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Mosses As Superior Bio-Indicators Of Potentially Toxic Element Contamination In Urban Environments

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Abstract

Since the advent of civilization, the environment has received various type of pollutants. The first record of anthropogenic pollution may well be traced back with the discovery of fire by humans that initiated adding up of toxic oxides of carbon, nitrogen and sulphur in the atmosphere. As civilization advanced, human activity contributes to creating new sources of environmental pollution. Atmospheric pollution is one of the major problems because it affects the fauna and flora, and people themselves. Nowadays the biggest provocative of atmospheric pollution is anthropogenic human activities and transport sector, main pollutants being heavy metals. A quick, cheap and easy way to investigate the state of the environment is to use Bryophytes which prove to be a potential bio-indicator of pollution. The habitat diversity, structural simplicity, totipotency, rapid rate of multiplication and high metal accumulation capacity make mosses an ideal organism for pollution studies. Bryophytes are reliable indicators of pollution as they are easy to handle and show a vast range of specific sensitivity and visible symptoms to pollutants. Mosses is one of the most popular bio-indicator of heavy metal pollution of atmosphere, perspective and cost-effective method to control, detect and evaluate pollution. Naturally-occurring mosses have been sampled across Europe to monitor the pollution. This study is made with anticipation of supporting the green city development with a natural, sustainable and low maintenance rate solution. For the work to identification of Potentially Toxic Elements in mosses Atomic Absorption Spectroscopy (AAS) technique used.

Key words: Mosses, Bio-indicator, pollution, heavy metals.

1. INTRODUCTION

Pollution is now a significant global issue, especially in developing countries, largely resulting from human activities[1]. This contributes to the deterioration of human health among exposed populations, forest decline, reduced agricultural productivity, and has become a growing cause of public concern worldwide[2]. Potentially toxic elements (PTEs) are a group of harmful chemical substances that accumulate in the environment primarily as a result of anthropogenic activities[3-6]. The rapid development of industry, motor transport, and urbanization has led to a dramatic increase in dust emissions containing potentially toxic elements. Common PTEs include heavy metals like lead, mercury, cadmium, arsenic, and chromium. As ecologists began focusing on the threats posed by heavy metals and other atmospheric pollutants to both biotic and abiotic components of the environment, the search for sensitive and cost-effective biological methods to assess environmental levels of heavy metals particularly toxic ones such as Cd, Pb, and Hg intensified.

The suitability of bryophytes for indicating and monitoring atmospheric heavy metal deposition is based on their ability to accumulate these metals, which depends on their morphological and physiological characteristics. Bryophytes possess rhizoids instead of true roots, limiting their ability to absorb nutrients from the soil. Nutrient uptake from the atmosphere is facilitated by their thin cuticle and one-cell-thick leaves. Their large surface to weight ratio enhances absorption, while a slow growth rate allows them to accumulate pollutants over time. Additional advantageous traits include their perennial nature, wide distribution, and ease of sampling makes them a good bio-indicator of heavy metal.

The main objective of this study was to determine the spatial distribution of toxic elements in moss and soil along urban roadside area. These observations were carried out over three seasons within a one-year period.

2. MATERIALS & METHODS

2.1 Study Sites:

Ranchi, the capital of Jharkhand, India, is known as the "City of Waterfalls" has been chosen as study area. Ranchi, is an important administrative and industrial centre in the state. It is connected through NH-33 and NH-23 and adjoining districts are Ramgarh & Hazaribagh in the North, Gumla and Latehar in the West, Purulia (West Bengal) in the East and Saraikela Kharsawan in the South. Ranchi lies at 23°22′N 85°20′E near the Tropic of Cancer. The average altitude of Ranchi is 600 meters above the sea level with undulating land features. Although Ranchi has a humid subtropical climate, its location and the forests surrounding it combine to produce the unusually pleasant climate for which it is known. Summer temperatures range from 20 to 42 °C, winter temperatures from 0 to 25 °C. December and January are the coolest months Average annual rainfall of the district is 1,430 mm and more than 80 percent precipitation is received during monsoon months. The city is surrounded by a large & green forest area, which provides many basic raw materials to a large number of industries.
Two ecologically distinct habitats in Ranchi city were selected from where moss samples were collected to identify and to assess the effect of potentially toxic elements (Pb, Cr, Cd) contents in samples of the moss. Moss samples were collected and subsequently examined from two locations:

