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Mixed uncertainty analysis of polycyclic aromatic hydrocarbon inhalation and risk assessment in ambient air of Beijing

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Abstract

This article presents the application of an integrated method that estimates the dispersion of polycyclic aromatic hydrocarbons (PAHs) in air, and assesses the human health risk associated with PAHs inhalation. An uncertainty analysis method consisting of three components were applied in this study, where the three components include a bootstrapping method for analyzing the whole process associated uncertainty, an inhalation rate (IR) representation for evaluating the total PAH inhalation risk for human health, and a normally distributed absorption fraction (AF) ranging from 0% to 100% to represent the absorption capability of PAHs in human body. Using this method, an integrated process was employed to assess the health risk of the residents in Beijing, China, from inhaling PAHs in the air. The results indicate that the ambient air PAHs in Beijing is an important contributor to human health impairment, although over 68% of residents seem to be safe from daily PAH carcinogenic inhalation. In general, the accumulated daily inhalation amount is relatively higher for male and children at 10 years old of age than for female and children at 6 years old. In 1997, about 1.73% cancer sufferers in Beijing were more or less related to ambient air PAHs inhalation. At 95% confidence interval, approximately 272–309 individual cancer incidences can be attributed to PAHs pollution in the air. The probability of greater than 500 cancer occurrence is 15.3%. While the inhalation of ambient air PAHs was shown to be an important factor responsible for higher cancer occurrence in Beijing, while the contribution might not be the most significant one.

Key words: polycyclic aromatic hydrocarbons (PAHs); uncertainty analysis; human health risk

Introduction

Polycyclic aromatic hydrocarbons (PAHs) has a wide range of toxic effects, including skin/eye irritation, immuno-toxicity, and developmental toxicity. The most serious toxicity of PAHs is carcinogenicity. Extensive mechanistic studies have proved that PAH compounds are complete carcinogens (Flowers *et al*., 2002). PAH exposure to some particular occupations or areas has been explored. Cases include those on on-duty traffic policemen (Liu *et al*., 2007; Ruchirawat *et al*., 2002), nonsmoking bus drivers and postal workers (Autrup *et al*., 1999), incense smoke in-vehicle (Kuo *et al*., 2003), fixed sites (Guo *et al*., 2003), fixed site with heavy traffic (Ho and Lee, 2002), urban site/ vegetation area/ forest area (Vasconcellos *et al*., 2003), bus station and traffic tunnel (Pereira *et al*., 2002), outdoor air (Velasco *et al*., 2004), roadside air (Marr *et al*., 2004; Chetwittayachan *et al*., 2002), and ambient traffic site (Lodovici *et al*., 2003). These studies have provided many valuable insights on the potential threat of PAHs to human health. However, they have hardly investigated the complicated uncertainty associated with the biological response of human health to ambient concentration, which is apparently a very important factor to be considered in understanding the human health risk from exposure to PAHs.

By their nature, risk estimates cannot be perfectly accurate. The main problem is that scientists rarely have sufficient information to precisely define actual exposure degree and functional effects (Liao *et al*., 2006). In an air pollution risk analysis, there are always a large number of inexact factors that would induce significant uncertainty in the result (Lau *et al*., 2003). Generally, the total uncertainty in an air pollution risk assessment can be attributed to four sources: (1) uncertainty in ingestion routes, which can be inhalation, oral intake or skin exposure; (2) uncertainty in the process of translating ambient concentrations to human effect, such as the extrapolation factor uncertainty (Tsai *et al*., 2001); (3) variability in the age, activity, and corporeity variety of urban residents; and (4) uncertainty associated with the lack of and the imprecision in monitoring data. To achieve a more reliable risk analysis for decision making, the aforementioned uncertainties need to be taken into consideration, and effective uncertainty analysis approaches should be applied to help address the uncertainty throughout the entire risk analysis process,

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thus estimating the confidence interval of the risk related to exposure of human body to hazardous substances such as PAHs. This paper reports a study applying an integrated mixed uncertainty analysis method that takes into account the variability in human activities, PAHs concentrations, and inhalation rate to estimate the confidence interval of risk.

