RESEARCH ARTICLE

Source apportionment and spatial distribution of heavy metals in atmospheric settled dust of Ulaanbaatar, Mongolia

Chultem Batbold[1] · Sonomdagva Chonokhuu[1,2] · Khulan Buuveijargal[2] · Khongor Gankhuyag[1]

Abstract

Atmospheric settled dust study was conducted with the purpose of to determine the source of heavy metal elements (As, Co, Cr, Cu, Ni, Pb, and Zn) in airborne dust from Ulaanbaatar using the multivariate analysis and spatial distribution mapping by geographic information system (GIS) with the systematic grid. A total of 57 dust samples were collected from the impervious surfaces at 2–4 m above the ground in January of 2020. The mean concentrations of heavy metals were increasing order of Co—10.4 ± 1.3 mg/kg > As—16.5 ± 5.9 mg/kg > Ni—21.3 ± 3.3 mg/kg > Pb—51.7 ± 26.4 mg/kg > Cu—65.5 ± 23.6 mg/kg > Cr—70.2 ± 18.7 mg/kg > Zn—571.3 ± 422.8 mg/kg. In terms of multivariate analysis, we used Pearson's correlation, principal component analysis (PCA), and hierarchical cluster analysis (CA). Three principal components, which are eigenvalues higher than 1, were determined accounting for 70.5% of the total variance by PCA. As a result, PC1 38.5% (As, Cr, Cu, and Ni), PC2 17.3% (Pb and Zn), and PC3 14.7% (Co and Pb) are attributable to coal combustion, vehicle exhaust emission, and resuspension of soil particles, respectively. The results of correlation analysis and CA were fairly in agreement with PCA. The spatial distribution maps of heavy metals were revealed in the downtown in which 40 covered sampling sites with about 700m intervals. In the spatial distribution mappings, generally, the southern part of the mapping area was higher concentrations of heavy metals. An increment of heavy metals concentration was presented for As, Cr, Co, and Ni with their similar trend in the southwestern part of the mapping. Besides, another trend for the distribution of the high concentrations of Cu and Zn was observed in the south and southeast parts. In terms of Pb, it had no noticeable pattern of distribution; however, a high spot was presented in the southwest part of the map.

Keywords Settled dust · Heavy metals · Ulaanbaatar · Source apportionment · Multivariate analysis · Mapping

Introduction

While the atmospheric pollution resulting from industrial activities is at persistent levels all over the year, pollutant emissions from household heating and vehicles increase during the winter, especially in developing countries. Because those countries are likely to burn more fossil fuels and other

✉ Sonomdagva Chonokhuu
  ch_sonomdagva@num.edu.mn

[1] Laboratory of Air and Environmental Monitoring, Graduate School, National University of Mongolia, Ulaanbaatar 14201, Mongolia

[2] Department of Environment and Forest Engineering, School of Engineering and Applied Science, National University of Mongolia, Ulaanbaatar 14201, Mongolia

combustibles for the energy supply (Fullerton et al. 2008; Tchounwou et al. 2012; Kicińska and Bożęcki 2018). Many pollutants spread over a wide area due to the combustion. Atmospheric dust is one of the main sinks of pollutants, and trace elements adhered to airborne particles are still under crucial attention in the urban environment. Many sources including traffic, heating systems, building deterioration, construction, renovation, and corrosion of galvanized metal structures, can release a significant amount of particles with environmentally hazardous pollutants into the atmosphere (Al-Momani 2007; Acosta et al. 2014; Wan et al. 2016a; Liu et al. 2018).

Studies on airborne particles of the urban environment are still being performed over the years in the world. One way of those studies is the atmospheric settled dust (or deposited dust) study using a casual sampling methodology in which allows to interpret the chemical and physical properties of airborne dust with the advantage of covering a wide area in a short

duration. Settled dust can be defined as the particles deposited from the atmosphere via their own gravity on the impervious surfaces at a certain height from the ground level, which is an acceptable approach to survey the airborne particle pollutants. Settled dust does not remain deposited on the surface for a long time because of resuspension or washout by human interventions and natural phenomena (e.g., precipitation, wind gust). A significant portion of heavy metals is attached to dust particles from anthropogenic emission sources and threaten human health and natural bodies (Ferreira-Baptista and De Miguel 2005; Wan et al. 2016b; Xu et al. 2019; Cai et al. 2019). The details of the effect of heavy metals on human health and the environment had been well introduced by (Srivastava et al. 2018; Briffa et al. 2020).

Ulaanbaatar, the capital city of Mongolia faces with severe air pollution in the heating season last few decades (Davy et al. 2011; Prikaz et al. 2018; Wang et al. 2017; Ganbat et al. 2020) and the main driving force for air pollution is cold air temperature. At the same time, a 3.5-fold increase in foetal deaths has been documented between winter and summer in Mongolia (National Center for Public Health and UNICEF 2018). The susceptible group of people, especially children and elders, are most afflicted by repercussions of air pollution. Children living in a highly affected district of Ulaanbaatar were found to have an up to 40% lower lung volume than children living in rural Mongolia (UNICEF, 2018 n.d.). Ganbat and Soyol-Erdene et al. 2020 studied the trend of particulate matter (PM) pollution in the last 6 years. Even if the pollution level revealed a notable reduction for the winter of 2019–2020 than that of previous years, the corresponding mean concentration is still a high level of $87.6 \pm 37.6 \ \mu g \ m^{-3}$.

Although there is natural source contribution to the PM emission, source identification of some heavy metals (e.g., As, Pb, Zn, and Cr) in urban dust are more associated with anthropogenic activities (Bilos et al. 2001), including coal-burning in households and power plants, motor vehicles, industrial boilers, and garbage burning. The adverse impact of PM pollution can be identified as regarding the distribution of particle size, pollutant concentration, and exposure duration (Csavina et al. 2012). Among them, pollutant concentration, particularly heavy metals in atmospheric dust, is still under the uncertainty, and a few studies have been made on trace elements in $PM_{2.5}$ and PM_{10} on limited scales in Ulaanbaatar (Davy et al. 2011; Nishikawa et al. 2011; Liu et al. 2018).

In order to determine the possible sources of heavy metals in airborne particles, this study applied the method of source apportionment, which helps to know what the sources of pollution are and to what extent those sources contribute to source apportionment. GIS mapping and multivariate analysis are the source apportionment methods extensively used in environmental studies.

Pollutant sources can be preliminarily assessed based on GIS dispersal mapping for heavy metals in urban dust and soil (Li et al. 2004; Zhang et al. 2008; Xie et al. 2011). Multivariate statistical analyses provide tools for classifying inter-relationships of heavy metals in different sampling points, which facilitates to determine the sources of pollutants (Charlesworth et al. 2003; Azimi et al. 2005; Peris et al. 2008). Two different analyses, PCA and CA have been widely used in the environmental studies (Charlesworth et al. 2003; Azimi et al. 2005; Tahri et al. 2005; Yongming et al. 2006; Meza-Figueroa, De la O-Villanueva, and De la Parra 2007). PCA summarizes data into a smaller number of independent factors by analysing relationships among observed variables and the result is interpreted in accordance with the hypothetical source of heavy metals based on the source profile or available data (Ahmed and Ishiga 2006; Peris et al. 2008), whereas CA groups variables into clusters by their similarities. CA is often coupled with PCA to check results and to group individual parameters and variables. A dendrogram is the most commonly used method for summarizing hierarchical clustering (Facchinelli, Sacchi, and Mallen 2001).

