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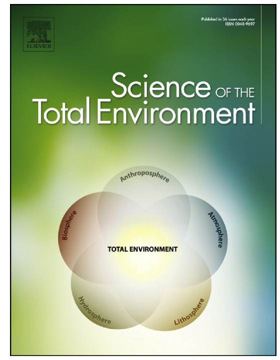

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Concentrations, spatial distribution, sources and environmental health risks of potentially toxic elements in urban road dust across China

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Abstract: Potentially toxic element (PTE) pollution is widespread in road dust across China, and the effects of PTEs in road dust on health cannot be ignored. In this study, the concentrations of six PTEs (Pb, Cd, Cr, Cu, Zn and Ni) in 4336 road dust samples from 58 cities in 31 provincial regions of China taken after 2000 were obtained from the literature. Based on these data, the spatial distribution, pollution sources, and ecological and human health risks of PTEs in road dust were comprehensively assessed and the main pollution factors and areas of high risk were identified. The results revealed that PTE levels are generally higher in eastern cities than western cities in China. The key driving factors are socioeconomic factors, including those related to transportation, industry, and population, for which the contribution rates are 57.80%, 55.39% and 37.19%, respectively. PTEs in the road dust with high ecological risks are mainly distributed in the southeastern coastal areas and the Beijing-Tianjin-Hebei region. No obvious noncarcinogenic risk was found for PTEs in road dust, but Cd and Pb may have potential noncarcinogenic risk, mainly distributed in cities in western China. Therefore, regions and pollution sources contributing to Pb and Cd levels should be monitored. The control of PTE pollution in China is a priority for ecological and environmental protection.

Keywords: Potentially toxic elements; Road dust, Correspondence analysis; Nemerow integrated risk index; Geodetector

1. Introduction

Urban road dust is a mixture of solid particles on outdoor impervious ground with both natural and anthropogenic origins (Padoan et al., 2017; Sutherland et al., 2012). Urban road dust can be affected by many factors, such as climate, human activities, surrounding soil and rocks (Safiur Rahman et al., 2019; Tian et al., 2018). As a consequence of road construction, mining and industrial activities, millions of tons of dust particles, which contain heavy metals or metalloids, remain in the environment (Li et al., 2013b; Zhang et al., 2017). It is critical to identify the sources of PTEs in road dust for both pollution prevention and environmental protection (Bourliva et al., 2018; Hou et al., 2019). The density of road networks and the number of motor vehicles have increased rapidly in China, and this has increased the deposition of urban road dust (Harrison et al., 2012; Kuhns et al., 2001).

Urban roads have the highest densities of human activities and vehicle operation (Acosta et al., 2015; Shi et al., 2011). Under external dynamic conditions, surface particles are easily mobilised (Kim and Sansalone, 2008). In addition, road dust enters human body through inhalation, dermal contact and ingestion, causing a potential threat to human health (Gwenzi et al., 2018; Hu et al., 2011). The migration and lifecycle of road dust are affected by complex factors (Amato et al., 2012; Liu et al., 2016). For example, the factors affecting the input process include atmospheric deposition, traffic sources, wear and decomposition of roads, discarded garbage debris, and green plant debris; factors affecting the output process include traffic disturbance, wind disturbance, runoff scouring, and street cleaning (Fig. 1) (Ali et al., 2019; Gugamsetty et al., 2012). Road dust can be transformed into atmospheric particulate matter. During the scouring by surface runoff, pollutants adsorbed by particulate matter will migrate into the urban watershed, causing additional potential ecological risks (Amato et al., 2014; Harrison et al., 2012).

[Insert Fig.1]

PTE pollution from road dust is an important issue related to human health and has caused widespread concern (Duan et al., 2020). Owing to rapid industrialization and urbanization, PTE contamination in road dust is especially serious in China (Hu et al., 2020). Many studies have found that traffic intensity is closely related to the accumulation of PTEs in urban road dust (Li et al., 2013a). Other studies have assessed road dust in different functional areas and found that Cd, Cu, Pb, and Zn levels are higher in industrial areas (Duzgoren-Aydin et al., 2006). Great progress has been made on controlling contamination levels (Wu et al., 2020), spatial distribution and hot spots (Gong et al., 2014), particle size characteristics (Acosta et al., 2011), sources points and potential environmental health risks of PTEs in urban road dust (Bartholomew et al., 2020; Bourliva et al., 2017). The study areas of previous work primarily focused in certain areas or cities (Acosta et al., 2015; Gope et al., 2017; Men et al., 2018), while nationwide comparative studies are lacking. Therefore, a comprehensive statistical analysis of PTEs in road dust on a national scale was necessary. This paper has three main goals: (1) to quantify the spatial distribution and influencing factors of PTE concentrations; (2) to identify the major sources and fates of PTEs in road dust; and (3) to explore the ecological risks and human health risks of PTEs in road dust and to identify key elements and hot spots that need to be controlled.

2. Data and methods

2.1. Data preparation

The published papers related to six PTEs (Ni, Cd, Zn, Cu, Cr, and Pb) in road dust across China since 2000 were reviewed with a total of 4336 sample sites covering 58 cities in31 provincial administrative regions. These publications were obtained from three major databases (China National Knowledge Infrastructure, Science Direct and Web of Science) and were filtered based on the following conditions: (1) the sample points were scattered throughout the country as much as possible, while ensuring that there were sampling site located in the capital cities of provinces; (2) studies in highly polluted areas such as those with mine tailings, e-waste disposal sites and landfills were discarded; and (3) the chemical analysis processes followed strict regulations for quality assurance and control (Hu et al., 2021). A list of these studies is provided in Table S1. The socioeconomic data of industrial added value, car ownership and population data came from the National Bureau of Statistics of China (National Bureau of Statistics, 2010-2019).

2.2. Data analysis

2.2.1. Nemerow integrated risk index

Nemerow integrated risk index (NIRI) is a new method to evaluate the integrated ecological risks of PTEs based on the NIPI and potential ecological risk index (RI), which was described by Men et al. (2020). In this study, NIRI values of PTEs in different cities were evaluated. Detailed information and classification on NIRI are presented in S1 and Table S2.

