Environmental Pollution 226 (2017) 385–393

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Relative importance of different exposure routes of heavy metals for humans living near a municipal solid waste incinerator☆

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ARTICLE INFO

Article history:
Received 7 November 2016
Received in revised form
29 March 2017
Accepted 1 April 2017
Available online 17 April 2017

Keywords:
Heavy metals
Multi-pathway exposure
Blood metal
Health risks

ABSTRACT

The potential health effects of toxic chemicals (e.g. heavy metals) emitted by municipal solid waste incinerators (MSWIs) are of great concern to local residents, however there have been few studies on the contributions of different exposure pathways and their subsequent effects on the body burden of residents living near MSWIs. In this study, multiple exposure routes of heavy metals including Pb, Cr, Cd and Mn were assessed by investigating the metals in foods (such as vegetables, crops, meats and fruits etc.), drinking water, ambient air and soil collected surrounding an MSWI in Shenzhen, south China. Vegetable ingestion played the most important role in the total average daily dose of Pb and Cr, and cereals were the key exposure routes for Mn and Cd. Compound-specific contaminations were observed in the investigated areas, with Pb and Cr present in the surrounding environment, having accumulated to relatively high levels in the local vegetables, and the intake of contaminated vegetable foods greatly influencing the body burden of Pb and Cr. Consistently, significantly high blood concentrations of Pb and Cr were detected in the local residents compared to a referenced population, and a lack of significant differences was found for Cd and Mn. The results possibly suggested that emission of MSWI influenced the external exposure doses of the major pathways of Pb and Cr in this study, and resulted in the different body burden of metals in humans living near a MSWI. MSWI-local food-humans is an important exposure pathway for residents living near MSWI, and thus should not be neglected in developing future strategies and policies to prevent the high risks suffered by residents living near MSWIs.

1. Introduction

The acceleration of urbanization has made waste reduction and disposal important factors restricting economic and social sustainable development (Li et al., 2015; Cheng and Hu, 2010). Although regulators consider incineration a strategic municipal solid waste treatment method (Abanades et al., 2002; Rimaityté et al., 2007), significant concerns have been raised regarding the installation of municipal solid waste incinerators (MSWIs) due to the potential effects of the toxic chemicals they emit (Domingo, 2002). Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) are among the many pollutants emitted by MSWIs, as municipal wastes such as leather waste shavings, batteries and lamps contain various toxic heavy metals (Louhab and Akssas, 2006). These heavy metals are emitted and carried out of the incinerator device among the hot flue gases and fly ash to cross environmental boundaries. It is well known that heavy metals can be absorbed by plants through uptake from the soil and air deposition, and by animals and humans through food, water, air, soil/dust ingestion and skin contact (Li et al., 2011; Zhao et al., 2010) posing health risks to those living near MSWIs.

Although studies all over the world have investigated the metals present in people living near MSWIs (Chen, 2004; Cheng et al., 2007), the latter's effect on blood metals in these populations remain controversial. In one study, no statistically significant difference was found between the group living within 300 m of an MSWI in Seoul and the reference group for Pb, Cd and Hg (Lee et al., 2013). Similarly, no significant differences between exposed and unexposed subjects were observed for blood metals in a pilot study in Modena, Italy (Ranzi et al., 2013). No associations were also observed between metal exposure from the incinerators and heavy metal body burden among the population living near MSWIs in Lisbon and Madeira, Portugal (Reis et al., 2007). In comparisons, Schroijen et al. found that adolescents living near an incinerator in the Northern part of Belgium had significantly higher Pb and Cd

☆ This paper has been recommended for acceptance by Prof. W. Wen-Xiong.

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http://dx.doi.org/10.1016/j.envpol.2017.04.002
0269-7491/

concentrations in their blood samples (Schroijen et al., 2008). Significantly high concentrations of Pb and Cd were also found in people proximity to the incinerators in Germany, compared with those who were not exposed (Wrbitzky et al., 1995). Given that the heavy metals can enter the human body through different routes, such as dermal contact, inhalation and ingestion (Li et al., 2011; Zhao et al., 2010), the different results about the influences of MSWI on human blood metals obtained in various countries might be due to the different contributions of multiple exposure pathways to the local residences. The importance of site-specific multi-pathway exposure of heavy metals has been reported in an investigation about the exposure of children to 10 metals near the largest coking plant in China (Cao et al., 2014). However, the current investigations about health risks of residents in the vicinity of MSWIs only focused on single exposure pathways such as foods, water, or dust/soil, and no studies is available on the contributions of different exposure pathways of heavy metals and their subsequent influences on the body burden of metals in populations near the MSWI.

The present research studied an MSWI in northwestern of Shenzhen, south China. Heavy metals including Pb, Cr, Cd and Mn were measured in foods (such as vegetables, crops, meats and fruits etc.), drinking water, ambient air and soil collected in the vicinities of the MSWI. Concentrations of the metals in blood samples were also investigated in the local residents (195 adults) living about 0–3 km away from MSWI, which were compared with a group of referenced persons (230 adults) living about 5–10 km away from the MSWI. The contributions of multi-pathway exposures of different metals were assessed, and help to understand the differences of blood metals in the two groups of populations. The results of the study provided a basis for guiding further strategies and policies aimed at preventing high risk suffered by residents living in the vicinities of MSWI.

