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Evaluating Heavy Metal Pollution in Soil and Wheat Crops Near Major Highways in Lucknow, Uttar Pradesh

Mohd Mohasin[1], P Smriti Rao[2], Khalid Habib[3]*
[123]Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST) Integral University, Lucknow, India 22 6026
Corresponding author Email: *Khalidh@iul.ac.in*

Abstract
This study evaluates the levels of lead (Pb) and cadmium (Cd) contamination in agricultural soils and wheat (Triticum aestivum) crops in Lucknow, Uttar Pradesh, India, along NH-24, NH-28, and NH-56. To examine the spatial effects of vehicle emissions on metal accumulation, soil and wheat grain samples were taken at two depths (0–15 cm and 15–30 cm) and at distances of 10 m, 20 m, and 50 m from these highways. Atomic absorption spectrophotometry (AAS), which is renowned for its accuracy in detecting trace metals, was used to measure the concentrations of Pb and Cd. There was a high risk of contamination close to the highways, according to the Pollution Load Index (PLI). Significant variations in metal concentrations and primary nutrients were found across depths and distances using statistical analysis using Duncan's Multiple Range Test (DMRT), indicating a definite impact of traffic density. Potential health hazards for local consumers were indicated by the Estimated Daily Intake (EDI) values for Pb and Cd, which were expressed in mg kg^{-1} per day from wheat consumption. The importance of EDI and PLI as crucial indicators in evaluating the risks to the environment and public health posed by metal contamination is highlighted by these findings, which also highlight the necessity of proactive pollution control measures and routine heavy metal monitoring in agriculture.
Key words: Pollution, nutrients, consumers, monitoring, emissions

