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RESEARCH ARTICLE

Chemical Profiling of Street Dust in Kathmandu Valley: A Preliminary Environmental Assessment

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Abstract

Street dust in urban agglomerations serves as a sink and secondary source of environmental contaminants, primarily in rapidly growing urban agglomerations. This first-time study investigates the chemical properties and concentration of heavy metal in street dust samples collected from six representative sites in Kathmandu Valley, Nepal. The dust samples were analyzed for pH, electrical conductivity (EC), bicarbonate presence, organic functional groups, and concentrations of heavy metals (Zn, Pb, Cd) using standardized techniques like Fourier Transform Infrared Spectroscopy (FTIR) and Atomic Absorption Spectroscopy (AAS). Results ranged consistently alkaline pH (7.2–8.05), varying EC concentrations (0.397×10^{-6} to 0.75×10^{-3} S/cm), and bicarbonate ion presence at specific sites. FTIR analysis showed the presence of major organic pollutants like alkanes, aromatic hydrocarbons, and halogenated compounds that reflect diverse anthropogenic sources. AAS analysis showed zinc as the dominant heavy metal (avg. >250 mg/kg), followed by lead (~180 mg/kg) and cadmium (~20 mg/kg), with highly significant spatial variation attributed to land-use category. Comparison to global urban dust standards ranks Kathmandu as one of the more polluted capital cities, pointing to immense deficiencies in environmental regulation and urban planning. The findings provide required baseline data to guide pollution monitoring and suggest pressing needs for targeted mitigation action to protect public and environmental health.

Keywords: Kathmandu Valley; Street dust; Chemical properties; Heavy metals; Environmental risk.

Introduction

Heavy metals are naturally occurring elements with relatively high atomic masses and densities, typically defined as having a specific gravity greater than five. While there is no universal definition, metals such as mercury, cadmium, lead, nickel, chromium, and silver are commonly categorized as heavy metals. These elements, though often present in trace amounts in the Earth's crust, pose significant environmental and health risks due to their toxicity, persistence, and tendency to bio accumulate [1]. Once released into the environment, heavy metals cannot be degraded and can enter the human body through ingestion, inhalation, or dermal contact. Some of them are essential micronutrients at trace levels, but many become hazardous at higher concentrations, disrupting biological functions and causing acute or chronic illnesses [2].

In urban environments, road dust acts both as a sink and a secondary source of heavy metals, accumulating pollutants from vehicular exhausts, industrial discharges, construction activities, and waste incineration [3], [4], [5]. Current studies in Nepal have begun to focus on the characteristics and degree of contamination of street dust in urban zones [1]. Neupane et. al. studied heavy metal street dust contamination in Kathmandu and identified vehicular exhausts and industrial operations as the primary sources of pollution and highlighted associated health risks [7]. Sharma et. al. explained seasonal variation in dust content, showing how monsoon and dry seasons influence particulate matter concentration and distribution. Similarly, Pandey R. has conducted morphological and chemical analyses of street dust particles from various sites in Kathmandu Valley, with strong correlation between traffic flow and heavy metal levels, attributing the anthropogenic nature of pollution [8]. Taken together, these works are informative but also indicate the need for ongoing, large-scale, and current monitoring in rapidly expanding urban areas.

Once deposited on impervious surfaces, these particles can be re-suspended into the air, contributing to poor air quality and facilitating human exposure. Street dust has long been considered a reliable indicator of urban heavy metal contamination. Inhalation of contaminated dust is particularly concerned for people living or working near busy roads. Additionally, through rainfall and surface runoff, heavy metals in dust can leach into soil and water bodies, entering the food chain and posing long-term ecological risks [9].

Kathmandu Valley, located in northeastern Nepal at an elevation of 1350 meters, has evolved into one of the country's most densely populated and urbanized regions [10]. Historically a crossroads for trans-Himalayan trade, the valley now faces critical environmental challenges due to unregulated urban expansion, aging transportation infrastructure, and weak enforcement of pollution control measures. The population density in core urban areas exceeds 6,000 persons per km^2, with vehicular emissions emerging as a major contributor to air pollution. High traffic volumes, outdated vehicles, substandard fuels, and the delayed adoption of emission standards have all exacerbated the city's environmental burden. For instance, the $PM_{2.5}/PM_{10}$ ratio of 0.64 and an average PM_{10} concentration of 198 µg/m^3 in 2002–2003 reflect severe air quality deterioration [11].

