Study of Lead and Mercury levels in Soils of Nainital and Almora Districts, Uttarakhand, India

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Abstract

Soils of hill districts are increasingly exposed to anthropogenic activities, raising concerns about heavy metal accumulation and ecological risk. The present study assessed the concentration and distribution of lead (Pb) and mercury (Hg) in soils of Nainital and Almora districts, Uttarakhand, India. A total of 24 soil samples were collected, comprising 12 samples from each district, representing cultivable, non-cultivable, and forest land-use types. Heavy metal concentrations were determined using standard laboratory techniques. The results revealed spatial variability in Pb and Hg levels across districts and soil types, with relatively higher concentrations in non-cultivable soils in Almora district while higher concentration in cultivable soil in Nainital district. Analysis revealed that the concentrations of both Pb and Hg were within the permissible limits set by CPCB (Pb:100ppm; Hg: 0.5ppm), indicating minimal heavy metal contamination. These findings suggest that the soils in the study area are environmentally safe and suitable for agricultural and ecological purposes. Two-way ANOVA revealed highly significant effects of district and soil type on both lead and mercury concentrations, with significant district x soil type interactions ($p<0.001$), indicating that metal distribution varied across soil types and districts.

Keywords

Heavy metals, Lead, Mercury, Land-use types.

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Introduction

Heavy metals such as lead (Pb) and mercury (Hg) are persistent environmental pollutants that pose serious ecological and human health risks due to their toxicity and bio-accumulative nature (Alloway, 2013; Kabata-Pendias & Pendias, 2011). Soil acts as a major sink for these metals, which may enter the food chain through plant uptake, ultimately affecting human health (WHO, 2007; FAO/WHO, 2011). Lead exposure is associated with neurological and developmental disorders, while mercury exposure causes neurotoxicity and renal impairment (Rana, 2014; Sharma & Dubey, 2005).

In mountainous regions like Uttarakhand, fragile ecosystems combined with increasing anthropogenic pressures such as agriculture, tourism, urbanization, vehicular emissions, and improper waste disposal contribute significantly to soil contamination (Gupta et al., 2017; Singh et al., 2010). Nainital and Almora districts, located in the Kumaun Himalayan region, represent diverse land-use systems including cultivable, non-cultivable, and forest areas. Previous studies have reported elevated heavy metal concentrations in Himalayan soils and surrounding environments (Kumar et al., 2019; Rai, 2012). However, limited information is available on Pb and Hg contamination specifically in soils of Nainital and Almora. Therefore, the present study aims to assess the concentration, distribution, and ecological risk of Pb and Hg in different land-use soils of these districts.

2. Study Area

Nainital and Almora districts are situated in the Kumaun region of Uttarakhand, India, characterized by mountainous terrain, temperate climate, and high annual rainfall. The Nainital district is located between latitude 29˚00 N and 29°35 N and longitude 78˚50 E and 79^{0}50 E, with height variations from 1,938 m in Nainital town to significantly higher places. The Almora district is situated next to Nainital district, spread over 29^0 26'N and 30^0 20'N latitude and 79^{0}35 to 80^{0}11'E longitudes covering 3083 sq. km geographical area and features rugged, hilly terrain with an average elevation of approximately 1,861 meters above sea level. The region supports diverse land uses including agricultural terraces, forested landscapes, and non-cultivable lands such as rocky slopes and urban fringes. The geological formations primarily consist of metamorphic rocks, which influence soil development and natural background metal levels (Kabata-Pendias & Pendias, 2011). The increasing intensity of tourism and vehicular traffic in these districts has raised concerns regarding environmental quality, particularly soil and air pollution (Pandey et al.,2014).