Materials and method

Study area

Ulaanbaatar is located in a valley within the southwestern area of Hentii mountainous (47° 55′ 13″ N, 106° 55′ 02″ E), about 1350 m above sea level. A river, called the Tuul, runs through the city from the east to the west. Similar to the geographical condition of most parts of Mongolia, this place exists under the cold and dry climate with long and cold seasons lasting for 7–8 months (mid-September to mid-May) as well as comparatively short and wet summer. The annual mean temperature is typically around −0.4 °C, making it the coldest capital city in the world. Monthly average temperature is generally −20 °C for winter months such as January and February, and night-time temperatures can go down as low as −40 °C. Annual average temperature in Ulaanbaatar is brought down by its cold winter temperatures. July, the warmest month, has an average temperature of 15–18 °C. Precipitation is scarce, about 250 mm annually, falling mostly during the short summer period; so, winters are extremely dry (Mongolian Academy of Science 2009; Hasenkopf 2012; NOAA 2015; WHO 2019). The average wind speed in the winter is 2–3 m/s, and the dominant direction occurs from north-easterly (Dugerjav et al. 2018).

This city is the main industrial centre of Mongolia. Industrial sectors produce a variety of consumer goods including cement, iron, and brick works and garment factories, vehicle-repair works, food-processing plants, and so on. Over the last 30 years, the urban population has tripled due to the continuous migration from the countryside to the capital. As of 2019, 47% of Mongolian population (~ 1.54 million)

live in this city (NSOMC 2020 n.d.). Uncontrollable migration and unarranged urban expansion have led to 60% of the city's population living in ger areas. Ger areas can be referred to as a part of the city where households live in either the traditional yurt or detached houses of insufficient infrastructure. A small portion of household in ger areas is connected to the central water supply and heating system while others heat their home using coal during the cold period, especially in the winter when air temperature regularly drops up to −30 degrees at night. Consequently, 600,000 t of coal burnt annually in ger areas is attributable more than 80% of the city's air pollution (Fuhrmann 2019).

Dust sampling and analysis

A total of 57 atmospheric dust samples were taken in January of 2020 representing the highest air pollution period (Fig. 1). Because of the importance of planning an appropriate sampling design to draw inferences from a limited number of samples, 40 out of 57 dust samples were taken from the downtown by systematic sampling grids. This is applicable in the case of settled dust due to its high spatial variability (Leharne, Charlesworth, and Chowdhry 1992). Whereas, other dust sampling sites were chosen randomly in the parts of the city. Dust particles had deposited onto any surfaces under stable weather conditions in the cold and dry periods. Evenly accumulated fine grain dust on the impervious surfaces such as windowsills, house roofs, glass surfaces were collected by sweeping up with brushes into self-sealing polythene bags. Each selection of sampling sites representing major residential areas of the urban areas was based on the absence of direct effect from pollution sources and human input. In preparation for chemical analysis, samples were dried in the oven for 2 days and then removed bulk debris.

For determining the elements in settled dust, ICP-OES was used in the chemical process, and initially, the samples were dissolved and turned into a solution using chemical acid ($HNO_3 + 3 HCl$). Afterward, the concentration of the element
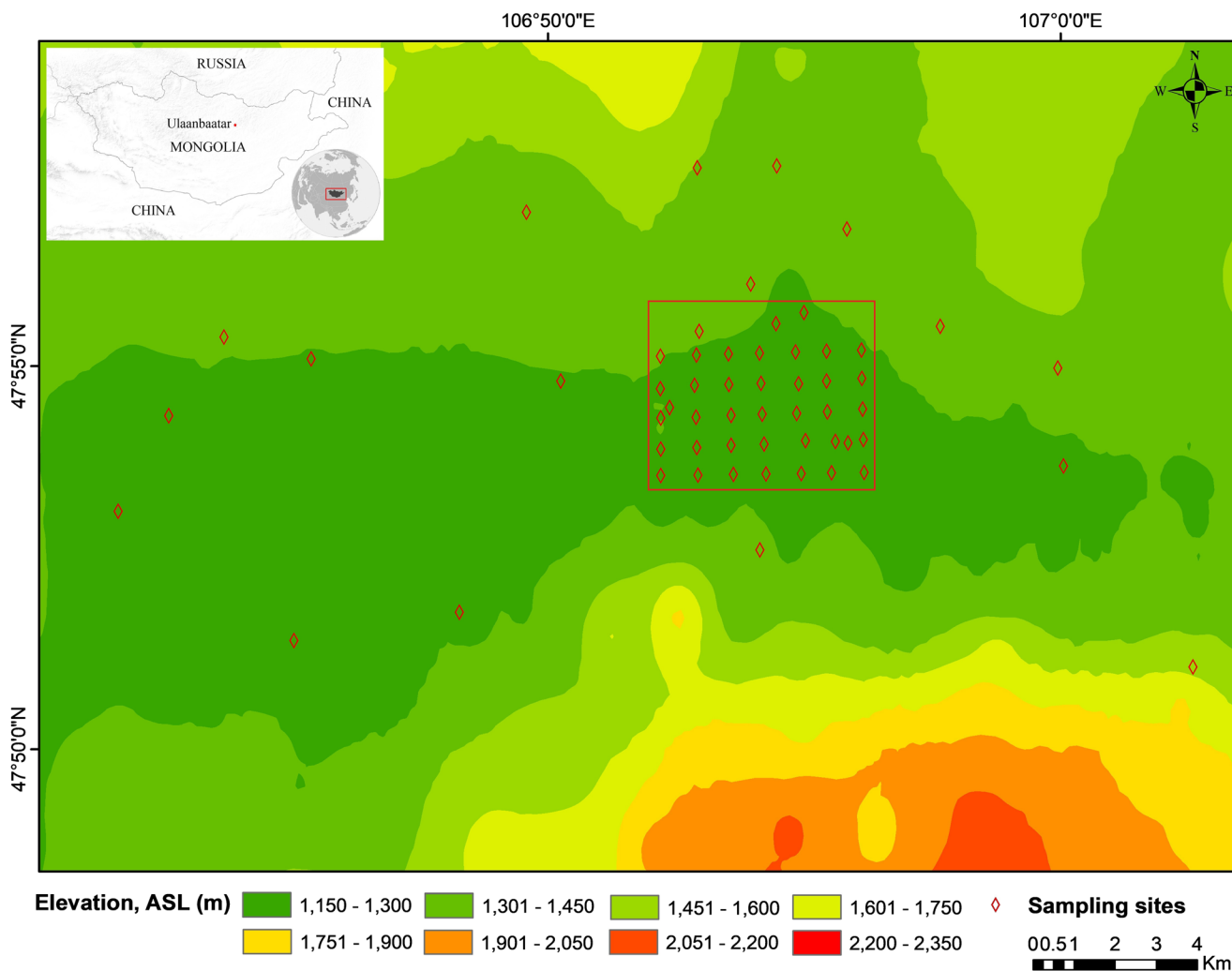
Fig. 1 The contour map of Ulaanbaatar, with settled dust sampling sites (shown by red rhombus) and the area of distribution mapping (delineated by a red rectangle and to see in Fig. 5)

was determined by iCAP-7400, recording the intensity of atomic light induced by the high-temperature plasma.

Settled dust samples (as shown in Fig. 2a) taken from the impervious surfaces were tenacious adhering particles that resist the typical weather phenomena in the winter including moderate wind, snow, etc. Their odours were like charcoal smoke but had a pale brown colour. The grain size distribution of settled dust is shown in Fig. 2b. Generally, it consisted of particles size of lower than 250 μm. Especially, the particles of 50–10 μm were dominant in accounting for about half of the total mass in the sample. Less than the particles of 10 μm or group of 10–5 μm, 5–1 μm, and <1 μm constituted the sample mass by 8.9%, 11.21%, and 8.05%, respectively.

