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Changqing Shan
Shandong University of Aeronautics
Jinfang Sun
Binzhou Polytechnic University
Ronghua Jiang
Shandong University of Aeronautics
Qian Zhu
Shandong University of Aeronautics
Jinghao Zhang
China Mobile Communications Group Shandong Co., Ltd
Jiangyan Chen
Binzhou Ecological Environment Monitoring Center of Shandong Province
Jiqiang Zhang
Shandong University of Aeronautics
Ping Liu
Shandong University of Aeronautics
Chaoyue Wang
Shandong University of Aeronautics
Yu Tang
Shandong University of Aeronautics
Xingchao Qi
Shandong University of Aeronautics
Zaiwang Zhang
zhangzw@sdua.edu.cn

Shandong University of Aeronautics

Article

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Heavy Metal Pollution Characteristics in Campus Dust from Vocational and Comprehensive Universities in a Developing City, East China

Changqing Shan[1], Jinfang Sun[2], Ronghua Jiang[1], Qian Zhu[1], Jinghao Zhang[3], Jiangyan Chen[4], Jiqiang Zhang[1], Ping Liu[1], Chaoyue Wang[1], Yu Tang[1], Xingchao Qi[1,*], Zaiwang Zhang[1,*]

1.Shandong Key Laboratory of Eco-Environmental Science for the Yellow River Delta, Shandong University of Aeronautics, Binzhou 256603, China；

2.College of Architecture Engineering, Binzhou Polytechnic University, Binzhou 256603,China;

3.China Mobile Communications Group Shandong Co., Ltd, Jinan, 250001, China;

4.Binzhou Ecological Environment Monitoring Center of Shandong Province, Binzhou, 256600, China.

* Correspondence: Qi X, qixingchao90@163.com; zhangzw@sdua.edu.cn

Abstract: Dust samples from indoor environments and outdoor roads on campuses of a vocational university (University A) and a comprehensive university (University B) in East China were collected and determined for heavy metals to investigate the pollution characteristics, sources, and potential risks of these elements. Similar variation patterns in heavy metal content were available for both indoor and outdoor dust samples, with great amounts of Zn and Mn, low levels of As and Cd, and comparable concentrations of Pb, Cu, Cr, and Ni. Concentrations of Zn, Pb, Cu and Cd in dust were observed frequently exceeding corresponding soil background values. Heavy metal concentrations were in low to mediate levels comparing with results from some other universities at different regions. Zn in indoor dust and of concentrations of Zn and Pb in outdoor dust at University A were observed significantly higher than those at University B. At each campus, contents of several elements in indoor dust varied among different functional zones. Correlation analysis and PCA results tended to suggest that in indoor dust, these elements might mainly originated from natural sources, vehicle exhaust and building paint weathering. In outdoor dust, these elements possibly mainly originated from natural sources, vehicle exhaust, tire wear, and road construction materials. The geoaccumulation index (I_{geo}) values indicated that As, Pb, Cr, Ni, and Mn in indoor dust from the two universities were both unpolluted, whereas Cu and Cd were slightly polluted, and Zn were moderately polluted. In outdoor dust, As, Cu, Cr, Ni, and Mn from University A and As, Pb, Cu, Cr, Ni, and Mn from University B were unpolluted, whereas Zn, Pb, and Cd from University A and Zn and Cd from University B were slightly polluted. Health risk assessment results showed that heavy metals in campus dust posed no non-carcinogenic/carcinogenic health risks to teaching staff and students. Relatively elevated Cu and Zn tended to be the key elements characterization the pollution pattern of vocational university.

Keywords: university dust; heavy metals; sources; risk assessment; comparative study

Introduction

Heavy metals, characterized by high density (>4.5 g/cm^3), persistence, and bioaccumulation are ubiquitous in the environment, and continuously migrate and transform in the environment [1-3]. They are toxic and harmful pollutants affecting ecological security and human health [4-6]. As, Cd, Cr, and Ni are all carcinogenic [7-9]. Excessive intake of Cu and Zn can significantly affect human liver, kidney, digestive system, and brain [10]. Monitoring heavy metal pollution in environmental matrices is always a crucial task in environmental management.

Urban dust is an important carrier of varieties of pollutants including heavy metals. Pollutants in dust can be transported to water, soil, and air through surface runoff and wind action, affecting urban environmental quality [11]; and they can enter the human body through ingestion, inhalation, and dermal contact [12-15], causing adverse health effects. Heavy metal pollution in dust exists in various micro-environments such as urban roads [16], households [17-18], subways [19-20],classrooms [21], and offices [22], directly or indirectly threatening public health.

University campuses are densely populated functional zones in cities. In the campus, faculty, staff, and students, along with service personnel, reside, study, and work for long periods. A large number of people circulate among functional zones on campus such as roads, dormitories, classrooms, cafeterias, and libraries encountering different dust exposure conditions on a daily basis. Dust can enter the human body through multiple pathways, and the heavy metals therein may affect the health of teachers and students [21-23]. Currently, heavy metal pollution in campus dust has been given increasing concerns and related studies mainly focus on comprehensive universities [24-26]. Comprehensive universities commonly feature a broad spectrum of academic disciplines spanning science, engineering, and humanities and social sciences[24]. In contrast, vocational schools are oriented toward skill cultivation, with curricula closely aligned with industrial demands [21]. Elevated training processes may generate heavy metal emissions that subsequently deposit and accumulate in both indoor and outdoor settings in the campus of the vocational universities resulting in different heavy metal pollution pattern comparing with the comprehensive ones. However, research on vocational colleges primarily focused on skill-based talent cultivation remains relatively scarce. In addition, previous investigations focusing on the metal pollution in the university campus were mainly conducted separately on either indoor dust or outdoor road dust, limiting the comprehensive assessment of human exposure risks across different functional zones within a campus environment. Conducting comparative investigations into the characteristics of heavy metal contamination in dust across different types of universities, and assessing the exposure doses and health risks faced by faculty and students under divergent educational models, carries significant theoretical and practical implications.

In this study, two different categories of universities in East China were selected as research area and dust samples from outdoor roads and different indoor zones on campus were collected. Concentrations of typical heavy metals including As, Zn, Pb, Cu, Cd, Cr, Ni, and Mn were analyzed.

The objectives were to 1) clarify the pollution characteristics of heavy metals in dusts on campus; 2) identify potential sources of those elements; and 3) evaluate associated health risks of heavy metals to faculty and students.

Materials and Methods

Study Area and Sample Collection

The study area comprised two different categories of universities located in Binzhou City, Shandong Province, East China (Fig. 1). University A is a vocational college primarily cultivating junior college students, established in 2001, with over 1,200 faculty and staff members and more than 20,000 full-time students. Its academic programs cover biological sciences, mechanical and electrical engineering, chemical engineering, medical sciences, architecture, information engineering, and so on. University B focuses on cultivating undergraduate and graduate students, with its campus inaugurated in 2002. It has over 1,200 faculty and staff members and nearly 23,000 full-time students, offering programs in aviation, ecological environment, biological sciences, mechanical and electrical engineering, chemical engineering, architecture, information engineering, and so forth. The two universities are comparable in geographical location, campus scale, student population, and academic disciplines, minimizing potential confounding from environmental background and human activity intensity. Consequently, observed differences can be reasonably attributed to institutional type rather than geographical or demographic variations.

Dust samples were collected in December 2025 when both faculty and students were on campus conducting normal work and study activities. Outdoor dust was collected from campus roads with dry surfaces and no rainfall for more than 15 consecutive days. Sampling points were evenly distributed. At each sampling point, dust within a 2 m × 8 m area was carefully swept into polyethylene scoops using clean brushes. Approximately 300 g of sample was collected and placed into polyethylene self-sealing bags. Indoor dust was collected from various functional areas including office buildings, canteens, teaching buildings, laboratory buildings, dormitories, gymnasiums, libraries, and supermarkets. Three sampling points were set in each functional area. At each sampling point, dust was collected from different floor areas using clean brushes and transferred into polyethylene self-sealing bags with polyethylene scoops. The samples from each point were mixed to serve as a representative sample for that location. All samples were brought back to the laboratory on the same day of collection. After removing large debris, the samples were passed through a 100-mesh sieve, placed into polyethylene self-sealing bags, and stored dry. A total of 24 outdoor samples and 21 indoor samples were collected from University A, while 24 outdoor samples and 24 indoor samples were collected from University B.

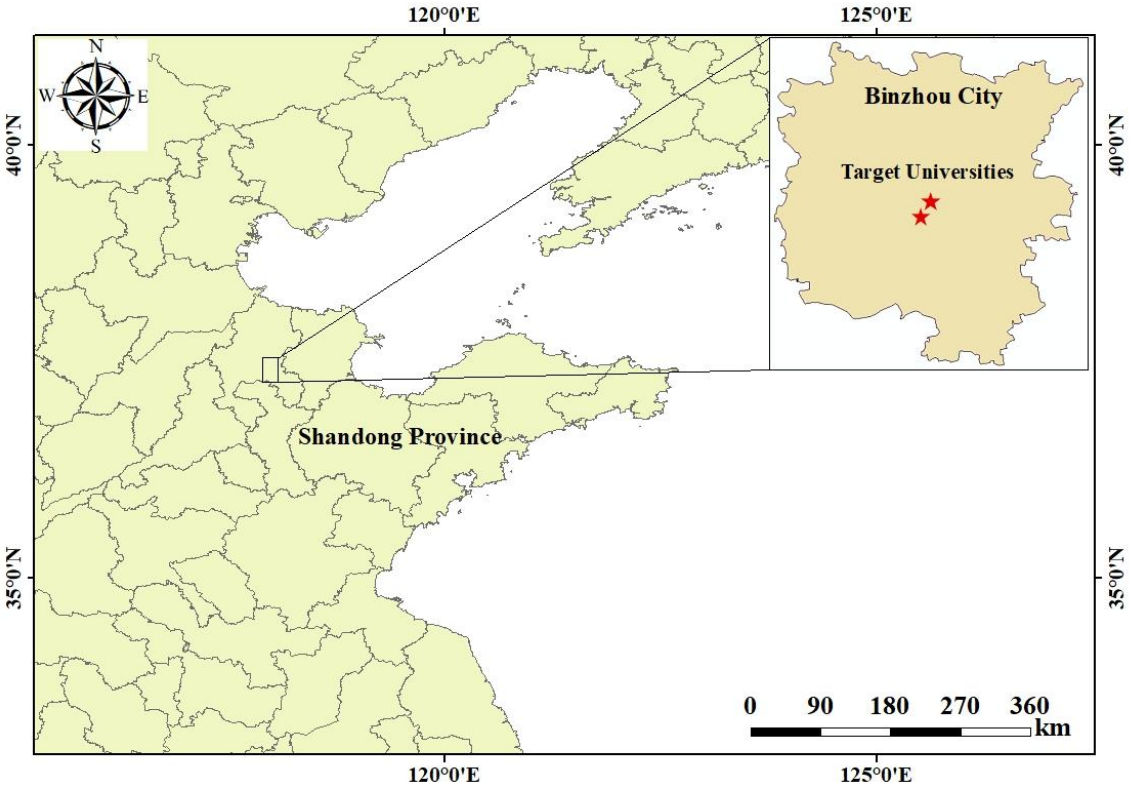


Figure 1. **Location map of study area**

Heavy Metal Determination

Dust samples were digested using an aqua regia method. Briefly, approximately 0.10 g of dust was digested with 8 mL aqua regia ($HCl:HNO_3$ = 3:1, v/v) on an electric hot plate for 2 h. The digests were filtered and diluted to 50 mL with ultrapure water, and analyzed by inductively coupled plasma-optical emission Spectrometry (ICP-OES, iCAP PRO X Duo, Thermo Fisher, Bremen, Germany). Each batch of experiments included 1 procedural blank, 3 parallel samples, and 1 reference material (ERM-S-510204). A calibration curve was constructed by plotting the response (y) against the concentration (x, mg/L). The correlation coefficient (R^2) was greater than 0.9997 (n= 8), and the linear range was 0.01–10 mg/L. The recovery rates of the metals in the reference material were 84.7%-103.4%, and the standard deviation of parallel samples was less than 5%.

