Ecotoxicology and Environmental Safety 106 (2014) 154–163

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

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

Risk assessment of toxic metals in street dust from a medium-sized industrial city of China

Xinwei Lu*, Xing Wu, Yiwen Wang, Hao Chen, Panpan Gao, Yi Fu

School of Tourism and Environment, Shaanxi Normal University, Xi'an 710062, People's Republic of China

ARTICLE INFO

Article history:
Received 22 February 2014
Received in revised form
14 April 2014
Accepted 19 April 2014
Available online 20 May 2014

Keywords:
Metal
Dust
Ecological risk
Health risk
Assessment

ABSTRACT

The concentrations of toxic metals As, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in street dust of Tongchuan, China were determined by wavelength dispersive X-ray fluorescence spectrometry. The risk of the analyzed metals to urban ecosystem and human health were evaluated by potential ecological risk index and human exposure model, respectively. The results show that, in comparison with Shaanxi soil, dust samples have elevated metal concentration as a whole expect for As, Mn, V and Ni. The assessment results of ecological risk indicate that the ecological risks of As, Cr, Mn, Ni, Cu, V and Zn in the dust were in the low level, while Pb and Co presented low to moderate level. Health risk assessment shows that ingestion was the main exposure route of all analyzed toxic metals in street dust to children and adults. The non-cancer risks of the studied metals to children and adults were within the safe range, and the cancer risks of As, Co, Cr and Ni were also within the currently acceptable range.

1. Introduction

Cites are concentrated centers of anthropogenic activities related to industrialization and urbanization, e.g. production, consumption, transportation and waste disposal, etc. Due to accelerated urbanization and industrialization, nearly half of the population in the world now lives in urban agglomerations (Grimm et al., 2008; Shi et al., 2008; Tang et al., 2013). The dense population, traffic, industry and economic activities cause an increasing amount of contaminants being discharged to urban environment. Consequently, a variety of environmental problems have emerged, of which toxic metal pollution is a major issue, especially in urban soil and street dust (Han et al., 2006; Shi et al., 2008; Thornton et al., 2008).

Street dust, one special type of environmental medium with complicated composition in urban regions (Shi et al., 2011), is referred to as solid particles that accumulate on outdoor hard pavement or cement road in urban areas (Al-Khashman, 2007). Road surfaces serve as sinks and sources of metals and other contaminants in urban environment (Deletic and Orr, 2005; Yuen et al., 2012). Elevated concentrations of metals are ubiquitous in street dust owing to a wide range of human activities including vehicle emissions, coal combustion, disintegration of vehicle brakes and tires, atmospheric deposition, road surface wear, municipal solid waste incineration, and residential heating (Duong and Lee, 2009; Zhao and Li, 2013). Dust contaminated by metals is becoming an important threat to urban environment and ecosystem because of the possible transmission of metals in dust to aquatic systems by urban runoff (Kong et al., 2012; Zhao et al., 2010) and to atmosphere by re-suspension in the wind (Ferreira-Baptista and De Miguel, 2005). As typical contaminants in urban environment, metals in street dust are useful indicators of environmental pollution (Christoforidis and Stamatis, 2009). Furthermore, metals in street dust can easily transfer into human body by inhalation, ingestion or dermal contact (Sezgin et al., 2004; Ferreira-Baptista and De Miguel, 2005; Ahmed and Ishiga, 2006; Aelion et al., 2008; Christoforidis and Stamatis, 2009; Zheng et al., 2010a, 2010b; Lu et al., 2014), and can be easily accumulated in fatty tissues or deposited in the circulatory system due to their toxicity and non-biodegradability (Tang et al., 2013), thus interfering with the normal functions of the internal organs, disrupting the nervous system or endocrine system, or acting as auxiliary factors of other diseases (Zheng et al., 2010a, 2010b; Tang et al., 2013). Therefore, more concerns have been addressed over the problem of street dust contamination with metals during past decades, and a large amount of researches have been done all over the world (Akhter and Madany, 1993; Li et al., 2001; Banerjee, 2003; Han et al., 2006, 2008; Al-Khashman, 2007; Faiz et al., 2009; Lu et al., 2009a, 2009b, 2010; Atiemo et al., 2011).

Hitherto, the existing researches on metals in street dust have mainly focused on concentration, distribution, contamination assessment, and source identification (Akhter and Madany, 1993;

---

* Corresponding author. Fax: +86 29 85303883.
E-mail address: luxinwei@snnu.edu.cn (X. Lu).

http://dx.doi.org/10.1016/j.ecoenv.2014.04.022
0147-6513/© 2014 Elsevier Inc. All rights reserved.

