

Assessment of Heavy Metal Contamination in Agricultural Soil Near Industrial Areas and Its Remediation Using Phytoremediation

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Abstract - Rapid industrialization and urbanization have led to severe environmental pollution, particularly heavy metal contamination of agricultural soils near industrial regions. This study assesses the extent of heavy metal contamination in soils surrounding the MIDC Kalmeshwar industrial area in Nagpur, Maharashtra, and evaluates the effectiveness of phytoremediation as a sustainable remediation method. Soil samples were collected from agricultural fields at depths of 0–15cm, 15–30cm, and 30–60cm to study the distribution of contaminants. Physicochemical properties such as pH, electrical conductivity, and organic matter content were analyzed to determine their influence on metal mobility and bioavailability. Heavy metals including lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu) were examined using standard laboratory procedures. The results revealed that Pb and Cd concentrations exceeded permissible limits in several locations, with maximum contamination observed in surface soil layer due to industrial discharge and atmospheric deposition. Contamination indices confirmed moderate to high pollution levels in study area. Phytoremediation experiments using *Brassica juncea*, *Helianthus annuus*, and vetiver grass showed that sunflower had highest heavy metal removal efficiency, while vetiver grass effectively stabilized contaminants. The study concludes that phytoremediation is an eco-friendly, economical, and sustainable approach for restoring contaminated soils.

Key Words: Heavy Metal Contamination, Agricultural Soil, Phytoremediation, Bioaccumulation, Environmental Pollution, Soil Remediation

1. INTRODUCTION

Soil is one of the most important natural resources that plays a fundamental role in supporting plant growth, maintaining ecological balance, and sustaining agricultural productivity. It serves as a medium for nutrient supply, water retention, and microbial activity, all of which are essential for crop development and food production. In a country like India, where a large portion of the population depends on agriculture for livelihood, maintaining soil health is of utmost importance. However, in recent decades, rapid industrialization,

urban expansion, and anthropogenic activities have led to significant degradation of soil quality, particularly due to contamination by heavy metals.

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu) are among the most hazardous pollutants found in soils. These metals are characterized by their non-biodegradable nature, high toxicity, and long persistence in the environment. Unlike organic pollutants, heavy metals do not decompose and tend to accumulate in soil over time, resulting in long-term contamination. At trace levels, some metals like zinc and copper may act as micronutrients for plant growth; however, at higher concentrations, they become toxic and adversely affect soil fertility, plant metabolism, and overall ecosystem stability [7]. The continuous accumulation of heavy metals in soil leads to changes in its physicochemical properties, reduces microbial activity, and disrupts nutrient cycling processes, thereby affecting agricultural productivity.

Industrial areas are considered major hotspots for heavy metal contamination due to the discharge of untreated or partially treated effluents, emission of pollutants into the atmosphere, and improper disposal of solid waste. The MIDC Kalmeshwar industrial area in Nagpur, Maharashtra, is one such region where various industries, including textile, chemical, and manufacturing units, contribute to environmental pollution. These industries release effluents containing toxic metals into nearby land and water bodies, which eventually infiltrate the surrounding agricultural soils. In addition to industrial discharge, vehicular emissions and atmospheric deposition further contribute to the accumulation of heavy metals in soil. Dust particles containing metal pollutants settle on agricultural fields and gradually increase contamination levels.

One of the most critical concerns associated with heavy metal contamination is its entry into the food chain. Plants absorb heavy metals from contaminated soil

through their root systems, and these metals get accumulated in different plant parts such as leaves, stems, fruits, and grains. When humans and animals consume these contaminated crops, the metals enter the biological system and may lead to serious health issues. Long-term exposure to heavy metals has been linked to various health problems, including neurological disorders, kidney damage, cardiovascular diseases, and carcinogenic effects [5]. Lead and cadmium, in particular, are highly toxic and pose significant risks even at low concentrations. The bioaccumulation and biomagnification of these metals in the food chain further amplify their impact on human health and the environment.

In recent years, increasing attention has been given to the assessment and management of soil contamination in industrial regions. Several studies have reported elevated levels of heavy metals in agricultural soils near industrial areas, highlighting the urgent need for effective monitoring and remediation strategies [2], [7]. Traditional remediation techniques such as soil excavation, washing, and chemical treatment are often expensive, technically complex, and may lead to secondary pollution. These limitations make them unsuitable for large-scale application, especially in agricultural lands.

