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Assessment of Heavy Metal Pollution in Sediment Soils from Tannery-Affected Areas in Different Taluks of Tamil Nadu

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Abstract
This study investigates seasonal variations in heavy metal concentrations in sediment soils from tannery-affected regions in Ambur, Pernambut, and Vaniyambadi Taluks, Tamil Nadu. Chromium, a predominant pollutant from tanning operations, consistently exhibited the highest levels across all sites. In Ambur and Pernambut, heavy metals such as chromium, lead, cadmium, iron, and zinc showed reduced concentrations post-monsoon, indicating rainfall-induced dilution, leaching, and sediment wash-off. Pernambut displayed significant post-monsoon reductions, particularly in chromium and aluminium, suggesting effective sediment redistribution. Conversely, Vaniyambadi showed minimal seasonal variation, with chromium levels remaining persistently high, implying ongoing contamination and limited hydrological flushing. Notably, cadmium levels in Vaniyambadi increased post-monsoon, pointing to remobilization or new inputs during runoff events. Comparative analysis revealed site-specific contamination patterns, with Ambur showing the highest pre-monsoon concentrations, and Vaniyambadi demonstrating consistent pollution throughout both seasons. Despite some seasonal mitigation, overall concentrations remained elevated, surpassing typical background levels and highlighting the persistent impact of industrial discharges. These findings underscore the need for continuous monitoring, improved tannery waste management, and targeted remediation strategies to prevent long-term ecological degradation and potential human health risks in these industrial regions.
Keywords: *Heavy metals, Environment monitoring, Tannery effluent,Soil pollution*

INTRODUCTION

The rapid industrialization of developing countries has led to increased environmental pollution, particularly in areas where industries such as tanning are concentrated. Tannery industries, especially in countries like India, are major contributors to heavy metal pollution due to the large volumes of untreated or partially treated effluents discharged into the environment (Rajaram & Das, 2008). These effluents typically contain high concentrations of heavy metals such as chromium (Cr), lead (Pb), cadmium (Cd), and others, which are byproducts of leather processing and chemical treatments (Kumar & Riyazuddin, 2011).Heavy metals are of significant concern due to their non-biodegradable nature, long biological half-lives, and potential to bioaccumulate in the food chain, posing risks to both ecological systems and human health (Alloway, 2013). When these metals enter water bodies or surrounding soils, they can be absorbed by sediments and remain in the environment for extended periods, often at toxic levels (Yadav, Shukla, & Srivastava, 2013). Sediment acts both as a sink and a source of heavy metals, depending on physicochemical conditions, and thus provides a reliable indicator of long-term pollution trends (Sundaray et al., 2011).

In Tamil Nadu, the towns of Ambur, Pernambut, and Vaniyambadi are major centers of the leather tanning industry. These regions have faced long-standing environmental challenges due to the improper handling of industrial waste, particularly chromium-laden effluents. Despite regulatory frameworks, ineffective treatment practices and poor enforcement have allowed heavy metal pollution to persist in local soils and water bodies (Jayaraj, Azariah, & Visvanathan, 2014). Seasonal variations, especially between pre-monsoon and post-monsoon periods, can further influence the distribution and mobility of these contaminants (Suresh et al., 2012).

The study evaluates heavy metals' concentration and seasonal variation in sediment from tannery-affected areas in Ambur, Pernambut, and Vaniyambadi, highlighting pollution dynamics and management practices.

MATERIAL AND METHODS

Study area

The study was conducted in the Tirupattur district's taluks of Ambur, Vaniyambadi, and Pernampet, Located between 78°42'0" East longitude and 12°47'0" North latitude, these areas host numerous small and large tanning industries, with at least one tannery in each village. The Palar river, a key water source, flows from west to east downstream of the industrial complex. The basin receives an average rainfall of 953.4 mm, characterized by a tropical and humid climate. Historically, irrigated crops included paddy, groundnut, pulses, sugarcane, and banana, but agricultural activity has declined due to tannery effluent discharge. The selection of these villages was based on industrial concentration, effluent discharge, and accessibility, with 500 farmers chosen as the study sample.

