Integrated Source Apportionment and Risk Assessment of Heavy Metals Using Car Air Filter Dust as a Semi-Quantitative Active Air Sampler in Dhaka, Bangladesh

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Introduction

- Heavy metals (HMs) from urbanization and traffic persist indefinitely, unlike organic pollutants.[1]
- In megacities like Dhaka, atmospheric toxins pose neurotoxic and carcinogenic risks, especially for children.
- Traditional air monitoring is costly and power-dependent, leaving gaps in resource-limited regions.
- Need for time-weighted, space-integrated data reflecting residents' actual movement.[2]
- Research supports SDGs 3, 11, 13, and 15 by identifying toxic sources for targeted policies.

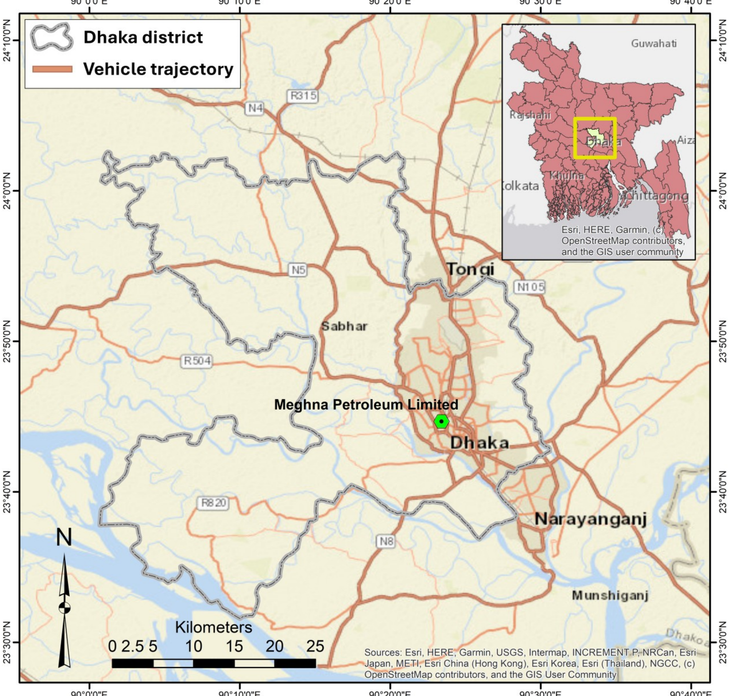


Fig. 1: Study area map.

Methodology

- Using car air filters (CAFs) as semi-quantitative active samplers, this method captures large air volumes from vehicles traveling through city corridors for broad pollutant profiling (Fig. 2).[2-5]
- CAFs provide space-integrated data along residents' actual breathing zone, capturing real-world, time-weighted exposure instead of a single grab-sample.
- CAFs are a low-cost, opportunistic method using existing automotive infrastructure recycling routine filter replacements to gather quality data without extra energy costs.

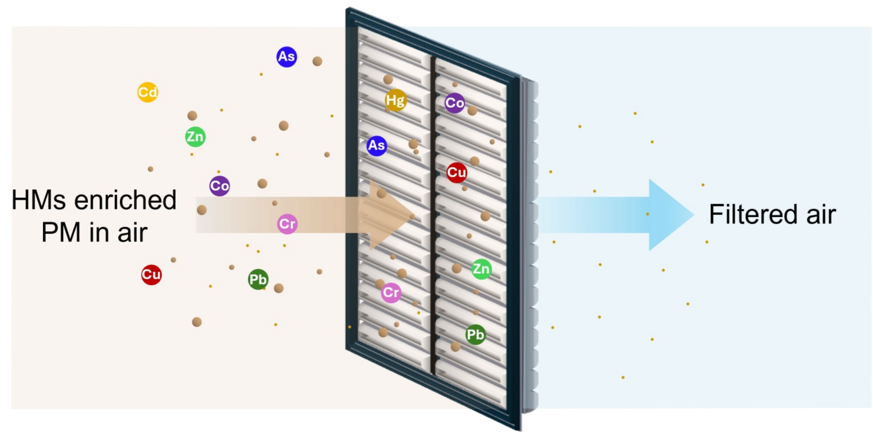


Fig. 2: Entrapment of HMs enriched dust into car air filter.

