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## HEALTH RISK ASSESSMENT OF HEAVY METALS AND POLYCYCLIC AROMATIC HYDROCARBONS IN SOIL AT COKE OVEN GAS PLANTS

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### Abstract

Sites contaminated with hazardous materials pose serious risks to human health and ecological environments. Quantitative health risk assessment is a site-specific complex procedure requiring evaluation of all possible pathways. Several studies have focused on the evaluation of heavy metals or organic pollutants; however, only few studies focused on the evaluation of diverse pollutants such as heavy metals and organics. In this study, the health risk of heavy metals and organic pollutants in the soils near coke oven gas plants, China, was assessed according to three human exposure pathways (peroral intake soil, skin exposure to soil, inhale soil.). The carcinogenic and noncarcinogenic risk values of the heavy metals and organic pollutants in each grid (divided into three zones and 60 grids) and grid layer (divided into three layers and 128 samples) were calculated. The total carcinogenic and noncarcinogenic risk values were calculated cumulatively as per the grid and grid layer. The grid area and the volume of contaminated soil corresponding to various risk factors were calculated. The results of the health risk assessment show that 49 out of the 60 grids have a carcinogenic risk factor  $>10^{-5}$  with a total area of 103,340 m<sup>2</sup>. This site has extremely high health risk if  $10^{-5}$  is regarded as the assessment standard for causing cancer. These results show that coke oven gas plants can pose serious risk to human health, and carcinogenic effects should cause more attention.

*Key words:* carcinogenic risk assessment, contaminated site, noncarcinogenic risk assessment, organic contaminant, soil

*Received:* July, 2013; *Revised final:* September, 2014; *Accepted:* September, 2014

### 1. Introduction

Sites contaminated with hazardous materials are a current and urgent problem globally (Stezar et al., 2011). Contaminated site refers to industrial zones where the hazardous material concentration in soil exceeds the standard value, and the soil or water pollution caused by industrial activities pose potential danger to human health and ecological environments. The pollutions caused by contaminated sites have become a major environmental problem for every nation, and the number of contaminated sites has been increasing (Sousa, 2001). Contaminated sites, particularly the

megasites, have become an issue of major concern because of their worldwide occurrence and the related extensive environmental and socio-economic effects (EEA, 2000; Stezar et al., 2011). Local contamination is one of the main threats to soil identified by the EU Soil Communication (COM, 2002). To date, 300,000 sites across the EU have been identified as definitely or potentially contaminated; however, the European Environment Agency estimated the existence of as many as 1.5 million contaminated sites (EEA, 2000).

Not all metals in soil are bioavailable and cause adverse effects to human health or the environment (Chapman et al., 2003; Jensen et al.,

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2006; Vasseur et al., 2008; Pizzol et al., 2011). However, even trace quantities of heavy metals, such as cadmium (Cd), arsenic (As), lead (Pb), and mercury (Hg), can cause adverse health effects (Ferré-Huguet et al., 2008; Martí-Cid et al., 2008; Martorell et al., 2011).

Organisms in different trophic levels are also believed to be suffering from metal toxicities (Popita et al., 2014; Rand et al., 1995); therefore, human health is under threat from the exposure to heavy metals by seafood intake (Hansen, 1981; Hansen et al., 1990). Organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs), are also a major reason for deformity and cancer. The presence of some PAHs has shown increased incidence of skin, lung, and bladder, liver, and stomach cancers in laboratory animals (Armstrong et al., 2004; Boffetta et al., 1997; Bosetti et al., 2007; Kogevinas et al., 2003). Total cyanide and volatile organic compounds (VOCs) are also considered as trace substances harmful to human health.

The human health risk assessment (HHRA) is a useful approach for quantifying the potential harmful index of environmental contaminants. Depending on land use, risks exist for human health, ecosystems (including ecosystem services), and groundwater (Swartjes et al., 2012). In recent years, extensive research has been focused on this area (Christopher et al., 2014; Health, 1994; Health, 2007; Khillare et al., 2012; MOE, 2005; Richardson, 1997; Stezar et al., 2011; Torretta et al., 2014; Xia et al., 2010; Zhenxing et al., 2011; Zhiyuan et al., 2014). However, many studies focused on heavy metals or organic pollutants, while fewer studies (Saedi et al., 2012) focused on diverse pollutants such as heavy metals and PAHs.

In this study, health risk assessment was conducted based on a comprehensive analysis of the risk assessment methods, such as pollution recognition, exposure assessment, toxicity parameters, and risk characterization, followed in the USA and developed European countries. The purpose of this study were (1) to perform environmental survey and risk assessment of original production sites and health risk assessment by monitoring data that can provide scientific references for site management, restoration, site development, and utilization decisions and (2) to use the quantitative risk assessment methods for heavy metals and PAHs in order to evaluate the health risk for both adults and children by three different exposure pathways.