2.2.2. Health risk assessment indices

The health risk assessment model was used to assess the noncarcinogenic effects of PTE exposure on humans developed by the US EPA (US EPA 2011). Among the 6 PTEs in this study, most are non-carcinogenic elements (He et al., 2020). Therefore, we studied the noncarcinogenic risks caused by ingestion, inhalation and skin contact. The noncarcinogenic risks for children and adults were also calculated separately. The daily intake via ingestion (ADD_{ing}), inhalation (ADD_{inh}) and dermal contact (ADD_{dermal}) were estimated for each elements (Eqs.(1)-(3)).

$$ADD_{ing} = \frac{C_S \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (1)$$

$$ADD_{inh} = \frac{C_S \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (2)$$

$$ADD_{dermal} = \frac{C_S \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (3)$$

Here, C_S represents the content of PTEs in road dust sample (mg/kg), and all the other parameters (*IngR, EF, ED, BW, AT, InhR, PEF, SA, AF and ABS*) were summarized in Table S4.

The potential noncarcinogenic effects of PTEs are determined via the following equations (Eqs. (4) and (5)):

$$HQ_i = \frac{ADD_i}{RfD_i} \quad (4)$$

$$HI = \sum HQ_i \quad (5)$$

HQ_i is defined by the quotient of the *ADD* of each PTE and its corresponding reference dose (*RfD*) for each exposure pathway, the parameter *RfD* was summarized in Table S5. Hazard index (*HI*) can be defined by adding *HQi* of each PTE.

2.2.3. Geographic detector

The geographic detector is a statistical analysis method to detect the spatial differentiation of variables and reflect the driving forces, the q-statistic was used to measure the contribution rate of the variable (Wang et al., 2010). It has been widely applied to study the relationship between environmental factors and human health, in recent years it has also been used to study the driving factors for the spatial variability of PTEs (Huang et al., 2014; Todorova et al., 2016; Wang et al., 2010). The model consists of four sub models: factor detectors, interaction detectors, risk detectors and ecological detectors. In this study, the effects of population factors (population data), traffic factors (car ownership) and industrial factors (industrial added value) on the spatial differentiation of PTEs in road dust were explored using factor detector and interaction detector. In order to avoid the mutual interference among the 6 PTEs, the Nemerow integrated risk index (NIRI) was selected as the response variable to represent the spatial distribution of PTEs, because NIRI integrates the spatial distribution characteristics of 6 PTEs and considers the ecological risks of PTEs in different regions. The flowchart of geographic detector analysis is shown in Fig.2. Detailed information of the geographical detector is presented in S3.

[Insert Fig.2]

2.2.4 Correspondence analysis

Correspondence analysis is a statistical analysis technique of multivariate dependent variables. Its basic idea is to reduce the dimension of data and explain the internal relationship between variables. Meanwhile, it can also reveal the differences between different categories of the same variable and the relationship between different categories of different variables (Sojka et al., 2018). Therefore, in this study, correspondence analysis was used to establish the relationship between 6 PTEs and 58 cities, because PCA has been widely used in the identification of pollution sources

(Huang et al., 2018b; Yang et al., 2013). The correspondence analysis was used to explain several major pollution sources in 58 Cities in China.

2.3. Statistical analysis

Summary statistics and correspondence analysis were employed from SPSS 25.0, the comparison of PTE concentrations in eastern and western cities was plotted using Origin2021, and the spatial distribution maps of ecological risk and health risk posed by PTEs in road dust were produced using ArcGIS 10.6.

3. Results and discussion

3.1. Descriptive statistics of PTEs in road dust

Table S1 summarizes the concentrations of PTEs (Ni, Cd, Zn, Cu, Cr, and Pb) in road dust based on published literature. Descriptive statistics are listed in Table 1. The mean levels for all six PTEs in dust are higher than their background values in Chinese soil. The mean concentrations of PTEs decrease in the order of Zn (667.3 mg kg^{-1}) > Cu (158.2 mg kg^{-1}) > Pb (146.6 mg kg^{-1}) > Cr (140.6 mg kg^{-1}) > Ni (42.5 mg kg^{-1}) > Cd (1.2mg kg^{-1}). The variable coefficients (CV) of Cd, Cu and Zn are relatively high, indicating the wide variation in concentrations in road dust. Comparing the PTE concentrations in urban road dust in China with those in other cities in the world (Table S7), Cd, Cr, Zn and Ni are higher in most Chinese cities, and the concentrations of Pb and Cu are higher in foreign cities.

[Insert Table 1]

3.2. Spatial distributions and influencing factors of PTEs in road dust

Fig. S1 shows the spatial distributions of 6 PTEs in road dust throughout China. The high concentrations of Ni, Cr, Pb and Cu are mainly distributed in southeastern China, including Zhuzhou, Ezhou and Daye, while the highest values of Cd and Zn are found in the northern cities of Beijing and Huludao. In contrast, the lowest concentrations of Pb, Cd, Cu, Zn are mainly observed in northwestern China, such as in Yinchuan, Naqu and Baotou. The concentrations of PTEs varied considerably among the different cities, showing an increasing trend from the northwest to the southeast.

Eastern China and Western China are divided by policies. Eastern China refers to the provinces and cities that first implemented the coastal open policy with a high level of economic development, while Western China refers to the economically underdeveloped western region (Yang, 2017). Fig. 3 shows the comparison of PTE concentrations in eastern and western cities of China. The concentrations of Pb, Cd, Cu, Zn, and Ni are significantly higher in Eastern China than in the Western part. The factors affecting the spatial distribution of PTEs in road dust are described below.

[Insert Fig.3]

3.2.1. Socio-economic factors

(1) Industrial activity

Excessive industrial and residential emissions directly cause an increase in PTE levels in road dust, and many industries are involved in PTE pollution (Cai et al., 2020). Industries such as mineral mining and smelting, electroplating, plastics, batteries, line printing, chemical production, and textiles are the main sources of PTEs emissions (Han et al., 2017; Igalavithana et al., 2015). Industrial production, fossil fuel combustion, etc., also release a variety of PTEs, so the 6 PTEs have high concentrations in industrial areas. The Cu level is 201.58 mg/kg, which is 8.9 times of the local soil background value. The concentrations of Cu, Cd, Ni and Pb related to industrial emissions appear to cause hot spots in the southeastern coastal areas with high industrial added value (Fig. 4(a)).