- **Dhurwa (Urban roadside)** – 23.317919°N, 85.279703°E
- **Bajra, Itki Road (Urban roadside)** – 23.371476°N, 85.260686°E

2.2 Moss Sampling Procedure:

Two moss samples were collected and examined for potentially toxic elements from urban roadside areas. To enable comparison of data from the present survey with previous surveys, mosses were sampled from the same locations used in earlier studies. For identification, the moss samples were collected from the surfaces of rocks by scraping with a hand hoe and stored in tightly sealed boxes. The locality information, including GPS coordinates of each sampling site, was also recorded.

2.3 Soil Sampling Strategy:

Soil samples were collected from same locations from where mosses are collected. Soils samples were collected at 15cm depth around the sample sites. Soil samples were collected over a period of one year, with seasonal observations conducted during summer, rainy, and winter seasons.

2.3 Sample preparation and Chemical Analysis:

Dead materials, soil particles and litter were manually removed from the moss samples. The green or greenish-brown parts of mosses were then cleaned from dust particles with deionized water. Moss and soil samples were dried in thermostatic drying machine for 48 hours at 40°C. The moss and soil samples were then homogenized with a mortar and pestle after coarse material was removed using 2mm sieve. Approximately 0.5g of each moss sample was transferred into a digestion tube and digested with 10mL of mixed acid (HNO_3:H_2O_2=1:1) and 0.25g of each soil samples was digested with 10mL of mixed acid (HNO_3:HCl:HF=3:1:1) for 30 min and then moved to a microwave oven for enhanced digestion until transparent solutions were obtained.

After cooling, the moss and soil digests were transferred to a 100mL volumetric flask. The moss was then then filled with deionized water to 100mL and soil to 100mL. The presence and concentrations of heavy metals (i.e.Cd, Cr, Pb) were determined by using the flame atomic absorption spectroscopy (FAAS) method. The use of metal equipment was avoided during the operation process to avoid affecting the results of the experimental measurements.

3. RESULTS

3.1 Identification of Moss samples

Two different moss specie were identified in the collected samples from two different areas of Ranchi:

Entosthodon buseanus- These are small, delicate moss species in the family Funariaceae**.** They were found grown on bare or disturbed soil and wall.

It is characterized by short, yellow-green, soft and velvety appearance. Numerous rhizoids that help anchor it to soil. The sporophyte of the moss *Entosthodon buseanus* is characterized by its long seta and a distinct capsule. Seta is longer, straight, and typically smooth, supporting the capsule above the plant body. Shape of the capsule is Obovoid or broadly pyriform (pear-shaped to inversed egg-shaped).

Funaria hygrometrica- Also known as bonfire moss. These are a type of water moss which grows on shady, moist soil.

The plant body is green, soft and upright, about half an inch tall. They have oblique septa. The main axis of the plant, which is upright, bears a set of spirally arranged, sessile leaves having a clearly distinguishable midrib. The leaves are usually medium green, semi-transparent and hair less. The leafy stem terminates in a long slender stalk (seta) with a spore bearing capsule. The stalk is 20-50mm long, light green (immature) to red (mature). The stalk has a tendency to nod and bend from the weight of the spore bearing capsule. Immature capsules are 2- 3.5mm long, light green, oblanceoloid- obovoid in shape, slightly curved[7].

Table 1: Identification of Mosses.

Scientific Name	Family
Entosthodon buseanus Dozy & Molk.	Funariaceae
Funaria hygrometrica Hedw.	Funariaceae

Source: Botanical Survey of India, Central National Herbarium

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Entosthodon buseanus and *Funaria hygrometrica* were recorded from the urban roadside areas of Dhurwa (23.317919° N and 85.279703° E) and Bajra, Itki road (23.371476° N and 85.260686° E).

3.2 Comparisons of Potentially Toxic Elements in Moss and Soil samples.

The spatial distribution of toxic elements (Cr, Cd & Pb) in moss and soil along urban roadside area was carried out over three seasons within a one-year period (Year 2024).

