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Environmental Susceptibility: Soil Contamination of Heavy Metals in the Territory of E-Waste Recycling Area

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Abstract

E-waste is a popular name given to those electronic products nearing the end of their useful life which has become a major source of heavy metal contamination in soil and hence, became the global concern. Various samples of soil were collected from different sites and were determined for heavy metal analysis by the ICP-AAS after the digestion process. The main source of contamination is illegal e-waste recycling activities such as burning of PCB's acid baths etc. Different soil indices like contamination factor, I-geo, pollution load index, were calculated to determine the quality of the soil. Results indicate that e-waste recycling and industrial area are strongly contaminated by the heavy metals. Physiological analysis of soil revealed that e-waste processing and industrial activities decrease the soil pH and organic matter while enhancing the electrical conductivity of soil. The exceedance of metal contamination imposed negative impact to the soil environment and human health.

1. Introduction

E-waste is a popular informal name for electronic products nearing the end of their useful life which includes old computers, cell phones, televisions, printer etc. Heavy metals are largely present in e-wastes, especially lead (Pb),copper (Cu), chromium (Cr), nickel (Ni), zinc (Zn), cadmium (Cd), arsenic (As) and mercury (Hg) as well as many other metals and rare earth elements that can impact the environment, once the material end up in landfill or if improperly managed or disposed (Sanusai, 2015). About 60% heavy metal found in various complex electronics are known to be potentially hazardous. So, it is a problem of global concern because due to nature of production and disposal of waste is burned or turned over to a landfill in a globalized world (Ojeda-Benitez *et al*., 2013; Singh *et al*., 2015).

Moradabad, in Western Uttar Pradesh, situated on the banks of the Ramganga River, popularly known as the Brass City of India, has become one of the biggest illegal e-waste recycling hubs in India. This city has also been affected by the global recession and consequent decrease in demand for brass products; manufacturers and handicraft; therefore workers are shifting towards the informal, unauthorized e-waste burning sector. Handicraft workers are now using their skilled art of extracting metals in an illegal way by processing e-waste for extracting heavy metals (Down to Earth, 2010). Moradabad buys only PCBs from Delhi, Kolkata, Chennai, Bangalore, Gujrat and other parts of India. According to an estimate, 50 percent of the PCBs used in appliances in India end up in Moradabad (Singh *et al*., 2015; Gangwar *et al*., 2016).

The methodology, tools, and techniques used for recycling e-waste in studied areas are basic, such as heating by blow torch or stove, breaking with the hammer, chemical stripping, melting and open burning, without any concern for the environment and human health. Recycling of waste circuit boards to extract lead, aluminum, and iron is the primary activity undertaken in the area of Moradabad. After dismantling and disordering the circuit boards, the waste is collected in heaps and set on fire in open fields to extract copper, leaving behind large quantities of ash in these fields (Wei and Liu, 2012; CSE Report, 2015).

The concentrated sulphuric and nitric acids were used by the local workers for processing the circuit boards to recover copper, left over and residual ashes are dispersed into open land thus leads to soil contamination. As the texture of soil plays a very important role in plant species establishment, development, and influences physical parameters of soil, the soil texture classes were evaluated for all the study sites. The soil is principally loamy-sand with sand constituting more than 75% of the inorganic mineral fragment (Benis *et al*., 2015).

As selected sampling sites support informal activities, making them an ideal location for this study and suitable sites for testing soil contamination by heavy metals. Therefore, the present study is undertaken to investigate the impact of e-waste processing on soil properties as compared to adjacent soil. This study was able to establish the basic understanding of the extent of contamination of soil by heavy metals and generate baseline data on the concentration of heavy metal from e-waste processing on the soil. The information obtained from this study is geared towards raising public awareness on the hazards of e-waste, for selecting appropriate clean-up measures for the deteriorated environment, and the protection of the local community from potential health hazards.

2. Materials and Methods

2.1. Determination of physico-chemical properties of soil

The pH was measured by 1:5 soil to water ratio by using digital pH meter (MK VI Systronics). The suspension was allowed to stand approx 30-40 minutes prior to pH determination. The textural class of the soil was measured by hydrometer method. The electrical conductivity (EC) was measured in the saturated extract of the soil, using a ELICO CM 180 conductivity meter. The organic carbon (OC) was measured by the wet oxidation method of Walkley and Black (1934).