1 Methodology

1.1 PAH concentrations and relative parameters

The research reported in this article was conducted on data collected in previous studies by other researchers. Zeng *et al*. (2002) used 15 samplers to sample several function areas in Beijing throughout the year 1997 to obtain information for characterizing the PAHs pollution in atmospheric aerosols in Beijing. These sampling efforts have detected seventeen species of PAHs, including naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[j+b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[l,2,3-c,d]pyrene, dibenzo[ah]anthracene, benzo [g,h,i]perylene and benzo[e]pyrene. The concentrations of each individual species generally range from 0.01 to 113.88 (ng/m^3), with the concentrations in some samples being below detection limit. The total concentration of all the PAHs species ranged from 1.96 to 872.83 ng/m^3.

Different PAHs species have different chemical properties. In practical study, BaP is generally used as the representative species of PAHs, and a Toxic equivalent factor (TEF) measuring the relative toxicity of a specific PAH species to BaP can be used to evaluate the total toxicity of the whole group of PAHs (Yassaa *et al*., 2001). In this study, inhalation rate (IR) and absorption fraction (AF) are used as the variants and parameters of TEF to assess PAHs associated health risk. The average daily IR for adult male, adult female, adult average, children age 6 and children age 10 are respectively 21.4, 11.8, 16.0, 16.74, and 21.02 m^3/d (USEPA, 1992, 1994). Several researchers have reported various TEF values. Table 1 summarizes seven groups of TEFs reported in pervious researches, and are used in the current study (Petry *et al*., 1996; Machala *et al.*, 2001; Liao *et al*., 2006).

The PAHs health risk assessment includes two parts: (1) to estimation of the effective accumulated PAH inhalation, as measured by total BaPeq (ng); (2) to estimation of the incremental human health risk from exposure to PAHs, as measured by the number of threatened people.

1.2 Toxic equivalent of PAH for inhabitants

For inhabitants in a specific city, the magnitude of exposure depends on the concentration of ambient PAHs and the exposure duration, and is represented in terms of concentration-time units (Lioy, 1990):

$$E = \int_{t_1}^{t_2} C(t) \times \mathrm{d}t \tag{1}$$

where, E is the magnitude of exposure (μg/(m^3·d)); $C(t)$ is the ambient PAHs concentration (μg/m^3); and $(t_2–t_1)$ is the exposure duration (ED).

PAHs influence human health after they entered human bodies through inhalation. The potential dose for inhalation processes is represented as the integration of the chemical IR over time (USEPA, 1992):

$$D_{\mathrm{pot}} = \int_{t_1}^{t_2} C(t) \times \mathrm{IR}(t) \times \mathrm{d}t \tag{2}$$

where, D_{pot} is potential dose (μg); IR(t) is inhalation rate (m^3/d).

Eq.(2) can also be expressed in discrete form as a summation of the doses received during various PAHs exposure periods (Zaki, 2001). When limited data are available, it is a good approximation to define C and IR as