The ranges of metal concentrations in the moss species *Entosthodon buseanus* and *Funaria hygrometrica* were displayed.

Table 2: Comparisons of Cr (mg/kg) in Moss and soil samples at two different locations near Ranchi, Jharkhand.

Location	Cr (Moss Samples)			Cr (Soil Samples)		
	Summer	Rainy	Winter	Summer	Rainy	Winter
Dhurwa (Urban Road side area)	16.62	13.85	15.11	10.56	9.24	9.9
Bajra, Itki road. (Urban Road side area)	13.46	9.24	9.9	5.74	8.91	4.49

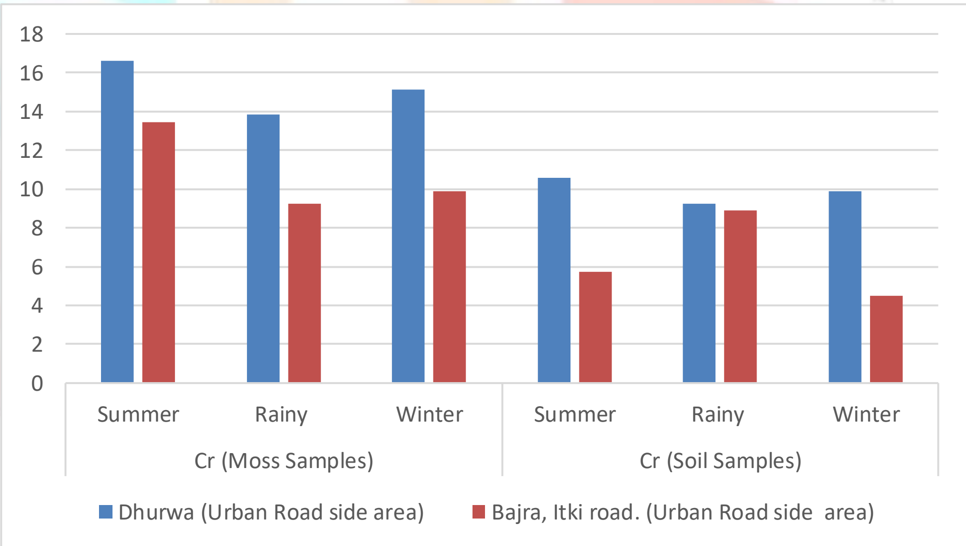

Fig 1: Comparisons graph of Cr (mg/kg) in Moss and soil samples at two different locations near Ranchi, Jharkhand.

Seasonal variations in chromium (Cr) concentrations were observed in both moss and soil samples collected from urban roadside areas at Dhurwa and Bajra (Itki Road). Overall, Cr concentrations were consistently higher in moss samples compared to the corresponding soil samples across all seasons and locations.

At Dhurwa, Cr concentrations in moss samples ranged from 13.85 mg/kg during the rainy season to 16.62 mg/kg in summer, with an intermediate value of 15.11 mg/kg recorded in winter. Soil samples from the same site showed lower Cr concentrations, varying from 9.24 mg/kg in the rainy season to 10.56 mg/kg in summer, while winter concentrations were 9.90 mg/kg.

At Bajra (Itki Road), moss samples exhibited Cr concentrations of 13.46 mg/kg in summer, decreasing to 9.24 mg/kg during the rainy season and 9.90 mg/kg in winter. In contrast, soil samples from this location recorded notably lower values, ranging from 4.49 mg/kg in winter to 8.91 mg/kg during the rainy season, with a summer concentration of 5.74 mg/kg.

Comparatively, both sites showed higher Cr accumulation during the summer season, particularly in moss samples, while lower concentrations were generally observed during the rainy season, likely due to wash-off effects. The consistently higher Cr levels in moss relative to soil highlight the effectiveness of moss as a bioindicator for monitoring atmospheric heavy metal pollution in urban roadside environments.

Table 3: Comparisons of Cd (mg/kg) in Moss and soil samples at two different locations near Ranchi, Jharkhand.