2.2. Determination of heavy metals concentration in soil samples

Samples collected from the selected sites which are situated near Ramganga River at distance of 1 km. About 250g of soil sample was collected with the help of separate soft touch brush and plastic dust pan for each site, pre treated polythene bags were used to avoid contamination. Collected samples air dried at room temperature then crushed and sieved to remove debris by using 200µm mesh nylon sieve.

For digestion process 0.5 g of dry soil was weighed and digested with 15ml of concentrated HNO_3, H_2SO_4, and HCl (5:1:1) at 80°C until the clear solution was obtained. Obtained solution cooled and filtered using Whatmann number 42 filter paper. The further filtrate was diluted with de-ionized water and kept at room temperature. For analysis of heavy metal ICP-AAS was used. Any sample exceeding the calibration range was diluted accordingly, in duplicate and re-analysed.

* Background value of heavy metal such as Pb and Cd are given on the basis of Taylor and McLennan, 1985 while background values of Hg and As are given on the basis of province background values of China (Toxic Link Report, 2014).

* All the soil indices in this paper are calculated on the basis of concentrations of heavy metal represented in Table 1.

2.3. Assessment of contamination

There are many soil quality indices that can be used to assess the extent of the contamination by heavy metals. For meeting the objectives of this study, three indices were selected to evaluate the contamination level of Pb, Cd, Hg and As in the soil of e-waste burning, industrial and residential areas of Moradabad. These were contamination factor, pollution load index and geo-accumulation index. The different class of soil indices which represented the quality of the soil is given in Table 2 and the results of different soil classes are represented in Table 3.

2.3.1. Contamination Factor (CF)

Contamination factor was determined by the following equation according to Thomilson *et al*. (1980).

CF = Cm Sample/ Cm Background

Where, Cm Sample = the concentration of the heavy metal in the soil sample, and Cm Background = the background concentration of the heavy metal.

Table 1: Concentration of heavy metals in soil samples at different study sites

Sites	Heavy Metal Concentration (mg/Kg)			
	Pb	Cd	Hg	As
SI (E-waste Processing Site)	697.8±10.17	67.5±19.03	1.62±0.78	82.35±0.78
SII (Industrial Site)	581.9±53.12	63.6±17.06	0.78±0.10	24.36±4.25
SIII (Residential Site/ Control area)	13.5±3.6	2.6±1.14	0.1±0.05	2.5±0.67
Background Values of heavy metal	**20**	**0.98**	**0.14**	**1.5**

Table 2: Classes of soil indices with respect to soil quality

Contamination Factor (CF)	Contamination Degree (CD)	Geo-accumulation Index (Igeo)	Pollution load index (PLI)
<1 (Class 1), Low contamination	<8 = Low degree of contamination	≤0 (Class 0) Practically unpolluted	< 1 Perfection (Class 0)
1≤ to < 3 (Class 2), Moderate contamination	8 to 16= Moderate degree of contamination	0 to 1 (Class 1), Slightly polluted	= 1 baseline level (Class 1)
3≤ to ≤6 (Class 3), Considerable contamination	16 to 32= Considerable degree of contamination	1≤ to ≤ 2 (Class 2) Moderately polluted	>1 (Class 2), Deterioration on soil quality
>6 (Class 4), Very high contamination	>32= Very high degree of contamination	2≤ to ≤ 3 (Class 3) Moderately severely polluted 3 to ≤ 5 (Class 4), Severely polluted 4 < to ≤ 5 (Class 5), Severely extremely polluted >5 (Class 6) Extremely polluted	

Table 3: Results of CF, I-geo, CD and PLI values at different study sites

Sites	Pb		Cd		Hg		As		CD	PLI
	CF	Igeo	CF	Igeo	CF	Igeo	CF	Igeo		
SI	34.89	4.53	68.87	5.52	11.57	2.94	54.9	5.19	170.23	35.15
SII	29.09	4.27	64.89	5.43	5.57	1.89	16.24	3.43	115.79	20.33
SIII	0.675	1.15	2.65	0.81	0.71	-1.07	1.66	0.15	5.69	1.2

2.3.2. Geo-accumulation Index (I-geo)

I-geo was determined by the following equation according to Muller (1969) which was described by Boszke *et al.* (2004) and Rabee *et al.* (2011).

$$\textbf{I-geo} = \log_2 [Cn/1.5 \times Bn]$$

Where, Cn = the measured concentration of heavy metal in the soil sample; and Bn = the geochemical background concentration of the heavy metal.

