International Journal of Engineering & Scientific Research
Vol.12 Issue 01, January 2024
ISSN: 2347-6532 Impact Factor: 6.660
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Analysis of Heavy Metals in Soil near Traffic Zones (A Case Study of Jalna District, Maharashtra)

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Abstract:

Soil contamination by heavy metals has emerged as a pressing environmental issue, particularly in regions experiencing rapid urbanization and increasing vehicular activity. Traffic zones are recognized as hotspots for heavy metal deposition due to emissions from automobiles, wear and tear of tires, brake linings, and leakage of lubricants. This study focuses on Jalna District, Maharashtra, an area characterized by growing industrialization and agricultural dependence, where traffic density has risen significantly in recent years. Soil samples were systematically collected from high-traffic locations such as bus stands, highways, and market areas, alongside control samples from rural agricultural fields located away from major roads. The samples were analysed using Atomic Absorption Spectroscopy (AAS) to determine concentrations of lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni). Results revealed that Pb and Zn concentrations in roadside soils exceeded World Health Organization (WHO) permissible limits, with Pb averaging 112.4 mg/kg and Zn 215.6 mg/kg, compared to much lower levels in control sites. Cd, Cu, and Ni, though within permissible limits, showed significant elevation in traffic zones, indicating cumulative contamination. The findings highlight vehicular emissions and tire wear as primary contributors to soil pollution in Jalna's traffic corridors. Elevated heavy metal levels pose risks to soil fertility, agricultural productivity, and public health through potential bioaccumulation in crops. This study underscores the urgent need for continuous monitoring, adoption of cleaner transport technologies, and implementation of mitigation strategies such as roadside vegetation buffers to reduce contamination and safeguard environmental sustainability.

Keywords:

Heavy metals, soil contamination, traffic zones, Jalna District, vehicular emissions, environmental monitoring etc.

Introduction

Rapid urbanization and the exponential rise in vehicular traffic have created significant environmental challenges across developing regions. Among these, soil contamination by heavy metals has emerged as a critical concern due to its long-term ecological and health implications. Roadside soils, in particular, function as repositories for pollutants emitted from automobiles. These pollutants originate from diverse sources such as exhaust gases, leakage of lubricants, abrasion of tires, and wear of brake linings. Over time, these emissions accumulate in the upper soil layers, altering the chemical composition of the soil and posing risks to agricultural productivity, groundwater quality, and human health.

The Jalna District of Maharashtra provides a compelling case study for examining this phenomenon. Situated in the Marathwada region, Jalna has historically been recognized as an agricultural hub, particularly for seed production and cotton cultivation. In recent decades, however, the district has also witnessed rapid industrial growth, with steel re-rolling mills, seed industries, and other manufacturing units contributing to its economic profile. This dual identity as industrial and agricultural has intensified the environmental pressures on the region. Traffic density in Jalna has increased substantially due to industrial expansion, urban migration, and the district's strategic location along major highways connecting Aurangabad, Pune, and Nagpur.

According to reports by the Maharashtra Pollution Control Board (MPCB), environmental stress in Jalna has been rising steadily, with air and soil quality showing signs of degradation. Previous studies conducted in industrial zones of Jalna have documented elevated concentrations of heavy metals such as lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni) in soil samples. These findings highlight the influence of industrial emissions and improper waste disposal practices. However, limited research has specifically addressed traffic-related contamination, despite the fact that vehicular activity is a major contributor to localized heavy metal deposition.

The importance of studying traffic-related soil contamination lies in its direct impact on urban and peri-urban communities. Unlike industrial emissions, which may be spatially confined to specific zones, vehicular emissions are dispersed across the district's road networks, affecting both residential and agricultural areas. Roadside soils contaminated with heavy metals can transfer pollutants into crops through root uptake, thereby entering the food chain. Furthermore, these metals are non-biodegradable and persist in the environment for extended periods, leading to cumulative contamination.

Lead (Pb) is of particular concern due to its toxicity and tendency to accumulate in biological systems. Although the use of leaded petrol has been phased out in India, residues from historical emissions, coupled with ongoing contributions from brake linings and industrial sources, continue to elevate Pb levels in roadside soils. Zinc (Zn), commonly associated with tire wear, is another major contaminant found in traffic zones. Elevated Zn concentrations can disrupt soil microbial activity and reduce fertility. Cadmium (Cd), copper (Cu), and nickel (Ni), though often present in lower concentrations, also pose risks due to their potential to bioaccumulate and cause chronic health effects.