Outlier detection

Outliers are the observations that appear to deviate markedly from other observations in the sample. Outliers may be due to random sampling issues (sampling site selection or loading in certain element's debris etc.) or may indicate something scientifically interesting. In a common sense using statistical tests, when 30% of your data is outliers, then it actually means that there is something interesting going on with the data, and need to look further into it. The 10.3% of a data set was determined as the outlier in this study. Most parametric statistics like means, standard deviations, and correlations, and every statistic based on these, are highly sensitive to outliers. Investigating the nature of the outlier is important before deciding. If it can be determined that an outlying point is in fact erroneous, then the outlying value should be deleted from the analysis or corrected if possible. Taking account of the above ideas, the data set was modified in this study. Once outliers have been removed from sample data, it is essential to trim data or fill the gaps. As for this, outliers were statistically determined by the out of boundary for data between the 5th and 95th percentiles. After trimming the data set, outliers were replaced with 5th and 95th percentiles nearest "good" data (this is called winsorization). For example, data points above the 95th percentile, they could set by the 95th percentile value (Hoo et al. 2002; Rousseeuw and Hubert 2011; Aguinis, Gottfredson, and Joo 2013).
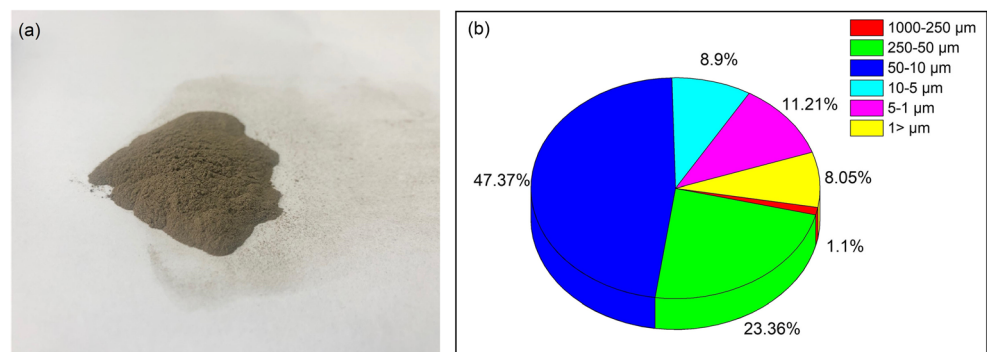
Multivariate analysis

Multivariate statistical methods such as correlation analysis, PCA, and CA were used to classify the inter-elemental relationships in the dust samples. The sampling adequacy for factor analysis was measured by the Kaiser-Meyer-Olkin (KMO) test. These statistical analyses were performed using Origin 2019b, and v.23.0 of the SPSS software.

Spatial analysis

The spatial distribution maps of heavy metals in this study were performed using kriging interpolation with ArcGIS 10.4.1 Kriging was used as a spatial interpolation technique to produce distribution maps because it is considered an optimal method of spatial prediction that provides a superior linear unbiased estimator for quantities that vary in space (Goovaerts 1997). The grid cells, drawn for spatial mapping with a spatial interval of about 700 m, are included in 40 sampling sites in an approximately 17 km^2 area of the downtown. The features of that area can help to interpret the results from the spatial distribution analysis.

Result

Heavy metal concentration in settled dust

The total concentration of heavy metals in settled dust is presented in Table 1 with the background values, world crust average, and other studies' results to allow comparison. The mean mg kg^{-1} concentration of heavy metals in settled dust samples are increasing order of Co–10.4 < As–16.5 < Ni–21.2 < Pb–51.7 < Cu–65.6 < Cr–70.2 < Zn–571.3. Among them, the mean concentration of Zn, Cr, and Cu is significantly excessive, 5.4, and 2.6, 4.0 times higher than their backgrounds, respectively. Even if the outliers of each element were determined and afterward filled the gaps, the maximum value for Zn (1366.3 mg kg^{-1}) was considerably high. The skewness coefficients of all examined metals were positive, except for Co. Pb and Zn showed skewness coefficients of >1

Fig. 2 a Representative photograph of settled dust sample of Ulaanbaatar. b Grain size distribution of atmospheric settled dust of Ulaanbaatar

Table 1 Descriptive statistics of heavy metals in settled dust of Ulaanbaatar. In addition, average concentrations of heavy metals in the background soil of the study area and dust from other cities and crust average are also listed

Location	Item	As mg kg^{-1}	Co	Cr	Cu	Ni	Pb	Zn	Type	Reference
Ulaanbaatar	Mean	16.5	10.4	70.2	65.6	21.3	51.7	571.3	Settled dust	This study
	Max.	33.2	13.0	109.7	113.5	28.7	128.4	1366.3		
	Min.	7.9	6.4	41.2	29.6	16.3	22.0	207.8		
	Median	15.4	10.2	70.9	66.1	20.7	47.9	362.0		
	S.D.	5.9	1.3	18.7	23.6	3.3	26.4	422.8		
	CV	35.8	12.4	26.6	36.0	15.7	51.0	74.0		
	Skewness	0.6	-0.2	0.4	0.2	0.6	1.6	1.1		
	Background soil	14.2	8.4	33.7	23.0	14.7	37.9	114.1	Soil	
World	Average	4.8	17.3	92.0	28.0	47.0	17.0	67.0	Crust	(Rudnick and Gao 2003)
Ulaanbaatar	Average	28.4	n/a	16.6	n/a	21.6	43.1	106.1	Soil	(Chonokhuu et al. 2019)
Ulaanbaatar	Average	22.9	7.6	29.0	28.9	n/a	34.5	135.6	Soil	(Battsengel et al. 2020)
Aviles	Average	17.5	5.0	41.6	183	27.5	514.0	4892	Street dust	(Ordóñez et al. 2003)
Luanda	Average	5.0	2.9	26.0	42.0	10.0	351.0	371.0	Street dust	(Ferreira-Baptista and De Miguel 2005)
Delhi	Average	n/a	n/a	148.8	191.7	36.4	120.7	284.5	Road dust	(Suryawanshi et al. 2016)
Krakow	Average	75.0	43	64.0	n/a	61.0	190.0	956.0	Park dust	(Kicińska and Bożęcki 2018)
Nanjing	Average	n/a	10.1	67.1	102.8	46.2	82.7	302.7	Street dust	(Li et al. 2013)
Beijing	Average	23.9	10.6	86.0	138.4	45.2	167.9	722.7	Settled dust	(Wan et al., 2016a)
Shijiazhuang	Average	n/a	8.1	137.9	99.6	39.2	146.9	466.9	Settled dust	(Wan et al., 2016b)
Gyumri	Average	n/a	n/a	68.3	43.7	40.8	77.24	158.3	Settled dust	(Sahakyan et al. 2016)
Qingdao	Average	n/a	n/a	153.1	456.7	60.9	176.0	708.3	Settled dust	(Xu et al. 2019)

n/a not available

indicating that the numbers of the high tails were greater than the numbers of the low tails.

