

RESEARCH ARTICLE

Assessment of heavy metal contamination in soil and groundwater near e-waste processing units in the Moradabad industrial area

Amrish Kumar¹, Sachin Sharma², Manisha Pandey², Akanksha Pandey^{3*}, Sachin Kumar³, Anamika Tripathi¹, Juhi Khan⁴ and Deen Dayal Giri⁵

¹Pollution Ecology Research Laboratory, Department of Botany, Hindu College, Moradabad – 244001, Uttar Pradesh, India

²Department of Botany, D.A.V. (P.G) College, Dehradun – 248001, Uttarakhand, India

³Department of Botany and Microbiology, Gurukula Kangri (Deemed to be University), Haridwar – 249404, Uttarakhand, India

⁴Department of Botany, IFTM University, Moradabad – 244001, Uttar Pradesh, India

⁵Department of Botany, Maharaj Singh College, Saharanpur – 247001, Uttar Pradesh, India

Corresponding author email: mantukpg@gmail.com

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Abstract

This paper investigates the presence of heavy metal pollution in the soil and groundwater near e-waste processing plants housed in India's Moradabad Industrial Area. Atomic absorption spectroscopy was used to collect twenty sites worth of samples; these were then searched for lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn). The results showed that the soil was rather contaminated, with values two to fifteen times higher than authorized limits. The groundwater testing especially for Pb and Cd also revealed quite significant levels. Geographic research found pollution hotspots near places of e-waste disposal. The report emphasizes the requirement for better local control of electronic trash and environmental cleansing to protect biodiversity.

Keywords: Groundwater pollution, E-waste, environmental impact, heavy metals, soil contamination.

1. Introduction

Globally e-waste generation has been boosted by the development of technology, short product lifecycles, and fast expansion of the electronics sector (Baldé et al., 2017). Given the rich metals found in e-waste, recycling it makes sense. It also addresses heavy metals, which under inadequate control could compromise the quality of living and health in the surrounding areas (Awasthi et al., 2016). Illegal businesses have significantly contributed to the growth of e-waste recycling in India, especially in Moradabad, Uttar Pradesh, where this practice is quite common, including the recycling of printed circuit boards (PCBs) (Pathak et al., 2017). While these activities provide income opportunities, they often lead to the release of harmful chemicals into the environment due to inadequate environmental regulations. Dealing with e-waste reveals several rather harmful heavy metals. Not biodegradable, they build up around their surroundings and compromise human health as well as ecosystems (Li et al., 2011). Electronics find use for metals present in e-waste; lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn). These heavy metals find their way into the Moradabad soil and water systems by illicit means of e-waste disposal including open burning, acid leaching, and inadequate residue disposal (Awasthi and Li, 2017). These poisons harm not only the ecology and people but also might contaminate food supplies (Song and Li, 2014). Although e-waste recycling is becoming more and more essential in India, not much is known regarding heavy metal pollution in the vicinity of several processing plants. This research will look at soil and groundwater heavy metal contamination next to Moradabad Industrial Area e-waste processing facilities to bridge this information gap.

The objective of this work is to estimate Pb, Cd, Cr, Cu, and Zn concentrations in groundwater and soil close to Moradabad e-waste processing facilities.

- Match detected heavy metal concentrations to criteria of national and worldwide environmental quality.
- To chart the research area's heavy metal contamination.
- From observed pollution levels, evaluate issues for human and environmental health.
- To offer changes in environmental remedial action and e-waste management.

This study contributes to the growing corpus of evidence on the environmental consequences of e-waste recycling in underdeveloped countries and supports environmental managers and legislators in addressing this main issue.

2. Material and method

2.1. Study area

The study was conducted in Uttar Pradesh, India's Moradabad Industrial Area at 28.8389° N, 78.7768° E. Among the various e-waste recycling facilities here is one meant to extract metal from PCBs, with 798 mm of annual rainfall and temperatures between 4°C and 45°C, semi-arid ecosystem rules here.