[Insert Fig.4 (a)]

(2) Traffic activity

With the continuous improvement of China's road network, car ownership is increasing rapidly, and PTE pollution from traffic sources has become an important issue. Factors such as traffic flow, vehicle type and vehicle scrappage lead to different release behaviours for pollutants (Harrison et al., 2012; Huang et al., 2018a). The concentrations of Cr, Cu and Zn in cities with high traffic flows, such as Beijing and Shanghai, are higher than those in cities with low traffic flows, such as Baotou and Naqu. There is a positive correlation between the proportion of heavy vehicles in the total number of motor vehicles and the PTE concentration (Davis and Birch, 2010), and the pollution derived from car scrapping has become increasingly serious with the increase in car ownership (Megido et al., 2016). Table S9 shows that Zn levels are

494.03 mg/kg and 607.14 mg/kg in traffic areas and commercial areas, respectively. In 2017, the density of the highway network in eastern China reached 118 km/100 km^2, while in Western China, it was only 27 km/100 km^2, indicating levels differing by a factor of 4.37 (Lin and Ding, 2021). In the eastern regions exhibiting high road density and extensive car ownership, such as the Yangtze River Delta and the Beijing-Tianjin-Hebei region , the concentrations of PTEs (Pb, Cd, Cu, Zn) related to traffic activities are relatively high (Fig. 4(b)).

[Insert Fig.4(b)]

(3) Urban functional zoning

PTE concentrations in different urban functional areas of the surveyed cities are listed in Table S8, and a summary is presented in Table S9. The concentrations of Cr, Ni, Pb, Cu, Zn are higher in the industrial areas and commercial areas. This indicates that in commercial areas with large flows of people and vehicles, human activities are diverse and road conditions are complex, which may release many PTEs that settle on the road surface. For example, the Zn level associated with traffic activity is 607.14 mg/kg in commercial areas, 9 times higher than the local soil background value. The mean value and maximum value of Cu in industrial area are higher than those in other functional areas, and the maximum value is 2 times in commercial area and 4 times in traffic area. In addition, rapid economic development produces more PTEs, such as higher PTE levels in the economically prosperous Southeast, possibly due to larger populations (Fig. S1).

(4) Contribution rate of different factors to the spatial distribution of PTEs, via geographical detectors

Table 2 represents the contribution rate of the three factors and their influences on the spatial distribution of PTEs. The q-statistic of the traffic factor is the largest, with an contribution rate of 57.80%, followed by the industrial factor (55.39%) and the population factor (37.19%). The interactions between the factors are nonlinearly enhanced. The q-statistic of the interaction between the industry factor and the traffic factor is 79.29%, between the industry factor and population factor it is 80.89%, and between the traffic factor and population factor it is 82.49%. This indicates that the industrial factor, traffic factor and population factor are important factors affecting the concentration levels and spatial distribution of PTEs in road dust, and the traffic factor is the most significant one ($q = 0.5780$; $P < 0.05$). The nonlinear enhancement of the interactions between factors also indicates that the spatial differentiation of road dust PTEs is affected by multiple factors. In addition to socioeconomic factors, it may also be related to other factors, which further indicates that understanding the sources of PTEs in road dust is complex (Wang et al., 2018; Yang et al., 2016).

[Insert Table 2]

3.3. Pollution sources of PTEs in road dust

The PTEs source of road dust in 58 cities mainly include natural and anthropogenic sources. Traffic sources appeared in all the cities studied, the occurrence frequency was 100%. Traffic sources are the most important factor for PTEs in road dust, followed by industrial sources. In some cities, natural sources also appeared. For example, in the northeast industrial bases of Huludao (Li et al., 2015), Shenyang (Zheng et al., 2016) and Changchun (Qiang et al., 2015), PTEs in road dust are mainly related to atmospheric deposition caused by industrial production and coal burning. However, in some areas less affected by human activities, such as park areas , PTEs in road dust are mainly related to local soil sources. The pollution sources of PTEs are sensitive to the surrounding environment.

Correspondence analysis and correlation analysis are applied to identify pollution sources in this study. There is a significant positive correlation between Pb-Cd-Zn, Cr-Cu (Fig. 5a). After fully considering the relationship between 58 cities and 6 PTEs, correspondence analysis also identified 3 factors, namely Pb-Cd-Zn, Cr-Cu and Ni (Fig. 5b), The corresponding pollution sources include traffic sources, industrial sources, natural sources and urban construction sources, which are analyzed as follows:

[Insert Fig.5]

3.3.1. Traffic sources

The correlation between Cd and Cu levels is significant, and it arises mainly from traffic sources. In the correspondence analysis, Daye, Wuhan, Hong Kong and Suzhou are the main related cities. Among them, Wuhan is an important transportation hub in China(Yang et al., 2011), and Hong Kong is one of the cities with the busiest traffic in the world(Yeung et al., 2003). Some studies have also found that the contents of Cd and Cu rapidly decrease with increasing distance from roads. Automobile exhaust and the wear of vehicle components will cause the accumulation of PTEs, especially the concentration of Pb have long been closely associated with vehicles (Li et al., 2020). Pb is the material for wheel weights, and vehicle tires also contain significant amounts of Cd and Cu. In some surveyed cities, the 2 PTEs are also emitted from vehicle exhaust (Lin et al., 2017). Traffic sources are one of the main sources of PTEs in road dust and involve not only the products of vehicle exhaust but also engine emissions and wear, tire wear, brake wear, car body wear, oil leaks, and erosion of the road surface (Harrison et al., 2003; Sternbeck et al., 2002). Cd and Cu were heavily contributed by traffic sources in most cities. For example, in the roads in different regions of Baoding, the contents of Cd and Cu vary in a consistent and significantly correlated way, which mainly derives from traffic emissions (Zheng et al., 2009).

3.3.2. Industry sources

The pairwise correlations between Pb, Zn and Cd indicate that their sources are similar, and the PTEs in this group arise from traffic sources of road dust. Xining, Kunming, Luoyang, Quanzhou, Huludao and Bayan Obo are the main cities related to this factor. Previous studies show that Bayan Obo is a typical mining city and an important industrial base (Li et al., 2015). Quanzhou is a modern industrial and trade port city in Fujian Province (Yu et al., 2014). Huludao city is a typical heavy industry city in China, mainly in ship manufacturing, petroleum refining and non-ferrous metal smelting (Zheng et al., 2009). For example, in Changsha (Li et al., 2016), Loudi (Zhang et al., 2012), Zhuzhou (Sun et al., 2017) and Xiangtan (Long et al., 2010), Cd and Zn are mainly derived from industrial production of nonferrous metals. Cd is the main element found in industrial smelting and waste gas emissions (Wang et al., 2016). Industrial smelting causes the emission of fly ash into the atmosphere, and the metals present in the fly ash are deposited in road dust (Raja et al., 2014). Zn is released during industrial activities such as metal processing and smelting and is also present in building materials (Buzatu et al., 2014). These activities release a large amount of polluted water, smoke and dust, which contain considerable amounts of metals, including Cu and Pb (Schwab et al., 2014). As a result of wind, contaminated water can flow into the soil and then migrate into road dust (Taylor et al., 2010). This indicates that industrial activity, deposition and resuspension are the main sources of PTEs in road dust.