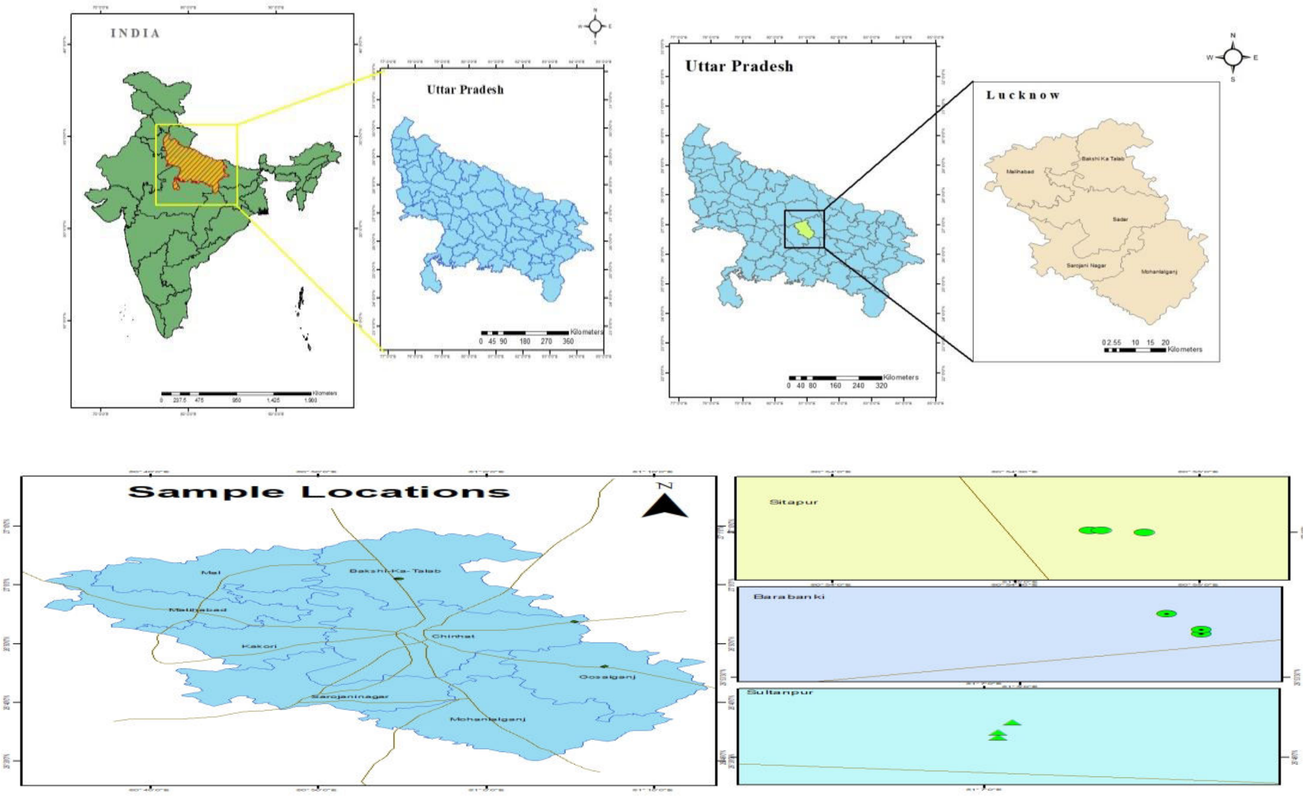
Introduction

Urban areas are a product of human activities, resulting in transformations of the physical, chemical, and biological properties of the original environment (Yuan et al. 2021; Sun et al. 2010). Although such environments have the capacity to reduce or remediate pollutants, they are also vulnerable to contamination as a result of urbanization and industrialization processes (Yuan et al. 2021). Urban soils are often characterized by high levels of contamination, varying with respect to contaminant type (Chen et al. 2015). Heavy metals including cadmium (Cd), lead (Pb) and mercury (Hg), known as major contaminants that have been introduced into the environment due to anthropogenic activities, particularly through industrial emissions or when combined with products such as fertilizers and pesticides in agriculture (Wei & Yang. 2010).Traffic-derived emissions represents one of the largest sources of heavy metal pollution in urban soil-environment. The vehicular traffic induces many kinds of heavy metals from its tailpipe like source, crankcase oil, worn-out tire fragments during braking and normal running conditions as well as from abrasion-oxydation wear of braking system materials' disc and blocks through hauling vehicle degradation. Therefore roadways usually suffer more contaminations by these metals because vehicular em has electrical wastes that can be absorbed into urban alleyways due to runoffs from roads' surfaces.In India, especially in densely populated areas like Uttar Pradesh, growing vehicular emissions, industrial effluents and urban runoff are the most important sources of Pb and Cd enrichment near road-sides (Gupta, V., & Arya, A. K. (2018).This contamination possess risk to soil quality, agricultural productivity and human health due to possibility of bioaccumulation in the crops. Therefore, there is an urgent need for effective management and remediation practices for heavy metal contaminated urban and roadside soils (Chandrasekaran et al. 2015).

Study area and sampling

The studies on highways are situated in Lucknow, Uttar Pradesh, India. This district is positioned along the Gomati River, which is part of the Central Ganga Plain. Geographically, it is located between latitudes 26°30' and 27°10'N and longitudes 80°30' and 81°13'E. Lucknow district boasts a comprehensive network of roads, with five national highways traversing the area: NH-24 (Sitapur Highway), NH-24B (Prayagraj Highway), NH-25

(Kanpur Highway), NH-28 (Barabanki Highway), and NH-56 (Sultanpur Highway). Among these exhibit varying levels of traffic density. NH-24 experiences a daily traffic volume of 25,000 to 30,000 vehicles, NH-28 sees between 20,000 and 30,000 vehicles, NH-24B traffic volume 10000-12000, NH- 25 daily traffic volume from 15000-20000 per day and NH-56 has a traffic count of 10,000 to 20,000 vehicles, as noted at the NHAI toll plaza. Out of these three national highway (NH-24, NH-28, NH-56) were chosen for their heavy traffic and potential risk of soil contamination by vehicular pollutants. Soil samples were gathered from different distances (10, 20, and 50 meters from the road edge) and at two depths: 0–15 cm (surface samples) and 15–30 cm (subsurface samples). Notably, these samples did not include any road construction materials. All samples were collected using a stainless-steel spatula and stored in polyethylene bags, each weighing approximately 1 kg. Wheat (*Triticum aestivum*) grain samples were obtained from three major highways (NH-24, NH-28, and NH-56) to investigate heavy metal contamination. Wheat Samples were collected at three distinct distances (10 m, 20 m, and 50 m) from the road site for each highway, allowing for an assessment of how proximity to the highway affects metal accumulation. The sampling process was conducted over two growing seasons to capture seasonal fluctuations in heavy metal concentrations. This methodology enabled a thorough evaluation of both spatial and temporal variations in lead (Pb) and cadmium (Cd) levels within the wheat samples.



