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Study of the Toxicity of Metal Contamination in Soil Samples Collected from Abandoned E-waste Burning Sites in Moradabad, India

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ABSTRACT

The present study investigates the concentration of heavy metals in the soils of Moradabad, famous for manufacturing brassware, in the vicinity of the abandoned sites of e-waste burning and industrial waste. Government of India has strengthened enforcement to impede such activity, however, heavy metal remains in the abandoned e-waste burning and industrial waste sites can still pose an ecological risk. Results indicate that the surface soil of the e-waste burning and acid leaching sites was still heavily contaminated with the heavy metals likes Pb, Cd, Cr, Zn, Ni, Cu and Fe originating from printed circuit board burning and recycling. Industrial waste has also affected the nearby areas, which have created potential threat to the environment. Samples were collected from the various contaminated sites, after the digestion process they were analysed by ICP-AAS. The excedance of metal contamination imposed negative impact to the environment and human health. Therefore, immediate remediation of the contaminated soil is necessary to prevent the dissemination of heavy metals and potential ecological disaster.

INTRODUCTION

Moradabad, a city in western Uttar Pradesh is situated at the banks of River Ramganga. This city is traditionally famous for bangles and brass works and is also known as “Peetal nagri” or the Brass City. It has the distinction of being the biggest exporter of brassware in the country. Many households, which were engaged in brass works earlier, were left with no choice but to search other means for their livelihood. E-waste was one of the choices because of their metal processing knowledge. E-waste recycling in India, till a few years back, was concentrated in large cities like Delhi, Kolkata, Mumbai, Bangalore and Chennai. But with the increase in the generation of e-waste and increasing land cost in big cities, the recycling centres have started spreading in neighbouring cities and towns. Moradabad is one such example, recyclers in Moradabad buy PCbs (Printed Circuit Boards) from various big cities. According to some estimation, 50% of the printed circuit boards used in appliances in India ends up in Moradabad. The unscientific process of burning the electronic goods to recover metals poses not only an environmental threat, but the poisonous toxins are being inhaled by the people of this city. Unaware of these poisonous fumes, 60% of the city’s workers are engaged in the illegal e-burning business, which is worth of crores. Many studies done on e-waste in Moradabad have found that the level of heavy metal contamination in areas in and around the city is extremely high. Soil samples were collected from the three main locations, which are situated on the banks of River Ramganga, the water of which is used for washing by residents and for drinking in downstream.

It is noteworthy that none of the laws and regulations emphasise on the remediation of contaminated soil and water in the vicinity of e-waste recycling sites; therefore, the pollutants remaining in abandoned e-waste recycling sites can still pose hidden danger to the surrounding environments (Leung et al. 2008 and Luo et al. 2011).

Owing to the rapid development of information technology and constant upgrade of electronic products, electronic waste (e-waste) has become the fastest growing stream of municipal solid waste over the last decade (Ni & Zheng 2009 and Robinson et al. 2009). A majority of e-waste is produced by the developed countries in which the US alone generated over 9.4 million tons in 2012. To handle the e-waste, many developed countries tend to export it (ca. 50%-80%) to the developing countries (e.g., India, Bangladesh China, Pakistan and Vietnam) for recycling and disposal in view of lower labour costs and less stringent environmental regulations (Ni & Zheng 2009). India has become the second largest importer of e-waste in the world, receiving over millions of tons of e-waste from US and European countries every year (Widmer et al. 2005). According to some estimates, India not only generates close to 40,000 tonnes of e-waste annually, but also imports another 50,000 tonnes of e-waste from countries like the US and Canada. Developed countries find it easy to export e-waste to developing countries in the name of free trade.

The present study was conducted in the abandoned e-waste processing and industrial waste sites Nawabpura and Peetal Nagri respectively in Moradabad, India. Nawabpura is the main hot bed for e-waste burning, processing and acid leaching. It is also situated near the banks of River Ramganga where the washing of circuit boards is done. After washing, burning and many recycling processes take on the bank of river which is indirectly polluting the river water. Since the local people living near the river usually rely on river water for irrigation and drinking, the potential ecological risk of heavy metals in the vicinity of abandoned e-waste processing sites should not be overlooked. The second site, Peetal Nagri, is the industrial site for most of the brassware industries.