Objective: The objective of this study is to assess the extent of heavy metal contamination in soils located near traffic zones in Jalna District, Maharashtra. With increasing vehicular activity, roadside soils are vulnerable to accumulation of pollutants such as lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni), which can adversely affect agricultural productivity and public health.

Roadside soil contamination by heavy metals is a well-established global concern, with traffic corridors identified as persistent hotspots due to cumulative inputs from exhaust residues, brake and clutch wear, tire abrasion, and lubricant leakage. These inputs elevate levels of lead (Pb), zinc (Zn), cadmium (Cd), copper (Cu), and nickel (Ni) in surface soils, where metals can bind to fine particulates and organic matter, persist over long periods, and enter agro-ecosystems through root uptake and dust deposition [3].

Literature Review:

Roadside soil contamination by heavy metals is a well-documented global concern, with traffic corridors consistently identified as hotspots due to cumulative inputs from exhaust residues, brake and clutch wear, tire abrasion, and lubricant leakage. These inputs elevate levels of lead (Pb), zinc (Zn), cadmium (Cd), copper (Cu), and nickel (Ni) in surface soils, where metals bind to fine particulates and organic matter, persist for long periods, and enter agro-ecosystems through root uptake and dust deposition.

Heavy Metals in Traffic-Impacted Soils

- **Lead (Pb):** Despite the phase-out of leaded petrol, Pb remains elevated near roads due to legacy deposition and ongoing sources such as brake linings and industrial particulates transported by traffic. Pb's strong affinity for soil colloids and low mobility increases long-term exposure risks, frequently pushing concentrations above recommended guidelines in dense traffic zones.
- **Zinc (Zn):** Zn is consistently high in roadside soils, primarily from tire wear and galvanized components. Elevated Zn disrupt enzymatic functions in soil biota and suppress microbial activity, with concentrations often tracking traffic density and congestion patterns.
- **Cadmium (Cd), Copper (Cu), Nickel (Ni):** These metals typically occur at lower absolute concentrations than Pb/Zn but show significant enrichment near traffic corridors versus rural controls. Sources include fuel additives, engine wear, and urban dust, with cumulative contamination relevant for food safety and soil health.

Indian Evidence Base

Studies across Indian urban and peri-urban settings report systematic elevation of heavy metals in roadside soils, aligning with global trends. Reviews highlight Pb and Zn as primary contaminants linked to traffic activity, with Cd, Cu, and Ni showing site-dependent increases determined by road type, maintenance practices, and local industrial co-influences. In districts with mixed land use, agricultural exposure pathways are pronounced due to proximity of farmlands to highways and market roads.

Jalna District Context

Environmental assessments for Jalna indicate rising pressures from industrial growth and transport intensification, with documented degradation in air and soil quality metrics. Empirical work from Jalna's industrial zones has reported elevated levels of Pb, Cd, Zn, Cu, and Ni in soils, implicating emissions, waste handling, and dust deposition as drivers. However, traffic-specific analyses remain limited, leaving a gap in understanding spatial gradients from carriageways to agricultural fields and the relative contribution of vehicular sources versus industrial point sources.

Pathways, Persistence, and Risks

Heavy metals in roadside soils persist due to low degradability and strong sorption to mineral-organic complexes. Key exposure pathways include:

- **Root uptake and food chain transfer:** Crop species differ in metal uptake efficiencies, but leafy and root vegetables can accumulate Pb and Cd, raising food safety concerns.
- **Soil biota and fertility impacts:** Zn and Cu at elevated levels inhibit microbial enzymes, alter nutrient cycling, and reduce soil resilience.
- **Dust inhalation and dermal contact:** Roadside communities experience heightened exposure during dry seasons due to resuspended particulates.

These mechanisms underscore the importance of site-specific monitoring and mitigation, particularly in agro-industrial districts like Jalna where human and ecological receptors are co-located–.