However, there is still a lack of recent, site-specific, and comprehensive studies in Kathmandu that combine both chemical composition and health risk perspectives. Earlier research has focused on either limited locations or lacked advanced analytical techniques like FTIR and AAS in combination. Despite extensive research in developed nations on heavy metal contamination in urban environments, similar assessments in developing regions such as Nepal remain limited [12], [13], [5]. There is a key knowledge gap in defining the total chemical composition of Kathmandu Street dust-especially in the context of accelerating urbanization, deteriorating infrastructure, and growing vehicular emissions. In the absence of current, site-specific information, policymakers lack the evidence on which to base site-specific interventions and emission-reducing strategies. This study is needed to fill this loophole by employing the use of the combination of FTIR and AAS to attain a deeper understanding of what Kathmandu urban areas' dust is made of. Outcomes will aid policymakers in determining the sources of pollution and establishing priorities for public health interventions. Therefore, the present study aims to fill this gap by analyzing street dust collected from six distinct urban sites in Kathmandu Valley. The research utilizes Fourier Transform Infrared Spectroscopy (FTIR) to identify organic functional groups and Atomic Absorption Spectroscopy (AAS) to quantify the concentrations of heavy metals (Zn, Pb, Cd). Complementary measurements of pH, electrical conductivity, and bicarbonate levels are also conducted to assess the chemical environment of the dust. The findings are expected to offer valuable baseline data for environmental managers, policy-makers, and public health officials concerned with pollution control and risk mitigation in Nepal's rapidly urbanizing regions.

Materials and Methods

Kathmandu Valley, situated in the central part of Nepal, comprises three districts: Kathmandu, Bhaktapur, and Lalitpur [10]. Covering an area of approximately 650 km², the valley has an average elevation of 1350 meters above sea level. It is encircled by hills such as Shivapuri to the north, Phulchoki to the southeast, Nagarjun to the northwest, and Chandragiri to the southwest (**Figure 1**). The central portion of the valley features relatively flat terrain, while the Bagmati River and its tributaries contribute to rich vegetation and influence the local climate.

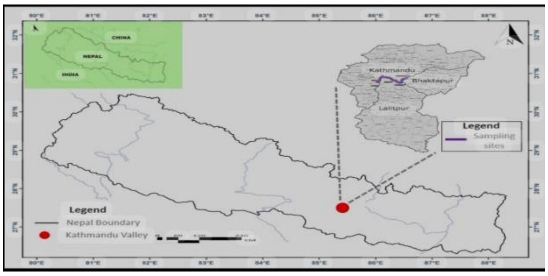

Figure 1: Adapted location map of the study area (Kathmandu Valley, Nepal). Source: Adapted from Silwal et al. (2020), CC BY-SA 4.0.

In this study, a total of six street dust samples were collected from various urban locations across Kathmandu Valley. Sampling was carried out during daytime under moderate weather conditions to minimize the possibility of rainwater washing away heavy metals, ensuring the integrity of the samples. Dust particles were collected from the surfaces of roadside advertising hoarding boards, which are effective accumulators of airborne particulate matter [14], [15]. The six selected sampling sites represent areas of high population density and vehicular activity: Narayangopal Chowk, Balaju, Ascol Campus, Ratnapark, Kalimati, and Lazimpat (**Table 1**). These locations were chosen to provide a representative overview of urban dust pollution across different functional zones within the valley.

Table 1: Description of sampling sites of Kathmandu district.