We aim to elucidate the contamination of heavy metals in these two areas by examining their concentrations in soil samples. In addition to this, pH and total organic matter (TOM) were also measured as they are important factors governing heavy metal accumulation in soils (Kashem et al. 2007). The findings emphasise focus on the environmental impacts of heavy metals in abandoned e-waste recycling and industrial waste sites and thus can raise awareness among the local residents and authorities concerned to take necessary steps for remediation.

Fig. 1: The sampling map showing the abandoned e-waste recycling site Nawabpura and industrial waste site Pital Nagri in Moradabad (Retrieved from Google Earth). ▼ indicate the sampling sites 1 and site 2 for soil samples, respectively (n = 3).

MATERIALS AND METHODS

Study area and sampling sites: Moradabad is located in semi-arid zones in the north-west of India. It is located at an average height of 76.19 m above sea level in the western Gangetic plain of the Indian subcontinent at latitude 28.15 N and longitude 74.49 E. It covers an area of 3516.62 km.

Soil samples were collected from the two areas of the Moradabad which is widely recognized as an electronic waste burning, dumping and dismantling site after the publication in report by CSE (Centre of Science and Environment). Meteorological conditions of the area during sample collection are given in Table 1. About 250 g of the soil was collected from each site in polythene bag. Minimum 3 samples were collected from each site, i.e., Mughalpura (e-waste burning site) and Peetal Nagri (industrial waste site), situated near the bank of the River Ramganga (Fig. 1).

Soil digestion and analytical methods: All soil samples were air dried at room temperature and sieved through a 200 µm mesh nylon sieve to remove debris. For each sample, 0.5g of dry soil was weighted and digested with mixed acids. Soil samples were digested with 15 mL of concentrated HNO_3, H_2SO_4 and $HCLO_4$ (5:1:1) at 80°C until the transparent solution was obtained. The digested solution was cooled, filtered using Whatman No. 42 filter paper and then diluted with deionised water before determination of Cu, Cr, Cd, Ni, Pb and Zn. The filtrate was kept at room temperature for further analysis of heavy metals. Heavy metals were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) and inductively coupled plasma atomic absorption spectroscopy (ICP- AAS). Any sample exceeding the calibration range was diluted accordingly and re-analysed (Yang 2009).

Analyses of pH, TOM and heavy metal concentrations: The soil samples were air-dried, ground and passed through a 2mm sieve. The water samples were filtered through a 0.45 µm micropore membrane and then acidified to 2% (v/v) with concentrated nitric acid, after pH measurement using a pH meter. The soil sample was mixed with distilled water (1:2.5, w/v) for 30 min and the pH of the mixture was measured using a pH meter. Total organic matter in soil was determined by mass loss upon ignition of oven-dried soil in a muffle furnace at 550°C for at least 6 h. To extract the heavy metals in soil, 0.3 g soil sample was digested by a mixture of concentrated hydrochloric acid and nitric acid (3:1, v/v) using automatic digestion block.

Table 1: Meteorological conditions at the study sites (mean) during sampling period.

Meteorological parameter	Summer	Winter	Monsoon
Temperature °C	36.53±15.65	18.45±7.40	31.1±11.54
Humidity (RH)%	30.46±20.76	46.75±23.40	60.54±18.67
Wind speed (kmph)	8.43±1.23	9.33±1.34	9.59±3.44
Rainfall (mm)	0.85±2.22	4±5.03	10.19±9.69

Table 2: The pH, TOM (%), concentrations of heavy metals (mg.kg^{-1}) in the surface soil at different sampling sites (mean ± SD, n = 3). Grade II guideline level for soil in Moradabad aims to protect the environment and public health. Dutch target value indicates the level at which the ecological risk is negligible.