Overview of HMs

- ICP-MS was used to analyze 11 HMs in 30 CAF dust samples.
- Order of HMs concentrations were: Zn (348.50 mg/kg) > Mn (115.42 mg/kg) > Pb (90.23 mg/kg) > Cu (55.17 mg/kg) > Ni (11.01 mg/kg) > Cr (10.95 mg/kg) > As (4.55 mg/kg) > Co (2.29 mg/kg) > Cd (2.14 mg/kg) (Fig. 3).
- Concentrations of Mn, Ni, Cu, Zn, As, Cd, and Pb in CAF dust are significantly higher than recently reported values for Dhaka road dust.[6]

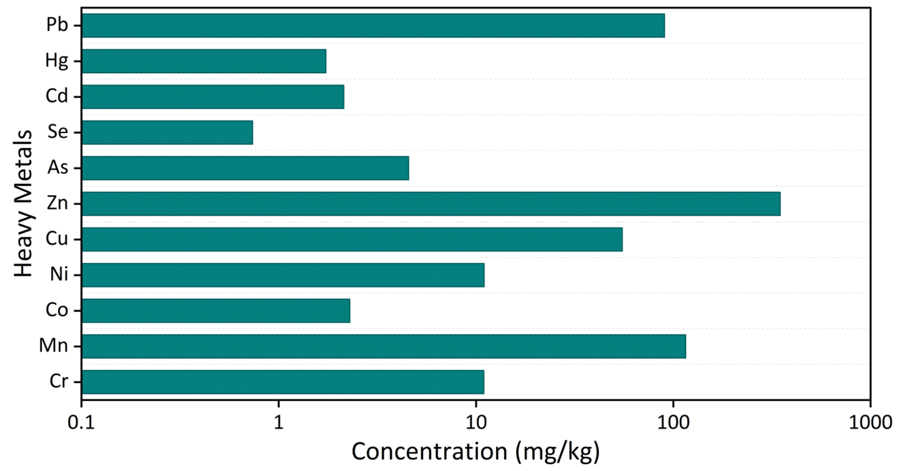


Fig. 3: Concentrations of analyzed HMs (mg/kg).

Health Risk

- Non-carcinogenic risk values for all HMs are below 1, indicating no immediate adverse effects for children or adults (Fig.4a).
- Carcinogenic risk for Cr, Ni, and As exceed the negligible risk level (10^{-6}), while Cd and Pb pose no substantial carcinogenic risk (Fig. 4b).

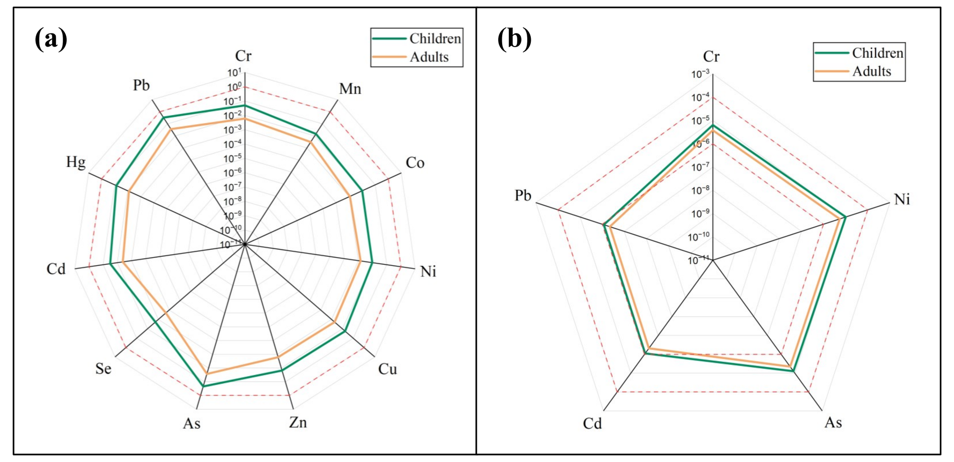


Fig. 4: Non-carcinogenic risk (a) and cancer risks (b) from HMs exposure in child and adult cohorts.

