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Heavy Metal Distribution in Road Dust Across Land-Use Types in Mizoram and Its Human Health Risk Assessment

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Abstract

Objectives: This study aimed to assess the levels and spatial distribution of heavy metals in road dust of various land-use areas of Aizawl and Lawngtlai, Mizoram and to assess the human health risk associated with the heavy metals. **Method:** Road dust samples were taken from agricultural, industrial, commercial, residential and solid waste disposal areas. Samples were digested using USEPA Method 3050B and analysed for Cr, Pb, Ni, Cu, Zn and Cd using atomic absorption spectroscopy. GIS was employed to investigate land-use and topographic factors, and the USEPA model was used to evaluate health risks to adults and children. **Findings:** The results showed that Zn was the predominant metal with mean concentration of 72.75 mg/kg in Aizawl and 60.60 mg/kg in Lawngtlai. The highest concentrations of Zn were 119.84 mg/kg and 80.30 mg/kg, respectively. Compared with Indian natural soil background values, Pb, Ni and Zn were enriched by 94.66%, 41.47% and 228.54% in Aizawl and 29.21%, 20.56% and 174.69% in Lawngtlai. There was no significant difference ($p > 0.05$) in metal concentrations between districts. Ingestion was the most important exposure pathway. The hazard indices were 0.070 and 0.218 for adults and children in Aizawl, respectively, and 0.035 and 0.176 in Lawngtlai, respectively, which are less than 1. **Novelty:** This study provides a baseline assessment of the integration of heavy metal concentration, land use, topography and human-health risk in two contrasting mountainous urban areas of Mizoram.

Keywords: Heavy metals; road dust; land use; topography; human health risk assessment

1 Introduction

Road surfaces receive and accumulate particles from both natural and anthropogenic sources and heavy metals are important environmental contaminants in road dust. Tyre and brake wear, vehicle emissions and road abrasion are all sources of metals to the roadside environment, with the metals most commonly associated with these traffic-related activities being Pb, Zn, Cu, Cr and Ni^{(1), (2), (3)}. Metal accumulation and redistribution can also result from agricultural activities, waste disposal, construction and other urban activities⁽⁴⁾. Once deposited, road dust particles can be re-entrained or

carried by surface runoff, which can lead to environmental redistribution and human exposure^{(5), (6)}.

Heavy metal levels in road dust have been shown to vary significantly based on land use, traffic volume and the surrounding anthropogenic activities. Differences between residential, commercial, industrial and high traffic areas have been reported in studies conducted in urban environments, reflecting the impact of land-use characteristics on metal accumulation^{(7), (8)}. More recent studies have also shown that contamination of road dust may be from several sources such as traffic, industrial processes, atmospheric deposition and mixed anthropogenic sources^{(9), (10)}. Even in a less industrialized mountainous area, vehicular emissions, industrial activities and atmospheric deposition were identified as potential sources of heavy metals in a recent study of the roadside soil in Aizawl⁽¹¹⁾.

Road dust containing high concentrations of heavy metals is also a concern as exposure can occur via ingestion, inhalation and dermal contact. Children may be at higher risk than adults due to differences in body weight and exposure behaviour as revealed by recent health-risk studies^{(5), (6)}. Although research on the contamination of urban road-dust has grown, the majority of studies have been conducted in large cities or in cities with a high concentration of industrial activity. Little information is available for smaller, more mountainous urban centres in Northeast India where steep terrain, variable traffic levels, vegetation cover and mixed urban–agricultural land use can affect the build-up and redistribution of metal-bearing particles.

The present study was aimed to evaluate the levels of Cr, Pb, Ni, Cu, Zn and Cd in the road dust samples collected from various land use categories in Aizawl and Lawngtlai. The study also investigated spatial patterns with respect to land use and topography, compared the observed concentrations with background concentrations found in India from natural soil, statistically compared concentrations between the two districts and assessed potential non-carcinogenic and carcinogenic health risks for adults and children.

