Pollution and health risk assessment of arsenic in street dust and soil from an industrial zone

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Abstract: Taking an industrial area in Wuhan as the research object, single factor index, Geoaccumulation index and EPA health risk model are utilized to evaluate the pollution pattern and health risk of arsenic (As) in street dust with different particle fractions and soil. The results showed that the content of As in street dust increased with the decrease of particle size. The average content of As in street dust with fine particle fraction and soil exceeded the soil background value of Hubei Province, but did not exceed the screening value of "Soil Environmental Quality Construction Site Soil Pollution Risk Control Standards (Trial)". The content of As in soil had a high correlation with that of dust with < 63 particle fraction at the corresponding point, with high fit degree (R²=0.6012). There was moderate to heavy pollution of As in areas surrounding industrial enterprises like Wuhan Iron and Steel, cement plants, and areas with high traffic flow and construction sites. The As of street dust and soil at some points posed a non-carcinogenic risk to children, but no carcinogenic risk. The ingestion pathway was the largest non-carcinogenic exposure route of As in street dust and soil from the research area.

1. Introduction
Street dust is an environmental medium with a very wide range of sources and a very complex composition. It contains a large amount of weathered animal and plant residues on both sides of the road, damaged and aged pavement substrates, worn and aged automobile tires, and automobile exhaust emissions, accumulated waste gas from industrial emissions, etc. [1]. In particular, the fine particles in street dust and soil are easily to transform into each other through rising and settling under the action of external forces [2, 3]. The impact of street dust and soil on the ecological environment and public health comes not only from the particulate matter itself, but also from other components contained in the particulate [4], such as metalloid arsenic (As). The elemental form of arsenic is non-toxic, while arsenic compounds are carcinogenic, teratogenic and mutagenic [5].

The issue of metal pollution in street dust and soil environment has attracted more and more attention. Shabbaj et al. found that street dust in Jeddah City, Saudi Arabia was polluted by As, which gathered in traffic areas and parking areas. There were no non-carcinogenic risk to both children and adults, with intake pathway dominated [6]. Li et al. found that As in industrial areas had a potential carcinogenic risk to the public, and the arsenic intake of residents’ drinking water through ingestion and inhalation should be restricted [7]. Scholars have increasingly noticed that seasonal differences and street dust particle size have a great influence on the content of metals.
Therefore, taking an old industrial area of Wuhan as the research object, the relationship and pollution pattern of As in seasonal street dust with different particle fractions and soil were explored. EPA health risk assessment model was utilized to evaluate the non-carcinogenic and carcinogenic risk of exposure to As for the public, to provide references for the management of street dust and soil environment in the industrial area.

2. Materials and Methods

2.1. Study area
An old industrial area in Wuhan was selected as the research object, which located on the south bank of the middle reaches of the Yangtze River, covering an area of 80.47 square kilometers, with population of 540,000. It is a new industrial base invested and constructed by the state during the "First Five-Year Plan" period and is one of the urban areas with the most concentrated industry and the largest production scale in central China [8]. In 2011, the area was listed as one of the eight key areas for heavy metal pollution prevention and control in Hubei Province.

2.2. Sample collection and analysis
26 street dust and 18 soil samples were collected in July 2017 and January 2018, with the location of each sampling point recorded by GPS, shown in Figure 1. For soil samples, 0-20 cm surface soil was collected by a plastic shovel from 3–5 ground locations near the sampling point. For street dust samples, 5 m × 5 m impermeable road surface were selected to collect dust samples from 3–5 locations near the sampling point. After passing through a 2 mm sieve to remove impurities in the dust, samples were sealed and stored in polyethylene ziplock bags.

The method for determining the pH of samples refers to "NY/T 1121.2-2006 Soil Testing Part 2: Determination of Soil pH". As was determined by Atomic Fluorescence Spectrometer (AFS, ZEEnit 700Q, Germany) in accordance with "Determination of Soil Mass Total Mercury, Total Arsenic, and Total Lead" (GB/T 22105.2-2008). The purity of all the chemical reagents involved in the experiment were excellent grade. Each batch of samples was quality controlled using blank test, parallel test and national standard references (GBW GSS-5). Each sample was tested more than 3 times, the test error of repeated samples and parallel samples were less than 5% and 10%, respectively.