- Oral ingestion is the dominant exposure route, with children having systematically higher risk (about 10× adults) due to lower body weight and hand-to-mouth behavior.

Ecological Risk

- Cd has the highest average contamination factor value of 7.12, indicating very high contamination in the urban air (Fig. 5a).
- Cd shows the most severe contamination, with 16% of samples classified as heavily contaminated and 3% as heavily to extremely contaminated. In contrast, Cr, Mn, Co, and Ni show no contamination across all samples (Fig. 5b).
- Overall ecological risk is considerable (RI = 472.86), mainly driven by Cd and Hg, both of which exhibit high ecological risk with average ecological risk values of 213.61 and 173.42, respectively (Fig. 5c).

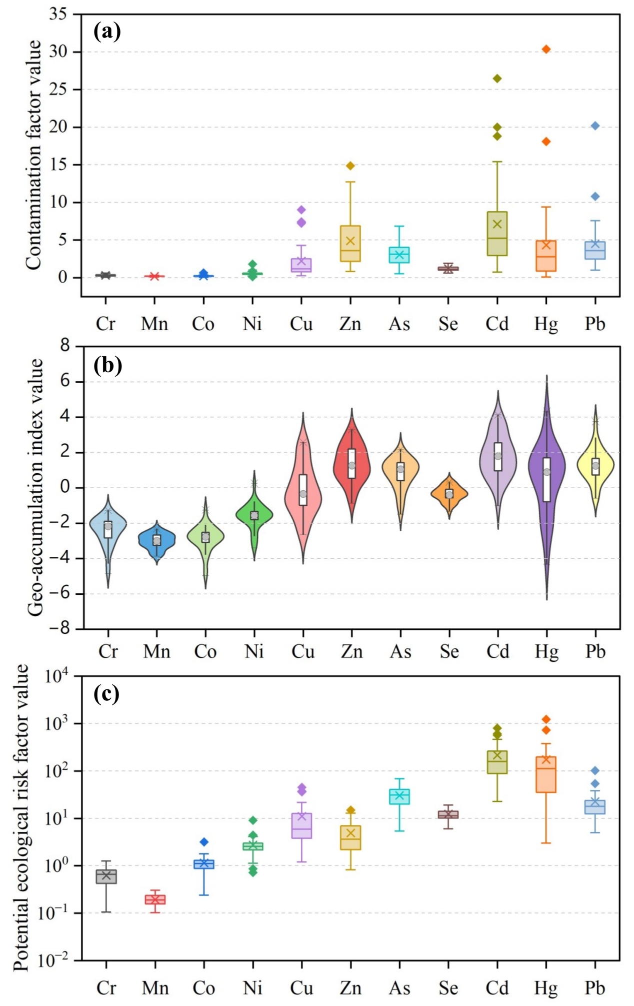


Fig. 5: Illustration of contamination factor (a) geo-accumulation index (b) and potential ecological risk factor (c) for HMs.

Source Apportionment

- Five major sources identified using Pearson correlation, PCA, and PMF together, five distinct HM sources in CAF dust were reliably resolved for Dhaka (Fig. 6a, 6b, and 7).