2 Methodology

2.1 Study Area

The study was carried out in Aizawl and Lawngtlai districts of Mizoram. Aizawl has a population of 400,309 as per 2011 census and is an important administrative and commercial centre. Lawngtlai is located in the southernmost region of Mizoram, with a population of 20,830 as per the 2011 Census, and is one of the three autonomous council areas of Mizoram. The locations of the study areas are presented in Figure 1.

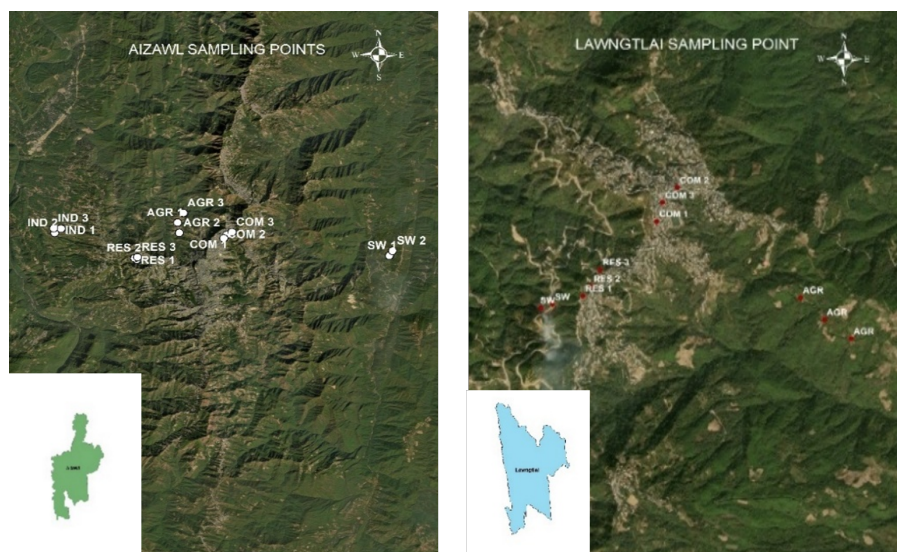


Fig 1. Locations of the study areas

2.2 Sampling Sites and Sample Collection

Road-dust samples were collected from March to April 2024. The sampling sites were chosen based on five land-use categories: agricultural, solid-waste disposal, industrial, commercial, and residential. Twenty samples were taken, two from each land-use category in each study area. The sampling sites are described in Table 1.

A clean plastic broom and dustpan were used to collect about 200 g of dust from the road surface at each sampling site. The samples were placed in labeled zip-lock plastic bags and brought to the lab for analysis.

Table 1. Description of the sampling sites in Aizawl and Lawngtlai

Land-use category	Road type	Description of the location
Agricultural	Alternative road	Area used for production of vegetables, rice, maize and other crops
Solid-waste disposal	Highway in Lawngtlai; alternative road in Aizawl	Area where wet and dry wastes are disposed
Industrial	Main road	Area associated with production activities
Commercial	Highway/alternative road	Area containing stores, restaurants, pharmacies, hospitals, vehicle workshops.
Residential	Main road	Residential area with comparatively lower surrounding pollution

2.3 Sample Preparation and Heavy-Metal Analysis

All samples were collected and cleaned manually to remove any visible debris and foreign material, and then oven dried to remove moisture. The dried samples were ground and sieved through <2 mm. A sample of 0.5 g was weighed for acid digestion. 10 mL of concentrated HNO₃ (69%) and 3 mL of concentrated HCl (37%) were added. The mixture was heated for about 2 h at 95°C. Then 2 mL of deionized water and 3 mL of H₂O₂ were added and the mixture was heated for an additional 2 h. Then a further 10 mL concentrated HCl was added and heated for 15 min to obtain a clear digest. The digest was cooled to room temperature, filtered through Whatman No. 41 filter paper, transferred to a 50-mL volumetric flask and made up to volume with deionized water.