3. Materials and Methods

3.1 Soil Sampling

A total of 24 surface soil samples (0–15 cm depth) were collected in the year 2023-2024, comprising 12 samples from each Nainital and Almora district. Samples were obtained from four different zones-East, West, North, South and three land-use categories: cultivable soil, non-cultivable soil, and forest soil. Composite samples were prepared at each site, air-dried, homogenized, sieved through a 2 mm mesh, and stored in clean polyethylene bags for laboratory analysis.

3.2 Laboratory Analysis

Soil samples were digested using standard acid digestion procedures (HNO_3 – $HC1O_4$) following established protocols (CPCB, 2012; ICAR, 2011). The concentrations of lead (Pb) and mercury (Hg) were determined using Atomic Absorption Spectrophotometry (AAS) or Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Analytical quality control was ensured using reagent blanks, standard reference materials, and replicate samples.

3.3 Data Analysis

Descriptive statistics were used to summarize Pb and Hg concentrations. The results were compared with established critical limits and guideline values for agricultural soils. Two-way analysis of variance (ANOVA) was used to assess the individual and interactive effects of zone and soil type on the concentration of heavy metals (Pb and Hg) in soil samples.

4. Results and Discussion

The available lead (Pb) and Mercury (Hg) of Almora district of Uttarakhand is shown in Table.1. The amount of Pb ranged from 0.3000 ppm to 0.4832 ppm with a mean value of 0.3683 ppm for cultivable soil, 0.1414 ppm to 0.7500 ppm with a mean value of 0.4724 ppm for non- cultivable and 0.008 ppm to 0.4100 ppm with a mean value of 0.1268 ppm for forest soils while the Hg content ranged from 0.1527 ppm to 0.1873 ppm with a mean value of 0.1639 ppm for cultivable soil, 0.0864 ppm to 0.1897 ppm with mean value of 0.1490 ppm for non- cultivable and 0.1337 ppm to 0.1950 ppm with a mean value of 0.1712 ppm for forest soils.

The available lead (Pb) and Mercury (Hg) of Nainital district of Uttarakhand is shown in Table.2. The amount of Pb ranged from 0.2447 ppm to 0.4666 ppm with a mean value of 0.3310 ppm for cultivable soil, 0.0511 ppm to 0.5218 ppm with a mean value of 0.2036 ppm for non- cultivable and 0.0900 ppm to 0.1614 ppm with a mean value of 0.1196 ppm for forest soils while the Hg content ranged from 0.1133 ppm to 0.1661 ppm with a mean value of 0.1416 ppm for cultivable soil, 0.0486 ppm to 0.1265 ppm with mean value of 0.0894 ppm for non- cultivable and 0.1079 ppm to 0.1492 ppm with a mean value of 0.1307 ppm for forest soils.

Table.1 Heavy metals in different zones of Almora district of Uttarakhand

Soil sample	Place	Zone	Soil type	Soil wt.(g)	Soil in(ml)	Pb(ppm)	Hg(ppm)
1	Almora	East	Cultivable	0.8833	50	0.3461	0.1527
2			Non-cultivable	1.0559	50	0.6900	0.1461
3			Forest	0.8068	50	0.0311	0.1337
4	Ranikhet	West	Cultivable	0.7906	50	0.4832	0.1584
5			Non-cultivable	1.0403	50	0.7500	0.1897
6			Forest	0.9335	50	0.0084	0.1950
7	Bagwali Pokhar	North	Cultivable	0.9646	50	0.3000	0.1873
8			Non-cultivable	0.9168	50	0.1414	0.1736
9			Forest	0.9969	50	0.0576	0.1711
10	Bhujan	South	Cultivable	1.0494	50	0.3439	0.1573
11			Non-cultivable	0.8660	50	0.3083	0.0864
12			Forest	0.9864	50	0.4100	0.1851