Data Statistics and Analysis

Raw data were organized and calculated using WPS Office to obtain the statistical values of heavy metal contents, geo-accumulation index (I_{geo}), and human health risk assessment values. Significance tests and principal component analysis (PCA) were performed using IBM SPSS Statistics 27. One-way analysis of variance (one-way ANOVA) was employed to examine the significant differences in heavy metal contents among different indoor and outdoor environments. Pearson correlation coefficients were used to represent the correlations among heavy metals, as calculated by Origin 2024 Pro.

Heavy Metal Pollution Assessment

The pollution degree of heavy metals in dust was evaluated using the geo-accumulation index [27], calculated as follows:

$$I_{geo}=log_2\left(\frac{Ci}{1.5\times Bi}\right) \quad (1)$$

Where I_{geo} is the geo-accumulation index (I_{geo}), C_i is the measured concentration of heavy metal i, and B_i is the background value of heavy metal i of soils of Binzhou City [28]. Based on the I_{geo} value, the metal pollution degree could be divided into 7 levels (Table 1).

Table 1. Classification of metal pollution degree based on I_{geo}

Class	I_{geo} value	Pollution degree
I	≤0	No pollution
II	0-1	Slight pollution
III	1-2	Moderate pollution
IV	2-3	Moderate severe pollution
V	3-4	Severe pollution
VI	4-5	Relatively severe pollution
VII	>5	Extremely severe pollution

Human Health Risk Assessment

According to the revised health risk model of the US EPA [29-30], the daily average exposure doses of non-carcinogenic risk heavy metals were calculated as follows:

$$ADD_{ing}=\frac{C\times IR_{ing}\times EF\times ED\times CF}{BW\times AT} \quad (2)$$

$$ADD_{inh}=\frac{C\times IR_{inh}\times EF\times ED}{BW\times AT\times PEF} \quad (3)$$

$$ADD_{der}=\frac{C\times SA\times SL\times ABS\times EF\times ED\times CF}{BW\times AT} \quad (4)$$

Where ADD_{ing}, ADD_{inh}, and ADD_{der} are the daily average exposure doses ($mg\cdot kg^{-1}\cdot d^{-1}$) through ingestion, inhalation, and dermal contact, respectively; C is the heavy metal content in dust ($mg\cdot kg^{-1}$); IR_{ing} and IR_{inh} are the dust ingestion rate ($mg\cdot d^{-1}$) and inhalation rate ($m^3\cdot d^{-1}$), respectively; EF is the exposure frequency ($d\cdot a^{-1}$); ED is the exposure duration (a); BW is the average body weight (kg); AT is the average exposure time (d); PEF is the particle emission factor ($m^3\cdot kg^{-1}$); SA is the exposed skin area (cm^2); SL is the skin adherence factor ($mg\cdot cm^{-2}\cdot d^{-1}$); ABS is the dermal absorption factor (dimensionless); and CF is the conversion factor ($kg\cdot mg^{-1}$).

For carcinogenic heavy metals As, Cd, Cr, and Ni, the daily average exposure dose through inhalation was calculated as follows:

$$CADD_{inh}=\frac{C\times IR_{inh}\times EF\times ED}{BW\times AT\times PEF} \quad (5)$$

Where $CADD_{inh}$ is the daily average exposure dose through inhalation ($mg \cdot kg^{-1} \cdot d^{-1}$); AT is the average exposure time for carcinogenic risk (d); and other parameters have the same meanings as above. The parameter values in the assessment model are shown in Table 2.

Table 2. Human health risk exposure parameter values

Parameter	Unit	Value	Reference
C	$mg \cdot kg^{-1}$	Measured value	This study
IR_{ing}	$mg \cdot d^{-1}$	100	[31]
IR_{inh}	$m^3 \cdot d^{-1}$	12.8	[21,32-33]
EF	$d \cdot a^{-1}$	200	[21,26]
ED	a	University A: 3(students),24(teachers); University B: 4(students),23(teachers)	Length of schooling: 3/4 years; Established in 2001/2002
BW	kg	58.6	[24,34]
AT	d	ED×365 (non-carcinogenic), 70×365 (carcinogenic)	[35]
PEF	$m^3 \cdot kg^{-1}$	1.36×10^9	[31]
SA	cm^2	5000	[21,26]
SL	$mg \cdot cm^{-2} \cdot d^{-1}$	1	[21,26]
ABS	Dimensionless	0.03 (As), 0.001 (others)	[31]
CF	$kg \cdot mg^{-1}$	1.00×10^{-6}	[35]

The health risk of heavy metals in dust was calculated as follows:

$$HQ_i = \frac{ADD_{ij}}{RfD_{ij}} \quad (6)$$

$$HI = \sum HQ_i \quad (7)$$

$$CR = \sum R = \sum CADD_{inh} \times SF_{inh} \quad (8)$$

Where HQ_i is the non-carcinogenic health risk index of heavy metal i; HI is the total non-carcinogenic risk index; ADD_{ij} is the daily average exposure dose of non-carcinogenic heavy metal i through pathway j ($mg \cdot kg^{-1} \cdot d^{-1}$); RfD_{ij} is the reference dose of non-carcinogenic heavy metal i through pathway j ($mg \cdot kg^{-1} \cdot d^{-1}$); HI≤1 indicates no non-carcinogenic risk, while HI>1 indicates non-carcinogenic risk. CR is the comprehensive carcinogenic risk value of multiple carcinogenic heavy metals; R is the carcinogenic health risk index of heavy metal; SF_{inh} is the slope factor of carcinogenic

heavy metal *i* through inhalation exposure ($kg \cdot d \cdot mg^{-1}$); when $CR<1\times10^{-6}$, there is no carcinogenic risk; when $1\times10^{-6}<CR<1\times10^{-4}$, it is an acceptable carcinogenic risk; when $CR>1\times10^{-4}$, it is an unacceptable carcinogenic risk. The reference values of RfD_{ij} and SF_{inh} for heavy metals are shown in Table 3.

Table 3. Non-carcinogenic risk reference dose values and carcinogenic risk slope reference values

Element	RfD_{ij}/（$mg \cdot kg^{-1} \cdot d^{-1}$）			SF_{inh}/（$kg \cdot d \cdot mg^{-1}$）
	Ingestion	Inhalation	Dermal	Inhalation
As	3.00×10^{-4}	1.23×10^{-4}	3.00×10^{-4}	4.30×10^{-3}
Zn	3.00×10^{-1}	3.00×10^{-1}	6.00×10^{-2}	-
Pb	3.50×10^{-3}	3.52×10^{-3}	5.25×10^{-4}	-
Cu	4.00×10^{-2}	4.02×10^{-2}	1.20×10^{-2}	-
Cd	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-5}	6.30
Cr	3.00×10^{-3}	2.86×10^{-5}	6.00×10^{-5}	42.00
Ni	2.00×10^{-2}	2.06×10^{-2}	5.40×10^{-3}	0.84
Mn	4.70×10^{-2}	1.40×10^{-5}	2.40×10^{-3}	

Note: Mn from reference [36], other elements from reference [21].

Results and Discussion

Heavy Metal Content Levels

The heavy metal concentrations in indoor and outdoor dust from the two universities are listed in Table 4. For University A, the indoor dust concentrations of As, Zn, Pb, Cu, Cd, Cr, Ni, and Mn (mean ± standard deviation, hereafter) were 5.71 ± 4.65, 426.06 ± 172.25, 31.58 ± 15.24, 117.21 ± 192.44, 0.33 ± 0.17, 84.62 ± 80.86, 45.51 ± 27.44, and 375.01 ± 113.16 mg/kg, respectively, ranking in descending order as Zn > Mn > Cu > Cr > Ni > Pb > As > Cd. The outdoor dust concentrations of these elements were 4.48 ± 4.04, 195.00 ± 169.43, 52.18 ± 26.57, 28.78 ± 175.25, 0.27 ± 0.16, 46.99 ± 81.46, 22.70 ± 26.83, and 333.54 ± 131.00 mg/kg, respectively, ranking in descending order as Mn > Zn > Pb > Cr > Cu > Ni > As > Cd. Except for Pb, all other elements showed higher indoor concentrations than outdoor concentrations. For University B, the indoor dust concentrations of As, Zn, Pb, Cu, Cd, Cr, Ni, and Mn were 5.00 ± 2.05, 278.81 ± 147.19, 41.68 ± 36.01, 59.50 ± 30.56, 0.63 ± 1.10, 63.29 ± 34.91, 35.26 ± 14.93, and 386.10 ± 187.81 mg/kg, respectively, ranking in descending order as Mn > Zn > Cr > Cu > Pb > Ni > As > Cd. The outdoor dust concentrations were 3.99 ± 0.97, 154.46 ± 56.12, 35.50 ± 15.87, 25.45 ± 8.71, 0.38 ± 0.11, 43.25 ± 9.55, 21.34 ± 6.38, and 301.03 ± 51.54 mg/kg, respectively, ranking in descending order as Mn > Zn > Cr > Pb > Cu > Ni > As > Cd. Overall, the two universities exhibited similar heavy metal pollution characteristics, with relatively high concentrations of Zn and Mn, comparable levels of Pb, Cu, Cr, and Ni, and relatively low concentrations of As and Cd. All elements exhibited higher indoor concentrations than outdoor concentrations. Indoor pollution sources are diverse and persistent, may including building decoration materials, furniture and equipment, high-

density and long-term human occupancy, as well as the introduction of contaminants through shoes, clothing, and cosmetics. Furthermore, the enclosed nature of indoor spaces limits dispersion and dilution, facilitating pollutant accumulation. Comparing the two universities, the mean indoor concentrations of As, Zn, Cu, Cr, and Ni in University A were higher than those in University B, whereas the mean indoor concentrations of Pb, Cd, and Mn were lower. For outdoor dust, the mean concentrations of all elements in University A except Cd were higher than those in University B. Statistically speaking, concentration of Zn in indoor dust and of concentrations of Zn and Pb in outdoor dust at University A were observed significantly higher than those at University B ($p < 0.05$). Cd concentrations in both the indoor and outdoor dust at University B were greater than those in University B ($p < 0.05$).