As a result, phytoremediation has emerged as a promising, eco-friendly, and cost-effective alternative for the remediation of heavy metal-contaminated soils. Phytoremediation involves the use of plants to absorb, accumulate, stabilize, or detoxify contaminants from soil and water systems. It is a sustainable approach that utilizes natural biological processes and is particularly suitable for large areas with low to moderate contamination levels [8], [9]. Various plant species, including *Brassica juncea* (mustard), *Helianthus annuus* (sunflower), and vetiver grass, have shown significant potential for heavy metal uptake and stabilization.

Therefore, in the context of increasing industrial pollution and its impact on agricultural soils, there is a critical need to assess the level of heavy metal contamination in specific regions and explore sustainable remediation techniques. The present study focuses on the agricultural soils near the MIDC Kalmeshwar industrial area in Nagpur, aiming to evaluate the extent of contamination and the effectiveness of phytoremediation as a viable solution. This research will contribute to the development of environmentally sustainable strategies for soil management and help in protecting agricultural productivity and public health.

2 . LITERATURE REVIEW

Heavy metal contamination of soil has been extensively studied worldwide due to its serious environmental and human health implications. Rapid industrialization,

urbanization, mining activities, and intensive agricultural practices have significantly increased the concentration of toxic metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu) in soil systems. These metals are persistent in nature, non-biodegradable, and capable of accumulating in soil over long periods, thereby posing long-term risks to ecosystems and food safety. According to Sur et al. (2025) [1], phytoremediation using crop species such as *Hordeum vulgare* has shown promising results in reducing heavy metal concentrations, particularly for chromium and cadmium, although the efficiency varies depending on soil conditions and plant characteristics. Similarly, Yadav et al. (2025) [2] emphasized that heavy metal contamination is a global environmental issue affecting both soil and water systems, and highlighted phytoremediation as a sustainable and eco-friendly approach for environmental restoration.

Tabassum and Singh (2025) [3] conducted a study on agricultural soils near industrial areas and reported that heavy metals such as Pb, Cd, and Ni accumulate in plant tissues, often exceeding permissible limits, especially in edible parts. This raises serious concerns regarding food safety and human health. Hanif et al. (2025) [4] further explained that heavy metal contamination leads to disruption of soil chemistry, reduction in microbial activity, and negative impacts on plant growth and productivity. Their study also highlighted that long-term exposure to contaminated soils can result in severe health issues such as cancer, kidney failure, and neurological disorders. In a similar context, Raza et al. (2024) [5] conducted a comprehensive environmental toxicology study and found that heavy metal concentrations in industrial regions are significantly higher compared to non-industrial areas, with a high ecological risk index indicating serious environmental threats.

The role of phytoremediation has been widely explored as a sustainable alternative to conventional remediation techniques. Waseem et al. (2024) [6] demonstrated that sunflower (*Helianthus annuus*) combined with indigenous bacterial inoculation significantly enhances heavy metal uptake and reduces soil toxicity. Wan et al. (2024) [7] provided a detailed analysis of heavy metal sources and influencing factors, identifying atmospheric deposition, fertilizers, and industrial emissions as major contributors to soil contamination. They also emphasized that soil properties such as pH, organic matter, and cation exchange capacity play a crucial role in determining metal mobility and bioavailability.

Sharma et al. (2023) [8] discussed the mechanisms of phytoremediation at the molecular level, including the role of metal-binding proteins, transporters, and enzymes in plant systems that facilitate metal uptake and detoxification. Their study highlighted the importance of

plant-microbe interactions in enhancing remediation efficiency. Verma et al. (2022) [9] also supported the effectiveness of phytoremediation and described various techniques such as phytoextraction, phytostabilization, and rhizofiltration as efficient methods for removing heavy metals from contaminated soils and water bodies. These techniques are considered environmentally friendly and suitable for large-scale applications.

Earlier studies such as Ramírez et al. (2021) [10] investigated industrially contaminated soils and found that lead (Pb) was the dominant pollutant, with several plant species showing limited accumulation capacity. However, the study emphasized the potential of native plants in stabilizing contaminants and reducing environmental risks. Morar et al. (2018) [11] evaluated the phytoremediation potential of common crop plants and concluded that species like wheat, soybean, and rape can be effectively used for remediation, depending on economic feasibility and environmental conditions. Wan et al. (2018) [12] studied the effect of water management on heavy metal uptake and found that irrigation practices significantly influence metal solubility and plant absorption.