Table.2 Heavy metals in different zones of Nainital district of Uttarakhand

Soil sample	Place	Zone	Soil type	Soil wt.(g)	Soil in(ml)	Pb(ppm)	Hg(ppm)
13	Ramgarh	East	Cultivable	0.9922	50	0.2500	0.1133
14			Non-cultivable	0.9007	50	0.5218	0.1265
15			Forest	0.9812	50	0.0900	0.1492
16	Kotabagh	West	Cultivable	0.9462	50	0.2447	0.1576
17			Non-cultivable	1.0053	50	0.1742	0.1060
18			Forest	1.0859	50	0.0907	0.1269
19	Garampani	North	Cultivable	1.0582	50	0.4666	0.1661
20			Non-cultivable	1.0161	50	0.0511	0.0764
21			Forest	0.8076	50	0.1614	0.1079
22	Kathgodam	South	Cultivable	0.9089	50	0.3628	0.1293
23			Non-cultivable	0.9217	50	0.0674	0.0486
24			Forest	1.0552	50	0.1362	0.1387

Table.3 Mean value of lead and mercury in Almora and Nainital district of Uttarakhand

Soil type	Almora				Nainital			
	Pb		Hg		Pb		Hg	
	Mean	S.D.	Mean	S.D.	Mean	S.D	Mean	S.D
Cultivable	0.3683	0.0790	0.1639	0.0165	0.3310	0.1069	0.1416	0.0245
Non-cultivable	0.4724	0.2906	0.1490	0.0437	0.2036	0.2147	0.0894	0.0336
Forest	0.1268	0.1944	0.1712	0.0276	0.1196	0.0379	0.1307	0.0173

Table.4 Two-way ANOVA for Lead

Tests of Between-Subjects Effects						
Dependent Variable: Pb						
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.299[a]	5	.060	1.796E3	.000	.999
Intercept	1.264	1	1.264	3.792E4	.000	1.000
District	.046	1	.046	1.380E3	.000	.991
Soil	.194	2	.097	2.906E3	.000	.998
District * Soil	.060	2	.030	892.667	.000	.993
Error	.000	12	3.333E-5			
Total	1.564	18				
Corrected Total	.300	17				
a. R Squared = .999 (Adjusted R Squared = .998)						

Table.5 Two-way ANOVA for Mercury

Tests of Between-Subjects Effects						
Dependent Variable:Hg						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.015[a]	5	.003	90.267	.000	.974
Intercept	.325	1	.325	9.761E3	.000	.999
District	.008	1	.008	240.667	.000	.953
Soil	.005	2	.003	80.667	.000	.931
District * Soil	.002	2	.001	24.667	.000	.804
Error	.000	12	3.333E-5			
Total	.341	18				
Corrected Total	.015	17				
a. R Squared = .974 (Adjusted R Squared = .963)						

