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Heavy metals and lead isotopes in soils, road dust and leafy vegetables and health risks via vegetable consumption in the industrial areas of Shanghai, China

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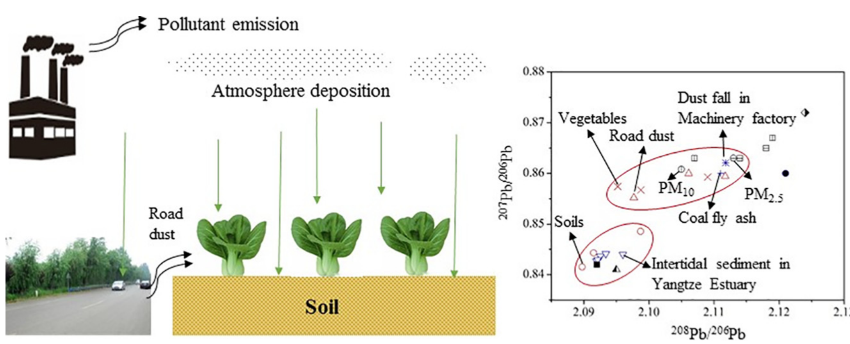
HIGHLIGHTS

- Hg in soils and Zn and Cu in road dust were present at relatively high levels.
- There was low health risk by consumption of vegetables.
- Industrial and combustion emissions were the major sources of Pb in dust and vegetables.
- Pb in leafy vegetables was mainly through foliar uptake.

GRAPHICAL ABSTRACT



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ABSTRACT

Vegetable fields have a high risk of heavy metal contamination from pollution sources in suburban and industrial areas of cities. Eighty-seven soil samples, 106 leafy vegetables and 48 road dust samples were collected from industrial areas of Shanghai, China. We studied the levels of heavy metals, health risk through consumption of leafy vegetables, and sources of Pb in soils, road dust and leafy vegetables. Soil Cd, Zn, Pb, Cu, Hg and As concentrations exceeded the soil background values in 73.6%, 97.7%, 52.3%, 37.8%, 95.1% and 20.2% soil samples, respectively, but were below the criteria for agricultural soil in China, with the exception of Hg. The concentrations of Cd, Zn, Pb, Cu and As in road dust were significantly higher than concentrations in soils, while Hg concentration in road dust was lower. Cd, Zn, Pb, Hg and Cu concentrations in soils and Zn, Pb and Cu concentrations in road dust were greatest near the municipal solid waste incineration power plant. Heavy metal concentrations in the edible tissues of vegetables were not correlated with their total values in soils and varied among vegetable species. The trends in transfer factors (TFs) in different vegetables were Cd > Zn > Cu > As > Hg > Pb. There was low health risk from heavy metal exposure by consumption of vegetables based on Hazard Quotients (HQ_M): As was the major contributor to HQ_M, followed by Cd and Pb. Parent material of the Yangtze River Estuary was the major source of Pb in soils, while coal-fired, stationary

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industrial emissions and municipal waste incineration emissions were the major sources of Pb in dust and vegetables based on use of the lead isotopic tracing method. Accumulation of Pb in leafy vegetables was through foliar uptake and directly related to atmospheric Pb.

1. Introduction

Soil and vegetable contamination by heavy metals in the industrial and suburban areas of cities has often been documented (Ferri et al., 2015; Nabulo et al., 2010; Zhuang et al., 2009). Industrial processes such as smelting, e-waste processing, coal combustion in power plants, waste incineration, vehicular traffic, pesticide use, and fertilization have contributed to increased heavy metal concentrations in the environment (Chiaradia and Cupelin, 2000; Dietrich et al., 2017; Li et al., 2015; Luo et al., 2009; Luo et al., 2011; Rodriguez-Iruretagoiena et al., 2015; Sun et al., 2010). With the rapid development of urbanization, vegetable fields are often located close to industrial areas and villages, placing them at high risk of contamination by local pollutants. Chronic exposure to heavy metals can have adverse effects on humans (Itoh et al., 2014; Zheng et al., 2007). Although Cu and Zn are essential elements in small amounts, they can be toxic to humans and animals at high levels (Shahid et al., 2015). Pb, Cd, Hg and As are non-essential elements, that may cause mutagenic, teratogenic and carcinogenic effects at extremely low levels (Järup, 2003; Abdul et al., 2015). The high stomach cancer rate in the Van region of Turkey was closely related to the high levels of Cd, Pb, Cu, Co and other metals in the soil, fruit and vegetables (Türkdoğan et al., 2002). For those living close to contaminated sites, consumption of vegetables may increase their health risk. Several studies of contaminated sites demonstrated that vegetable consumption alone can lead to exposures above toxicological threshold levels (Cui et al., 2004; Xu et al., 2013; Zheng et al., 2007).

