Evaluating Heavy Metals Contamination in Campus Dust in Wuhan, the University Cluster in Central China: Distribution and Potential Human Health Risk Analysis

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Evaluating heavy metals contamination in campus dust in Wuhan, the university cluster in Central China: Distribution and potential human health risk analysis

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Abstract: The potential health risk of heavy metals (HMs) in campus dust may threaten the health of thousands of students, teachers, and their families in Wuhan, the university cluster in Central China every day. In this research, the pollution characteristics and health risk with HMs was the first time presented in campus dust from the canteen, playground, dormitory, and school gate to date. The average HMs concentration in campus dusts ranked Pb (83.5 mg kg-1) > Cu (70.2 mg kg-1) > Zn (47.2 mg kg-1) >Cr (46.0 mg kg-1) > Ni (22.7 mg kg-1) > As (15.2 mg kg-1) > Cd (3.38 mg kg-1). The HMs would more likely to accumulate in dormitory dust and canteen dust. In the downtown area, Zn, As, and Cd had been preliminarily identified from fossil fuel combustion and natural geochemical processes. Cu and Pb would source from cooking and traffic transportation. Ni and Cr would likely reflect the contributions of natural soil weathering. Although, no significant non-carcinogenic health risks were found to students or teachers from campus dust. Their children would more likely to exposure health risks when eating in the canteen, playing on the playground, or walking around the school gate. While the incremental lifetime cancer risk values revealed respiratory intake of HMs does not pose a carcinogenic risk on the campus.

Keywords: Heavy metals; Campus dust; Risk assessment; Spatial distribution; Students and teachers

1. Introduction

Heavy metals (HMs) are ubiquitous in the environment. They originate from both natural and anthropogenic activities (Wei and Yang, 2010). Based on recent studies, HMs would have strong capacities to migrate, enrich, and contaminate (Rahman et al., 2019). Additionally, HMs are usually non-degradable and there is no known homeostasis mechanism for them (Doabi et al, 2018). People would be exposed to them via multi-pathway exposure (Sun et al., 2019). HMs in particulates, such as chromium (Cr), Zinc (Zn), copper (Cu), lead (Pb), nickel (Ni), cadmium (Cd), and arsenic (As), have

already been proved to lead to significant threats to ecosystems and cause carcinogenic and non-carcinogenic risk for people (Doabi et al., 2018; Men et al., 2018; Sahakyan et al., 2019). Additionally, as the source and sink for HMs, surface dust has become a hot topic in environmental pollution research, especially for urban atmospheric particulate (Men et al., 2018). Among all the assessment methods, the geo-accumulation index has been widely in HMs pollution assessment due to its comprehensive consideration of anthropogenic influences as well as natural sources for environmental input (Qadeer et al., 2020;). Moreover, health risk models origination at the U.S. Environmental Protection Agency (USEPA), have also been widely used to evaluate the health risk of HMs pollutants in urban dust, such as Kermanshah (Doabi et al., 2018), Beijing (Wei et al., 2015), and Dhaka (Rahman et al., 2019). Indicating, the infrastructural development in urban areas has placed great stress on the local environment (Soltani et al., 2015).

Even though lots of studies about HMs health assessment had been done in modernize cities (Doabi et al., 2018), the information about the health assessment to a particular group in a specific living environment, such as the education area, was still limited. Only a few pieces of research had a focus on HMs pollution in the education area. For example, based on the pollution characteristics and spatial distribution of HMs from nursery and primary school dust in Xi'an, Chen et al. (2014) had revealed the hot-spot area of HMs area mainly associated with industrial activities and traffic density, and limited adverse non-cancer health risk to children due to dust exposure. Li et al. (2017) had compared the pollution characteristics and risk assessment of HMs from street dust in different functional areas in Chengdu. Revealing, the concentration of HMs in the education area was relatively lower than in commercial area, traffic area, residential area, and park area.

As we know, universities or colleges is a place with a high density of students, teachers, and their

62 families (Li et al., 2017; Wei et al., 2015). They study, work, and live on campus every day. With
63 relatively large-scale campuses, universities or colleges can be always considered relatively isolated
64 communities (Li et al., 2017). Especially in Wuhan, one of the four biggest capitals of education in
65 China, with 84 colleges and universities including over 150,000 graduate students and 1 million
66 undergraduate students by the end of 2019. The lack of studies would limit our understanding of the
67 contributions of spatial distribution characteristics, pollution, and potential human health risks to HMs
68 in dust from different functional areas on campus, such as dormitory, canteen, playground, and school
69 gate. Indicating, thousands of students, teachers, and their families may expose to the danger of HMs
70 when they are studying, eating, playing, and resting every day, and we never evaluate the potential
71 health risk at these places.

72 To fill the knowledge gap discussed above, in the present research, our study were (1) to determine
73 the current status of HMs (including Cu, Pb, Zn, Cd, Ni, As, Cr) in dust from different universities
74 and colleges in Wuhan; (2) to analyze the spatial distribution of these HMs in dust from four different
75 functional areas (including the playground, dormitory, canteen, and school gate) in universities and
76 colleges; (3) to evaluate the pollution of these HMs in campus dust using the Geo-accumulation Index;
77 and (4) to assess the carcinogenic and non-carcinogenic health risks associated with these HMs.

78 2. Materials and methods

79 2.1 Study area

80 Wuhan is the capital of Hubei province in Central China (Fig. 1), with a total resident population of
81 over 10 million. With a total of eighty-four universities and colleges, Wuhan is the university cluster
82 in Central China. Most of the colleges and universities are located on the east side of the Yangtze
83 River, which is the educational and resident area in Wuhan. Moreover, Wuhan is also the biggest

developing city in Central China. The GDP of Wuhan had reached 1.62 trillion yuan by the end of 2019. The climate of the area is humid subtropical with an average annual temperature of 15.8-17.5°C and an annual rainfall of 1269 mm. Based on the meteorological statistics of the Hubei meteorological service since 1990, the local dominant wind direction is northeaster in winter (Liu et al., 2020b).

2.2 Sampling and preparation

From November 5th to 9th, 2019, a total of seventy samples were collected from fourteen universities and colleges in two parallel zones (Fig. 1). Zone A is the downtown area with heavy traffic and intensive residence, while Zone B is the economic development area with lots of construction projects and industrial parks (Fig. 1).

The sampling universities and colleges are including famous universities, such as Wuhan University (WH-U), Huazhong University of Science and Technology (HZ-U), and Wuhan University of Technology (WT-U). The campus area of them were 3.47 km^2, 4.67 km^2, and 2.66 4.67 km^2, respectively (Fig. 1). These kinds of universities are almost small independent communities. However, some local universities would have a relatively small campus. The campus area of Wuhan University of Science and Technology (ST-U), Hubei University (HB-U), Zhongnan University of Economics and Law (ZE-U), Hubei University Of Technology (HT-U), China University Of Geosciences (CG-U), Wuhan Textile University (WHT-U), Hubei University Of Education (HE-U), City College, Wuhan University of Science and Technology (CC-C), Hubei University of Traditional Chinese Medicine (CM-U) and Wuchang University of Technology (WT-U) was1.70 km^2, 1.4 km^2, 1.87 km^2, 1.11 km^2, 1.43 km^2, 1.33 km^2, 1.14 km^2, 0.57 km^2, 0.79 km^2, and 0.82 km^2, respectively (Fig. 1). These kinds of universities would have a relatively tight link to local development. Moreover, the ZE-U was divided into Shouyi Campus (ZE-SC) and Nanhu Campus (ZE-NC), which are located in different areas (Fig.

1).