Table 4. Heavy metal content in indoor and outdoor dust from the two universities (mg/kg)

	Heavy metal		As	Zn	Pb	Cu	Cd	Cr	Ni	Mn
University A	Indoor	Maximum	17.71	769.95	72.83	761.53	0.96	427.11	125.83	615.40
		Minimum	2.10	182.12	10.64	13.22	0.11	30.49	11.00	172.89
		Mean	5.71	426.06	31.58	117.21	0.33	84.62	45.51	375.01
		SD	4.65	172.25	15.24	192.44	0.17	80.86	27.44	113.16
		CV	0.82	0.40	0.48	1.64	0.52	0.96	0.60	0.30
	Outdoor	Maximum	8.21	355.00	105.92	103.82	0.55	74.76	29.95	468.43
		Minimum	1.69	35.43	11.82	6.39	0.10	8.32	12.31	74.21
		Mean	4.48	195.00	52.18	28.78	0.27	46.99	22.70	333.54
		SD	4.04	169.43	26.57	175.25	0.16	81.46	26.83	131.00
		CV	0.90	0.87	0.51	6.09	0.58	1.73	1.18	0.39
University B	Indoor	Maximum	8.68	637.39	178.59	149.61	5.58	165.66	73.79	973.23
		Minimum	1.79	94.87	10.77	22.10	0.02	28.59	15.75	166.52
		Mean	5.00	278.81	41.68	59.50	0.63	63.29	35.26	386.10
		SD	2.05	147.19	36.01	30.56	1.10	34.91	14.93	187.81
		CV	0.41	0.53	0.86	0.51	1.75	0.55	0.42	0.49
	Outdoor	Maximum	6.30	294.78	68.81	42.47	0.55	60.08	46.49	445.31
		Minimum	2.78	44.36	10.96	11.75	0.21	26.21	16.06	233.79
		Mean	3.99	154.46	35.50	25.45	0.38	43.25	21.34	301.03
		SD	0.97	56.12	15.87	8.71	0.11	9.55	6.38	51.54
		CV	0.24	0.36	0.45	0.34	0.29	0.22	0.30	0.17

Heavy metal	As	Zn	Pb	Cu	Cd	Cr	Ni	Mn
Background value	11.2	69.1	22.1	23.8	0.147	68.4	29.5	597

When compared with the soil background values of Binzhou City, the indoor dust from University A had higher average concentrations of Zn, Pb, Cu, Cd, Cr, and Ni, which were 6.2, 1.4, 4.9, 2.2, 1.2, and 1.5 times the background values, respectively, while those of As and Mn were below the background values. In the outdoor dust from University A, average concentrations of Zn, Pb, Cu, and Cd were 2.8, 2.4, 1.2, and 1.8 times the background values, respectively, while the other elements were below the background values. For University B, the average concentrations of Zn, Pb, Cu, Cd, and Ni in indoor dust samples were 4.0, 1.9, 2.5, 4.3, and 1.2 times the background values, respectively, whereas As, Cr, and Mn were below the background values. In the outdoor dust from University B, mean values of concentrations of Zn, Pb, Cu, and Cd were 2.2, 1.6, 1.1, and 2.6 times the background values, respectively, with the remaining elements below the background values. The above results suggested emissions of Zn, Pb, Cu and Cd from anthropogenic activities exist in the university campuses.

Table 5 listed the levels of heavy metals in dusts from university campus of different regions. It could be observed that the heavy metal concentrations in dusts at the two universities were generally at low to medium levels among those investigations. As for the indoor dusts, the concentrations of Cd, Pb, Cr, Zn, and Cu in this study were higher than those in four universities in Nigeria [37] and a school in Malaysia [38], while the concentrations of As, Cd, Cr, Cu, Ni, Pb, and Zn were far lower than those in a university in Guangdong, China [21]. The concentrations of Zn, Pb, and Cd were lower than those in a university in Henan, China[26]. As for the outdoor dusts, the heavy metal levels in the present study were lower than those in most urban road dusts [39-42], and the contents of Zn, Pb, Cu, Cd, Cr, and Ni were lower than those in most universities in Beijing [24].

Table 5.Heavy metal levels in campus dust from different universities (mg/kg)

	Heavy metal	As	Zn	Pb	Cu	Cd	Cr	Ni	Mn
Indoor	University A/China(This study)	5.71	426.06	31.58	117.21	0.33	84.62	45.51	375.01
	University B/China(This study)	5.00	278.81	41.68	59.50	0.63	63.29	35.26	386.10
	Federal University of Technol Ogy, Akure/Nigeria[37]	-	0.23	0.02	0.200	ND	0.17	-	-
	Federal College of Agriculture, Akure/Nigeria[37]	-	0.24	0.11	0.31	0.02	0.25	-	-
	Ondo State College of Health Science Technology, Akure/ Nigeria[37]	-	0.11	0.05	0.24	0.01	0.12	-	-
	Adeyemi College of Education, Ondo/Nigeria[37]	-	0.25	0.07	0.18	0.01	0.20	-	-
	A certain school in Rawang /Malaysia[38]	0.02	12.5	0.005	0.96	0.01	0.05	0.53	-

	Heavy metal	As	Zn	Pb	Cu	Cd	Cr	Ni	Mn
Outdoor	A certain university in Henan/China[26]	-	444.90	109.44	56.35	1.45	78.25	34.01	-
	A certain university in Guangdong /China[21]	58.54	3909.31	315.90	356.16	5.35	494.39	200.59	-
	University A/China(This study)	4.48	195.00	52.18	28.78	0.27	46.99	22.70	333.54
	University B/China(This study)	3.99	154.46	35.50	25.45	0.38	43.25	21.34	301.03
	Tsinghua University/China[24]	-	212.01	32.11	52.68	1.01	68.54	31.03	-
	Peking University/China[24]	-	145.92	28.76	38.88	0.22	48.87	22.04	-
	Renmin University of China/China[24]	-	351.56	82.94	99.94	0.65	93.93	35.02	-
	Beijing Normal University/China[24]	-	328.71	75.11	151.25	0.60	139.60	39.59	-
	Beijing University of Posts and Telecommunications/China[24]	-	420.68	73.24	88.26	0.87	88.61	27.06	-
	Beijing Institute of Technology/China[24]	-	286.04	38.27	72.00	0.70	73.23	38.86	-
	Beijing Foreign Study University/China[24]	-	221.11	41.66	69.55	0.53	76.01	31.34	-
	Central University for Nationalities/China[24]	-	342.12	68.04	75.98	1.77	78.71	40.39	-
	Beijing University of Chemical Technology/China[24]	-	304.10	50.18	84.88	0.64	84.11	38.57	-
	Beijing University of Chinese Medicine/China[24]	-	470.88	52.70	90.72	0.75	99.07	36.38	-

Pollution Characteristics of Indoor and Outdoor Heavy Metals

The heavy metal concentrations in dusts from 7 types of indoor environments at University A and 8 types of indoor environments at University B were shown in Figure 2. It could be observed that heavy metal concentrations in dusts varied among different functional zones.

For University A, the highest As concentration was observed in the office building (13.54 mg/kg), which was significantly higher than those in the library, teaching building, laboratory, canteen, and gymnasium. The highest Zn concentration was found in the gymnasium (639.39 mg/kg), significantly higher than those in the office building, laboratory, and dormitory, likely reflecting the high-frequency use of sports facilities (metal equipment wear and floor coating). The highest Pb concentration was detected in the laboratory (50.52 mg/kg), significantly higher than those in the office building, teaching building, and dormitory, may be related to practical training activities. The highest Cu concentration was recorded in the teaching building (503.69 mg/kg), significantly higher than those in all other functional areas, likely reflecting the peeling of indoor coatings, mechanical wear of metallic materials

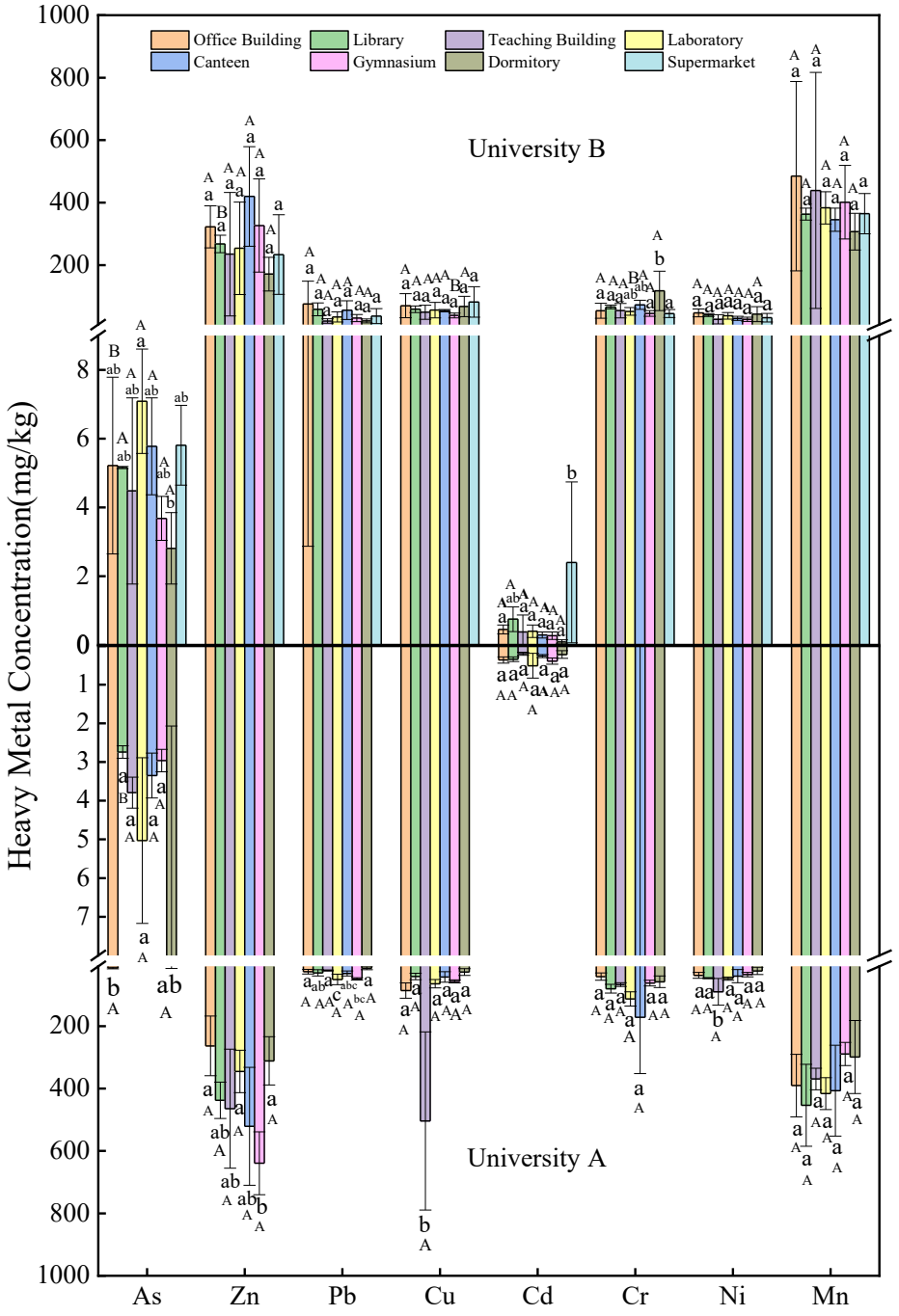


Figure2. Heavy Metal Content in Dust from Different Indoor Environments at the two Universities