Sampling sites	Location Type	Coordinates (Latitude, Longitude)	Surrounding Features
Narayangopal Chowk	Residential-Commercial	27.7340°N 85.3214°E	Residential housing
Balaju	Industrial	27.7301°N 85.3031°E	Industries, Workshops, main road
Ascol Campus	Institutional	27.7130°N 85.3175°E	Educational zone
Ratnapark	Urban Commercial	27.7060°N 85.3158°E	Bus hub, dense human flow
Kalimati	Market-Residential	27.6945°N 85.2901°E	Vegetable market, river nearby
Lazimpat	High-end Residential	27.7272°N 85.3212°E	Hotels, embassies, main road

Analysis of dust particles

The street dust collected from the test locations was air-dried and then passed through a sieve using a 250µm stainless steel mesh to remove pebbles, leaves, and other debris. After sieving, the dust samples were stored in labeled zip-lock plastic bags for later analysis and use. Some of the chemical parameters measured included electrical conductivity (EC) and pH.

Instrumentation and Metal Detection Method

Heavy metal (Zn, Pb, Cd) concentrations were determined using Atomic Absorption Spectroscopy (AAS), a widely used and accepted method for trace metal quantification. Determination was done at the Nepal Academy of Science and Technology (NAST), Khumaltar, Lalitpur, using a PerkinElmer AAnalyst 400, air-acetylene flame atomizer.

The wavelengths used for detection were: Zn (213.9 nm), Pb (217.0 nm), and Cd (228.8 nm). The calibration was carried out using certified standard solutions, and the analysis was done in triplicate for every sample to ensure precision. The detection limits of the metals were: Zn = 0.01 mg/kg, Pb = 0.02 mg/kg, Cd = 0.005 mg/kg.

Determination of pH and EC

The EC and pH of the dust samples were measured using 1:5 dust-to-water suspensions, following the standard procedures for testing water and wastewater (APHA, 1995), with necessary adjustments. For each measurement, 20 g of dust was weighed and mixed with 100 mL of distilled water in a beaker. The mixture was stirred for one hour using a magnetic stirrer. The pH of the unfiltered suspension was measured using a glass electrode digital pH meter, while the electrical conductivity (EC) was measured using a digital conductivity meter [16]. Both instruments were calibrated according to their respective user manuals before recording the pH and EC values.

Heavy metal Digestion and AAS Analysis

The concentration of heavy metals in the dust samples was determined following a standard protocol [17]. A mixture of 10 mL of 1:1 nitric acid (HNO_3) and 5 g of sieved dust particles was prepared to form a slurry, which was then covered with a watch glass [18]. The sample was heated to approximately 95°C, allowed to cool slightly, and then 5 mL of concentrated HNO_3 was added. The mixture was reheated for about 10 minutes and allowed to evaporate until the volume was reduced to approximately 5 mL. Subsequently, 1 mL of hydrogen peroxide (H_2O_2) was added, followed by 30 mL of distilled water. After cooling to room temperature, the solution was filtered, and 25 mL of the filtrate was collected in a clean vial for further analysis.

FTIR analysis

Fourier Transform Infrared Spectroscopy (FTIR) to find organic functional groups in dust samples. The analysis was done at Department of Chemistry, Amrit Campus, and Tribhuvan University using Shimadzu IRTracer-100 FTIR spectrometer. Spectra were recorded in the range 4000–400 cm^{-1} at 4 cm^{-1} resolution using the KBr pellet method. All spectra were recorded at a scan speed of 2 mm/s, 32 scans averaged, and referenced to a background spectrum obtained from a blank KBr pellet.

Approximately 1 mg of finely powdered dust was mixed with 100 mg of KBr of spectroscopic quality, pelletized, and scanned. Intense absorption bands were found by comparison to standard reference spectra from observed peaks.

Quality Assurance and Quality Control (QA/QC)

To ensure data accuracy and reliability, quality control steps were implemented during the entire analytical process. In the case of Atomic Absorption Spectroscopy (AAS), analysis was triply performed for every sample, and the equipment was calibrated with certified standard solutions. Certified Reference Materials (CRMs), procedural blanks, and replicated samples were present in all analytical batches. Recovery levels of CRMs were within ±5% of the certified values, while blank results were extremely low, reflecting minimal contamination and high analytical accuracy.