Sample collection

Sediment soil samples were collected in Ambur, Pernambut, and Vaniyambadi during pre-monsoon and post-monsoon seasons. Ten composite samples per season were obtained using a stainless-steel grab sampler at a depth of 0–10 cm. Each composite comprised 3 to 5 subsamples mixed together, packed in labeled polyethylene bags, and transported in ice boxes for laboratory analysis.

Processing of Sample

Digestion of Soil samples

Soil samples were oven dried at 40°C, ground finely (<0.01 mm), and then ashed in a crucible. One gram ash was treated with conc. HCl and HNO_3 successively in a ratio of 3:1 and heated gently until the sample was digested, indicated by the formation of a clear solution above the soil residue. The mixture was filtered through Whatman no. 42 filter paper. Doubled distilled water was added to make up the volume of the filtrate to 100 mL solution. The filtrates were analyzed in the CVR Laboratory Pvt.Ltd, Chennai by Atomic Absorption Spectrophotometer (AA-6401 F, Shimadzu, Japan). The working standard solutions for each metal were prepared before every analysis. The analytical procedures were verified with National Institute of Standards and Technology (NIST) traceable certified reference standards. Concentrations of Fe, Mn, Cu, Ni, Zn, Cr and Cd were measured by an air acetylene flame Atomic Absorption Spectrometer.

Statistical analysis

Descriptive statistics, including mean, standard deviation, and range, were analyzed through Excel and SPSS. Seasonal pre-monsoon and post-monsoon comparisons assessed rainfall effects on heavy metal levels, referencing WHO and USEPA guidelines for interpretation.

RESULT AND DISCUSSION

The analysis of sediment soil samples collected from tannery-affected areas in Ambur Taluk revealed notable seasonal variations in heavy metal concentrations between the pre-monsoon and post-monsoon periods (Fig 1). Across all measured metals, concentrations were consistently higher during the pre-monsoon season, indicating the influence of seasonal runoff and dilution due to monsoonal rainfall. Chromium, a key pollutant associated with tannery waste, showed the highest concentration with a mean of 148.64 mg/kg pre-monsoon, dropping to 124.74 mg/kg post-monsoon. Similar trends were observed for other metals such as lead, cadmium, iron, copper, and zinc, all showing reduced mean concentrations after the monsoon. Manganese and aluminium exhibited particularly sharp declines, suggesting significant wash-off or mobility under wet conditions. The seasonal drop in metal levels reflects the flushing effect of monsoon rains, yet the persistently high concentrations—especially of chromium and lead—raise environmental concerns. These findings align with previous studies that emphasize the risk of heavy metal accumulation in industrial regions and the potential for long-term ecological and health impacts if not properly managed (Alloway, 2013; Kumar & Riyazuddin, 2011; Rajaram et al., 2008).

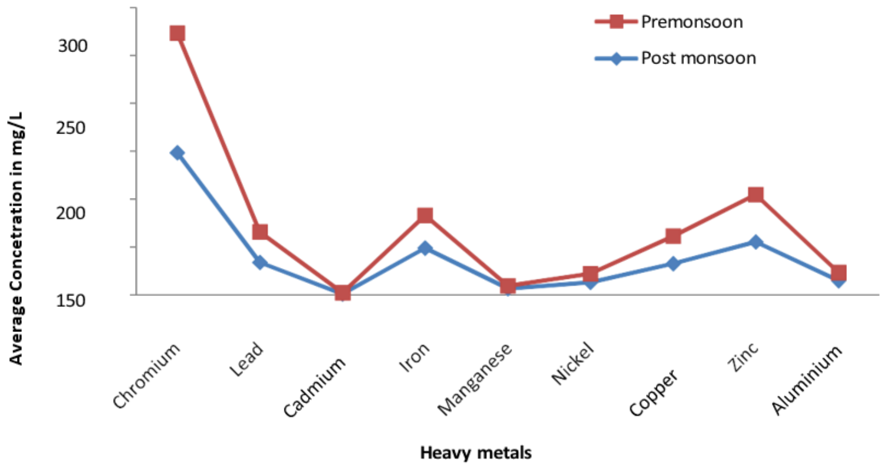

Fig 1. Comparison of heavy metal concentration of soil in pre-monsoon andpost-monsoon - Ambur taluk