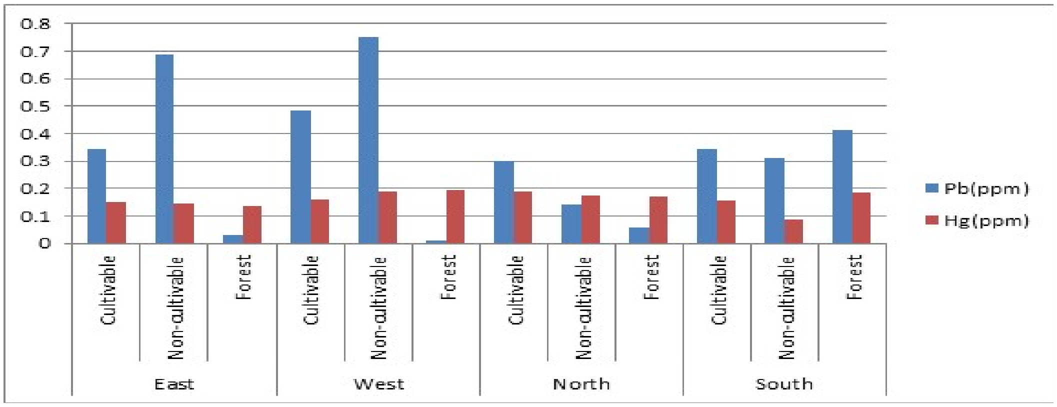

Fig.1 Heavy metal distribution in Almora district

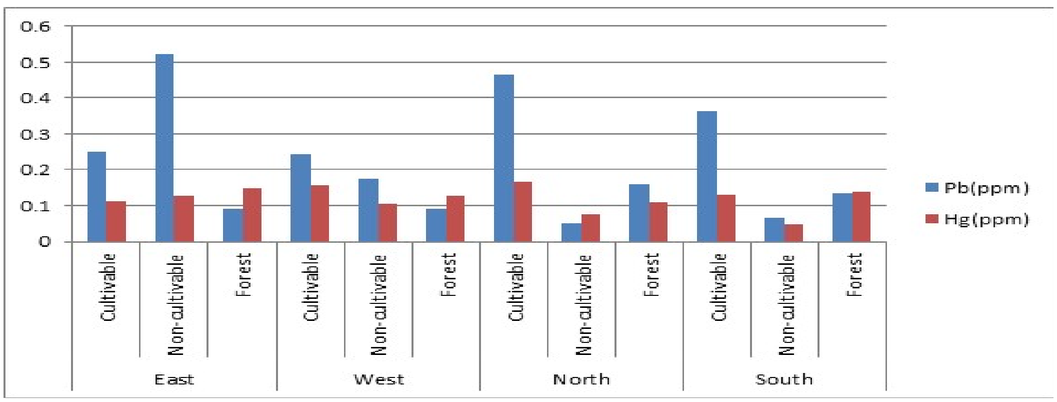

Fig.2 Heavy metal distribution in Nainital district

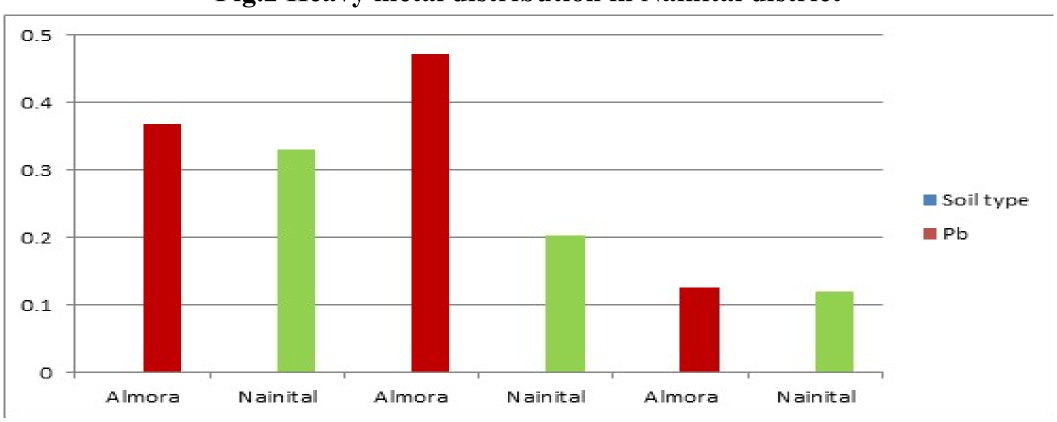

Fig.3 Distribution of Lead in Almora and Nainital district

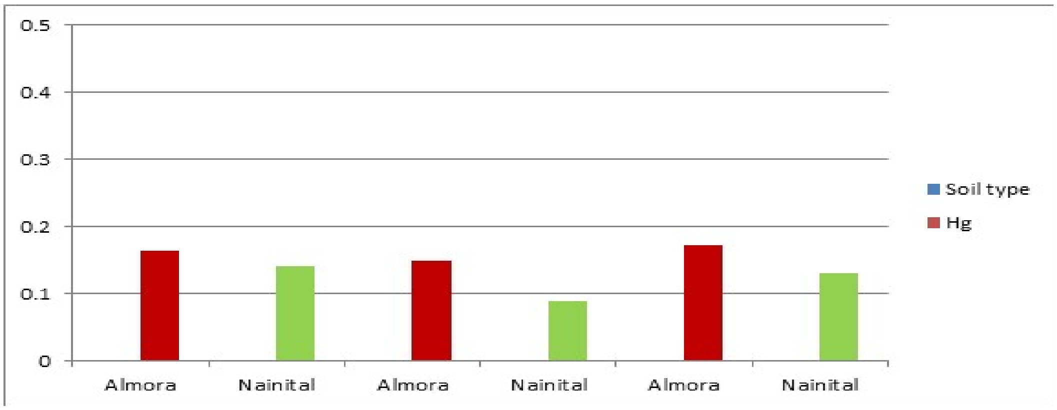

Fig.4 Distribution of Mercury in Almora and Nainital district

4.1 Distribution of Lead and Mercury

The concentrations of Pb and Hg varied significantly across districts and land-use types. Generally, higher concentrations were observed in non-cultivable and forest soils compared to cultivable soils in Almora district. Similar trends have been reported in other Himalayan and mountainous regions, where atmospheric deposition and limited soil disturbance contribute to metal accumulation in forest soils (Kumar et al., 2019; Rai, 2012). It is due to natural geochemical background, weathering of parent rocks, forest litter accumulation, and limits soil disturbance, allowing metals to remain and concentrate over time. While in Nainital district generally cultivable soil show higher concentrations as compared to non-cultivable and forest soils due to agricultural inputs such as fertilizers, pesticides, irrigation water and atmospheric deposition from traffic and tourism- related activities, which accumulate in farm soils.Urban and roadside locations exhibited comparatively elevated Pb levels, likely due to vehicular emissions and construction activities (Sharma et al., 2008; Gupta et al., 2017).

Two-way ANOVA revealed a highly significant effect of district and soil type on both Lead and Mercury concentration ($p<0.001$), with a significant interaction between district and soil type ($p<0.001$), indicating that the influence of soil type on both heavy metals (Pb & Hg) levels varied across districts.

4.2 Comparison with Soil Quality Standards

