



A Comparative Study of Heavy Metal Concentration in Different Layers of RICCO Near Border Soil and Near Agricultural Soil (Sriganganagar, Raj)

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Abstract

The present investigation was undertaken to assess the extent of heavy metal contamination in soils from the RICCO industrial zone (border vicinity) and to compare them with uncontaminated agricultural soils, with particular emphasis on the influence of untreated industrial effluents. Soil samples from multiple depths were analyzed for chromium (Cr), lead (Pb), cadmium (Cd), and zinc (Zn) concentrations using the atomic absorption spectrophotometric (AAS) flame method. The findings revealed pronounced spatial and vertical heterogeneity in metal distribution at the RICCO site, where concentrations ranged from 559.81–32.59 mg/kg (Cr), 160.32–74.6 mg/kg (Zn), 69.59–23 mg/kg (Pb), and 2.26–0.69 mg/kg (Cd). By contrast, the agricultural reference soils exhibited substantially lower values: 26.79–23.49 mg/kg (Cr), 27.0–12.61 mg/kg (Zn), 24.59–23.59 mg/kg (Pb), and 2.29–0.67 mg/kg (Cd). These results demonstrate that soils adjacent to industrial effluent discharge zones harbor markedly elevated concentrations of toxic metals relative to agricultural soils. The enrichment of such pollutants in soil matrices not only compromises crop quality and productivity but also facilitates their translocation into the food chain, thereby posing severe ecological and public health risks.

Keywords: Heavy metals; soil contamination; industrial effluents; atomic absorption spectrophotometry (aas); agricultural soils

Introduction

In contemporary environmental discourse, the ramifications of heavy metal contamination have attained the status of a profound global concern, primarily due to their deleterious consequences for ecological integrity and human health [1]. Soil, as a fundamental substrate underpinning terrestrial ecosystems, assumes a pivotal role in regulating environmental quality; however, the perturbation of its composition by heavy metals has become an issue of escalating significance [2]. The infiltration of toxic trace elements into soil systems induces profound alterations in physicochemical attributes, ultimately diminishing fertility and precipitating agricultural yield decline [3]. With the intensification of industrialization and the accelerated trajectory of economic globalization, the incidence of heavy metal accumulation in soils has markedly amplified, thereby engendering substantial ecological degradation [4].

Soil contamination by metallic effluents frequently occurs via irrigation with polluted water, indiscriminate industrial discharge, and other anthropogenic interventions. These contaminants enter biogeochemical cycles and progressively accumulate, infiltrating food webs with consequential implications for food safety and human nutrition [5]. Indeed, the indiscriminate deposition of toxic industrial residues has been recognized as a transboundary environmental crisis [6]. Industrial effluents are typically enriched with hazardous concentrations of metallic ions including Ca, Fe, Mg, Na, Ni, Cr, Cd, Pb, and Zn, all of which compromise agricultural productivity and soil sustainability [7]. Beyond environmental repercussions, the toxicokinetics of these metals permit direct human exposure through ingestion, dermal absorption, and inhalation. Once integrated into agricultural matrices, heavy metals are assimilated by crops and bioaccumulate within edible tissues, rendering the soil–

crop–human pathway the principal vector of associated health adversities [12]. Accordingly, this investigation endeavors to quantify the concentrations of chromium (Cr), lead (Pb), zinc (Zn), and cadmium (Cd) within soils influenced by industrial effluents and juxtapose these findings with the elemental profiles of uncontaminated agricultural soils.

Materials and Methods

- 1. Study Area:** -Soil specimens were procured from five geospatially distinct points encompassing the industrial zone (RICCO, proximal to the border) and a comparative reference site comprising conventional agricultural soils within the Sriganganagar district, Rajasthan. RICCO represents a highly industrialized and densely inhabited sector within the region.
- 2. Sampling Protocol:** -Sampling operations were executed in April 2025. Utilizing a stainless-steel Ekman Grab Sampler, stratified soil cores were extracted and contained in pre-sterilized, acid-washed polyethylene vessels. At each site, stratification included surface (0–15 cm), subsurface (15–30 cm), and deeper substratum (30–45 cm) layers. Samples underwent sequential washing, oven desiccation at 105 °C until weight constancy, and post-drying stabilization in a desiccator. Subsequently, materials were pulverized to fine powder in an agate mortar, homogenized, and stored in sealed glass receptacles under anhydrous conditions pending analytical evaluation.
- 3. Soil Digestion Procedure:** -For quantitative elemental determination, the ISO 11466 wet-digestion protocol was employed. Precisely 3 g of homogenized soil were

preconditioned with 1 ml of distilled water, followed by incremental addition of 21 ml HCl and 7 ml HNO₃. Subsequently, 15 ml of diluted nitric acid (0.5 M) was incorporated. The suspension was stabilized at ambient temperature, thereafter subjected to reflux digestion for two hours on a thermostatic heating platform. Upon cooling, digests were filtered through Whatman No. 40 filter media and preserved in inert vessels for spectrometric interrogation.