![Figure 1. Sampling points from an industrial zone in Wuhan](image-url)
2.3. Single factor index method

The single factor index \( P_i \) is conducted to evaluate the accumulation degree of a certain metal element in the environment, calculated as follows:

\[
P_i = \frac{C_i}{C_s}
\]

where \( C_i \) refers to the detected content of metal element \( i \), mg/kg; \( C_s \) represents the safety limit of metal elements in the national soil quality standards. \( P_i > 1 \) means that the environment is polluted by metals. The larger the value, the more serious the contamination.

2.4. Geoaccumulation index method

The geoaccumulation index method takes the dual effects of natural diagenesis and human activities on heavy metals into account [9], calculated as follows:

\[
I_{geo} = \log_2 \left( \frac{C_i}{kB_i} \right)
\]

where \( C_i \) is the detected content of heavy metal \( i \), mg/kg; \( B_i \) is the geochemical background value of the measured element, mg/kg; \( k \) is a coefficient set for correcting the background fluctuations caused by rock-making movement, generally taken as 1.5. The geoaccumulation index divides the degree of metal contamination into seven grades, details shown in the previous paper [10].

2.5. EPA health risk assessment model

EPA health risk assessment model is conducted to appraise the health risk of metals. There are three exposure pathway for the public exposed to metals: ingestion, inhalation and dermal contact. The daily average exposure of metal elements are calculated as follows:

\[
ADD_{ing} = \frac{C \times hr \times EF \times ED}{BW \times AT} \times 10^{-6}
\]

\[
ADD_{inh} = \frac{C \times inh \times EF \times ED}{PEF \times BW \times AT}
\]

\[
ADD_{dermal} = \frac{C \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6}
\]

\[
LADD_{inh} = \frac{C \times EF}{PEF \times AT} \times \left( \frac{inhR_{child \times ED \text{child}}}{BW_{child}} \times \frac{inhR_{adult \times ED \text{adult}}}{BW_{adult}} \right)
\]

where \( ADD_{ing} \), \( ADD_{inh} \) and \( ADD_{dermal} \) are the average daily intake from ingestion, inhalation and dermal contact, respectively (mg/kg·day); \( C \) is the measured content of metal element (mg/kg). The specific meanings and sources of other parameters are shown in the previous paper.

The non-carcinogenic and carcinogenic risk of metals are calculated as follows:

\[
HI = \sum_i HQ_i = \sum_i \frac{ADD_i}{RfD_i}
\]

\[
CR = \sum LADD \times SF
\]

where \( RfD_i \) is the corresponding reference dose for exposure pathway \( i \), mg·kg\(^{-1}\)·d\(^{-1}\), the values of which selected as 3E-04 (ingestion), 1.23E-04 (dermal contact) and 3E-04 (inhalation) [12]. SF is the corresponding carcinogenic slope factor for each metal, kg·d·mg\(^{-1}\), with the value of 15.1 selected in this research [12]. When \( HI < 1 \), the non-carcinogenic risk of toxic metals is considered to be small or negligible; when \( HI > 1 \), it is considered that there is a non-carcinogenic risk of toxic metals. When \( CR \) is below 10\(^{-6}\), the carcinogenic risk of toxic metals is negligible; when \( CR \) exceeds 10\(^{-4}\), it is considered that there is a carcinogenic risk of toxic metals.

3. Results and discussion

3.1. The characteristic of As content

The average pH of street dust in summer and winter in the study area was 8.70 and 9.26, respectively, and the average pH of soil was 8.26. The content and related statistical values of As are shown in Table 1. The As content in dust showed a trend of increasing with the decrease of particle size in summer and
winter, with little difference between the two seasons. The average As content in dust with fine particle size and soil exceeded the corresponding background value (12.3 mg/kg), but did not exceed the risk screening value (20 mg/kg). However, the content of As were highly variable (CV > 35%) [13], indicating that the spatial distribution was significantly different and it was greatly affected by external factors [14]. The correlation between the As content in the soil and corresponding dust was of 0.775** (< 63 μm), 0.757** (63-100 μm) and 0.746** (100-150 μm), with high degree of fit (R²=0.6012) between the As content in soil and corresponding dust with < 63 particle size. In addition, the As content in soil was slightly lower than that of corresponding dust with fine particle size, which is more likely to be lifted by external forces to form a secondary suspension [15]. Thence, it can be judged that the settlement of street dust is one of the sources of As in soil [2].