Results and Discussion

Site-wise Comparison of pH and Electrical Conductivity in Street Dust of Kathmandu Valley

The comparative values of pH and electrical conductivity (EC) are presented in **Table 2**. The pH of street dust samples collected from various locations within the Kathmandu Valley consistently showed an alkaline nature, ranging from 7.2 to 8.05. The sample from Ascol Campus exhibited the highest pH (8.05), indicating a strongly alkaline condition, whereas the sample from Balaju had the lowest pH (7.2), which still falls within a slightly basic range. The remaining locations—Lazimpat, Narayangopal Chowk, and Kalimati—also displayed moderate alkalinity.

Table 2: Site-wise Comparison of p^H and Electrical Conductivity in Street Dust of Kathmandu Valley.

Sampling site	pH value	Electrical Conductivity (S/cm)
Balaju	7.2	0.75 × 10-3
Lazimpat	7.76	0.370 × 10-3
Narayangopal Chowk	7.9	0.544 × 10-3
Ascol Campus	8.05	0.587 × 10-3
Ratnapark	7.58	0.677 × 10-3
Kalimati	7.86	0.397 × 10-3

This alkaline nature can likely be attributed to the presence of bicarbonate and carbonate salts, possibly originating from construction materials, road dust, and debris from old infrastructure, as supported by previous studies [19], [20], [17], [21]. The EC values of the dust samples varied from 0.397×10^{-6} S/cm (Kalimati) to 0.75×10^{-3} S/cm (Balaju), reflecting differences in the ionic content across locations. The highest EC value at Balaju indicates a greater presence of dissolved ions or conductive substances, possibly resulting from industrial activities or vehicular emissions [22]. In contrast, the low EC at Kalimati suggests minimal ionic content, indicating relatively cleaner conditions or lower anthropogenic impact. Together, the pH and EC measurements provide meaningful insights into the chemical properties of street dust and their potential environmental implications.

Bicarbonate and Carbonate Test

The bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions in the street dust samples were detected by a routine acid-base titration method, following the APHA (1995) guidelines outlined. A 1:5 dust suspension in water was prepared by placing 20 g of dust in 100 mL of distilled water. The mixture was shaken for an hour and filtered. The filtrate was first titrated using 0.02 N sulfuric acid (H_2SO_4) in the presence of an indicator phenolphthalein to test for the existence of carbonate ions. When no color shift was observed, methyl orange was added and titration was resumed to find bicarbonate ions. Solution that is methyl orange color-changed but phenolphthalein color-changed was presumed to have only bicarbonate ions. All the titrations were carried out in duplicate for duplication (APHA, 1995). The values of bicarbonate and carbonate ions present in the samples are shown in **Table 3**. All the samples tested negative for carbonate ions, indicating their absence. These results help in understanding the variation in bicarbonate ion concentrations across different sampling locations.

Table 3: Bicarbonate tests of different samples.

Sample Location	Bicarbonate value
1. Balaju	0.4
2. Lazimpat	2.4
3. Narayangopal Chowk	1.6
4. Ratnapark	0.2

The sample from Lazimpat showed the highest concentration of bicarbonate ions, while Balaju exhibited the lowest. Samples from Ascol Campus and Kalimati did not show a positive test for bicarbonate, suggesting negligible or undetectable levels of bicarbonate ions [23].

FT-IR Analysis

Fourier Transform Infrared Spectroscopy (FTIR) was employed to identify the organic functional groups present in street dust samples collected from six urban sites in Kathmandu Valley. The FTIR spectra (**Figure 2**) and corresponding wavenumber assignments (**Table 4**) revealed several characteristic functional groups. Strong absorption bands in the range of 2854–2926 cm^{-1}, particularly in samples from Lazimpat, Narayangopal Chowk, and Ascol Campus, were attributed to C–H stretching vibrations in alkanes or alkyl groups, indicating the presence of saturated hydrocarbons. Peaks around 1433, 1018, and 1002 cm^{-1} were associated with alkenes and aromatic compounds, while out-of-plane C–H bending typical of aromatic systems appeared near 778–777 cm^{-1}.

