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Health risks of children's cumulative and aggregative exposure to metals and metalloids in a typical urban environment in China

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HIGHLIGHTS

- 12 heavy metals and metalloids in an urban environment were investigated.
- Health risks and pathways of children's exposure to metal(loid)s were assessed.
- Soil and indoor dust and duplicate food were contaminated by metal(loid)s.
- Food ingestion was the major pathway for children's exposure to most metal(loid)s.
- Higher potentially non-cancer and cancer risks happened to the local children.

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ABSTRACT

Rapid development of industrialization and urbanization results in serious environmental contamination by metal(loid)s, which would consequently cause deleterious health effects to the exposed people through multi-pathways. Therefore, total health risk assessment for the population in urban environment is very important. Unfortunately, few studies to date investigate the cumulative health risks of metal(loid)s through aggregative pathways in Children who are often susceptible population. 12 metal(loid)s including Lead(Pb), Cadmium(Cd), Arsenic(As), Chromium(Cr), Zinc(Zn), Copper(Cu), Nickel(Ni), Manganese(Mn), Cobalt(Co), Selenium(Se), Antimony(Se) and Vanadium(V), were analyzed in PM_{10}, drinking water, food, soil and indoor dust in this study. The cumulative and aggregative risks of these metal(loid)s among the local children were then evaluated on a field sampling and questionnaire-survey basis. The results showed that the environments were heavily polluted by metal(loid)s. For most metal(loid)s, food ingestion accounted for more than 80% of the total daily exposure dose. The non-cancer risks were up to 30 times higher than the acceptable level due to the food ingestion via Pb, Cr, Cu, Zn, As, Se, Cd and Sb, and the PM_{10} inhalation via Cr and Mn. While, the cancer risks were mainly attributed to Cr via food ingestion and As via food and dust ingestion, and approximately 100 times of the maximum acceptable level of 1.0×10^{-4}. The study highlights the cumulative and aggregative exposure assessment, instead of pollutant investigation to evaluate the potential health risks and emphasizes concerns to improve indoor hygienic and environmental quality and to decrease the potential harmful health effects of children living in urban area.

1. Introduction

Researches both from epidemiological and toxicological studies show that some metals and/or metalloids such as Pb, Cd and As do not have any beneficial physiological function and can lead to high damages on human. Pb exposure in high level remains a ubiquitous

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environmental health threat to the human beings, with numerous adverse health effects on nervous system, hematopoietic and reproductive systems (Haefliger et al., 2009). Accumulation of Cd exposure can cause kidney, bone and pulmonary damage (Godt et al., 2006). The exposure of As had been reported to lead to diabetes mellitus, cognitive development and cardiac disorders (Smith et al., 2006). Moreover, many recent researches highlight that detrimental health effects may occur at very low exposure level. For example, the neurological damage happens in children at low blood lead levels (BLLs, 2–10 μg L^{-1}), indicating that there is no “safe” threshold for lead exposure (Lanphear et al., 2005). Coincidentally, a recent report states that there is also no safe level for As exposure, since any exposure dose could increase the risks of diabetes, heart disease, immune problems and cancers (Schmidt, 2014). Due to child-specific phase of growth and development as well as behavior patterns, Children are more prone to metal(loid)s poisoning (Fitzgerald et al., 1998). Thus, children's exposure to metal(loid)s is still common in China (Gao and Xia, 2011).

It's accepted that impacts of pollutant exposure are usually attributed to aggregative exposure pathways and sometimes a long-term accumulation. The main pathways include dermal contact, inhalation and/or ingestion of aerosol particles, dust/soils, food, and drinking water (USEPA, 2006). To reduce the exposure, it is important to identify predominant exposure pathways, which include both non-dietary and dietary pathways (Villanueva et al., 2014). With the development of industries and urbanization, the surrounding environments are polluted by contaminants such as metals and organic matters (Luo et al., 2015; Yu et al., 2011). Some previous studies assessed health risks in the vicinities of various industrial areas through the single pathway of soil (Cai et al., 2015; Izquierdo et al., 2015), dust (Kurt-Karakus, 2012), food (Cheng et al., 2013; Lu et al., 2015) or drinking water (Qin et al., 2013; Villanueva et al., 2014), but little is on the cumulative and aggregative exposure of typical toxic heavy metal(loid) via multi-pathways (Cao et al., 2014, 2015; Qu et al., 2012). A cumulative and aggregative exposure over time via a variety of multimedia and multi-pathways of environmental pollutants could be applied for assessing the total detrimental risks and identifying hazardous exposure factors. This would be of great importance for the identification of predominant exposure pathways and pollutant controls to reduce the risks of detrimental health effects.