Moreover, ST-U located in the north of Zone A. HB-U, WH-U, ZE-SC, WT-U, and HT-U located in the center of Zone A. CM-U located in the southwest of Zone A. While, CC-C located in the northeast of Zone B. HZ-U, CG-U, WHT-U, HE-U and ZE-NC located in the center of the Zone B. WCT-U located in the south of Zone B (Fig. 1). Additionally, four different functional areas in each campus were chosen to collect dust samples, including playground dust, dormitory dust, canteen dust, and school gate dust. Details of the sampling sites are provided in Table S1.

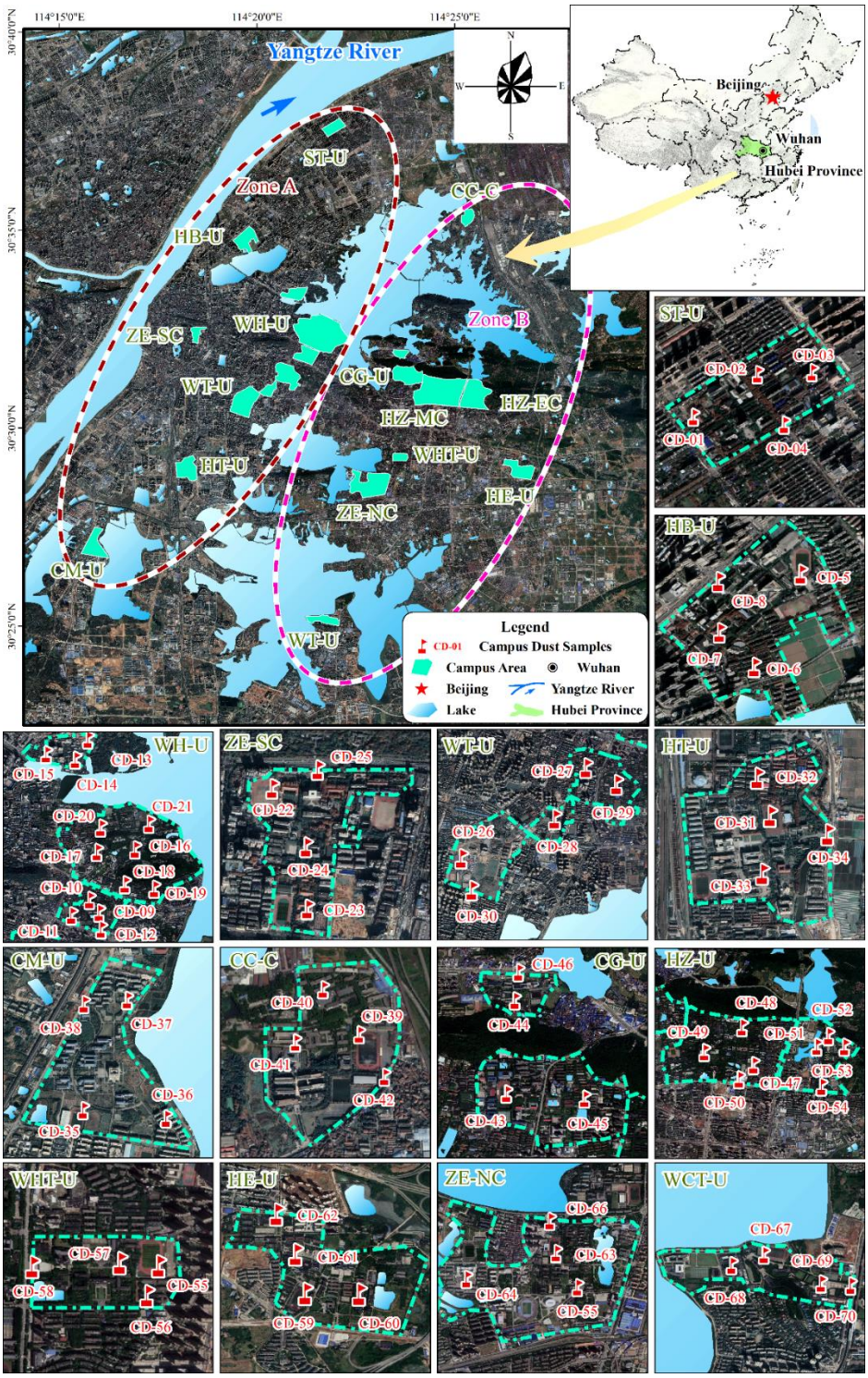

Fig. 1. General map showing location of study area and sampling sites at universities and colleges in Wuhan.

During sampling, approximately 100 g of the dust particles were collected using plastic brushes and dustpans by a gentle sweeping motion from buildings at a height of 1.5-2m. After each sampling,

brushes, and dustpans were cleaned with paper towels. All samples were stored in paper bags wrapped with solvent-rinsed aluminum foil and then sealed in polyethylene bags for transport to the laboratory. The samples were then placed in a desiccator to get rid of moisture, and then a 100 μm sieve was used to remove coarse debris and small stones. And an agate mortar was used to grind and homogenize. Then all the samples had been sieved to 63 μm. Eventually, after homogenization, samples were placed in an air-tight container for storage.

2.3 Chemical analyses

Seven kinds of heavy metals (Cu, Pb, Zn, Cd, Ni, As, and Cr) in all dust had been determined in this research. They were analyzed according to the procedure explained by Cui et al. (2020). Briefly, the sieved samples (0.2g) were weighed and placed into a digestion vessel with HNO_3, HCl, and HF. The vessel was sealed tightly and placed in a digestion chamber. After cooling, the samples were collected, filtered, and diluted to a constant volume. To prevent contamination of the samples, all-glass dished and digestion vessels were immersed in 5% nitric acid for 24h, then washed and dried before use. The concentrations of As were measured using an AFS-203E atomic fluorescence spectrophotometer. The concentrations of Cu, Pb, Zn, Cd, Ni, and Cr were measured with an inductively coupled plasma source-mass spectrometer (Perkin – Elmer Elan 9000).

The purity of all reagents was an excellent level of pure. The accuracy and precision of analysis were established by analysis of the national one-level soil standard materials. These tests showed that the analytical results were accurate and reliable. The logarithmic deviation (Δlg[C]) for all heavy metals was smaller than 0.05, and the quoted rate was 100%. Procedural blanks, spiked blanks, sample duplicates (10%) were analyzed to evaluate the precision. The relative double difference (RD)

is<10% and the analysis yield was up to 100%. The heavy metals found in the procedural blanks were generally below the limit of detection. No target heavy metals were detected in blanks. All the test results conform to monitoring requirements.

2.4 Heavy metals contamination assessment

The geo-accumulation index (I_{geo}) was used to estimate the natural variation in the heavy metal distribution in soil and identify the effects of human activities on the environment by Muller (1969) by using the following equation.

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

where C_n is the concentration of heavy metal in the surface dust and B_n is the geochemical background concentration value of corresponding measured heavy metals in Hubei province, China. Factor 1.5 is considered to be a background matrix correction value to accommodate some human effects and to allow possible fluctuations and variations in the reference background values (Kusin et al., 2018). The I_{geo} is evaluated by dividing it into seven classes as given in Table S2.

2.5 Source apportionment method

To evaluate the obtained results, principal component analysis (PCA) was used. It was widely used to extract a smaller number of independent factors among available data for analyzing variables relationships (Liu et al., 2020a). PCA could make it easier to interpret a given multidimensional system by displaying the correlations among the original variables (Zhao et al., 2020). Additionally, PCA has also widely applied to various environmental media, to identify pollution sources and to apportion natural versus anthropogenic contributions (Bi et al., 2020). The components of the PCA were transformed using varimax rotation with Kaiser Normalization after the analysis (Kaiser, 1960).

In the current study, PCA was used to elucidate the latent relationships between variables and for investigating pollutant sources. The statistical analyses were performed using SPSS package version 22.0.