Data Processing and Statistical Analysis

The recorded data on Nitrogen (N), Phosphorus (P), and Potassium (K) concentrations in soil samples collected at different distances from highways (NH-24, NH-28, and NH-56) and at varying soil depths, as well as Lead (Pb) and Cadmium (Cd) concentrations in both soil and wheat grain samples, were analyzed statistically using analysis of variance (ANOVA) under a Completely Randomized Design (CRD). The average data collected over two years for all parameters, including NPK and heavy metal concentrations at different depths, were subjected to statistical analysis. Duncan's Multiple Range Test (DMRT) was applied at a 5% level of significance ($P \leq 0.05$) to compare treatment means, with Critical Difference (CD) and Least Significant Difference (LSD) values calculated to assess significant differences between treatments. Statistical analysis was conducted using IBM SPSS Statistics software (Version 20) for Windows. ANOVA was employed to determine the significance of differences between treatments (distances from highways and soil depths), and DMRT was used to separate the means where significant differences were observed.

Contamination assessment

To assess the extent of contamination of heavy metals in roadsite surface soils and degree of overall contamination for a particular highway and distance, contamination factor (CF) and pollution load index (PLI) has been applied. The calculation of CF is as follows:

$$CF = C\_metal \,/\, C\_background$$

Where CF is the contamination factor, Cmetal is the concentration of pollutant in sediment C background is the background value for the heavy metal. The CF reflects the heavy metal enrichment in the sediment. The CF was classified into four groups i.e. contamination factor CF < 1 refers to low contamination; 1 ≤ CF < 3 means moderate contamination; 3 ≤ CF ≤ 6 indicates consiterable contamination and CF > 6 indicates very high contamination. Each land type is evaluated for the extent of heavy metal pollution by calculating the pollution load index as follows (Hakanson, L ;1980)

$$PLI = n\sqrt{}(CF1 \times CF2 \times CF3 \times \dots\dots CFn)$$

Where n is the number of heavy metals studied (seven in this study) and CF is contamination factor of each heavy metal at a particular site. The PLI provides simple but comparative means for assessing a site quality, where a value of PLI < 1 denote perfection; PLI = 1 present that only baseline levels of pollutants are present and PLI >1 would indicate deterioration of site quality. Distribution map of different heavy metals in surface soils along the highway is prepared by using raster interpolation technique in Arc GIS 10 software. (Tomlinson et al.1980).

$$EDI = \frac{C \times IR \times EF}{BW}$$

Where

(C) concentration of the contamination in the food (mg kg^{-1})
(IR) ingestion rate of the food (Kg /day)
(EF) exposure frequency (days/year)
(BW) body weight

- Concentration of Metal in Wheat Grain: Measured in mg kg^{-1}.
- Daily Consumption of Wheat Grain: Measured in kg/person/day (Average 197 gm /day).
- Body Weight: Measured in kg (Average body weight 65 Kg).

The **Estimated Daily Intake (EDI)** of heavy metals through dietary sources is a critical aspect of risk assessment, particularly in populations with high consumption of contaminated food products. (JECFA; 1993) For context, the average daily consumption rate of flour, a staple food in many diets, is approximately **197 grams**. This consumption pattern necessitates careful monitoring of heavy metal concentrations in flour and other agricultural products to ensure they remain within the established safety limits to mitigate potential health risks.