The digested samples were analysed by atomic absorption spectroscopy (AAS) for the elements Cr, Pb, Cd, Ni, Cu and Zn. Calibration standards were prepared independently from 1000 mg/L stock solutions, and three calibration standards were made for each metal. The analytical wavelengths were 357.9 nm for Cr, 217.0 nm for Pb, 228.8 nm for Cd, 232.0 nm for Ni, 324.8 nm for Cu and 213.9 nm for Zn. The concentrations measured in mg/L were converted to mg/kg using the sample mass and digest volume.

2.4 Quality Assurance and Quality Control

All digestion and analysis glassware was cleaned with detergent, rinsed and soaked in 10% HNO₃ for 24 h prior to use. Monitoring of contamination and analytical performance was accomplished by analysing method blanks and calibration standards.

2.5 Spatial Mapping

The study areas LULC and slope layers were acquired from Bhuvan Thematic Services. The sampling points were geo-referenced and plotted on the LULC and slope layers in ArcGIS. The spatial overlay was employed to determine the land-use categories and topographic conditions for each sampling location (Figure 2).

2.6 Statistical Analysis

The mean, median and standard deviation were calculated for the concentrations of the heavy metals. Pearson correlation analysis was performed to investigate the linear relationships between the analysed metals. The mean concentration of Cr, Pb, Ni, Cu and Zn were compared between Aizawl and Lawngtlai using an independent-sample t-test at 0.05 level of significance. Microsoft Excel with the Real Statistics add-in was used to perform statistical analyses.

2.7 Human Health Risk Assessment

The USEPA risk-assessment approach was used to assess human-health risks from exposure to heavy metals in road dust⁽¹²⁾. Ingestion, dermal contact and inhalation were both taken into account for adults and children. The exposure parameters presented in Supplementary Table 2 were used to calculate average daily doses (ADDs). The average daily dose through

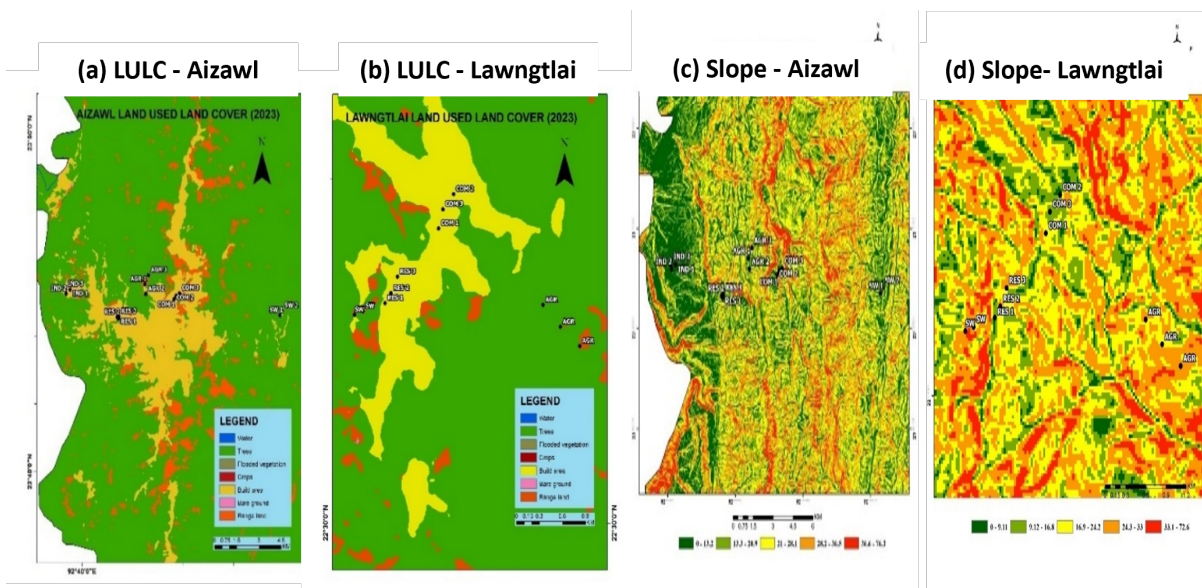


Fig 2. (a) Land Use/Land Cover map of Aizawl; (b) Land Use/Land Cover map of Lawngtlai; (c) Slope map of Aizawl; and (d) Slope map of Lawngtlai.