The objectives of the present study were (1) to quantify the concentrations of 12 metal(loid)s in water, food, PM_{10}, soil/dust in a typical modern urban area in China; (2) quantify the exposure levels and relative contributions from each medium to the local children; and (3) estimate children's health risks due to metal(loid)s exposure from various media. Hazard quotients (HQ) and the incremental lifetime cancer risk (ILCR) were used to assess the non-cancer and cancer risks, respectively (Mari et al., 2009). Since risk assessment is inherently linked with uncertainty (Li et al., 2006), Monte Carlo simulation working with probability distributions of each parameter was conducted to determine the inherent uncertainty in predicted risks (Mari et al., 2009).

2. Materials and methods

2.1. Study area

The studied city, well-known as a hometown of nonferrous metals, is an industrial city situated to the southeast in Hunan Province, China. Hills are the primary terrains accounting for 75% of the total city area. It has a subtropical monsoon climate, characterized by warm and wet, abundant sunshine and rainfall. The traffic in the city is quite convenient with many expressways, national highways and provincial roads. To accurately assess health risks of children from the exposure of various metal(loid)s via multi-pathways, a typical modern primary school which includes the students from large part of the city was chosen as a model to select the participants. There was no enterprise or manufacture located near the school, but existed moderate traffic volumes.

2.2. Sample collection and analysis

2.2.1. Human behavior pattern survey

After obtaining the ethics approval from ethics committee of the National Center for Disease Control, the study was then conducted. Before the survey and sampling, 70 participants were selected on a personal and parental voluntary basis with written informed consents concerning the behavior pattern survey and the household sampling were obtained. All participants were native-born and aged 5–8 years old. A questionnaire-based survey was then conducted among the participants accompanied with their parents to identify the factors influencing the exposure risks such as, dietary habits, behavior patterns and nutritional factors (e.g. iron status).

2.2.2. Field sampling

To determine the aggregative and accumulative exposure and risk levels to the target metal(loid)s, 20 of the 70 participants were then randomly selected to join the field sampling on an informed and voluntary basis.

A total of 20 tap water samples were collected in 1 Lacid-washed polyethylene bottles from each volunteer's family. Additional 2 tap water samples were respectively collected from two classrooms of the school to reflect the water quality consumed by the children in the school. During sampling, two drops of 65% concentrated HNO_3 were added into the sampled water, which was then refrigerated and stored at −20 °C until analysis.

Since all the children dwelled at buildings, and there is less ground or courtyard around the children's homes. Therefore, 10 soil samples (0–20 cm) were collected in 6 typical parks and gardens, and another 2 soil samples were collected from the school in undisturbed locations. In each sampling site, the soil samples were integrated with 4–5 equal sub-samples in an area of 100 cm^2 (Zhang et al., 2010). 4 dust samples from the floor and stairs of the school and 20 indoor dust samples from the windowsill, furniture surface and the corner of the children's house were collected using a dust-free nylon brush. Each dust sample was mixed with 4 or 5 sub-samples.

The inhalable particles (PM_{10}) from 2 representative monitoring sites of inside classrooms and from indoor of the 20 participants' houses were sampled on pre-combusted (500 °C, 6 h) quartz microfiber filters (MunktellIn C., Sweden) using a low-volume breathing sampler (Buck Libra Plus, AP BUCK In C., U.K) with a flow rate of 2 L min^{-1} for 24 h. Another 2 PM_{10} samples outside the classrooms of the schools were respectively collected simultaneously. Each sampling lasted for 3 days. Before and after sampling, all filters were pretreated using previously established methods (Hu et al., 2012). The particle-loaded filters were then stored at 4 °C until analysis.

Duplicate daily foods of the 20 volunteers, which were partly locally produced, were directly sampled from each family to represent the actual amount and species of the dietary consumed by each participant. After the food items in each child's diet were weighed separately, a portion of each item consumed in one day was blended for freeze-drying and cryopreservation.

2.2.3. Sample treatment and analysis

The water samples were filtered using a filter membrane (Whatman no.1, Ø = 0.45 μm) before concentration analysis. The PM_{10}-loaded filter was cut into pieces and then wholly digested (Hu et al., 2012). After being air-dried, ground and sieved, 0.1000 g of