Results Discussion

Different investigations have examined the contamination of roadsite soils and crops by lead (Pb) and cadmium (Cd), consistently indicating elevated concentrations of these heavy metals in proximity to highways, primarily due to emissions from vehicles. (Zwolak et al. 2013). conducted an extensive evaluation of the potential health risks associated with heavy metals in the soil-plant system, finding Pb concentrations in urban soils ranging from 42.1 to 85.3 mg kg^{-1} and Cd levels between 0.5 and 2.3 mg mg kg^{-1}. The findings suggested that these concentrations present consiterable health risks when crops are consumed. This aligns with the current study's results, which identified high levels of Pb and Cd in corn crops located near highways, underscoring the necessity of monitoring these hazardous elements in agricultural areas adjacent to high-traffic zones (Gupta, V., & Arya, A. K. 2018) conducted an evaluation of lead (Pb) and cadmium (Cd) concentrations in soil and crops located near highways in Beijing, China. Their findings indicated that Pb levels in the soil varied from 38.6 to 102.5 mg kg^{-1}, while Cd concentrations ranged from 1.2 to 3.6 mg kg^{-1}. In the crops analyzed, Pb concentrations were found to be between 0.18 and 0.56 mg kg^{-1}, with Cd levels ranging from 0.07 to 0.21 mg kg^{-1}. The study concluded that the proximity to roadways significantly heightened the risk of heavy metal absorption by crops, paralleling the contamination levels noted in the wheat crops of the current study. These findings underscore the influence of vehicular emissions and irrigation methods on the contamination of soil and crops adjacent to highways.

Heavy metals in plants: lead (pb) and cadmium (cd) uptake and effects

Lead (Pb) and cadmium (Cd) accumulation in plants mainly disturbs essential physiological processes, leading to growth inhibition, decreased photosynthetic capacity, and overall reduced plant fitness (Cannata et al. 2013; Collin et al. 2022). Elevated levels of these elements can interfere with nutrient availability and enzyme function, affecting cellular metabolism and physiological pathways. Pb- or Cd-induced toxicity enhances the production of reactive oxygen species, which in turn can cause oxidative damage to cellular components such as lipids, proteins, and DNA (Meng et al. 2022). Thus, the presence of these elements in plant tissues restrains performance, productivity, and stress tolerance.

DMRT Evaluation of Nutrient (NPK) and Heavy Metal (Cd, Pb) Variations

Soil contamination and nutrient stages have been assessed at various distances (10 m, 20 m, 50 m) and depths (0-15 cm, 15-30 cm) adjacent to highways NH-24, NH-56, and NH-28. The study present the concentrations of Cadmium (Cd), Lead (Pb), Nitrogen (N), Phosphorus (P), and Potassium (K) measured in mg kg^{-1} and kg h^{-1}. Cadmium concentrations ranged from 0.07 to 0.30 mg kg^{-1}, with NH-28 displaying the highest degrees. The result shows that Cd concentrations decrease with increasing distance from the highways and are decrease in the deeper soil layers (15-30 cm). Lead (Pb) levels, which ranged from 6.0 to 12.Four mg kg^{-1}, additionally confirmed a lowering fashion with distance from the highways. Notably, NH-24 and NH-28 recorded higher Pb concentrations in comparison to NH-56

Table 1 *Status of heavy metals and macro nutrient at different sampling site*

Sampling highway	**NH24**						**NH56**						**NH28**					
Sampling depth (cm)	**0-15**			**15-30**			**0-15**			**15-30**			**0-15**			**15-30**		
Distance (m) from site	**10**	**20**	**50**	**10**	**20**	**50**	**10**	**20**	**50**	**10**	**20**	**50**	**10**	**20**	**50**	**10**	**20**	**50**
Cd (mg kg^{-1})	.28 d	.20 bc	.14 a	.24cd	.15ab	.10a	.21d	.20 cd	.11 ab	.18 cd	.15bc	.08 a	.30e	.24 d	.12 b	.26d	.20 c	.07a
Pb (mg kg^{-1})	12.3d	10.0b cd	7.3 ab	11.4 cd	9.0ab c	6.5a	12.3d	10.6 bc	7.3 a	11.1 bc	9.8 b	6.2a	12.4 c	10.7b	6.5a	11.2b c	9.7 b	6.0 a
N (kg h^{-1})	232.7 ab	239.0 c	247.5 d	230.0 a	237.3 bc	240.7 c	226.3 a	237.8 bc	241.8 c	222.0 a	234.8 b	237.5 bc	220.1 a	226.7 b	239.1 c	218.3 a	227.7 b	229.4 b
P (kg h^{-1})	12.9b	12.8 b	10.9a b	12.1 b	11.4a b	9.9 a	12.8 b	11.9a b	11.1a b	12.2a b	11.2a b	10.4a	12.8 c	12.1b c	11.0a b	12.4b c	11.8a bc	10.4 a
K (kg h^{-1})	208.3 ab	207.1 ab	225.3 c	202.7 a	205.2 a	219.0 bc	209.8 ab	222.6 cd	224.8 d	202.4 a	212.1 abc	219.6 cd	208.9 abc	212.2 bc	225.2 d	200.9 a	207.3 ab	219.6 cd