2.6 Health risk assessment

Nowadays, health risk assessment has been used to quantitatively describe the possibility of carcinogenic and non-carcinogenic risks of heavy metal pollutants to human beings, thus human health with linking environmental pollution. Basing on behavioral and physiological differences, people could be divided into adults and children (Liu et al., 2019). In Chain, most of the undergraduate and graduate students are over 18 years old. Indicating, they have already been adults. Therefore, in our research, adults mainly refer to students and teachers. Moreover, surface dust mainly enters the human body through skin contact, respiration, and hand-mouth direct intake (USEPA, 2009). The average daily dose (ADD) was calculated for the three exposure pathway: ingestion, inhalation, and dermal absorption using the following formulas (USEPA, 2009; Zhang et al., 2019)

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

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

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

where ADD_{ing} is the average daily exposure to particulates in dust through the hand-mouth intake in mg (kg d)$^{-1}$, ADD_{inh} is the average daily exposure to particulates in dust through respiration pathways in (kg d)$^{-1}$, ADD_{derm} is the average daily exposure to particulates in dust through skin contact in (kg d)$^{-1}$. The other parameters are defined, and values are provided in Table S3. Parameters were taken from the USEPA evaluation standards and corrected for local factors in China.

Non-carcinogenic risks were evaluated by comparison to the reference dosage associated with chronic toxicity. The heavy metals are unlikely to cause harm when the dose below the reference value, otherwise they are risks. The non-carcinogenic risk posed by heavy metals can be expressed as follow (USEPA, 2009; Wahab et al. 2020; Zhang et al. 2019):

$$HQ = \frac{ADD_i}{RfD} \quad (5)$$

$$HI = \sum HQ_i \quad (6)$$

where RfD is the reference dose (mg kg^{-1} d^{-1}), which is regarded as an estimate of daily exposure to the human population (Gao et al. 2015), HQ is the ratio of the average daily dose to the RfD of a specific metal for a single pathway, HI is a cumulative metric for HQs for individual heavy metals and exposure pathways. Base on USEPA (2001) report, if HI<1, it is unlikely to hurt the health of the exposed individual. However, if HI>1, it indicates that heavy metals would cause non-carcinogenic risk to the population (Eziz et al. 2018).

Unlike the non-carcinogenic risk, for health risks associated with carcinogenic heavy metals, the incremental lifetime cancer risk (ILCR) was estimated as the incremental probability of an individual developing cancer over time due to exposure to carcinogenic heavy metals(USEPA, 1989). The ILCR was determined as in the following formula (Doabi et al., 2018; Zhang et al., 2019):

$$ILCR = ADD \times SF \quad (7)$$

where SF is the carcinogenic slop factor of heavy metals (mg kg^{-1} d^{-1}). If the ILCR value is below 1×10^{-6} it is accepted that there are no significant health risks for humans. While the acceptable range of ILCR is between 1×10^{-6} - 1×10^{-4} (Liu et al. 2019). According to the previous researches, RfD and SF values in different exposure routes are given in Table S4 (Chen et al., 2015; Eziz et al., 2018;

202 Ferreira-Baptista and De Miguel, 2005; Lu et al., 2014).

203 **2.7 Data analysis**

204 The minimum, maximum, median, mean, standard deviation (SD), and coefficient of variations
205 (CV) of research data were calculated with SPSS 22.0 statistical package (Statistical Product and
206 Service Solutions, SPSS Inc., USA). The standard deviation and coefficient of variations were
207 incorporated to reflect the degree of dispersion distribution of different heavy metals (Cui et al. 2020).
208 Two data mapping software packages were used including ArcGIS desktop 10.5 (ESRI, Redlands, CA,
209 USA) and OriginPro 2018C (OriginLab, Northampton, Massachusetts, USA).

210 **3. Results and discussion**

211 **3.1 Heavy metal concentration in campus dust**

212 Table 1 had shown the concentrations of HMs (Cu, Pb, Zn, Cd, Ni. As, and Cr) in campus dust in
213 different universities and colleges. In all samples, HMs concentration were ranked Pb (83.5 ± 57.8 mg
214 kg^{-1}) > Cu (70.2 ± 52.2 mg kg^{-1}) > Zn (47.2 ± 102 mg kg^{-1}) >Cr (46.0 ± 27.8 mg kg^{-1}) > Ni (22.7 ±
215 13.2 mg kg^{-1}) > As (15.2 ± 6.20 mg kg^{-1}) > Cd (3.38 ± 2.25 mg kg^{-1}). Moreover, the CV values of all
216 HMs in all campus dust were relatively high (over 39.9%). The CV values were usually used to
217 reflect the average degree of variation between HM contents at different sampling sites (Cui et al.,
218 2020). Indicating, HM concentrations in campus dust in Wuhan were highly variable. Especially, the
219 CV value of Zn was 122%, indicating a spatially heterogeneous distribution of Zn. The concentration
220 of Zn varies significantly in campus dust in Wuhan. This is attributed to local pollution sources or
221 artificial non-point pollution sources (Lyu et al., 2017). Comparing with local background values, the
222 median concentrations of Cu, Pb, Zn, Ni, As, and Cr were 2.54, 3.61, 1.00, 0.73, 1.26, and 0.58 times

223 higher than their corresponding background values, respectively. These results indicated that Cu, Pb,
224 and As in most campus dust mainly originated from anthropogenic activities, whereas Ni, Zn, and Cr
225 might primarily derive from natural sources (Zhao et al., 2019).

226 Compared with the reported concentration of HMs in school dust and road dust in the education
227 area of some typical cities in China, the concentrations of Cu, Pb, Ni, and Cr in campus dust from
228 Wuhan was similar to those in road dust in education from Chengdu (Li et al., 2017) and Beijing (Wei
229 et al., 2015) (Table S5). Moreover, the concentrations of Pb, Ni, and Cr in campus dust from Wuhan
230 were lower than those in school dust from Xi'an (Chen et al., 2014). Especially, the concentrations of
231 Zn in Wuhan campus dust were typically lower than those from Chengdu (Li et al., 2017), Beijing
232 (Wei et al., 2015), and Xi'an (Chen et al., 2014) (Table S5). Comparing the concentration of HMs in
233 road dust and urban dust of some typical cities within and outside the country, the concentrations of
234 most HMs in campus dust in Wuhan were lower than those in Turin (Padoan et al., 2017) and
235 Thessaloniki (Bourliva et al., 2017), except for Cd (Table S5). Moreover, the concentration of Cu, Pb,
236 Zn, Ni, As, and Cr from urban dust and road dust of some big cities in China are much higher than
237 those in our study, such as Beijing (Men et al., 2018), Xi'an (Cao et al., 2011), Shanghai (Bi et al.,
238 2018), Nanjing (Hu et al., 2011), and other 58 cities (Zhang et al., 2019). A big city like Wuhan is an
239 assembly of different land-use types, the distinctive artificial activities in each functional area could
240 release different kinds of heavy metals content (Trujillo-Gonzalez et al., 2016). As universities and
241 colleges always have relatively large campus areas, artificial activities may have less influence on
242 campus areas (Li et al., 2017). Showing the concentration of most HMs in campus dust from Wuhan
243 was lower than that in urban dust or road dust from other cities.

244 However, only the concentration of Cd in Wuhan was significantly higher than those in other cities

(Table S5) and 25.7 times higher than the local background value (Table 1). Previous studies had already supported that Cd had a relatively higher concentration in Wuhan (Tadesse et al., 2018). As Cd was relatively abundant in the crust rocks of the Yangtze River basin and Hanjiang River basin, the natural factors may be a source for the relatively high level of Cd concentration in Wuhan (Ma et al., 2005; Zhang et al., 2015). Still, fossil fuel combustion and industrial discharges from smelting and electric plating may significantly contribute to the wide spreading of Cd in Wuhan (Wei et al. 2009; Zhang et al., 2015).