ingestion, dermal contact and inhalation was calculated using:

$$ADD_{\text{ingest}} = \frac{C \times \text{Ing R} \times EF \times ED \times CF}{BW \times AT} \quad (1)$$

$$ADD_{\text{dermal}} = \frac{C \times AF \times SA \times EF \times ABSd \times ED \times CF}{BW \times AT} \quad (2)$$

$$ADD_{\text{inhale}} = \frac{C \times \text{Inh R} \times EF \times ED \times CF}{BW \times PEF \times AT} \quad (3)$$

Non-carcinogenic risk was evaluated using the hazard quotient (HQ):

$$HQ = \frac{ADD}{RfD} \quad (4)$$

The overall non-carcinogenic risk was assessed using the hazard index (HI):

$$HI = \sum HQ \quad (5)$$

An $HI < 1$ being interpreted as low likelihood of non-carcinogenic effects and $HI > 1$ being interpreted as potential non-carcinogenic concern⁽¹²⁾. The reference doses for the various metals and exposure routes are given in Supplementary Table 3.

Cancer slope-factor data were only available for the inhalation pathway, so the assessment of carcinogenic risk was conducted via this pathway. The corresponding cancer slope-factor values are provided in Supplementary Table 4.

$$\text{Cancer risk via inhalation} = \frac{\sum ADD_{\text{inhale}}}{CSF_{\text{inhale}}}$$

Table 2. Exposure factors for dose model. Source: Du et al., (2013)

Parameters	Definition	Unit	Value		References
			Children	Adult	
C	average concentration of HMs in dust	mg/kg			This study
Ing R	ingestion rate	mg/day	200	100	USEPA (1989)
EF	exposure frequency	days/year	350	350	ESA Guideline
ED	exposure duration	year	6	24	USEPA (2001)
CF	conversion factor	kg/mg	10 ⁻⁶	10 ⁻⁶	USEPA (2004)
BW	average body weight	kg	15	55.9	ESA Guideline
AF	adherence factor for dust	mg/cm ²	1	1	ESA Guideline
SA	surface area of skin contact to dust	cm ³	1800	5000	ESA Guideline
ABSd	dermal absorption factor		0.001	0.001	ESA Guideline
Inh R	inhalation rate	m ³ /day	5	20	ESA Guideline
PEF	particle emission factor	m ³ /kg	1.32 X 10 ⁹	1.32 X 10 ⁹	ESA Guideline
AT	average time	days	365 X ED	365 X ED	USEPA (1989)

Table 3. USEPA reference dose of heavy metals

Reference dose	Cadmium	Nickel	Chromium	Zinc	Copper	Lead
RfD-ADD _{ingest}	1.00E-03	2.00E-02	3.00E-03	3.00E-01	4.00E-02	3.50E-03
RfD-ADD _{inhale}	1.00E-03	5.40E-03	6.00E-05	3.01E-01	1.20E-02	3.52E-03
RfD-ADD _{dermal}	1.00E-05	2.06E-02	2.86E-05	6.00E-02	4.02E-02	5.25E-04

Table 4. USEPA reference dose values of heavy metal (carcinogenic risk assessment)

Reference dose	Cadmium	Nickel	Chromium	Zinc	Copper	Lead
RfD-CSF _{inhale}	6.30+00	8.40E-01	4.20E+01	-	-	-