Table 1 Proposed toxic equivalency factors (TEFs) for individual PAHs

Compound (abbreviation)	TEFs						
Naphthalene (Naph)	0	N/A	N/A	N/A	0.001	N/A	0.001
Acenaphthylene (Aceny)	0	N/A	N/A	N/A	0.001	N/A	0.001
Acenaphthene (Ace)	0	N/A	N/A	N/A	0.001	N/A	0.001
Fluorene (Flu)	0	N/A	N/A	N/A	0.001	N/A	0.001
Phenanthrene (Phen)	0	N/A	N/A	N/A	0.001	N/A	0.001
Anthracene (Ant)	0	N/A	0.32	N/A	0.01	N/A	0.01
Fluoranthene (Fluor)	0	N/A	N/A	N/A	0.001	0	0.001
Pyrene (Pyr)	0	N/A	0.081	N/A	0.001	0	0.001
Chrysene (Chr)	1	0.001	0.0044	0.0044	0.01	0.017	0.01
Benzo[a]anthracene (BaA)	1	0.0131	0.145	0.145	0.1	0.082	0.1
Benzo[j+b]fluoranthene (BjbF)	1	0.08	0.14	0.12	0.1	0.26	N/A
Benzo[k]fluoranthene (BkF)	1	0.004	0.066	0.052	0.1	0.11	0.1
Benzo[a]pyrene (BaP)	1	1	1	1	1	1	1
Indeno[l,2,3-c,d]pyrene (IND)	1	0.017	0.232	0.078	0.1	0.31	0.1
Dibenzo[ah]anthracene (DahA)	1	0.69	1.1	1.11	1.0	0.29	1.0
Benzo[g,h,i]perylene (BgP)	0	N/A	0.022	0.021	0.01	0.19	0.01
Benzo[e]pyrene (BeP)	N/A	N/A	N/A	N/A	N/A	0.0017	0.01
Reference	Petry *et al.* (1996)					Machala *et al.* (2001)	Liao *et al.* (2006)

N/A: not available.

average values over a period of time, leading to a discrete form of Eq.(2):

$$D_{pot} = C \times IR \times ED \quad (3)$$

Among the total PAHs that enter a human body through inhalation, only a fraction of them is absorbed in a person's body after a certain period to impose health threat to the person. This fraction is defined as absorption fraction (AF), and is used to represent the effective inhalation quantity:

$$ADD_{int} \cong ADD_{pot} \times AF \quad (4)$$

where, ADD_{int} (average daily internal dose) represents the effective inhalation quantity to a human body in a day (μg); ADD_{pot} (average daily potential dose) is the potential quantity for human inhalation in a day, which is equivalent to the daily average value of D_{pot}. According to USEPA (1992), AF represents the absorption proportion in units of mass absorbed or applied, hence it is dimensionless.

From a statistical perspective, AF reveals the correlation expressed between ADD_{pot} and ADD_{int} (USEPA, 1992), and it displays two aspects: (1) applied dose is the amount of a chemical at the absorption barrier (skin, lung, gastrointestinal tract) available for absorption. A relationship between applied dose and internal dose usually is very difficult to measure directly, as many of the absorption barriers are internal to the human and are not localized in such a way to make measurement easy; (2) applied dose may often be less than the potential dose if the chemical is only partly bio-available.

The value of AF depends on both absorption barriers and the chemical's bio-availability. It is a cumulative number and can increase with time to a potentially maximum value of 1 (or 100% absorption). However, due to the impact of multiple competing processes in the absorption process, it may reach steady state long before reaching 100% absorption. Thus AF may be expressed as an interval parameter ranging from 0 to 1. Through this way the AF would then take into account the ability of the chemical to be extracted from the matrix, absorption through the exchange boundary, and any other losses between inhalation and contact with the lung or gastrointestinal tract.

To estimate the effect from all the PAHs species, the factor TEF is used to convert the effect of PAH species *i* to the equivalent values measured based on BaP (Yang *et al*., 2007):

$$BaP_{eq_i} = C_i \times TEF_i \quad (5)$$

Based on Eqs (1)–(5), the total BaP_{eq} for an individual in one day, which is defined as totality of equivalent toxic quantity (TEQ), can be expressed as (Chen and Liao, 2006):

$$TEQ = \left[\left(\sum_{i=1}^{n} C_i \times TEF_i\right) \times AF_i\right] \times IR \times ED \quad (6)$$

where, TEQ is the sum of PAHs accumulation from ambient air through one day, ng BaPeq.

1.3 Inhalation cancer risk for inhabitants

By adopting parameter TEF, the inhalation cancer risk (ICR) resulting from PAHs inhalation can be derived following three steps:

(1) Cancer risk has been assessed through using the risk of cancer from unit pollutant inhalation (Lau *et al*., 2003). The estimated cancer risk for each pollutant can be calculated using the following equation:

$$R_i = C_i \times IUR_i \quad (7)$$

where, R_i is the estimated individual lifetime cancer risk from pollutant *i*. C_i is the concentration of hazardous air pollutant (*i*) in μg/m^3. IUR_i is the risk of cancer from inhalation of unit mass of pollutant *i* (m^3/μg). The interpretation of the IUR_i would be as follows: if $IUR_i = 2 \times 10^{-6}$ μg/m^3, not more than 2 excess tumors are expected to develop per 10^6 people if exposed continuously for a lifetime to 1 μg of the chemical per cubic meter of inhaled air. The number of expected tumors is likely to be less; it may even be none (USEPA, 2006).