	pH	TOM(%)	Heavy Metal (mg.kg^{-1})			
			Pb	Cd	Cr	Cu
Site 1	5.65±0.32	9.52±0.85	693.3±181.0	82±23.57	163.3±145.22	915.3±93.08
Site 2	5.23±0.11	7.82±054	738.6±402.7	96±10.58	268.6±369.4	4797.3±667.8
Site 3	4.82±0.19	1.13±0.09	1832.6±1610	230.6±25.48	0	13646.6±254.8
Site 4	5.02±0.17	10.6±0.51	654.6±293.5	93.3±31.30	80±101.37	2336.6±1127.5
Site 5	4.04±0.19	12.1±1.79	556.6±44.23	111.3±8.08	236.6±215.07	8550.6±1061.7
Site 6	5.08±0.28	9.22±0.46	532.6±162.1	83.3±30.61	0	2080±43.58
Grade I	/	/	35	0.2	90	35
Grade II	/	/	250	0.3	250	50
Dutch	/	/	85	08	100	36Target Value

Table 3: Concentration of heavy metals at different e-waste burning and industrial waste sites, where N = 3 (mg/kg).

Sites	N=3	Pb	Cu	Cd	Cr
Site A	1	530	820	56	96
	2	662	920	88	330
	3	888	1006	102	64
Site B	1	804	5284	88	0
	2	690	4036	92	690
	3	722	5072	108	116
Site C	1	818	13480	214	0
	2	990	13520	218	0
	3	3690	13940	260	0
Site D	1	832	4214	104	46
	2	822	4202	118	194
	3	310	2254	58	0
Site E	1	576	9776	102	0
	2	506	7942	116	290
	3	588	7934	116	420
Site F	1	346	2130	48	0
	2	638	2050	102	0
	3	614	2060	100	0

Table 4: Pearson correlation analysis correlating the concentrations between heavy metals in the surface soil (n = 18).

	Pb	Cd	Cr	Cu
Pb	1	-0.448	0.965	0.798
Cd		1	-0.419	-0.159
Cr			1	0.919
Cu				1

RESULTS AND DISCUSSION

The pH and TOM in the surface soil at different sampling sites are given in Table 2. Compared to the reference site (pH 5.52), the soil was found acidified in the burning and acid-leaching sites (about pH 4). Total organic matter, ranging from 11.5% to 1.13%, a significantly lower TOM was observed in the acid leaching site than all the other sam-

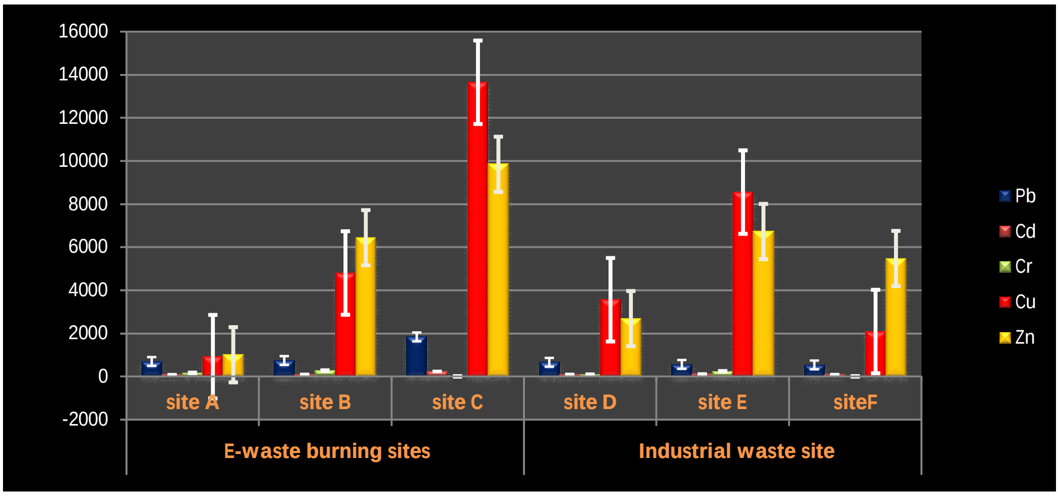

Fig 2: Concentration of trace elements (Mean±SD) at different study sites during the study period in Moradabad.