## 2. Materials and methods

### 2.1. Study area

Shenyang Coke Oven Gas Co. Ltd., located at the intersection of Beisi Road and Zhaogong Street in Tiexi district and in the west of Shenyang downtown in Liaoning province, with  $-130,000 \text{ m}^2$  areas, 3,800 m maximum length, and 3,400 m maximum width, was chosen as the study site. This company was

established in 1958, which is the only manual gas production company, providing 30% of Shenyang's daily gas requirement. The designed production capability of the company is 450,000 tons of coke, 23,000 tons of tar, 6,000 tons of ammonium sulfate, and 6,000 tons of crude benzene. Major products of the company are metallurgical coke and coke oven gas, and the by-products are ammonium sulfate, tar, and crude benzene. The specific pollutants of the study area are hydrocarbon organic matter and heavy metals.

### 2.2. Sampling

Seven points and thirteen soil samples were collected from the original Shenyang Coke Oven gas factory on April 12<sup>th</sup>, 2011 (Fig. 1). Table 2 lists the monitoring methods used in our laboratory for the soil testing, and the results indicate the presence of pollutants such as heavy metal, cyanide, PAH, mononuclear aromatics, petroleum, and hydrocarbons in the soil samples.

Considering the complexity of pollution, comprehensive sampling and monitoring methods were used for the soil analysis. According to the preliminary survey results and the functional use of the original sites, the factory was divided into three zones: (i) chemical product recovery zone (zone A), (ii) coal preparation zone (zone B), and (iii) public zone (zone C). Grids were drawn in the three zones, and the areas of grids increased from zone A to C. Zone A has 25 grids with an area of  $\sim 900 \text{ m}^2$  for each grid; zone B has 18 grids with an area of  $\sim 1,600 \text{ m}^2$  for each grid; and zone C has 17 grids with an area of  $\sim 4,600 \text{ m}^2$  for each grid.

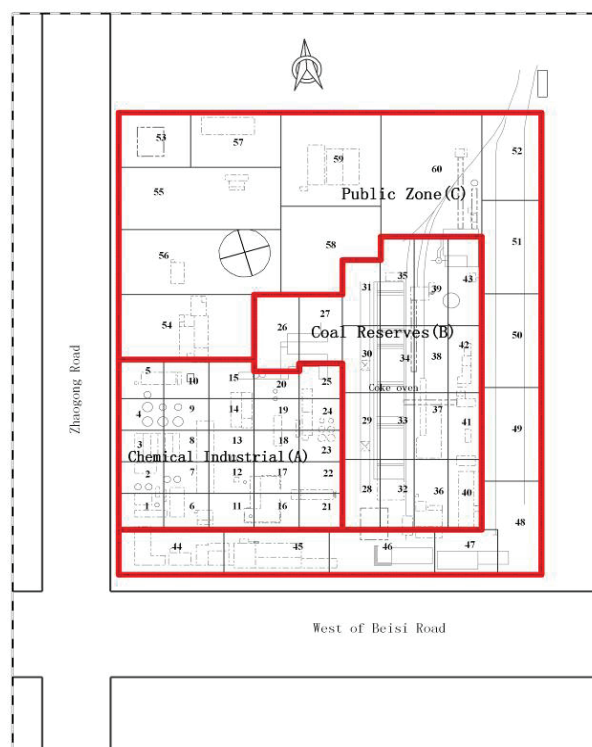


Fig. 1. Study site and sample points

A fixed point in the center of each grid was selected for sampling arrangement principle for zones A and B. However, for the removal project of the original factory, the original site was damaged significantly; therefore, in principle, the samples could be collected nearby the central point. The sampling point arrangement principle for zone C was selected based on the original sites of facilities that caused most of the pollution. From June 28<sup>th</sup> to July 1<sup>st</sup>, 2011, 60 points and 128 samples were collected from the site.

In zone A, the soil samples were collected from three layers, and the layer depths from the top to the bottom were 0–0.2 m surface soil, 0.2–0.4 m, and 0.4–1 m (Peijun, et al., 2009). In zone B, the soil samples were collected from two layers, and the sample depths from the top to the bottom were 0–0.2 m surface soil and 0.2–0.4 m. In zone C, the soil samples were collected from one layer, and the sample depth was 0.4–1 m. The samples for metals analyses were stored in closed polyethylene bags at <4 °C. The samples for PAHs (organic matter) were stored in PTFE (polytetrafluoroethylene) gasket brown jar.