(2) The total excess lifetime inhalation cancer risk from the combination of these pollutants is calculated by summing the cancer risk from individual pollutants (Wu *et al*., 2006). To estimate the number of cancer cases from exposure to these pollutants in a city, the total cancer risk should be multiplied by the population the city, leading to:

$$ICR = \sum_{i=1}^{n} EC_i \times IUR_i \quad (8)$$

where, EC_i is the exposure concentration of chemical in air (μg/m^3); ICR is the population that is affected by cancer risk per 10^6 people (USEPA, 2006).

(3) As limited data is available to directly define *IUR* values, *TEF* is introduced to link the PAH concentration to BaP_{eq} in order to transfer the C_i to equivalent concentration expressed in the form of BaP. So the *ICR* could be expressed as (Wu *et al*., 2006; USEPA, 2005):

$$ICR = \left(\sum_{i=1}^{n} C_i \times TEF_i\right) \times IUR_{BaP} \quad (9)$$

where, IUR_{BaP} is a slope factor of inhalation unit risk for BaP as the exposure-carcinogenic effect is considered as linear (USEPA, 2005). Extrapolation of cancer risk using the linear model, which results in a linear extrapolation of risk in the low dose region, has been used for most chemicals ever since 1986 (USEPA, 1986; USEPA, 2000a). However, as emphasized in the proposed guidelines (USEPA, 1996), unless there are adequate mechanistic data to suggest a more appropriate estimation other than linearity, usually in the case of data absence, the assumption of response linearity is maintained as well as the modeling scheme is simplified (USEPA, 2000a).

Thus a slope factor expressed as IUR_{BaP} is used in this research to link the linearity between ambient concentration and risk. California Environmental Protection Agency (CEPA, 2004) recommended a unit risk of cancer value for benzo[a]pyrene as: $IUR_{BaP} = 1.1 \times 10^{-3}$ (m^3/μg). As shown

in Eq.(9), cancer risk attributable to inhalation exposure of target PAHs is estimated as the sum of the individual PAHs concentrations (expressed as equivalent of BaP) times its unit risk factor. Here additive type is used in respect that USEPA (2000b) declared when there is no adequate interactions information, dose- or response-additive models are preferred. Several studies have demonstrated that dose (or concentration) addition often predicts reasonably well the toxicities of mixtures composed of a substantial variety of both similar and dissimilar compounds (Feron *et al*., 1995; Backhaus *et al*., 2000).

1.4 Mixed uncertainty analysis

There are four aspects of uncertainties when assessing the risk of PAHs from Beijing's ambient air. Fig.1 shows the risk assessment steps with mixed uncertainty analysis methods. To obtain the comprehensive uncertainty in the whole assessing process, three kinds of uncertainty analysis methods are hybridized and used in the analysis, including interval number, random sampling and bootstrap method.

(1) As a human body exposes to pollutions through multiple ways including inhalation, direct or indirect ingestion, dermal contact, and other pathways (USEPA, 1999), it is necessary to define the specific exposure pathway for a risk assessment. This study focuses on the unit risks induced by the inhalation of airborne PAHs chemicals only, without considering other routes such as ingestion or skin absorption. Hence any conclusions from this research should be considered valid only for inhalation related risk.

(2) A major issue in a health impact assessment is the lack of numeric standards for unit risk (Lau *et al*., 2003). Currently, no established standard exist for PAHs in Beijing, therefore, this study adopts a standard from CEPA documents, which has been applied and accepted in the field of PAHs risk assessment for a long time. It should be noted, however, the direct application of the CEPA unit risk is subjected to significant uncertainty. To statistically demonstrate this uncertainty, the risk at an upper and a lower limit of different confidence interval (95%, 75%, 50%, and 25%) are presented and discussed.