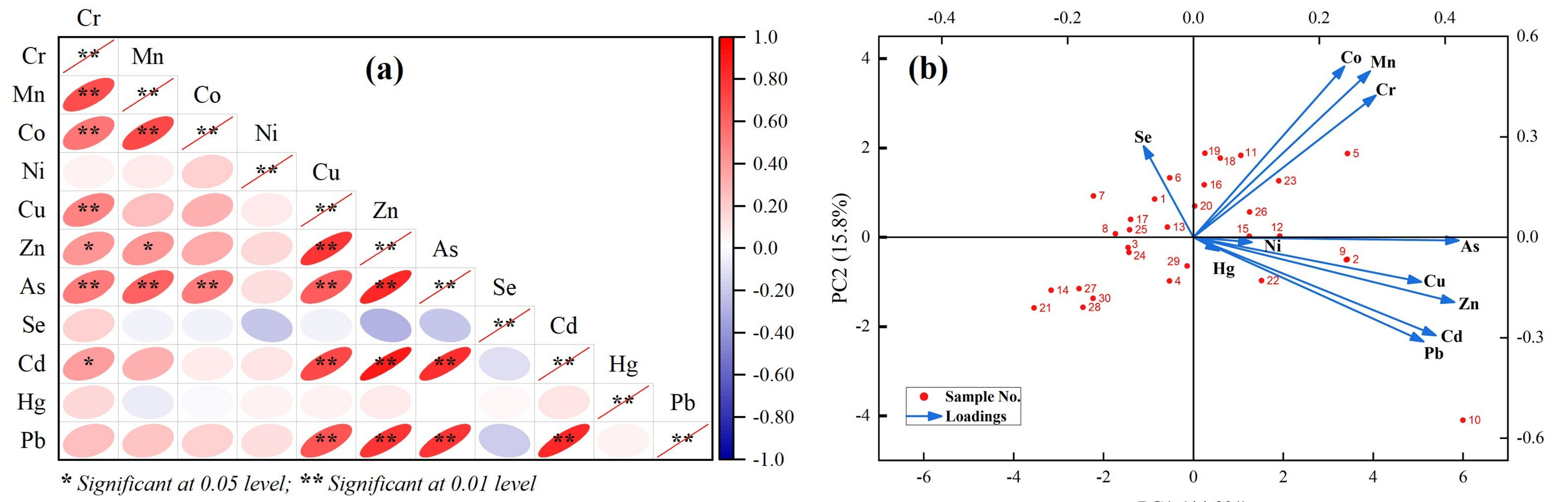
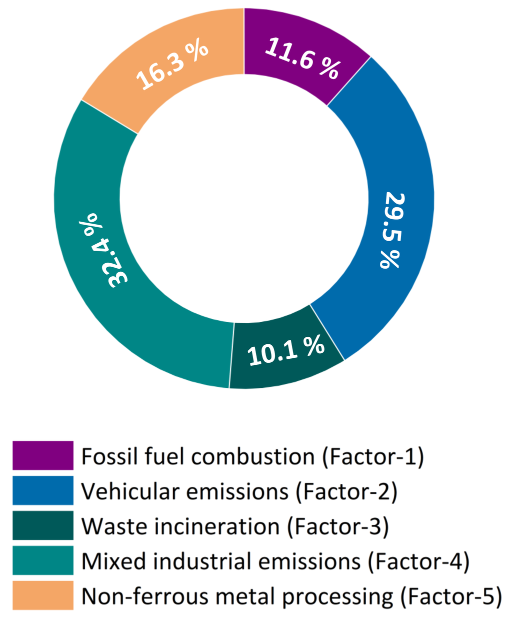


Fig. 6: Pearson correlation matrix (a) and PCA biplot (b) for analyzed HMs.

- Factor 1 (Se 52.2%): Low-grade coal combustion in brick kilns surrounding Dhaka, a major point source of Se-enriched particulates.[1]
- Factor 2 (Zn 47%, As 33.7%, Cd 61.6%, and Pb 51.4%): Mixed exhaust and non-exhaust sources (tire wear, brake wear, battery-operated rickshaws).
- Factor 3 (Hg 83.3%): Municipal/medical waste incineration and waste-to-energy plants in Aminbazar, Matuail, and Narayanganj.[6]
- Factor 4 (Cr 58.7%, Mn 53.5%, Co 69.5%, Ni 53.8%, and As 47.6%): Ferroalloy production, tanneries, informal e-waste/ battery recycling, and electroplating.
- Factor 5 (Cu 74.6%, Zn 22.9%, and Cd 20.4%): Brass recycling, electroplating, and metal finishing workshops.