Muller designed the classification for geo-accumulation and this application is widely used by many researchers (Hu *et al.*, 2010; Gowd *et al.*, 2010; Mmolawa *et al.*, 2011; Al- Jaber *et al.*, 2014; Singh *et al.*, 2016).

2.3.3. Pollution Load Index (PLI)

The pollution load index (PLI) developed by Thomilson *et al.* (1980), as follows;

$$\textbf{PLI} = [CF_1 \times CF_2 \times CF_3 ......CF_n]^{1/n}$$

Where n = No. of studied metal at each site, CF = Contamination Factor.

3. Results and Discussion

3.1. Physico-chemical characteristics of soil

The mean values of different physico-chemical parameters viz. pH, texture, electrical conductivity and organic carbon of soil at all sites are represented in Table 4. The measurement of pH shows the acidity or alkalinity of the soil and it plays a major role in the speciation and bio-availability of the presence of heavy metals in the soils. Thus the maximum allowable concentration of heavy metal in soil varies with the soil pH (Luo *et al.*, 2011). From the evidence available neither a high pH, above 8.4 nor a low, below 5.0 is favourable for maximum yield of crops. The type of soil controlled by pH value at about 6.0 to 8.2 pH is usually bacteria predominant. The present findings show that the pH of all sites is ranged from 6.3 to 6.5 which is tending towards acidic while the pH of control site i.e. P.T.C. is 7.1 tending towards neutral. So, the soil pH indicates that all sites are favourable for crop production.

The measurement of electrical conductivity is done for measuring the current that gives a clear idea of

Table 4: Physicochemical properties of soil of studied sites

Sites	Physicochemical Characteristics			
	pH	Texture	Electrical Conductivity (EC)	Organic Carbon (%)
SI	6.3	Loam	12.48	0.16
SII	6.5	Sandy Loam	7.5	0.31
SIII	7.1	Sandy Loam	0.28	0.78

soluble salts present in the soil. Conductivity depends upon the dilution of soil suspension. The conductivity of soil of e-waste processing and industrial sites are found higher i.e. 12.48 and 7.5 mS/cm respectively which may be toxic to plant growth and shows the presence of large ionic substances and soluble salts in soil. Although, the electrical conductivity of the soil of control site is found to be very low.

The source of organic carbon in soil includes crop residues, animal manure, cover crops, green manure and organic fertilizers etc. It was observed that control site showed a fairly higher percentage of organic carbon i.e. 0.78% while Nagphani showed relatively less percentage of organic carbon i.e. 0.16%. This is because of the accumulation and subsequent decomposition of plant residues at the control site, resulting in the building of organic matter.

3.2. Contamination Factor (CF) and degree of contamination

Contamination factor of soil caused by different heavy metals is presented in the Fig. 1. Lead **(**Pb) at all study sites are classified in Class 4 (represents high contamination) while Pb at SIII is classified in class I category (represents very low contamination). It is one of the most commonly used heavy metals of e-waste - it is used in both computer and television screens, and in the solder used to anchor various circuit board components (Annamalai, 2015). High contamination of soil by Pb may be due to the disposal of cathode ray tubes, printing wiring boards and acid lead batteries, incandescent lightbulbs directly on the soil after recovery of metals or even the burning of printed circuit boards. Recycling of computer monitor for extracting the valuable metals is also increases the concentration of Pb in the soil because it consists glass panels and gaskets monitors which have the high concentration of Pb (Li *et al*., 2008; Frazzoli *et al*., 2010; Xu *et al*., 2012). Short-term exposure to high levels of Pb can cause vomiting, diarrhoea, convulsion, coma, headache, sleeplessness etc. while long-term exposure damage vital organs and also reduce the IQs and understanding capabilities of children (Anuradha, 2011).