Laghlimi et al. (2015) [13] provided a comprehensive review of phytoremediation mechanisms and highlighted the importance of soil properties, plant species, and climatic conditions in determining the success of remediation. Their study emphasized that although phytoremediation is a promising technique, it has limitations such as slow remediation rates and depth restrictions. Malik et al. (2010) [14] conducted field studies in industrial areas and reported high levels of heavy metal accumulation in both soil and vegetation, indicating strong anthropogenic influence. Similarly, Gupta et al. (2008) [15] studied soil and crop contamination near industrial discharge zones and found significant accumulation of heavy metals in agricultural soils and plants, which directly affects crop quality and human health.

From the above literature, it is evident that heavy metal contamination is a widespread problem in industrial regions, and its impact on soil, plants, and human health is significant. Most studies agree that phytoremediation is a sustainable and cost-effective solution; however, its efficiency depends on site-specific conditions such as soil type, climate, and plant species. Despite extensive research, there is a lack of localized studies focusing on specific industrial areas like MIDC Kalmeshwar in Nagpur. Therefore, the present study aims to fill this research gap by assessing heavy metal contamination and evaluating phytoremediation potential under local conditions.

III. METHODOLOGY

The present study adopts a systematic and scientifically structured methodology to assess the level of heavy metal contamination in agricultural soils near the MIDC Kalmeshwar industrial area in Nagpur and to evaluate the effectiveness of phytoremediation as a sustainable remediation technique. The methodology includes study area selection, soil sampling, laboratory analysis, contamination assessment, and experimental evaluation of phytoremediation potential. Each step is carefully designed to ensure accuracy, reliability, and reproducibility of results.

The study area was selected based on its proximity to industrial activities, which are considered major sources of heavy metal pollution. Agricultural fields located near MIDC Kalmeshwar were identified as sampling locations due to their exposure to industrial effluents, vehicular emissions, and atmospheric deposition. Multiple sampling points were selected at varying distances from industrial units to capture spatial variation in contamination levels. A control site away from industrial influence was also considered for comparison.

Soil sampling was carried out using standard procedures to ensure representative samples. Samples were collected from three different depths, namely 0–15 cm (surface soil), 15–30 cm (subsurface soil), and 30–60 cm (deep soil), to analyze the vertical distribution of heavy metals. An auger and core sampler were used for sample collection, and multiple samples from each location were mixed to form composite samples. The collected samples were properly labeled, stored in clean polyethylene bags, and transported to the laboratory for further analysis. Prior to testing, the samples were air-dried, ground, and sieved through a 2 mm sieve to remove debris and ensure uniformity.

The laboratory analysis involved the determination of physicochemical properties of soil, including pH, electrical conductivity (EC), and organic matter content, as these parameters influence the mobility and bioavailability of heavy metals. The pH of soil was measured using a pH meter, EC was determined using an EC meter, and organic matter content was analyzed using the Walkley–Black method. These parameters provide essential information about soil characteristics and help in understanding the behavior of heavy metals in the soil environment.

Heavy metal analysis was carried out to determine the concentration of selected metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu). Advanced analytical techniques such as Atomic Absorption Spectroscopy (AAS) or Inductively Coupled Plasma Mass Spectrometry (ICP-

MS) were used for accurate measurement of metal concentrations. The obtained values were compared with standard permissible limits to assess the level of contamination.

To quantify the degree of pollution, various contamination indices were calculated. The Contamination Factor (CF) was used to evaluate the extent of contamination by comparing the measured concentration with background values. The Pollution Index (PI) was calculated to determine the overall pollution level of the soil. Additionally, the Geo-accumulation Index (Igeo) was used to classify the contamination status based on logarithmic comparison with baseline concentrations. These indices provide a scientific and quantitative basis for environmental assessment.

A significant part of the methodology includes the phytoremediation study, which was conducted to evaluate the potential of selected plant species in removing heavy metals from contaminated soil. Plants such as *Brassica juncea* (mustard), *Helianthus annuus* (sunflower), and vetiver grass were selected based on their known ability to tolerate and accumulate heavy metals. The experiment was carried out in controlled conditions using pots filled with contaminated soil. Seeds were sown, and plants were allowed to grow under regular irrigation and natural environmental conditions. Growth parameters such as plant height, biomass, and overall health were monitored throughout the experimental period.

After a specific growth period, plant samples were harvested and analyzed to determine the concentration of heavy metals in different plant parts, including roots and shoots. The removal efficiency of each plant species was calculated based on the reduction in metal concentration in soil before and after the experiment. This helped in identifying the most effective plant species for phytoremediation.