3.3.3. Natural sources and urban construction sources

The Ni may arise from natural sources and urban construction sources. Ni are considered to be derived from natural sources in some places, such as the study of Quanzhou (Yu et al., 2014), Suzhou (Ma et al., 2015), Baoji (Lu et al., 2010), and Kaifeng (Duan et al., 2016); these places are less affected by human activities. Cr and Ni are also related to urban construction sources. Nickel-chromium alloys are commonly used as building materials. Urban construction pollution mainly includes construction dust, corrosion and shedding of building metal parts, and ageing or shedding of various building materials (Zhu et al., 2013). These Ni-Cr-containing building materials are widely used in modern buildings (Amjadian et al., 2016). Therefore, natural sources and urban construction are the main sources of PTEs pollution in urban streets.

3.4. Ecological risk of PTEs in road dust

The ecological health risk of PTEs in road dust includes the risks of specific pollutants and sources of pollution (Men et al., 2020). The potential ecological risks of Pb, Cd, Cr, Cu, Zn, and Ni were in the ranges of 4.4-131.3, 35.8-24066.08, 0.67-50.17, 3.51-413.59, 0.84-88.14, and 3.21-23.04, respectively. In terms of the potential ecological risk factor for a single element, Pb, Cr, Cu, Zn and Ni primarily exhibit low risk and moderate risk, and only a few cities are at considerable risk or high risk levels. For example, the Cu in Daye poses high risk (Fig. S2). The potential ecological risk factors for Cd are relatively high, which poses a high risk in most cities, indicating that most cities are polluted by Cd. According to the NIRI results, most cities in China, which are mainly located in the southeast coastal areas (such as Guangzhou, Quanzhou, Suzhou, Hangzhou) and the Beijing-Tianjin-Hebei region (such as Tianjin, Baoding, Shijiazhuang,Langfang), exhibit extreme risks, while most cities in the western regions (such as Naqu, Karamay, Xining) exhibit low risks (Fig. 6). However, some provincial capitals, such as Lanzhou, Chengdu and Urumqi, have high ecological risks. Generally, provincial capitals have better production conditions and attract higher populations, which lead to intensive labour, heavy traffic and developed production activities that pose higher risks to the ecological environment.

[Insert Fig.6]

3.5. Human health risk assessment

The noncarcinogenic risks of children and adults caused by different exposure routes were shown in Table S10. The potential health risks to adults and children are different. Generally, the descending order of exposure level is: ingestion > inhalation > dermal contact. Children are always at higher risk of exposure to PTEs than adults, possibly because children have a stronger metabolism and are so sensitive to pollutants that they can absorb more metals from the environment; this is similar to previous studies (Ferreira-Baptista and De Miguel, 2005).

The noncarcinogenic risk of exposure to PTEs in road dust is higher for children. The order of HI values in both children and adults is Cr > Pb > Cd > Cu > Ni >Zn, and the PTEs that need to be controlled are Cr and Pb. For noncarcinogenic risk, the HI value is less than 1 in most cities, indicating that there is no noncarcinogenic risk from PTEs in road dust. However, the HI values for Cr and Pb are close to 1, and more attention should be paid to potential noncarcinogenic risks. Cr and Pb are the metals that need to be controlled, children are the key population that needs to be protected.

The noncarcinogenic risks for children exposed to Pb, Cd, Cr, Cu, Zn, Ni in different regions are shown in Fig. S3. The spatial distribution of non-carcinogenic risk for PTEs was similar in children and adults. For example, the HI values of Pb are higher in Huludao, Baoji, Changzhou, Quanzhou, Zhuzhou, Xiangtan; the values of Cr are higher in Daye, Naqu, Luoyang, Xining, Xuanwei. These places are mainly located in cities in western China, where the economic level and medical conditions are relatively backward. Therefore, attention should be paid to the potential non-carcinogenic risks caused by Cr and Pb.

Other factors that affect human health risks include the particle size of road dust and the phases of PTEs (Sutherland et al., 2012). Due to their large specific surface areas, the fine particles of road dust with diameters less than 63 μm almost control the metal mass load of all particle size fractions (Acosta et al., 2011). Additionally, finer particles have higher health risks because they are more likely to penetrate the respiratory tract, thereby increasing the risk of inhalation and ingestion (Chen et al., 2020; Ikegami et al., 2014). PTEs adsorbed by road dust can exist in many phases, which have different reactivation potentials affecting bioavailability and toxicity (Yu et al., 2001). The phases of the elements in road dust are not fixed. With changes in external environment factors, such as pH and redox potential, the phases of PTEs in road dust will also change (Lu et al., 2003). In acidic environments, heavy metals are more likely to exist in available states. Cd, in particular, easily migrates and transforms and is then released into the environment. If the soil pH decreases, the availability of Cd will increase significantly, so it is easier for the plants to absorb it. Generally, with the decrease of pH, the dissolution rate of adsorbed Cd on the soil colloid increases, and the solubility of Cd increases, thus accelerating the migration and transformation of Cd in the soil (Liao et al., 2005; Ottosen et al., 2008). The environmental pH in southeastern China is lower than those in other areas, so the PTEs in road dust in southeastern China is more unstable (Lu et al., 2003). Therefore, attention should be paid to the health hazards caused by different phases of PTEs.

4. Conclusions

This study provides comprehensive knowledge on road dust PTE pollution in 31 provinces across China. There is an obvious accumulation of PTEs in road dust in most cities of China, and the concentrations of PTEs are higher in eastern cities than in western cities due to the high degree of industrial and economic development in eastern cities. There is no obvious noncarcinogenic risk from PTEs in road dust, but the HI values of Cr and Pb are close to 1, indicating potential noncarcinogenic risk, which is mainly distributed in cities in western China due to relatively poor economic and medical level. Furthermore, Children are always at higher risk of exposure to PTEs than adults. Additionally, the southeastern coastal region, Beijing-Tianjin-Hebei region and some western provincial capitals show high levels of Ecological risks, and priority should be given to controlling PTE pollution in these cities and regions. Cities with the accumulation of road dust PTEs were affected by socioeconomic factors such as transportation, industry, and population, and the contribution rates for these factors were 57.80%,55.39% and 37.19%, respectively. Overall, these findings have important implications for understanding road dust PTE pollution in China. They reveal the health risks posed by exposure to road dust on a national scale.

