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Quantitative Health Risk Assessment of Inhalation Exposure to Polycyclic Aromatic Hydrocarbons on Citizens in Tianjin, China

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Abstract Considering the large amounts of PAHs emitted into the ambient air in China, it is urgent to take preliminary health risk assessment of citizens through inhalation exposure to PAHs in China. The incremental lifetime cancer risk (ILCR) model was used to get the risk level of Tianjin citizens as an example, and Monte Carlo simulation was adopted to deal with the uncertainty. Exposure analysis found that the average values of B[a]P equivalent (B[a]Peq) daily exposure doses for children in the indoor, traffic and outdoor settings were estimated to be 2,446.8, 478.4, and 321.6 ng day^{-1}, respectively. And those for adults were 3,344.1, 794.9, and 519.0 ng day^{-1}, respectively. Much attention must be paid to indoor exposure, as it contributes more than 70% of the B[a]Peq daily exposure dose. ILCR falls within the range of 10^{-5}–10^{-3}, which is higher than the acceptable risk level of 10^{-6}, and lower than the priority risk level (10^{-3}). So this risk should be compared with those of other public health issues in the purpose of risk management. Sensitivity analysis found that the two variables, indoor air PAHs concentration distribution and the cancer slope factor (CSF) of BaP, contribute about 89% of the total risk uncertainty. Thus they are considered as the two main factors influencing the accuracy of the PAHs health risk assessment.

Keywords PAHs · Inhalation exposure · Health risk assessment · Tianjin

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Polycyclic aromatic hydrocarbons (PAHs) have become of scientific interest for many years (Brown et al. 1999), because the US Environmental Protection Agency (US EPA) and the National Institute of Environmental Health Sciences (NIEHS) have classified a number of PAHs as probable human carcinogens (US EPA 1993; NIEHS 1998). Several studies have investigated the health risks of citizens and workers caused by PAHs exposure (Kameda et al. 2005; Chen and Liao 2006).

A number of researches have documented severe PAH contamination in ambient air in China (Wu et al. 2005). The total 16PAHs emitted into the ambient air in China was estimated a figure of 25,300 tons in 2003 (Xu et al. 2006), and the total emission of the seven PAHs (BaA, Chr, BbF, BkF, BaP, IcdP, and DahA) with higher carcinogenic potentials was much higher in China than that in the United States.

Health risk assessment of hazardous pollutants is essential for effective environmental management (Asante-Duah 2002). Considering the carcinogenic potential and large emission of PAHs in China, getting the cancer risk level of the citizens caused by PAHs exposure is urgent to environmental risk managers. However, no such information is currently available in the mainland of China, leaving a great information gap.

The objective of the present study was to estimate the rough risk level for general Tianjin citizens exposed to PAHs, and identify the input variables that are critical to the accuracy of the risk assessment.

Materials and Methods

Tianjin is a typical metropolis of northern China, with a population of $\sim$10 million, and an area of 11,919 km^2. It

is located at the lower reaches of the Haihe River and adjacent to the Bohai Sea (120 km SE from Beijing). It is an important industrial center and a well-developed hub with a sea-land-air transportation network. The Tianjin urban/industrial complex is polluted with the rapid urbanization. The particle-phase BaP in Tianjin in winter was measured to vary from 13 to 219 ng m^{-3}, with an average value of 89 ng m^{-3} (Wu et al. 2005), much greater than the recommended daily exposure limit (REL) of 10 ng m^{-3}, regulated by State Environmental Protection Administration of China (SEPA 1996. SEPA has been upgraded to Ministry of Environmental Protection of China – MEP in 2008 by the government), and the WHO criteria of 1 ng m^{-3} (WHO 1987).

The incremental lifetime cancer risk (ILCR) model was used to calculate the risk of Tianjin citizens caused by PAHs exposure. Ambient PAHs concentration data at the indoors, traffic and other outdoor environments in Tianjin are available (Dai and Zhang 1996; Wu et al. 2005; Hu et al. 2007) and were adopted in this study. And the TEFs (toxicity equivalency factors), developed by Nisbet and LaGoy (Nisbet and LaGoy 1992), were proved to be a better set (Petry et al. 1996) to assess the carcinogenic potency of PAHs mixtures. Thus they were adopted in this study to calculate BaP equivalent concentration (BaPeq).

In this study, some questionnaires were directly distributed to randomly selected Tianjin citizens. And questionnaires from 298 children and 97 adults of different age groups were recruited. The time spans of a day were divided into these three environments of indoors, traffic and other outdoors accordingly. Different inhalation rates while doing different activities for different age groups were used according to US EPA (1997).