### 2.3. Analytical methods

Pebbles, plant branches, etc. were removed from the collected wet soil samples, and then drying, grinding, and screening were performed using a 100-mesh stainless steel sieve. Soil was mixed and then stored in plastic bags at 0–4 °C after sealing. Sample analysis was conducted by the standard monitoring methods developed by Aoshi Analysis and Detection (Shanghai) Co. Ltd. as shown in Table 1. All the samples including blank, parallel samples, and standard recoveries were analyzed in duplicates for quality assurance/quality control (QA/QC) of laboratory analyses. For PAHs, the QA/QC was performed by field and laboratory blanks and standard spiked recoveries.

The recoveries of SRM (standard reference materials) and internal standards varied from 88% to 107%. The degree of precision was analyzed by the standard parallel experiments to reflect the random error of the analysis method. The relative standard deviations of PAHs, VOCs, and heavy metals in the parallel samples ranged from 1.29% to 25.6%, approaching the standard US EPA RSD <30%, thus demonstrating good precision in the experimental data.

### 2.4. Risk assessment method

The possible exposure scene of this study was a sensitive residential land. According to the site environment research studies and different functional plannings of different regions, many situations were analyzed where the concerned pollutants may cause harm to human health. Various exposure approaches of the concerned pollutants confirmed the pollutants' migration exposure model for environment and

human body, and then relevant parameter values corresponding to the exposed quantities under various exposure approaches were calculated. For heavy metals, where humans were exposed to site pollutants, the main approaches include three computation modules: peroral intake soil, skin exposure to soil, inhale soil. The exposure dosage was calculated by Eqs. (1) and (2), adapted from (Celebi et al., 2014; US EPA 1989; US EPA 1997).

$$ADD_i = \frac{C_w \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where  $ADD_i$  is the daily exposure dose of the heavy metals or PAHs through three pathways  $\mu\text{g}/(\text{kg d})$ ,  $C_w$  is the concentration of heavy metals or PAHs ( $\text{mg}/\text{kg}$ ),  $IR$  is the ingestion rate (including three exposures: peroral intake soil, skin exposure to soil, inhale soil.) ( $\text{mg}/\text{d}$ ),  $EF$  is the exposure frequency which is 350 d/year in this study.  $ED$  is the exposure duration (year),  $BW$  is the body weight (adult: 55.9 kg; child: 15.9 kg).  $AT$  is the averaging time (d), which is calculated as 72 (expectation of life)  $\times$  365 = 26,280 d in this study (Ruzhong et al., 2012).

$$LADD = \frac{c \cdot EF}{AT} \left[ \frac{CR_{child} \cdot ED_{child}}{BW_{child}} + \frac{CR_{adult} \cdot ED_{adult}}{BW_{adult}} \right] \quad (2)$$

$LADD$  is the daily exposure dose ( $\text{mg}/(\text{kg d})$ ) and  $CR$  is the intensity of three exposures.  $CR$  refers to intake rate for peroral intake soil ( $\text{mg}/\text{d}$ ).  $CR$  refers to respiratory rate for inhale soil ( $\text{m}^3/\text{d}$ ).  $CR = \text{skin exposure area} \times \text{skin adhesion} \times \text{dermal absorption factor} (\text{mg}/\text{d})$ . Based on pollutant identification and exposure assessment, the carcinogenic and noncarcinogenic hazards of the concerned pollutants were analyzed. The toxicity parameter values such as reference dose, reference concentration, carcinogenic slope factor, and unit carcinogenic factor of the concerned pollutants were also determined according to the relevant toxicity assessment parameter data of the US EPA, which mainly focuses on the pollutant's physiochemical, carcinogenic and noncarcinogenic properties, and the hazard effects on human health by different pathways and the corresponding reaction dosages (Table 2).

According to the toxicity parameters (Steven et al., 2010) and partial literature of the Ministry of Environmental Protection (SFo, SFi, and SFd refer to the slope factor of direct ingestion, inhalation, and dermal absorption; URF: unit carcinogenic factor; RfDo, RfDi, and RfDd refer to the reference dose of direct ingestion, inhalation, and dermal absorption; and RfC: reference concentration) Based on the exposure and toxicity assessments, each sample was analyzed for the concentration of concerned pollutants, and the carcinogenic risk value and hazard quotient were calculated based on the risk assessment of each type of exposure's risk value of the same type of pollutant and the total risk value of all the pollutants from all the exposure pathways.