Sutherland and Tolosa, 2000; Banerjee, 2003; Charlesworth et al., 2003; Sezgin et al., 2004; Ahmed and Ishiga, 2006; Han et al., 2006; Al-Khashman, 2007; Faiz et al., 2009; Lu et al., 2009a, 2009b, 2010; Atiemo et al., 2011; Tang et al., 2013), as well as potential ecological risk assessment (Tang et al., 2013; Zhao and Li, 2013) and health risk assessment (Ferreira-Baptista and De Miguel, 2005; Zheng et al., 2010a, 2010b; Hu et al., 2011; Shi et al., 2011). Ecological risk index (Håkanson, 1980) has widely used in literatures (Zhu et al., 2008; Tang et al., 2013; Zhao and Li, 2013) to assess the potential ecological risk of metals in street dust. The health risk of metals in street dust to people was often determined using the USEPA model according to the metal concentration in samples (Ferreira-Baptista and De Miguel, 2005; De Miguel et al., 2007; Zheng et al., 2010a, 2010b; Hu et al., 2011; Shi et al., 2011; Lu et al., 2014). However, most of the existing studies were done in the developed countries or the megacities, and little information is available for the developing countries (Banerjee, 2003), as well as the medium and small size cities. In China, the contamination characteristics and environmental risk of toxic metals in street dust from megacities, e.g. Beijing (Tang et al., 2013; Zhao and Li, 2013), Shanghai (Shi et al., 2008, 2011), Guangzhou (Duzgoren-Aydin et al., 2006), Hong Kong (Li et al., 2001), Nanjing (Hu et al., 2011; Li et al., 2013) and Xi'an (Han et al., 2006, 2008), have caused concerns by scientists, while the researches about the rapid development medium and small size city is limited (Zheng et al., 2010a, 2010b). Compared to the megacities, the environmental issues are even more serious in the medium and small size industrial cities due to the neglect of environmental protection or the lack of pollution treatment technology.

Tongchuan is a medium-sized industrial city of Shaanxi province in northwestern China and has experienced rapid urbanization and industrialization since the Chinese Great Western Development policy implementation in 1990s, and unprecedented environmental changes have accompanied this development. Nevertheless, the information about metal contamination in urban environment is lacking in literature. The objectives of this study were to investigate the concentration levels of toxic metals As, Co Cr, Cu, Mn Ni, Pb, V and Zn in street dust of Tongchuan and to evaluate their potential risks to local ecosystem and human health. The results could offer the basic information for regulators and engineers in environmental planning, monitoring and risk management.

2. Materials and methods

2.1. Study area

Tongchuan, a prefecture-level city of central Shaanxi, is located in the southern edge of the Loess Plateau (latitude 34°50′–35°34′ N, longitude 108°34′–109°29′E) of northwestern China (Fig. 1). The climate of Tongchuan city is a typical temperate continental semi-humid climate, with annual average temperature, sunlight time and precipitation of 8.9–12.3 °C, 2346–2413 h and 550–710 mm, respectively. Tongchuan urban area covers four districts, i.e. Yintai district, Wangyi district, Yaozhou district and New district. Wangyi district and Yaozhou district are the old downtowns of Tongchuan city. Coal and battery industries locate in Wangyi district. Cement plants, building materials factories and ceramic factories concentrate in Yaozhou district. Aluminum electrolytic plant and pharmaceutical factory distribute in Yintai districts. New district, built after 2000, is designed as a new political, economical and cultural center, with many construction sites. Before the 2000s, this area consisted of agricultural land and a village. Automobile industry and food processing plants settled in New district in 2012. Tongchuan city is an important part of Guanzhong economic belt with abundant natural resources, e.g. coal, oil shale, limestone, refractory clay and ceramic clay etc., and is now becoming a comprehensive industrial city of Shaanxi province. The main industries are coal, building material, ceramic, aluminum smelter, chemical industry, cement plant and textile. The gross domestic product (GDP) of Tongchuan was 28,293 million RMB in 2012, with 15 percent growth rate, and the industrial output value accounted for ~66 percent of GDP. The total area and urban area of Tongchuan is 3882 and 2406 km^2, respectively, and its population was 855,000 in 2011. The number of motorized vehicle was 131,000 in 2011. The traffic volumes of Yaozhou and Wangyi district are heavier than Yintai and New district.