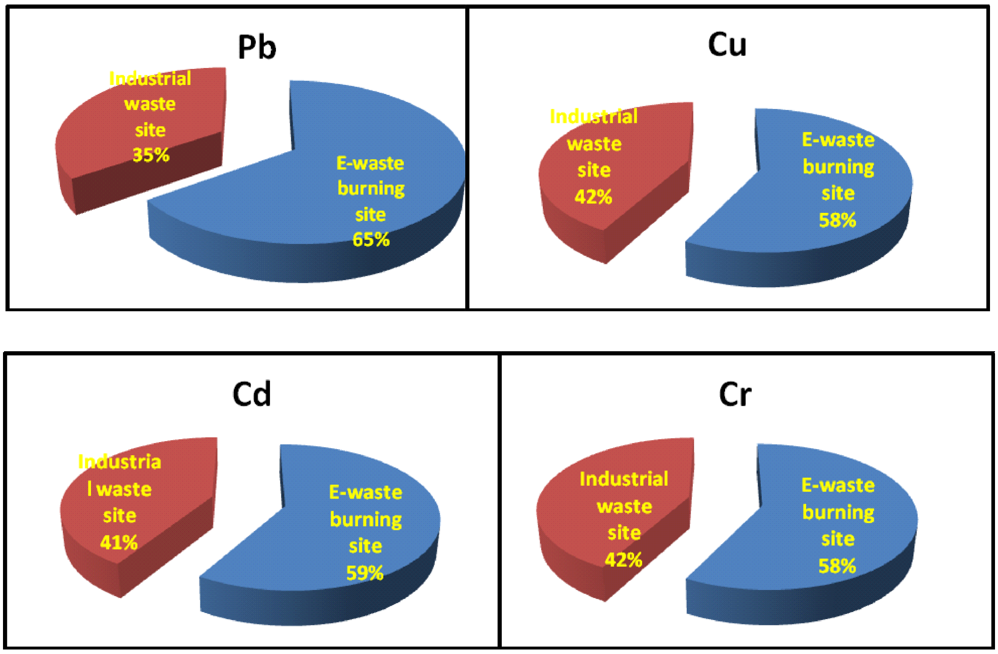

Fig. 3: Pie graph showing comparisons of heavy metals in E-waste site and industrial waste site.

pling sites. The degree of heavy metal contamination among sampling sites generally followed the order with few exceptions: acid-leaching site > burning site > dumping site > acid leaching > industrial waste sites (Table 3). This indicates that the abandoned e-waste recycling site was still contaminated with heavy metals. A disproportionally high concentration of Cu was found in all the sites. Copper exceeded the Grade II guideline value and Dutch target value in all the sampling sites. The mean and standard deviation of trace meals concentrations on the different sites are shown in Fig 2. Cadmium in the burning site, acid-leaching site and industrial waste site exceeded the Grade II guideline value and the Dutch target value. Cadmium in the acid-leaching site exceeded the respective Grade II guideline value. Lead in the dumping, burning and acid-leaching and industrial sites also exceeded their respective Dutch target values. On the basis of the pie graph of the comparison between the e-waste sites and the industrial waste (Fig. 3), it is manifested that the site C has higher concentration of Pb and Cd than all the other sampling sites (Fig. 4).

