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Heavy metal and persistent organic compound contamination in soil from Wenling: An emerging e-waste recycling city in Taizhou area, China

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ABSTRACT

The present study was conducted to investigate the levels and sources of heavy metals (Cu, Cr, Cd, Pb, Zn, Hg and As) and persistent organic compounds including polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in soils taken from Wenling, an emerging e-waste recycling city in Taizhou, China. The results suggested that most heavy metals exceeded the respective Grade II value of soil quality standards from State Environmental Protection Administration of China and also exceeded the Dutch optimum values. Total PAHs in soil ranged from 371.8 to 1231.2 μg/kg, and relatively higher PAHs concentrations were found in soils taken from simple household workshops. PCBs were detectable in all samples with total concentrations ranging from 52.0 to 5789.5 μg/kg, which were 2.1–232.5 times higher than that from the reference site (24.9 μg/kg). Results of this study suggested soil in the Wenling e-waste recycling area were heavily contaminated by heavy metals, PAHs and PCBs. Furthermore, compared with large-scale plants, simple household workshops contributed more heavy metals, PAHs and PCBs pollution to the soil environment, indicating that soil contamination from e-waste recycling in simple household workshops should be given more attention.

1. Introduction

Electronic and electric waste (e-waste) refers to end-of-life electronic products including computers, printers, photocopy machines, television sets, mobile phones, and toys [1,2]. It has been estimated that over 500 million computers became obsolete between 1997 and 2007 in the United States alone and more than 50 million tonnes of e-waste are produced annually in the world [3,4]. Large quantities of e-waste represent an emerging environmental problem, as electrical and electronic waste equipment already constitutes more than 5% of municipal waste and is still growing fast in developed countries [5]. Taking advantage of lower labor costs, and less stringent environmental regulations, developing countries, especially China, face a rapidly increasing amount of e-waste that is imported illegally from developed countries for recycling. A report by Toxics Link found that 70% of the e-waste collected at recycling units in New Delhi, India, was actually exported or dumped by developed countries and about 50–80% of the e-waste collected for recycling in the western U.S. is being exported to Asia, about 90% of which is sent to China for recycling [6,7]. However, the recycling techniques in these countries are often crude and do not have the appropriate facilities; the processes include toner sweeping, dismantling of electronic equipment, selling computer monitors to copper recovery operations, plastic chipping and melting, burning wires to recover copper, heating circuit boards over honeycombed coal blocks, and using acid chemical strippers to recover gold and other metals [8,9]. In addition, open burning of unwanted e-waste and their open dumping has been found universally. Such unregulated salvaging operations and optional dumping of the e-waste have resulted in severe and complex contamination of the surrounding environment by toxic chemicals such as heavy metals (Cd, Pb, Cu and Hg), as well as persistent organic compounds such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) [1,10–12]. These compounds could expose the workers and local residents through inhalation, dermal exposure, and even oral intake (of contaminated food), with the health risk being highest for the workers. Once taken into the body, these compounds are stored in certain tissues, leading to intoxication episodes that can be described as acute or long-term intoxications and producing illness when the levels reach critical values [13].

Taizhou area, located in Zhejiang province, East China, has been involved in e-waste recycling for nearly 25 years. It is one of the best known e-waste processing centres of China [10]. The e-waste in Taizhou includes many varieties, such as electric power capacitors, transformers and electromotors and their components, which could contain and release more persistent toxic substances like

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PCBs during the crude recycling operation [8,9]. Since Chu et al. [14] first reported that the soil in the vicinity of a PCB-containing equipment trading and dismantling site was heavily contaminated with PCBs in Luqiao district, the centre city of Taizhou, numerous research studies have been focused on Luqiao [8–11,15]. Therefore, the local government in Luqiao had to take action to regulate the e-waste recycling industry to protect the local environment, which led to the formation of strict environmental policy in this district.

Wenling city is one of the major cities involved in e-waste recycling close to the city centre in Taizhou area, where the economy is not so developed and has less strict environmental policies. Due to this weaker environmental policy in Wenling, a large fraction of e-waste shifted to Wenling for recycling. Furthermore, most of the crude simple household workshops which were previously banned in Luqiao also shifted to Wenling. Therefore, environmental problems arising from e-waste recycling have become serious in Wenling city. Fu et al. [16] investigated 10 heavy metals (As, Ba, Cd, Co, Cr, Cu, Hg, Mn, Ni and Pb) contents in paddy soil from one village in Wenling and found the paddy soil was primarily contaminated by Cd (1.19 mg/kg), followed by Cu (9.98 mg/kg) and Hg (0.32 mg/kg). Recent studies by Zhao et al. [17,18] reported that soil samples ($n = 6$) collected from four e-waste disassembly sites in Wenling had higher PCBs levels (ranging from 27.8 to 738.9 μg/kg, with a mean of 152.8 μg/kg) compared with those observed in soils from the control site. These limited studies investigated only a few soil samples and focused on several e-waste recycling sites, but there has been no systematic study of soil pollution effected by primitive e-waste recycling in this area. Leung et al. [12] had identified the sources and quantified the levels of various heavy metals and persistent organic compounds resulting from e-waste recycling in Guiyu, another e-waste recycling centre in Guangdong Province, China. This did much to elucidate the extent of contamination by e-waste recycling activities and assess the human health risk for local residents in Guiyu. With the above background in mind, the main objective of this study is to identify the levels and sources of heavy metals (Cu, Cr, Cd, Pb, Zn, Hg and As) and persistent organic compounds (PAHs and PCBs) generated from the emerging e-waste recycling activities in Wenling, located in Taizhou area, Zhejiang Province, China.