**Table 1.** Monitoring methods for test index

No.	Test index	Test method	Detection limit (mg/kg)
1	Metals (8) (As, Pb, Cd, Cr, Hg, Zn, Cu, and Ni)	US EPA 6010C US EPA 7470A	As:1 Hg:0.05 others:0.5
2	PAHs	US EPA 8270D	0.1–0.2

**Table 2.** Partial toxicity parameters of concerned pollutants

Pollutants	SFo	SFi	SFd	URF	RfDo	RfDi	RfDd	RfC
Arsenic			1.5			0.0003	0.0003	
Mercury						0.0003	0.0003	
Benzene	0.055	0.027	0.055	0.008	0.004	0.009	0.004	0.030
Naphthalene		0.12		0.034	0.020	0.001	0.020	0.003
Chrysene	0.007	0.039	0.007	0.011				
Fluorene					0.040	0.040	0.040	
Fluoranthene					0.040	0.040	0.040	
Phenanthrene					0.040	0.040	0.040	
anthracene					0.040	0.040	0.040	
Benzo(g,h,i)pyrene					0.040	0.040	0.040	
Benzo(a)pyrene	7.300	3.850	7.300	1.100				
Dibenzo(a, h)anthracene	7.300	4.20	7.300	1.200				
Benzo(a)anthracene	0.73	0.385	0.730	0.110				
Benzo(b)fluoranthene	0.730	0.385	0.730	0.110				
Indene(1,2,3-cd)pyrene	0.730	0.385	0.730	0.110				
Benzo(k)fluoranthene	0.073	0.385	0.073	0.110				

The carcinogenic risk (CR) associated with ingestion and dermal exposure was calculated by Eqs. (3) and (4) adapted from US EPA (1989) and (2004), where *HI* is the probability of developing cancer over a lifetime because of exposure to a contaminant, *LADD* is the daily exposure dosage obtained from Eqs. (1) and (2), and *SF* is the slope factor.

$$HI_i = \sum_{j=1}^{17} LADD_{ij} \times SF_{ij} \tag{3}$$

$$THI = \sum_{i=1}^3 HI_i \tag{4}$$

The total *HI* values for children and adults were calculated by adding the *HIs* calculated from three pathways.

For the non-carcinogens, the dosages calculated for each element and exposure pathway were subsequently divided by the corresponding reference dosage (*RfD*) to afford the hazard quotient (*HQ*), and the hazard index (*THQ*) is equal to the sum of *HQs* (Eqs. 5-6).

$$HQ_i = \frac{ADD_{ij}}{RfD_i} \tag{5}$$

$$THQ = \sum_{i=1}^{17} \sum_{j=1}^3 HQ_i \tag{6}$$

In general, the value of *HQ* or *HI* < 1 indicates no significant risk of noncarcinogenic effects; the value of *HQ* or *HI* > 1 indicates significant noncarcinogenic effects, which increased with increasing value of *HQ* or *THQ* (Siyue et al., 2010; US EPA, 2001).

### 3. Results and discussion

#### 3.1. Site pollution status assessment

During the sampling at the polluted site of coking gasworks, 128 samples of 60 grids were collected. The relevant indexes of 19 plot layers' pollutants were lower than the limiting values formulated by the *Exhibition land Standard* (Table 3), which covered 16.1% of the total plot layers. The 19 plot layers include: 6-3, 8-3, 10-3, 11-3, 13-3, 15-3, 27-1, 35-1, 37-1, 37-2, 40-2, 41-1, 41-2, 45, 48, 50, 51, 52, and 53. The total polluted area of 112 plot layers was ~113,040 m<sup>2</sup>, and the total soil volume was 168,425 m<sup>3</sup>. The soil in Coke Oven gas factory was polluted by organic pollutants for a long time (since the factory was established). The main pollutants identified were cyanide, PAH, and total petroleum hydrocarbon. The pollution characteristics were complexity in pollutant types, pollution areas, pollutant migration, transformation downward, etc.

The laboratory test analysis of seven sampling sites showed the major total cyanide pollution, PAH pollution, and TPH pollution in soil samples of Coke Oven gas factory, and lighter heavy metal pollution

in several grids. All the grids except 27, 30, 41, 49, 50, 51, and 52 showed total cyanide pollution with the highest level  $>2136.5$  times of the standard; all the grids except grid 48 showed PAH pollution with the highest level  $>7961.48$  times of the standard; all the grids except 13, 17, 28, 30, 34–37, 39–41, 44–53, 55, and 57–59 showed TPH pollution with the highest level  $>219.83$  times of the standard; four grids showed slight excess of heavy metals such as As, Cu, Pb, and Hg (Fig. 2).