Compared with the background values of Ulaanbaatar's soil, the concentrations of each heavy metal were somehow higher than their corresponding background values (Table 1), and further, the significantly high concentrations of Cr, Cu, Pb, and Zn in the dust samples suggest the anthropogenic sources of these elements. While rest of the heavy metals (As, Co, and Ni) concentration in dust samples were close to their corresponding background values. As well, Chonokhuu et al. 2019 and Battsengel et al. 2020 studied the heavy metal elements of the soil in Ulaanbaatar. Hence Cr, Cu, Pb, and Zn

concentrations in settled dust were considerably high compared to soil heavy metals viewing at their results (Table 1).

The availability of the comparison of the result of Ulaanbaatar to other studies is provided in Table 1. The concentrations of Cr, Cu, Ni, Pb, and Zn are all available in representative cities, while those of As and Co are unavailable in some studies, especially for As. In most cases, the concentrations of heavy metals in this study are lower than that of compared studies. The average concentrations of As and Co in settled dust from Ulaanbaatar are close to the available results of other cities, but the mean concentration of As is 3.4 times higher than the world crust average (Rudnick and Gao 2003). The higher mean concentrations of As (Table 1) for Aviles (17.5) (Ordóñez et al. 2003), Krakow (75.0) (Kicińska and Bożęcki 2018), and Beijing (23.9) (Wan et al., 2016a) were discussed suggesting that those elements were probable owing to anthropogenic sources of metallurgical industry, emission from old mining area and fly ash from coal-burning, respectively. For Chinese cities, Nanjing, Beijing, Shijiazhuang, and Qingdao, the average concentrations of Cr, Cu, Ni, and Pb are higher than that of Ulaanbaatar, except for only Cr concentration (67.1) for Nanjing (Li et al. 2013; Wan et al., 2016b; Wan et al., 2016a; Xu et al. 2019). All these element sources were associated with anthropogenic sources such as coal-burning, vehicle exhaust, and metal

Table 2 Pearson's correlation coefficient of heavy metals in settled dust Ulaanbaatar (correlation coefficient >0.4 are shown in bold)

Elements	As	Co	Cr	Cu	Ni	Pb	Zn
As	**1**	0.26	**0.57**	0.40	**0.46**	0.03	0.16
Co	0.26	**1**	0.10	0.20	**0.53**	0.11	0.03
Cr	**0.57**	0.10	**1**	**0.54**	**0.51**	0.26	0.09
Cu	**0.40**	0.20	**0.54**	**1**	**0.48**	−0.04	0.13
Ni	**0.46**	**0.53**	**0.51**	**0.48**	**1**	0.03	−0.12
Pb	0.03	0.11	0.26	−0.04	0.03	**1**	0.16
Zn	0.16	0.03	0.09	0.13	−0.12	0.16	**1**

Fig. 3 Three-dimensional plot of the result of PCA from heavy metals in settled dust of Ulaanbaatar
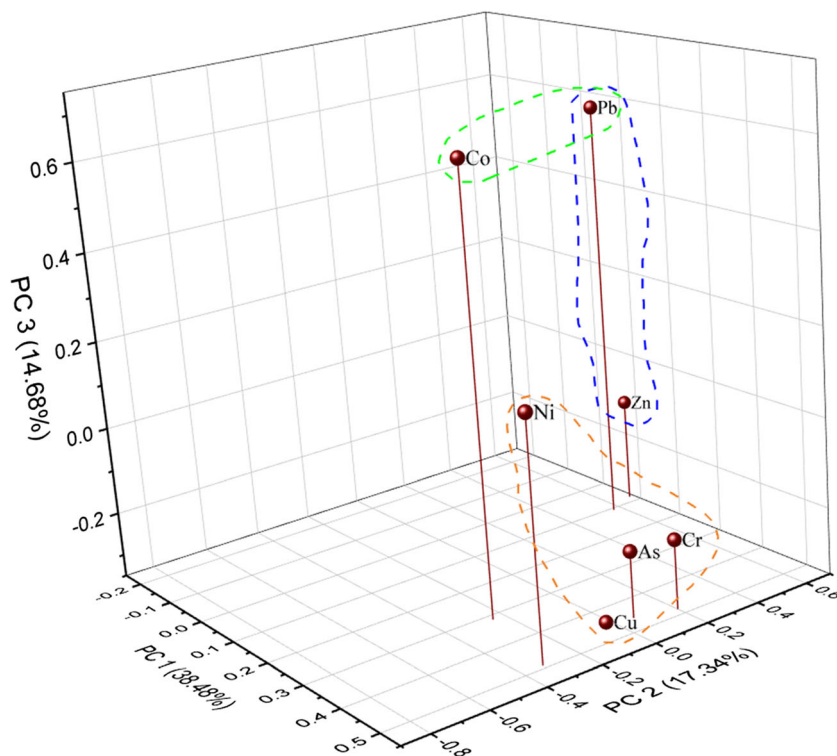
corrosion in those areas. Excessive Zn concentrations of some cities compared to this study were mostly associated with the deposition from the mining site, metallurgical factory, and emission from vehicle exhaust and coal combustion (Ordóñez et al. 2003; Wan et al., 2016b; Kicińska and Bożęcki 2018; Xu et al. 2019).

Multivariate analysis

To present the relationship between the heavy metals in settled dust and define their sources, Pearson's correlation coefficient analysis, PCA, and CA were used. Pearson's correlation

Table 3 Rotated component matrix for heavy metals concentration in settled dust of Ulaanbaatar (PCA loadings > 0.4 are shown in bold)

Elements	PC1	PC2	PC3	Communalities
As	**0.46**	0.07	−0.20	0.26
Co	0.32	−0.24	**0.63**	0.56
Cr	**0.48**	0.20	−0.20	0.31
Cu	**0.44**	−0.01	−0.35	0.32
Ni	**0.49**	−0.33	0.18	0.38
Pb	0.11	**0.57**	**0.60**	0.69
Zn	0.08	**0.68**	−0.12	0.49
Eigenvalue	2.73	1.13	1.02	
Percentage of variance, %	38.5	17.3	14.7	
Cumulative, %	38.5	55.8	70.5	

coefficients for the analysed heavy metals in this study are presented in Table 2. It can be seen that Ni had a significant correlation with As, Co, Cr, and Cu (0.46, 0.53, 0.51, and 0.48, respectively), indicating the similarity. Besides, As was the positive correlations with all of the other elements. Namely, Cr (0.57), Cu (0.40), and Ni (0.46) were correlated particularly to As. A significant correlation (0.54) between Cu and Cr was also observed. In the contrast, Cu–Pb (−0.04) and Ni–Zn (−0.12) were negative correlations between them. The remaining correlations of heavy metals indicated slightly positive, and but their values are lower than 0.3.

Relationships between heavy metals for the three principal components of the dust are shown in three-dimensional space in Fig. 3. The KMO measure of sampling adequacy (0.604) and Barlett's test of sphericity (101.66, p is 0.000) showed that the data set of seven heavy metals was acceptable for the factor analysis. Three principal components, eigenvalues higher than 1, accounted for 70.5% of the total variance were extracted by the performance of PCA.