2. Materials and methods

2.1. Research area and sampling

A preliminary survey of contaminant levels in Wenling was conducted in August 2008, with the aid of a global positioning system. The location of the sampling sites in addition to e-waste activity sites is shown in Fig. 1. Sites A–G were relatively large-scale recycling plants, sites H and I were large-scale gold recovering plants, while sites J–L were small simple household recycling workshops. Site M was chosen as the reference site and was located in the JQ town in Taizhou city, about 15 km north of Wenling city (not shown in Fig. 1), where there was no e-waste recycling industry. Three subsamples (0–30 cm) adjacent to the sampling location were mixed to obtain about 1000 g representative composite samples. All of the surface soils ($n = 39$) were collected using acid-washed stainless steel scoops and were immediately transferred to prewashed aluminum boxes. Description of the sampling sites and characteristics of samples are shown in Table 1.

2.2. Sample treatment and analysis

The soil samples were air-dried and sieved to <0.25 mm, then stored in desiccators prior to analysis of heavy metals, PAHs and PCBs.

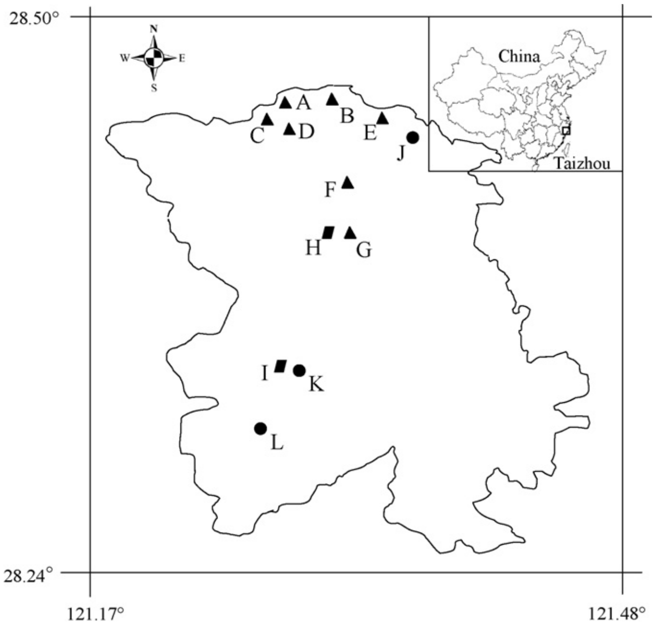

Fig. 1. Map of study area in Wenling city and sampling locations: (▲) large-scale e-waste recycling plants; (■) Large-scale gold recovering plants; (●) Simple household e-waste recycling workshops. Also see Table 1 for a description of sample sites A–L.

2.2.1. Heavy metals analysis

The samples were digested using the method described by Hseu et al. [19]. 0.5 g of dry sample was weighed and digested with a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$). Concentrations of Cu, Cr, Cd, Pb and Zn were determined by flame atomic absorption spectrometry (AAS, Solaar-MK II-M6). Hg and As concentrations in the digestion liquid were determined by atomic fluorescence spectrometry (AFS-2202a) [20].

2.2.2. PAHs analysis

Samples (5 g) were extracted for 24 h with 200 ml hexane and acetone (v:v, 1:1) in a Soxhlet apparatus. Soxhlet extracts were passed through a silica gel/aluminum oxide column to obtain PAHs fractions by eluting with 70 ml of dichloromethane/hexane (3:7, v/v). The eluate was evaporated to less than 2 ml prior to analysis [9,21]. GC–MS analysis was performed on a Agilent 6890 GC system coupled to a mass selective detector and a 30 m × 0.25 mm × 0.25 μm DB-5 capillary column (J & W Scientific Co. Ltd., USA). The EPA Standard Method 8270C [22] was used to determine the following 16 PAHs: naphthalene (Nap), acenaphthylene (Any), acenaphthene (Ane), fluorene (Fle), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fla), pyrene (Pyr), benz(a)anthracene (BaA), chrysene (Chr), benzo(a)pyrene (BaP), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), indeno(1,2,3-cd)pyrene (IcdP), dibenz(a,h)anthracene (DahA) and benzo(g,h,i)perylene (BghiP).

2.2.3. PCBs analysis

Following the soxhlet procedure as described above, the concentrated extract was cleaned up by a Florisil/anhydrous sodium sulphate column and eluted with 100 ml hexane. The concentrations of 58 PCB congeners, including six indicator PCBs (PCB-28, -52, -101, -118, -153, -138), were measured by a gas chromatograph equipped with a ^{63}Ni electron capture detector (Agilent 6890) [9].

2.3. Quality control

All procedures were performed under strict quality control to meet USEPA requirements for field studies. Phenanthrene-d_{10},