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Original Research Paper

Comparative Ecophysiological and Health risk assessment of heavy metal contamination in Rabi and Kharif crops of Kanpur Region

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Abstract
Heavy metal contamination in agricultural ecosystems is a growing concern in industrial regions. The present study evaluates seasonal variation (Rabi and Kharif) in heavy metal accumulation, associated ecophysiological responses in crops, and potential human health risks in the Kanpur region of Uttar Pradesh, India. Soil and crop samples were analyzed for cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu). Results indicate higher metal accumulation during the Kharif season, likely due to increased solubility under moist conditions. Risk assessment revealed that Cd and Cr may pose non-carcinogenic health risks. The studies highlight the need for continuous monitoring sustainable soil management strategies and provides information protecting ecosystem health and supporting agricultural production.

Key Words- Ecophysiological, Transfer Factor (TF), non-carcinogenic, Daily Intake of Metals (DIM), and Hazard Quotient (HQ)

Introduction

Heavy metal contamination in agricultural ecosystems has become a major environmental issue due to rapid industrialization and urban expansion. These metals are non-biodegradable, persist in soils for long periods, and can accumulate to toxic levels, adversely affecting soil quality, crop productivity, and ecosystem health (Ali *et al*., 2021; Singh and Kalamdhad, 2021, Singh et al., 2026). Agricultural soils in industrial regions are particularly vulnerable to contamination from anthropogenic sources such as industrial effluents, sewage irrigation, mining activities, and excessive use of fertilizers and pesticides. In northern India, especially in the Kanpur region, the presence of leather tanneries, textile industries, and chemical manufacturing units has significantly contributed to the accumulation of heavy metals such as chromium (Cr), cadmium (Cd), and lead (Pb) in surrounding agricultural lands (Tiwari and Tripathi, 2023).

Heavy metals disrupt vital plant processes including photosynthesis, biomass, and nutrient uptake. Exposure to elevated metal concentrations induces oxidative stress in plants by generating reactive oxygen species (ROS), which damage cellular components such as membranes, proteins, and DNA. This results in reduced chlorophyll content, impaired enzyme activity, and overall decline in plant growth and yield (Kumar *et al*., 2022; Sharma and Dubey, 2020, Geeta & Choudhary, 2025). The transfer of heavy metals from soil to plants represents a critical pathway for entry into the food chain. Once accumulated in edible plant parts, these metals can be ingested by humans, leading to potential health risks. Chronic exposure to toxic metals such as cadmium and lead has been associated with kidney dysfunction, neurological disorders, and increased risk of cancer (Gupta *et al*., 2022; WHO, 2020, Khan et al., 2025). Seasonal variation plays an important role in influencing the mobility and bioavailability of heavy metals in soil. During the Kharif season, increased rainfall and soil moisture enhance the solubility and transport of metals, leading to greater uptake by plants. In contrast, the relatively dry conditions of the Rabi season may limit metal mobility and reduce bioavailability. Therefore, comparative seasonal studies are essential for understanding the dynamics of heavy metal contamination and its ecological and health implications (Tiwari and Tripathi, 2023, Chand et al., 2025, Singh et al., 2026).

Despite growing research on heavy metal contamination, there is limited integration of ecophysiological responses and human health risk assessment within a seasonal framework. The present study aims to bridge this gap by evaluating the comparative impact of heavy metals on crop

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physiology and human health in Rabi and Kharif seasons in the Kanpur region.

Objectives

To determine heavy metal concentration in soil and crops during Rabi and Kharif seasons

To determine soil-to-crop transfer of metals

To compare ecophysiological response of seasonal crop to different level of heavy metal contamination

Study Area

The study was conducted in agricultural fields of Kanpur, Uttar Pradesh. The region experiences a subtropical climate with distinct Rabi and Kharif seasons. Major crops include wheat and mustard (Rabi) and rice and maize (Kharif). Irrigation sources include canal water and wastewater, contributing to soil contamination.