PC1, which dominated by As, Cr, Cu, and Ni, accounted for 38.5% of the total variation. With regard to these elements, Cr and Cu are always derived due to industrial and vehicle emissions. Cr is extensively used in automobile parts aluminium alloy and titanium alloys (Lu et al. 2010). Cu is a key component of building materials (Zhang et al. 2004; Buzatu et al. 2015), and also more than 90% of Cu emission of traffic was due to brake wear (Johansson, Norman, and Burman 2009). As and Ni as well as other elements in PC1 can emit from a common source of coal combustion (Kursun Unver

Fig. 4 Dendrogram extracted from CA of heavy metals in settled dust of Ulaanbaatar

Dendrogram using Ward Linkage
Rescaled Distance Cluster Combine
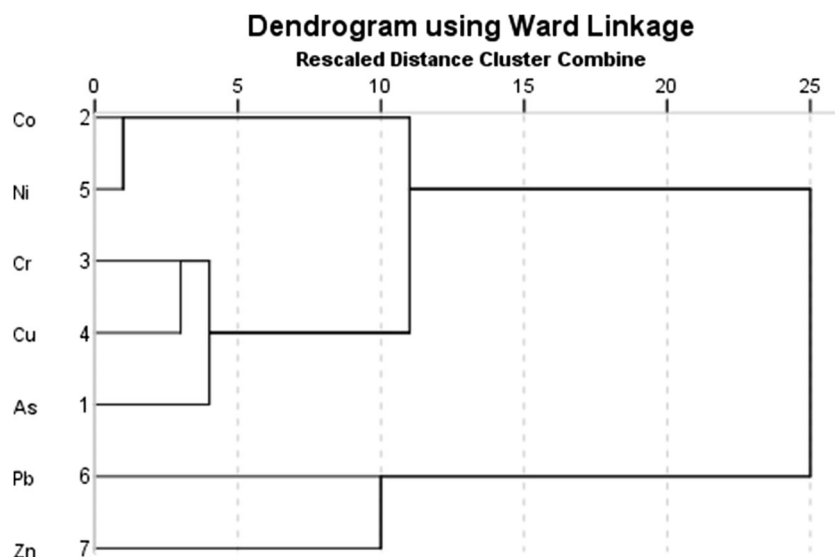
and Terzi 2018). Therefore, PC1 belongs to fly ash from coal combustion and vehicle emissions.

For PC2, it revealed the high value of Pb and Zn, explaining 17.3% of the total variance. The concentration of Zn in settled dust is the most attention-getting one among all of the heavy metals analysed in this study. Extremely high Zn concentrations of some samples are observed that those samples were mostly taken from the galvanized cast iron sheets (Suplementary 1). Thus, this result is probably due to the sampling surfaces affected by the input of Zn. However, the median concentration of Zn is 362 mg/kg, indicating significantly higher than the background value in Table 1. On the other hand, zinc alloy and galvanized components are widely used in motor vehicles and as antioxidants and as detergent/dispersant improvers for lubricating oils (de Miguel et al., 1997). And also, it is added to tires during the vulcanizing process, comprises from 0.4 to 4.3% of the resulting tire tread (Chen, Lu, and Yang 2012). However, unleaded gasoline for all vehicles was introduced in Mongolia, and there are still permanent sources of Pb including lead-acid batteries and the metal product in the vehicles in the urban environment (Tchounwou et al. 2012; Guttikunda et al. 2013). Therefore, PC2 belongs to vehicular emissions such as exhaust emissions, tire abrasion, and brake wear.

PC3 was notably dominated by Co and Pb, accounting for 14.7% of the total variance. For Co, its concentration in settled dust was close to the corresponding background value and slight variance in total sampling sites, whereas the mean concentration of Pb is above a corresponding background value, but slightly or 1.4 times high (Table 1). Therefore, PC3 might be more related to the resuspension of soil particles.

Afterward, hierarchical cluster analysis applying Ward's method was performed on the data set. The result of CA is illustrated in a dendrogram (Fig. 4). Figure 4 showed three clusters: (1) Co–Ni, (2) Cr– Cu–As, and (3) Pb–Zn. The group

of Pb–Zn is the farthest away from other cluster groups and presented a separate cluster. On the other hand, clusters 1 and 2 including Co, Ni, Cr, Cu, and As were relatively solid. The clustering results of CA are in fairly agreement with PCA results (Table 3 and Fig. 3). Three main sources were identified according to PCA and CA. For example, three main components of (1) As–Cr–Cu–Ni, (2) Pb–Zn, and (3) Co–Pb were determined in PCA (Fig. 3). In terms of CA, the distinct groups of (1) Cr–Cu–As, (3) Pb–Zn, (2) Co–Ni were presented in Fig. 4.

In general, seven heavy metals analysed in this study are higher than corresponding background values, and it may imply that there is a common source of pollution. With the exception of a few fuels, all fuels have a residue that is called deposition when burned. Coal combustion emits a lot of ash. A portion of it—fly ash—is released into the air with the smoke in Ulaanbaatar in winter. Depending on the chemical characterization of the various kind of coals, fly ash typically contains heavy metals including arsenic, lead, chromium, cadmium, and selenium, as well as aluminium, cobalt, nickel, vanadium, and zinc (Nalb and Sugden n.d.; Kursun Unver and Terzi 2018). The analysis of airborne particulate matter indicated that Zn, Pb, As, and Cu was considered to be derived from coal combustion in heating season in Ulaanbaatar (Nishikawa et al. 2011), and the excessive concentrations of those elements were also found in the fly ash during coal combustion in a household (Karthe et al. 2020).

Spatial distribution

The depiction of the area of the spatial distribution map was presented in Fig. 1, and the spatial distribution result of each heavy metal is shown in Fig. 5. The mapping area covered a margin of ger district, considered the main source of PM pollution, and the downtown of the city. Most of the universities,

Fig. 5 Spatial distribution of the concentration of heavy metals in settled dust from Ulaanbaatar
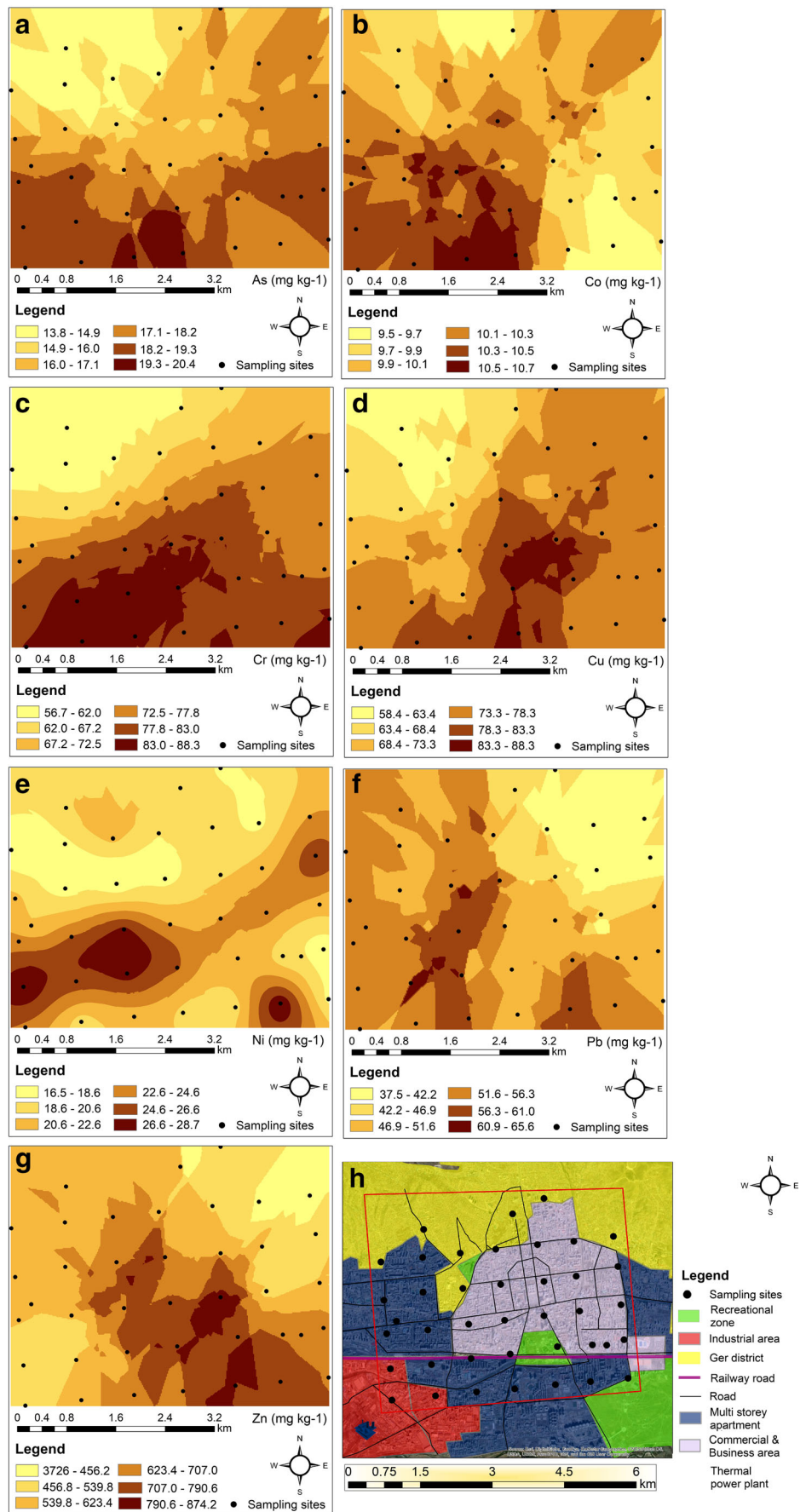
administrative organizations, and kindergartens are located in this area. Along with this situation, it has become a hotspot of traffic and has a high population density. Darker colours showed the places where a heavy metal concentration was high. Overall, the southern part of the distribution map was a higher concentration of heavy metals. Among all analysed elements, the spatial distribution of As, Cr, Co, and Ni were in a similar trend, and their concentration generally increased at the southwestern side of the mapping (Fig. 5 a, b, c, and e). Furthermore, another trend of the distribution of Cu and Zn can be observed, which spreads over the direction of south and southeast with high concentrations (Fig. 5 d and g). In terms of Pb, it had no noticeable pattern of distribution; however, a high spot was presented in the southwest part of the map (Fig. 5f).