Table 1 Statistical results of heavy metals in campus dusts (Unit: mg kg^{-1})

Statistic	Cu	Pb	Zn	Cd	Ni	As	Cr
All (N[a]=70)							
Minmum	22.4	27.1	0.386	1.87	11.3	4.37	0.260
Maximum	441	314	623	16.4	83.3	33.5	161
Median	77.8	96.5	84.0	3.84	27.1	15.5	49.9
Mean	70.2	83.5	47.2	3.38	22.7	15.2	46.0
SD[b]	52.2	57.8	102	2.25	13.2	6.20	27.8
CV[c](%)	67.0%	59.9%	122.0%	58.5%	48.6%	39.9%	55.7%
Zone A (N[a]=38)							
Minmum	22.4	30.7	0.386	1.87	11.3	6.19	15.4
Maximum	218	314	623	6.31	83.3	33.5	119
Median	77.1	96.8	107	3.38	29.8	15.6	53.9
Mean	73.7	85.6	83.2	3.22	25.8	15.6	48.9

SD[b]	34.0	56.0	114	0.95	15.2	5.84	23.5
CV[c](%)	44.1%	57.8%	107.0%	28.2%	51.2%	37.5%	43.5%
Zone B (N[a]=32)							
Minmum	24.4	27.1	1.06	2.23	13.2	4.37	0.26
Maximum	441	308	381	16.4	49.4	31.0	161
Median	78.7	96.1	56.7	4.40	23.9	15.5	45.3
Mean	65.8	81.8	31.3	3.58	21.3	13.9	42.0
SD[b]	67.7	59.8	77.8	3.07	9.12	6.60	31.6
CV[c](%)	86.0%	62.3%	137%	69.9%	38.2%	42.6%	69.9%
Reference values[d]	30.7	26.7	83.6	0.172	37.3	12.3	86.0

N[a] indicates samples number.

SD[b] indicates standard deviation.

CV[c] indicates coefficient of variation.

Reference values [d] indicates local soil background values CNEMC (1990)

3.2 Spatial distribution of heavy metal pollution in campus dust

3.2.1. Spatial distribution of heavy metal pollution

The mean values of I_{geo} for Cu, Pb, Zn, Cd, Ni, As, and Cr in dust samples of universities and colleges were shown in Fig. 2. The contamination level of Cd was the highest of the seven HMs, followed by Pb and Cu. According to the standard of contamination degree by I_{geo} (Förstner et al., 1990), the mean values of I_{geo} indicated heavily contaminated with campus dust by Cd, slightly to moderately contaminated by Cu and Pb, uncontaminated to slightly contaminated by As and Zn, uncontaminated by Ni and Cr. These results also revealed that the education areas were relatively low

contaminated by most HMs (Pan et al., 2017). Indicating, artificial activities would have less influence on universities and colleges (Li et al., 2017). However, as Cd had a relatively higher concentration in Wuhan (Tadesse et al., 2018), education areas were also contaminated by Cd.

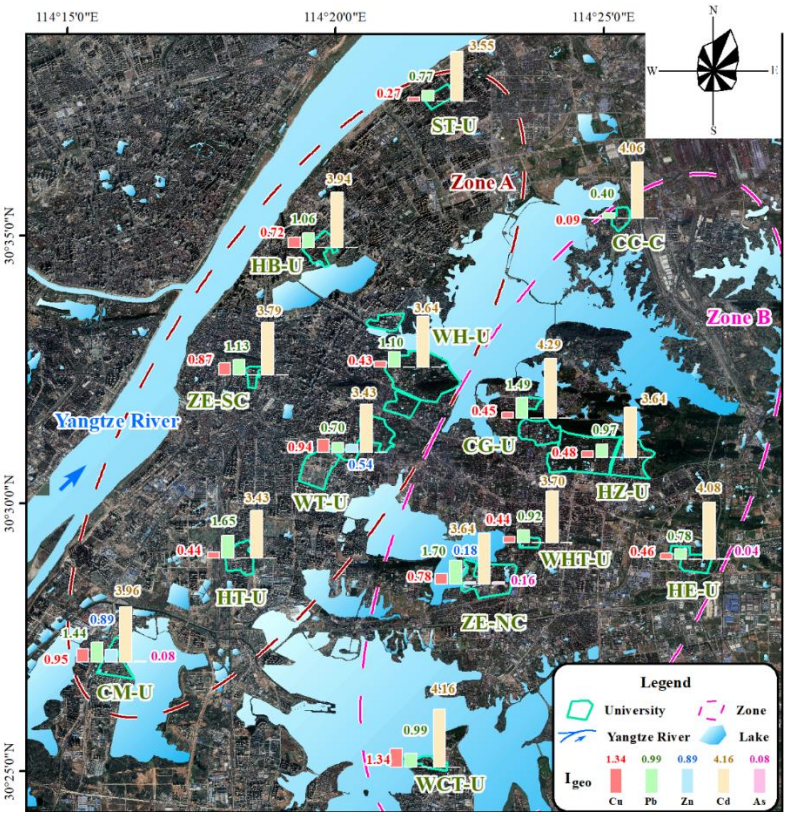

Fig. 2. Spatial distribution of Geo-accumulation index (I_{geo}) for HMs in campus dusts from different universities and colleges. The I_{geo} value lower than zero, indicating no contaminated, was not shown on the figure.

Fig. 2 also showed the local dominant wind, which is northeaster in winter, may affect the distribution of I_{geo} values of HMs. Such as, in Zone A, the mean I_{geo} values of HMs in campus dust from the seven universities were ranked as follows: ST-U (northeast of Zone A) < HB-U, ZE-SC, WH-U, WT-U, and HT-U (center of Zone A) < CM-U (southwest of Zone A). Additionally, the same results were also found in zone B, such as CC-C (northeast of Zone B) < CG-U, HZ-U, WHT-U,

HE-U, and ZE-NC (center of Zone B) < WCT-U (southwest of Zone B), indicating the accumulation of HMs in campus dust would be influenced by local meteorological conditions.

Additionally, comparing the I_{geo} values of Cu and Pb from different universities in Zone A and B, the results showed that the I_{geo} value of Cu from the universities in Zone A was relatively higher than that from the universities, which is located in a similar position in Zone B (Fig. 2). Such as, I_{geo} value of Cu from ST-U (northeast of Zone A) was relatively higher than that from CC-C (northeast of Zone B). I_{geo} values of Cu from HB-U, ZE-SC, WH-U, WT-U, and HT-U (center of Zone A) were relatively higher than that from CG-U, HZ-U, WHT-U, HE-U, and ZE-NC (center of Zone B). And I_{geo} value of Cu from CM-U (southwest of Zone A) was relatively higher than that from WCT-U (southwest of Zone B). However, the I_{geo} values of Pb from the universities in Zone A and Zone B showed opposite results. As we know, Zone B is an economic development area with lots of construction projects and industrial parks, Cu and Pb may source of traffic emission, industrial emission, and city construction (Dong et al., 2017). Especially, I_{geo} values of HMs in WCT-U were higher than those in other universities. During sampling, a construction site is located just 100 m away from the south of WCT-U. It kept construction for one year already (Fig.1). The campus dust in WCT-U would already be affected by local city construction. While Zone A is the downtown area with heavy traffic, Cu accumulation may commonly release through the wear of vehicular materials, such as brakes (Świetlik et al., 2015). And Pb may also from anthropogenic source, such as the use of leaded gasoline (Doabi et al., 2018). Moreover, the I_{geo} values of Pb in Zone A were relatively lower than those in Zone B. These results also revealed that traffic-related exhaust emissions of metals were substantially reduced through the phasing out of leaded gasoline and the implementation of other exhaust pollution controls measures in the downtown area (Tang et al., 2017).