(3) Various groups of people live in different social-economic status in Beijing, and their difference in life style can influence their inhalation rate and absorption factor, resulting in a range of values that is hard to be defined using a crisp number. Interval numbers are thus used in representing IR, which usually fluctuate around a mean value within a range of 5%. This allows a more reliable representation of the true condition than using only a single value (USEPA, 1997). The true position of the computed exposure dose in the theoretical distribution of the exposure computed by each model could not be determined (Leslie *et al.*, 2004). This uncertainty was observed among different volunteers, which results in the distribution of a median value among each group (Frédéric D *et al*., 2003). Combined with the discussion above in Section 1.2, the parameter of AF might be close to the center of their distribution with its minimum as 0% and maximum as 100% (USEPA, 1992). So random sampling for different human absorbing rate is reasonable, which is supposed to be normally distributed with the interval of [0, 1].

(4) The number of sampling locations is inadequate to represent the spatial variability in Beijing due to its tremendous size. The lack of a comprehensive monitoring system results in another uncertainty. So it's necessary to find out a method to simulate whole Beijing's PAH distribution, that is, to repeat the effective concentrations, instead of interpolation or diffusion (Bennett *et al*., 2002). Bootstrap is an excellent technique for repeatedly sampling, especially when there are limited numbers of data to a full-city scale. This is an approximation of the true exposure and it can simulate the whole Beijing's PAHs distribution in the ambient air without more assumptions. Bootstrap method is also used in the uncertain sampling of TEF values with the same method.

Researchers reported that bootstrap iteration as many as 1000 is enough for a robust sampling (Gatz and Smith,

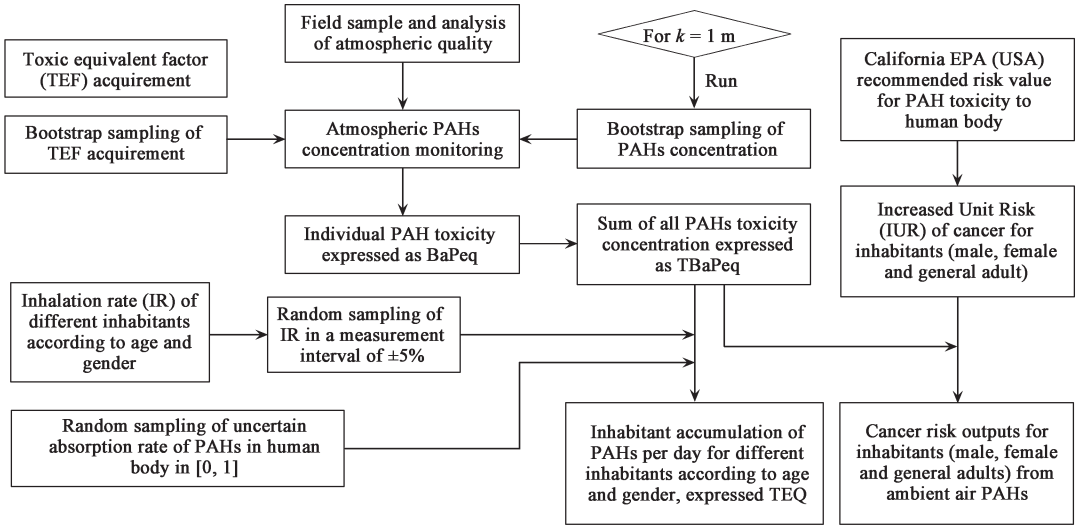

Fig. 1 Inhabitant PAHs risk assessment steps with mixed uncertainty analysis.

1995; Efron and Tibshirani, 1993). For this study, the PAH concentration's bootstrap sampling number m was set as 10^3, which means $m \times n$ concentrations are produced as input parameter for risk assessment, where n is the type number of PAHs, n=17. For TEF, the bootstrap sampling number is the same as that of concentrations. The whole sampling and analysis is programmed by MATLAB (version 7.04) and run in this software, with output exported at the relevant interface.