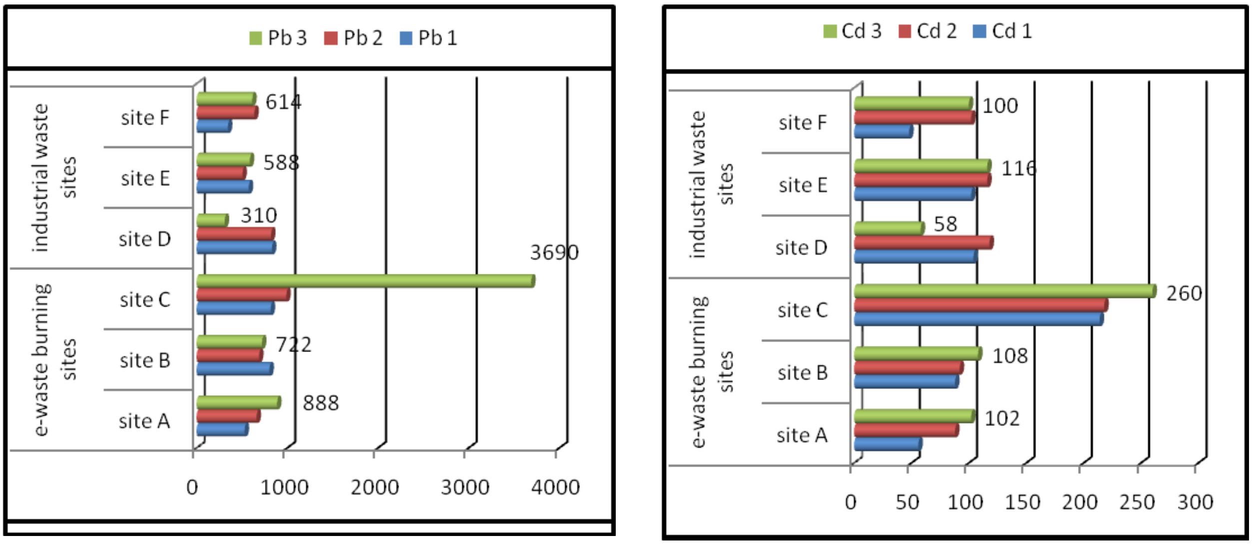

Fig. 4: Concentrations of lead and cadmium of the E-waste and industrial waste sites ($mg.kg^{-1}$) during the study period in Moradabad.

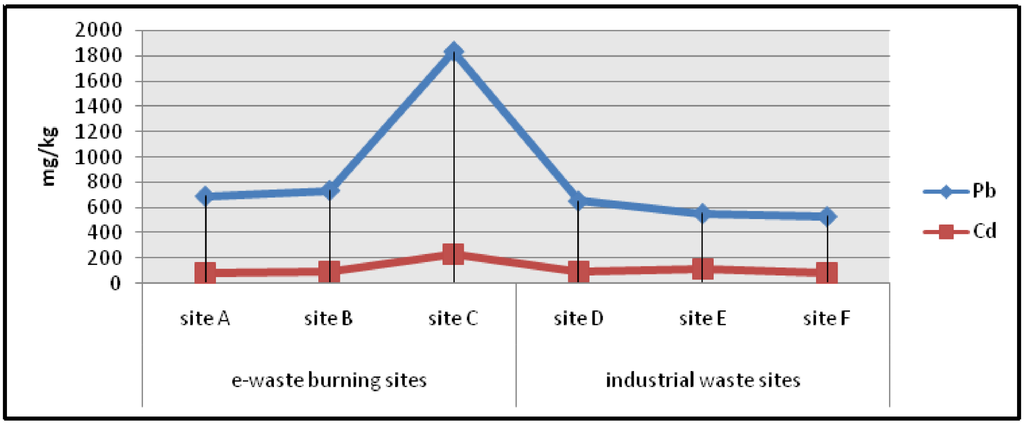

Fig. 5: Graphs considering two heavy metals lead and cadmium concentrations showing the peak of their levels present in the different sites ($mg.kg^{-1}$).

Table 4 shows the correlation between heavy metals in the surface soil and found that all heavy metals are highly correlated with each other. This suggests that the heavy metals were likely originated from the same sources. The ecological risk of Cd and Pb in site C was high and very high, respectively (Fig. 5).

