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Contamination source apportionment and health risk assessment of heavy metals in soil around municipal solid waste incinerator: A case study in North China

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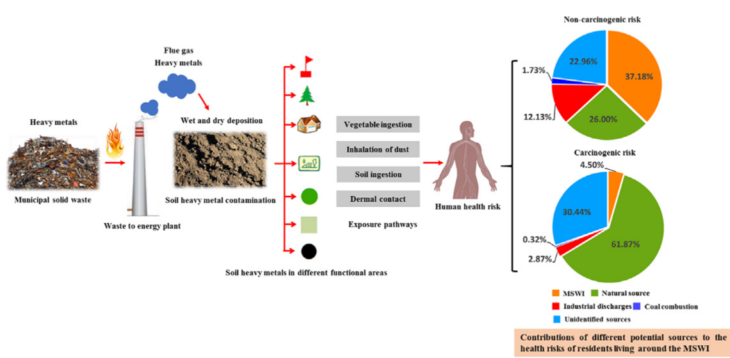
HIGHLIGHTS

- Soils around the MSWI were moderately polluted by Cu, Pb, Zn, and Hg, and heavily polluted by As and Cd.
- MSWI significantly contributed 36.08% to the soil heavy metal contamination.
- Sources contribution to human health risk was firstly studied by APCS-MLR and dose-response model jointly.
- MSWI had a significant influence on human health risks mainly through Pb and Ni emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

Few studies have comprehensively taken into account the source apportionment and human health risk of soil heavy metals in the vicinity of municipal solid waste incinerator (MSWI) in high population density area. In this study, 8 elements (Cr, Pb, Cu, Ni, Zn, Cd, Hg, and As) in fly ash, soil samples from different functional areas and vegetables collected surrounding the MSWI in North China were determined. The single pollution index, integrated Nemerow pollution index, principal component analysis (PCA), absolute principle component score-multiple linear regression (APCS-MLR) model and dose-response model were used in this study. The results showed that the soils around the MSWI were moderately polluted by Cu, Pb, Zn, and Hg, and heavily polluted by As and Cd. MSWI had a significant influence on the distribution of soil heavy metals in different distances from MSWI. The source apportionment results showed that MSWI, natural source, industrial discharges and coal combustion were the four major potential sources for heavy metals in the soils, with the contributions of 36.08%, 29.57%, 10.07%, and 4.55%, respectively. MSWI had a major impact on Zn, Cu, Pb, Cd, and Hg contamination in soil. The non-carcinogenic risk and carcinogenic risk posed by soil heavy metals surrounding the MSWI were unacceptable. The soil heavy metals concentrations and health risks in different functional areas were distinct. MSWI was the predominate source of non-carcinogenic risk with the average contribution rate of 36.99% and carcinogenic risk to adult male, adult female and children with 4.23×10^{-4}, 4.57×10^{-4}, and 1.41×10^{-4}

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respectively, implying that the impact of MSWI on human health was apparent. This study provided a new insight for the source apportionment and health risk assessment of soil heavy metals in the vicinity of MSWI.

1. Introduction

With the rapid economic growth and population size, the amount of municipal solid waste (MSW) generated in China increased from 164 million tons (2011) to 191 million tons (2015) (NBS, 2015). Waste disposal became a crucial part of the social sustainable development (Li et al., 2015b). Incineration plays an important role in MSW management in China and incinerators run with a total disposal capacity of 219,080 tons day^{-1} of MSW which is 34.28% of total MSW treated by the end of 2015 (NBS, 2015). Although incineration can significantly reduce the waste volume and produce energy (Song et al., 2017), significant concerns have been raised regarding the potential effects of the toxic chemicals emissions from MSWI (Domingo, 2002; Li et al., 2017). Heavy metals present in MSW evaporate during the combustion process and mainly transfer to the fly ash and flue gas (Weibel et al., 2017), then released into the atmosphere either from the chimney or as fugitive emissions and eventually accumulated in soil by wet and dry deposition (Rimmer et al., 2006). This leads to soil contamination and threatens food safety, posing a health risk to people living in the neighborhood of MSWI (Deng et al., 2016; Li et al., 2015b; Li et al., 2017; Tepanosyan et al., 2017).