The measured concentrations were compared with permissible limits prescribed by the Central Pollution Control Board (CPCB), World Health Organization (WHO), and Food and Agriculture Organization (FAO) (CPCB, 2012; WHO, 2007; FAO/WHO, 2011). The concentrations of Pb and Hg in all soil samples were found to be within the permissible limits prescribed by CPCB and WHO guidelines, indicating no significant heavy metal contamination in the study area. This suggests that the soils of Almora and Nainital districts are environmentally safe and pose minimal risk to agricultural productivity and human health.

4.3 Source Identification

Potential sources of Pb include vehicular exhaust, battery waste, industrial emissions, and construction materials (Sharma et al., 2008; Gupta et al., 2017). Mercury contamination may arise from fossil fuel combustion, waste incineration, long-range atmospheric transport, and improper disposal of mercury-containing products (WHO, 2007; Yadav et al., 2017). Natural geological sources and weathering of parent rock material may also contribute to background levels (Kabata-Pendias & Pendias, 2011).

4.4 Ecological and Health Implications

Elevated Pb and Hg levels can adversely affect soil microbial activity, plant growth, and nutrient cycling, thereby reducing soil fertility (Singh & Kalamdhad, 2011; Sharma & Dubey, 2005). Long-term exposure to these metals poses serious health risks, including neurological disorders, renal dysfunction, endocrine disruption, and developmental abnormalities, particularly in children and pregnant women (Rana, 2014; WHO, 2007; Singh et al., 2010).

5. Conclusion

The present study reveals that the concentrations of lead(Pb) and mercury(Hg) in soils of Almora and Nainital districts vary significantly with soil type and district; however, all observed values remain within the permissible limits prescribed by national and international standards. Higher metal levels were recorded in cultivable soils of Nainital and non-cultivable soils of Almora, reflecting the influence of land use and natural geochemical factors.