The pollution level and pollution area intensity decreased successively in the sequence of recovery zone, coal preparation zone, and public zone. The concentration of heavy metals was higher than the surrounding surface soil concentration (Wanxia et al., 2012), but lower than the concentration of soil previously irrigated with industrial wastewater (Peijun et al., 2009). The concentration of TPH was lower than the concentration of the soil at the petroleum-contaminated sites (In-Sun et al., 2011). The concentration of PAHs was higher than that of vegetables grown in the vicinity of thermal power plants (Khillare et al., 2012).

### 3.2. Risk assessment results of three zones

Notably, an excess lifetime cancer risk of  $\geq 10^{-6}$  has been consistently considered as insignificant and  $\geq 10^{-4}$  as significant (Man et al., 2013). Through risk assessment on the site in zone A grids, where the pollution indexes exceed value B in *Exhibition land Standard* (HJ350-2007), the pollutants with a relatively higher risk are naphthalene, benzantracene (a), benzofluoranthrene (b), benzopyrene (a), indenopyrene (1,2,3-cd), dibenzanthracene (a, h), and benzene.

Naphthalene and benzene showed extremely high carcinogenic and noncarcinogenic risks, respectively, and some grids' carcinogenic risk even reached  $10^{-2}$ , which was similar to the study of Lake Chaohu (Ning et al., 2013). Some grids' carcinogenic risk even reached  $10^{-3}$ , illustrating extremely high environmental risk in zone A soil (Fig. 3). During the sampling process, some sampling grids' soil was black and had several oily substances with pungent smell. Therefore, zone A is a heavy pollution zone, and some grids in zone A are heavy pollution grids.

In zone B, the pollutants with relatively higher concentrations are naphthalene, fluoranthene, benzantracene (a), chrysene, benzofluoranthrene (b), benzofluoranthrene (k), benzopyrene (a), indenopyrene (1,2,3-cd), and dibenzanthracene (a, h). Benzantracene (a), benzofluoranthrene (b), and benzopyrene (a) showed relatively high carcinogenic risk, and some grids' carcinogenic risk even reached  $10^{-3}$ , indicating that zone B soil (Fig. 3) has a relatively higher environmental risk. The result is similar as the PAHs in soil of the Chenzhou industrial zone. The PAHs in soil of pyroelectric industrial sites exceed the standard (0.3 mg/kg) 60 times with high risk environment (Ganghui et al.,

2012). During the sampling process, some sampling grids' soil had traces of oily substance with slight pungent smell. Therefore, zone B is mid-level pollution zone, and some grids in zone B are mid-level pollution grids.

In zone C, the pollutants with a relatively higher risk are naphthalene, fluoranthene, benzantracene (a), chrysene, benzofluoranthrene (b), benzofluoranthrene (k), benzopyrene (a), indenopyrene (1,2,3-cd), and dibenzanthracene (a, h). Benzopyrene (a) showed a relatively higher carcinogenic risk, and some grids' carcinogenic risk even reached  $10^{-4}$ . Grid 56 showed a relatively higher carcinogenic risk, indicating that some soil in this zone still has environmental risk. However, zone C (Fig. 3) showed a relatively lower environmental risk as a whole, thus belonging to mild-contamination zone and a part of the grids are mild-contamination grids.

By the risk value calculation, 49 grids among 60 monitored grids with area of 103,340 m<sup>2</sup> showed carcinogenic risk  $>10^{-5}$ , confirming that PAHs can cause cancer. However, the minimum PAH concentrations for causing cancer are different for different areas and different intake approaches. Canadian soil quality guidelines for the protection of environmental and human health consider a cancer risk of  $\leq 10^{-5}$  at contaminated sites as insignificant (CCME, 2010). Most regulatory bodies cite an incremental lifetime cancer risk (ILCR) between  $10^{-6}$  and  $10^{-4}$  for potential risk (Xia et al., 2010). In zone A, the risk value was extremely high as the whole. The risk value of most grids exceeded  $10^{-3}$ , and some even reached  $10^{-2}$ . The risk value of grid 18 was the highest which reached 4.041E-02. In zone B, the risk value was relatively higher as the whole. The risk value of some grids exceeded  $10^{-4}$ , and some even reached  $10^{-3}$ . The risk value of grid 43 was the highest which reached 2.152E-03. In zone C, only few grids showed environmental risk with risk value  $>10^{-4}$ , in which the carcinogenic risk exceeded  $10^{-4}$ . The risk value of grid 56 was the highest which reached 1.925E-04. B[a]P<sub>eq</sub>-based (B[a]P<sub>eq</sub> was calculated by the multiplication of the individual PAH concentration by its PEF) lifetime lung cancer risks estimated for both the exposure groups were  $4.35 \times 10^{-2}$  and  $5.42 \times 10^{-2}$  exposed to the PAHs in a carbon black manufacturing industry, respectively, for palletizing and packaging workers. For dermal exposure, B[a]P<sub>eq</sub>-based lifetime skin cancer risks for both the exposure groups were estimated to be  $1.13 \times 10^{-3}$  and  $1.56 \times 10^{-3}$ , respectively (Tsai et al., 2001).