Location	Cd (Moss Samples)			Cd (Soil Samples)		
	Summer	Rainy	winter	Summer	Rainy	winter
Dhurwa (Urban Road side area)	1.11	1.06	0.98	0.44	0.32	0.42
Bajra, Itki road. (Urban Road side area)	1.06	1.06	0.69	3.17	0.22	3.07

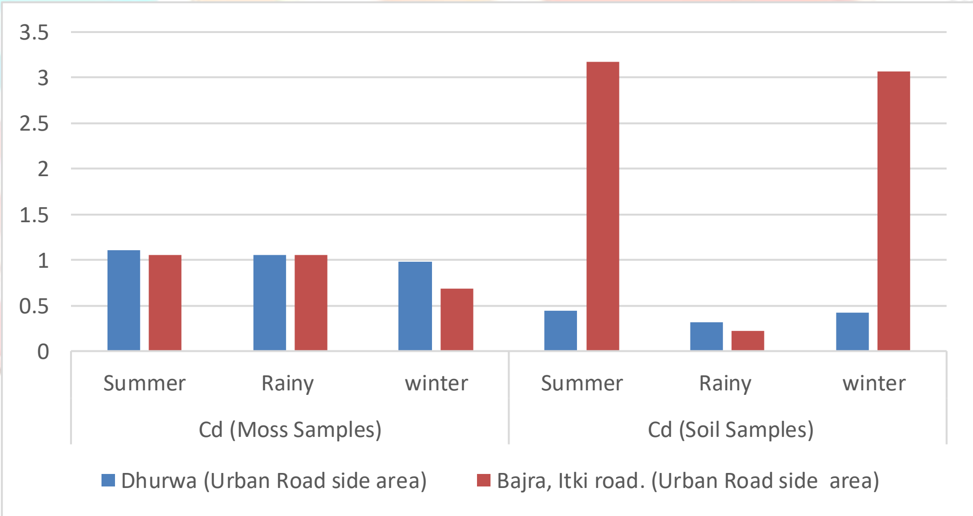

Fig 2: Comparisons graph of Cd (mg/kg) in Moss and soil samples at two different locations near Ranchi, Jharkhand.

Seasonal variation in cadmium (Cd) concentrations was observed in both moss and soil samples collected from the urban roadside areas of Dhurwa and Bajra (Itki Road). The distribution of Cd differed notably between moss and soil samples as well as between the two locations.

At Dhurwa, Cd concentrations in moss samples showed relatively minor seasonal variation, with values of 1.11 mg/kg in summer, 1.06 mg/kg during the rainy season, and 0.98 mg/kg in winter. Corresponding soil samples from this site recorded lower Cd concentrations, ranging from 0.32 mg/kg in the rainy season to 0.44 mg/kg in summer, with a winter value of 0.42 mg/kg.

In contrast, at Bajra (Itki Road), moss samples exhibited Cd concentrations of 1.06 mg/kg in both summer and the rainy season, which decreased to 0.69 mg/kg in winter. Soil samples from this location showed markedly higher Cd levels during the summer (3.17 mg/kg) and winter (3.07 mg/kg) seasons, while a substantially lower concentration (0.22 mg/kg) was observed during the rainy season.

Overall, moss samples generally displayed more stable Cd concentrations across seasons, whereas soil samples, particularly at Bajra, exhibited pronounced seasonal fluctuations, with elevated Cd levels during dry seasons. The relatively higher accumulation of Cd in moss samples at Dhurwa supports their role as effective bioindicators of atmospheric metal deposition, while the elevated soil Cd levels at Bajra suggest potential localized contamination influenced by roadside activities.

Table 4: Comparisons of Pb (mg/kg) in Moss and soil samples at two different locations near Ranchi, Jharkhand.