The statistical analysis of sediment soil samples from tannery-impacted areas in Pernambut Taluk revealed distinct seasonal variations in heavy metal concentrations (Table 1). Chromium, one of the most prominent tannery-related pollutants, recorded a high pre-monsoon mean concentration of 149.0 mg/L, which decreased substantially to 99.78 mg/L post-monsoon, likely due to dilution and leaching caused by rainfall. This significant reduction in chromium levels also came with an increase in variability (SD = 35.05), indicating uneven distribution post-rainfall. Lead concentrations slightly decreased from 42.54 mg/L to 39.60 mg/L, while cadmium showed a marginal reduction from 0.841 mg/L to 0.749 mg/L, suggesting that although monsoonal runoff plays a role in reducing surface metal accumulation, residual contamination remains persistent. Iron levels declined notably from 61.36 mg/L pre-monsoon to 45.53 mg/L post-monsoon, reflecting possible sediment transport or dilution. Similarly, manganese, nickel, copper, and zinc all showed a decrease in post-monsoon mean values, supporting the hypothesis that seasonal hydrological changes impact metal mobility and retention in the soil. Aluminium levels dropped significantly from 17.96 mg/L to 8.72 mg/L post-monsoon, again emphasizing monsoon-induced sediment redistribution. Despite these seasonal reductions, the overall concentration levels—especially of chromium and lead—remain environmentally concerning and above typical background levels, posing ongoing ecological and health risks. These findings are consistent with studies highlighting the influence of industrial activities on heavy metal accumulation and the partial mitigating effect of seasonal rainfall (Alloway, 2013; Rajaram et al., 2008; Kumar & Riyazuddin, 2011).

Table 1: Statistical description of heavy metal concentration in sediment soilsamples collected from near tannery areas in Pernambut taluk throughout Pre-Monsoon & Post Monsoon

S.No	Heavy metals	Pre - monsoon (N = 10)				Post – monsoon (N= 10)			
		Min	Max	Mean	SD	Min	Max	Mean	Sd
1	Chromium	36.95	187.4	149.0	16.69	40.0	136.8	99.78	35.05
2	Lead	28.17	59.75	42.54	9.26	9.37	57.18	39.60	9.16
3	Cadmium	0.21	1.82	0.841	0.473	0.26	1.73	0.749	0.466
4	Iron	39.6	96.2	61.36	18.01	23.6	78.86	45.53	17.77
5	Manganese	6.64	20.78	11.07	3.82	3.35	17.48	8.15	3.58
6	Nickel	1.10	18.85	8.80	5.81	1.08	13.84	6.08	3.57
7	Copper	26.5	48.72	35.73	7.39	19.68	43.88	30.83	7.55
8	Zinc	26.93	66.98	46.13	11.60	18.05	58.12	38.50	11.59
9	Aluminium	8.95	27.96	17.96	5.88	2.25	22.02	8.72	25.68