Columns followed by the same letters do not differ significantly at P≤0.05 according to Duncan's Multiple Range Test (DMRT)

As presented in Table 1. Nitrogen (N) levels in the soil vary from 218.3 and 247.5 kg h^{-1}, with elevated concentrations found further away from highways, suggesting a decrease in vehicular influence. Phosphorus (P) levels range from 9.9 to 12.9 kg h^{-1}, exhibiting no clear pattern in relation to distance. Potassium (K) concentrations, which range from 200.9 to 225.3 kg h^{-1}, tend to increase moderately with distance, particularly in deeper soils at NH-28. The results of the DMRT (Duncan's Multiple Range Test) indicate significant variations in both metal and nutrient concentrations, with distinct letters (a-e) denoting statistically significant differences among the observed data. Cadmium (Cd) and lead (Pb) concentrations are highest near NH-28, while nutrient levels remain relatively stable, showing some increase at greater distances.

Component	**Cd (Cf)**						**Pb(Cf)**					
Distance (m)	**10**		**20**		**50**		**10**		**20**		**50**	
Depth (cm)	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
NH-24	2.8	2.4	2.0	1.5	1.4	1.0	1.2	1.2	1.1	0.9	0.7	0.6
NH-56	2.1	1.8	2.0	1.5	1.1	0.9	1.2	1.2	1.0	0.9	0.7	0.6
NH-28	3	2.6	2.4	2.0	1.2	0.7	1.2	1.1	1.0	0.9	0.6	0.6

Table 2 *Contamination in wheat grain at sampling site*

Component	**Cd (mg kg^{-1})**			**Pb(mg kg^{-1})**		
Distance (m)	10	20	50	10	20	50
NH24	.3a	.1a	.3a	4.6a	2.8a	1.6a
NH56	.4c	.2b	.1a	4.4b	3.4ab	1.5a
NH28	.3c	.3b	.1a	3.7c	2.2b	1.1a

Table 3 *Contamination factor of metals*

Columns followed by the same letters do not differ significantly at P≤0.05 according to Duncan's Multiple Range Test (DMRT)

The proximity to highways has a notable impact on the concentrations of lead (Pb) and cadmium (Cd) in wheat grains. Pb levels consistently decline as the distance from the highway increases, with NH-28 recording the highest Pb concentrations at all measured distances: 3.7 mg kg^{-1}at 10 meters, 2.2 mg kg^{-1}at 20 meters, and 1.1 mg kg^{-1}at 50 meters. In contrast, Cd concentrations peaked near NH-56 at 10 meters (0.4 mg/kg) but decreased to 0.1 mg kg^{-1}at 50 meters. NH-24 also exhibited elevated Cd levels at 10 meters (0.3 mg kg-1), which fell to 0.1 mg kg^{-1}at 20 meters. The findings indicate that highways with greater traffic volumes, such as NH-24 and NH-56, are linked to higher levels of Cd contamination, while NH-28 consistently shows the highest Pb concentrations as detailed in Table 2. These significant differences highlight the influence of traffic and proximity to highways on the accumulation of heavy metals in agricultural crops.

Contamination Factor

The contamination levels of Cadmium (Cd) and Lead (Pb) were assessed at different distances from highways NH-24, NH-56, and NH-28. Cd reached its highest contamination factor of 3.0 (Cf) at a distance of 10 meters from NH-28 within the 0-15 cm soil depth, with a notable decrease as the distance increased. In contrast, Pb concentrations peaked at 1.2 (Cf) at 10 meters from both NH-24 and NH-56, demonstrating a consistent trend across all examined highways As summarized in Table 3. These contamination factors underscore the significant anthropogenic influence of vehicular emissions, suggesting a strong correlation between proximity to these roads and increased heavy metal levels in the soil. This observation is consistent with findings from (Wei and Yang 2010), which indicate that vehicular emissions play a crucial role in elevating heavy metal concentrations in soil (Huang et al. 2022).