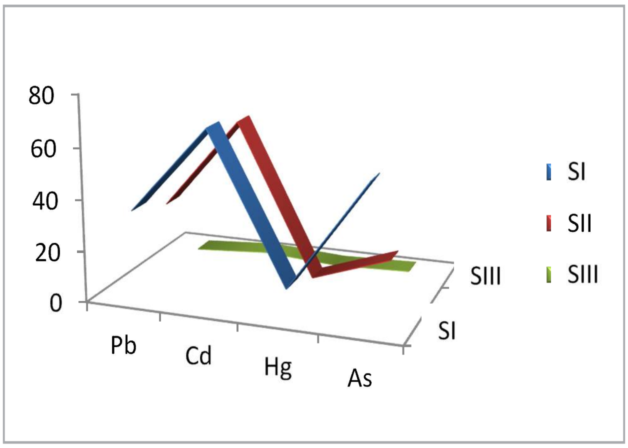

Fig. 1: Contamination factor of soil by different heavy metals at different study sites

The contamination factor (CF) for Cd and As at all the study sites are classified in Class 4 represents a very high contamination, except at SIII which is further classified in Class 2 representing a moderate contamination (Fig. 1). The major source Cd are vehicular emission and industrial activities along with e-waste processing activities such as direct heating, burning and other chemical processes to recover materials from semiconductor chip, photocopy machine, computer monitor and cell phones etc. These are known to induce carcinogenic effects in humans through inhalation (Guo *et al*., 2010; Li *et al*., 2011; Singh *et al*., 2015) and also shows negative effects on the reproductive health. Arsenic is used in semiconductors, diodes, LEDs, solar cells of e-waste and it is toxic to both plants as well as animals while inorganic arsenicals are proven carcinogens in human health and (Murcutt, 2012).

The contamination factor for Hg at SI is classified in Class 4 represents a very high contamination, while SII is placed in Class 3 category representing a considerable contamination (Fig. 1). Mercury (Hg) is an important component of the computer monitor, cell phones, PCBs, the crude extraction methods of gold using Hg are contributing to the higher Hg contamination in the soil of SI. It is bio-accumulative in nature so accumulates in the food through the transfer from soil and affects the human health causing mental illness and DNA damage (Stephan *et al*., 2010; Frazzoli, 2010; Zheng *et al.*, 2013).

The results of degree of contamination showed that SI have very high degree of contamination, SII have considerable degree of contamination while SIII have low degree of contamination.

3.3. Geo-accumulation Index (I-geo)

I-geo values of different heavy metals are presented in Fig. 2 and from the figure it is clear that high average values of I-geo in soil of all studied site indicated a high level of soil contamination with heavy metals.

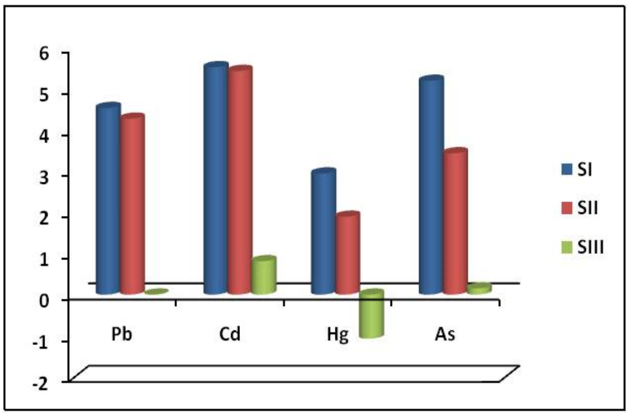

Fig. 2: Geo-accumulation index of different heavy metals at different study sites

The Pb and Hg have negative I-geo values at SIII which represents to "Class 0" indicating that Pb concentration is lower in soil than the background value. I-geo values of Cd and As at SIII was found positive which represents "Class 1" indicating the concentration of these two metals slightly polluted the soil.

