential extraction for metal partitioning in environmental solid samples. *Journal of Environmental Monitoring*, 4, 823–857.
- Kaschl, A., Römheld, V., & Chen, Y. (2002). Cadmium binding by fractions of dissolved organic matter and humic substances from municipal solid waste compost. *Journal of Environmental Quality*, 31, 1885–1892.
- Kashem, M. A., Singh, B. R., Kondo, T., Imamul Huq, S. M., & Kawai, S. (2007). Comparison of extractability of Cd, Cu, Pb and Zn with sequential extraction in contaminated and non-contaminated soils. *International journal of Environmental Science and Technology*, 4, 169–176.
- Krauss, P., Blessing, R., & Korherr, U. (1987). Heavy metals in compost from municipal refuse- strategies to reduce their content to acceptable levels. In M. de Bertoldi, M. P. Ferranti, P. L'Hermite, & F. Zucconi (Eds.), *Compost: production, quality and use* (pp. 254–265). London: Elsevier.
- Kumar, S., Bhattacharyya, J. K., Vaidya, A. N., Chakrabarti, T., Devotta, S., & Akolkar, A. B. (2009). Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: an insight. *Waste Management*, 29, 883–895.
- Leege, P. B., & Thompson, W. H. (1997). *Test methods for the examination of composting and compost*. Bethesda: The US Composting Council.
- Petruzzelli, G., Szymura, I., Lubrano, L., & Pezzarossa, B. (1989). Chemical speciation of heavy metals in different size fractions of compost from solid urban wastes. *Environmental Technology Letters*, 10, 521–526.
- Saha, J. K., Panwar, N., & Singh, M. V. (2010). An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. *Waste Management*, 30, 192–201.
- Zhao, S., Liu, X., & Duo, L. (2012). Physical and chemical characterization of municipal solid waste compost in different particle size fractions. *Polish Journal of Environmental Studies*, 21, 509–515.