Materials and Methods

Sampling Strategy

Soil samples (0–15 cm depth) and crop samples (edible parts) were collected during both seasons using stratified random sampling with four replicates per site and mixed thoroughly to obtain sample transfer to laboratory polyethylene bags. (Kumar *et al*., 2022,).

Sample Preparation and Analysis

Samples were air-dried, sieved, and digested using nitric and perchloric acid. Heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) were analyzed using Atomic Absorption Spectrophotometry (AAS) (Ali *et al*., 2021).

Statistical Analysis

Data were expressed as mean ± SD and statistical analyzed using SPSS. Difference between Rabi and Kharif season were evaluated by ANOVA ($p < 0.05$).

Soil-to-crop Transfer factor

The transfer of heavy metals from soil to crops was evaluated using the Transfer Factor (TF):

$$TF = C_{crop} \div C_{soil}$$

where

C_{crop} is the concentration of the metal in the edible part of the crop (mg kg^{-1})

Result

Table- 1: Heavy metal concentration (mg/kg) in soil and agricultural crop during rabi and kharif

Metal	WHO value	Soil		Crop	
		Rabi	Kharif	Rabi	Kharif
Cd	0.30	0.82	1.31	0.32	0.62
Pb	10	15.4	21.5	6.2	8.1
Cr	2.3	30.2	46.2	11.0	16.8
Ni	10	12.1	15.3	5.1	7.3
Zn	60	40.1	49.5	21.3	27.6
Cu	40	19.2	26.5	8.6	12.5

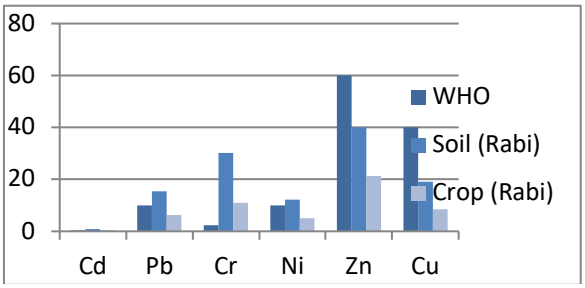

Fig. 1. Comparison of WHO standards and Rabi Soil and Crop

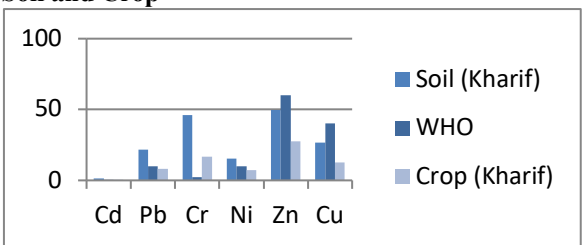

Fig. 2. Comparison of WHO standards and Kharif Soil and Crop

Table-2: soil to crops Transfer Factor (TF) of heavy metals

Metal	Rabi			Kharif		
	Crop	Soil	TF	Crop	Soil	TF
Cd	0.32	0.82	0.39	0.62	1.31	0.47
Pb	6.2	15.4	0.40	8.1	21.5	0.37
Cr	11.0	30.2	0.36	16.8	46.2	0.36
Ni	5.1	12.1	0.42	7.3	15.3	0.47
Zn	21.3	40.1	0.53	27.6	49.5	0.55
Cu	8.6	19.2	0.44	12.5	26.5	0.47