3.2.2. Pollution characteristics of different functional areas dusts

The results of I_{geo} of HMs from different functional areas were presented in Fig. 3 and Table S6. Generally, for most HMs, the I_{geo} value from different functional areas showed as similar in Fig. 3. Indicating, the pollution characteristics for most HMs in campus dust were effect by local atmospheric conditions (Liu et al., 2020b). Moreover, the mean values of I_{geo} of As, Ni, Zn, and Cr were lower than 0. Indicating, the campus area in Wuhan had less affected by these metals. All the I_{geo} values for Ni and Cr in playground dust, dormitory dust, and school gate dust were lower than 0. Revealing, these areas were not threatened by these metals.

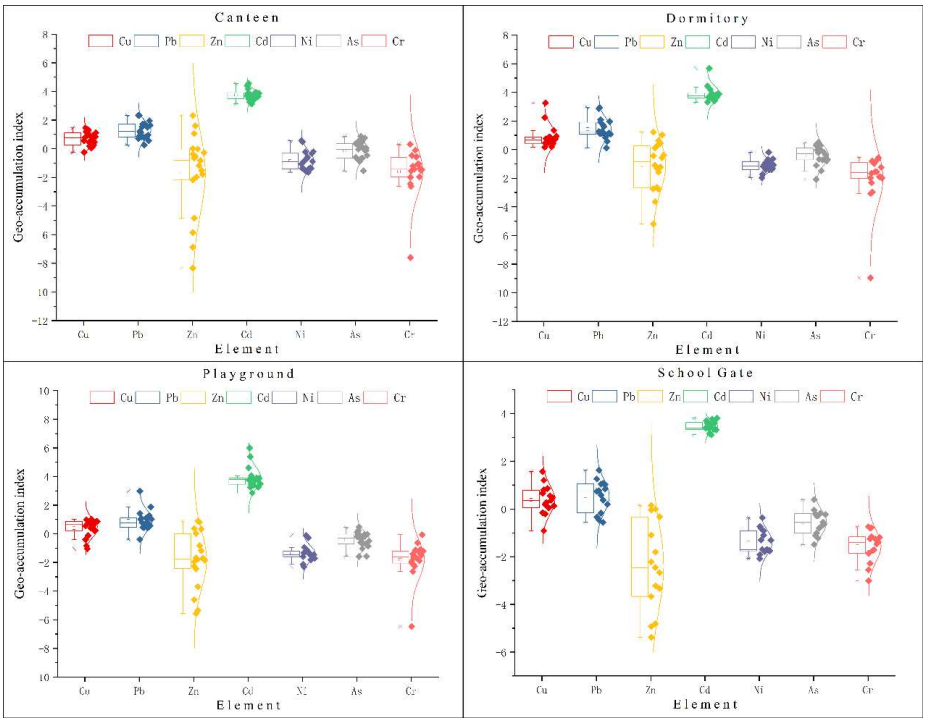

Fig. 3. The statistic of Geo-accumulation index (Igeo) values of HMs in campus dusts around canteen, dormitory, playground, and school gate areas.

Fig. 3 and Table S6 also showed, the playground dust was uncontaminated or slightly contaminated by As and Zn, while it was slight to moderately contaminate by Cu and Pb in most universities and colleges. The highest I_{geo} value for Cd (5.99) was found in playground dust. And all the I_{geo} values for

Cd were over 2. Indicating, playground dust was heavy to extremely contaminated by Cd. In dormitory dust, the mean I_{geo} value for Pb (1.43) and Cu (0.86) was almost significantly higher than that in playground dust, respectively. While it was uncontaminated or moderately contaminated by Zn. The mean I_{geo} value for Cd was 3.89 in dormitory dust. Showing, dormitory dust was also heavily to extremely contaminated by Cd. Comparing with dormitory dust and playground dust, the I_{geo} values for all HMs were relatively lower in school gate dust. Most I_{geo} values for As and Zn were below 0. The I_{geo} values for Cu in 87% samples and Pb in 67% samples were below 1. Indicating, school gate dust was uncontaminated or moderately contaminated by these metals. Moreover, all the I_{geo} values for Cd were between 3 and 4. Heavily contaminated by Cd could be revealed in school gate dust. Canteen dust was contaminated by all the HMs in different degrees. The I_{geo} value for Cr in 5% samples, As in 47% samples, Ni in 11% samples, Zn in 21% samples, Cu in 99% samples, Pb in all samples, and Cd in all samples was over 0 in canteen dust. The I_{geo} value for Zn in 5% samples and Pb in 11% samples was over 2. Additionally, 16% of the I_{geo} value for Cd was over 4 and others were over 3. Revealing, the canteen dust was also heavily to extremely contaminated by Cd.

As far as the overall behavior of the HMs understudy is concerned, based on I_{geo}, it could reveal that the playground dust, dormitory dust, school gate dust and canteen dust samples in universities and colleges were practically uncontaminated to moderately contaminated for Cr, Ni, As and Zn, practically uncontaminated to heavily contaminated for Cu and Pb, and heavily to extremely contaminated for Cd. The highest I_{geo} value for Cd (5.99) was shown in playground dust.

According to the I_{geo} values, only canteen areas were threatened by all the HMs. In general, cooking fumes may be the main reason for these HMs (Sun et al., 2017). Li et al. (2017) had already revealed the direct emission of food, cooking oil, ingredients, and fuel in the cooking process in

Chinese kitchens would increase the content of HMs, such as Pb, Zn, As, Fe, Cu, and Cr. Additionally, unqualified cookstoves and other cooking utensils would also release heavy metals at high temperatures (Zhang et al., 2017). Indicating, HMs would easily accumulate in the dust around the canteen. Except for the highest I_{geo} value for Cd (5.99) in playground dust, the mean I_{geo} values for HMs were lower in playground dust and school gate dust than that in dormitory dust and canteen dust. As the playground and school gate area are relatively spacious areas. The dust in spacious areas would easily effect by local atmospheric flow and hardly accumulate for a long time (Kolakkandi et al., 2020). However, the dormitory and canteen areas are always surrounded by buildings, which would benefit HMs accumulation (Adimalla et al., 2020).

3.3 Source apportionment of HMs in campus dust

Source identification of HMs is critical for pollution prevention and human health protection (Li et al., 2020). In general, significant correlations between pairs of HMs always suggest a common or combined origin, whereas weak correlations indicate different origins (Yang et al., 2020).

For the universities in Zone A, the Kaiser – Meyer – Olkin index was 0.739 and the result of Bartlett's sphericity test was significant at $p < 0.001$. Revealing, the HMs concentrations in Zone A was suitable for PCA (Liu et al., 2020a). The loading plot of PCA was shown in Fig. 4. The results demonstrate that there are three eigenvalues higher than 1.00, and these three factors explain 71.8 % of the total variance.

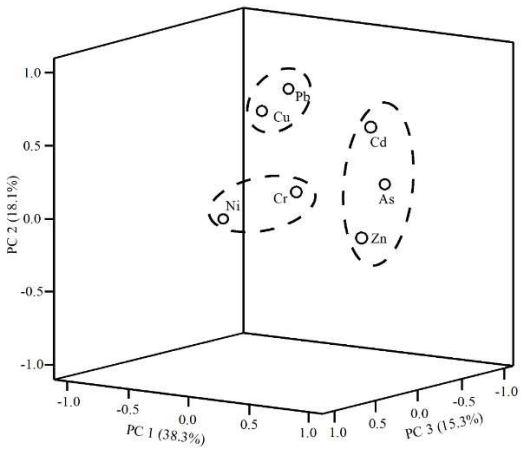

Fig. 4. PCA results of HMs from campus dust in Zone A in the three-dimensional space: plot of loading of the first three principal components.