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Tables

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Fig. 6 Nemerow integrated risk index for PTEs in urban road dust

Table 1 Descriptive statistics for PTE concentrations in road dust in 58 Chinese cities

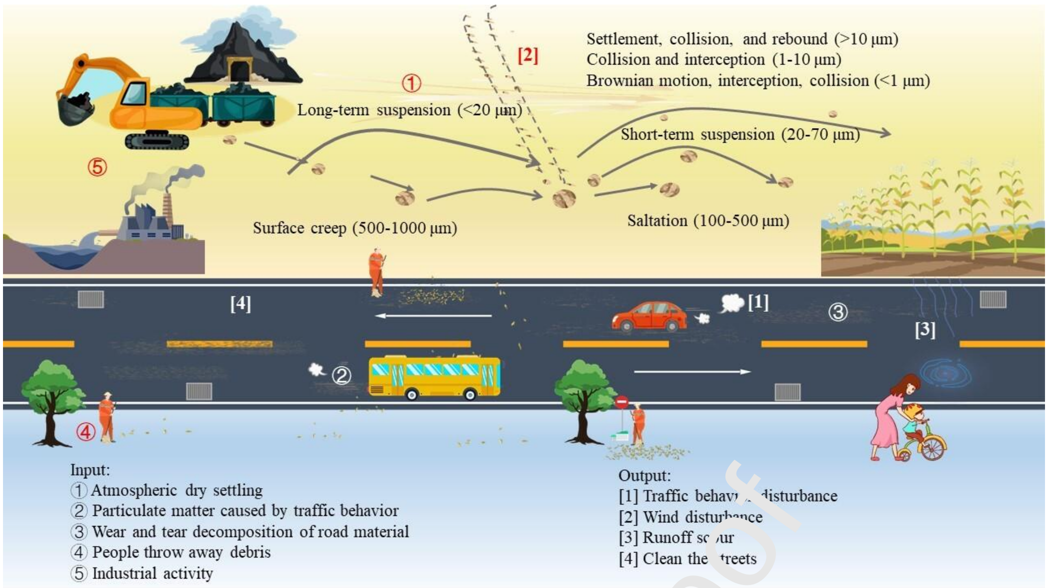
(mg kg^{-1})

	Pb	Cd	Cr	Cu	Zn	Ni
Min	0.9	0.1	26	15	50	16.4
Max	956	72.8	576.8	2332.6	5271	148.4
Mean	146.6	5.1	140.6	158.2	667.3	42.5
Median	78.2	1.2	115	99	354.5	25.8
SD	166.6	12	100	302.5	930	25.8
CV%	113.7	236.1	71.1	191.3	139.4	60.8
Background[a]	26	0.1	61	22.6	74.2	26.9

[a] Background level of China soil.

Table 2 The contribution rate (q-statistic) of three factors and their interactions

Factors	Industrial	Traffic	Population
Industrial	55.39%		
Traffic	79.29%	57.80%	
Population	80.89%	82.49%	37.19%



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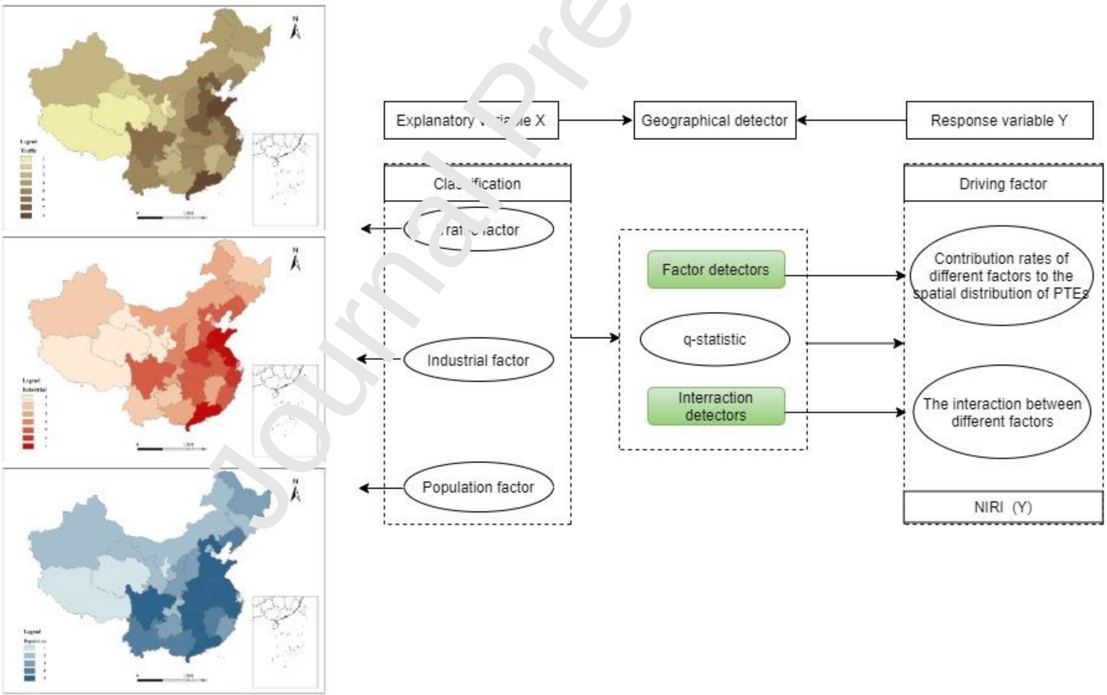