There are no major sources of pollution in the south, but as shown in Fig. 1, the mapping area is located at the lowest altitude of the valley of mountains. Therefore, such a geographical feature and very cold temperatures form the inversion layer, which leads further to restriction of the pollutants dispersion. By doing so, PM pollution persists for quite a long time and evenly diffuses from the sources to the downstream. In addition to this feature, the presence of high traffic density on the major roads (Fig. 5h) might make that the southern part of the mapping area was more polluted associated with vehicle emissions according to the discussion in the multivariate analysis. There are unpaved roads and barren land surfaces in the ger areas, and thus, vehicle movement generates dust from the surface of the surrounding apart from the combustion. Whereas, other areas such as multistory buildings and commercial and business areas are more likely to perceive the suspended particles emitted from the combustion process of the household and vehicle emission (Fig. 5h).

In addition to the coal combustion in ger district of Ulaanbaatar, vehicle emission has drawn attention cause of the increment in fuel consumption and deterioration of vehicles in wintertime (Li et al. 2007; Carlson et al. 2007; Jehlik, Rask, and Christenson 2010). Higher fuel consumption means higher emissions. On the other hand, as of 2019, the average aging of the vehicle in Ulaanbaatar is considerably high in which 71.5% of total vehicles were aging upper 10 years. (Mongolian Statistical Information Service 2020). Therefore, it is obvious their mechanical depreciation has become a crucial issue.

Conclusions

This study presented the result of heavy metals concentration of atmospheric settled dust from Ulaanbaatar in winter 2020 representing the extreme pollution period under the main purpose of determining the possible sources of atmospheric dust and concluded with the following notes.

- The results only belong to particle deposition from the atmosphere during the heating season.
- In settled dust of Ulaanbaatar, particles consisted of a size of less than 50 μm accounted for 75.5% of the mass of the total sample.
- The mean values of each heavy metal are higher than their corresponding background values, and/or it means settled dust is originated from anthropogenic sources.
- The result of source apportionment revealed that the main source of the heavy metals (As, Co, Cr, Cu, Ni, Pb, and Zn) was attributable to coal combustion, vehicle exhaust emission, and soil suspension by multivariate analysis. Airborne PM resulted from coal burning in over 200 thousand households is supposed to be as a common source of heavy metals in settled dust while the significant high concentration of elements such as Cr, Cu, and Zn is more related to vehicle emissions.
- The northern side of the mapping area stretches through the bound of the ger district referred to as the main source of PM, but generally, the high pollution of each heavy metal was observed through the southern part of the area of the downtown (Fig. 5).

Air pollution is a temporary incident influenced by weather conditions, which is dependent on seasonality and diurnal variabilities in the Mongolian settlement areas. It is mostly associated with the situation that the household burn the copious amount of coal and other organic materials. As a result, the population in the study area is suffered from high PM pollution in the winter. Mitigation of the air pollution caused by combustion is not only the issue of the PM but also toxic heavy metals attached to small particles. Generally, in the scope of this study, it can be considered that the population who live in Ulaanbaatar breathe in the air containing fine particles with a high concentration of heavy metals in the heating period.

Code availability Not applicable

Declarations

Ethics approval Not applicable

Consent to participate Not applicable

Consent for publication Yes

Conflict of interest The authors declare no competing interests.

References

Acosta JA, Faz A, Kalbitz K, Jansen B, Martínez-Martínez S (2014) Partitioning of heavy metals over different chemical fraction in street dust of Murcia (Spain) as a basis for risk assessment. *J Geochem Explor Potent Harmful Elements Soils: concentration, distribution, risk assessment and remediation* 144(September):298–305. https://doi.org/10.1016/j.gexplor.2014.02.004

Aguinis H, Gottfredson RK, Joo H (2013) Best-practice recommendations for defining, identifying, and handling outliers. *Organ Res Methods* 16(2):270–301. https://doi.org/10.1177/1094428112470848

Ahmed F, Ishiga H (2006) Trace metal concentrations in street dusts of Dhaka City, Bangladesh. *Atmos Environ* 40(21):3835–3844. https://doi.org/10.1016/j.atmosenv.2006.03.004

Al-Momani IF (2007) Trace elements in street and household dusts in Amman, Jordan. *Soil Sediment Contam Int J* 16(5):485–496. https://doi.org/10.1080/15320380701490184

Azimi S, Rocher V, Muller M, Moilleron R, Thevenot DR (2005) Sources, distribution and variability of hydrocarbons and metals in atmospheric deposition in an urban area (Paris, France). *Sci Total Environ* 337(1):223–239. https://doi.org/10.1016/j.scitotenv.2004.06.020

Battsengel E, Murayama T, Fukushi K, Nishikizawa S, Chonokhuu S, Ochir A, Tsetsgee S, Davaasuren D (2020) Ecological and human health risk assessment of heavy metal pollution in the soil of the ger district in Ulaanbaatar, Mongolia. *Int J Environ Res Public Health* 17(13):4668. https://doi.org/10.3390/ijerph17134668

Bilos C, Colombo JC, Skorupka CN, Presa MJR (2001) Sources, distribution and variability of airborne trace metals in La Plata City Area, Argentina. *Environ Pollut* 111(1):149–158. https://doi.org/10.1016/S0269-7491(99)00328-0

Briffa J, Sinagra E, Blundell R (2020) Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon* 6(9):e04691. https://doi.org/10.1016/j.heliyon.2020.e04691

Buzatu T, Talpoş E, Petrescu MI, Ghica VG, Iacob G, Buzatu M (2015) Utilization of granulated lead slag as a structural material in roads constructions. *J Mater Cycles Waste Manag* 17(4):707–717. https://doi.org/10.1007/s10163-014-0297-z

Fuhrmann JC. (2019). Ulaanbaatar is suffocating in smog. Int Rep . https://www.kas.de/en/web/auslandsinformationen/artikel/detail/-/content/ulaanbaatar-is-suffocating-in-smog.

