Science of the Total Environment 630 (2018) 53–61

Contents lists available at ScienceDirect

Science of the Total Environment

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

Assessment of heavy metal pollution and human health risks in urban soils around an electronics manufacturing facility

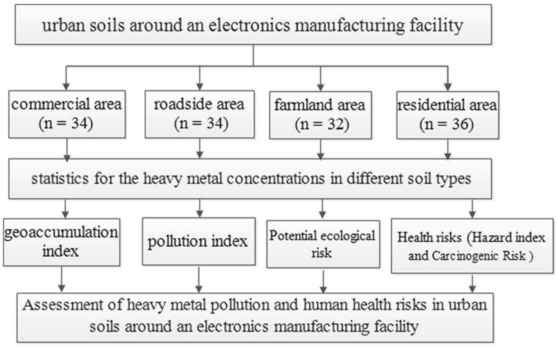
Wei Wu [a,*], Ping Wu [a], Fang Yang [a], Dan-ling Sun [a], De-Xing Zhang [a], Yi-Kai Zhou [b]

[a] *School of Laboratory Medicine, Hubei University of Chinese Medicine, 1 Huangjia Lake West Road, Wuhan 430065, China*
[b] *MOE Key Laboratory of Environment & Health, Institute of Environmental Medicine, School of Public Health, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, Hubei, China*

HIGHLIGHTS

- Metal contamination was detected in soils near an electronics manufacturing facility.
- Chromium, zinc, and lead were the most abundant metals detected.
- Risks assessment results indicate that these soils may pose health risks.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 December 2017
Received in revised form 14 February 2018
Accepted 15 February 2018
Available online xxxx

Editor: Frederic Coulon

Keywords:
Heavy metal pollution
Electronics manufacturing facility
Pollution index
Health risk

ABSTRACT

Heavy metal pollution has pervaded many parts of the world, especially in developing countries. The purpose of this study was to determine the concentrations and health risks of heavy metals in urban soils around an electronics manufacturing site in the Hubei Province of China. Soils samples were collected from commercial, roadside, farmland, and residential areas around the electronics manufacturing facility. A total of 136 topsoil samples were collected, and these samples were analyzed for Cr, Cu, Zn, As, Cd, Ni, and Pb. The geoaccumulation index (Igeo), pollution index (PI), and potential ecological risk index (PER) were calculated to assess the soil pollution levels. The hazard index (HI) was used to assess the human health risks posed by the presence of heavy metals. The total concentrations of the seven congeners ($\sum$metals) ranged from 3738.86 to 5173.25 mg kg^{-1}, and the concentrations were highest in the commercial area followed (in decreasing order) by the roadside, farmland, and residential areas. The HI for children and adults descended in the order of Cr > As > Pb > Cd > Cu > Ni > Zn. The carcinogenic risks of two metals, namely, Cr and As, for children and adults were higher than 10^{-4}, and children faced greater health risks.

1. Introduction

Heavy metals such as chromium (Cr), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), nickel (Ni), and lead (Pb), which are generally referred to as metals and metalloids, have densities >5 g cm^{-3} (Chowdhury et al., 2016). This kind of pollution not only degrades the quality of the atmosphere, water bodies, and food crops, but also accumulates in vital organs such as the kidney, bone, and liver where it can pose threats to the health of human beings (Bosch et al., 2016; Lamas et al., 2016; Ma et al., 2016). For example, Pb is a non-essential element to the human body, and excessive intake of this metal can

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[*] Corresponding author.
E-mail address: wuwei@hbtcm.edu.cn (W. Wu).

https://doi.org/10.1016/j.scitotenv.2018.02.183
0048-9697/

lead to enzyme inhibition and nervous, skeletal, circulatory, endocrine, and immune system damage (Pareja-Carrera et al., 2014; Pascaud et al., 2014). Exposure to As can lead to dermal lesions, skin cancer, peripheral neuropathy, and peripheral vascular disease (Patlolla et al., 2012; Tan et al., 2016). Moreover, chronic exposure to Cd can lead to adverse effects such as lung cancer, prostatic proliferative lesions, pulmonary adenocarcinomas, kidney dysfunction, and bone fractures. Even chronic exposures to essential metals with important biological functions can impair health. Generally, when metals penetrate into cells, they can interfere with the oxidation–reduction (redox) potential, which can disrupt many of the reactions occurring in living cells; if such a metal enters the nucleus, it can cause chromatin damage, which can lead to neoplastic transformations.

Heavy metal contaminated soils have become a serious problem in many parts of the world (Duan et al., 2016a, b; Li et al., 2014). Numerous studies have reported on heavy metal concentrations in urban soils around the world including China (Moore et al., 2016; Xia et al., 2017). For instance, the concentrations of Cr and Pb were found to be in the range of 54–265 mg kg^{-1} and 5–425 mg kg^{-1} in urban topsoils from the metropolitan area of Mexico City (Morton-Bermea et al., 2009). In agricultural topsoils in the Ebro basin (Spain), the content of Pb is in the range of 4–147 mg kg^{-1} (average 17.54), which is 10–25 times higher than the regulatory level in Spain (Rodriguez Martin et al., 2006). Zhou et al. (2011) reported that the heavy metal concentrations in soils of the study area greatly surpassed the maximum allowable concentration levels for Chinese agricultural soils, and the exceedance levels were as high as 24-fold and 13-fold for As and Cd, respectively. In a separate report, Xiao et al. (2017) suggested that 49.62% of all soil samples contained significantly high pollution loads and posed high potential ecological risks in the gold-mining region of Shaanxi, China. In addition, Zhuang et al. (2009) found that the average concentrations of Cu, Zn, and Cd (502, 498, and 3.92 mg kg^{-1}, respectively) in paddy soil were 10, 2.5, and 13 times above the Grade II environmental quality standards for soils in China (CEPA, 1995), respectively.