The first principal component (PC1) explains 38.3 % of the total variance. It includes significant loadings for Zn, As, and Cd with loading values of 0.85, 0.80, and 0.56, respectively. Moreover, the concentration of Cd was significantly higher than the local background value. Many studies (Bhuiyan et al., 2021; Zhang et al., 2015) had already revealed Cd may relatively abundant in the crust rocks of the Yangtze River basin and Hanjiang River basin, indicating that Cd probably originated from natural geochemical processes such as weathering. Additionally, universities would like a small community, people would use fossil fuel for cooking every day. Indicating, fossil fuel combustion would also the probable source for Cd (Bi et al., 2020). The concentration of Zn was relatively lower than the local background value. While the concentration of As was slightly higher than the local background value. Indicating, they may source from natural geochemical processes. Additionally, Kolakkandi et al. (2020) also proved As and Zn may also source from fossil fuel combustion. Indicating, the sources of As, Zn, and Cd had been preliminarily identified to be a mixture of anthropogenic sources, such as fossil fuel combustion and natural geochemical processes such as weathering. In the loading plot (Fig. 4), Pb and Cu formed a group, with similar loading for PC2. I_{geo} values indicate the campus dust was

practically uncontaminated to be heavily contaminated for Cu and Pb. Revealing, they would source from many anthropogenic activities, such as heavy traffic, fossil fuel combustion, and industrial exhausting (Zhang et al., 2012). However, in Wuhan, the universities would more like isolated communities. Teachers and students learning, eating, and living here. Especially, in Zone A, which is the downtown area without industrial activities, the Cu and Pb in campus dust would more likely source from cooking. In Chinese kitchens, the use of cooking oil, ingredients, and fuel would emission Pb and Cu (Li et al., 2015). And the unqualified cook stoves and other cooking utensils would also release Pb and Cu at high temperatures (Zhang et al., 2017). Moreover, previous researches also revealed, the accumulation of Cu and Pb would commonly release through traffic sources, such as wearing of the vehicular materials and using leaded gasoline (Zhang et al., 2012). Therefore, in some universities with a relatively small campus in Zone A, traffic problems would also affect by anthropogenic activity. Indicating, the sources of As, Zn, and Cd had been preliminarily identified to be anthropogenic sources, such as cooking and traffic transportation. PC3 accounted for 15.3 % of the total variance and was dominated by Ni and Cr. The concentration of these two HMs was lower than their soil background values. We observed no obvious geo-accumulation of Ni and Cr for most campus dust from Zone A. Therefore, PC3 would likely reflect the contributions of the natural soil weathering.

However, for the universities in Zone B, the Kaiser – Meyer – Olkin index was 0.372 and the result of Bartlett's sphericity test was significant at $p > 0.001$. Indicating, the HMs concentrations in Zone B were suitable for PCA (Liu et al., 2020a). Moreover, Table S7 also revealed the HMs from campus dust showed no significant correlation with each other in Zone B. Zone B is the economic development area with lots of construction projects and industrial parks in Wuhan. HMs in this area

would from multiple sources. Indicating, the source of HMs from campus dust in Zone B would mainly infect affect by local development, such as industrial activities, heavy traffic, local construction, etc.

3.4 Potential health risk assessment of heavy metals in campus

The non-carcinogenic health risks posed by HMs in campus dust for different intake pathways were shown in Table S8. The non-carcinogenic health risk posed by different HMs in campus dust and for the different exposure pathways varies significantly. Generally speaking, among the three routes of exposure, the HQ value of the ingestion pathway was the highest. Similarly, results are also revealed from surface dust and street dust (Tang et al., 2017). Considering the lower body weight than adults, children are believed to be of higher intake of HMs (Zhang et al., 2020). Additionally, health risks through ingestion are greater for children also due to their hand-to-mouth activity (Liu et al., 2020b; Zhang et al., 2020). Their nervous system is still developing and prone to high rates of HMs diffusion (Cui et al., 2020).

For all the people, the health risks were ranked As > Pb > Cr > Cd > Cu > Ni > Zn, based on the HQ value. Additionally, the HQ values for single heavy metal did not exceed the USEPA safe threshold (Wei et al., 2017). Indicating, for teachers and students, single heavy metal would not cause significant non-carcinogenic health risks on campus in Wuhan. However, for children, the HI values of HMs in campus dust from HB-U, WH-U, ZE-SC, WT-U, HT-U, CM-U, CG-U, HZ-U, WHT-U, HE-U, ZE-NC, and WCT-U were 1.39, 1.40, 1.38, 1.25, 1.55, 1.89, 1.37, 1.26, 1.32, 1.50, 1.74, and 1.52, respectively. Indicating, multiple HMs from campus dust from these universities above would cause harm to the physical health of children, and that measures should be taken to mitigate the risks.

Fig. S1 showed for all the people, the HI values of different areas campus dust were ranked

canteen > dormitory > playground > school gate. For children, the HI values for HMs in these places were all over 1.00. Most children living in university would be the teacher's son and daughter. They would barely go to the dormitory, which is the living place for undergraduate and graduate students. Indicating, the children would more likely to exposure health risks, when eating in the canteen, playing on the playground, or walking around the school gate. Moreover, Fig. S1 also suggested that HMs in campus dust will not damage the physical health of teacher, undergraduate, or graduate students.

Additionally, the carcinogenic risks posed by Pb, Cd, Ni, As, and Cr in campus dust was showed in Table S9. Based on the findings, the ILCR values of students and teachers in the study area were higher than that of children. Indicating, the relatively high respiration rate would increase the carcinogenic risks for students and teachers (Wahab et al., 2020). However, the carcinogenic risks posed by HMs in campus dust were lower than 10^{-6}. Indicating, it was significantly lower than the carcinogenic risk level (Adimalla et al., 2020). Therefore, the respiratory intake of HMs does not pose a carcinogenic risk and will not damage human physical health on the campus.

4. Conclusions

Our study demonstrated that the average concentrations of HMs in campus dust from universities or colleges in Wuhan ranked Pb > Cu > Cr > Zn > Ni > As > Cd. The contamination level of Cd was the highest of the seven HMs, followed by Pb and Cu. And I_{geo} values also showed uncontaminated to slightly contaminated with campus dust by As and Zn, while uncontaminated by Ni and Cr. The distribution of I_{geo} values in all universities revealed the accumulation of HMs in campus dust would be influenced by local meteorological conditions. According to the I_{geo} values, only canteen areas were threatened by all the HMs. The HMs would more likely to accumulate in dormitory dust and

canteen dust, as the dormitory and canteen areas were always surrounded by buildings. In Zone A, according to the results of PCA, Zn, As, and Cd had been preliminarily identified to be a mixture of anthropogenic sources, such as fossil fuel combustion and natural geochemical processes such as weathering. Cu and Pb would source from anthropogenic activities, such as cooking and traffic transportation. While Ni and Cr would likely reflect the contributions of the natural soil weathering. However, HMs from campus dust showed no significant correlation with each other in Zone B. Indicating, the source of HMs from campus dust in Zone B would mainly infect affect by the local development, such as industrial activities, heavy traffic, local construction, etc. No significant non-carcinogenic health risks were found to students and teachers by campus dust. However, multiple HMs from campus dust would cause harm to the physical health of children. They would more likely to exposure health risks when eating in the canteen, playing on the playground, or walking around the school gate, especially around the canteen. While the ILCR values revealed respiratory intake of HMs does not pose a carcinogenic risk and will not damage human physical health on campus. However, the accumulation process of HMs in different functional areas in universities would still need to be solved in further research.

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(2018103).

Declarations

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Conflicts of interest/Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material

All data generated or analysed during this study are included in this published article [and its supplementary information files].