2 Results and discussion

2.1 TEQ for inhabitants and uncertainty analysis

The TEQ per day for different inhabitants (age and gender) are shown in Figs.2 and 3. Due to the large number of outputs produced by the bootstrap sampling method, two commercial software tools, SPSS (version 13.0) and OriginPro (version 7.5714) were used to process the output data. The histogram in Fig.2a shows the TEQ distribution for ordinary adults. As shown, the distribution is dense in the interval of 0–100 ng/d and it accounts for up to 52.1% of the total population. For the interval of 100–200 ng/d, 200–300 ng/d, 300–400 ng/d, 400–500 ng/d and >500 ng/d, the rate are 22.6%, 9.2%, 5.3%, 3.7% and 7.1%. Menzie *et al*. (1992) estimated that potential doses of carcinogenic PAHs by inhalation range between about 0.02 and 3 μg/d with median value of 0.16 μg/d. World Health Organization (WHO) Environmental Health Criteria (EHC202) also recommended daily PAHs inhalation standards for six representative countries (WHO, 1998) as: 0.36 μg/d (Austria); 0.14–1 μg/d (Germany); 0.1–0.3 μg/d (Italy); 0.12–0.42 μg/d (The Netherlands); 0.48 μg/d (The United Kingdom); 0.16–1.6 μg/d (USA). Since no corresponding standard is available for China, this study adopted a USA standard as the basis of further analysis. Both the median value of Menzie *et al*. (1992) and the lower limit of the USA standard indicate people are in general safe when the exposure level is less than 0.16 μg/d. Based on this criterion, the result suggests that in Beijing City at least 67.8% of adults might be safe from daily PAH carcinogenic inhalation. Note that the USA's lower bound standard of 0.16 μg/d is more critical than most of the other five countries value interval, especially with regard to their upper bounds.

The box chart in Fig.2b shows the comparison between that of male, female, ordinary adults, children of 6 and 10 years old. Table 2 shows the descriptions of these five groups. Fig.2b and Table 2 show some differences in TEQ according to age and gender. There is a significant difference between the values for male and female, for example, the mean for male is 220.35 ng/d while female is 121.50 ng/d, and the maximum value for male is 1702.20 ng/d and for female is 938.59 ng/d, which means the cumulative dose in a day for male is higher than that of female. TEQ for children of 6 or 10 years old is also different. The mean value for children at 6 is 172.36 ng/d while for children at 10 is 216.43 ng/d. Thus the elder children are a little more sensitive than younger ones. TEQ of general adults and children of 6 years old are much alike, with their mean value as 164.74 and 172.36 ng/d, relatively. TEQ for children at 10 years old is similar to that of male, with their mean value as 216.43 and 220.35 ng/d, respectively. The TEQ for male and for children of 10 years old stay in a relatively higher level, compared with that of female and children of 6 years old.

2.2 ICR for different inhabitants and uncertainty analysis

The values of ICR for inhabitants are calculated and listed in Table 3 and Fig.3. The mean values of the whole population, male and female are respectively: 290.74, 147.41, and 143.33; and the median values are 176.41, 89.44, and 86.96, respectively. The upper and lower bounds of the 95% confidence interval for mean are: entire

Table 2 Descriptions of TEQ for different person groups (unit: ng/d)

Type	Number	Range	Min.	Max.	Mean	SE	STD	Variance
Male	1,000	1,702.20	0.00	1,702.20	220.35	7.94	250.93	62,966.19
Female	1,000	938.59	0.00	938.59	121.50	4.38	138.36	19,144.42
Adult	1,000	1,272.70	0.00	1,272.70	164.74	5.93	187.61	35,197.92
Children age 6	1,000	1,331.50	0.00	1,331.50	172.36	6.21	196.29	38,529.00
Children age 10	1,000	1,672.00	0.00	1,672.00	216.43	7.79	246.47	60,749.33