Transfer of heavy metals from soil to plants and their subsequent consumption is the major exposure route for humans. Many studies of heavy metals in soil-vegetable systems have been published (Hu et al., 2017; McBride, 2013; Nabulo et al., 2010; Pan et al., 2016). High transfer capability of Cd from soil to edible tissues of vegetables (Luo et al., 2011; Zhuang et al., 2009) and high contributions to health risks made by Cd and Pb through vegetable consumption (Nabulo et al., 2010; Pan et al., 2016) were reported. Leafy vegetables can accumulate higher heavy metal concentrations in the edible tissues than non-leafy vegetables (Hu et al., 2017; Liu et al., 2013). Soils were not the only contamination sources of heavy metals in vegetables. Direct foliar uptake of atmospheric Pb and Hg has been demonstrated as the dominant pathway for Pb and Hg accumulation in the above-ground tissues of vegetables (Bi et al., 2009; De Temmerman et al., 2009).

Particles with heavy metals emitted by industrial sources and waste incineration can be directly deposited on the top surface of soil, road dust and crop leaves through wet and dry atmospheric deposition (Shi et al., 2008; Luo et al., 2011). Through external forces such as vehicles, wind, and rain, heavy metals in road dust can easily enter the surrounding soil through resuspension and runoff processes. The dust also becomes a source of heavy metals in nearby soils (Chen et al., 2010) and is likely to be deposited on crops. Vegetables can accumulate heavy metals through root and foliar uptake (Hu et al., 2017; McBride, 2013; Uzu et al., 2010), both of which would cause human health risks. Road dust can contribute to foliar dust and further increase the heavy metal contamination of vegetables. There are many studies of heavy metals in soil-vegetable systems but few studies of heavy metal pollution in a complex system of top soils, road dust and vegetables near the industrial facilities and traffic roads.

Shanghai is one of the most highly developed and densely populated cities in China. We reported contamination characteristics of potentially toxic metals in urban soils and roadside dust in a previous study (Shi et al., 2008). The objectives of the present study were to the following: (1) explore the extent of local heavy metal pollution in the complex system of top soils, road dust and leafy vegetables in a suburban environment; (2) determine the influence of industrial activities and waste incineration on heavy metal accumulation in this complex; (3) quantify the potential health risk from consuming leafy vegetables grown in suburban environments; and (4) identify the sources of Pb in soils, road dust, and the edible parts of leafy vegetables using a Pb isotopic tracing method. This study can provide a scientific basis for reducing human health hazards and provide theoretical support for the rational planning of urban land use.

2. Materials and methods

2.1. Study area

The study area is situated on seven agricultural sites used to grow vegetables. The sites are near industrial areas, a municipal solid waste incineration power plant, and highways. One contrasting site is used to grow strawberries and vegetables in a suburban area of West Shanghai (Fig. 1). There were 3.15×10^5 ha of agricultural land in the Shanghai suburbs in 2014, and this covered 37.7% of the total land area (Shanghai Municipal Planning and Land & Resources Administration). With the rapid urbanization, vegetable fields are often located near industrial areas and around residential areas, forming an industrial-residential-agricultural mixed use area. The vegetables and soils are therefore at a high risk of contamination from industrial pollution, vehicle traffic emissions, and waste disposal. This poses a health risk to local residents. Criteria for study site selection included pollution sources from solid waste disposal, industry activities, vehicle traffic emissions, and agriculture. Locations near Shanghai Baoshan iron and steel plant, Yuqiao municipal waste incineration power plant, Wujing chemical industry area, and several highways were selected for study areas (Table 1). Two coal-fired thermal power plants were located near study areas. One is Baogang thermal power plant located in the eastern Baoshan iron and steel plant, and the other is the Wujing thermal power plant located in the southern Wujing chemical industry area.

2.2. Sample collection and preparation

Considerable diversity in vegetable cultivation is found in Shanghai. Four of the most popular leafy vegetables grown at all study sites were collected during April 2014 and January 2015, including 22 bok choys (*Brassica campestris* L. ssp. *chinensis* Makino), 37 Shanghai Green cabbages (*Brassica chinensis* L.), 16 water spinaches (*Ipomoea aquatica* Forsk.) and 31 leaf lettuces (*Lactuca sativa* L. var. ramosa Hort.). Vegetable samples were taken from 3 to 5 plants ($N = 3–5$) to provide a composite sample. Soil from the upper 20 cm was collected close to the sampled plants and dust on the roadside (from the curb stone into the road for 1 m) (Shi et al., 2008) was collected close to the sampled agriculture field. Both the soil and the dust samples were formed into composite samples from five subsamples respectively. All of the samples were placed into polyethylene bags and transported to the laboratory on the day of sampling. A total of 87 soil samples and 48 dust samples were gathered.

The fresh vegetable samples were washed with tap water, rinsed with deionized water, and the fresh weight was recorded. Then the samples were oven dried at 80 °C to a constant weight, ground using a mortar and passed through a 2 mm size nylon sieve. Soil and dust samples were freeze dried at −54 °C, then ground and sieved through a