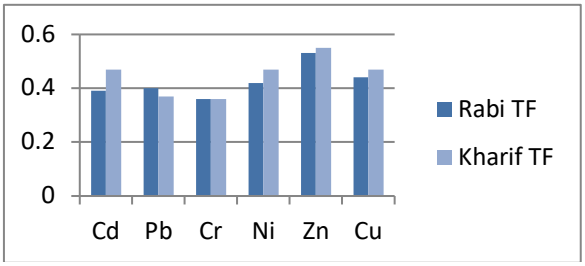

Fig. 3. Comparison of rabi TF and Kharif TF

Discussion

The results indicate higher heavy metal contamination during the Kharif season due to increased moisture and solubility (Tiwari & Tripathi, 2023, Yadav & Kamal, 2025). Transfer factor analysis suggests higher uptake of Cd and Zn, consistent with their bioavailability (Gupta *et al*., 2022, Suhani et al., 2026). The concentration of heavy metals in soil and agricultural crops exhibited clear seasonal variations, with generally higher concentrations during the Kharif season than in the

Rabi season (Table 1). Soil concentrations of Cd, Pb, Cr, Ni, Zn, and Cu increased from Rabi to Kharif, indicating greater accumulation during the monsoon period. Increased industrial runoff, wastewater irrigation, atmospheric deposition, and enhanced metal mobility under wetter soil conditions may explain the elevated concentrations during Kharif (Alloway, 2013; Shahid *et al*., 2020, Singh et al., 2024)).

Among the studied metals, chromium (Cr) showed the highest concentration in soil (46.2 mg kg^{-1} in Kharif), followed by zinc (49.5 mg kg^{-1}) and lead (21.5 mg kg^{-1}). Cadmium concentrations exceeded the WHO permissible limit in both seasons, while Pb and Cr were also above recommended limits, indicating contamination of agricultural soils. Although Zn and Cu remained below their permissible limits, their increasing trend suggests continuous accumulation that may become hazardous over time.

Heavy metal concentrations in crop tissues reflected the contamination status of the corresponding soils. Crops grown during Kharif accumulated greater amounts of all metals than those grown during Rabi. Chromium increased from 11.0 to 16.8 mg kg^{-1}, zinc from 21.3 to 27.6 mg kg^{-1}, and copper from 8.6 to 12.5 mg kg^{-1}, demonstrating enhanced uptake under Kharif conditions. This finding indicates that seasonal environmental conditions strongly influence metal bioavailability and plant uptake.

The soil-to-crop transfer factor (TF) ranged from 0.36 to 0.55, suggesting moderate translocation of metals from soil into edible plant parts (Table 2). Zinc exhibited the highest TF values (0.53 in Rabi and 0.55 in Kharif), indicating its relatively greater mobility and essential role in plant metabolism. Cadmium and nickel also showed relatively high TF values during Kharif (0.47), reflecting their higher bioavailability under moist soil conditions. Chromium showed the lowest TF (0.36) in both seasons, indicating stronger retention within the soil matrix and comparatively limited plant uptake.

The observed seasonal differences also indicate contrasting eco-physiological responses of crops. Elevated heavy metal concentrations during Kharif are likely to induce oxidative stress, chlorophyll degradation, reduced photosynthetic efficiency, membrane damage, nutrient imbalance, and inhibition of plant growth. Essential metals such as Zn and Cu are required for enzymatic activity and photosynthesis; however, excessive accumulation may disturb cellular metabolism. Toxic metals including Cd, Pb, and Cr interfere with nutrient uptake, impair root development, reduce biomass production, and decrease crop productivity. Consequently, Kharif crops are expected to experience greater physiological stress than Rabi crops because of their higher metal burden.

Conclusion

This study revealed that heavy metal concentrations in both soil and crops were higher during the Kharif season than in the Rabi season, indicating greater contamination under monsoon conditions. Cadmium (Cd), lead (Pb), and chromium (Cr) exceeded the recommended permissible limits in soil, while the soil-to-crop transfer factor (TF) ranged from 0.36 to 0.55, showing moderate metal uptake by crops. Kharif crops exhibited greater heavy metal accumulation and were therefore more susceptible to eco-physiological stress, including reduced growth and metabolic disturbances. These findings emphasize the need for regular monitoring of agricultural soils, safe irrigation practices, and appropriate remediation measures to minimize heavy metal contamination, protect crop productivity, and reduce potential human health risks.

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