on seats[26]. No significant differences were observed in the concentrations of Cd, Cr, Ni, and Mn among the different indoor environments. For University B, the highest As concentration was observed in the laboratory (7.09 mg/kg), significantly higher than that in the dormitory (2.81 mg/kg), may be related to experimental activities and aged building decoration materials. The highest Cd concentration was detected in the supermarket (2.40 mg/kg), significantly higher than those in the office building,

teaching building, laboratory, canteen, gymnasium, and dormitory, indicating more significant inputs from supermarket logistics packaging and shelf coatings. The highest Cr concentration was found in the dormitory (117.65 mg/kg), significantly higher than those in the office building, campus supermarket, teaching building, gymnasium, and library, indicating more significant inputs from dormitory renovation materials and metal furniture. No significant differences were found in the concentrations of Zn, Pb, Cu, Ni, and Mn among the different indoor environments.

Comparison of indoor heavy metal concentrations between the two universities revealed that the As concentration in offices, Cr concentration in laboratories, Cu concentration in gymnasiums, and Zn concentration in libraries of University A were significantly higher than those of University B ($p < 0.05$). Conversely, the As concentration in the libraries of University A was significantly lower than that of University B ($p < 0.05$). No other significant differences were detected.

As for the results in outdoor samples (Figure 3), no significant difference was observed between the high-traffic intensity roads and the low-traffic intensity roads at either university. Dust-borne heavy metals originate not only from traffic activities, but also from pavement materials and atmospheric deposition [12,24]. Vehicle movement and wind can repeatedly resuspend dust, facilitating its migration and re-deposition elsewhere. At the campus scale, despite varying traffic intensities, the overall heavy metal concentrations in the roads tend to be homogeneous. Under high traffic intensity, the Cd concentration at University A was significantly lower than that at University B ($p < 0.05$). Conversely, under low traffic intensity, the Pb and Ni concentrations at University A were significantly higher than those at University B ($p < 0.05$), with no other significant differences detected. The two universities had comparable founding years and campus scales. Moreover, as both are located within the same urban district with limited spatial extent and similar surrounding environmental conditions, traffic intensity had a relatively minor influence on most heavy metals in outdoor dust at the two universities.

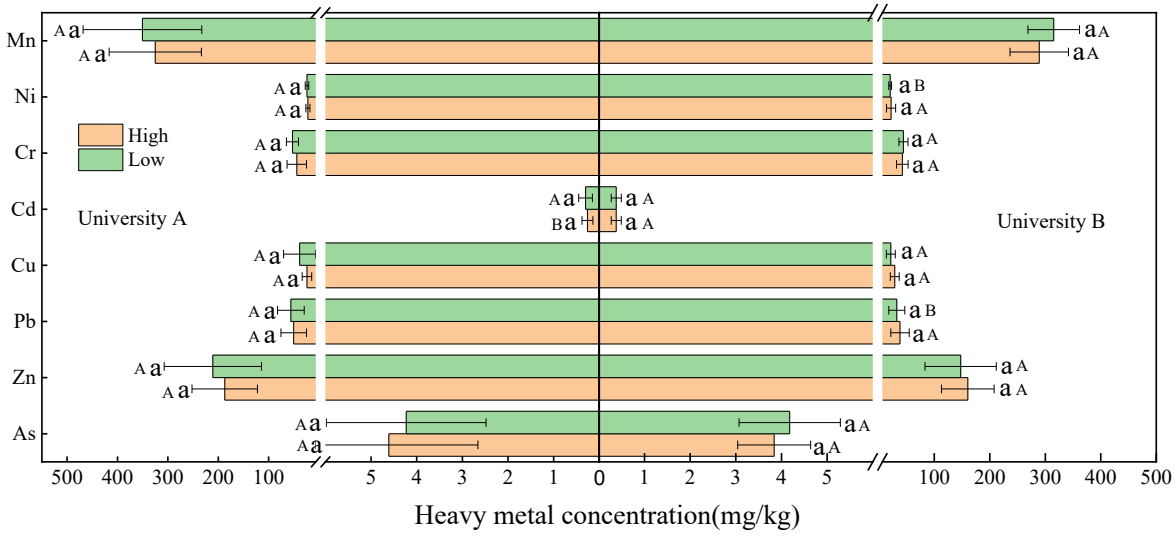
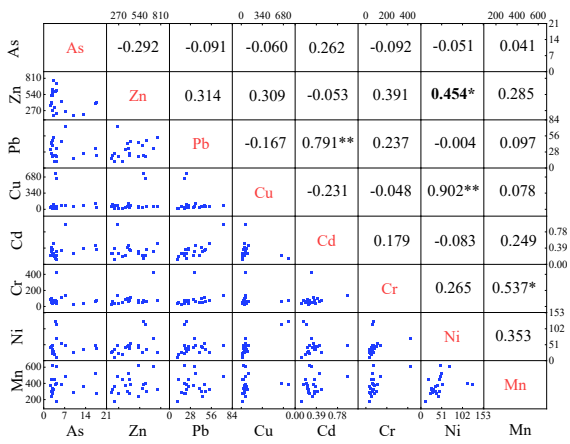


Figure3. Heavy Metal Content in Dust from Roads with different traffic intensity at the two universities

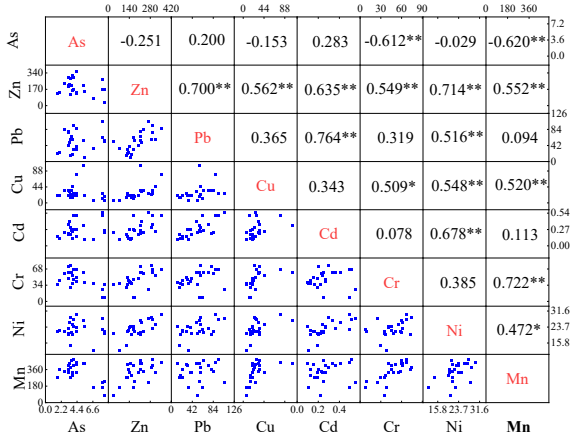
Source Analysis of Heavy Metals

Heavy metals in dust are influenced by both natural and anthropogenic factors. The similarity of sources can lead to certain correlations between different elements [43-44], and correlation analysis is an important basis for inferring heavy metal sources. In the present study, the Pearson correlation analysis results of heavy metals in indoor and outdoor dusts were shown in Figure 4. In indoor dust from University A, extremely significant correlations were found between Pb and Cd, as well as between Cu and Ni, while significant correlations were observed between Zn and Ni, and between Cr and Mn. In indoor dust from University B, extremely significant correlations existed between Pb and As, Cu, and Ni; between Cu and Cd, Cr, and Ni; and between Ni and Cr, whereas significant correlations were found between Cu and As, Zn, and between Zn and Mn. These results indicate that the sources of heavy metals in indoor dust from both universities are relatively complex.

In outdoor dust from University A, Zn showed extremely significant correlations with all other elements except As; Ni exhibited significant or extremely significant correlations with all other elements except As and Cr; and Mn displayed significant or extremely significant correlations with all other elements except Pb and Cd. Additionally, significant correlations were observed between As and Cr, Mn, as well as between Pb and Zn, Cd, and Ni. These findings suggest that the sources of heavy metals in outdoor dust from University A are relatively concentrated. In outdoor dust from University B, Zn showed significant correlations with all other elements except As and Mn; Pb exhibited extremely significant correlations with Zn, Cu, and Cr, as well as between As and Mn; Cu showed significant correlations with Zn, Pb, Cd, and Cr; and Cr displayed significant correlations with Zn, Pb, Cu, and Ni. These results indicate that the sources of heavy metals in outdoor dust from University B are relatively complex.



Indoor(University A)



Outdoor(University A)

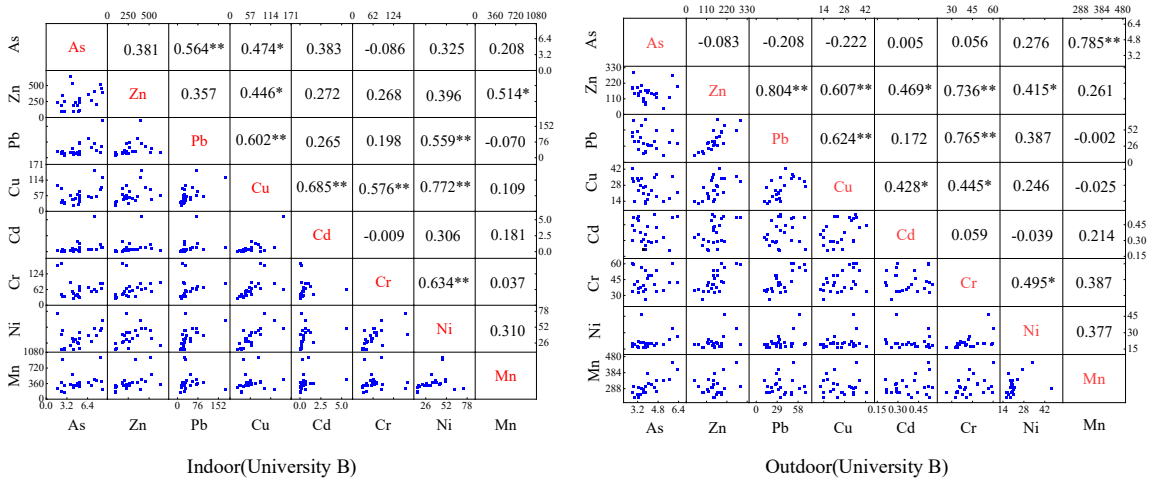


Figure 4. Pearson correlation coefficients of heavy metals in dust

In addition to natural sources, heavy metals are greatly affected by human activities. To further analyze the sources of heavy metals, principal component analysis (PCA) was performed on the heavy metal data. The factor loadings of heavy metals were shown in Figure 5. For indoor dust in university A, three principal components were extracted, explaining 31.5%, 26.6%, and 15.3% of the total variance, respectively. Zn, Cu, Cr, Ni, and Mn had high loadings on the first principal component (0.743, 0.616, 0.607, 0.835, and 0.613, respectively). These elements might mainly originated from vehicle exhaust drifting indoors [45] and peeling wall paint [46-47]. Pb and Cd had high loadings on the second principal component (0.789 and 0.866, respectively), possibly from vehicle exhaust [45]. As had a high loading on the third principal component (0.850), and because its content was lower than the local soil background value, it was speculated to likely come from natural geochemical processes. For outdoor dust, two principal components were extracted, explaining 50.1% and 26.6% of the total variance, respectively. Zn, Pb, Cu, Cd, Cr, Ni, and Mn had high loadings on the first principal component (0.910, 0.682, 0.732, 0.649, 0.713, 0.816, and 0.701, respectively), indicating that they might have the same sources or behaviors. In addition to natural sources, they might also come from vehicle exhaust emissions [45], tire wear [48], and road construction materials [49]. As had a high loading on the second principal component (0.844), possibly from natural geochemical processes.