The sediment analysis from tannery-affected zones in Vaniyambadi Taluk shows consistently elevated levels of heavy metals, with only minor seasonal variation(Fig 2). Chromium, a major pollutant associated with leather industries, exhibited the highest concentrations in both seasons, with a mean of 157.5 mg/L pre-monsoon and 155.6 mg/L post-monsoon—indicating minimal seasonal dilution and a persistently high contamination load. Lead concentrations showed a slight increase from 32.54 mg/L to 37.00 mg/L post-monsoon, which may reflect redistribution or new inputs, possibly from surface runoff. Cadmium presented a more noticeable seasonal shift, increasing markedly from 0.128 mg/L pre-monsoon to 1.14 mg/L post-monsoon, which could suggest mobilization from upstream or sediment release during monsoonal flows. Iron and manganese levels remained relatively stable across seasons, with only slight variations in their mean concentrations. Nickel concentrations declined post-monsoon (from 12.62 mg/L to 10.83 mg/L), as did copper and zinc, which both showed modest decreases in their mean values—possibly due to dilution or sediment resuspension. Aluminium concentrations showed minimal variation, though a slight increase in post-monsoon variability (as seen in standard deviation) suggests redistribution due to hydrological forces. Compared to Ambur and Pernambut, the Vaniyambadi region shows less pronounced seasonal fluctuation, implying either more stable pollution sources or limited rainfall-induced flushing. Nonetheless, consistently high chromium levels across seasons reinforce the ongoing impact of untreated tannery discharges, emphasizing the urgent need for continuous monitoring and remediation (Rajaram et al., 2008; Alloway, 2013).

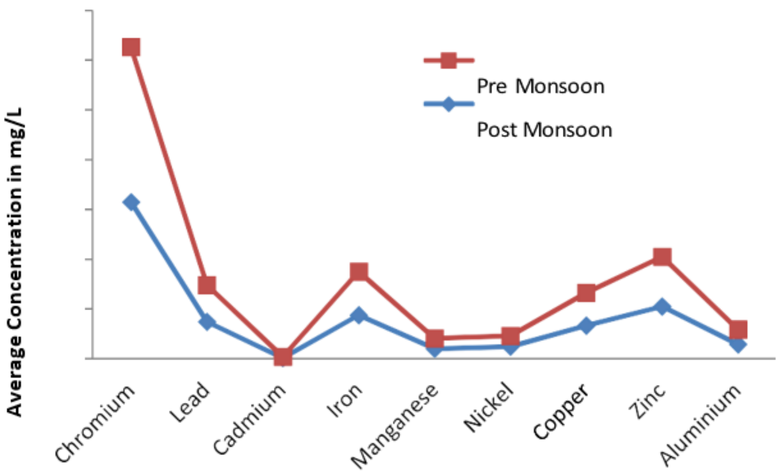

Fig 2. Comparison of heavy metal concentration of soil samples in Pre-monsoon and Post-monsoon-Vaniyambadi taluk.

A comparative analysis of sediment soil samples from tannery-heavy regions in Ambur, Pernambut, and Vaniyambadi Taluks indicates significant heavy metal contamination, characterized by seasonal patterns and site-specific variations. Chromium (Cr) consistently had the highest concentrations across all areas due to its extensive use in tanning and environmental persistence. Ambur and Pernambut registered a decline in chromium levels from pre-monsoon to post-monsoon, attributed to rainfall-induced dilution. In contrast, Vaniyambadi showed little seasonal variation, suggesting ongoing contamination and ineffective flushing. Additional heavy metals, including lead (Pb), cadmium (Cd), iron (Fe), and zinc (Zn), were also present in elevated levels, often surpassing safe limits, indicative of prolonged industrial pollution. Seasonal reductions in metal concentrations were more pronounced in Ambur and Pernambut, while Vaniyambadi displayed stable levels, implying persistent contamination. Ambur recorded the highest pre-monsoon concentrations, raising concerns about industrial discharge, whereas Pernambut showed significant post-monsoon reductions, potentially due to better sediment management (Kumar & Riyazuddin, 2011; Rajaram et al., 2008). The persistent presence of heavy metals presents serious environmental and health threats, as these toxic substances could infiltrate water bodies and food chains without proper waste management and remediation efforts.

CONCLUSION

The current research highlights a notable level of heavy metal pollution in sediment soil samples gathered from tannery-impacted regions in Ambur, Pernambut, and Vaniyambadi Taluks, with chromium identified as the primary contaminant. The information reveals both seasonal fluctuations and specific site variations in metal levels. Certain metals like chromium, lead, cadmium, and iron displayed slight reductions after the monsoon season—implying the effects of rainfall-driven dilution and leaching—while others maintained or even raised concentrations, pointing to continuous industrial discharge and remobilization.

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