Table 3 Descriptions of the different citizen type inhalation cancer risk (ICR)

Object		Total	Male	Female
Mean		290.74	147.41	143.33
5% Trimmed mean		258.00	130.81	127.19
Median		176.41	89.44	86.96
Variance		89,018.51	22,883.62	21,634.46
SD		298.36	151.27	147.09
Min.		7.51	3.81	3.70
Max.		1292.80	655.46	637.32
Range		1285.29	651.65	633.62
Confidence	95%	[272.22, 309.25]	[138.02, 156.80]	[134.20, 152.46]
interval	75%	[279.88, 301.60]	[141.90, 152.92]	[137.98, 148.68]
for mean	50%	[284.37, 297.11]	[144.18, 150.64]	[140.19, 146.47]
	25%	[287.73, 293.75]	[145.88, 148.93]	[141.85, 144.81]

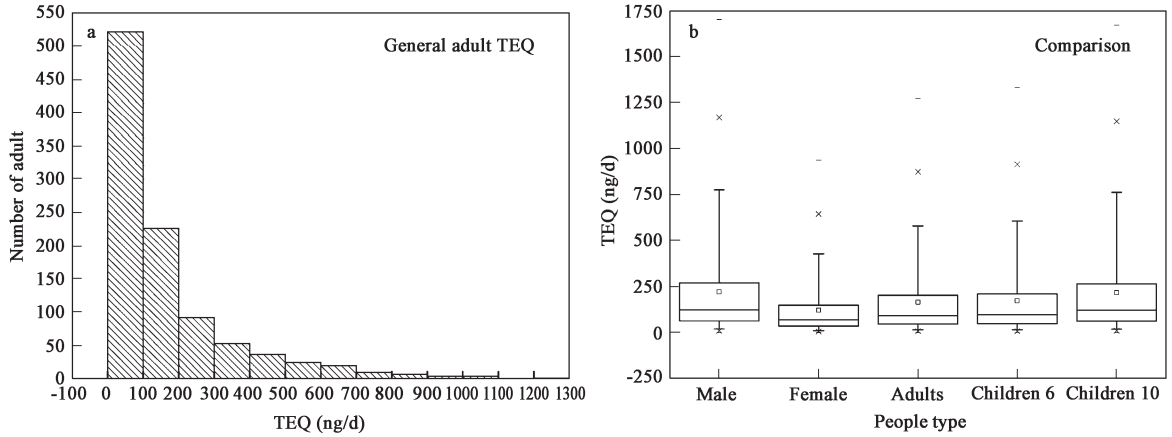

Fig. 2 TEQ inhalation amount for inhabitants (ng).