The average upper-bound B[a]P<sub>eq</sub>-based inhalation incremental lifetime cancer risk for three age groups was  $1.57 \times 10^{-4}$  ( $3.10 \times 10^{-7}$ – $4.46 \times 10^{-4}$ ), whereas for dermal incremental lifetime cancer risk was  $1.19 \times 10^{-4}$  ( $2.19 \times 10^{-6}$ – $2.99 \times 10^{-4}$ ) (Szuchich et al., 2006). The US Environmental Protection Administration indicated a different unit risk of  $6.4 \times 10^{-7}$  (ng/m<sup>3</sup>)<sup>-1</sup> based on the total PAH content (US



EPA, 1984). If the magnitude  $10^{-5}$  is taken as the evaluation standard for causing cancer, the health risk of this site was extremely high.

The noncarcinogenic risk value of 25 grids was  $>1.0$  in the 60 monitored grids. The noncarcinogenic risk value of some grids was very high. The total area of the 25 grids was  $35,120 \text{ m}^2$ , and the carcinogenic risk of the grids with noncarcinogenic risk  $>1.0$  exceeded  $10^{-5}$ .

### 3.3. Risk assessment result of layer

A total of 128 grid layers were evaluated. Using the equations and parameters in risk assessment guide rule and assuming that each grid layer is a surface layer and the pollutant concentration of the upper layer soil (Fig. 3) is the same as that of the lower layer soil (Figs. 4 and 5), the definite carcinogenic risk and noncarcinogenic risk values of each grid layer were calculated. Calculated risk value was considered as the main basis of soil classification, governance, and restoration technical solutions, which fully considered the comprehensive effects of various pollutants in polluted soil on human health and the environment and is a more scientific definite risk value of grid layers with indexes exceeding A value in Exhibition land Standard. Through layer

assessment and calculation, the surface soil was found to have larger pollution area and heavier pollution level. The definite carcinogenic risk of 18 grids in the upper layer exceeded  $10^{-3}$ , and that of 20 grids even exceeded  $10^{-4}$  (Fig. 3). The definite carcinogenic risk of 12 grids in the middle layer exceeded  $10^{-3}$ , and that of 16 grids even exceeded  $10^{-4}$  (Fig. 4). The definite carcinogenic risk of 10 grids in the bottom layer exceeded  $10^{-3}$ , and that of two grids even exceeded  $10^{-4}$  (Fig. 5). The definite carcinogenic risk of surface soil of most grids in zones A and B exceeded  $10^{-4}$  by rigorous technical method for sites' environment management.

The definite noncarcinogenic risk of 22, 20 and 11 grids in the upper, middle and bottom layer exceeded 1.0, respectively (Figs. 3, 4, 5). The total soil volume of grid layers, with absolute carcinogenic risk value  $>1 \times 10^{-3}$ , was  $69,310 \text{ m}^3$ . The total soil volume of grid layers, with an absolute carcinogenic risk value between  $1 \times 10^{-3}$  and  $1 \times 10^{-4}$ , was  $42,105 \text{ m}^3$ , whereas  $30,695 \text{ m}^3$  of it was the earth volume of parcel layers with the absolute noncarcinogenic risk value  $>1.0$ . The total earth volume of grid layers where the absolute carcinogenic risk value was between  $1 \times 10^{-4}$  and  $1 \times 10^{-5}$  was  $62,720 \text{ m}^3$ , and  $18,935 \text{ m}^3$  of it was the earth volume of grid layers with the absolute noncarcinogenic risk value  $>1.0$ .

Table 3. Exhibition land Standard

	Pollutant	A level	B level
PAH	Naphthalene	54	530
	Chrysene	9	40
	Fluorene	210	8200
	Fluoranthene	310	8200
	Phenanthrene	2300	61000
	anthracene	2300	10000
	Benzo(g,h,i) pyrene	230	6100
	Benzo(a) pyrene	0.3	0.66
	Diphenyl(a,h)anthracene	0.3	0.66
	Benzo(a) anthracene	0.9	4
	Benzo(b)fluoranthene	0.9	4
	Indene (1,2,3-cd) pyrene	0.9	4
	Benzo(k)fluoranthene	0.9	4
	Mononuclear aromatics	Benzene	0.2
Heavy metals	Arsenic	20	80
	Mercury	1.5	50