The principal component analysis (PCA) results for University B indicated that three principal components were extracted for indoor dust, explaining 45.0%, 17.0%, and 15.5% of the total variance, respectively. As, Zn, Pb, Cu, Cd, and Ni showed high loadings in the first principal component, with values of 0.620, 0.656, 0.708, 0.922, 0.595, and 0.838, respectively. These elements might originate from vehicle exhaust drifting indoors [45] and peeling wall paint [46-47]. Cr exhibited a high loading in the second principal component, with a value of -0.775, possibly derived from vehicle exhaust [45]. Mn showed a high loading in the third principal component, with a value of 0.784; as its concentration

was lower than the local soil background value, it is speculated to likely originate from natural geochemical processes.

For outdoor dust, three principal components were extracted, explaining 43.4%, 25.2%, and 14.6% of the total variance, respectively. Zn, Pb, Cu, and Cr showed high loadings in the first principal component, with values of 0.922, 0.862, 0.719, and 0.854, respectively, possibly originating from vehicle exhaust emissions [45], tire wear [48], and road construction materials [49]. As and Mn exhibited high loadings in the second principal component, with values of 0.931 and 0.867, respectively, likely derived from natural geochemical processes. Cd showed a high loading in the third principal component, with a value of 0.871, possibly originating from road construction materials [49].

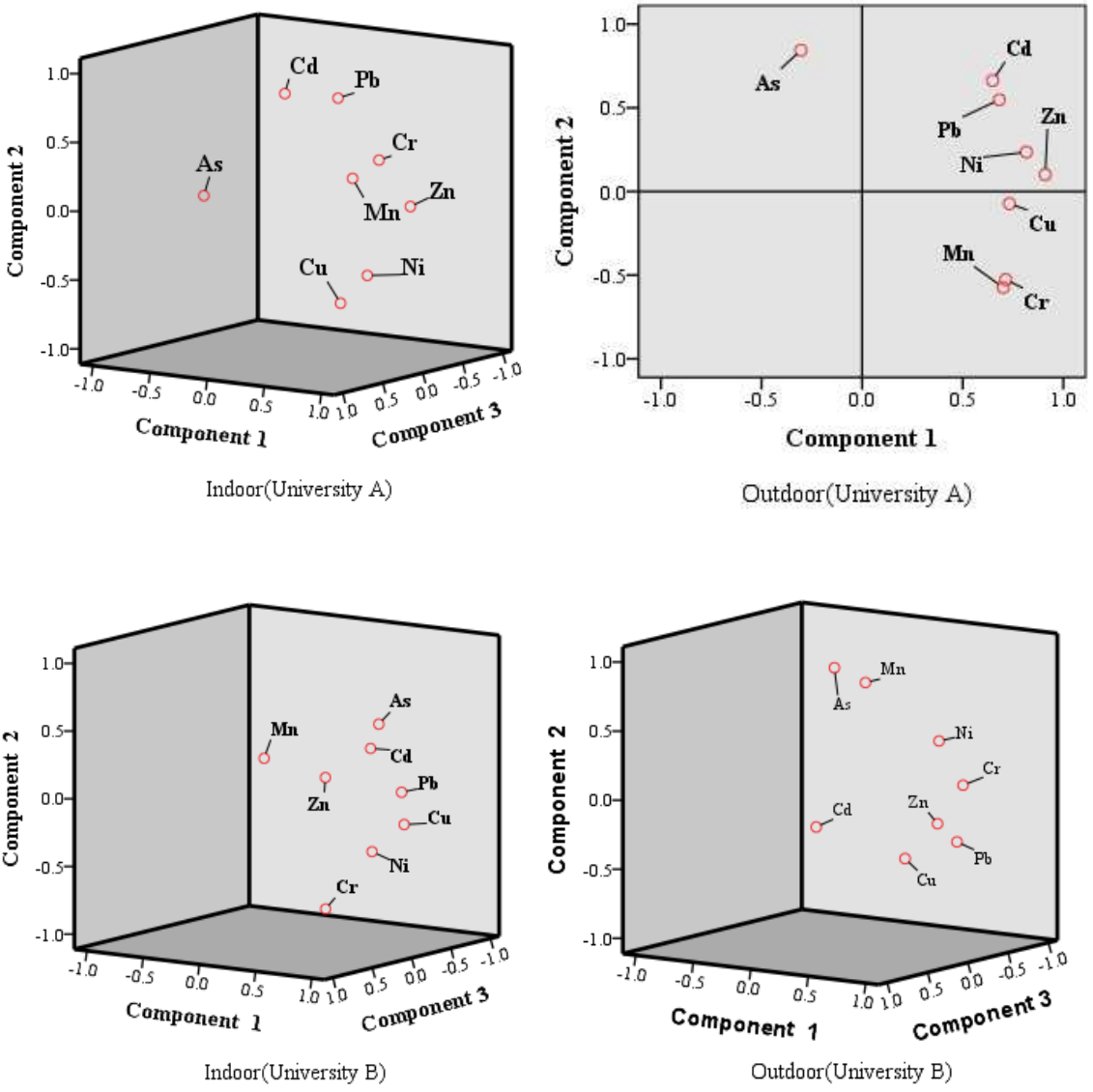


Figure 5. Distribution of heavy metal load in the dust

Assessment of Heavy Metal Pollution Degree

The geoaccumulation index was used to evaluate the pollution degree of heavy metals in indoor and outdoor dust from two universities, as shown in Figure 6 and 7, respectively. The indoor dust heavy metals in the two universities exhibited similar pollution characteristics. The average I_{geo} values of As, Pb, Cr, Ni, and Mn were all bellow 0, with University A showing values of -1.90, -0.24, -0.58, -0.17, and -1.32, respectively, and University B showing values of -1.88, -0.04, -0.87, -0.46, and -1.34, respectively, indicating no pollution to the environment. The average I_{geo} values of Cu and Cd ranged between 0 and 1, with University A showing 0.82 and 0.42, and university B showing 0.57 and 0.29, respectively, indicating slight pollution to the environment. The I_{geo} values of Zn in dust from University A and University B were 1.91 and 1.21, respectively, both greater than 1, indicating moderate pollution to the environment. In indoor dust from University A, the average I_{geo} values of Zn, Cu, Cr, Ni, and Mn were higher than those in University B, while the average I_{geo} values of As, Pb, and Cd were lower than those in University B.

In outdoor dust from University A, the average I_{geo} values of As, Cu, Cr, Ni, and Mn were -2.03, -0.59, -1.29, -0.99, and -1.52, respectively, while those of As, Pb, Cu, Cr, Ni, and Mn in outdoor dust from University B were -2.11, -0.06, -0.58, -1.28, -1.10, and -1.59, respectively, all less than 0, indicating no pollution to the environment. The average I_{geo} values of Zn, Pb, and Cd in outdoor dust from University A were 0.76, 0.44, and 0.15, respectively, while those of Zn and Cd in outdoor dust from University B were 0.47 and 0.72, respectively, ranging between 0 and 1, indicating slight pollution to the environment. In outdoor dust from University A, the average I_{geo} values of As, Zn, Pb, Ni, and Mn were higher than those in University B, while the average I_{geo} values of Cr, Cu, and Cd were lower than those in University B. Compared with research results from some universities in Beijing, the pollution degrees of Pb, Zn, and Ni were consistent, while the pollution degrees of Cr, Cu, and Cd were lower in our study [24].

