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Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China

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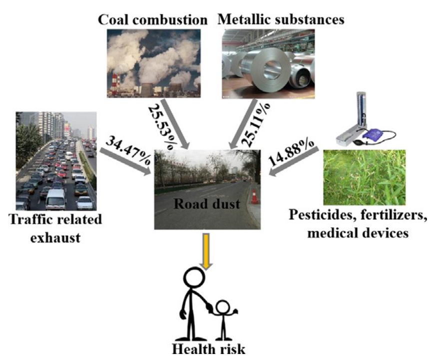
HIGHLIGHTS

- Methods were used to explore contamination and sources of metals in Beijing.
- Beijing suffered potential ecological risks, especially risks related to Cd and Hg.
- Four factors influenced metal content, with traffic-related exhaust contributed most.
- The contribution of pesticides and fertilizers should be paid attention to.

GRAPHICAL ABSTRACT



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ABSTRACT

To analyze the spatial distribution patterns, risks, and sources of heavy metals (As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Zn, Fe), 36 road dust samples were collected from an urbanized area of Beijing in June 2016. The mean concentration of most metals, except As and Mn, exceeded their corresponding background values, with the mean concentration of Cd being 8 times that of its background. Spatially, for most heavy metals, except As and Mn, the high concentration areas were mainly within the 5th ring road, especially the northern area. The geo-accumulation index of Cd and Cu indicated moderate contamination at many sites. The entire study area was prone to potential ecological risks, with higher risks within the 4th ring road. Cd caused high potential ecological risk at most sites. According to the health risk assessment results, the non-carcinogenic risks that human beings suffered from heavy metals were insignificant. However, the carcinogenic risks due to Ni and Cr exceeded the acceptable level. Based on the source apportionment using positive matrix factorization, four factors were defined for the heavy metals. Factor 1, which was traffic-related exhaust, accounted for 34.47% of the concentration of heavy metals. The contributions of Factors 2 and 3 were approximately 25% each. Factor 2 was potentially related to coal combustion, while Factor 3 could be related to the manufacture and use of metal components. Factor 4, which could be related to the use of pesticides, fertilizers, and medical devices, accounted for 14.88%, which was the lowest.

1. Introduction

Cities have large population densities, causing them to be strongly influenced by anthropogenic activities (Wang et al., 2016). The high population density consumes substantial resources, producing massive amounts of waste (Selonen et al., 2015). Persistent anthropogenic activities emit large quantities of various pollutants, threatening the environment in many aspects (De et al., 2015). The amount of garbage generated in cities is far greater than that in rural areas. That leads to water pollution, thus aggravating the shortage of drinking water (Xu et al., 2010). The air quality in cities is much poorer than that in rural

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areas, with the haze typically threatening ecosystem safety in cities (Sheng and Tang, 2015; Rui et al., 2016). Moreover, artificial environments replace the natural environment, leading to poor self-regulation of the urban ecosystem (Kováčik et al., 2016). Therefore, the concentration of pollutants tends to exceed its background values in many cities, causing varying degrees of contamination (Joshi et al., 2009; Zhao et al., 2015).

Heavy metals caused significant and serious contamination in many large cities (Nagarajan et al., 2014; Li, 2015). Heavy metals are priority environmental pollutants which are obviously cytotoxic, concealed, persistent, and biological accumulated (Zhang et al., 2017). They may cause permanent harm to the ecosystem and the human (Adamiec et al., 2016; Khorshid and Thiele-Bruhn, 2016). Therefore, it is necessary and emergent to know clearly about heavy metals such as their contamination levels and sources (Trujillo-González et al., 2016; Li et al., 2017). Various anthropogenic activities can release heavy metals. The traffic in large cities is congested, causing the consumption of more fuel and allowing more waste gas to escape from the exhaust (Kováčik et al., 2016). Fuel combustion in factories also releases substantial amounts of heavy metals (Bergthorson et al., 2015). The heavy metals thus released could accumulate in media such as water, soil, and the atmosphere (Zhang et al., 2012). Heavy metals found in such media have been reported to cause environmental pollution in many cities (Tripathi et al., 2008; Ghariani et al., 2010).

The road dust is the source and sink of heavy metals. It receives particles in the atmosphere which contains heavy metals (Zhao and Li, 2013). Moreover, pollutants released by anthropogenic activities, such as vehicles and industrial activities, could also be included in road dust (Song et al., 2015). Road dust could enter the atmosphere through the resuspension of particles, causing air pollution (Jordanova et al., 2014; Salo et al., 2016). They could also enter a water body through surface runoff during rainy season, resulting in sediment contamination and enter into the food chain eventually (Gunawardana et al., 2014; Liang et al., 2016). Road dust could enter the human body through direct ingestion of dust, inhalation of dust particles through the mouth and nose, and dermal absorption, threatening people's health (Soltani et al., 2015). Therefore, to protect the ecological environment and the public, attention should be paid to the heavy metals in road dust in large cities.