3 Results and Discussion

3.1 Heavy-Metal Concentrations

The mean concentrations of the different elements (Cr, Pb, Ni, Cu and Zn) in road dust of the various land-use categories of Aizawl and Lawngtlai are shown in Figure 3. In Aizawl, Cr ranged from 18.19–36.28 mg/kg, Pb from 20.64–27.12 mg/kg, Ni from 32.32–47.91 mg/kg, Cu from –0.51–32.49 mg/kg and Zn from 30.80–119.84 mg/kg. The corresponding mean concentrations were 28.82 ± 7.04 , 25.47 ± 2.72 , 39.19 ± 5.96 , 11.88 ± 12.27 and 72.75 ± 34.26 mg/kg, respectively. The overall abundance was in the order of Zn>Ni>Cr>Pb>Cu, with Zn being the most abundant metal.

In Lawngtlai, Cr, Pb, Ni, Cu and Zn ranged from 17.38–31.95, 11.25–25.27, 29.06–42.48, 2.54–26.49 and 31.95–80.30 mg/kg, respectively. Their mean concentrations were 25.62 ± 6.69 , 16.91 ± 5.93 , 33.37 ± 6.25 , 13.81 ± 11.69 and 60.60 ± 20.50 mg/kg, respectively, giving the order Zn > Ni > Cr > Cu > Pb. The dominance of Zn is in line with recent studies on road-dust which have shown that traffic and other anthropogenic activities are significant contributors to the accumulation of Zn^{(1), (2), (6)}.

The solid waste disposal site of Aizawl showed the highest concentration of Cr (36.28 mg/kg) indicating that activities related to solid waste disposal and metal containing waste materials could be a source of Cr accumulation in the area. Heavy metal contamination in road dust is suspected to be caused by waste handling and mixed anthropogenic activities^{(2), (6)}.

The highest concentration of Pb was observed in the commercial area, which could be related to increased traffic activity and traffic-related metal inputs. Traffic and mixed anthropogenic sources have been found to be significant contributors to the accumulation of Pb in recent road-dust studies^{(2), (6), (10)}. The highest concentration of Zn was found in the commercial zone (119.84 mg/kg), which may be related to increased traffic and possible sources of tyre and brake wear and road abrasion^{(1), (2), (10)}. Traffic related activities such as tyre and brake wear have been recently identified as significant sources of Zn and other metals in road dust^{(2), (10)}. These potential sources were not quantified in the present study and are therefore potential sources and not confirmed sources.

The concentration of Cu was also the highest (32.49 mg/kg) in Aizawl in the solid waste disposal area. This local enrichment may be associated with waste-related inputs, but in the present study, the source of Cu was not specifically identified, but brake

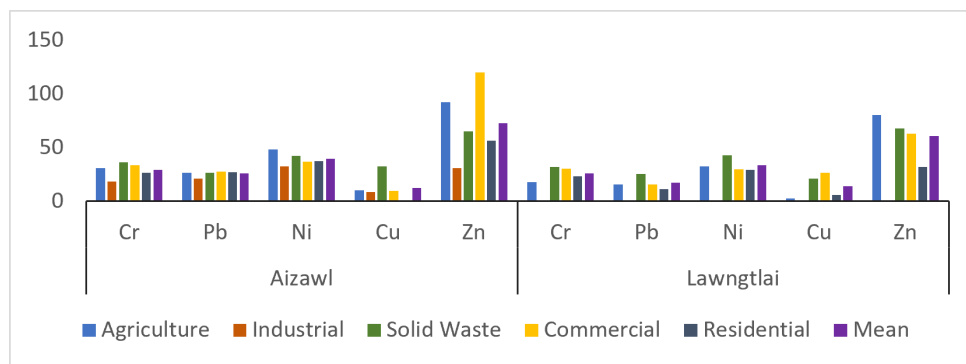


Fig 3. Mean heavy metal concentrations in road dust from study area (mg/kg).

wear is known to be a source of Cu in road dust^{(2), (10)}. The concentrations of Cr and Ni were relatively high in the agricultural and waste-related areas in Lawngtlai, while the agricultural areas had relatively high concentrations of Zn.