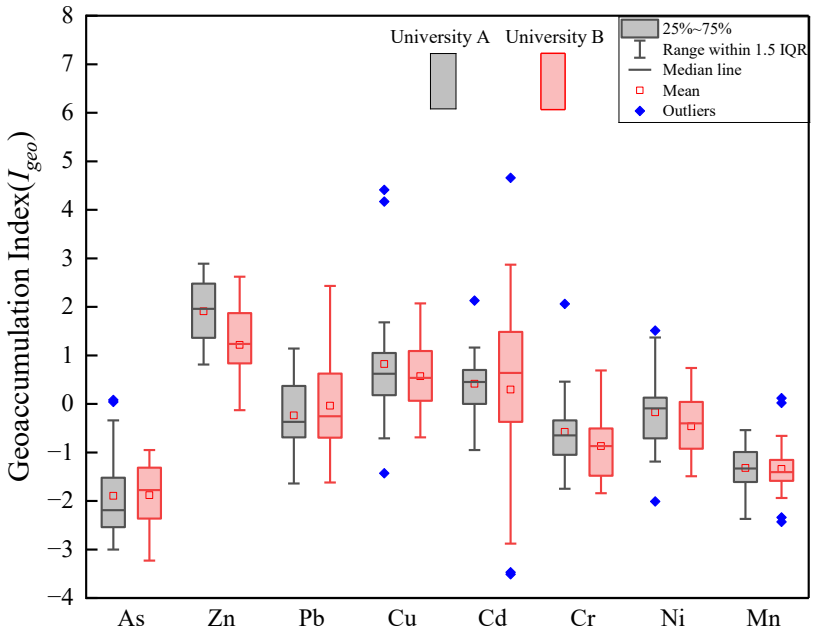


Figure 6. Geoaccumulation Index of heavy metals at sampling points indoor

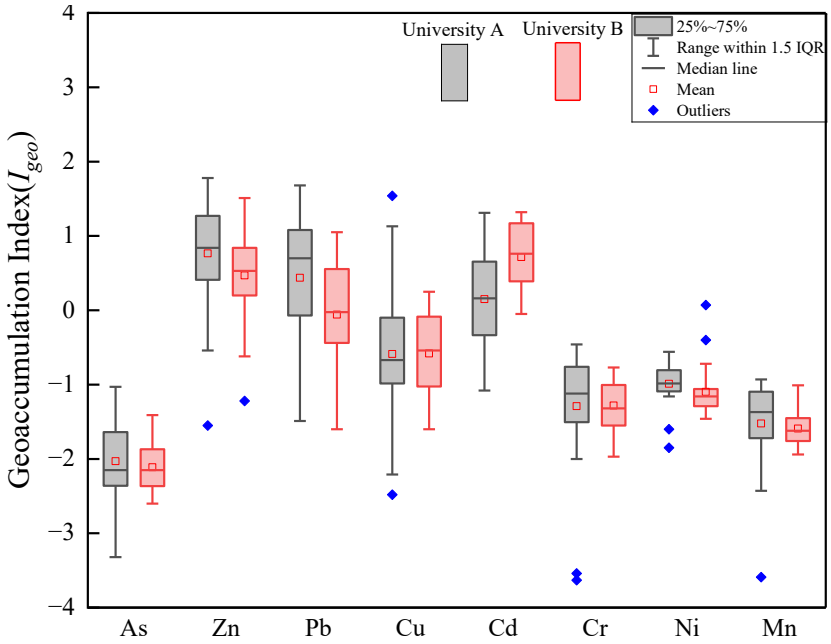


Figure 7. Geoaccumulation Index of heavy metals at sampling points outdoor

Health Risk Assessment of Heavy Metals

The non-carcinogenic risk values of heavy metals in dust through ingestion, inhalation, and dermal contact were shown in Table 6. The HI values of 8 heavy metals were in the order of Cr > As > Mn > Pb > Cu > Ni > Cd > Zn at University A and in the order of Cr > As > Mn > Pb > Cd > Ni > Cu > Zn

at University B, and all less than 1, indicating no non-carcinogenic health risk caused by all these elements. From the perspective of different exposure pathways, the total HI values of various heavy metals were in the order: dermal contact > ingestion > inhalation . The HI value of Cd in dust at University A is lower than that at University B, while the HI values of the other seven elements are all higher than those at University B.

Table 6. Non-carcinogenic risk values of heavy metals in dust through different exposure pathways

Heavy metal	University A			HI	University B			HI
	HQ_{ing}	HQ_{inh}	HQ_{der}		HQ_{ing}	HQ_{inh}	HQ_{der}	
As	1.57×10^{-2}	3.62×10^{-6}	2.36×10^{-2}	3.93×10^{-2}	1.40×10^{-2}	3.22×10^{-6}	2.10×10^{-2}	3.51×10^{-2}
Zn	9.44×10^{-4}	8.88×10^{-8}	2.36×10^{-4}	1.18×10^{-3}	6.75×10^{-4}	6.35×10^{-8}	1.69×10^{-4}	8.44×10^{-4}
Pb	1.14×10^{-2}	1.06×10^{-6}	3.79×10^{-3}	1.52×10^{-2}	1.03×10^{-2}	9.65×10^{-7}	3.44×10^{-3}	1.37×10^{-2}
Cu	1.64×10^{-3}	1.53×10^{-7}	2.73×10^{-4}	1.91×10^{-3}	9.93×10^{-4}	9.30×10^{-8}	1.65×10^{-4}	1.16×10^{-3}
Cd	2.79×10^{-4}	2.63×10^{-8}	1.40×10^{-3}	1.68×10^{-3}	4.71×10^{-4}	4.44×10^{-8}	2.36×10^{-3}	2.83×10^{-3}
Cr	2.01×10^{-2}	1.99×10^{-4}	5.03×10^{-2}	7.06×10^{-2}	1.66×10^{-2}	1.64×10^{-4}	4.15×10^{-2}	5.83×10^{-2}
Ni	1.56×10^{-3}	1.42×10^{-7}	2.89×10^{-4}	1.85×10^{-3}	1.32×10^{-3}	1.21×10^{-7}	2.45×10^{-4}	1.57×10^{-3}
Mn	7.02×10^{-3}	2.22×10^{-3}	6.87×10^{-3}	1.61×10^{-2}	6.84×10^{-3}	2.16×10^{-3}	6.69×10^{-3}	1.57×10^{-2}
HI	5.86×10^{-2}	2.42×10^{-3}	8.68×10^{-2}	1.48×10^{-1}	5.12×10^{-2}	2.33×10^{-3}	7.56×10^{-2}	1.29×10^{-1}

Considering the indoor and outdoor exposure conditions, Table 7 presented the HI values of dust heavy metals via different exposure pathways in both indoor and outdoor dust. The HI values were all less than 1, which was consistent with research results from some other universities [21,24,26]. The total HI values of all elements were higher indoors than outdoors at the two universities. Except for Pb, the HI values of other elements in indoor dust were higher than those in outdoor dust at University A, while the HI values of all elements in indoor dust were higher than those in outdoor dust at University B. The total HI values of all elements, both indoors and outdoors, at University A are higher than those at University B. Specifically, the indoor HI values of As, Zn, Cu, Cr, and Ni at University A are higher than those at University B, while the indoor HI values of Pb, Cd, and Mn are lower than those at university B. Except for Cd, the outdoor HI values of other elements at University A are higher than

those at University B.The indoor HI values at University A were in the order of Cr > As > Mn > Pb > Cu > Ni > Cd > Zn, whereas the indoor HI values at University B were in the order of Cr > As > Mn > Pb > Cd > Ni > Cu > Zn. The outdoor HI values at University A were in the order of Cr >As > Pb > Mn > Cd > Ni > Cu > Zn, whereas the outdoor HI values at University B were in the order of Cr > As > Mn > Pb > Cd > Ni > Cu > Zn .

Table 7. Non-carcinogenic risk values for indoor and outdoor heavy metals

Heavy metal		Indoor				Outdoor			
		HQ_{ing}	HQ_{inh}	HQ_{der}	HI	HQ_{ing}	HQ_{inh}	HQ_{der}	HI
University A	As	1.78×10^{-2}	4.08×10^{-6}	2.67×10^{-2}	4.45×10^{-2}	1.40×10^{-2}	3.63×10^{-6}	2.37×10^{-2}	3.77×10^{-2}
	Zn	1.33×10^{-3}	1.25×10^{-7}	3.32×10^{-4}	1.66×10^{-3}	6.08×10^{-4}	8.96×10^{-8}	2.38×10^{-4}	8.46×10^{-4}
	Pb	8.44×10^{-3}	7.89×10^{-7}	2.81×10^{-3}	1.13×10^{-2}	1.39×10^{-2}	1.06×10^{-6}	3.77×10^{-3}	1.77×10^{-2}
	Cu	2.74×10^{-3}	2.57×10^{-7}	4.57×10^{-4}	3.20×10^{-3}	6.73×10^{-4}	1.56×10^{-7}	2.77×10^{-4}	9.50×10^{-4}
	Cd	3.05×10^{-4}	2.87×10^{-8}	1.53×10^{-3}	1.84×10^{-3}	2.56×10^{-4}	2.63×10^{-8}	1.40×10^{-3}	1.66×10^{-3}
	Cr	2.64×10^{-2}	2.60×10^{-4}	6.59×10^{-2}	9.26×10^{-2}	1.46×10^{-2}	2.00×10^{-4}	5.06×10^{-2}	6.54×10^{-2}
	Ni	2.13×10^{-3}	1.94×10^{-7}	3.94×10^{-4}	2.52×10^{-3}	1.06×10^{-3}	1.44×10^{-7}	2.91×10^{-4}	1.35×10^{-3}
	Mn	7.46×10^{-3}	2.36×10^{-3}	7.31×10^{-3}	1.71×10^{-2}	6.64×10^{-3}	2.22×10^{-3}	6.88×10^{-3}	1.57×10^{-2}
	HI	6.66×10^{-2}	2.63×10^{-3}	1.05×10^{-1}	1.75×10^{-1}	5.17×10^{-2}	2.43×10^{-3}	8.72×10^{-2}	1.41×10^{-1}
University B	As	1.56×10^{-2}	3.58×10^{-6}	2.34×10^{-2}	3.90×10^{-2}	1.25×10^{-2}	2.86×10^{-6}	1.87×10^{-2}	3.12×10^{-2}
	Zn	8.69×10^{-4}	8.18×10^{-8}	2.17×10^{-4}	1.09×10^{-3}	4.81×10^{-4}	4.53×10^{-8}	1.20×10^{-4}	6.01×10^{-4}
	Pb	1.11×10^{-2}	1.04×10^{-6}	3.71×10^{-3}	1.48×10^{-2}	9.49×10^{-3}	8.88×10^{-7}	3.16×10^{-3}	1.27×10^{-2}
	Cu	1.39×10^{-3}	1.30×10^{-7}	2.32×10^{-4}	1.62×10^{-3}	5.95×10^{-4}	5.57×10^{-8}	9.91×10^{-5}	6.94×10^{-4}
	Cd	5.89×10^{-4}	5.54×10^{-8}	2.94×10^{-3}	3.53×10^{-3}	3.54×10^{-4}	3.33×10^{-8}	1.77×10^{-3}	2.12×10^{-3}
	Cr	1.97×10^{-2}	1.95×10^{-4}	4.93×10^{-2}	6.92×10^{-2}	1.35×10^{-2}	1.33×10^{-4}	3.37×10^{-2}	4.73×10^{-2}
	Ni	1.65×10^{-3}	1.51×10^{-7}	3.05×10^{-4}	1.96×10^{-3}	9.98×10^{-4}	9.12×10^{-8}	1.85×10^{-4}	1.18×10^{-3}
	Mn	7.68×10^{-3}	2.43×10^{-3}	7.52×10^{-3}	1.76×10^{-2}	5.99×10^{-3}	1.89×10^{-3}	5.86×10^{-3}	1.37×10^{-2}
	HI	5.86×10^{-2}	2.63×10^{-3}	8.76×10^{-2}	1.49×10^{-1}	4.39×10^{-2}	2.03×10^{-3}	6.36×10^{-2}	1.10×10^{-1}

The carcinogenic risk (CR) values of As, Cd, Cr, and Ni through inhalation to students and faculties were calculated separately, as shown in Table 8. The CR values were all less than 1×10^{-6}. Thus no carcinogenic risk from inhalation could be cause by heavy metals, which was consistent with research results from other universities [21,26,32,50]. The carcinogenic risk order for both students and teachers

at University A, both indoors and outdoors, was Cr > Ni > Cd > As. For University B, the indoor carcinogenic risk order for both students and teachers was Cd > Cr > Ni > As, while the outdoor carcinogenic risk order for both students and teachers was Cr > Cd > Ni > As.