Electronics factories are critical for socio-economic development, and they have produced electronic resources essential to China's modernization (Duan et al., 2016a, b; Wu et al., 2015). Despite the importance of such development, it is well known that electronics factories can inflict serious environmental damage. Previous studies have identified a high diversity of materials and contaminants including heavy metals, polybrominated diphenyl ethers (PBDEs), and phthalate esters (PAEs) in electronic equipment and electrical waste streams (Wang et al., 2015a; Wu et al., 2017a; Yu et al., 2016). Urban soils have been shown to be good diagnostic tools of environmental contamination (Awasthi et al., 2016; Liu et al., 2009), and many studies have demonstrated the negative effects of heavy metals on human health (Akortia et al., 2017; Liu et al., 2009; Wu et al., 2017b), but the possible human health risks posed by metal contamination from electronics manufacturing regions are still not well understood.

China, as one of the largest global producers and consumers of metals, is facing serious threats from pollution caused by industrial activities and rapid urbanization (Wang et al., 2016). Especially in recent years, many industrial factories in China have moved from the south coastal region to the midwest region. Xiangyang, as an emerging industrial city, has built several electronics manufacturing factories and has been subject to soil contamination for the last few decades. Therefore, the purpose of this study was to assess the pollution levels and health risks of heavy metals in the soils surrounding an electronics manufacturing facility in Xiangyang. The main objectives of this research were as follows: (1) to determine the concentrations and distributions of heavy metals (Cd, Cr, Cu, Zn, Pb, and Ni) in soils around an industrial electronics district, (2) to identify the potential sources of heavy metals by multivariate analysis, and (3) to assess the pollution levels, potential ecological risks, and human health risks of the heavy metals in the urban soils.

2. Materials and methods

2.1. Study area and sample protocol

This study was carried out in the city of Xiangyang, Hubei Province, central China, which has a total area of 19,774 km^2 and a population size of >5.5 million. The area has a subtropical climate with an average annual temperature between 15.1 and 16.9 °C. The average annual rainfall and sunlight amount to about 878.8 mL and 1987 h, respectively. Alluvial plains account for 88% of the total area.

The factory site is located within a longitude of 110°45′ to 113°43′ E and a latitude of 31°14′ to 32°37′N, and it covers an area >0.3 km^2 (Fig. 1), the factory produces batteries, wires, and cables and has an annual output of approximately $20 million USD. The factory was founded in 1995, and it may have discharged a large amount of heavy metals over the past 20 years. Meanwhile, some residential communities and life supporting infrastructure have been established in this region. We divided the area into four zones (commercial, roadsides, farmland, and residential) for the investigation. Approximately 400 people live in the area north of the factory, and most of them are farmers; we regarded this area as the residential zone. In the area south of the factory, there are some shops that mainly sell products produced by the factory, and we regarded this area as the commercial zone. Large tracts of farmland are located in the area west of the factory, and the crops consist of corn and wheat; we regarded this area as the farmland zone. A main road extends out from the eastside of the factory, on which numerous trucks transport the factory products in and out, and we regarded this area as the roadside zone.

Sample collection was conducted in July 2015 within 1 km of the factory, and a total of 136 topsoil samples were collected from the study area. The soil properties were typical for the yellow brown earth, which was characterized by relatively viscous, slightly alkaline, moderate organic matter contents and low cation exchange capacities. Each sample was a mixture of five subsamples taken from the upper horizon (0 to 10 cm) in an area of 5 m × 5 m. All soil samples were collected by using a bamboo spade and were stored in sealed packages. After removing stones and other debris, soils were air dried at room temperature (20 to 23 °C) and then sieved through a 0.149 mm mesh by gently crushing the aggregates.

2.2. Chemical analysis

Seven heavy metals, namely, Cr, Cu, Zn, As, Cd, Ni, and Pb, and the total concentrations of the these congeners ($\sum$metals) were evaluated in this study; all of these represent priority heavy metal pollutants as designated by the U.S. Environmental Protection Agency (Boyd, 2016). Soils (0.5 g) were digested with a mixture of concentrated HF–HClO$_4$–HNO$_3$ on a hot plate (Da Silva et al., 2015). First, approximately 0.5 g of a soil sample was weighed and digested with 10 mL of HCl on an electric hot plate at ~190 °C until the solution was reduced to 3 mL. Approximately 5 mL of HF (40%, w/w), 5 mL of HNO$_3$ (63%, w/w), and 3 mL of HClO$_4$ (70%, w/w) were then added and the solution was digested until no black material remained. The digestion was continued further with 3 mL of HNO$_3$, 3 mL of HF, and 1 mL of HClO$_4$ until the silicate minerals had completely disappeared. Finally, the digestion solution was transferred to a 25 mL volumetric polypropylene tube, and 1% HNO$_3$ was added to bring the sample up to a fixed volume for the metal determinations. After filtering the digested samples through a syringe filter (0.45 μm), the concentrations of heavy metals were measured by using inductively coupled plasma mass spectrometry (ICP-MS, 7900, Thermo Electron Corporation).

Quality assurance and quality control (QA/QC) procedures were performed. For each set of 10 samples, a procedural blank and a matrix sample spiked with standards were used to calculate the accuracy. Each soil sample was analyzed in triplicate ($n = 3$). The relative