Lead exposure characteristics and pollution evaluation of indoor and outdoor dust in primary school campuses of Baoji city in northwest China

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Abstract. Lead in dust is an important potential source of human exposure to lead. The indoor and outdoor dust in the urban and rural areas of Baoji City, a typical industrial city of northwest China, including the urban, suburban towns, rural and lead-zinc smelters, was collected. The Pb content of the dust was analyzed by ICP-MS after microwave digestion. The results reveal that the lead content was 627.18 mg/kg and 679.39 mg/kg in indoor and outdoor school of the city center area, respectively. The average content of lead was 593.61 mg/kg and 635.46 mg/kg in indoor and outdoor school of the urban area, respectively. The lead content in the rural area was lower than city center area and the urban area, the results were 217.33 mg/kg and 268.57 mg/kg. The lead content in lead and zinc smelters area was highest than other area, the results were reached 2717.62 mg/kg and 3296.27 mg/kg. Pb pollution level and potential ecological risk in Baoji City had reached a serious level based on two kinds of evaluation methods. The results are expected to provide important scientific basis for regional environmental protection, environmental pollution controlling, management and health protection of Baoji city.

1. Introduction

Dust is an environmental medium found almost everywhere. Due to the influence of human activities such as industry, transportation and nonferrous metallurgy, large amounts of toxic and harmful substances are accumulated in dust. Harmful substances contained in dust can enter human bodies through respiration, skin absorption and direct ingestion, resulting in harmful health effects, especially in children [1, 2]. The results of research indicate that the heavy metal lead found in urban street dust is a potentially important source of blood lead in children. The effects of dust on blood lead are far greater than those of atmospheric lead and soil lead, especially for children with “hand-mouth addiction” [3-6]. The prevalence rate of lead poisoning in urban children in China is approximately 51.6%. More than 40 countries have listed dust as the primary lead exposure source for blood lead in children. There have been serious blood lead incidents in typical industrial western city of Baoji. Due to the high concentration of students on school campuses, the influence of heavy metal lead content from indoor and outdoor dust on students’ health is particularly important. Therefore, there is important practical and scientific significance for studying heavy metal lead pollution of the indoor and outdoor dust at the primary school campuses of typical industrial city [7, 8].

This paper selects the indoor and outdoor dust at primary school campuses in representative areas of Baoji City, including urban areas, suburban towns, villages and the lead and zinc smeltery as research
objects. Based on the findings from tests of lead content levels in dust, the situation has been evaluated to provide scientific observational data for local environmental improvement and the health protection of residents.

2. Materials and methods

2.1. Instruments
Inductively coupled plasma mass spectrometer: PE ICP-MS (Perkin Elmer-Nexion 300D, PerkinElmer Corporation, USA). The ICP-MS instrument operating parameters were established by automatically optimizing the instrument conditions. They met the instrument standard requirements, such as sensitivity, background values, and stability.

Microwave-digestion system (model: Ultraclave, Milestone, Italy).
Milli-Q ultrapure water system (Millipore Corporation, USA).

2.2. Sample collection and pretreatment
The primary school campuses in the representative area of Baoji City, including urban areas, suburban towns, villages and lead and zinc smeltery areas, were selected for the study. Indoor and outdoor dust samples were collected in sunny and dry weather conditions.

The first step was the pretreatment of the sample. Any hair, cigarette filters, large stones, etc. in the collected samples were removed using stainless steel tweezers before the samples were air-dried at room temperature in a cool location. After air drying, the dust samples were ground less than 0.075 mm. The ground dust samples were sealed in polyethylene sample bags.

In a polytetrafluoroethylene digestion tank, 0.5 g of the sieved sample was weighed and wetted with water, to which a nitric and hydrofluoric acid reagent mixture with a 5:1 ratio was added, followed by mixing. An UltraCLAVE super microwave from Milestone, Italy was used for the digestion [9, 10]. After the digestion was completed, the samples were cooled to room temperature, transferred to a 25-mL centrifuge tube, and brought to volume for testing. Each batch of samples was prepared with both reagent blanks and standard soil samples.

2.3. The determination of Pb content
The concentration of Pb was measured using PE NexION 300D ICP-MS. Analytical precision was better than 1.5% for the Pb concentration. The standard, sample and blank solutions were tested under optimal operating parameters according to the instrument’s operating procedures. Standard curves were drawn, the blank and sample solutions were measured and the measurement results were obtained.

3. Results and discussion

3.1. Indoor and outdoor dust lead content in primary school campuses of Baoji City
Figure 1 plots the indoor and outdoor dust lead content of the primary schools in Baoji City. The results show that the campus dust in Baoji City has been polluted by heavy metal lead to varying degrees.