The contamination level and risks associated with heavy metals in road dust have attracted much attention in recent years, with many methods being used for their evaluation (Shi et al., 2008; Soltani et al., 2015). Among these methods, both the index of geo-accumulation (I_{geo}) and potential ecological risk index (RI) have been used widely (Zhao and Yang, 2005; Xu et al., 2008; Hasan et al., 2013). A combination of those two methods could make a relatively accurate assessment by considering the lithology, toxicity variance of heavy metals and comprehensive effect of multiple contaminants (Trujillo-González et al., 2016). The health risk assessment method has also been widely applied to the assessment of non-carcinogenic and carcinogenic risks to the public due to heavy metals (Zheng et al., 2010). Combined with Geographic Information System (GIS), the spatial variation of heavy metals and the risks associated with them can be assessed (Liu et al., 2016).

To control the contamination from heavy metals directly and effectively, it is essential to identify the sources of heavy metals (Brady et al., 2014). Positive matrix factorization (PMF) is a source apportionment model which has been applied in more and more researches in recent years (Yu et al., 2015; Gholizadeh et al., 2016). Compared with other models, the factor matrix is restricted to non-negative values to obtain more meaningful factors (Liu et al., 2015; Manousakas et al., 2017). PMF could also provide quantitative information regarding the contribution of each source type, which is very significant in source apportionment (Wang et al., 2015). PMF is applicable to various media, such as the atmosphere, soil, sediment, and water (Wang et al., 1998; Saba and Su, 2013; Haji et al., 2016; Milic et al., 2016). However, for road dust, PMF was rarely used in its source apportionment. Some scholars recognized this situation, and explored the application of PMF on the source apportionment of PAHs (Li et al., 2016). Even so, for the heavy metals in road dust, less researches were developed with PMF for the source apportionment. Most models used in the source apportionment of metals in road dust were not quantitative for each element (Mathur et al., 2016; Mummullage et al., 2016). Therefore, using PMF to evaluate the sources of heavy metals in road dust would be meaningful.

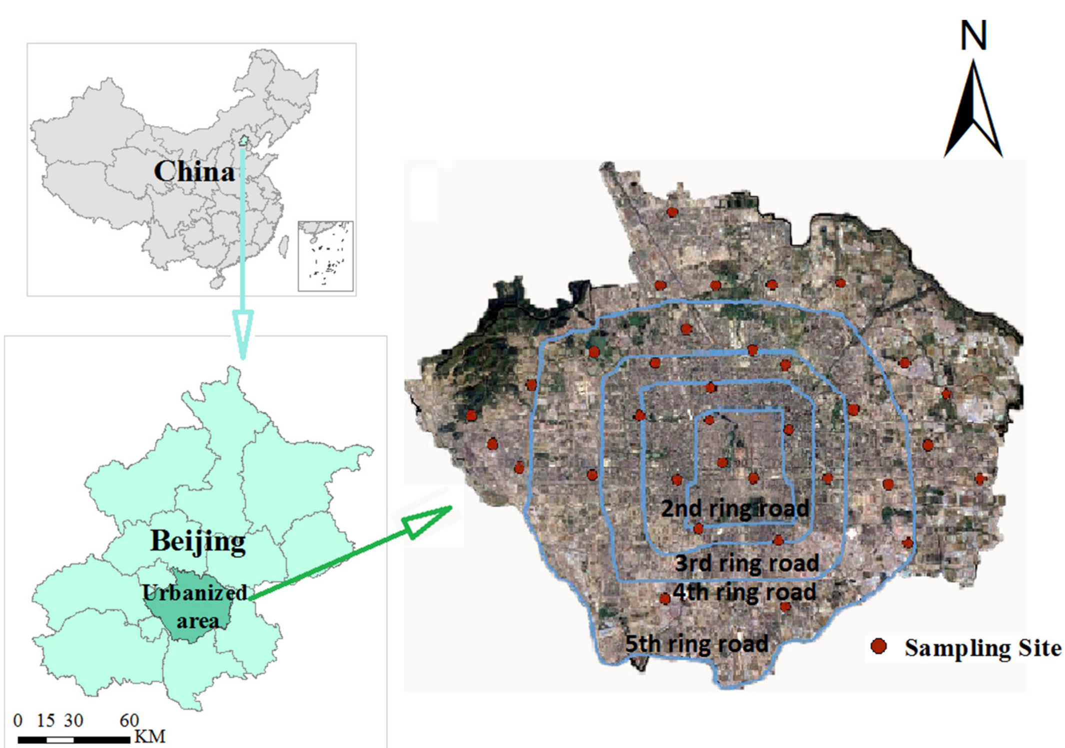

Fig. 1. Locations of the study area.