The relatively high concentration of Zn in agricultural areas may be related to agricultural inputs, biomass burning and soil disturbance, which may affect the redistribution and mobility of metal-bearing particles. Other studies have found that the levels of metals in road-dust can be from several anthropogenic and land-use sources and not just one^{(4), (6), (7)}. These potential sources were not directly quantified in the present study and are therefore regarded as potential and not confirmed sources.

3.2 Comparison with Indian Background and Other Studies

The concentrations observed found in the present study shown in Figure 4 are typically lower than those found in more urbanized areas. Gupta et al.⁽¹³⁾ reported mean road-dust concentrations of 289.85 mg/kg Zn, 139.66 mg/kg Cu, 97.34 mg/kg Pb, 87.29 mg/kg Cr and 54.23 mg/kg Ni in Lucknow, India. The mean concentrations of Zn in Aizawl (72.75 mg/kg) and Lawngtlai (60.60 mg/kg) were about 75% and 79% lower, respectively, than these values.

Rehman et al.⁽⁵⁾ reported substantially higher concentrations of Cr (101–222 mg/kg) and Zn (114–228 mg/kg) in road dust from Lahore, Pakistan. The mean concentration of Cr and Zn in Aizawl were 28.82 and 72.75 mg/kg, respectively, and in Lawngtlai were 25.62 and 60.60 mg/kg, respectively. The highest concentration of Zn observed in Aizawl (119.84 mg/kg) was in the lower end of the range for Lahore, indicating that localized enrichment can occur even when the mean concentration for the district is comparatively low.

Khundrakpam et al.⁽⁶⁾ reported the order of Zn > Pb > Cu > Cr > Ni > Cd for road dust from Shillong and identified anthropogenic/crustal, traffic/e-waste and geogenic sources. The dominance of Zn in the present study is thus in accordance with the regional pattern, but the concentrations and source contributions varied between the two studies.

The mean concentrations of Pb, Ni and Zn were higher in both the study areas than the Indian natural-soil background values, while the concentration of Cr and Cu were below the natural soil background values. In Aizawl, the concentration of Pb, Ni and Zn were found to be 94.66%, 41.47% and 228.54% above the background values, respectively, while in Lawngtlai the concentration of Pb, Ni and Zn were found to be 29.21%, 20.56% and 174.69% above the background values, respectively. The high level of enrichment of Zn indicates a significant anthropogenic source, but the present study did not conduct quantitative source apportionment.

3.3 Comparison of Heavy-Metal Concentrations between Aizawl and Lawngtlai

Independent-sample t-test revealed that there was no statistically significant difference between Aizawl and Lawngtlai for any of the analysed metals ($p > 0.05$). Cr concentrations were 28.82 ± 7.04 and 25.62 ± 6.69 mg/kg, respectively ($p = 0.699$); Pb concentrations were 25.47 ± 2.72 and 16.91 ± 5.93 mg/kg ($p = 0.453$); Ni concentrations were 39.19 ± 5.96 and 33.37 ± 6.25 mg/kg ($p = 0.365$); Cu concentrations were 11.88 ± 12.27 and 13.81 ± 11.69 mg/kg ($p = 0.486$); and Zn concentrations were 72.75 ± 34.26 and 60.60 ± 20.50 mg/kg ($p = 0.508$).

The differences were the highest for Pb (51% higher in Aizawl) followed by Zn (20%), Ni (17%) and Cr (13%) while Cu was around 16% higher in Lawngtlai. The t-test thus does not show that the two districts have the same contamination level, but rather that there are no statistically significant differences between the two districts.

