Journal of Hazardous Materials 261 (2013) 770–776

Contents lists available at ScienceDirect

Journal of Hazardous Materials

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

Cancer risk assessments of Hong Kong soils contaminated by polycyclic aromatic hydrocarbons

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HIGHLIGHTS

- High levels of soil organic matter in soils render PAHs more resistant to degradation.
- Open burning site contain high concentrations of PAHs in Hong Kong.
- Car dismantling workshop can increase potential cancer risk on human.

ARTICLE INFO

Article history:
Received 18 September 2012
Received in revised form
21 November 2012
Accepted 24 November 2012
Available online 1 February 2013

Keywords:
Car dismantling workshop
Open burning
Farm soil
Lifetime cancer risk
Bioaccessible PAHs

ABSTRACT

The aim of this study was to evaluate soils from 12 different land use types on human cancer risks, with the main focus being on human cancer risks related to polycyclic aromatic hydrocarbons (PAHs). Fifty-five locations were selected to represent 12 different types of land use (electronic waste dismantling workshop (EW (DW)); open burning site (OBS); car dismantling workshop (CDW) etc.). The total concentrations of 16 PAHs in terms of total burden and their bioaccessibility were analysed using GC/MS. The PAHs concentrations were subsequently used to establish cancer risks in humans via three exposure pathways, namely, accident ingestion of soil, dermal contact soil and inhalation of soil particles. When the 95th centile values of total PAH concentrations were used to derive ingestion and dermal cancer risk probabilities on humans, the CDW land use type indicated a moderate potential for cancerous development (244×10^{-6} and 209×10^{-6}, respectively). Bioaccessible PAHs content in soil samples from CDW (3.60×10^{-6}) were also classified as low cancer risk. CDW soil possessed a higher carcinogenic risk based on PAH concentrations. Bioremediation is recommended to treat the contaminated soil.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are usually produced via the incomplete combustion of organic substances and comprised of a diverse group of organic compounds. Their general structure consists of two or more fused aromatic rings arranged in different structural configurations [1]. Polycyclic aromatic hydrocarbons in the environment have drawn much attention due to their toxicity and potential carcinogenic effects on humans [2]. They may be released into the surroundings by anthropogenic pathways, such as incomplete combustion, or via pyrolysis of organic materials that are commonly used as energy sources [3].

Soil serves as an enormous sink for the accumulation of organic contaminants and may allow the entry of PAHs into food chains [4]. A number of studies have focused on the variation of PAH concentrations in different soil types. In general, it has been found that PAH concentrations in soil increase with the degree of anthropogenic impact, in both industrial and domestic land use [5].

Hong Kong's rapid industrial development and expeditious urbanization since the 1970s have led to a shift in rural land use pattern. The massive decline in agricultural products supplied by local farms in the 1950s have been attributed to increased profit margins, which have been gained from converting fish ponds and agricultural land to other uses such as electronic waste (e-waste)

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0304-3894/$ – see front matter
http://dx.doi.org/10.1016/j.jhazmat.2012.11.067

recycling sites, open burning sites and car dismantling workshops [6,7]. Man et al. [8], demonstrated that the absence of non-cancer risk and very low cancer risk may be exerted on humans associated with 1,1,1-trichloro-2,2-bis(p-chlorophenyl)-ethanes (DDTs) and hexachlorocyclohexanes (HCHs) contents after changing the use of agricultural land in Hong Kong. However, Lopez et al. indicated that e-waste recycling activities including dismantling and open burning have generated a large amount of heavy metals (e.g. arsenic (As), chromium (Cr), copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb)) and persistent toxic substances (polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and PAHs) on existing abandoned farm soils in Hong Kong. In addition, Man et al. revealed that e-waste dismantling workshops can be detrimental to both adults and children, and car dismantling workshops may also prove to be harmful to children, based on metal concentrations. Furthermore, e-waste recycling activities have been shown to exert relatively high cancer risks on humans after exposure to PBDE and PCB contaminated soils [9]. Hence, agricultural land use conversions to other purposes are potentially jeopardizing the health of residents in Hong Kong. Elevation of PAH concentrations resulting from these practices have caused scientific concern as these increased concentrations in soil will increase human health risk as a consequence of exposure [10].

We hypothesize that soils from different types of land use may generate different levels of PAHs to the surrounding environment, leading different degree of cancer risk exert on humans. This study aimed to assess cancer risk that is attributable to PAHs in soil of different land use types in order to evaluate the potential health hazards of the PAHs from the soil samples. Therefore, a cancer risk assessment was conducted to examine the potential risks that may be exerted upon human health via PAHs through 3 exposure pathways, namely ingestion, dermal contact and inhalation.