Then, the daily inhalation exposure dose was calculated according to Eq. 1:

$$E_j = \sum_{i=1}^{3} C_i \times \mathrm{IR}_{ij} \times t_{ij} \quad (1)$$

$i = 1, 2, 3$ referring to different environments of indoors, at traffic, other outdoors, $j = 1, 2, 3$ referring to different age groups: adults, children and infants, E_j = daily exposure dose for the jth group (mg day^{-1}), C_i = BaPeq concentration in the ith environment (mg m^{-3}), IR_{ij} = Inhalation rate in the ith environment of the jth group (m^3 h^{-1}), t_{ij} = Daily exposure time span in the ith environment of the jth group (h day^{-1}).

And ILCR was calculated based on Eq. 2:

$$\mathrm{ILCR} = \frac{\mathrm{CSF} \times \mathrm{EF}}{\mathrm{AT}} \sum_{j=1}^{3} \frac{E_j \times \mathrm{ED}_j}{\mathrm{BW}_j} \quad (2)$$

ILCR = Incremental lifetime cancer risk of the PAHs exposure (dimensionless), CSF = inhalation cancer slope factor of BaP (kg day mg^{-1}), EF = exposure frequency (day $year^{-1}$), AT = averaging time (equal to 70 years for carcinogens) (US EPA 1991), E_j = daily exposure dose for the jth group (mg day^{-1}), ED_j = exposure duration for the jth group (year), BW_j = body weight for the jth group (kg).

According to the US EPA's opinion, a one in a million chance of additional human cancer over a 70 year lifetime (ILCR = 10^{-6}) is the level of risk considered acceptable or inconsequential, since this compares favorably with risk levels from some 'normal' human activities, such as diagnostic X-rays, fishing, skiing, etc., (Asante-Duah 2002); And an additional lifetime cancer risk of one in a thousand or greater (ILCR > 10^{-3}) is considered serious, and there is high priority for paying attention to such health problem.

High uncertainty exists in risk assessment. Thus, the Monte Carlo simulation was implemented using Crystal Ball7.2 software. The software randomly selects a value of each variable according to its distribution function, and calculates one risk value according to Eqs. 1 and 2. This step repeats thousands of times and all the calculated risk values form a risk distribution.

Sensitivity analysis can be done to find the input parameters that have most strongly influenced the risk level. Rank correlation coefficients between each input variable and the output (risk) are calculated, and then by squaring the output variance and normalizing it to 100%, we can get the contribution of each input variable to the output (risk) variance, to evaluate the sensitivity of each input variable relative to one another.

Results and Discussion

The mean values of B[a]Peq concentrations in indoor, traffic and outdoor settings are 155, 450, and 96 ng m^{-3}, respectively. The B[a]Peq concentrations in Tianjin is much higher, compared with in Taiwan (Chen and Liao 2006).

Shown in Fig. 1, the B[a]Peq daily exposure dose of infants is much lower compared with those of children and adults, because of their much lower inhalation rates.

Then, the exposure doses from different environments were analyzed for the children and adults. The average values of B[a]Peq daily exposure doses for children in the indoor, traffic and outdoor settings were estimated to be 2,446.8, 478.4, and 321.6 ng day^{-1}, respectively (Fig. 2a). And those for adults were 3,344.1, 794.9, and 519.0 ng day^{-1}, respectively, (Fig. 2b).

Although the B[a]Peq concentration is highest in the traffic environment, indoor exposures contribute most to the daily exposure doses of both children and adults, about 75% and 71%, respectively. This is because people spent much more time indoors, including at home and in classrooms (for children) or in offices (for adults), than at traffic.

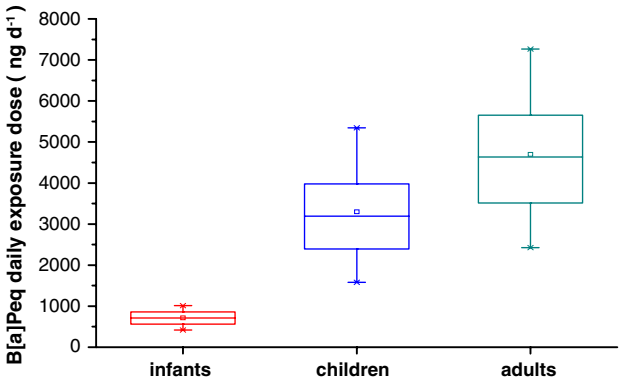

Fig. 1 B[a]Peq daily exposure doses of different age groups

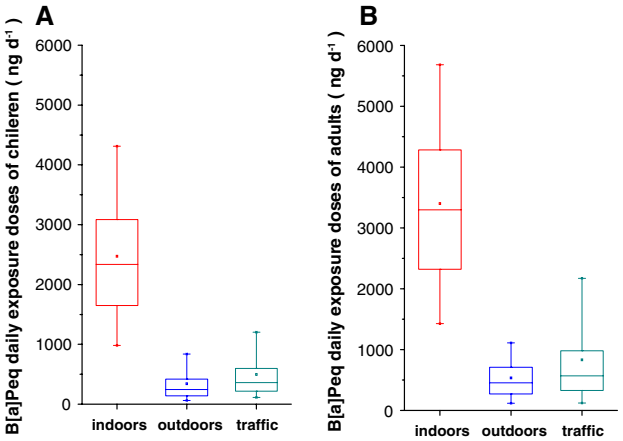

Fig. 2 B[a]Peq daily exposure doses of children and adults from different environments

