ATMOSPHERIC METAL PRECIPITATION IN MUSSOORIE HILLS OF GARHWAL REGION, INDIA BY ACTIVE BIOMONITORING USING *PLAGIOMNIUM UNDULATUM*

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Abstract

This systematic research presents an in-depth analysis of metal load in the Mussoorie Hills of Uttarakhand, India, conducted during the monsoon, summer, and winter seasons of 2021. The widely used biomonitoring agent, *Plagiomnium undulatum*, was employed to assess the metal concentrations in the region. A total of 36 samples were transplanted using the active biomonitoring technique known as the moss bag technique. These samples were placed at distances of 0.5, 1.0, and 3.0km in all four directions, with triplicates for an exposure period of four months. The concentrations of Ni, Zn, Cu, and Pb were determined using Inductively Coupled Plasma Mass Spectrometry (ICPMS). The results revealed significant variations in the mean concentrations of Ni, Zn, Cu, and Pb, with the highest values observed in summer at a distance of 0.5km and the lowest values in monsoon at 3.0km from the Mussoorie region. Moreover, distinct seasonal variations were observed, with metal concentrations following the order of summer > monsoon > winter. Notably, the summer season exhibited significantly higher metal concentrations compared to both winter and monsoon seasons. Based on the findings, it is recommended to implement regular monitoring programs to reduce metal concentration levels by minimizing pollutant emissions and curbing the exploitation of hill stations. Additionally, it is an invaluable resource for policymakers for future strategy and mitigation plans.

Keywords: Heavy metals, Mussoorie, ICPMS

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Introduction

The rapid urbanization of tourism hotspots poses a serious problem to the environment. Tourists from all over the country are likely to be attracted to the scenic beauty of the mountain ecosystem. For visits to the Mussoorie hill, tourists use public or personal vehicles. Which results in a high load of pollutants including gaseous and metal pollution. Significant changes in morphology, physiology, and genetic level of organisms[2,3]. It is well documented that the increasing levels of gaseous and metal pollutants in the atmosphere have been observed, highlighting the importance of monitoring heavy metal contamination to today's society [11].

Numerous living organisms have been used in studies to biomonitoring of soil, air, and water[5]. Moss is an excellent indicator of various pollutants. This is attributed to various morphological and physiological properties of moss, including the absence of cuticles and the presence of large cation exchange properties within the cell wall. Moss is mainly used as a bio-indicator of the accumulation of heavy metals, radionuclides, and toxic substances, among other organic compounds[10].

The aim of the present research was to pay greater attention towards highlighted areas of Mussoorie hill. High concentrations of heavy metals in mountain ecosystems can lead to excessive accumulation, which can be toxic to plants and cause health problems for humans and animals.

Material and Method Study area

Mussoorie Hills, situated at a latitude of 30°45'N and a longitude of 78°08'E, rest in the lower Shivalik foothills. With an average elevation of 2,005 meters (6,578 feet), it is located approximately 35km from the municipal corporation of Dehradun in the Dehradun district. Mussoorie is also 290km away from New Delhi. The area is renowned among tourists for its proximity to attractions like Dhanaulti, Kempty Falls, and Gun Hills.

Mussoorie has a fairly cold climate from October to April, followed by moderate warmth in May and June, accompanied by monsoon rains that continue until September. The average rainfall during July and August is between 70 and 80 millimeters, with relative humidity ranging from 75% to 85%. Temperature variations are notable, with midsummer temperatures ranging from 30 °C to 10 °C, and during the winter season, temperatures ranging from 15 °C to -2 °C[4].

Sampling and transplantation

Plagiomnium undulatum was collected from the dense forest of Chamba (Control post). Located at a height of 1600 m above sea level. A complete green moss was transferred to the nylon bags (moss bags, by weight of 3.0 grams). Moss bags were transplanted cross-sectionally of 0.5km, 1.0km, and 3.0km in all four directions with triplicate at polluted site. After a 4-month exposure period, the moss samples were harvested and brought to the laboratory for cleaning and removal of dust and foreign particles. The cleaned samples were analyzed using ICPMS for metal analysis.

Statistical analysis

All the statistical analysis was performed using JMP (SAS) to determine significant and non-significant errors using alphabets, and Microsoft Excel for graphical representation.