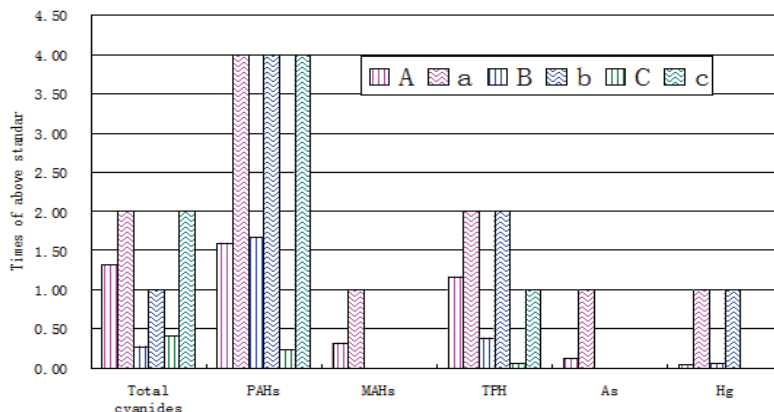


Fig. 2. Times of above standard of six factors (A: average of Zone A; a: maximum of Zone A; B: average of Zone B; b: maximum of Zone B; C: average of Zone C; c: maximum of Zone C)

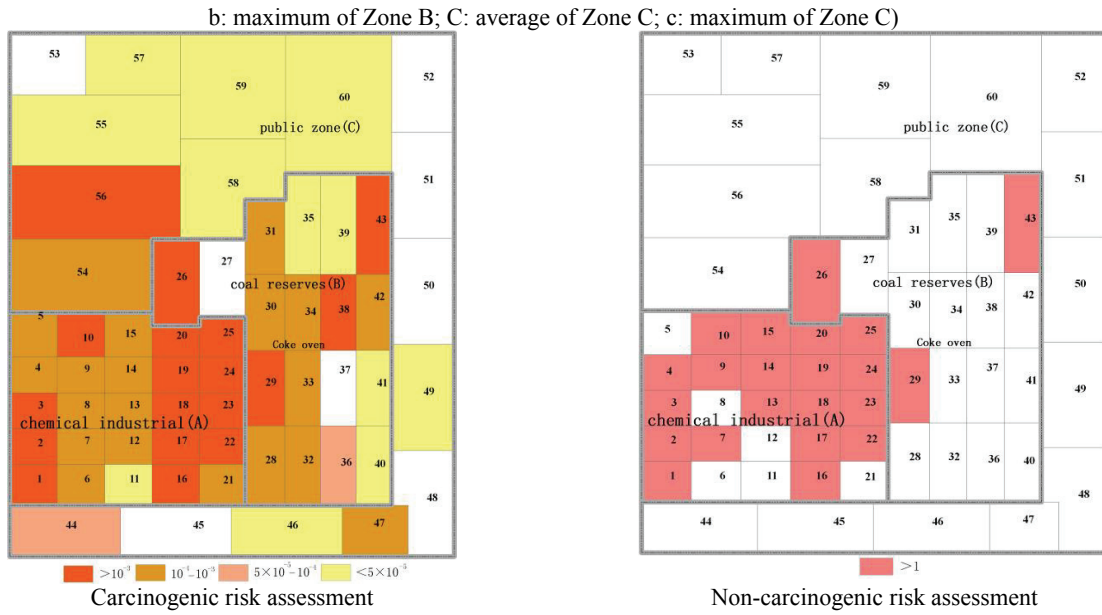


Fig. 3. Risk assessment result of upper layer (A, B, C)