The indoor carcinogenic risk values for both students and faculties were higher than outdoor values, and faculties had higher carcinogenic risk values than students due to longer exposure duration.The total indoor and outdoor carcinogenic risks for students at University A were both lower than those at University B, while the total indoor and outdoor carcinogenic risks for teachers at University A were both higher than those at University B.

Table 8. Carcinogenic risk values of heavy metals in dust

Heavy metal		Students		Teachers	
		Indoor R_{inh}	Outdoor R_{inh}	IndoorR_{inh}	Outdoor R_{inh}
University A	As	9.26×10^{-14}	8.22×10^{-14}	7.41×10^{-13}	6.57×10^{-13}
	Cd	7.75×10^{-12}	7.11×10^{-12}	6.20×10^{-11}	5.68×10^{-11}
	Cr	1.34×10^{-8}	1.03×10^{-8}	1.07×10^{-7}	8.24×10^{-8}
	Ni	1.44×10^{-10}	1.06×10^{-10}	1.15×10^{-9}	8.52×10^{-10}
	CR	1.36×10^{-8}	1.04×10^{-8}	1.08×10^{-7}	8.33×10^{-8}
University B	As	1.08×10^{-13}	8.64×10^{-14}	6.22×10^{-13}	4.97×10^{-13}
	Cd	8.83×10^{-9}	4.89×10^{-9}	5.08×10^{-8}	2.81×10^{-8}
	Cr	8.80×10^{-9}	7.50×10^{-9}	5.06×10^{-8}	4.31×10^{-8}
	Ni	2.51×10^{-10}	1.07×10^{-10}	1.45×10^{-9}	6.18×10^{-10}
	CR	1.79×10^{-8}	1.25×10^{-8}	1.03×10^{-7}	7.18×10^{-8}

Comparison of heavy metal pollution in dust of the two types of university

A comparison of heavy metal pollution characteristics in campus dust of the two universities was presented in Table 9. As for the pollution levels, Mn and Zn were abundant, while As and Cd were present in relatively small amounts, and this pattern was observed at both universities. Zn, Pb, Cu and Cd were frequently observed with concentrations exceeding the corresponding soil background values. Several elements showed significantly higher concentrations in certain functional zones, suggesting that human activities may affect the spatial distribution of heavy metals in dust. The heavy metal pollution degrees were relatively comparable between the two universities, with Zn and Cd mainly at low to moderate pollution levels. Regarding non-carcinogenic health risks, dermal contact and ingestion were the dominant exposure pathways, and Cr was the primary contributing element. Cr was also the major

417 contributor to carcinogenic risk. Regarding speculated sources, dust heavy metal concentrations were
418 determined by both natural factors and anthropogenic activities, with different elements affected to
419 different extents.

420 As mentioned above, the average concentrations of metals (except Cd) in both indoor and outdoor
421 dust samples were generally higher at vocational University A. The average concentrations of Zn in
422 indoor dust and of Zn and Pb in outdoor dust at vocational University A were significantly higher than
423 those at comprehensive University B ($p < 0.05$). In contrast, the Cd concentration in campus dust at
424 University A was significantly lower than that at University B ($p < 0.05$). This might suggest that
425 elevated Cu and Zn are characteristic elements in the dust of the vocational university. The relatively
426 high concentrations of Cd at the comprehensive university might be attributed to the greater human
427 activity intensity and higher population density on campus (~190 persons/ha in University B vs. ~150
428 persons/ha in University A). The sources of individual elements in different dust types may vary
429 between the two universities due to differences in human activity intensity.

430 The present study has certain limitations, too. For example, dust samples in this study were
431 collected merely in winter ignoring the seasonal variations, inter-semester differences and activity-
432 scheduled disparities. Actually, teaching activity arrangements in the universities differ across semesters,
433 potentially resulting in differing exposure levels and durations for students and faculty and staff.
434 Subsequent detailed investigations could be performed in accordance with actual semester teaching
435 schedules. Besides, future research could incorporate the particle size information to comprehensively
436 reveal the bioavailability and potential human exposure risks across various particle size fractions. The
437 contamination of heavy metals in the campus dust should be explored in a more precise and
438 comprehensive manner.
439
440 **Table 9.** Comparison of heavy metal pollution characteristics in dust from Universities A and B

	University A		**University B**	
	Indoor	**Outdoor**	**Indoor**	**Outdoor**
Order of elements content	Zn > Mn > Cu > Cr > Ni > Pb > As > Cd	Mn > Zn > Pb > Cr > Cu > Ni > As > Cd	Mn > Zn > Cr > Cu > Pb > Ni > As > Cd	Mn > Zn > Cr > Pb > Cu > Ni > As > Cd
Elements exceeding background values	Zn, Pb, Cu, Cd, Cr, and Ni	Zn, Pb, Cu, and Cd	Zn, Pb, Cu, Cd, and Ni	Zn, Pb, Cu, and Cd
Elements with greater concentrations	Zn	Zn, Pb	Cd	Cd
Major polluting elements	As / office building; Zn / gymnasium; Pb / laboratory; Cu / teaching building	Mn, Zn	As / laboratory; Cd / supermarket; Cr / dormitory	Mn, Zn

Pollution degree	**No pollution**：As, Pb, Cr, Ni, Mn； **Slight pollution**：Cu, Cd； **Moderate pollution**：Zn	**No pollution**：As, Cu, Cr, Ni, Mn； **Slight pollution**：Zn, Pb, Cd	**No pollution**：As, Pb, Cr, Ni, Mn； **Slight pollution**：Cu, Cd； **Moderate pollution**：Zn	**No pollution**：As, Pb, Cu, Cr, Ni, Mn； **Slight pollution**：Zn, Cd
Major non-carcinogenic exposure pathways	dermal contact；ingestion	dermal contact；ingestion	dermal contact；ingestion	dermal contact；ingestion
Major non-carcinogenic risk elements	Cr	Cr	Cr	Cr
Major carcinogenic risk elements	Cr	Cr	Cd, Cr	Cr
Major sources	**Zn, Cu, Cr, Ni, and Mn**：vehicle exhaust drifting indoors and peeling wall paint； **Pb and Cd**：vehicle exhaust； **As**：natural sources	**Zn, Pb, Cu, Cd, Cr, Ni, and Mn**：vehicle exhaust emissions, tire wear , and road construction materials； **As**：natural sources	**As, Zn, Pb, Cu, Cd, and Ni**：vehicle exhaust drifting indoors and peeling wall paint. **Cr**：vehicle exhaust； **Mn**：natural sources	**Zn, Pb, Cu, and Cr**：vehicle exhaust emissions , tire wear, and road construction materials. **As and Mn**：natural geochemical processes. **Cd**：road construction materials

Conclusions

Urban dust is a significant carrier of heavy metals and universities with large numbers of faculty and students are key population hubs. The present study investigated the heavy metals in indoor and outdoor dust from two different categories of universities, providing insights regarding heavy metal pollution in higher education environments. Average concentrations of most elements exceeded local soil background levels, suggesting extra anthropogenic inputs existed. All elements except Pb at university A showed higher concentrations indoors than outdoors, indicating distinct contamination profiles between indoor microenvironments and outdoor traffic corridors. Those metal elments were with complex sources and varying anthropogenic activities leading to divergent pollution profiles across indoor and outdoor environments as well as different functional zones. Traffic, construction, and other human activities were considered key contributors to most heavy metals in dust. Cu and Zn seemed to be the key elements characterization the pollution pattern of vocational university. I_{geo} results indicated varying degrees of contamination for different heavy metals, with Zn posing moderate pollution. Health risk characterization demonstrated that both non-carcinogenic and carcinogenic risks remained within acceptable thresholds for all assessed metals, with dermal contact and ingestion representing the primary exposure pathways. Future research should expand surveillance to diverse universities and establish longitudinal monitoring frameworks to refine environmental health benchmarks for educational settings.

Author contributions statement

C.S. Formal analysis,Writing-original draft and Visualization. J.S., C.W. and Q.Z. Investigation and Data curation. R.J. and P.L. Investigation and Visualization. J.Z. and J.C. Formal analysis and Visualization. J.Z. Methodology and Writing- review & editing. Y.T. Data curation and Formal

analysis. X.Q. Investigation, Methodology and Supervision. Z.Z. Conceptualization,Writing-review & editing, Supervision and Funding acquisition. All authors approved the final version.

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Data availability

Data sets generated during the current study are available from the corresponding authors on reasonable request.

Additional information

Correspondence and requests for materials should be addressed to R.M.

Competing interests The authors declare no competing interests.

References

1. Zhang R.H. *et al*. Levels and associated potential ecological risks of heavy metals in surface sediments from wetlands in the western Yellow River Delta. *Reg. Stud. Mar. Sci.* **93**, 104653, DOI10.1016/j.rsma.2025.104653(2026).
2. Yang Q.; Wang Y.J.; Zhong H. Remediation of mercury-contaminated soils and sediments using biochar: a critical review. *Biochar.* **3**, 23-25, DOI:10.1007/s42773-021-00087-1(2021).
3. Liu H.F. *et al*. The temporal distribution of platinum group elements (PGEs) in $PM_{2.5}$. *Environ. Monit. Assess.* **194**, 1-11, DOI:10.1007/s10661-021-09706-7(2022).
4. Qin X.F. *et al*. Resource utilization of multi-source coal-based humic acid residues: Enhancing the remediation potential of cadmium pollution in water-soil-plant systems. *J. Water. Process. Eng*. **82**, 109498, DOI:10.1016/j.jwpe.2026.109498(2026).
5. Diao F.M.; Chen M.L.; Tong L.Y.; Chen Y.N.; Diao Z.H. A green synthesized medicine residue carbon-based iron composite for the removal of chromium (VI) and cadmium (II): Performance, kinetics and mechanism. *Environ. Sci. Pollut. R.* **30**, 84011-84022, DOI:10.1007/s11356-023-28429-5(2023).
6. Rong K.; Wang J.Y.; Zhang Z.W.; Zhang J.Q. Green synthesis of iron nanoparticles using Korla fragrant pear peel extracts for the removal of aqueous Cr(VI). *Ecol. Eng*.**149**, 105793, DOI:10.1016/j.ecoleng.2020. 105793(2020).
7. Yang C.P. *et al*. Heavy metal concentrations and associated health risks in edible tissues of marine nekton from the outer Pearl River Estuary, South China Sea. *Environ. Sci. Pollut. R.* **28**, 2108-2118, DOI:10.1007/s11356-020-10605-6(2021).