2. Materials and methods

2.1. Study sites

An MSWI in Shenzhen, Guangdong Province, China, is featured in this study. It initiated regular operation in December 2005 and had three incineration units, each of which incinerate 400 tons of waste per day. The combustion temperature of the burning treatment lines is more than 850 °C, even up to 1100 °C. The average temperature at this site is 22.3 °C. The rainy season is April to September with an annual rainfall of 1924.7 mm. As shown in the wind rose map in Fig. 1, the average annual wind speed is 2.1–3.0 m/s with the wind coming from the northeast from September to February and from the southwest from March to May. From June to August, southwest and southeast winds is dominant.

2.2. Sampling of food, total suspended particulates, soil and water samples

Fifty-three types of food samples (each comprising at least three subsamples and selected according to the local population's dietary composition) were collected over four seasons from August 2013 to July 2014 (Table S1 in supplementary material). Of all the food samples, 39 were purchased from a market about 3 km away from the MSWI (Fig. 1) and included 8 types of fruit, 22 types of vegetables, 3 types of cereals, 9 types of fish and shrimp, 4 types of meat and 3 kinds of eggs. All the commercial foodstuffs in the market were not local products, and the commercial vegetables generally came from the commodity vegetable bases in Shandong and He'nan Province. In addition to the food samples purchased from the market, a farmers' garden situated about 1 km from the MSWI was found that grew vegetables for the commercial consumption of residents living close to the MSWI and no other potential heavy metal pollution sources nearby could be found. Based on the local topographical and meteorological conditions, the garden was in the areas affected by the pollution of the MSWI. Fourteen types of vegetable samples were purchased from this garden, and 11 of the local vegetables obtained were the same as those purchased from the market: BCL = cabbage (*Brassica campestris* L.); SOL = spinach (*Spinacia oleracea* L.); GBL = garlic bolt (*Garlic bolt* L.); BCL= Chinese cabbage (*Brassica chinensis* L.); SLL = leaves of asparagus lettuce (*Strobilanthes lactucifolia Levl.*); AA = chive (*Allium ascalonicum*); LSL = leaf lettuce (*Lactuca sativa* L.); IAF = water spinach (*Ipomoea aquatica Forsk*); CAL = green pepper (*Capsicum annuum* L.); CSL = cucumber (*Cucumis sativus Linn*); VU = cowpea (*Vigna unguiculata*).

9 fly ash samples were collected from the discharge of filters from the gas cleaning system from November 2013 to July 2014. Ambient air monitoring was conducted at five stations (A1 to A5) with increases in the distance to the MSWI as shown in Fig. 1. Total suspended particulates (TSP) samples were collected on Whatman glass fiber filters with a diameter of 47 mm (0.1 mm pore-size and 99.9% collection efficiency) using a medium volume sampler (Laoying, Qingdao) operated at a constant flow rate (100 L/min) and programmed to collect 24 h samples. The medium volume samplers at all of the stations were kept at a height of 1.5 m. The TSP mass was determined by gravimetric analysis on glass fiber filters stabilized and weighed before and after sampling. Overall, 45 TSPs samples were collected over nine months from August 2013 to July 2014.

During the sampling period, 46 soil samples were collected from the areas surrounding the MSWI. Surface soil samples (0–5 cm depth; approximately 1 kg) were collected using plastic brushes, wrapped in aluminum foil and stored in sealed polyethylene bags. The soil samples were grouped into five areas, based on the distance of the sampling locations from the MSWI: 1 km north (−1.6-0 km, n = 9), within (0 km, n = 11), 1–3 km south (1–3 km, n = 20), 5–6 km south of MSWI (5–6 km, n = 4), and 9–10 km southeast (9–10 km, n = 2).

Eighteen tap water samples were collected from areas located about 0–1, 5–6 and 9–10 km away from the MSWI over a 1-year sampling period. Water samples were collected in polyethylene bottles pre-washed with concentrated nitric acid (1:1) and deionized water several times before use. To avoid possible contamination during water sampling, we turned on the water taps completely to release water for at least 5 min.

2.3. Blood sampling

A scheme devised for the collection of human blood samples was approved by the Ethical Committee of the Peking University Health Science Center. The population comprising 425 adults ranging in age from 24 to 45 years was divided into two groups: 195 from areas with potential exposure (0–3 km away from the MSWI) and 230 from the reference area (5–10 km away from the MSWI). All the participants have lived and worked in the current addresses for at least two years, and these persons spent most their daily time in the areas. In 2014, venous blood samples taken from all of the participants; that is, drawn into vacutainers containing sodium heparin anticoagulant, after thoroughly cleaning the arm with an ethanol swab. All of the samples were stored at −80 °C until analysis. Before the sample collection, we asked each participant, with the assistance of qualified public health workers, to complete a written informed consent and answer a questionnaire covering lifestyle information and social demographic characteristics including age, gender, body mass index (BMI), resident history,