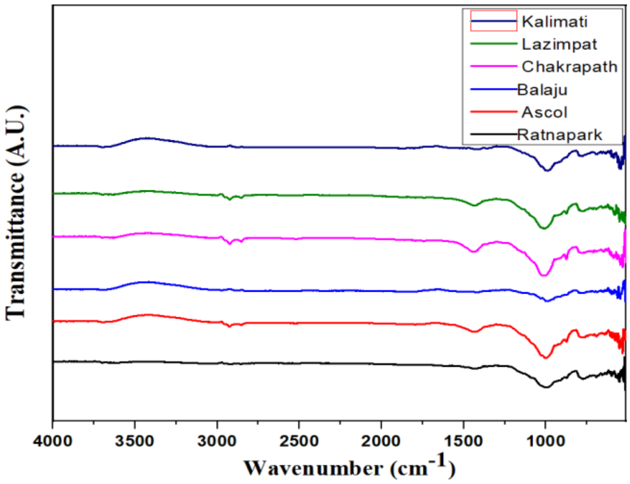

Figure 2: FTIR analysis showing characteristic peaks of organic functional groups in street dust samples from sampling sites.

Table 4: Identified FTIR absorption bands and corresponding functional groups detected in dust samples from six locations in Kathmandu Valley.

Area	Frequency range (cm^{-1})	Functional group
Kalimati	i. 990.07 cm^{-1} ii. 777.27 cm^{-1} iii. 588.93 cm^{-1} iv. 563.04 cm^{-1} v. 532.66 cm^{-1}	Alkanes or cyclic hydrocarbons, Aromatic compounds or substituted aromatic system.
Lazimpat	vi. 2856.5 cm^{-1} vii. 2926 cm^{-1} viii. 1433.78 cm^{-1} ix. 1007.89 cm^{-1} x. 778.12 cm^{-1}	Alkanes or alkyl group, Alkenes or aromatic compounds.
Narayangopal Chowk	xi. 2854 cm^{-1} xii. 2924 cm^{-1} xiii. 1433.98 cm^{-1} xiv. 1018.24 cm^{-1} xv. 878.66 cm^{-1} xvi. 588.64 cm^{-1}	Alkanes or alkyl group, Alkenes or aromatic compounds, Bromine atom.
Balaju	xvii. 990.68 cm^{-1} xviii. 563.40 cm^{-1} xix. 548.24 cm^{-1}	Alkanes or cyclic hydrocarbons, Aromatic compounds or substituted aromatic system.
Ascol Campus	xx. 2856 cm^{-1} xxi. 2925 cm^{-1} xxii. 1432.40 cm^{-1} xxiii. 1002.74 cm^{-1} xxiv. 875 cm^{-1} xxv.778.61 cm^{-1}	Alkanes or alkyl group, Alkenes or aromatic compounds.
Ratnapark	xxvi. 1432.1 cm^{-1} xxvii. 1002.83 cm^{-1} xxviii. 774.24 cm^{-1} xxix. 541.14 cm^{-1}	Alkenes, Alkanes, Aromatic compounds, Bromine atom.

Moreover, weak absorptions in the 500–600 cm^{-1} region such as 588.64 cm^{-1} in Narayangopal Chowk and 541.14 cm^{-1} in Ratnapark were indicative of halogen-containing compounds, possibly brominated organics. Functional group assignments were supported by standard IR spectral databases and previous literature [24]. Since, calibration standards were not used, the analysis remained qualitative, focusing solely on the presence and relative intensity of the observed peaks.

AAS analysis

The total concentrations of heavy metals in the bulk street dust samples were assessed across six different land-use types in the Kathmandu Valley, as presented in **Table 5**. Based on the findings, the metal contents at all locations were arranged according to their relative abundance. The experimental results revealed the following order of metal concentration: Zn > Pb > Cd (**Figure 3**). Among these, Zinc (Zn) exhibited the highest concentration, while cadmium (Cd) showed the lowest. This distribution also suggests that Zn has the highest mobility, whereas Cd is the least mobile under the given environmental condition. [2]