2.2. Organizational sample

20 sample sites were selected 5km from areas of creation of e-waste. The sites were selected to show varying land use from industrial, residential, agricultural, and processing centres. Every site included soil samples taken along with groundwater. We collected surface (0–15 cm) and subsurface (15–30 cm) soil samples using a stainless-steel auger. Every composite sample site pooled five subsamples from each sampling location. Groundwater

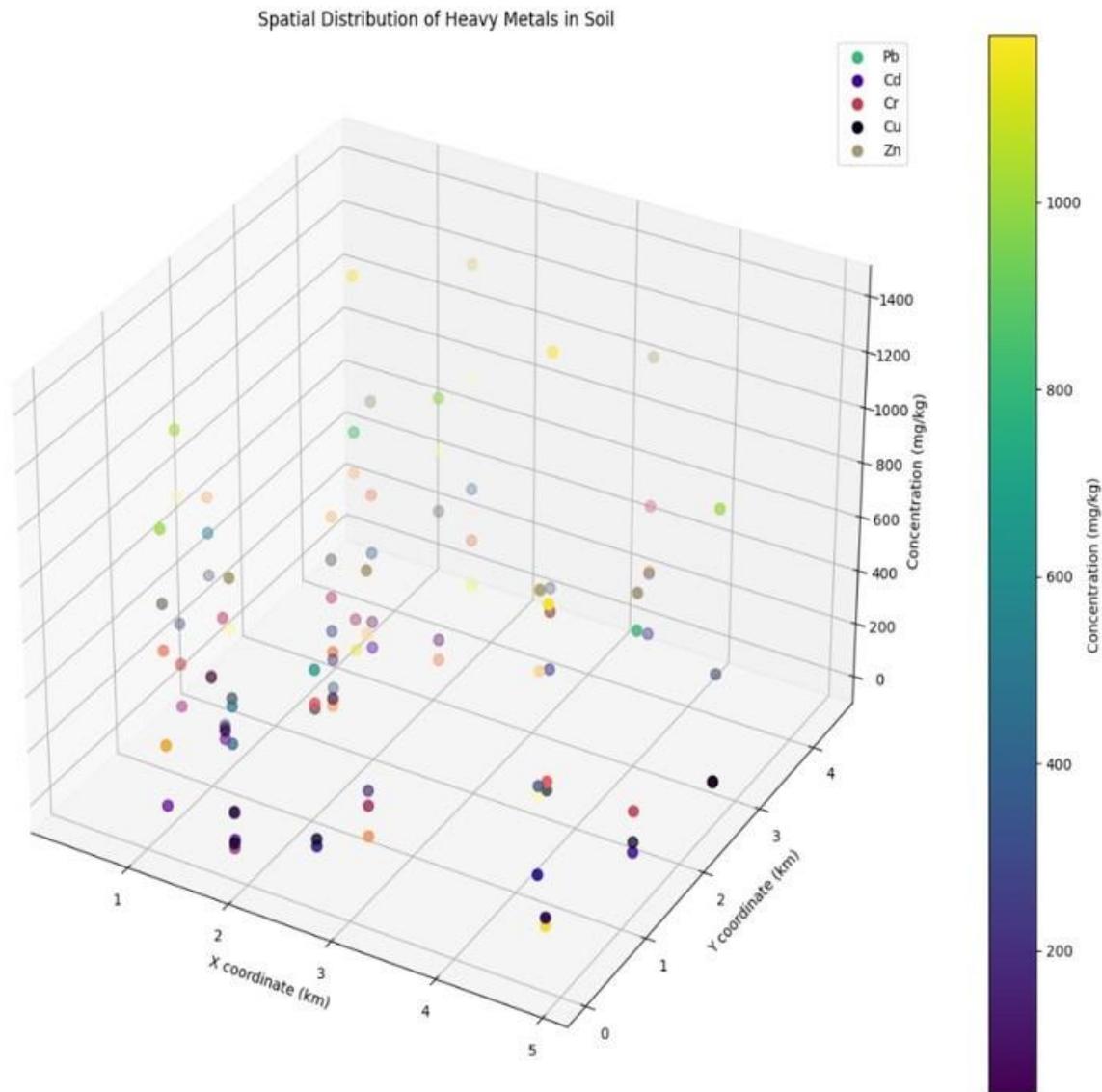


Figure 1. Spatial distribution of heavy metal concentrations in soil samples.

samples were taken from wells or boreholes at every site with a water sampler. Every sample came to the lab in 4°C freezers inside neat, labelled plastic bags or bottles.