Fig. 2 Flowchart of geographic detector analysis

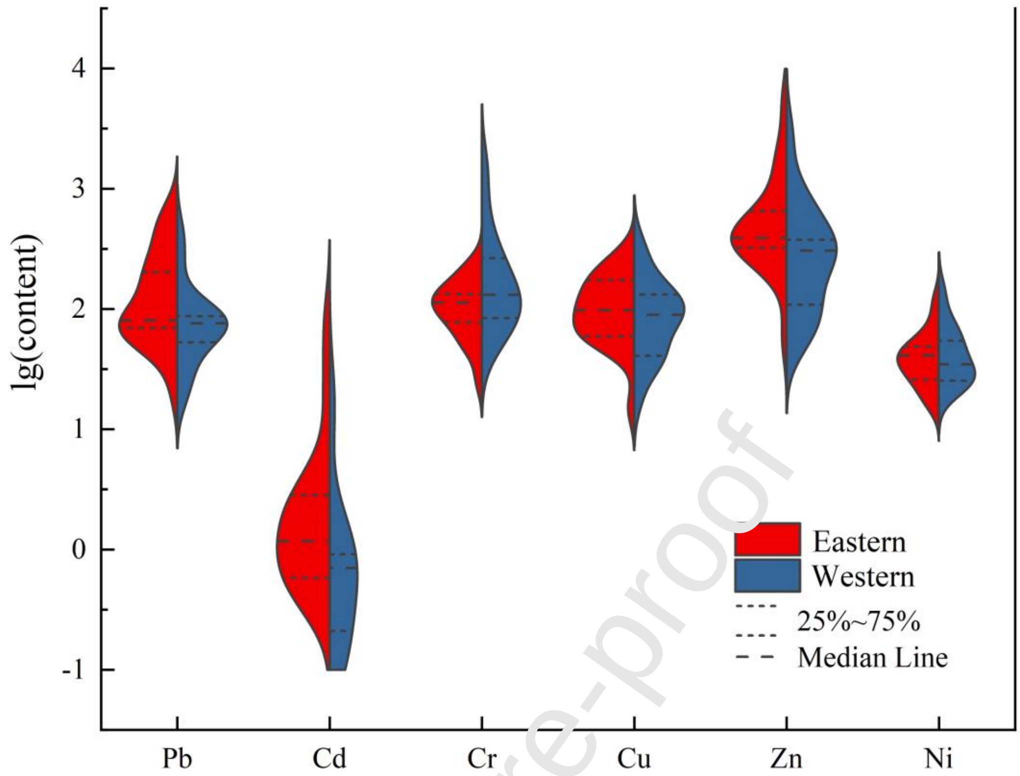


Fig. 3 Comparison of the concentration of PTEs in road dust in the eastern and western cities of China