Pollution Load Index

The Pollution Load Index (PLI) evaluated at varying distances (10 m, 20 m, and 50 m) and soil depths (0-15 cm and 15-30 cm) from highways NH-24, NH-56, and NH-28 reveals a distinct trend of diminishing contamination as the distance from the highways increases and as the soil depth increases. The highest PLI values were observed at a distance of 10 m and at the 0-15 cm depth, with averages of 2.5 prior to sowing and 2.3 following harvesting. (Shikha et al. 2023)

Table 4 *Pollution load index on sampling site*

PLI						
Distance (m)	**10**		**20**		**50**	
Depth (cm)	0-15	15-30	0-15	15-30	0-15	15-30
NH24	2.6	2.3	2.0	1.6	1.4	1.1
NH56	2.2	2.0	2.0	1.7	1.2	1.0
NH28	2.7	2.4	2.2	1.9	1.2	0.9

<1: No pollution, 1: Baseline level of pollution, >1: Pollution present, >2: Significant pollution

This indicates a notable influence of vehicular emissions and road dust in areas close to the highways. Conversely, the lowest PLI values, recorded at a distance of 50 m and a depth of 15-30 cm, underscore the diminished effect of highway proximity on the accumulation of heavy metals in the soil As shown in Table 4. This trend is consistent with findings from related research, including studies by (Pathak et al. 2015), which illustrate that urban soils adjacent to roadways are significantly impacted by heavy metal concentrations due to traffic density and their distance from pollution sources.

Estimated daily intake :

This study evaluated the estimated daily intake (EDI) of cadmium (Cd) and lead (Pb) along National Highways 24, 28, and 56 at distances of 10 m, 20 m, and 50 m over a two-year period. The permissible daily limits for Cd and Pb, as set by the Food Safety and Standards Authority of India (FSSAI), WHO, and FAO, are 1.625 mg/day and 195 mg/day, respectively, serving as reference points.

Distance from highway	**NH-24**				**NH-56**				**NH-28**			
	Ist Year		**IInd Year**		**Ist Year**		**IInd Year**		**Ist Year**		**IInd Year**	
	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb
10 m	0.3	10.5	1.5	17.3	1.2	11.7	1.5	15.2	1.2	11.0	1.1	11.6
20 m	0.2	7.0	0.9	9.94	0.6	8.3	0.9	12.4	0.9	7.4	0.9	5.9
50 m	0.06	5.0	0.06	5.0	0.09	4.3	0.2	5.0	0.3	3.6	0.3	3.0

Table 5 *Estimated daily intake (EDI)*

**(EDI) Estimated daily intake calculated as mg kg^{-1} per day*

Daily Permissible Limit (FSSAI, WHO, FAO): Cadmium (Cd): 0.025 mg kg^{-1} body weight/day, Lead (Pb): 3 mg kg^{-1} body weight/day

Along NH-24, the EDI for Cd ranged from 0.01 to 0.2 mg kg^{-1} per day, and for Pb from 5.0 to 17.3 mg kg^{-1} per day. For NH-28, Cd ranged from 0.3 to 1.2 mg kg^{-1} per day, and Pb from 3.0 to 11.6 mg kg^{-1} per day. Along NH-56, Cd levels varied between 0.09 and 1.5 mg kg^{-1} per day, while Pb ranged from 4.3 to 15.2 mg kg^{-1} per day. Importantly, all EDI values for both Cd and Pb were well below the established permissible limits, even at the closest distance of 10 m. Although the current intake levels are within safe limits, ongoing monitoring is essential as long-term exposure could pose health risks (Li et al. 2021).

Table 6 *Pearson correlation matrix between metals and NPK*

Metal	*Cd*	*Pb*	*N*	*P*	*K*
Cd	1				
Pb	0.85207	1			
N	-0.47281	-0.38283	1		
P	0.709139	0.830147	-0.15494	1	
K	-0.35654	-0.28481	0.650143	-0.03392	1

Pearson correlation matrix

The Pearson correlation matrix illustrates the relationships between Cadmium (Cd), Lead (Pb), Nitrogen (N), Phosphorus (P), and Potassium (K) in soil samples. Understanding these correlations is crucial for evaluating soil quality and its implications for agricultural practices.