Contamination of heavy metals in soil: Our findings revealed that the soil in the vicinity of abandoned e-waste recycling site and industrial waste site was influenced by the e-waste recycling and industrial activity. For example, severe soil acidification was found in the acid leaching and burning sites due to the *ex situ* washing of e-waste by sulphuric acid and nitric acid. The soil in the acid-leaching site (e-waste burning site) was infertile as compared to industrial waste site (i.e., low TOM), because the organic matter in the soil was digested by the acid on e-waste burning and acid leaching sites. The ecological risk of heavy metals was still very high in the burning and acid-leaching sites, largely attributed to the contamination of Cd, Cu and Pb. Alarmingly, the concentrations of Cu in the dumping, burning and acid-leaching sites were found to be 40 to 70 times higher than the Grade II guideline level. Such high concentration of Cu is probably because of the electric wires and printed circuit boards, which contain huge amount of Cu, and are the major recycled products in Moradabad. Printed circuit boards also contain substantial quantities of Cd and Pb, explaining the dominance of these heavy metals in e-waste recycling sites (Lugon-Moulina et al. 2006, Tang et al. 2010, Kumar 2014 and Wong et al. 2007). The industrial waste sites were also highly contaminated with Cu, Cd and

Table 5: The mean concentrations of heavy metals ($mg.kg^{-1}$) in soil surface in the vicinity of the abandoned e-waste recycling site in Moradabad in the present and previous studies.

	Heavy Metal ($mg.kg^{-1}$)				Reference
	Pb	Cr	Cd	Cu	
E-waste dumping site	198	0.14	22.5	513	Wu et al. (2015)
	693	163	82	915	Own results (2015)
Burning site	618	ND*	20	2485	CSE Report Moradabad (2015)
	480	320	10.02	12200	Jinhui et al. (2011)
	793	269	96	4797	Own results (2015)
Acid leaching	736	13	136	24957	CSE Report Moradabad (2015)
	150	2600	1.21	4800	Jinhui et al. (2011)
	1833	0	231	13647	Own results (2015)
Industrial waste dumping	4500	17.1	68.9	11140	Sampson (2012)
	655	80	93	3557	Own results (2015)
Electroplating and grinding	65	433	0.7	193	Gowd (2010)
	557	237	111	8551	Own results (2015)

Pb, indicating the same pollution source as the e-waste processing site. Atmospheric deposition is another possible pathway because the residual ash generated by burning of e-waste contains high concentrations of heavy metals, especially Cu and Pb (Li et al. 2011 and Luo et al. 2011).

Comparisons with previous studies and implications: To minimise the illegal e-waste recycling activity, the local government in Moradabad is trying to construct more legal e-waste disposal centres and strengthened enforcement in coming years. It is important to evaluate the effectiveness of these measures by comparing the present findings with the previous findings conducted in Moradabad (Table 5). We found that the concentrations of heavy metals in the present study were comparatively higher than those in the study by Wu et al. (2014), but were more or less the same as those in CSE Report Moradabad. The concentrations of heavy metals, however, suggest that the heavy metals are likely transported from the surface soil to the river Ramganga by rainfall, especially in the wet season (Rahman et al. 2012). Comparisons with previous studies and implications to minimise the illegal e-waste recycling activity, the local government in Moradabad has constructed more legal e-waste disposal centres and strengthened enforcement in recent years. Therefore, we recommend that immediate actions (e.g., soil washing, soil removal and phytoremediation) should be taken to remediate the severely contaminated areas (Wuana & Okieimen 2011), especially the burning and acid-leaching sites which are the source of release of heavy/toxic metals.

CONCLUSION

The heavy metals from e-waste recycling sites in Moradabad suggests that the measured levels of heavy metals have been derived from the primitive e-waste processing operations. This study provides a clear evidence that there is an urgent need for reducing the harmful impacts on environment as well as on human health due to the e-waste recycling activities. There is decrease in the pH and organic matter of soil, while increase the solubility of heavy metal concentration, which may have toxic impacts on environment. On the basis of the above study, all the sites have very high amount of Pb, Cd, Cr and Cu. This concludes that the studied sites are not suitable for the people to reside and for the cultivation of plants and crops. The intensive and uncontrolled e-waste burning and dismantling in Moradabad resulted in the release of large amounts of heavy metals in the local environment, especially in soil and in the River Ramganga. The exceedance of various international standards imposes negative effects to the environment.

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