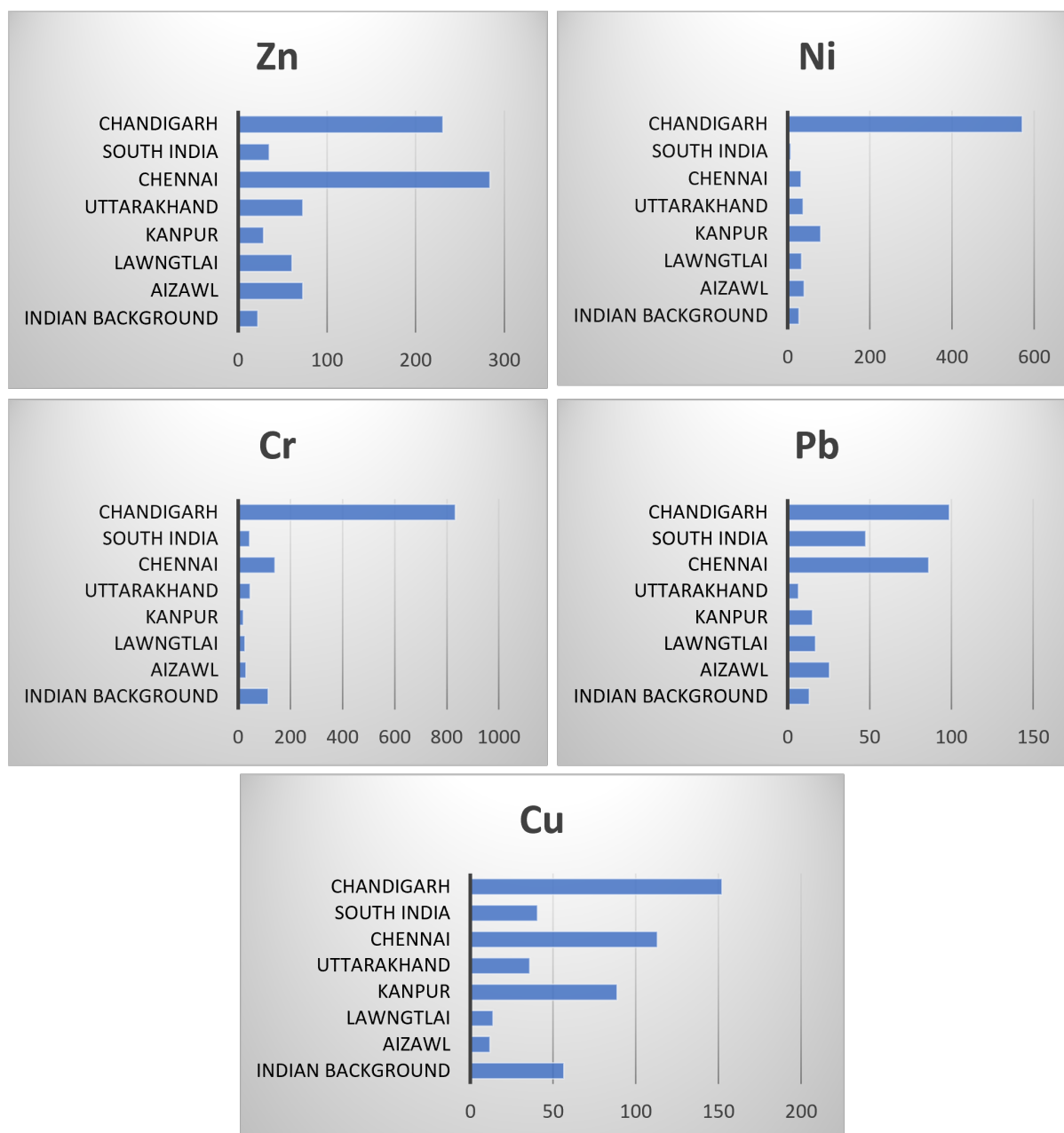


Fig 4. Comparison with Indian Natural Soil Background value and other studies

3.4 Land Use, Topography and Spatial Distribution

Figure 2(a, b) shows the LULC characteristics of Aizawl and Lawngtlai. Aizawl has more built-up and commercial influence whereas Lawngtlai has more vegetation and agricultural influence. Spatial distribution of selected metals shows localized enrichment in commercial, industrial and solid waste zones of Aizawl and in agriculture and waste related zones of Lawngtlai.