Vetiver Grass

Brassica juncea (Mustard)

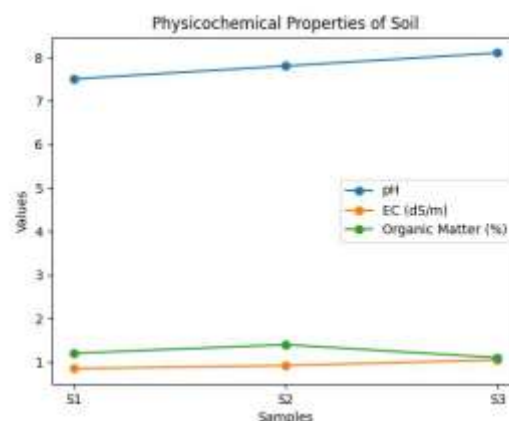
IV. RESULTS AND DISCUSSION

4.1 Physicochemical Properties of Soil

Soil properties play an important role in determining the behavior and mobility of heavy metals.

Table 4.1: Physicochemical Properties of Soil

Sample	pH	EC (dS/m)	Organic Matter (%)
S1	7.5	0.85	1.2
S2	7.8	0.92	1.4
S3	8.1	1.05	1.1



Graph 4.1: Physicochemical Properties of Soil

Discussion:

1. Soil pH is slightly alkaline, which may reduce metal mobility
2. EC values indicate moderate salinity
3. Organic matter is low, affecting nutrient availability



Brassica juncea (Mustard)



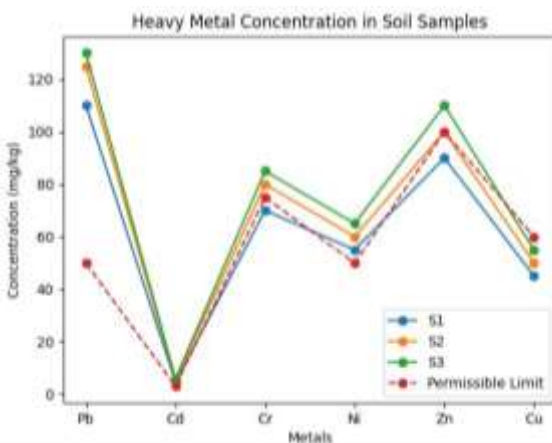
Helianthus annuus (Sunflower)

4.2 Heavy Metal Concentration in Soil

The concentration of heavy metals in soil samples is analyzed and compared with permissible limits.

Table 4.2: Heavy Metal Concentration (mg/kg)

Metal	S1	S2	S3	Permissible Limit
Pb	110	125	130	50
Cd	4.5	5.2	5.8	3
Cr	70	80	85	75
Ni	55	60	65	50
Zn	90	100	110	100
Cu	45	50	55	60



Graph 4.2: Heavy Metal Concentration (mg/kg)

Discussion:

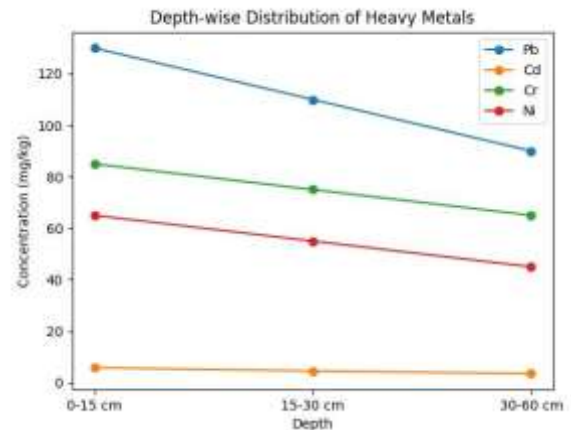
1. Pb and Cd levels exceed permissible limits significantly
2. Cr and Ni also show higher values in some samples
3. Zn and Cu are within or slightly above limits
4. Highest contamination observed near industrial discharge points

4.3 Depth-Wise Distribution of Heavy Metals

Heavy metal concentration varies with depth.