Result and discussion

Figure 1-3 presents the measured concentration of heavy metals (in µg/g) during the summer, monsoon, and winter seasons. The average concentrations of the studied metals, namely Ni, Zn, Cu, and Pb, were found to be significantly higher compared to the control post in Chamba. This indicates that Mussoorie, the polluted site, is experiencing elevated levels of these metals due to various sources, including pollutants and human activities. The unpolluted site, on the other hand, provides an ideal environment for the growth of *Plagiomnium undulatum,* as it remains unaffected by pollutants and human interference. In terms of seasonal tendencies, the accumulation of metals Ni, Zn, Cu, and Pb in *Plagiomnium undulatum* followed the order of summer > monsoon > winter during the year 2021. This suggests that the metal load increases significantly during the summer season, which can be attributed to increased tourist activity and higher gasoline consumption.

Furthermore, the concentration of heavy metals showed a notable spatial pattern. The metal load was found to be highest within a 0.5km radius of Mussoorie city, indicating a strong influence of urban activities. As the distance increased to a 3.0km radius, the metal concentration gradually decreased[11,12].

Within a 0.5km distance during the summer season (Figure 1), the concentrations of heavy metals were recorded as follows: Ni had a concentration of

97.299 µg/g to the East, Zn had a concentration of 183.580 µg/g to the South, Cu had a concentration of 90.332 µg/g to the West, and Pb had a concentration of 9.464 µg/g to both the East and West.

During the monsoon season, as illustrated in Figure 2, there was a notable decrease in the concentrations of metals at the same distance. Specifically, the recorded values were 35.332 µg/g for Ni to the West, 59.149 µg/g for Zn to the East, 16.665 µg/g for Cu, and 3.227 µg/g for Pb, both metals to the West.

In the winter season, the concentrations of certain elements were measured in different locations. To the East, the concentration of Ni was found to be 77.832 µg/g, while Zn was measured at 133.94 µg/g, moving to the West, the concentration of Cu was 71.965 µg/g. Finally, to the North, the concentration of Pb was determined to be 7.864 µg/g. These findings specifically pertain to the winter season as indicated in Figure 3.

In both Figure 1 and Figure 3, the metal concentrations were observed to be higher compared to Figure 2. It is evident that the concentrations of these heavy metals were significantly lower during the monsoon season. These elevated concentrations during the winter and summer season could be influenced by factors such as decreased rainfall, reduced dispersion of pollutants, and potential accumulation due to limited environmental processes.

The concentration of Ni, expressed as a percentage increase compared to the monsoon season, was 226% higher during winter and 282% higher during summer. This substantial variation suggests a significant influence of seasonal factors, including changes in tourist activity and the leaching of pollutants through monsoon precipitation[11]. The summer season showed the highest concentration of Ni, primarily influenced by the increased number of tourist visits. Other sources contributing to Ni contamination include the corrosion of batteries containing Ni and Cd, as well as the corrosion of pipes, which can result in the release of nickel into drinking water[13]. Additionally, heavy rainfall and high wind velocity experienced at Mussoorie hill stations during the monsoon season discourage tourists from traveling during this time.

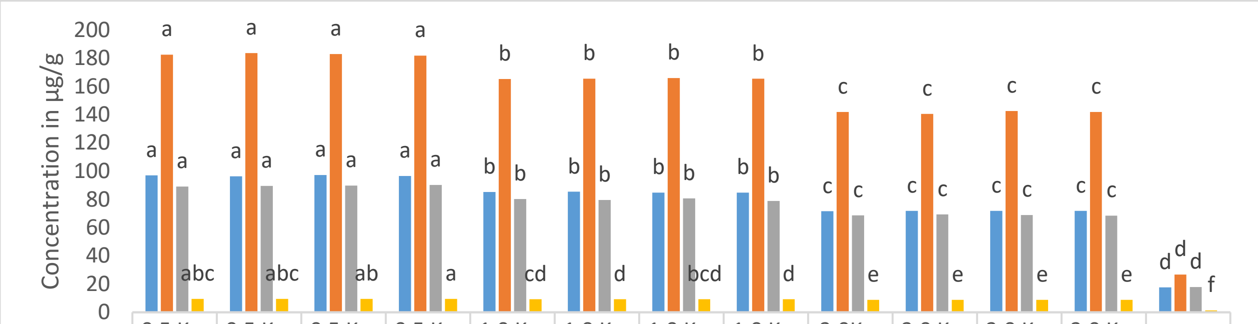
The concentrations of zinc, were analyzed during different seasons in the study area. In winter, Zn concentrations were found to be 228% higher compared to the monsoon, while in summer, Zn concentrations were 310% higher. This significant increase in Zn levels during winter and summer can be attributed to several factors. High traffic areas and road surfaces, which contain zinc, nickel, and cobalt, contribute to the elevated concentrations of Zn[11]. Industrial sources located at Haridwar and Dehradun also contribute to the highest levels of Zn. Additionally, transboundary pollution from neighboring regions impacts the Himalayan ecosystem and may contribute to the observed increase in Zn concentrations. Another potential source of Zn contamination is the use of insecticides and pesticides containing zinc in local agricultural practices such as step cultivation[9].