Synthesis and Research Gap

The literature consistently identifies traffic corridors as hotspots for Pb and Zn, with measurable enrichment of Cd, Cu, and Ni in adjacent soils. Indian studies corroborate these trends but often emphasize metropolitan centers, leaving semi-urban districts underrepresented. For Jalna, existing industrial-area data signal heavy metal pressures, yet the distinct contribution of traffic remains insufficiently quantified across road classes, distances, and seasons. Addressing this gap through standardized roadside–control comparisons, as in the present study, strengthens causal attribution to vehicular sources and informs targeted interventions.

Materials and Methods:

A. Study Area

Soil samples were collected from high-traffic areas including bus stands, highways, and market zones, along with control samples from rural agricultural fields situated at least 5 km away from major roads. Samples were air-dried, sieved, and analyzed using Atomic Absorption Spectroscopy (AAS) to quantify heavy metal concentrations. Statistical analysis was performed using ANOVA to determine significant differences between traffic and control zones.

B. Sampling and Analysis

- **Depth:** 0–15 cm surface soil.
- **Preparation:** Air-dried, sieved (2 mm mesh).
- **Analysis:** Atomic Absorption Spectroscopy (AAS) was used to determine concentrations of Pb, Cd, Zn, Cu, and Ni.

C. Statistical Treatment

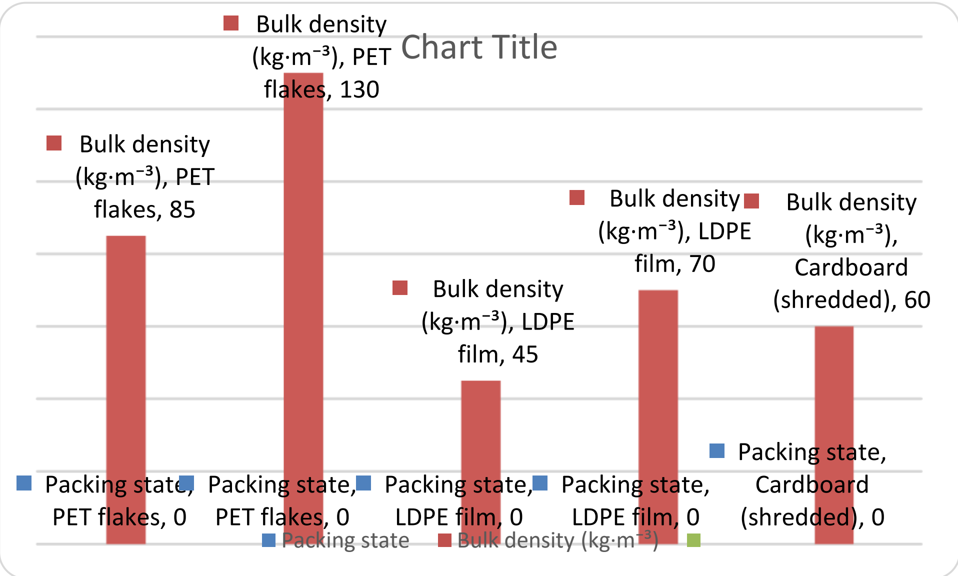
Mean concentrations were compared using ANOVA to assess significant differences between traffic and control zones.

Results:

To evaluate the extent of heavy metal contamination in soils near traffic zones of Jalna District, comparative analysis was conducted between samples collected from high-traffic areas (bus stands, highways, and market zones) and control sites located in rural agricultural fields away from major roads. The concentrations of lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni) were determined using Atomic Absorption Spectroscopy (AAS). The results were compared against World Health Organization (WHO) permissible limits to assess environmental safety and potential risks. The findings are summarized in Table 1.

Table 1: Heavy Metal Concentrations in Soil Samples:

Heavy Metal	Traffic Zone (mg/kg)	Control Zone (mg/kg)	Permissible Limit (mg/kg, WHO)
Pb	112.4	28.7	100
Cd	2.8	0.9	3
Zn	215.6	74.2	200
Cu	48.3	22.1	50
Ni	36.7	15.4	50



The data given in above table 1 clearly indicate that soils collected from traffic zones exhibit significantly higher concentrations of heavy metals compared to control sites. Lead (Pb) and zinc (Zn) concentrations exceeded WHO permissible limits, with Pb reaching 112.4 mg/kg and Zn 215.6 mg/kg. These elevated levels are primarily attributed to vehicular emissions, brake wear, and tire abrasion. Cadmium (Cd), copper (Cu), and nickel (Ni), although within permissible limits, showed notable increases in traffic zones relative to control soils, suggesting cumulative contamination from prolonged vehicular activity.