Location	Pb (Moss Samples)			Pb (Soil Samples)		
	Summer	Rainy	Winter	Summer	Rainy	Winter
Dhurwa (Urban Road side area)	43.81	32.98	35.93	40.85	18.7	20.18
Bajra, Itki road. (Urban Road side area)	96.47	55.13	96.47	58.08	44.3	62.02

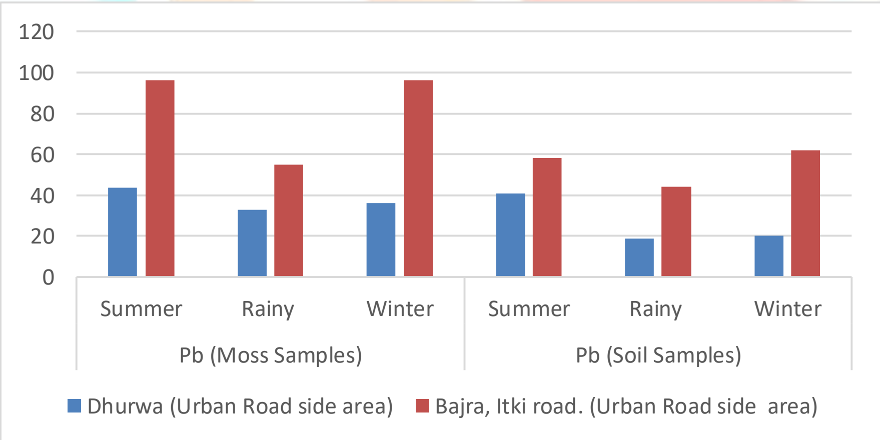

Fig 3: Comparisons graph of Pb (mg/kg) in Moss and soil samples at two different locations near Ranchi, Jharkhand.

Seasonal variations in lead (Pb) concentrations were observed in both moss and soil samples collected from urban roadside areas at Dhurwa and Bajra (Itki Road). Overall, Pb concentrations were substantially higher at Bajra compared to Dhurwa, with moss samples generally exhibiting greater accumulation than soil samples across most seasons.

At Dhurwa, Pb concentrations in moss samples ranged from 32.98 mg/kg during the rainy season to 43.81 mg/kg in summer, with a winter value of 35.93 mg/kg. Soil samples from the same location recorded Pb concentrations of 40.85 mg/kg in summer, which declined markedly during the rainy season (18.70 mg/kg) and remained relatively low in winter (20.18 mg/kg).

At Bajra (Itki Road), markedly higher Pb concentrations were observed in both moss and soil samples. Moss samples showed elevated Pb levels of 96.47 mg/kg during both summer and winter, while a comparatively lower concentration (55.13 mg/kg) was recorded in the rainy season. Soil samples at this site also exhibited high Pb concentrations, ranging from 44.30 mg/kg in the rainy season to 62.02 mg/kg in winter, with a summer value of 58.08 mg/kg.

In general, Pb concentrations were highest during the summer and winter seasons and lowest during the rainy season, likely due to reduced atmospheric deposition and surface wash-off during rainfall. The consistently higher Pb levels observed at Bajra indicate greater anthropogenic influence, possibly associated with intensified vehicular activity. The enhanced accumulation of Pb in moss samples further supports their suitability as effective bioindicators for monitoring lead pollution in urban roadside environments.

4. DISCUSSION

The present study evaluated the spatial and seasonal distribution of potentially toxic elements (Cr, Cd, and Pb) in moss (*Entosthodon buseanus* and *Funaria hygrometrica*) and corresponding soil samples collected from urban roadside areas of Dhurwa and Bajra (Itki Road), Ranchi, Jharkhand. The findings clearly demonstrate differential accumulation patterns between moss and soil samples, emphasizing the role of mosses as effective biomonitors of atmospheric heavy metal pollution.

4.1 Spatial Variation of Heavy Metals:

Marked spatial differences in metal concentrations were observed between the two study sites. Bajra (Itki Road) consistently exhibited higher concentrations of Pb and Cd, particularly in soil samples, compared to Dhurwa. This spatial variation can be attributed to differences in traffic density, roadside activities, and local land-use patterns. Bajra, being a more congested roadside area, is likely subjected to greater vehicular emissions, tire wear, brake abrasion, and resuspension of contaminated road dust, all of which contribute to elevated metal loads.

In contrast, Dhurwa showed comparatively lower metal concentrations in both moss and soil samples, suggesting relatively reduced anthropogenic pressure. These observations indicate that roadside intensity and traffic volume play a critical role in determining the spatial distribution of potentially toxic elements in urban environments.