Figure 1 shows that the average dust lead content from streets near urban primary schools was 679.39 mg/kg, and the indoor dust lead content in urban primary schools was 627.18 mg/kg; the average dust lead content from streets near suburban primary schools was 635.46 mg/kg, and the indoor dust lead content in suburban primary schools was 593.61 mg/kg; the average dust lead content from streets near village primary schools was 268.57 mg/kg, and the indoor dust lead content in village primary schools was 217.33 mg/kg; The average dust lead content from streets near the primary schools around the lead and zinc smeltery was 3,296.27 mg/kg, and the indoor dust lead content in the primary schools around the lead and zinc smeltery was 2,717.62 mg/kg.
Figure 1. The Lead content of indoor and outdoor dust in primary schools of Baoji city in China.

3.2. Heavy metal lead pollution situation of indoor and outdoor dust in primary schools in Baoji City

The lead content of the indoor and outdoor dust in primary schools in Baoji was generally high, measuring 10-154 times the lead background value (21.4 mg/kg) of surface soil in Shanxi Province [11]. Except for the slightly lower lead content in village dust, the dust lead content in other areas totaled more than 30 times the background value of surface soil in Shanxi. The lead content of urban dust increased by approximately 40% compared with the research data measurements of 408.41 mg/kg from ten years ago [12]. The dust lead content around the lead and zinc smeltery was similar to that of previous studies [13]. Compared with the dust lead content of some cities from reports, the lead content of the indoor and outdoor dust in primary schools in Baoji City was significantly higher. The lead content in Baoji City was several times higher than that of other Chinese cities of Beijing (69.56 mg/kg), Xi’an (230.52 mg/kg), Guiyang (259 mg/kg), Shanghai (264 mg/kg) and Shenyang (199.72 mg/kg) [14-18].

There are significant differences between the lead content levels of the indoor and outdoor dust at campuses in different areas of Baoji City. First, the dust lead content around the lead and zinc smeltery was much higher than that at other areas, as high as 3,296.27 mg/kg, which is more than ten times higher than other urban areas, towns and villages, indicating that the contribution of industrial waste gas, waste water and waste residue to the lead content in these areas was high. Such high lead content levels in dust may severely affect students' health. Compared with the higher lead content levels found at the lead and zinc smeltery, the lead content was much lower in Baoji City’s urban areas and towns. The heavy metal lead content in the indoor and outdoor dust of urban and suburban campuses was not much different. This may be because the lead source is primarily from dust fall, and the difference in atmospheric aerosol changes is relatively small. However, compared to the lead data from ten years ago, the lead content increased by approximately 40% in the most recent decade. Why have the lead content levels increased in Baoji City’s urban areas and towns? First, gasoline lead emissions from motor vehicles have been strictly regulated in recent years. Therefore, the greatest lead contribution likely comes from the emissions of chemical companies. However, testing and proving this theory requires more advanced technical measures, such as lead isotope technology. Although the heavy metal lead content of indoor and outdoor dust in villages was lower than that in urban areas, towns and the lead and zinc smeltery, it was as high as 217.33 mg/kg, indicating that indoor dust in villages has been polluted by lead and the pollution level is comparable to the environments of other large cities. As there are no obvious sources of artificial pollution in the surrounding village areas, the source of environmental lead should be different from that of cities. However, what the sources are and which sources are dominant must be further proved by data.
3.3. Comparison of indoor and outdoor heavy metal lead pollution in Baoji City’s primary school campuses and lead pollution at other urban campuses

He et al. studied the lead content of indoor and outdoor dust at Shenyang City’s college campus [17]. Although the average lead content of the indoor and outdoor dust at campuses in Shenyang was less than 100 mg/kg, it exceeded the background value for soil in Liaoning Province (22.15 mg/kg), and the lead content during the winter heating period was higher than that during the non-heating season. In the present study, there was no sampling during the heating period, and a comparison is only made for the non-heating season. The dust lead content in the Baoji City campuses, with an average value that exceeded 500 mg/kg, was much higher than that of Shenyang City. This finding further indicated that the dust lead pollution in Baoji City has been very severe. In addition, according to the data, the lead content of indoor dust at both the Baoji City and Shenyang City campuses was found to be lower than that of outdoor dust, which may be attributed to frequent indoor cleaning.

3.4. Evaluation of lead pollution in indoor and outdoor dust of Baoji City’s primary school campus

Currently, there is no uniform evaluation standard and method for determining heavy metal pollution in urban street dust domestically and abroad. Frequently used methods are predominantly borrowed from methods for evaluating heavy metal pollution in sediments, including the accumulation index, pollution load index, regression over analysis and potential ecological risk index methods [18]. In this paper, the potential ecological risk index and geoaccumulation index methods were used to compare and evaluate the lead pollution in indoor and outdoor dust in Baoji City’s primary schools.