Cadmium (Cd) shows a significant positive correlation with Lead (Pb) at 0.85207, implying that an increase in one metal's concentration is linked to a rise in the other. This relationship may indicate common sources of pollution, as both metals can be released through vehicle emissions and industrial processes (Zaprjanova et al.2010). Furthermore, Cd presents a moderate negative correlation with Nitrogen (N) at -0.47281, indicating that higher levels of Cd could restrict nitrogen availability, which may adversely affect soil fertility. These findings are consistent with earlier research conducted by (Anju, M., & Banerjee, D. K. 2011).

Lead (Pb) exhibits a significant positive correlation with Phosphorus (P) at 0.830147, suggesting that regions with increased lead contamination tend to have higher phosphorus concentrations as illustrated in Table 6. This relationship may arise from comparable environmental processes affecting both elements (Wang et al.2020). Conversely, the negative correlation with Nitrogen at -0.38283 supports the notion that lead could adversely impact nitrogen-fixing bacteria, which play a crucial role in sustaining soil nutrient levels (Qaswar et al.2020).

Nitrogen (N) shows a positive correlation with Potassium (K) at a value of 0.650143, indicating that higher nitrogen concentrations may improve the availability of potassium, a vital nutrient for plant health and growth (Mwilola et al.,2020). In contrast, the negative correlations with Cadmium (Cd) and Lead (Pb) suggest that contamination by heavy metals could negatively impact nitrogen levels, potentially disrupting the dynamics of soil nutrients.

Phosphorus (P) exhibits a significant positive correlation with both cadmium (Cd) and lead (Pb), suggesting that elevated concentrations of these heavy metals may be linked to increased phosphorus levels. This relationship could stem from common sources or environmental factors that facilitate the movement of these nutrients (Qaswar et al.2020). Conversely, the weak negative correlation with nitrogen (-0.15494) indicates a more intricate interaction, where higher phosphorus concentrations might correspond to reduced nitrogen availability, although this connection is not as strong.

Potassium (K) exhibits a positive correlation with Nitrogen, with a coefficient of 0.650143, suggesting that higher nitrogen concentrations could enhance the availability of potassium. Conversely, the negative correlations observed with Cadmium (Cd) and Lead (Pb) imply that the presence of these heavy metals may adversely affect potassium levels in the soil. (Chen et al.2007)

Conclusion

In Lucknow, Uttar Pradesh, India, this study highlights the substantial lead (Pb) and cadmium (Cd) contamination of agricultural soils and wheat (Triticum aestivum) in the vicinity of major highways (NH-24, NH-28, and NH-56). The direct effects of vehicle emissions and related human activities on environmental quality are demonstrated by elevated concentrations of these metals, especially within 10 and 20 meters from the highways. According to the study's Enrichment Factor (EF) analysis, traffic density is a significant contributor to the buildup of Pb and Cd in soils and crops, confirming that the contamination is primarily anthropogenic. Metal concentrations were accurately quantified using atomic absorption spectrophotometry (AAS), and assessments of the Pollution Load Index (PLI) showed a high risk of contamination near these roads. There are serious issues with food safety and public health when Pb and Cd are found in wheat grains, which are a staple diet in the area. Considering how much wheat flour is consumed in India, extended exposure to these metals may pose serious health risks, especially for vulnerable groups, including neurological and developmental problems. This study recommends regular heavy metal level monitoring, pollution control measures along busy highways, and the development of safe crop cultivation guidelines close to high-traffic areas as ways to reduce these risks. In order to lower heavy metal concentrations, improve soil health, and guarantee local communities' access to safe food, future research should look into phytoremediation, soil amendments, and other sustainable soil restoration methods.

Strategies for mitigating soil heavy metal contamination

There are a number of strategies that can be used to address soil heavy metal pollution. Hyperaccumulator plants are used in phytoremediation, which provides an affordable way to extract metals from soil. By immobilizing pollutants, soil additions such as lime or biochar can lower the bioavailability of metals. For the removal of metal, cutting-edge technologies like electrokinetic and Nano remediation offer creative solutions. Stricter laws governing industrial emissions and agricultural practices are crucial for preventing pollution. Crop rotation and conservation tillage are two integrated land management techniques that can reduce metal intake. Buffer zones and green infrastructure should be incorporated into urban development. Stronger regulation and research funding support lasting solutions, while monitoring with tools like GIS and public awareness campaigns can improve prevention.

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