- 4. Heavy Metal Quantification:** -Elemental analyses were undertaken at the Centre for Advanced Research and Science (CARS) utilizing a Perkin-Elmer Atomic Absorption Spectrophotometer (Model Analyst 800, USA). Monochromatic hollow cathode lamps specific to Cd (228.8 nm), Cr (357.9 nm), Pb (283.3 nm), and Zn (213.9 nm) were employed. The instrument's detection thresholds were 0.01 mg/L (Cd), 0.10 mg/L (Cr), 0.20 mg/L (Pb), and 0.01 mg/L (Zn). Calibration curves were constructed with graded standards, yielding correlation coefficients of 0.999 (Cd), 0.994 (Cr), 0.999 (Pb), and 0.999 (Zn), attesting to analytical precision and linearity.

Results and Discussion

Empirical outcomes reveal that chromium levels within RICCO soils were markedly elevated relative to the agricultural control, with concentrations frequently transgressing internationally recognized permissible thresholds. The apex of contamination was observed at effluent dumping loci, while progressively attenuated values were discerned with increasing soil depth and distance from the emission source.

At the RICCO site, Cr content attained a maximum of 561.71 mg/kg in surface soils (Point 1: dumping locus), whereas the nadir of 31.23 mg/kg was documented at 30–45 cm depth in Point 5. Concentrations in surface horizons varied between 561.71–170.83 mg/kg; subsurface (15–30 cm) layers exhibited 220.89–34.2 mg/kg; and deeper substrata (30–45 cm) ranged 90.09–28.72 mg/kg (Table 1). Conversely, reference agricultural soils demonstrated considerably lower Cr values: 27.87 mg/kg (surface), 26.04 mg/kg (15–30 cm), and 24.54 mg/kg (30–45 cm) (Table 2). The observed gradient reflects both vertical attenuation with increasing depth and lateral diminution with greater distance from effluent discharge. Notably, surface horizons manifested the steepest decline. In comparison with European Commission soil quality guidelines (50 mg/kg permissible Cr), all RICCO surface soils substantially exceeded recommended thresholds, whereas agricultural soils remained compliant [13].

Table 1. Heavy Metal Content in Tannery Area Soil.

Sampling Points	Depth of layers from the surface level (cm)	Cr (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Zn (mg/kg)
Point-1	0 - 15	561.71	70.58	2.25	158.23
	15 - 30	220.89	42.95	1.28	118.52
	30 - 45	90.09	26.61	0.88	98.73
Point-2	0 - 15	423.43	65.21	2.01	137.31
	15 - 30	191.73	38.90	1.26	107.65
	30 - 45	33.25	26.29	0.98	101.48
Point-3	0 - 15	290.67	31.09	1.12	73.5
	15 - 30	34.20	26.31	0.898	121.33
	30 - 45	28.72	26.50	0.7660	107.33
Point-4	0 - 15	230.15	30.73	1.01	107.23
	15 - 30	98.88	27.29	0.97	115.66
	30 - 45	33.33	24.37	0.81	103.15
Point-5	0 - 15	170.83	27.97	0.93	123.72
	15 - 30	35.63	26.44	0.80	129.25
	30 - 45	31.23	28.29	0.71	115.88
Maximum permissible limit recommended by EC (1986) [13]		50 mg/kg	300 mg/kg	3 mg/kg	—

Table 2. Heavy Metal content in agricultural area soil.

Sampling Points	Depth of layers from the surface level (cm)	Cr (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Zn (mg/kg)
Soil of agricultural area	0 - 15	27.867	23.60	0.64	28
	15 - 30	26.0416	25.76	0.82	134.167
	30 - 45	24.54166	22.49	1.30	80.5
Maximum permissible limit recommended by EC (1986) [13]		50 mg/kg	300 mg/kg	3 mg/kg	—

Conclusion

The findings of this investigation underscore the severity of heavy metal contamination as an emergent environmental and public health dilemma, particularly in rapidly industrializing contexts such as India where effluent treatment infrastructures are inadequate. The soils of the RICCO industrial sector were unequivocally found to be enriched with chromium far beyond permissible standards, attributable to chronic exposure to untreated industrial discharges and sludge. Furthermore, appreciable accumulations of Pb, Cd, and Zn were detected.

Such pollutants not only persist within pedological matrices but also bioaccumulate within edible flora, thereby integrating into trophic chains and culminating in significant toxicological risks. Given the mutagenic, teratogenic, and carcinogenic potential of Cr, Pb, and Cd, their environmental proliferation constitutes an exigent hazard to both human and animal populations. It is therefore imperative that stringent waste management protocols, advanced effluent treatment technologies, and systematic soil monitoring frameworks be instituted to mitigate the deleterious impacts of heavy metal contamination.

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