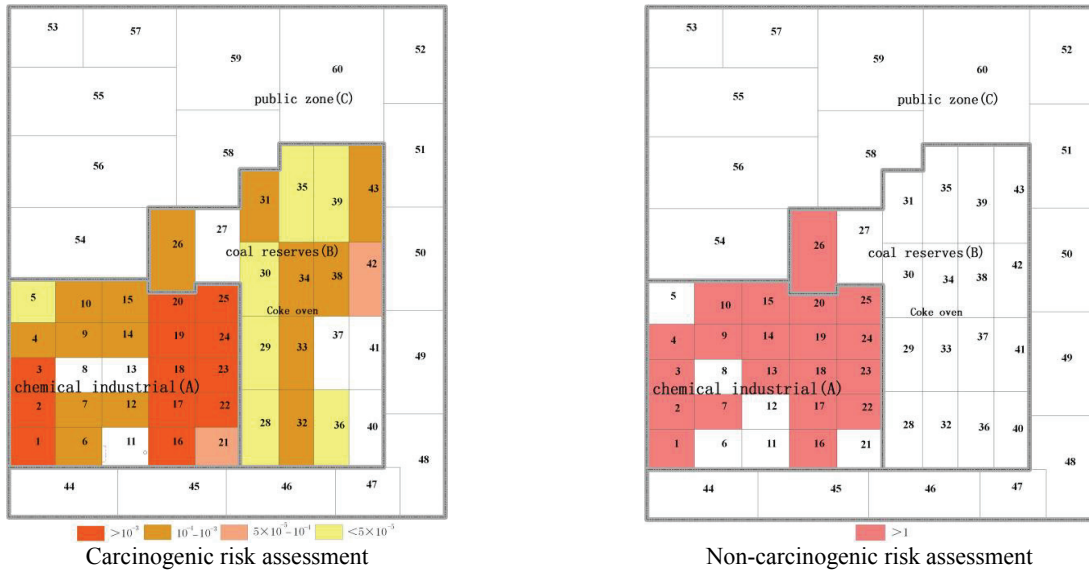


Fig. 4. Risk assessment result of middle layer (A, B, C)

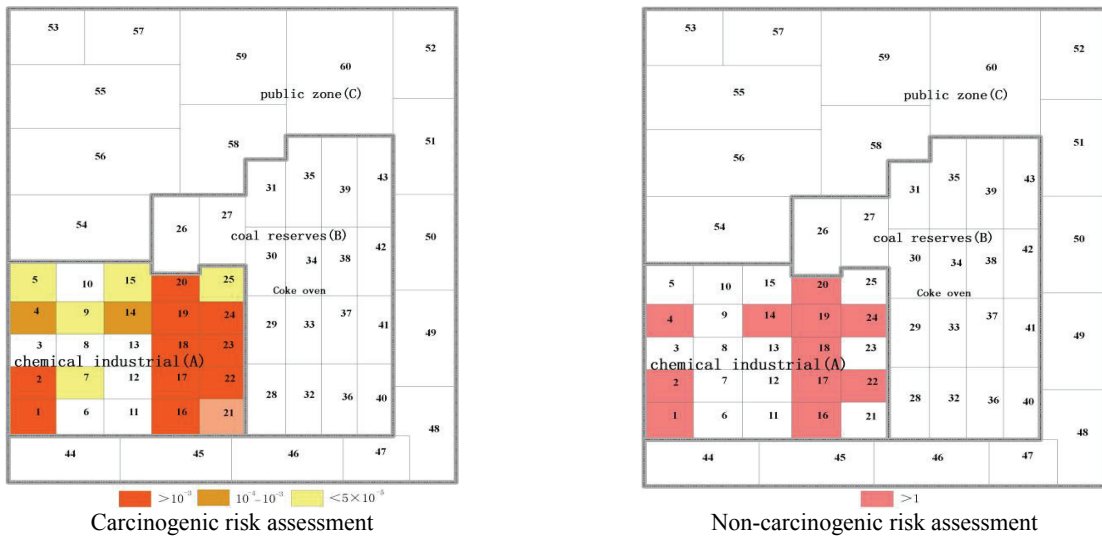


Fig. 5. Risk assessment result of bottom layer (A, B, C)

The total earth volume of grid layers with the absolute carcinogenic risk value  $<1 \times 10^{-5}$  was 9,514 m<sup>3</sup>, and 2,910 m<sup>3</sup> of it was the earth volume of grid layers with the absolute noncarcinogenic risk value  $>1.0$ .

#### 4. Conclusions

Sites contaminated with hazardous materials pose serious risks to human health, and the health risk assessment caused by contaminated sites will be the focus of future research. Combining the site's future planning uses and assessing contaminated site's environmental risk may provide a scientific basis for the implementation of environment management decision and restoration engineering.

The pollution level and pollution area intensity decreased successively in the order of chemical industrial zone, coal reserve zone, and public zone. The soil was contaminated by heavy metals, TPH, and PAHs, clearly indicating that the soil should be remediated immediately.

The health risk assessment indicates that 49 out of the 60 grids have a carcinogenic risk factor  $>10^{-5}$  with a total area of 103,340 m<sup>2</sup>, and grid 18 has the highest value-at-risk of 0.0404. This site has extremely high health risk if  $10^{-5}$  is regarded as the assessment standard for causing cancer.

The heavy and mid-level contaminated soils of the grid layers with a risk value  $>5 \times 10^{-5}$  should be dug out and transferred to conditional disposal facilities for remote centralized processing; mild-contaminated soil of the grid layers with a risk value  $<5 \times 10^{-5}$  can be processed collectively in the site.

#### Acknowledgments

This research is supported by NSFC (Natural Science Foundation of China (31100349)).

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