The concentrations of copper (Cu) exhibited distinct seasonal variations in the study area. During winter, Cu concentrations were 244% higher compared to the monsoon season, while in summer, Cu concentrations were 281% higher. These variations can be attributed to several factors, including increased tourist activity during summer and winter, which results in higher vehicular pollution levels. Vehicular emissions, especially engine emissions, are believed to be a significant contributor to Cu pollution, as supported by the observed elevated Cu levels along roads in the study area[9,11]. It is noteworthy that the use of CuSO4 mixed with kerosene has been prohibited by the government, but it has been found that some villagers continue to use it for their own purposes. This practice may contribute to the elevated Cu concentrations in the area. Furthermore, CuSO4 is commonly employed in various agricultural products, such as fungicides and insecticides, leading to additional Cu contamination in the study area[7].

The concentrations of lead (Pb) showed notable increases during winter, with levels 216% higher than the monsoon season, and even more substantial increases of 261% during summer. These findings indicate a significant contribution of automobile emissions to the elevated Pb concentrations in the study area. Lead is a non-biodegradable heavy metal that persists in the environment for an extended period, posing risks to both the local ecosystem and visitors. Automobile emissions, primarily from fossil fuels, have been identified as a major source of Pb contamination in the study area, as supported by previous research studies[1,14,15].

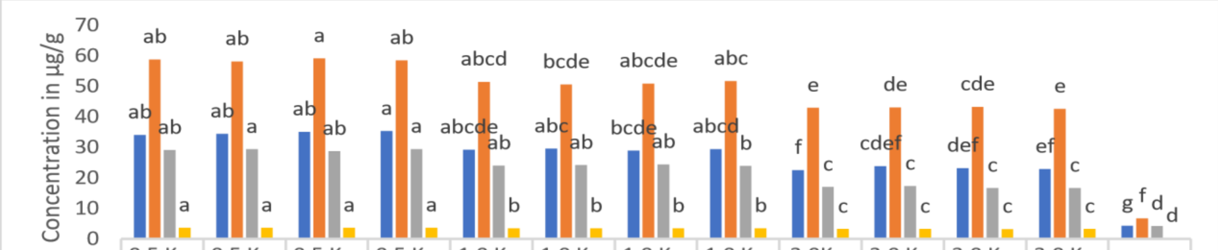
In addition to automobile emissions, other sources of Pb contamination include activities related to fossil fuel and mining. The extraction of zinc, silver, and copper ores, along with other metals, can release Pb into the environment, further contributing to the overall contamination levels[11]. Given the persistence and potential risks associated with Pb contamination, it is crucial to address and mitigate the sources of Pb emissions in the study area. Additionally, monitoring and regulating activities related to fossil fuel and mining can help minimize Pb contamination from these sources.

Figure 1 Concentration of metals Ni, Zn, Cu, and Pb (µg/g) in Mussoorie during summer 2021 by active biomonitoring