2.3. Sample study and prepare-ready

After room temperature air-drying, soils were grinded and then sieved at 2 mm. For heavy metal analysis, a microwave digestion machine ran 1 g of each soil sample with HNO₃, HCl, and H₂O₂ (3:1:1). Groundwater samples were acidified with HNO₃ and then preserved at pH 2 by passing them through 0.45 µm membrane filters. Digested soil and acidified water samples yielded Pb, Cd, Cr, Cu, and Zn using atomic absorption spectroscopy (AAS) PerkinElmerA Analyst 800. Quality control called for duplicate samples, process blanks, and CERs.

2.4. Local study

Every sampling location had geolocation done using GPS. ArcGIS 10.8 shows the heavy metal distribution. IDW interpolation helped every map of soil and groundwater heavy metal pollution produced.

2.5. Risk analysis

Ecological risk was assessed using the Potential Ecological Risk Index (RI) (Hakanson, 1980). Human health risk was evaluated using the US EPA's 2019 Hazard Index (HI) and cancer risk (CR).

2.6. Statistics and graphs

R (4.1.0) was statistically applied. Analyses of heavy metal concentrations and properties including e-waste processing unit distance and land use type using descriptive statistics, correlation analyses, and ANOVA.

3. Result and discussion

3.1. Heavy metal concentrations in soil

Table 1 shows the heavy metal concentrations found in the soil samples of study sites. With different degrees of contamination, the soil samples revealed all five of the examined heavy metals. The study site location exposed considerable soil heavy metal pollution. Lead (Pb) values varied from 45.2 to 1245.6 mg/kg, mean of 387.3 mg/kg beyond the Indian limit of 250 mg/kg. Cadmium (Cd) topped it with 85% of the samples beyond the 3 mg/kg limit. Copper (Cu) and zinc (Zn) also indicated somewhat high contamination with mean values of 2.2 and 1.9 times their standards (Figure 1).