Cai K, Li C, Na S (2019) Spatial distribution, pollution source, and health risk assessment of heavy metals in atmospheric depositions: a case study from the sustainable city of Shijiazhuang, China. *Atmosphere* 10(4):222. https://doi.org/10.3390/atmos10040222

Carlson R, Duoba M, Bocci D, and Lohse-Busch H. (2007). *On-road evaluation of advanced hybrid electric vehicles over a wide range of ambient temperatures.*

Charlesworth S, Everett M, McCarthy R, Ordóñez A, de Miguel E (2003) A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK. *Environ Int* 29(5):563–573. https://doi.org/10.1016/S0160-4120(03)00015-1

Chen X, Lu X, Yang G (2012) Sources identification of heavy metals in urban topsoil from inside the Xi'an Second Ringroad, NW China Using Multivariate Statistical Methods. *CATENA* 98(November): 73–78. https://doi.org/10.1016/j.catena.2012.06.007

Chonokhuu S, Batbold C, Chuluunpurev B, Battsengel E, Dorjsuren B, Byambaa B (2019) Contamination and health risk assessment of heavy metals in the soil of major cities in Mongolia. *Int J Environ Res Public Health* 16(14):2552. https://doi.org/10.3390/ijerph16142552

Csavina J, Field J, Taylor MP, Gao S, Landázuri A, Betterton EA, Eduardo Sáez A (2012) A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. *Sci Total Environ* 433(September):58–73. https://doi.org/10.1016/j.scitotenv.2012.06.013

Davy PK, Gunchin G, Markwitz A, Trompetter WJ, Barry BJ, Shagjjamba D, Lodoysamba S (2011) Air particulate matter pollution in Ulaanbaatar, Mongolia: determination of composition, source contributions and source locations. *Atmos Pollut Res* 2(2): 126–137. https://doi.org/10.5094/APR.2011.017

Dugerjav O, Erdenebadrakh M, Erdenebat E, and Byamba-Ochir M. (2018). Current status of PM2.5 pollution and its mitigation in Ulaanbaatar City of Mongolia. Global Environ Res 22

Facchinelli A, Sacchi E, Mallen L (2001) Multivariate statistical and GIS-based approach to identify heavy metal sources in soils. *Environ Pollut* 114(3):313–324. https://doi.org/10.1016/S0269-7491(00)00243-8

Ferreira-Baptista L, De Miguel E (2005) Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. *Atmos Environ* 39(25):4501–4512. https://doi.org/10.1016/j.atmosenv.2005.03.026

Fullerton DG, Bruce N, Gordon SB (2008) Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Trans R Soc Trop Med Hyg* 102(9):843–851. https://doi.org/10.1016/j.trstmh.2008.05.028

Ganbat G, Soyol-Erdene T-O, Jadamba B (2020) Recent improvement in particulate matter (PM) pollution in Ulaanbaatar, Mongolia. *Aerosol Air Qual Res* 20(10):2280–2288. https://doi.org/10.4209/aaqr.2020.04.0170

Goovaerts P (1997). Geostatistics for natural resource evaluation. In *Technometrics* 42.

Guttikunda SK, Lodoysamba S, Bulgansaikhan B, Dashdondog B (2013) Particulate pollution in Ulaanbaatar, Mongolia. *Air Qual Atmos Health* 6(3):589–601. https://doi.org/10.1007/s11869-013-0198-7

Hasenkopf C. (2012). Clearing the Air. *World Policy*. https://worldpolicy.org/2012/03/26/clearing-the-air/.

Hoo KA, Tvarlapati KJ, Piovoso MJ, Hajare R (2002) A method of robust multivariate outlier replacement. *Comput Chem Eng* 26(1):17–39. https://doi.org/10.1016/S0098-1354(01)00734-7

Jehlik F, Rask E, and Christenson M. 2010. *Simplified methodology for modeling cold temperature effects on engine efficiency for hybrid and plug-in hybrid vehicles.* https://doi.org/10.4271/2010-01-2213.

Johansson C, Norman M, Burman L (2009) Road traffic emission factors for heavy metals. *Atmos Environ Urban Air Qual* 43(31):4681–4688. https://doi.org/10.1016/j.atmosenv.2008.10.024

Karthe D, Hafer T, Battulga B, Sereeter L, Stehr G (2020, 2020) Pollution reduction potential by implementing electrostatic dust precipitators on Mongolian small-scale stoves (a pilot study in Ulaanbaatar). Text Serial J Geogr Environ Sustain. https://doi.org/10.24057/2071-9388-2020-50

Kicińska A, Bożęcki P (2018) Metals and mineral phases of dusts collected in different urban parks of Krakow and Their Impact on the

Health of City Residents. *Environ Geochem Health* 40(1):473–488. https://doi.org/10.1007/s10653-017-9934-5

Kursun Unver I, Terzi M (2018) Distribution of Trace Elements in Coal and Coal Fly Ash and Their Recovery with mineral processing practices: a review. *J Min Environ* 9(3):641–655. https://doi.org/10.22044/jme.2018.6855.1518

Leharne S, Charlesworth D, Chowdhry B (1992) A survey of metal levels in street dusts in an inner London neighbourhood. *Environ Int* 18(3):263–270. https://doi.org/10.1016/0160-4120(92)90109-H

Li, Hu, Gordon Andrews, Dimitrios Savvidis, Basil Daham, Karl Ropkins, Margaret Bell, and James Tate. 2007. *Study of thermal characteristics, fuel consumption and emissions during cold start using an on-board measuring method for SI car real-world urban driving.* Vol. 1. https://doi.org/10.4271/2008-01-1307, 804, 819.

Li H, Qian X, Hu W, Wang Y, Gao H (2013) Chemical speciation and human health risk of trace metals in urban street dusts from a Metropolitan City, Nanjing, SE China. *Sci Total Environ* 456–457(July):212–221. https://doi.org/10.1016/j.scitotenv.2013.03.094

Li X, Lee S-l, Wong S-c, Shi W, Thornton I (2004) The study of metal contamination in urban soils of Hong Kong using a GIS-based approach. *Environ Pollut* 129(1):113–124. https://doi.org/10.1016/j.envpol.2003.09.030

Liu K, Shang Q, Wan C, Song P, Ma C, Cao L (2018) Characteristics and sources of heavy metals in PM2.5 during a typical haze episode in rural and urban areas in Taiyuan, China. *Atmosphere* 9(1):2. https://doi.org/10.3390/atmos9010002

Lu X, Wang L, Li LY, Lei K, Huang L, Kang D (2010) Multivariate statistical analysis of heavy metals in street dust of Baoji, NW China. *J Hazard Mater* 173(1–3):744–749. https://doi.org/10.1016/j.jhazmat.2009.09.001

Meza-Figueroa D, De la O-Villanueva M, De la Parra ML (2007) Heavy metal distribution in dust from elementary schools in Hermosillo, Sonora, México. *Atmos Environ* 41(2):276–288. https://doi.org/10.1016/j.atmosenv.2006.08.034

de Miguel E, Llamas JF, Chacón E, Berg T, Larssen S, Røyset O, Vadset M (1997) Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead. *Atmos Environ* 31(17):2733–2740. https://doi.org/10.1016/S1352-2310(97)00101-5

Mongolian Academy of Science (2009) *Mongolian National Atlas*, vol II. MAS, Ulaanbaatar

Mongolian Statistical Information Service. (2020). Number of vehicles passed the technical inspection, by age and by region, Aimag and Soum, Yearly. 2020. https://www.1212.mn/tables.aspx?tbl_id=DT_NSO_1200_013V2&13999001_select_all=0&13999001SingleSelect=_T3_T2_T1_T4&Aimags_soums_select_all=0&Aimags_soumsSingleSelect=_0_0501&YearY_select_all=0&YearYSingleSelect=_2019&viewtype=columnchart (accessed on 16 June 2020).