Code availability

Not applicable

Authors' contributions

We would like to introduce the individual author contributions as follows: Conceptualization: [Shan Liu], [Jiaquan Zhang], Data Curation: [Xihao Zhang], [Jun Xu], Formal analysis: [Shan Liu], Funding acquisition: [Jiaquan Zhang], [Xianli Liu], Investigation: [Xihao Zhang], [Jun Xu], [Anglv Wang], [Huidi Zhang], [Jiangyan Xu], [Yulun Xiao], Project administration: [Jiaquan Zhang],

Resources: [Jianlin Guo], [Xinli Xing], Supervision:[Junji Cao], Writing – original draft: [Shan Liu], Writing – review & editing: [Changlin Zhan].

Ethics approval

Not applicable

Consent to participate

All authors read and approved the final manuscript.

Consent for publication

All authors read and approved for publication.

References

Adimalla, N., Chen, J., Qian, H. 2020. Spatial characteristics of heavy metal contamination and potential human health risk assessment of urban soils: A case study from an urban region of South India. *Ecotoxicology and Environmental Safety*. 194, 110406.

Bhuiyan, M. A. H., Karmaker, S. C., Bodrud-Doza, M., Rakib, M. A., Saha, B. B. 2021. Enrichment, sources and ecological risk mapping of heavy metals in agricultural soils of dhaka district employing SOM, PMF and GIS methods. *Chemosphere*. 128339.

Bi, C., Zhou, Y., Chen, Z., Jia, J., Bao, X. 2018. Heavy metals and lead isotopes in soils, road dust and leafy vegetables and health risks via vegetable consumption in the industrial areas of Shanghai, China. *Science of The Total Environment*. 619-620, 1349-1357.

Bi, X., Zhang, M., Wu, Y., Fu, Z., Sun, G., Fu, Z., Sun, G., Shang, L., Li, Z., Wang, P. 2020. Distribution patterns and sources of heavy metals in soils from an industry undeveloped city in Southern China. *Ecotoxicology and Environmental Safety*. 111115.

Bourliva, A., Christophoridis, C., Papadopoulou, L., Giouri, K., Papadopoulos, A., Mitsika, E.,

Fytianos, K., 2017. Characterization, heavy metal content and health risk assessment of urban road dusts from the historic center of the city of Thessaloniki, Greece. *Environmental Geochemistry and Health*. 39, 611-634.

Cao, Z., Yang, Y., Lu, J., Zhang, C., 2011. Atmospheric particle characterization, distribution, and deposition in Xi'an, Shaanxi Province, Central China. *Environmental Pollution*. 159, 577-584.

Chen, H., Lu, X., Li, L. Y., Gao, T., Chang, Y. 2014. Metal contamination in campus dust of Xi'an, China: A study based on multivariate statistics and spatial distribution. *Science of the Total Environment*. 484, 27-35.

Chen, H., Teng, Y., Lu, S., Wang, Y., Wang, J. 2015. Contamination features and health risk of soil heavy metals in China. *Science of The Total Environment*. 512, 143-153.

CNEMC China National Environmental Monitoring Center. 1990. The Background Values of Elements in Chinese Soils. Environmental Science Press of China, Beijing (in Chinese).

Cui, X., Wang, X., Liu, B. 2020. The characteristics of heavy metal pollution in surface dust in Tangshan, a heavily industrialized city in North China, and an assessment of associated health risks. *Journal of Geochemical Exploration*, 210, 106432

Doabi, S. A., Karami, M., Afyuni, M., Yeganeh, M. 2018. Pollution and health risk assessment of heavy metals in agricultural soil, atmospheric dust and major food crops in Kermanshah province, Iran. *Ecotoxicology and Environmental Safety*, 163: 153-164.

Dong, S., Gonzalez, R.O., Harrison, R.M., Green, D., North, R., Fowler, G., Weiss, D., 2017. Isotopic signatures suggest important contributions from recycled gasoline, road dust and non-exhaust traffic sources for copper, zinc and lead in PM_{10} in London, United Kingdom. *Atmospheric Environment*. 165, 88–98.

Eziz, M., Mohammad, A., Mamut, A., Hini, G. 2018. A human health risk assessment of heavy metals in agricultural soils of Yanqi Basin, Silk Road Economic Belt, China. *Human & Ecological Risk Assessment An International Journal*. 24(5), 1-15.

Ferreira-Baptista, L., De Miguel, E. 2005. Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. *Atmospheric Environment*. 39(25), 4501-4512.

Förstner, U., Ahlf,W., Calmano, W., Kersten, M., 1990. In: Dietrich, Heling (Ed.), Sediment Criteria Development-Contributions From Environmental Geochemistry to Water Quality Management.

Gao, P., Liu, S., Ye, W., Lin, N., Meng, P., Feng, Y., Zhang, Z., Cui, F., Lu, B., Xing, B. 2015. Assessment on the occupational exposure of urban public bus drivers to bioaccessible trace metals through resuspended fraction of settled bus dust. *Science of The Total Environment*. 508, 37–45.

Hu, X., Zhang, Y., Luo, J., Wang, T. J., Lian, H. Z., Ding, Z. H.,2011.Bioaccessibility and health risk of arsenic, mercury and other metals in urban street dusts from a mega city, Nanjing, China. *Environmental Pollution*. 159, 1215-1221.

Kaiser, H.F., 1960. The application of electronic computers to factor analysis. Educational and Psychological Measurement. 20, 141–151.

Kolakkandi, V., Sharma, B., Rana, A., Dey, S., Rawat, P., Sarkar, S. 2020. Spatially resolved distribution, sources and health risks of heavy metals in size-fractionated road dust from 57 sites across megacity Kolkata, India. *Science of the Total Environment*. 705, 135805.

Kusin, F. M., Azani, N. N. M., Hasan, S. N. M. S., Sulong, N.A. 2018. Distribution of heavy metals and metalloid in surface sediments of heavily-mined area for bauxite ore in Pengerang, Malaysia and associated risk assessment. *Catena* 165, 454-464.

Li, H. H., Chen, L. J., Yu, L., Guo, Z. B., Shan, C. Q., Lin, J. Q., Gu, Y. G., Yang, Z. B., Yang, Y. X., Shao, J. R., Zhu, X. M., Cheng, Z. 2017. Pollution characteristics and risk assessment of human exposure to oral bioaccessibility of heavy metals via urban street dusts from different functional areas in Chengdu, China. *Science of the Total Environment*. 586,1076-1084.

Li, Y., Chen, H., Teng, Y. 2020. Source apportionment and source-oriented risk assessment of heavy metals in the sediments of an urban river-lake system. *Science of The Total Environment*. 140310.

Liu, P., Wu, Z., Luo, X., Wen, M., Huang, L., Chen, B., Zheng, C., Zhu, C., Liang, R. 2020a. Analysis of Heavy Metals in Acidic Farmland of the Karst Region in Southern China—A Case Study of Quanzhou County. *Applied Geochemistry*. 104764.

Liu, S., Pan, G., Zhang, Y., Xu, J., Ma, R., Shen, Z., Dong, S. 2019. Risk assessment of soil heavy metals associated with land use variations in the riparian zones of a typical urban river gradient. *Ecotoxicology & Environmental Safety*, 181, 435-444.

Liu, S., Zhan, C., Zhang, J., Liu, H., Xiao, Y., Zhang, L., Guo, J., Liu, X., Xing, X., Cao, J. 2020b. Polycyclic aromatic hydrocarbons in railway stations dust of the mega traffic hub city, central China: Human health risk and relationship with black carbon. *Ecotoxicology and Environmental Safety*. 205, 111155.

Lu, X., Zhang, X., Li, L.Y., Chen, H. 2014. Assessment of metals pollution and health risk in dust from nursery schools in Xi'an, China. *Environmental Research*. 128, 27-34.