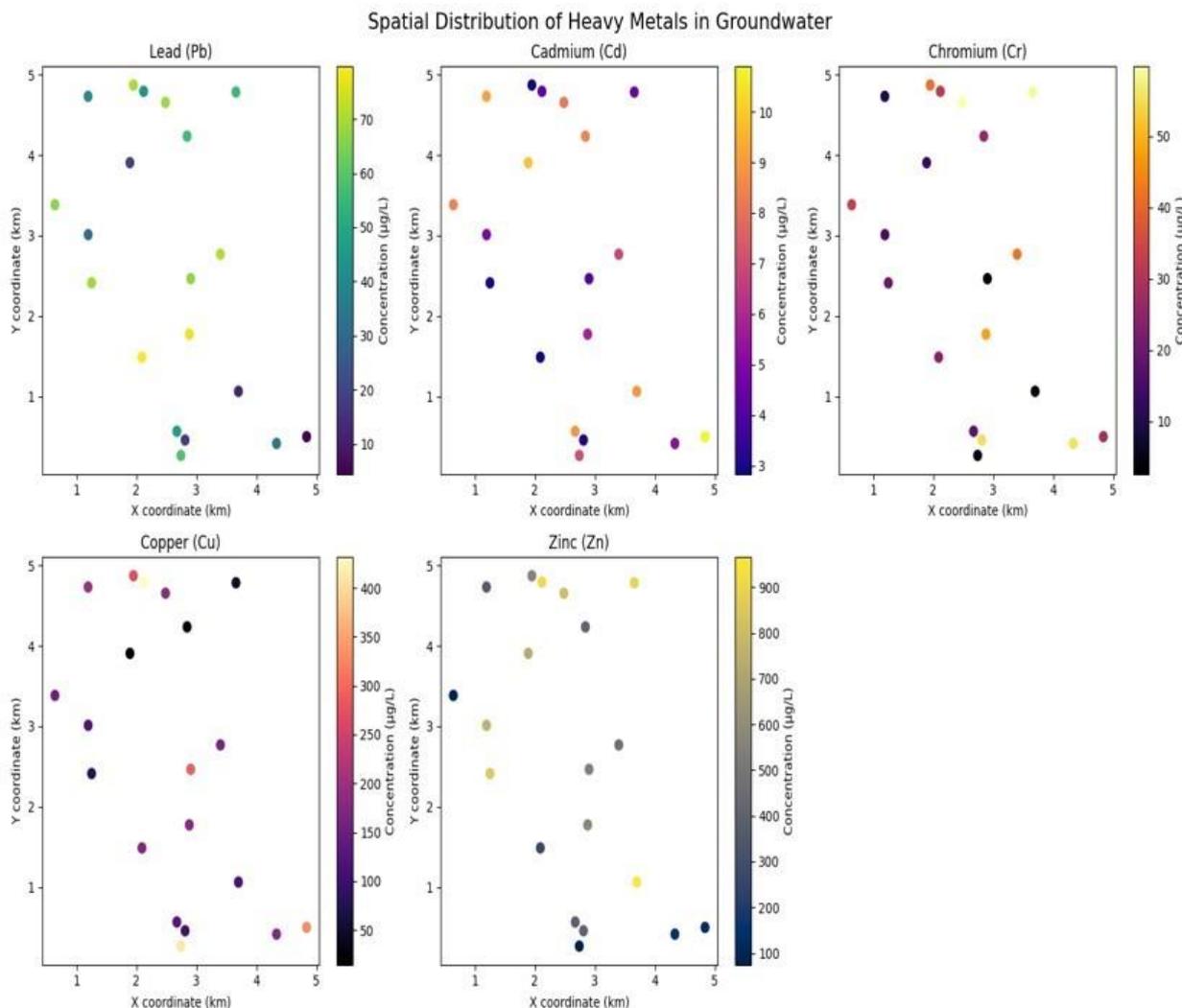


Figure 2. Spatial distribution of heavy metal concentrations in groundwater samples

Geographical investigation indicates trends in pollution over the studied area. Facilities managing e-waste, and industrial centres of pollution revealed high levels of heavy metals. This inclination suggests that ground contamination by recycling e-waste is possible.

Similar heavy metal contamination of soil exists at other e-waste disposal sites dispersed around. Luo et al (2011) found similar Pb (50–1500 mg/kg) and Cu (30–5300 mg/kg) in soils close to South Chinese e-waste dumping sites. Our high Cd results in this study are alarming considering Cd is transportable and harmful in soil (Kabata-Pendias, 2010).

3.2. Groundwater Rich Metal Concentrations

The heavy metal concentration of groundwater samples varied. In 75% of samples maximum of 84.5 µg/L, lead (Pb) concentrations above WHO limits of 10 µg/L. Since 45% of the samples exceeded the 3 µg/L standard, cadmium (Cd) pollution was rather high. Chromium (Cr) readings were usually below the limit except for one sample at 65.2 µg/L. Every sample had copper and zinc levels below the recommended limits (Table 2) (WHO, 2017).

Like in soil samples, groundwater contamination levels are more around e-waste processing facilities. Still, local hydrogeology and groundwater flow patterns can help to explain the various distributions. Groundwater is troublesome since even low levels of Pb and Cd are dangerous (Figure 2). These results match earlier studies on groundwater contamination close to sites of e-waste disposal groundwater at an e-waste recycling town in southeast

China, Wu et al (2015) reported Pb levels ranging from 0.3 to 139 µg/L.

Table 1. Heavy metal concentrations in soil samples (mg/kg dry weight)

Metal	Min	Max	Mean	Median	SD	*Indian Standard
Pb	45.2	1245.6	387.3	298.5	312.4	250
Cd	0.8	24.7	7.9	6.3	5.8	3
Cr	28.4	312.5	118.6	95.2	72.1	250
Cu	52.3	876.4	295.8	237.1	201.3	135
Zn	124.7	1587.2	573.9	487.5	354.6	300

*Indian Standard: Permissible limits for heavy metals in soil (CPCB, 2009)

Table 2. Groundwater samples' heavy metal concentrations (µg/L).