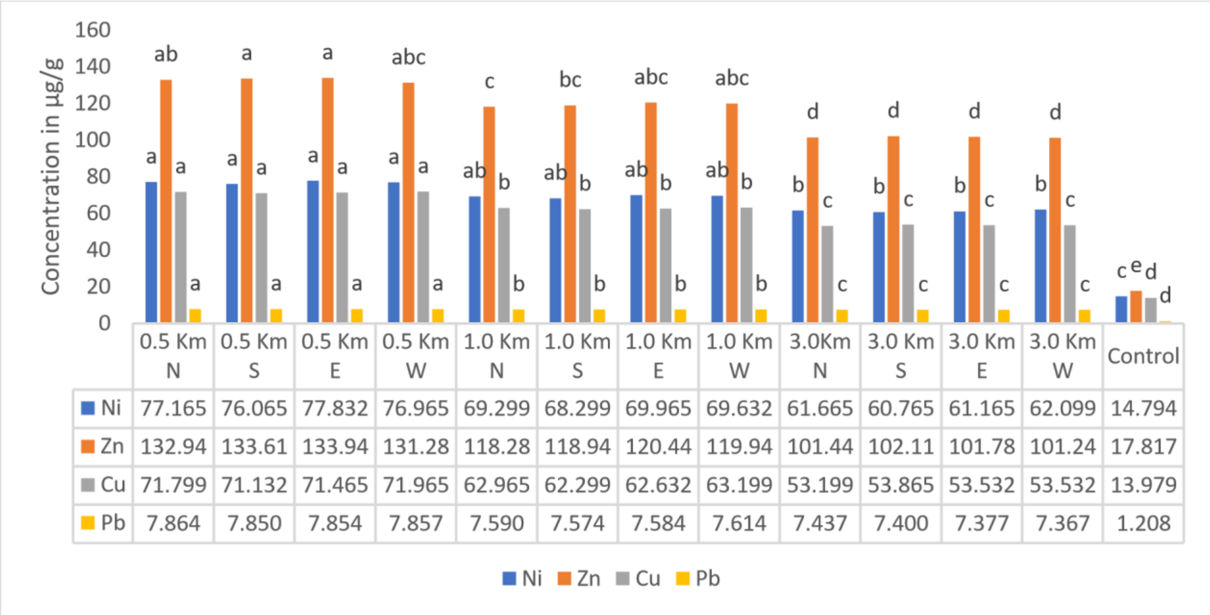
	0.5 Km N	0.5 Km S	0.5 Km E	0.5 Km W	1.0 Km N	1.0 Km S	1.0 Km E	1.0 Km W	3.0Km N	3.0 Km S	3.0 Km E	3.0 Km W	Control
Ni	96.965	96.299	97.299	96.632	85.132	85.365	84.799	84.799	71.632	71.765	71.799	71.965	17.681
Zn	182.58	183.58	182.91	181.91	165.24	165.58	165.91	165.48	141.91	140.58	142.58	141.91	26.663
Cu	89.099	89.432	89.765	90.332	80.332	79.665	80.665	78.999	68.665	69.332	68.999	68.432	17.925
Pb	9.454	9.437	9.464	9.464	9.194	9.191	9.191	9.192	8.838	8.821	8.854	8.828	1.340

Figure 2 Concentration of metals Ni, Zn, Cu, and Pb (µg/g) in Mussoorie during monsoon 2021 by active biomonitoring



	0.5 Km N	0.5 Km S	0.5 Km E	0.5 Km W	1.0 Km N	1.0 Km S	1.0 Km E	1.0 Km W	3.0Km N	3.0 Km S	3.0 Km E	3.0 Km W	Control
Ni	34.099	34.432	35.099	35.332	29.232	29.565	28.899	29.432	22.532	23.865	23.199	22.882	4.349
Zn	58.815	58.149	59.149	58.482	51.482	50.582	50.915	51.715	42.949	43.115	43.282	42.615	6.700
Cu	29.099	29.365	28.765	29.432	23.999	24.165	24.432	23.899	16.999	17.332	16.665	16.665	4.204
Pb	3.640	3.627	3.634	3.660	3.454	3.467	3.450	3.464	3.253	3.261	3.227	3.237	0.198

Figure 3 Concentration of metals Ni, Zn, Cu, and Pb (µg/g) in Mussoorie during winter 2021 by active biomonitoring



	0.5 Km N	0.5 Km S	0.5 Km E	0.5 Km W	1.0 Km N	1.0 Km S	1.0 Km E	1.0 Km W	3.0Km N	3.0 Km S	3.0 Km E	3.0 Km W	Control
Ni	77.165	76.065	77.832	76.965	69.299	68.299	69.965	69.632	61.665	60.765	61.165	62.099	14.794
Zn	132.94	133.61	133.94	131.28	118.28	118.94	120.44	119.94	101.44	102.11	101.78	101.24	17.817
Cu	71.799	71.132	71.465	71.965	62.965	62.299	62.632	63.199	53.199	53.865	53.532	53.532	13.979
Pb	7.864	7.850	7.854	7.857	7.590	7.574	7.584	7.614	7.437	7.400	7.377	7.367	1.208

Conclusions

The study introduces a novel approach using active biomonitoring techniques in the Mussoorie hill station of Uttarakhand, India. It aims to provide data on metal pollution caused by tourism, considering seasonal variations and influencing factors. Plagiomnium undulatum is identified as an effective bio-monitoring tool for assessing atmospheric heavy metal concentrations in mountain ecosystems. The study emphasizes the importance of moss biomonitoring in detecting and addressing metal contamination, and its potential for warning nearby residents. The findings contribute to environmental management and highlight the significance of biomonitoring techniques in similar ecosystems.

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