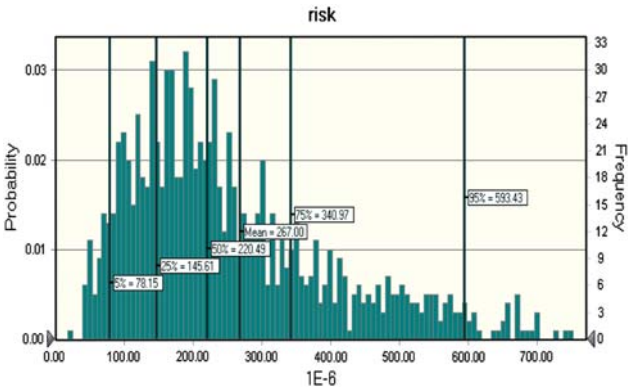

Fig. 3 Inhalation incremental lifetime cancer risk

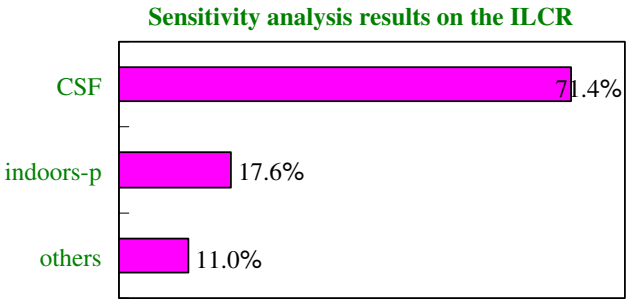

Fig. 4 Sensitivity analysis results on ILCR. *Note*: CSF, inhalation cancer slope factor of BaP (kg day mg^{-1}); indoors-p, concentration distribution of particulate BaPeq indoors (mg m^{-3})

The average time spent indoors was investigated to be 20.4 and 19.4 h day^{-1}, while that spent at traffic were 0.84 and 1.1 h day^{-1}, for children and adults, respectively. Thus much attention should be paid to indoor exposure.

The probability distributions of the calculated ILCR were presented in Fig. 3. The mean and median values of ILCR are estimated to be 2.7 and 2.2 $\times$ 10^{-4}, respectively. ILCR almost falls inside the range of 10^{-5}–10^{-3}, higher than the acceptable risk level (10^{-6}), and lower than the priority risk level (10^{-3}). So this risk should be compared with the risk levels of other public health problems, while doing risk management.

Sensitivity analysis was done on ILCR. The two variables most strongly influencing the risk were the inhalation cancer slope factor of B[a]P (CSF) and the particulate BaPeq concentration indoors (indoors-p) (Fig. 4). The sum of their contributions counts about 89%. Some previous studies have got similar results (Chen and Liao 2006). And the CSF occupied more than 70% of the total variance of ILCR. Thus in order to greatly improve the accuracy of the risk assessment, improving the accuracy of CSF might be much more effective than improving the accuracy of the exposure concentrations. Great efforts must be made to improve the accuracy of the inhalation cancer slope factor of BaP.

Despite its great uncertainty of such pilot study, we should not neglect its great merit. In this study, the rough risk level of Tianjin citizens through inhalation exposure to PAHs were calculated, which filled the great information gap in the mainland of China. This risk information could be compared with other public health risk problems, to use the limited resources to the most urgent problems. Furthermore, this preliminary study found the most influential factors, to which further researches should be directed. Thus, such pilot study can help to make better use of the scientific fund and other resources. In China, such preliminary health risk assessments of citizens exposed to air pollutants in needed over the country, for rapid economic development together with severe environmental deterioration occurred during the past two decades. This research provides an example of such pilot risk assessments.

Another important problem that the risk managers have to consider is that very limited data of the concentrations of pollutants indoors have been documented. Based on this study, exposure in the indoor environment is the main part of daily exposure, because people spend most of their time indoors, and the indoor environments are sometimes

seriously contaminated. Also, a lot of time-activity pattern surveys should be conducted; as such data is quite limited in China, to link the exposure concentrations with the daily exposure doses.

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