Table 4.3: Depth-wise Distribution (mg/kg)

Depth	Pb	Cd	Cr	Ni
0–15 cm	130	5.8	85	65
15–30 cm	110	4.5	75	55
30–60 cm	90	3.5	65	45



Graph 4.3: Depth-wise Distribution (mg/kg)

Discussion:

1. Maximum contamination observed in surface soil
2. Concentration decreases with depth
3. Indicates deposition from industrial sources

4.4 Contamination Indices

Table 4.4: Contamination Factor (CF)

Metal	CF Value	Category
Pb	2.6	Moderate
Cd	1.9	Moderate
Cr	1.2	Moderate
Ni	1.3	Moderate

Table 4.5: Pollution Index (PI)

Sample	PI Value	Pollution Level
S1	1.5	Moderate
S2	1.8	Moderate
S3	2.0	High

Discussion:

1. Moderate to high pollution observed
2. Industrial activities are main source
3. Pollution increases near source

4.5 Phytoremediation Results

The phytoremediation study carried out as part of this research provides a detailed understanding of the potential of selected plant species in reducing heavy metal contamination from agricultural soils near the MIDC Kalmeshwar industrial area. The experiment was conducted under controlled conditions using contaminated soil samples, where three plant species—*Brassica juncea* (mustard), *Helianthus annuus*

(sunflower), and vetiver grass—were cultivated to evaluate their growth performance, metal uptake capacity, and overall remediation efficiency. The results clearly indicate that phytoremediation is an effective and environmentally sustainable technique for the treatment of heavy metal-contaminated soils.

4.5.1 Plant Growth Observation

Table 4.6: Plant Growth Parameters

Plant	Height (cm)	Biomass (g)
Mustard	45	120
Sunflower	60	150
Vetiver	35	100

4.5.2 Metal Removal Efficiency

Table 4.7: Removal Efficiency (%)

Plant	Pb	Cd	Cr
Mustard	45	40	35
Sunflower	50	45	40
Vetiver	30	35	25

Discussion:

1. Sunflower shows highest removal efficiency
2. Mustard also performs well
3. Vetiver shows moderate removal
4. Plants absorb metals mainly in roots

3. CONCLUSIONS

The present study on “Assessment of Heavy Metal Contamination in Agricultural Soil Near Industrial Areas and Its Remediation Using Phytoremediation” clearly highlights the growing environmental concern associated with industrial pollution and its impact on agricultural lands. Based on detailed field investigation, laboratory analysis, and experimental evaluation, it is evident that the agricultural soils located near the MIDC Kalmeshwar industrial area in Nagpur are significantly affected by heavy metal contamination. The analysis of soil samples reveals that heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) are present in concentrations exceeding the permissible limits in most cases. This indicates that continuous industrial activities, including effluent discharge, vehicular emissions, and atmospheric deposition, are major contributors to soil pollution in the study area. The physicochemical analysis of soil shows slightly alkaline pH, moderate electrical conductivity, and low organic matter content, which influence the mobility and availability of heavy metals in soil. The depth-wise distribution of metals demonstrates that the highest

concentration is present in the surface layer (0–15 cm), suggesting direct exposure to pollution sources. The concentration decreases with increasing depth, indicating limited vertical migration of metals. However, long-term accumulation may eventually pose a threat to deeper soil layers and groundwater resources. The calculated contamination indices, such as Contamination Factor (CF) and Pollution Index (PI), confirm that the soil falls under moderate to high contamination categories, highlighting the severity of pollution in the region. The study also emphasizes the adverse effects of heavy metal contamination on soil health, crop productivity, and human well-being. The presence of toxic metals in soil reduces microbial activity, disturbs nutrient balance, and affects plant growth. Moreover, the transfer of heavy metals from soil to plants and subsequently to humans through the food chain poses serious health risks, including kidney damage, neurological disorders, and carcinogenic effects. A significant outcome of this research is the evaluation of phytoremediation as a sustainable and eco-friendly remediation technique. The experimental results demonstrate that selected plant species, particularly *Helianthus annuus* (sunflower) and *Brassica juncea* (mustard), show high efficiency in removing heavy metals from contaminated soil. Sunflower exhibits the highest removal efficiency, followed by mustard, while vetiver grass is effective in stabilizing contaminants within the root zone. These findings confirm that phytoremediation is a practical, low-cost, and environmentally sustainable solution for managing soil contamination, especially in large agricultural areas where conventional methods are not feasible.

ACKNOWLEDGEMENT

This study assesses heavy metal contamination in agricultural soils near the MIDC Kalmeshwar industrial area in Nagpur and measures phytoremediation as a sustainable remediation method. Soil samples collected from site showed increased levels of lead, cadmium, chromium, and nickel, especially in surface layers near industrial discharge zones. Contamination indices indicated moderate to high pollution levels. Mustard, sunflower, and vetiver grass were used for heavy metal removal. Sunflower showed the highest remediation efficiency, while vetiver effectively stabilized contaminants. The research concludes that phytoremediation is an eco-friendly, cost-effective, and sustainable solution for restoring heavy metal-contaminated agricultural soils.

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