2.2. Dust sampling and analytical procedures

Forty-two street dust sampling sites were selected in Tongchuan urban area, i.e. Yintai district, Wangyi district, Yaozhou district and New district (Fig. 1). At every sampling site, a dust composite sample of about 500 g composed of 3–5 sub-dust samples was collected from street by sweeping using a clean plastic brush and tray (Akhter and Madany, 1993; Lu et al., 2009a, 2009b, 2010) during the cold and dry season in January to March 2013. Forty-two dust composite samples were collected in this manner. The collected dust samples were stored in the self-sealed polyethylene sample bags, labeled, and then taken back to the laboratory. All samples were air-dried naturally in the laboratory for two weeks, and then sieved through a 1.0 mm mesh nylon sieve to remove refuse and small stones before halving. One half was stored, while the other was then ground with agate mortar and pestle, then carefully homogenized and sieved through a 75 μm nylon mesh (Lu et al., 2009a, 2009b). All procedures of handling were carried out without contact with metals, to avoid potential cross-contamination of the samples.

To analyze metal concentrations, 4.0 g of milled dust sample and 2.0 g of HBO_3 were weighed out, placed in a mold, and pressed into a 32 mm diameter pellet under 30 t pressures. The concentrations of As, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in street dust samples were determined by wavelength dispersive X-ray fluorescence spectrometry (XRF, PANalytical PW-2403 apparatus) (Lu et al., 2010). For quality assurance and control (QA/QC), duplicate samples and standard samples (GSS1 and GSD12) (Lu et al., 2010), purchased from the Center of National Standard Reference Material of China, were simultaneously analyzed in the same procedure. The precision, calculated the relative standard deviation of duplicate samples, was routinely 3–5 percent. The analyzed accuracy, calculated from the relative error of standard reference materials, was less than 5 percent.

2.3. Potential ecological risk assessment model

The method of potential ecological risk assessment was first introduced by Håkanson (1980) and then widely used in the pollution assessment of sediment (Caeiro et al., 2005), soil (Sun et al., 2010, 2013; Yuan et al., 2014) and dust (Tang et al., 2013; Zhao and Li, 2013). The potential ecological risk index (RI) of toxic metals was defined as

$$RI = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} T_i \times C_f^i = \sum_{i=1}^{n} T_i \times \frac{C_s^i}{C_n^i} \tag{1}$$

where RI is the potential ecological risk index of toxic metals in the study sample. E_i is the potential ecological risk factor of metal i. T_i is the toxic-response factor of metal i as calculated by Håkanson (1980) and Xu et al. (2008), i.e. As=10, Pb=Cu=Ni=Co=5, Cr=V=2, Zn=Mn=1. C_f^i, the pollution index of metal i, is equal to the concentration of metal i in the sample (C_s^i) divided by its background value (C_n^i). In this study, C_n^i is the background value of Shaanxi soil (CNEMC, 1990). Since the pollutants considered in this study are different from that of Håkanson (1980), the ecological risk degree was classified as low ecological risk ($E_i < 15$, $RI < 50$), moderate ecological risk ($15 \le E_i < 30$, $50 \le RI < 100$), considerable ecological risk ($30 \le E_i < 60$, $100 \le RI < 200$), high ecological risk ($60 \le E_i < 120$, $RI \ge 200$) and very high ecological risk ($E_i \ge 120$) (Zhu et al., 2008; Zhao and Li, 2013).

2.4. Health risk assessment model

The model used in this study to calculate the exposure of children and adults to toxic metals in street dust is based on those developed by the US Environmental Protection Agency (USEPA, 1996) and the Dutch National Institute of Public Health and Environmental Protection (Van den Berg, 1995) for the definition of guidelines or screening levels of dust contaminants in urban exposure scenarios. Children and adults are exposed to dust through three main pathways, i.e. ingestion of dust particles, inhalation of dust particles through mouth and nose, and dermal contact (Ferreira-Baptista and De Miguel, 2005, Zheng et al., 2010a, 2010b). The dose received through each of the three pathways can be estimated by the following Eqs. (2)–(4) (USEPA, 1989, 1996). For carcinogens, the lifetime average daily dose ($LADD$) (inhalation exposure route for Co, Cr and Ni; ingestion, inhalation and dermal adsorption exposure route for As) was used in the assessment of cancer risk (USEPA, 1996, 2001; Ferreira-Baptista and De Miguel, 2005).

$$D_{\text{ing}} = C \times \frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \tag{2}$$

$$D_{\text{inh}} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \tag{3}$$

$$D_{\text{dermal}} = C \times \frac{\text{SL} \times \text{SA} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \tag{4}$$