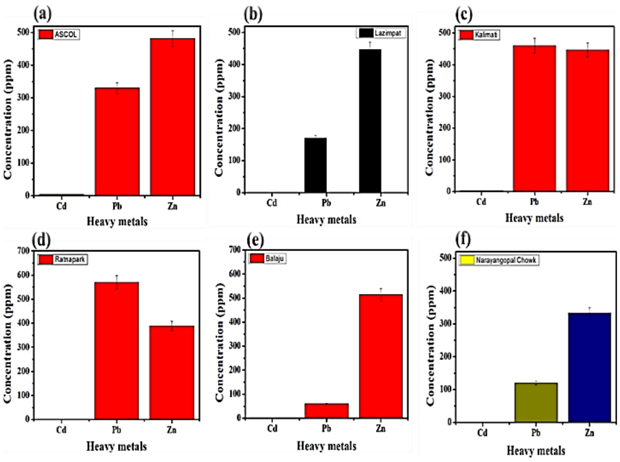

Figure 3: Concentration of different heavy metals present in the sampling sites of Kathmandu.

Among the measured heavy metals, cadmium showed the lowest concentration, while lead and zinc exhibited comparatively higher and closely rivaling concentrations. The significantly elevated levels of lead may be attributed to emissions from vehicles and other anthropogenic sources [26], [27].The graphical representation of heavy metal concentrations in the studied areas is presented in **Figure 5**. The complete diagrammatical representation of measured heavy metal in air of measured place and image shows that the concentrations of lead (II) and zinc (II) are high which is shown in **Figure 4.**

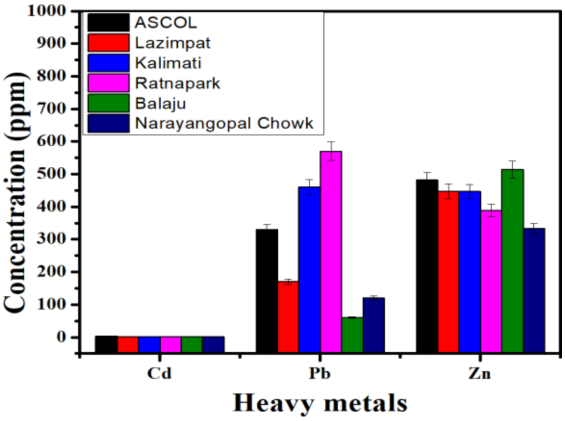

Figure 4: Concentration of heavy metals in different parts of Kathmandu valley.

Table 5. Concentration of heavy metals (Cd, Pb, Zn).

Samples	Ascol Campus	Lazimpat	Kalimati	Ratnaprk	Balaju	Narayangopal Chowk	Mean value
Unit →	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
Cd	3.8	1.6	2.5	1.1	2.1	1.1	2.03
Pb	330	170	460	570	60	120	285
Zn	481.7	447.5	446.7	389.1	514.5	333.4	435.483

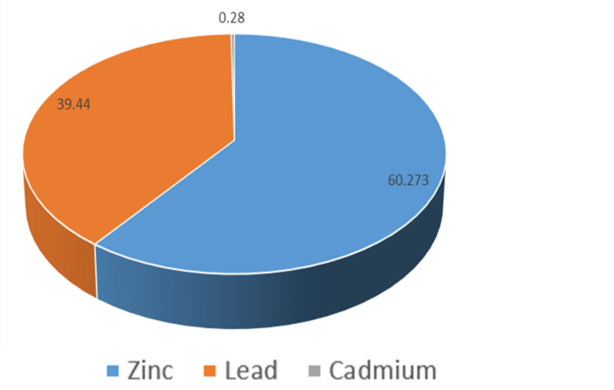

Figure 5: Proportional representation of the average concentrations of heavy metals (Zn, Pb, Cd) in Kathmandu street dusts sample.

The graphical representation (pie chart) in **Figure 5** illustrates the relative concentrations of various heavy metals present in street dust samples collected from different locations across Kathmandu.

Table 6 World Health Organization (WHO) recommended maximum permissible limits for selected heavy metals in urban environment along with their associated human health.