Lyu, Y., Liu, L., Guo, L., Yang, Y., Qu, Z., Hu, X., Zhang, G. Deposited atmospheric dust as influenced by anthropogenic emissions in northern China. *Environmental Monitoring and Assessment*. 189,390.

Ma, Z. D., Zhang, D. C., Bi, X. Y., Liu, G. Q., Ren, L. M., Quan, H. L. (2005). Origin of cadmium high-value zones along the Yangtze River and Hanjiang River in Wuhan, Hubei, China (in Chinese). *Geological Bulletin of China*, 24(8), 740-743.

Men, C., Liu, R., Xu, F., Wang, Q., Guo, L., Shen, Z. 2018. Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. *Science of the Total Environment*. 612, 138–147.

Muller, G. 1969. Index of geo-accumulation in sediments of the Rhine River. *Geojournal*. 2, 108-118.

Pan, H., Lu, X., Lei, K. 2017. A comprehensive analysis of heavy metals in urban road dust of Xi'an, China: Contamination, source apportionment and spatial distribution. *Science of the Total Environment*. 609, 1361-1369.

Padoan, E., Romè, C., Ajmone-Marsan, F., 2017. Bioaccessibility and size distribution of metals in road dust and roadside soils along a peri-urban transect. *Science of The Total Environment*. 601-602, 89-98.

Qadeer, A., Saqib, Z. A., Ajmal, Z., Xing, C., Khalil, S. K., Usman, M., Huang, Y., Bashir, S,. Ahmad, Z., Ahmed, S., Thebo, K, H., Liu M. 2020. Concentrations, pollution indices and health risk assessment of heavy metals in road dust from two urbanized cities of Pakistan: Comparing two sampling methods for heavy metals concentration. *Sustainable Cities and Society*. 53, 101959.

Rahman, M. S., Khan, M. D. H., Jolly, Y. N., Kabir, J., Akter, S., Salam, A. 2019. Assessing risk to human health for heavy metal contamination through street dust in the Southeast Asian Megacity: Dhaka, Bangladesh. *Science of the Total Environment*. 660, 1610–1622.

Sahakyan, L., Tepanosyan, G., Maghakyan, N., Kafyan, M., Melkonyan, G., Saghatelyan, A. 2019. Contamination levels and human health risk assessment of mercury in dust and soils of the urban

environment, Vanadzor, Armenia. *Atmospheric Pollution Research*. 10, 808–816.

Soltani, N., Keshavarzi, B., Moore, F., Tavakol, T., Lahijanzadeh, A. R., Jaafarzadeh, N., Kermani, M. 2015. Ecological and human health hazards of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in road dust of Isfahan metropolis, Iran. *Science of the Total Environment*.. 505, 712–723.

Sun, J., Shen, Z., Zhang, L., Lei, Y., Gong, X., Zhang, Q., Zhang, T., Xu, H., Cui, S., Wang, Q., Cao, J., Tao, J., Zhang, N., Zhang, R. 2019. Chemical source profiles of urban fugitive dust $PM_{2.5}$samples from 21 cities across China. *Science of the Total Environment*. 649, 1045–1053.

Sun, J., Shen, Z. X., Cao, J. J., Zhang, L. M., Wu, T. T., Zhang, Q., Yin, X. L., Lei, Y. L., Huang, Y., Huang, R.J., Liu, S.X., Han, Y.M., Xu, H.M., Zheng, C.L., Liu, P.P., 2017. Particulate matters emitted from maize straw burning for winter heating in rural areas in Guanzhong Plain, China: current emission and future reduction. *Atmospheric Research* 184, 66–76.

Świetlik, R., Trojanowska, M., Strzelecka, M., Bocho-Janiszewska, A., 2015. Fractionation and mobility of Cu, Fe, Mn, Pb and Zn in the road dust retained on noise barriers along expressway-A potential tool for determining the effects of driving conditions on speciation of emitted particulate metals. *Environmental Pollution*. 196, 404–413.

Tadesse, A. W., Gereslassie, T., Xu, Q., Tang, X., Wang, J. 2018. Concentrations, distribution, sources and ecological risk assessment of trace elements in soils from Wuhan, Central China. *International Journal of Environmental Research and Public Health*. 15, 2873.

Tang, Z., Chai, M., Cheng, J., Jin, J., Yang, Y., Nie, Z., Huang, Q., Li, Y. 2017. Contamination and health risks of heavy metals in street dust from a coal-mining city in eastern China. *Ecotoxicology and Environmental Safety*. 138, 83-91.

Trujillo-Gonzalez, J.M., Torres-Mora, M.A., Keesstra, S., Brevik, E.C., Jimenez-Ballesta, R., 2016. Heavy metal accumulation related to population density in road dust samples taken from urban sites under different land uses. *Science of The Total Environment*. 553, 636–642.

USEPA, 1989. Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A), Interim Final. US Environ Prot Agency, Off Emerg Remedial Response, Washington.

USEPA, 2001. Risk Assessment Guidance for Superfund: Volume III-Part A, Process for Conducting Probabilistic Risk Assessment; EPA540-R-02-002. U.S. Environment Protection Agency, Washington, DC, USA.

USEPA, 2009. Office of Solid Waste Emergency Response, Waste and Cleanup Risk Assessment. Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Interim.

Wahab, M. I. B. A., Razak, W. M. A. A., Sahani, M., Khan, M. F. 2020. Characteristics and health effect of heavy metals on non-exhaust road dusts in Kuala Lumpur. *Science of the Total Environment*, 703, 135535.

Wei, B., Yang, L. 2010. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. *Microchemical Journal*. J. 94, 99–107.

Wei, B. G., Jiang, F. Q., Li, X. M., Mu, S. Y. 2009. Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China. *Microchemical Journal*, 93(2), 147-152.

Wei, X., Gao, B., Wang, P., Zhou, H., Lu, J. 2015. Pollution characteristics and health risk assessment of heavy metals in street dusts from different functional areas in Beijing, China. *Ecotoxicology*

and Environmental Safety. 112, 186-192.

Yang, Y., Yang, X., He, M., Christakos, G. 2020. Beyond mere pollution source identification: Determination of land covers emitting soil heavy metals by combining PCA/APCS, GeoDetector and GIS analysis. *CATENA*. 104297.

Zhang, C., Qiao, Q., Appel, E., Huang, B. 2012. Discriminating sources of anthropogenic heavy metals in urban street dusts using magnetic and chemical methods. Journal of Geochemical Exploration. 119-120. 60-75.

Zhang, C., Yang, Y., Li, W., Zhang, C., Zhang, R., Mei, Y., Liao, X., Liu, Y. 2015. Spatial distribution and ecological risk assessment of trace metals in urban soils in Wuhan, central China. *Environmental Monitoring & Assessment*. 187, 556.

Zhang, N., Han, B., He, F., Xu, J., Zhao, R.J., Zhang, Y.J., Bai, Z.P., 2017. Chemical characteristic of $PM_{2.5}$ emission and inhalational carcinogenic risk of domestic Chinese cooking. *Environmental Pollution*. 227, 24–30.

Zhang, Z., Anwar, M., Zibibula, S. 2019. Pollution assessment and health risks evaluation of (metalloid) heavy metals in urban street dust of 58 cities in China. *Environmental Science & Pollution Research*. 26, 126-140.

Zhao, L., Hu, G., Yan, Y., Yu, R., Cui, J., Wang, X., Yan, Y. 2019. Source apportionment of heavy metals in urban road dust in a continental Bcity of eastern China: Using Pb and Sr isotopes combined with multivariate statistical analysis. *Atmospheric Environment*. 201, 201-211.

Zhao, L., Yan, Y., Yu, R., Hu, G., Cheng, Y., Huang, H. 2020. Source apportionment and health risks of the bioavailable and residual fractions of heavy metals in the park soils in a coastal city of China using a receptor model combined with Pb isotopes. *CATENA*. 104736.

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