| Table 1. The content and related statistical values of As in street dust and soil |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Items                           | Dust <63 | 63-100 | 100-150 | Summer | Winter | Soil | Dust <63 | 63-100 | 100-150 | Summer | Winter | Soil |
| Min                              | 4.70     | 3.30   | 3.45    | 7.38   | 5.88   | 4.50 | 4.30 |
| Max                              | 83.28    | 44.44  | 47.93   | 53.72  | 52.22  | 49.92 | 38.73 |
| Mean                             | 14.14    | 10.83  | 9.92    | 13.11  | 12.12  | 10.41 | 12.94 |
| Median                           | 8.08     | 7.17   | 6.28    | 11.30  | 10.08  | 7.75 | 9.40 |
| SD                               | 15.18    | 8.64   | 9.03    | 8.93   | 8.94   | 8.94 | 9.74 |
| CV                               | 1.07     | 0.80   | 0.91    | 0.68   | 0.74   | 0.86 | 0.75 |

3.2. Single factor pollution evaluation of As

The As at most points was at a clean level, except for a certain particle size at some points (Figure 2). Specifically, street dust at S17 (< 63 μm) in summer, S20 (63-100 μm) in summer, S17 (all particle size) in winter and soil at S19 and S25 were slightly polluted. Street dust at S2 (100-150 μm) in summer, S8 (63-100 μm) in summer and S19 (all particle sizes) in winter were heavily polluted. Street dust at S19 (<63 μm) in summer was heavily polluted. In general, the As pollution in street dust at S2, S8, S17, S19, S20 and in soil at S19, is worthy of further attention.

3.3. Geoaccumulation index pollution evaluation of As

ArcGIS10.4.1 software is utilized to present the spatial distribution characteristics of As in dust and soil, shown in Figure 3. As in dust and soil showed an unpolluted level as a whole. However, as for dust, the
large-size fraction of street dust at S2 and S8 ($I_{geo}=3$) in summer was at moderate to severe pollution levels. Street dust at S17 ($I_{geo}=2$) in summer and winter were at non-polluted to moderate pollution level. Street dust S19 in summer ($I_{geo}=4$) and winter ($I_{geo}=3$) were at heavy pollution level and moderate to heavy pollution level, respectively. As for soil, As at S19 and S25 were at moderate to severe pollution level. Based on the actual sampling situation and Figure 1, S17 is located near the Wuhan Iron and Steel Co., Ltd. (WISCO), and S19 and S25 are scattered by cement plants and industrial parks with high traffic density of heavy vehicles, indicating that the industrial zone in this region has great impact on the local environment. It is necessary to strengthen the monitoring of the surrounding environment and the management and control of pollutant discharge from industrial enterprises [7]. In addition, there is high traffic flow and plenty of construction sites near S2 and S8, indicating that traffic emissions and construction sites are important sources of As pollution in street dust and soil [16, 17].

Figure 3. The spatial distribution characteristics of As in street dust and soil

3.4. Health risk assessment of As

The non-carcinogenic and carcinogenic risk of As in dust and soil is shown in Figure 4. The non-carcinogenic risks of As in street dust and soil to children were 0.298–3.36 and 0.173–1.56, respectively, with that of adults less than 1, which indicated that there were non-carcinogenic risks of As to children in some areas, but not non-carcinogenic risks to adults. The exposure does of As with each exposure pathway decreased as ingestion > dermal contact > inhalation, illustrating that ingestion was the largest non-carcinogenic exposure route of As. Specifically, the non-carcinogenic risk at points S2 of 1.93, S8 of 1.79, S19 of 3.36 in dust, and S19 of 1.56, S25 of 1.50 in soil cannot be ignored for children. It is worth noting that there are double non-carcinogenic risks from dust and soil for children exposed near the S19 point, promoting that measures need to be taken to strengthen supervision and reduce risks. Moreover, although the non-carcinogenic risk of some points does not exceed the risk threshold, actually quite close, such as S17 and S20, which require attention to strengthen prevention. The carcinogenic risk of As in street dust and soil were 1.27E-08–1.43E-07 and 7.39E-09–6.66E-08, respectively, which did not exceed the carcinogenic risk threshold, indicating that there was no carcinogenic risk of As.
4. Conclusions

The smaller the street dust particle size, the higher the As content, with no obvious seasonal difference. There are high correlation between the content of As in soil and corresponding street dust with $< 63$ particle size, with high degree of fit ($R^2 = 0.6012$). The As in dust near points S2, S8, S17 and S19 showed moderate to severe pollution levels, and the soil As at points S19 and S25 were at moderate to severe pollution levels. The surrounding industrial enterprises such as the WISCO and cement plants, high traffic volume and construction sites have important negative impacts. As from street dust and soil in some areas posed non-carcinogenic risk to children, but not to adults. Ingestion pathway was the largest non-carcinogenic pathway for the public exposure to As.

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