Overall, the soils of the study are currently safe for agricultural and environmental use, though regular monitoring is recommended to prevent future contamination

6. References

1. Alloway, B. J. (2013). *Heavy Metals in Soils* (3rd ed.). Springer, Dordrecht.
2. CPCB. (2012). *Guidelines for Assessment of Soil Contamination in India*. Central Pollution Control Board, New Delhi.
3. FAO/WHO. (2011). *Joint FAO/WHO Food Standards Programme: Codex Alimentarius Commission*. FAO, Rome.
4. Gupta, N., Yadav, K. K., & Kumar, V. (2017). A review on current status of heavy metal contamination in India. *Environmental Pollution*, 223, 336–351.

5. Hakanson, L. (1980). An ecological risk index for aquatic pollution control: A sedimentological approach. *Water Research*, 14(8), 975–1001.
6. ICAR. (2011). *Soil Health Management*. Indian Council of Agricultural Research, New Delhi.
7. Kabata-Pendias, A., & Pendias, H. (2011). *Trace Elements in Soils and Plants* (4th ed.). CRC Press, Boca Raton.
8. Kumar, M., Ramanathan, A. L., Tripathi, R., & Singh, G. (2019). Assessment of heavy metal contamination in Himalayan soils. *Environmental Earth Sciences*, 78, 487.
9. Pandey, B., Agrawal, M., & Singh, S. (2014). Assessment of air pollution around coal-fired thermal power plants in India. *Environmental Monitoring and Assessment*, 186, 1297–1312.
10. Rai, P. K. (2012). Heavy metal phytoremediation from aquatic ecosystems with special reference to macrophytes. *Critical Reviews in Environmental Science and Technology*, 42(7), 697–753.
11. Rana, S. V. S. (2014). Perspectives in endocrine toxicity of heavy metals—A review. *Biological Trace Element Research*, 160, 1–14.
12. Sharma, P., & Dubey, R. S. (2005). Lead toxicity in plants. *Brazilian Journal of Plant Physiology*, 17(1), 35–52.
13. Sharma, R. K., Agrawal, M., & Marshall, F. (2008). Heavy metals (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: A case study in Varanasi. *Environmental Pollution*, 154, 254–263.
14. Singh, A., Sharma, R. K., Agrawal, M., & Marshall, F. (2010). Health risk assessment of heavy metals via dietary intake of food crops in India. *Environmental Monitoring and Assessment*, 157, 473–495.
15. Singh, J., & Kalamdhad, A. S. (2011). Effects of heavy metals on soil, plants, human health and aquatic life. *International Journal of Research in Chemistry and Environment*, 1(2), 15–21.
16. Tóth, G., Hermann, T., Da Silva, M. R., & Montanarella, L. (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. *Environment International*, 88, 299–309.
17. Tripathi, R. M., Raghunath, R., & Krishnamoorthy, T. M. (1997). Dietary intake of heavy metals by adults in Bombay City, India. *Science of the Total Environment*, 208, 149–159.

18. WHO. (2007). *Evaluation of Certain Food Additives and Contaminants: Sixty-Seventh Report of the Joint FAO/WHO Expert Committee on Food Additives (JECFA)*. World Health Organization, Geneva.
19. Yadav, K. K., Gupta, N., Kumar, V., Sharma, S., & Arya, S. (2017). A review of heavy metal toxicity and removal techniques. *Environmental Chemistry Letters*, 15, 61–84.
20. Zhang, C., Liu, G., Xue, Y., & Wang, M. (2014). Heavy metal contamination in soils and vegetables from industrial areas of China. *Environmental Earth Sciences*, 72, 4523–4534.
21. Guidelines for Assessment and Management of Contaminated sites in India.CPCB(2015).