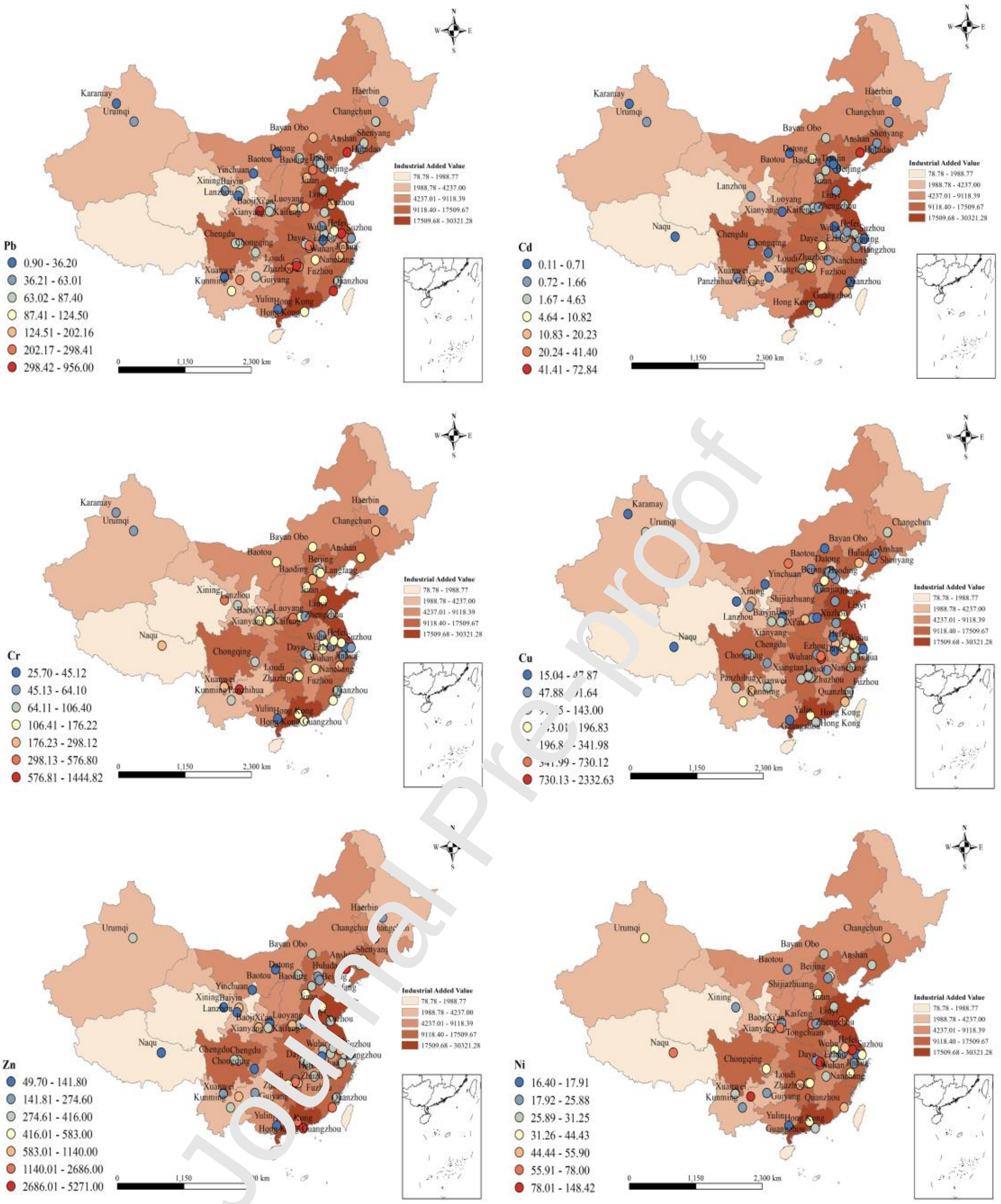


Fig. 4(a) Distribution of Industrial Added Value and PTE concentrations

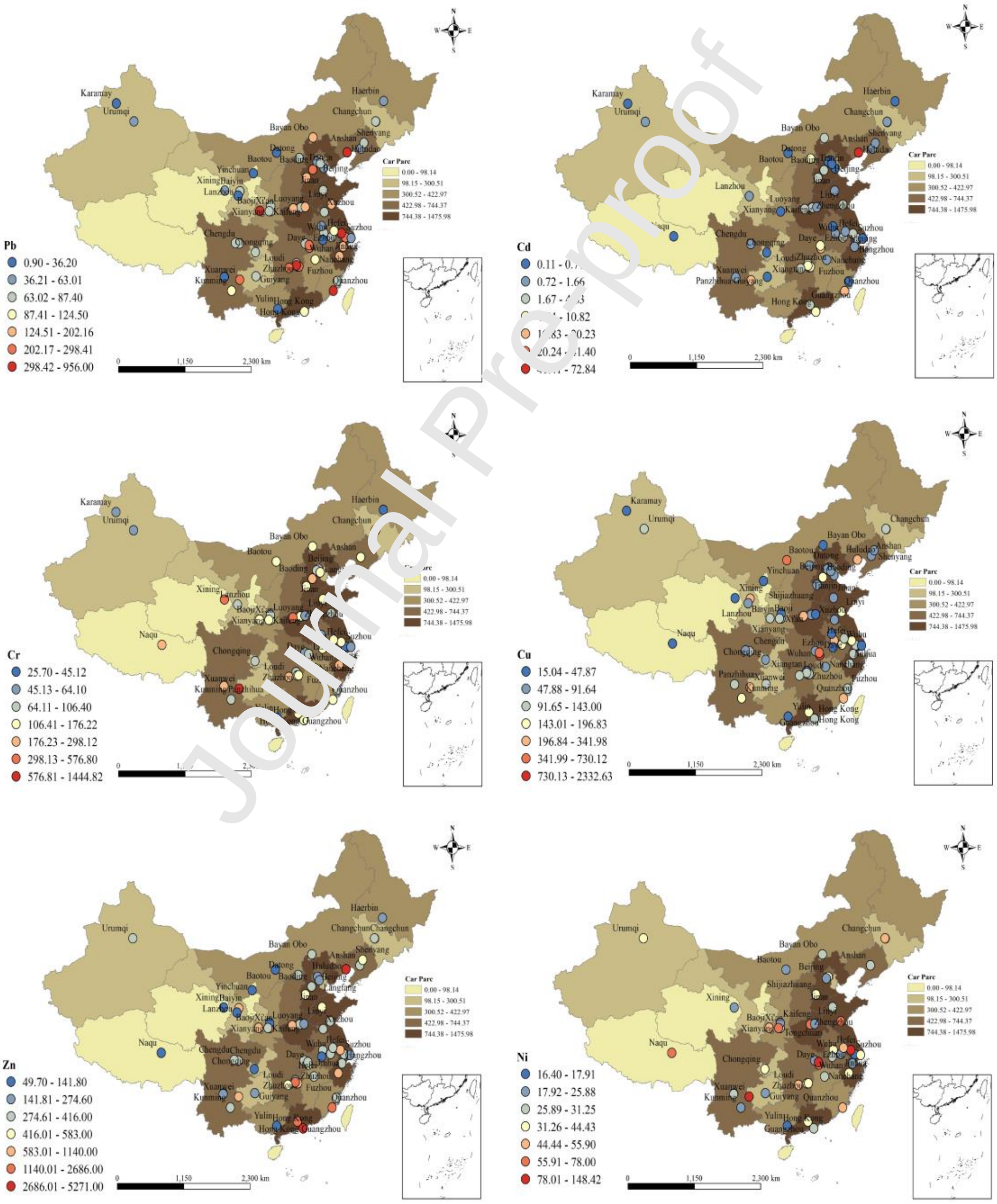


Fig. 4(b) Distribution of Car Ownership and PTE concentrations

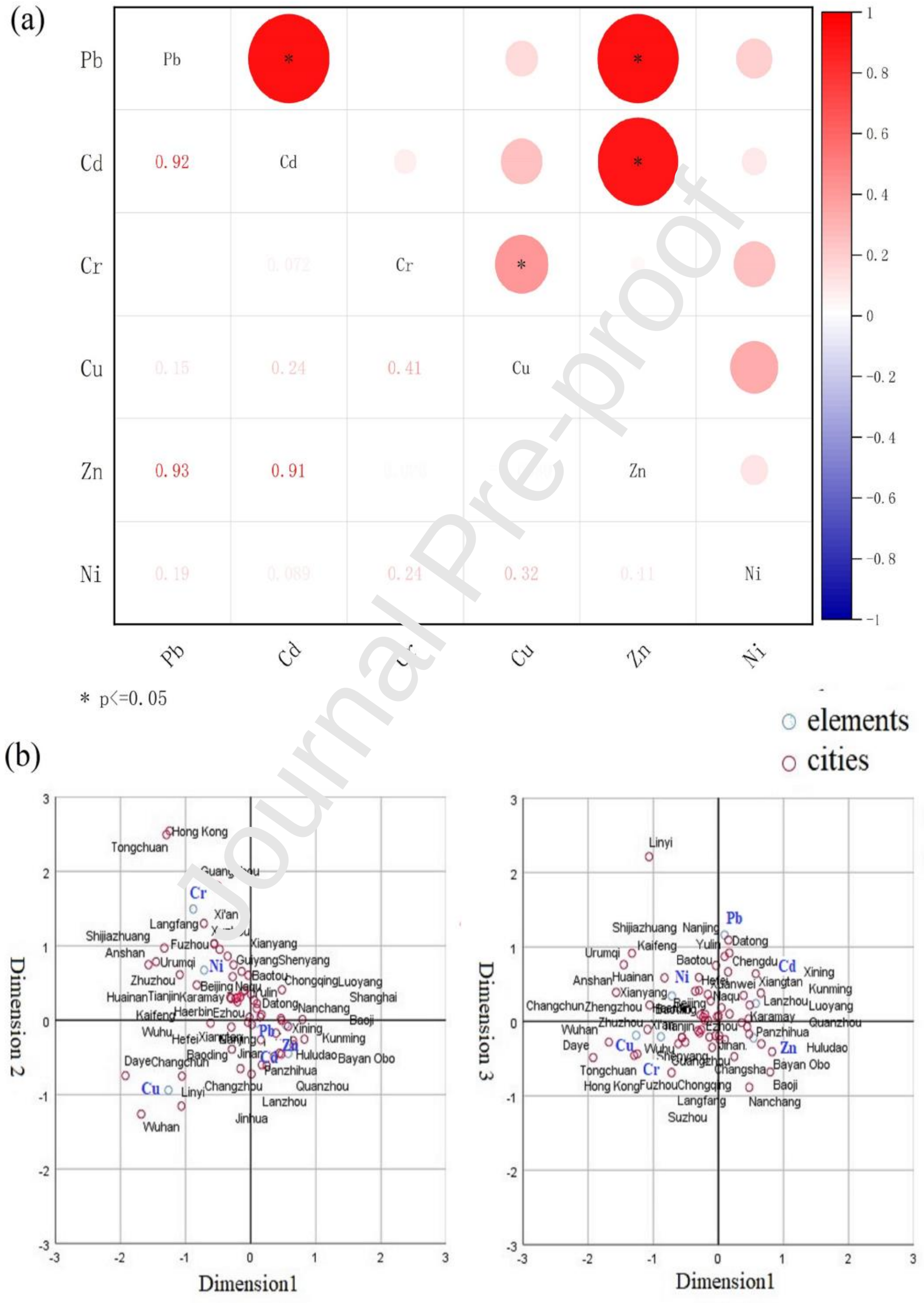


Fig. 5 (a) Correlation analysis and (b) factor correspondence analysis

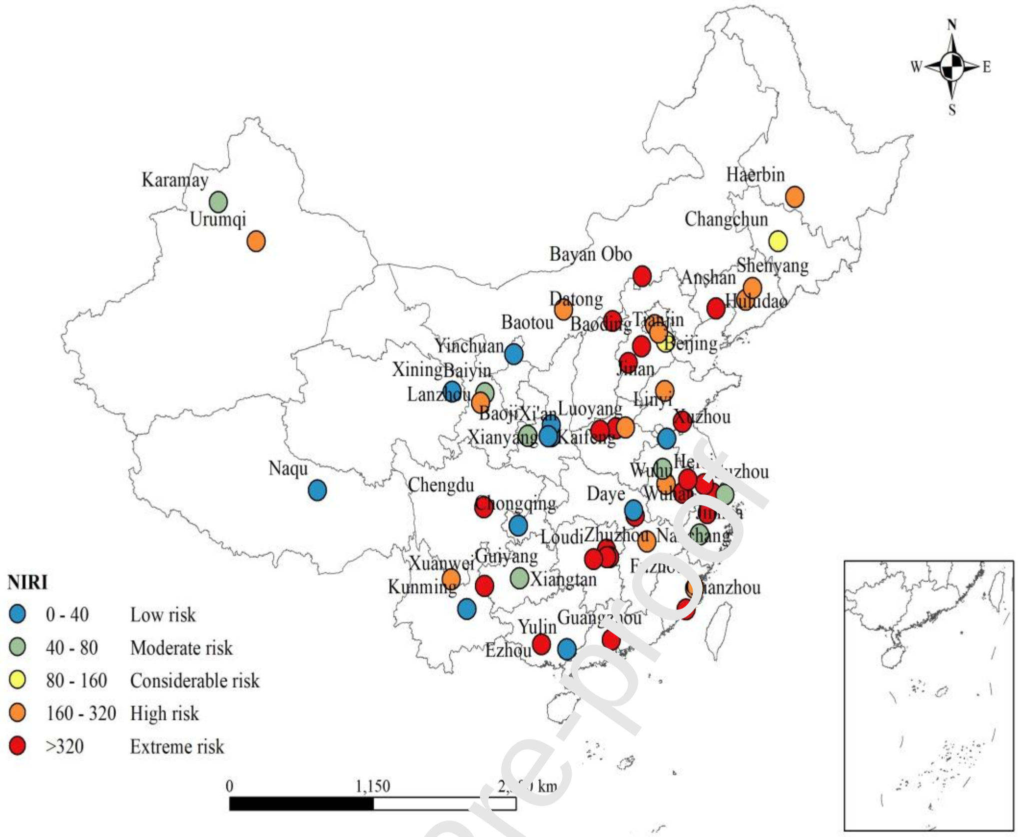


Fig. 6 Nemerow integrated risk index for PTEs in urban road dust

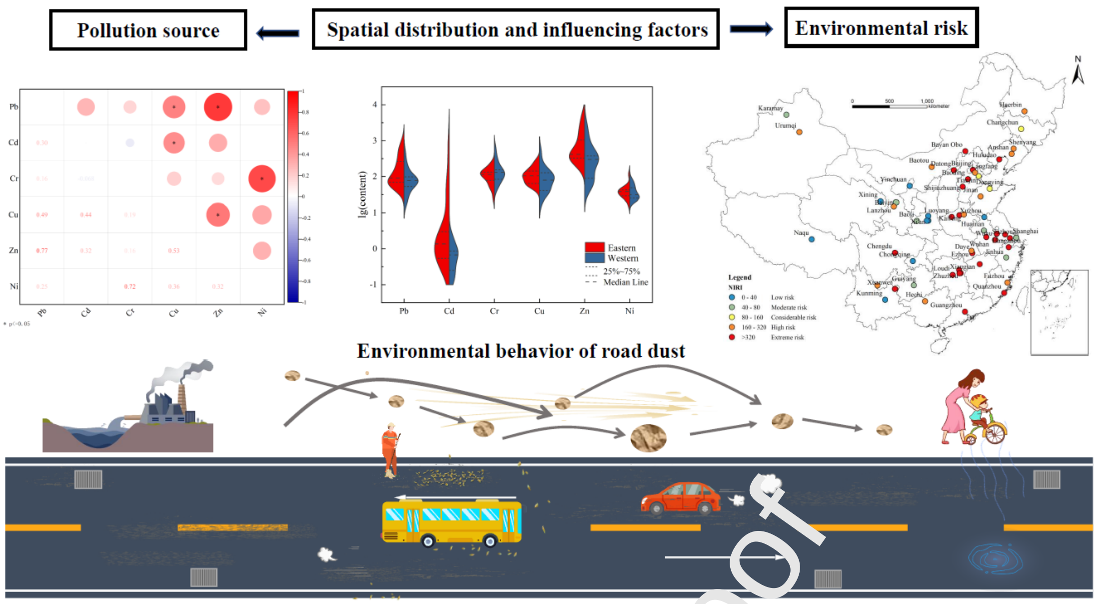
CRediT authorship contribution statement

Wang Siyu: Investigation, Formal analysis, Writing – original draft, Validation, Visualization. **Tao Liang:** Conceptualization, Investigation, Methodology, Resources, Formal analysis, Writing - review & editing, Visualization, Validation, Supervision. **Lingqing Wang:** Methodology, Validation, Resources, Supervision. **Yizhong Huan:** Methodology, Resources, Data curation. **Rui Wang:** Methodology, Visualization.

Declaration of 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:



Graphical abstract

Highlights

- Accumulation of PTEs in road dust in most cities of China was observed
- The southeast coastal and the Beijing-Tianjin-Hebei regions need to be controlled
- The influencing factors of spatial distribution include transportation, industry and population
- PTEs in the road dust of most cities have high ecological risk
- There is no obvious noncarcinogenic risk from PTEs in road dust