Elements	WHO maximum permissible values (mg/kg)	Effects
Lead (Pb)	0.3	Lead poisoning, brain and kidney damage, reproductive problem etc.
Nickel (Ni)	67.9	Skin allergies, Lung irritation, Cancer risk
Copper (Cu)	73.3	Liver damage, Vomiting, Diarrhea
Cadmium (Cd)	0.2	Kidney and Lung damage, cancer risks, Digestive and Reproductive issues etc.

Table 7. Comparing the average of all the identified land uses in the Kathmandu district to the street dust concentration of some heavy metals (mg/kg) in other cities of the world [30].

Countries	Cd	Pb	Zn	Reference
Kathmandu, Nepal	2.03	285	435.483	Current study
Delhi, India	2.65	120.7	284.5	Suryawanshi et al. (2016)
Birmingham, UK	1.62	48	534	Charlesworth et al. (2003)
Hongkong	3.77	181	1450	Li et al. (2001)
Seoul, South Korea	3	245	296	Chon et al. (1995)
Calcutta, India	3.12	536	159	Chatterjee and Banergee et al. (1999)

The data highlights the predominant presence of specific metals, emphasizing the need for environmental monitoring and pollution management in urban areas. These findings are compared with those from other major cities around the world. Although the experiments were conducted at different times, a comparison is made in this study [28], [29]. No statistical weighting or error analysis was performed. According to World Health Organization (WHO) recommended maximum permissible limits for selected heavy metals in urban environment along with their associated human health (**Table 6**). Therefore, the chart serves as a qualitative indicator of metal dominance, not a statistically derived distribution. Moreover, **Table 7** presents the average concentrations of selected heavy metals (mg/kg) in street dust from various land uses in the Kathmandu district alongside those reported in other cities worldwide. As reported in **Table 7**, mean Zn and Pb levels in Kathmandu street dust are higher than those recorded in cities like Seoul (Chon, 1995) and are comparable with those reported in highly polluted urban areas like Delhi and Calcutta. This shows that Kathmandu is carrying a significant vehicle and industrial pollution load despite its relatively small urban footprint.

Conclusion

This study presents a comprehensive analysis of street dust collected from six distinct urban sites within Kathmandu Valley in 2081 BS (2024 AD), focusing on their physicochemical properties and heavy metal contamination. The pH values of the dust suspensions reveal consistently alkaline characteristics, ranging from 7.2 (Balaju) to 8.05 (Ascol Campus), suggesting the influence of bicarbonate ions possibly originating from construction residues and road surface materials. Electrical conductivity measurements varied significantly between sites—from 0.397×10^{-6} S/cm in Kalimati to 0.75×10^{-3} S/cm in Balaju—reflecting differential ionic loads likely due to local anthropogenic activity. FT-IR spectral data confirmed the presence of alkanes (C–H stretching at 2854–2926 cm^{-1}), aromatic compounds (700–1000 cm^{-1}), and occasional traces of brominated compounds (500–600 cm^{-1}), pointing to diverse organic pollutant sources such as traffic emissions and urban waste. Atomic Absorption Spectroscopy (AAS) revealed that among the analyzed heavy metals, zinc exhibited the highest concentrations, with average values exceeding 250 mg/kg across sites, followed by lead (~180 mg/kg) and cadmium (~20 mg/kg). These concentrations varied with land use, underscoring the influence of traffic density, industrial activities, and waste accumulation patterns. The findings highlight the complex chemical profile of Kathmandu's urban dust and provide a crucial baseline for environmental monitoring, pollution source identification, and the formulation of effective mitigation policies.

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Author's Contribution Statement

B. Karki: Methodology, Investigation, Formal analysis, Data curation, Writing-original draft preparation **M. R. Kandel:** Conceptualization, Data curation, Writing-original draft, Writing-review and Editing **M. Ghimire:** Formal analysis, **L. N. Kandel:** Formal analysis **S. Khanal:** Writing-review and editing**, D. P. Bhattarai:** Conceptualization, Resources, Supervision, Project handling.

Conflicts of Interest: The authors declare no conflict of interest.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding authors upon reasonable request

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