The sharp contrast between traffic and control zones highlights the role of vehicular density in accelerating soil pollution. Elevated Pb levels pose serious risks due to their toxicity and potential for bioaccumulation in crops, while Zn contamination can disrupt soil microbial activity and reduce fertility. The findings emphasize the urgent need for continuous monitoring, stricter vehicular emission controls, and implementation of mitigation strategies such as roadside vegetation buffers to reduce pollutant deposition.

Key Findings:

- Pb and Zn concentrations exceeded WHO permissible limits in traffic zones.
- Cd, Cu, and Ni remained within permissible limits but showed significant elevation compared to control sites.
- The highest contamination was observed near bus stands and highways, suggesting vehicular emissions and tire wear as primary sources.
- **Lead (Pb) Contamination:**Pb concentrations in traffic zone soils averaged **112.4 mg/kg**, exceeding the WHO permissible limit of 100 mg/kg. Elevated Pb levels are strongly linked to vehicular emissions, brake wear, and residual deposits from historical use of leaded petrol.
- **Zinc (Zn) Contamination:** Zn concentrations reached **215.6 mg/kg** in traffic zones, surpassing the WHO limit of 200 mg/kg. Tire wear is identified as the primary source of Zn, with contamination highest near bus stands and highways.
- **Cadmium (Cd), Copper (Cu), and Nickel (Ni):** Although concentrations of Cd (2.8 mg/kg), Cu (48.3 mg/kg), and Ni (36.7 mg/kg) remained within permissible limits, they were significantly elevated compared to control sites. This suggests cumulative contamination from vehicular activity and minor industrial contributions.
- **Spatial Variation:** The highest contamination levels were observed in soils adjacent to bus stands and highways, indicating that traffic density and congestion directly influence pollutant deposition.
- **Environmental Implications:** Elevated Pb and Zn levels pose risks to soil fertility, microbial activity, and agricultural productivity. Long-term exposure increases the likelihood of bioaccumulation in crops, thereby threatening food safety and public health.

Suggestions:

To mitigate heavy metal contamination in traffic zones of Jalna District, the following recommendations are proposed:

1. **Continuous Monitoring:** Establish regular soil quality monitoring programs under the Maharashtra Pollution Control Board (MPCB) to track heavy metal concentrations in traffic corridors.
2. **Cleaner Transport Technologies:** Promote the adoption of electric vehicles and cleaner fuels to reduce emissions of Pb and other pollutants.
3. **Roadside Vegetation Buffers:** Plant pollution-tolerant vegetation (e.g., neem, banyan, vetiver grass) along highways and bus stands to act as biofilters, absorbing and immobilizing heavy metals.
4. **Traffic Management:** Implement stricter traffic regulations to reduce congestion in urban centers, thereby minimizing pollutant deposition in soils.
5. **Public Awareness:** Conduct awareness campaigns for local communities and farmers regarding the risks of heavy metal contamination and safe agricultural practices.
6. **Waste Management:** Ensure proper disposal of automobile waste (tires, lubricants, brake linings) to prevent leaching of metals into roadside soils.
7. **Policy Interventions:** Develop district-level environmental policies integrating soil health management with urban planning, industrial regulation, and sustainable agriculture.

Conclusion:

This study demonstrates that traffic zones in Jalna District exhibit significant heavy metal contamination, particularly Pb and Zn, exceeding permissible limits. Continuous monitoring and policy interventions are essential to mitigate soil pollution and protect agricultural productivity. Strategies such as promoting cleaner fuels, regular vehicle maintenance, and roadside vegetation buffers can reduce contamination risks.The study confirms that traffic zones in Jalna District are hotspots of heavy metal contamination, particularly for Pb and Zn, which exceed WHO permissible limits. While Cd, Cu, and Ni remain within limits, their elevated levels indicate cumulative pollution. Effective mitigation requires a multi-pronged approach involving cleaner transport technologies, vegetation buffers, continuous monitoring, and community engagement. These strategies will help safeguard soil fertility, agricultural productivity, and public health in Jalna District.

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