2. Materials and methods

2.1. Sampling, preparation and analysis

The soil PAH concentrations of the e-waste sites and open burning sites [11], human health risk assessments of heavy metals (As, Cr, Cu, Zn, Cd and Pb) [non-cancer risks], DDTs and HCHs [non-cancer and cancer risks], and PCBs and PBDEs [cancer risks] at the same locations have been previously reported [8,9,12]. For this study, 275 composite soil samples were collected from existing and former agricultural land in Hong Kong. Each site was grouped according to their current land use, resulting in 12 identified soil types: (i) agricultural (A); (ii) abandoned agricultural (Ab); (iii) organic farm (OF); (iv) container storage (CS); (v) construction waste (CW); (vi) e-waste storage (EW (S)); (vii) e-waste dismantling workshop (EW (DW)); (viii) e-waste open burning site (EW (OBS)); (ix) open burning site (OBS); (x) petrol station (PS); (xi) metal recycling workshop (MRW); and (xii) car dismantling workshop (CDW). Descriptions of each type of land use and the number of sites investigated were also shown in Man et al. [8,9,12]. The soils of existing (A and OF) and abandoned (Ab) farmlands were used to compare with other types of land use. Soil sampling, preparation and analysis of texture and soil organic matter used in this study are described in Man et al. [9].

2.2. Extraction and analysis of total PAHs

Soxhlet extraction was performed according to the US EPA Standard Method 3540C [13] in which 5 g of soil sample was added to 10 g of anhydrous sodium sulphate (S6264, Sigma Chemical Co.). The mixture was transferred into a cellulose extraction thimble and inserted into a Soxhlet fitted with a 250 mL flask. Dichloromethane and acetone (v:v 1:1) (150 mL) was added and the whole set up then heated for 18 h in a water bath at 69 °C. The extracts were concentrated to 10 mL by a rotary evaporator and used for subsequent clean ups. In order to remove the organic and inorganic constituents other than those of interest, clean up steps were performed before analysis. Florisil column clean up was thus applied for purification of the concentrated extract (US EPA Standard Method 3620B) [14]. The extracts were concentrated to less than 5 mL by a rotary evaporator afterwards, and then n-hexane (10 mL) was added and concentrated to less than 2 mL. Subsequently, deuterated PAHs (acenaphthene-$_{d10}$, phenanthrene-$_{d10}$, chrysene-$_{d12}$, and perylene-$_{d12}$) were injected into the sample extracts as internal standards for quantitation. Finally, the extract was topped up to 2 mL with n-hexane for the analysis of PAHs.

GC-MS analysis was carried out on a Hewlett Packard 6890 GC system, equipped with 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 US EPA Standard Method 8270C [15] was applied for the determination of the following 16 PAHs of 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). The peaks of BbF and BkF were close together and difficult to separate, therefore these two compounds were regarded as one and referred to as BbkF.

2.3. Quality control

Every 20th sample of the 275 composite soil samples used for analysing PAH concentrations were run in duplicate to check data consistency. A standard reference material (SRM), 1941b – organics in marine sediment (National Institute of Standards and Technology (NIST, USA)) and an analytical blank were included in every batch of extraction to assess the performance and recoveries of the entire analytical process. No detectable PAH concentrations were found in any of the analytical blanks, whilst the mean recoveries of PAHs ranged from 82 ± 10% for Ant to 118 ± 9% for BghiP.

2.4. Exposure scenarios and cancer risk equations

In this study, potential cancer risk imposed on workers or farmers as a result of being in contact with contaminated soil was assumed to occur via 3 major exposure pathways. These included: accidental ingestion of soil particles; dermal absorption of pollutants via soil particle contact; and inhalation of fugitive soil particle, with potential cancer risks via these means estimated using the following Eqs. (1) and (2) [16] and (3) [17].

$$\text{Cancer risk}_{\text{ingest}} = \frac{C_{\text{soil}} \times \text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times \text{CF} \times \text{SFO} \quad (1)$$

where Cancer $\text{risk}_{\text{ingest}}$ is the cancer risk via ingestion of soil particles; C_{soil} is the concentration of the pollutant in soil (mg/kg); IngR is the ingestion rate of soil (mg/day); EF is the exposure frequency (days/year); ED is the exposure duration (years); BW is the average body weight (kg); AT is the averaging time (days); CF is the conversion factor (1×10^{-6} kg/mg); SFO is the oral slope factor $(\text{mg/kg/day})^{-1}$.

$$\text{Cancer risk}_{\text{dermal}} = \frac{C_{\text{soil}} \times \text{SA} \times \text{AF}_{\text{soil}} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times \text{CF} \times \text{SFO} \times \text{GIABS} \quad (2)$$

where Cancer $\text{risk}_{\text{dermal}}$ is the cancer risk via dermal contact of soil particles; SA is the surface area of the skin that contacts soil (cm^2/day); AF_{soil} is the skin adherence factor for soil (mg/cm^2);