8. Aendo P.; Netvichian R.; Thiendedsakul P.; Khaodhiar S.; Tulayakul P. Carcinogenic Risk of Pb, Cd, Ni, and Cr and Critical Ecological Risk of Cd and Cu in Soil and Groundwater around the Municipal Solid Waste Open Dump in Central Thailand. *J. Environ. Public. Hea*. **2022**, 3062215, DOI:10.1155/2022/3062215 (2022).
9. Mohamed F.M. *et al*. Attenuation of Carcinogenic Cr (VI) Using Tea Waste-Anthracite @ Chitosan Composite(Tw-An@Cs) from Wastewater; Statistical Analysis. *Int. J. Environ. Res.* **19**, 203, DOI:10.1007/s41742-025-00865-w(2025).
10. Yang C.P. *et al*. Heavy metal pollution and stable isotope ratios (δ 13C and δ 15N) in marine organisms from the Northern Beibu Gulf, South China Sea. *Mar. Pollut. Bull.* **166**, 112230, DOI:10.1016 /j.marpolbul.2021.112230(2021).
11. Kose T.; Yamamoto T.; Anegawa A.; Mohri S.; Ono Y. Source analysis for polycyclic aromatic hydrocarbon in road dust and urban runoff using marker compounds. *Desalination*. **226**, 151-159, DOI:10.1016/j.desal.2007.01.239(2008).
12. Aguilera A. *et al*. Heavy metal pollution of street dust in the largest city of Mexico, sources and health risk assessment. *Environ. Monit. Assess.* **193**, 1-16, DOI:10.1007/s10661-021-08993-4(2021).
13. Naimabadi A.; Gholami A.; Ramezani A.M. Determination of heavy metals and health risk assessment in indoor dust from different functional areas in Neyshabur, Iran. *Indoor. Built. Environ.* **30**, 1781-1795,DOI:10.1177/1420326X20963378(2021).
14. Safiur Rahman M. *et al*. Assessing risk to human health for heavy metal contamination through street dust in the Southeast Asian Megacity: Dhaka, Bangladesh. *Sci. Total. Environ.* **660**, 1610-1622,DOI:10.1016/j.scitotenv.2018.12.425(2019).
15. Zhou L. *et al*. Characteristics and health risk assessment of heavy metals in indoor dust from different functional areas in Hefei, China. *Environ. Pollut.* **251**, 839-849,DOI:10.1016/j.envpol.2019.05.058(2019).
16. Isinkaralar O.; Isinkaralar K.; Nguyen T.N.T. Spatial distribution, pollution level and human health risk assessment of heavy metals in urban street dust at neighbourhood scale. *Int. J. Biometeorol*. **68**, 2055-2067, DOI:10.1007/s00484-024-02729-y(2024).
17. Yadav A. K.; Gupta K.; Bodhale R.; Phuleria H.C. Metals and trace element associated health risk in size-segregated household dust of an industrial town in India. *Air. Qual. Atmos. Hlth.* **18**, 2669-2685, DOI:10.1007/s11869-025-01794-5(2025).
18. Ibrahim F.K.; Mustafa H.K.; Mohammed A.A.; Al Heety E. Concentration, Pollution Level, and Sources of Heavy Metals from Household Dust in Ramadi City, Iraq. *Asian. J. Water. Environ*. **21**, 35-43, DOI:10.3233/AJW240032(2024).
19. Yang X. Z. *et al*. Characteristics of heavy metal pollution and health risk assessment in subway dust in Beijing. *China Environ. Sci.* **31**, 944-950, DOI:10.3724/SP.J. 1011.2011.00468(2011). (in Chinese)

20. Park E.J. *et al*. Subway station dust-induced pulmonary inflammation may be due to the dysfunction of alveolar macrophages: Possible contribution of bound elements. *Toxicology.* **496**, 153618, DOI:10.1016/j. tox.2023.153618(2023).
21. Cai Y.M.; Huang H.S.; Ren L.L.; Zhang Y.L. Levels, Sources, and Health Risk Assessments of Heavy Metals in Indoor Dust in a College in the Pearl River Delta. *Environ. Sci.* **38**, 3620-3627, DOI:10.13227/j.hjkx.201703256(2017). (in Chinese)
22. Lei T.M.T. *et al*. Quantification of Heavy Metals in Indoor Dust for Health Risk Assessment in Macao. *Atmosphere.* **16**, 1294, DOI:10.3390/atmos 16111294(2025).
23. Fan X.Y.; Lu X.W.; Liu H. M.; Qin Q. Pollution and Source Analysis of Heavy Metal in Surface Dust from Xi'an University Campuses. *Environ. Sci.* **41**, 3556-3562,DOI:10.13227/j.hjkx.201912041(2020). (in Chinese)
24. Yan Y.; Li P.P.; Tao J.; Gu W. Pollution characteristics and health risk assessment of heavy metals in road dusts of universities in Beijing. *Environ. Pollut. Control.* **2016**, 38, 58-63+38. (In Chinese)
25. Liu S. *et al*. Evaluating heavy metals contamination in campus dust in Wuhan, the university cluster in Central China: distribution and potential human health risk analysis. *Environ. Earth. Sci.* **81**, 210, DOI:10.1007/s12665-022-10321-z(2022).
26. Li Y.Y. *et al*. Pollution characteristics and ecological health risk assessment of heavy metals in indoor dust in different environmental areas of a university in Henan Province. *Environ. Chem.* **42**, 3368-3380(2023). (In Chinese)
27. Ackah M. Soil elemental concentrations, geoaccumulation index, non-carcinogenic and carcinogenic risks in functional areas of an informal e-waste recycling area in Accra,Ghana. *Chemosphere.* **235**, 908-917, DOI:10.1016/j.chemosphere.2019.07.014(2019).
28. Pang X.G. *et al*. Soil geochemical background value of 17 cities in Shandong Province. *Shandong Land Resour.* **35**, 46-56(2019). (In Chinese)
29. Bux R.K. *et al*. Spatial analysis and human health risk assessment of elements in ground water of District Hyderabad, Pakistan using ArcGIS and multivariate statistical analysis. *Environ. Res.* **210**, 112915, DOI:10.1016/j.envres.2022. 112915(2022).
30. Duan H.J.; Cai X.Q.; Ruan X.L.; Tong Z.Q.; Ma J.H. Assessment of Heavy Metal Pollution and Its Health Risk of Surface Dusts from Parks of Kaifeng,China. *Environ. Sci.* **36**, 2972-2980(2015). (In Chinese)
31. U.S. Environmental Protection Agency (USEPA). Risk Assessment Guidance for Superfund: Volume III-PartA.Process for Conducting Probabilistic Risk Assessment. Washington DC: EPA, EPA 540-R-02-002(2001).
32. Aminiyan M.M.; Baalousha M.; Aminiyan F.M. Evolution of human health risk based on EPA modeling for adults and children and pollution level of potentially toxic metals in Rafsanjan road dust:a case study in a semi-arid region, Iran. *Environ. Sci. Pollut. Res.* **25**, 19767-19778, DOI:10.1007/s11356-018-2176-y(2018).

33. Wang Z.S. *et al*. Research on inhalation rate exposure factors of Chinese residents in environmental health risk assessment. *Res. Environ. Sci.* **22**, 1171-1175(2009). (In Chinese)
34. Wang Z.S. *et al*. Human exposure factors of Chinese people in environmental health risk assessment. *Res. Environ. Sci.* **22**, 1164-1170(2009). (In Chinese)
35. Aguilera A.; Bautista F.; Goguitchaichvili A.; Garcia-Oliva F. Health Risk of Heavy Metals in Street Dust. *Front. Biosci-Landmark.* **26**, 327-345,DOI:10.2741/4896(2021).
36. Tang R.L.; Ma K.M.; Zhang Y.X.; Mao Q.Z. Health risk assessment of heavy metals of street dust in Beijing. *Acta Sci. Circumst.* **32**, 2006-2015(2012). (In Chinese)
37. Ajayi O.O. *et al*. Bio-accessibility and health risk assessment of some selected heavy metals in indoor dust from higher institutions in Ondo State, Nigeria. *Environ. Sci. Pollut. R.* **30**, 25256-25264, DOI:10.1007/s11356-022-22034-8(2022).
38. Tan S.Y.; Praveena S.M.; Abidin E. Z.; Cheema M.S. Heavy metal quantification of classroom dust in school environment and its impacts on children health from Rawang (Malaysia). *Environ. Sci. Pollut. R.* **25**, 34623-34635,DOI:10.1007/s11356-018-3396-x(2018).
39. Ma Y.Y.; Zhang Y.; Song L. Ecological and health risk assessment and anthropogenic sources analysis of heavy metals in different types of urban road dust. *Process. Saf. Environ.* **195**, 106813,DOI:10.1016/j.psep. 2025.106813(2025).
40. Khan A.R. *et al*. Assessing Heavy Metal Contamination and Health Risks in Urban Street Dust: Insights from Pakistan's Industrial Growth. *Water. Air. Soil. Poll.* **236**, 738,DOI:10.1007/s11270-025-08359-3(2025).
41. Chen Y. *et al*. Heavy metal pollution of the urban street dust and health risk assessment in Xi'an. *J. Saf. Environ.* **16**, 370-376(2016). (In Chinese)
42. Li C.D. *et al*. Pollution assessment and source analysis of heavy metals in road dust in different functional areas of Jiaozuo City. *Huanjing Kexue Yu Jishu*. **46**, 150-157(2023). (In Chinese)
43. Xu L. *et al*. Integrated survey on the heavy metal distribution, sources and risk assessment of soil in a commonly developed industrial area. *Ecotox. Environ. Safe.* **236**, 113462,DOI:10.1016/j.ecoenv. 2022.113462(2022).
44. Liu S.Q.; Peng B.; Li J.F. Ecological Risk Evaluation and Source Identification of Heavy Metal Pollution in Urban Village Soil Based on XRF Technique. *Sustainability.* **14**, 5030, DOI:10.3390/su14095030(2022).
45. Wu Y. *et al*. The study of adsorption of heavy metals in automobile exhaust by talc. *Appl. Chem. Ind.* **48**, 1103-1105(2019). (In Chinese)
46. Hu B.N.; Xie H.L.; Hu H.X.; Li A.Y. Determination of trace Heavy Metals in Coatings by ICP-MS Method. *Paint & Coat. Ind.* **34**, 46-48+60(2004). (In Chinese)
47. Wu J.X.; Yao C.L. The Process Research of Analysis of Heavy Metals in Coatings. *Henan Chem. Ind.* **32**, 23-25(2015). (In Chinese)

48. Chen G.F.; Zhang Y.; Chen S.Y.; Ma C.Y. Content and Speciation of Heavy Metals in Residues of Used Tires Treated with Supercritical Water. *Appl. Mech. Mater.* **448-453,** 3082-3087, DOI:10.4028/www.scientific.net/AMM.448-453.3082(2013).
49. Iwuoha G.; Udoh C. Volatile organic compounds and heavy metals in asphalt concrete used in road surfacing of east west road, nigeria. *J. Chem. Soc. Niger.* **41**, 94-98, https://www.journals.chemsociety.org.ng/index.php/jcsn/article/view/54(2016).
50. Gohain M; Deka P. Trace metals in indoor dust from a university campus in Northeast India: implication for health risk. *Environ. Monit. Assess.* **192**, 741,DOI:10.1007/s10661-020-08684-6(2020).