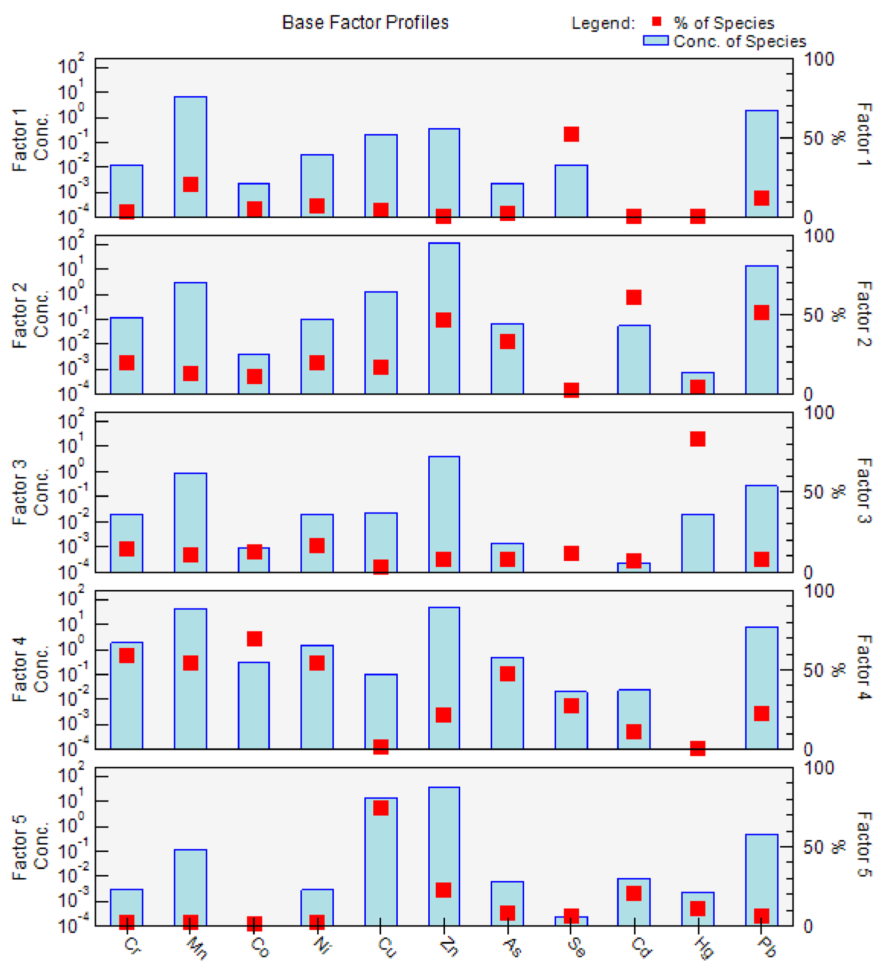


Fig. 7: Factor contribution profile for each HMs.

Conclusion

- CAF dust successfully served as a low-cost, semi-quantitative active air sampler, capturing spatial and long-term HM pollution in Dhaka.
- Non-carcinogenic risk and carcinogenic risks for Cr, Ni, and As are below USEPA thresholds. Children are more vulnerable, with ingestion as the main exposure route.
- Cd and Hg drive considerable overall ecological risk (R_I = 472.86), with very high contamination factor for Cd.
- Integrated modeling revealed five pollution sources: industrial emissions, coal combustion (brick kilns), waste incineration, vehicular wear/exhaust, and non-ferrous metal processing.

Future Research

- Cross-calibrate CAF dust with standardized active air samplers.
- Target high-traffic corridors and industrial zones.
- Investigate synergistic toxic effects.

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