Although vast researches have been done about the soil heavy metals in the vicinity of MSWI, there is still controversy on whether the MSWIs have significant impact on the heavy metals concentrations in surrounding soils (Bretzel and Calderisi, 2011; Deng et al., 2016; Han et al., 2016; Li et al., 2017; Meneses et al., 1999; Rimmer et al., 2006; Rovira et al., 2015). Rovira et al. (2015) showed that the soil heavy metals concentrations were irrelevant to the distance from the MSWI and did not show temporal variations in Catalonia. Similarly, no evidences for increased heavy metals pollution due to MSWI emissions were found in a study by (Rimmer et al., 2006) who found that the effect of MSWI could be interfered by the contamination of hotspots due to other anthropogenic activities in Newcastle. In contrast, Han et al. (2016) found that soil heavy metals concentrations were relatively high in the downwind zone indicating a significant effect by MSWI in Beijing. Li et al. (2017) also found that the concentrations of Pb, Cr, and Mn in soils decreased with increasing distance from MSWI in Shenzhen, because the high accumulation in soil affected by the emission from MSWI. The different results about the influence of MSWI on the soil heavy metals contaminations might originate from the variation in MSWI emission, local climate (precipitation, temperature and wind direction), geological characteristics of different sites (soil type, total organic carbon and pH) and the anthropogenic activity intensity in the vicinity of MSWI (Iwegbue, 2014; Zhao et al., 2015; Zupancic, 2017). However, few studies considered the potential exposure scenarios (exposure pathways, exposure time) related to different functional areas in the health risk assessment for people living around the MSWI. There was no study combined the source apportionment with the health risk assessment to quantify the contribution of MSWI on human health risk. As the pollutions in different functional areas may cause different impacts on public health (Li et al., 2001; Xia et al., 2011), and the soils in the vicinity of MSWI are affected not only by MSWI, but also by other associated anthropogenic activities, the study on the soil heavy metal contamination, source apportionment and health risk assessment in different functional areas surrounding the MSWI is desired.

The present research studied the soil heavy metal contamination in areas surrounding MSWI located in the high population density area in North China. The soil background values of Cr, Cu, Ni, Zn, and Hg in study area are higher than the mean values in China (Wei et al., 1991). There are residential areas and primary school (~1500 students) <500 m from the MSWI. Therefore, it is urgent to investigate the influences of MSWI to the soil heavy metals contaminations and the health risk for public healthy safety. The objectives of this study were to: (1) quantify the pollution levels of soil heavy metals using the single pollution index (PI_i) and the integrated Nemerow pollution index (PI_N); (2) identify the potential sources of soil heavy metals by principal component analysis (PCA) and apportion the sources using APCS-MLR model; (3) assess the human health risks associated with varied functional areas using the dose-response model and quantify the contributions of MSWI. The results of this study provided a basis for guiding further strategies and policies aimed at preventing health risk from soil heavy metal suffered by residents living in the vicinity of MSWI.

2. Materials and methods

2.1. Study area

The studied MSWI, located in North China (116°43′-118°04′E and 38°34′-40°15′N) (Fig. 1), is in the warm temperate zone, with a continental monsoon climate. The prevalent wind is southwest and the average annual temperature and precipitation are 11.9 °C and 556 mm respectively. The area is characterized by light expanded clay and silty clay soils. It is surrounded by high population density area which are primary school and residential areas. There are also a number of industrial factories in the vicinity of MSWI. The MSWI began operating in 2005 with a capacity of 1200 tons per day. The flue gas treatment system consisted of a semi-dry scrubber, an activated carbon adsorption unit, a bag filter and an 80-m-high stack for flue gas emission.

2.2. Sample collection

A total of 64 surface soil samples (0–20 cm) within 3 km around the MSWI were collected in December 2016. The study area was divided into four sectors (NW, NE, SW, SE), based on the dominant southwest wind direction. Each sector consisted of four distance bands (0–0.5 km, 0.5–1 km, 1–2 km, 2–3 km) and four sampling sites were distributed in each band (Fig. 1). According to the types of land use, the sampling sites were classified into industrial area (IA), wild area (WA), green land (GL), agricultural area (AA), residential area (RA), wood land (WL) and schools (SH) with the amount of samples 3, 15, 9, 6, 12, 12, and 7, respectively. The coordinates of sampling sites were recorded by GPS. Each sample (>1 kg dry weight) was composed of 3 subsamples obtained by stainless steel hand auger. The soil samples were sealed in PVC bags, and then transferred to the lab for analysis. Since the most agricultural area surrounding the MSWI was covered by vegetables which could accumulate soil heavy metals and pose health risk to human beings, vegetables samples (Chinese cabbage, sponge gourd, green onion, pumpkin) were also collected to assess human health risk. Each vegetable sample comprised at least 9 subsamples collected from three different sample sites. One fly ash sample from the MSWI was also collected in December 2016 to examine the relationship between heavy metals concentrations in soil and MSWI.

2.3. Sample treatment and analysis

After air-dried, ground and sieved through a 0.15 mm mesh, the soil samples (approximately 0.5 g) were digested with a 8 ml solution of 5:2:1 HNO_3: HF: H_2O_2 (*v*/v) by microwave digestion method. The