Mercury (Hg) at site SI and SII had positive value but the difference is that SII represents "Class 2" (moderately polluted) while SI represents "Class 3" (moderately severely polluted) category. Likewise arsenic (As) was also found positive at SII and SI, representing "Class 4" and "Class 6" category respectively (Table 2) and indicates that the concentration of As polluted the soil of these sites from severe to severely extremely polluted category.

The Pb and Cd had positive values at SI and SII ranging from 4.27-4.53 and 5.43-5.52 respectively (Table 3). These results are fall in the category of "Class 5" (severely extremely polluted) and "Class 6" (extremely polluted) respectively. Moreover, the contamination of Pb and Cd are associated. It probably means that they have the same sources, i.e., e-waste recycling activities (like PCB burning, acid bath of waste material to extract metal) and industrial activities (like smelting and scrapping of brass items). The other major source is vehicles but accumulation occurred at different chronological periods, which could be associated with the motor fuel quality (unleaded petrol).

Comparison of average Igeo value among the three sites of soil indicates a following order: SIII (control site) < SII (industrial site) < SI (e-waste processing site).

3.4. Pollution Load Index (PLI)

The PLI is aimed to provide a measure of the degree of overall contamination and it effectively compares whether the study sites suffer from contamination or not. Based on the result presented in Fig. 3, the overall degree of contamination by four metals in of the order SI>SII>SIII. SI (62%) and SII (36%) show strong signs of pollution or deterioration of soil quality while SIII (2%) is almost at the baseline level.

Relatively high PLI at SI, SII and at SIII suggests input of anthropogenic sources attributed to increasing as burning and processing of e-waste, burning of plastic, solid waste, litter burning as well as vehicular emission. Except this, another reason for higher values of PLI factor may be due to contaminated soil in the study area by brassware industries. This city known as a Peetal Nagri (big transporter of Brassware items throughout the world) caused to enrich the sediments by some heavy metals like Pb, Cd, Ni, Zn, Cu etc (Pal *et al*., 2014).

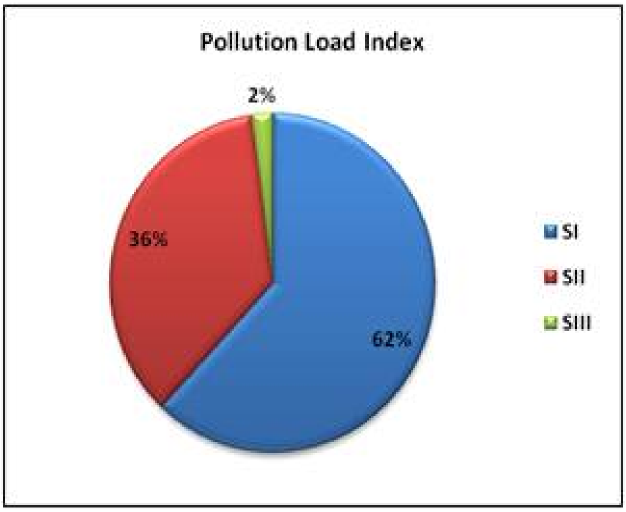

Fig. 3: Pollution load index of soil at different study sites

4. Conclusion

The result of the spot samples gathered for the above study, indicates the hazardous implication of e-waste processing on the environment and human health; however, values are found very high than the expected. The extent and long term effects of these particular e-waste activities in Moradabad city still needs to be learned.

The decrease in the pH and organic matter and increase in heavy metal and solubility of salts is directly affecting the soil of that area ultimately causing harm to plants as well as the health of people.

Besides this, the result of soil indices i.e. geo-accumulation (I-geo) and pollution load index (PLI) showed that almost all sites are polluted with Pb, Cd, Hg and As except control area. Control site is a police training centre with a small forest area, is relatively clean. These results were further confirmed by contamination factor (CF).

Due to the high level of contamination of soil from heavy metals, the people living in study areas are suffering from many diseases (as per record of government hospital). Since electrical and electronic equipments (source of e-waste) are the need of the hour to progress there should be guidelines for the proper disposal of e-waste. Workers should be trained to use environment friendly methods for recycling e-waste properly.

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