4.2 Seasonal Variation of Metals:

Seasonal trends revealed that concentrations of Cr, Cd, and Pb were generally highest during the summer and winter seasons, while the rainy season exhibited comparatively lower levels. The reduction in metal concentrations during the rainy season can be attributed to wash-off effects, dilution, and leaching of deposited particulates due to rainfall. Additionally, reduced atmospheric dust suspension during the monsoon season may further limit metal deposition on moss surfaces.

Higher concentrations during summer may result from increased dust resuspension, dry atmospheric conditions, and enhanced vehicular movement. Winter accumulation may be influenced by reduced dispersion of pollutants due to temperature inversion and limited atmospheric mixing, leading to prolonged retention of pollutants near ground level.

4.3 Comparison between Moss and Soil Samples:

Across all locations and seasons, moss samples generally accumulated higher concentrations of Cr and Pb compared to soil, whereas Cd showed relatively stable concentrations in moss but pronounced fluctuations in soil, particularly at Bajra. Mosses lack a well-developed root system and absorb nutrients and pollutants directly from atmospheric deposition, making them highly sensitive indicators of airborne metal pollution.

The consistently higher metal concentrations observed in moss samples reflect their capacity to accumulate metals from dry and wet deposition, particulate matter, and aerosols. In contrast, soil metal concentrations are influenced not only by atmospheric inputs but also by factors such as leaching, runoff, and soil physicochemical properties, leading to greater variability.

4.4 Element-Specific Behavior:

Chromium showed moderate accumulation in both moss and soil samples, with moss exhibiting consistently higher concentrations, indicating atmospheric input as a dominant source. Cadmium displayed relatively low concentrations in moss samples but showed elevated levels in soil at Bajra during dry seasons, suggesting localized contamination possibly linked to vehicular wear components and roadside activities.

Lead exhibited the highest concentrations among the studied metals, particularly at Bajra. Despite the phase-out of leaded petrol, Pb persists in roadside environments due to historical deposition, resuspension of contaminated dust, and ongoing contributions from brake linings, tire wear, and lubricating oils. The strong accumulation of Pb in moss samples further underscores its atmospheric origin and persistence in urban environments.

5. CONCLUSION

The present study assessed the spatial and seasonal distribution of potentially toxic elements chromium (Cr), cadmium (Cd), and lead (Pb) in moss (*Entosthodon buseanus* and *Funaria hygrometrica*) and corresponding soil samples from urban roadside areas of Dhurwa and Bajra (Itki Road), Ranchi, Jharkhand. The investigation, conducted over three seasons during the year 2024, provides valuable insights into heavy metal accumulation patterns in roadside environments.

The results revealed clear seasonal variations, with higher concentrations of Cr, Cd, and Pb generally recorded during the summer and winter seasons, while comparatively lower levels were observed during the rainy season, likely due to wash-off and dilution effects. Spatial variation was also evident, with Bajra (Itki Road) showing significantly higher metal concentrations than Dhurwa, indicating greater anthropogenic pressure, primarily from vehicular emissions and roadside activities.

Across both locations and seasons, moss samples consistently exhibited higher or more stable metal concentrations than soil samples**,** particularly for Cr and Pb. This reflects the ability of mosses to directly absorb metals from atmospheric deposition, confirming their effectiveness as sensitive and reliable bio-indicators of airborne heavy metal pollution. Cadmium showed relatively uniform accumulation in moss but pronounced fluctuations in soil, especially at Bajra, suggesting localized contamination sources.

Among the studied elements**,** lead (Pb) was the most dominant metal, especially at Bajra, highlighting its persistence in urban roadside environments despite regulatory measures. The elevated levels of Pb and Cd in certain locations raise environmental concerns and underscore the need for continued monitoring and pollution control strategies.

Overall, the study demonstrates that *Entosthodon buseanus* and *Funaria hygrometrica* are suitable bio-monitoring species for assessing urban roadside pollution. The combined analysis of moss and soil provides a comprehensive understanding of heavy metal dynamics and can serve as an effective tool for environmental assessment and management in rapidly urbanizing regions.

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