3.4.1. Potential ecological risk index

Single heavy metal pollution coefficient ($C_{i}^{f}$): $C_{i}^{f} = C_{i}^{i}/C_{ni}$

Potential ecological risk coefficient of a single heavy metal ($E_{ri}$): $E_{ri} = T_{ri}C_{i}^{f}$

where $C_{i}$ is the measured heavy metal concentration value; $C_{ni}$ is the reference value required for calculation; and the background value of Shanxi Province’s soil environment is selected as the reference value. According to the standardized heavy metal toxicity coefficient established by Hakanson, the $T_{ri}$ value of lead is 5.

The classification standard for the single heavy metal pollution coefficient is based on the summaries of previous researchers, and the classification levels for heavy metal pollution’s ecological hazards are listed in Table 1.

| $E_{ri}$ | Level                  |
|----------|------------------------|
| $E_{ri} < 40$ | Minor ecological hazard (I) |
| 40 $\leq E_{ri} < 80$ | Medium ecological hazard (II) |
| 80 $\leq E_{ri} < 160$ | Strong ecological hazard (III) |
| 160 $\leq E_{ri} < 320$ | More strong ecological hazard (IV) |
| $E_{ri} \geq 320$ | Extreme ecological hazard (V) |

According to the above formula, the average potential ecological hazard coefficient $E_{ri}$ of the indoor and outdoor dust in Baoji City’s primary schools is calculated. According to the classification in Table 1, the ecological risk indexes corresponding to $E_{ri}$ are obtained (Table 2).

| $E_{ri}$ | Level                  |
|----------|------------------------|
| City     | Town | Village | Lead and zinc smeltery |
| Indoor   | III  | III     | II   | V                |
| Outdoor  | III  | III     | II   | V                |

According to the data in Table 2, the indoor and outdoor dust in Baoji City’s primary schools has become a severe ecological hazard, except for villages, indicating the great contribution of potential ecological hazards from dust lead.
3.4.2. Geoaccumulation index method

The calculation formula of the geoaccumulation index $I_{\text{geo}}$ is:

$$I_{\text{geo}} = \log_2\left[\frac{C_n}{(1.5 \times B_n)}\right]$$

where $C_n$ is the measured value of lead in dust and $B_n$ is the environmental background value of heavy metal lead in Shanxi Province’s soil, which is 21.4 mg/kg. The Müller pollution index is graded in Table 3.

| Pollution index ($I_{\text{geo}}$) | Level                  |
|-----------------------------------|------------------------|
| 10-5                              | Serious pollution      |
| 4-5                               | Heavy pollution        |
| 3-4                               | More heavy pollution   |
| 2-3                               | Medium pollution       |
| 1-2                               | Less medium pollution  |
| 0-1                               | Light pollution        |
| ≤0                                | None pollution         |

According to the $I_{\text{geo}}$ calculation formula and Müller pollution index grading, the pollution index of lead in indoor and outdoor dust in Baoji City’s primary and middle school campuses is calculated, the results of which are presented in Table 4. These results indicate that the indoor and outdoor dust of Baoji City’s primary and middle school campuses are all severely polluted by lead.

| Pb Pollution index | City        | Town        | Village     | Lead and zinc smeltery |
|--------------------|-------------|-------------|-------------|------------------------|
| Indoor             | Heavy pollution | Heavy pollution | Medium pollution | Serious pollution |
| Outdoor            | Heavy pollution | Heavy pollution | Medium pollution | Serious pollution |

4. Conclusions

(1) The heavy metal lead content of the indoor and outdoor dust of Baoji City’s primary school campuses was generally high, and significantly higher than that in other cities. The content of lead is 10-154 times of the background value (21.4 mg/kg) of the surface soil in Shanxi Province. Except for the slightly lower lead content in villages, the dust lead content levels in other areas are all more than 30 times the background value of surface soil in Shanxi Province. The lead content of urban dust has increased by approximately 40% compared with the research data measurements of 408.41 mg/kg from ten years ago. The dust lead content level around the lead and zinc smeltery was similar to that of previous studies.

(2) The potential ecological risk index and geoaccumulation index methods were used to compare and evaluate the lead pollution levels of the indoor and outdoor dust in Baoji City’s primary school campuses. Both evaluation methods show that lead in the indoor and outdoor dust of Baoji City’s primary school campuses has reached severe levels of pollution.

(3) Multiple isotope tracer methods are urgently needed to determine the sources of lead pollution, and measures are needed to control lead emissions.

Acknowledgments

This work was supported by Cultivation project of Natural Science Foundation of Xi'an Medical University (2017GJFY17) and the Natural Science Basis Research Plan in Shaanxi Province of China (2020JQ-875).

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