The slope maps in Figure 2(c, d) indicate that there are some agricultural sampling sites located on steep to extremely steep slopes. This type of land can increase surface runoff and soil erosion and can promote the movement of fine particles containing metals. The pattern observed in the present study should be interpreted as a potential influence, however, as there was no statistical modelling of the relationship between slope and individual metal concentrations.

3.5 Health risk assessment of heavy metals in road dust

3.5.1. Non carcinogenic and carcinogenic risk assessment

The potential non-carcinogenic risks from exposure to heavy metals were evaluated by applying the Hazard Index (HI) which is the sum of the Hazard Quotients (HQs) from all exposure pathways. The order of contribution of metals to non-carcinogenic risk in Aizawl was similar for both adults and children, with $Pb > Cr > Ni > Cu > Zn > Cd$. The overall HI values were 0.070 for adults and 0.218 for children in Aizawl and 0.035 and 0.176 in Lawngtlai, respectively. The HI values for all of the exposures were less than 1, suggesting a low potential for non-carcinogenic effects under the exposure assumptions in this study.

The ingestion contribution for children is in line with recent road-dust health-risk studies that have found ingestion to be an important exposure pathway and have generally reported higher estimated risks for children than for adults^{(2), (5), (6), (14), (13)}. This difference suggests that the estimated non-carcinogenic risk in the present study is relatively lower, but caution should be exercised when comparing with other studies due to differences in sampling design, metal concentrations and exposure parameters.

The total carcinogenic risk values were found to be 1.15×10^{-6} for adults and children in Aizawl, 1.05×10^{-6} for adults in Lawngtlai and 9.76×10^{-9} for children in Lawngtlai. These values were lower than the 10^{-6} - 10^{-5} risk range that is generally accepted for the interpretation of potential carcinogenic risk, suggesting a negligible estimated carcinogenic risk under the exposure conditions evaluated.

3.6 Study contribution and novelty

The novelty of this study is the combination of road-dust heavy-metal concentrations of different contrasting land-use categories with natural-soil background comparison of India, statistical comparison of Aizawl and Lawngtlai, LULC and topographic interpretation and human-health risk assessment in the mountainous landscape of Mizoram.

4 Conclusion

The present study aimed to determine the levels and distribution of the selected metals (Cr, Pb, Ni, Cu and Zn) in road dust of various land-use categories of Aizawl and Lawngtlai and their potential human-health risks. Both districts were dominated by Zn with mean concentration of 72.75 ± 34.26 mg/kg in Aizawl and 60.60 ± 20.50 mg/kg in Lawngtlai followed by Ni and Cr. In comparison with the background values of Indian natural soils, the concentration of Pb, Ni and Zn was found to be enriched in both districts with highest enrichment of Zn (228.54% in Aizawl and 174.69% in Lawngtlai) indicating anthropogenic influence. The independent-sample t-test showed no statistically significant differences between Aizawl and Lawngtlai for Cr ($p = 0.699$), Pb ($p = 0.453$), Ni ($p = 0.365$), Cu ($p = 0.486$) and Zn ($p = 0.508$). Ingestion was the major route of exposure, especially for children. The total HI values for adults and children in Aizawl were 0.070 and 0.218, respectively, which are below 1, and 0.035 and 0.176, respectively, in Lawngtlai. The estimated cancer risks were also within the interpreted acceptable range, suggesting low potential health risk for the assessed exposure conditions. Commercial, high traffic and waste disposal areas should be monitored regularly. Future research should include a larger sample size, seasonal monitoring, source apportionment techniques, metal bioaccessibility and quantitative spatial modelling to better identify sources and quantify long-term changes in road-dust contamination.

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Author details: Lalropeki Mualchin is a research Scholar; Hilda Lalrinpuia and Lallawmkimi are Assistant Professors.

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