Nalb H, and Sugden I. (n.d.) Trace element emissions from coal, CCC/203. *IEA Clean Coal Centre* (blog). Accessed February 28, 2021. https://www.iea-coal.org/report/trace-element-emissions-from-coal-ccc-203/.

National Center for Public Health and UNICEF (2018). Mongolia's air pollution crisis. https://www.unicef.org/eap/sites/unicef.org.eap/files/press-releases/eap-media-Mongolia_air_pollution_crisis_ENG.pdf.

National Statistics Organization of Mongolia Committee. (n.d.) Total population of Mongolia. Accessed April 13, 2020. https://www.1212.mn/tables.aspx?tbl_id=dt_nso_0300_004v1.

Nishikawa M, Matsui I, Batdorj D, Jugder D, Mori I, Shimizu A, Sugimoto N, Takahashi K (2011) Chemical composition of urban airborne particulate matter in Ulaanbaatar. *Atmos Environ* 45(32):5710–5715. https://doi.org/10.1016/j.atmosenv.2011.07.029

NOAA. 2015. Ulaanbaatar Climate Normals 1961–1990. 4, 2015.

Ordóñez A, Loredo J, De Miguel E, Charlesworth S (2003) Distribution of heavy metals in the street dusts and soils of an industrial city in

Northern Spain. *Arch Environ Contam Toxicol* 44(2):160–170. https://doi.org/10.1007/s00244-002-2005-6

Peris M, Recatalá L, Sánchez R, Sánchez J (2008) Increasing the knowledge of heavy metal contents and sources in agricultural soils of the European Mediterranean Region | SpringerLink. *Water Air Soil Pollut* 192:25–37

Prikaz M, Fang C, Dash S, Wang J (2018) Origin and background estimation of sulfur dioxide in Ulaanbaatar, 2017. *Environments* 5(12):136. https://doi.org/10.3390/environments5120136

Rousseeuw P, Hubert M (2011) Robust statistics for outlier detection. *Wiley Interdisc. Rew. Data Min Knowl Disc* 1(January):73–79. https://doi.org/10.1002/widm.2

Rudnick R, Gao S (2003) Composition of the continental crust. Treatise Geochem 3:1-64. *Treatise Geochem* 3(November):1–64. https://doi.org/10.1016/B0-08-043751-6/03016-4

Sahakyan L, Maghakyan N, Belyaeva O, Tepanosyan G, Kafyan M, Saghatelyan A (2016) Heavy metals in urban dust: contamination and health risk assessment: a case study from Gyumri, Armenia. *Arab J Geosci* 9(2):142. https://doi.org/10.1007/s12517-015-2159-y

Srivastava, Abhinav, N. A. Siddiqui, Rupesh Kumar Koshe, and Vishal Kumar Singh. (2018). Human health effects emanating from airborne heavy metals due to natural and anthropogenic activities: a review. In *Advances in Health and Environment Safety*, edited by Siddiqui NA, Tauseef SM, and Bansal K, 279–96. Springer transactions in civil and environmental engineering. Singapore: Springer. https://doi.org/10.1007/978-981-10-7122-5.

Suryawanshi PV, Rajaram BS, Bhanarkar AD, Chalapati Rao CV (2016) Determining heavy metal contamination of road dust in Delhi, India. *Atmósfera* 29(3):221–234. https://doi.org/10.20937/ATM.2016.29.03.04.

Tahri M, Benyaïch F, Bounakhla M, Bilal E, Gruffat JJ, Moutte J, Garcia D (2005) Multivariate Analysis of heavy metal contents in soils, sediments and water in the region of Meknes (Central Morocco). *Environ Monit Assess* 102(1–3):405–417. https://doi.org/10.1007/s10661-005-6572-7

Tchounwou PB, Yedjou CG, Patlolla AK, and Sutton DJ. (2012). Heavy metal toxicity and the environment. In *Molecular, Clinical and Environmental Toxicology: Volume 3: Environmental Toxicology*, edited by Andreas Luch, 133–64. Experientia Supplementum. Basel: Springer. https://doi.org/10.1007/978-3-7643-8340-4_6.

UNICEF, (2018)(n.d.) Mongolia's air pollution is a child health crisis. Accessed December 28, 2020. https://www.unicef.org/eap/press-releases/mongolias-air-pollution-child-health-crisis.

Wan D, Han Z, Yang J, Yang G, Liu X (2016a) Heavy metal pollution in settled dust associated with different urban functional areas in a heavily air-polluted city in North China. *Int J Environ Res Public Health* 13(11). https://doi.org/10.3390/ijerph13111119

Wan D, Zhan C, Yang G, Liu X, Yang J (2016b) Preliminary assessment of health risks of potentially toxic elements in settled dust over Beijing urban area. *Int J Environ Res Public Health* 13(5). https://doi.org/10.3390/ijerph13050491

Wang M, Kai K, Jin Y, Sugimoto N, Dashdondog B (2017) Air particulate pollution in Ulaanbaatar, Mongolia: variation in atmospheric conditions from autumn to winter. *Sola* 13:90–95. https://doi.org/10.2151/sola.2017-017

WHO. (2019). Air Pollution in Mongolia. February 2019. https://doi.org/10.2471/BLT.19.020219.

Xie Y, Chen T-b, Lei M, Yang J, Guo Q-j, Song B, Zhou X-y (2011) Spatial distribution of soil heavy metal pollution estimated by different interpolation methods: accuracy and uncertainty analysis. *Chemosphere* 82(3):468–476. https://doi.org/10.1016/j.chemosphere.2010.09.053

Xu H, Wang Y, Liu R, Wang M, Zhang Y (2019) Spatial distribution, chemical speciation and health risk of heavy metals from settled dust

in Qingdao urban area. *Atmosphere* 10(2):73. https://doi.org/10.3390/atmos10020073

Yongming H, Peixuan D, Junji C, Posmentier ES (2006) Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Sci Total Environ* 355(1):176–186. https://doi.org/10.1016/j.scitotenv.2005.02.026

Zhang T, Wu A-L, Guan L, Qi Y-H (2004) Simulations of metal Cu in heating process. *Chin J Chem* 22(2):148–151. https://doi.org/10.1002/cjoc.20040220208

Zhang X, Lin F, Wong M, Feng X, Wang K (2008) Identification of soil heavy metal sources from anthropogenic activities and pollution assessment of Fuyang County, China. *Environ Monit Assess* 154(August):439–449. https://doi.org/10.1007/s10661-008-0410-7