Metal	Min	Max	Mean	Median	SD	WHO Guideline*
Pb	3.2	84.5	28.7	22.4	19.6	10
Cd	0.4	12.3	3.8	2.9	2.7	3
Cr	1.8	65.2	22.4	18.7	15.3	50
Cu	12.5	452.7	138.6	112.3	105.9	2000
Zn	45.3	987.6	324.5	278.1	223.8	3000

*WHO Guideline: Drinking water quality guidelines (WHO, 2017)

Table 3. Correspondence between groundwater and soil heavy metal concentrations

Metal	Correlation Coefficient	p-value
Pb	0.78	<0.001
Cd	0.82	<0.001
Cr	0.65	<0.01
Cu	0.71	<0.001
Zn	0.69	<0.01

Table 4. Potential Ecological Risk Index (RI) for soil samples

Risk Level	RI Value	Percentage of Samples
Low	RI < 150	15%
Moderate	150-300	30%
Considerable	300-600	40%
High	RI > 600	15%

Table 5. Human health risk assessment results

Risk Type	Soil	Groundwater
Non-carcinogenic	HI = 3.24 (Pb, Cd)	HI = 2.87 (Pb, Cd)
Carcinogenic	CR = 1.8×10^{-4} (Cd)	CR = 1.2×10^{-4} (Cd)

3.3. Groundwater–Soil connection

Pearson correlation coefficients were derived (Table 3) to assess soil and groundwater heavy metal concentrations. Every heavy metal content in soil and groundwater shows a pretty substantial positive connection with values ranging from 0.65 to 0.82. These close ties imply that in the study area groundwater is affected by soil pollution which indirectly affect plant health and biodiversity of the area. Knowing that Cd is relatively mobile in soil, the strongest link ($r = 0.82$, $p = 0.001$) was found for Cd (Kabata-Pendias, 2010).

3.4. Ecological risk evaluation

The whole ecological risk resulting from soil heavy metal pollution is evaluated using the Potential Ecological Hazard Index (RI) (Table 4). According to the ecological risk assessment, 15% of the soil samples reveal high risk. Lead ranked second in ecological risk; cadmium took the front stage. This great risk suggests that in the study area soil bacteria, vegetation, and overall biodiversity components living in soil could suffer significant ecological damage.

3.5. Evaluating medical risk

Evaluation of human health risk addresses carcinogens as well as non-carcinogens. Approximations for non-carcinogens and carcinogens respectively were the Hazard Index (HI) and Cancer Risk (CR) (Table 5). Particularly from Pb and Cd pollution, the non-carcinogenic risk assessment reveals that the Hazard Index (HI) for soil and groundwater exposure exceeds the safe limit ($HI < 1$). This suggests a possibility of negative consequences on population health under interaction. Based on carcinogens risk assessment, groundwater and soil exposure exceeds the US EPA's allowed limit— (1×10^{-4} to 1×10^{-4}) (US EPA, 2019). The main cancerogenic is cadmium. These results imply that groundwater and soil pollution increase cancer risk.

4. Conclusion and recommendation

This study reveals considerable heavy metal pollution of soil and groundwater close to Moradabad Industrial Area e-waste processing facilities. Key results and suggestions:

- Generally, above Indian standards, samples of soil revealed considerable Pb, Cd, Cu, and Zn pollution. Generally speaking - especially for Pb and Cd - the

pollution of groundwater samples surpassed WHO recommendations.

- Spatial analysis found pollution hotspots near e-waste processing facilities, therefore tying recycling to environmental harm.
- Strong relationships between soil and groundwater pollution levels suggest that contaminated soil most likely originates the groundwater pollution.
- Environmental risk assessment shows that Cd is mostly responsible for over half of the soil samples showing either significant to high risk.
- Studies on human health risk expose, particularly Pb and Cd, non-carcinogenic and carcinogenic hazards from soil and groundwater contamination.
- These results direct one to the following recommendation:
- Apply stricter e-waste recycling regulations and monitoring rights in Moradabad Industrial Area.
- Development and encouragement of greener e-waste recycling solutions to lower heavy metal pollution.
- Cleaning highly contaminated soil and groundwater by means of phytoremediation or chemical stabilization.
- Regular studies of soil quality and groundwater, with reference to Pb and Cd.
- Public awareness programs highlight the need for proper management and the risks of illegal e-waste disposal.
- Still much needed is a study on the long-term consequences of heavy metal exposure on the local human population and biodiversity health as well as remedial policies.

This paper makes the case that the Moradabad Industrial Area has to improve e-waste management and environmental cleaning including protection of local biodiversity health. The results can help environmental managers and legislators handle this important problem and protect the surroundings as well as human health.

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