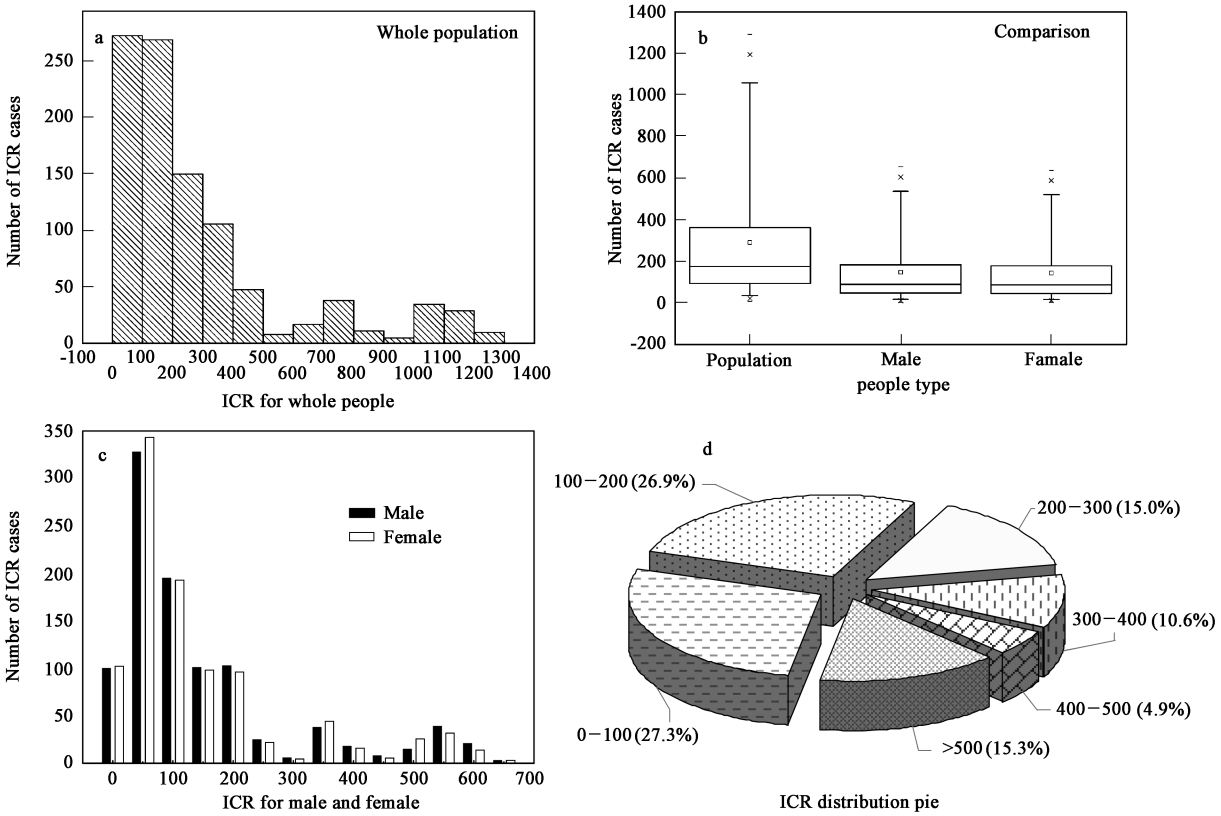

Fig. 3 Inhalation cancer risk (ICR) for inhabitants (persons).

population [272.22, 309.25], male [138.02, 156.80], and female [134.20, 152.46]. This means at 95% confidence interval, there are 272–309 cancer sufferers which could be traced back to ambient air PAHs pollution. Among them, 138–157 are male and 134–152 are female. The 75%, 50% and 25% confidence intervals turn out to be much alike to that of 95%.

The maximum value for the entire population is 1292.80, indicating that at the current ambient air PAH concentration level, there would be 1293 persons at maximum in Beijing who might have cancer caused by exposure to PAH inhalation. Considering the total population of Beijing in 1997 is 1.240×10^7, and the death rate for this year is 6.02‰ (BSB, 2006), this suggests that at most about 1.73% cancer sufferers of this year were related to ambient air PAHs.

Figure 3a shows that the two intervals [0, 100] and [100, 200] cover the largest portion of the whole ICR distribution. Fig.3b shows the ICR distribution comparisons between the entire population, male and female. Fig.3c shows that there is a little difference between male and female ICR values, especially from a statistically point of view. Considering the similar difference in total population of these two genders, it could be concluded that men and women have similar level of risk from the ambient air PAHs. Fig.3d demonstrates the percentages of ICR for the entire population, which is a probabilistic distribution pie of 6 parts, including intervals 0–100, 100–200, 200–

300, 300–400, 400–500, and >500, respectively. It shows that for Beijing's inhabitants, the probability of 0-100 people having cancer risk is 27.3%; for 100–200 people it is 26.9%; for 200–300 people it is 15.0%; for 300–400 people it is 10.6%; and for 400–500 people it is 4.9%. The probability of more than 500 sufferers is 15.3%. In other words, there is about 84.7% of the risk distribution is likely to be less than 500 sufferers in the whole city. As mentioned in earlier text, there are 1.73% of cancer sufferers related to ambient air PAHs. Therefore, these probability results suggest that while inhalation of ambient air PAHs does contribute to increasing the cancer risk of the residents in Beijing, but the contribution might not be the significant one, considering the low percentage (1.73%).

Figures 2b, 3b and 3c show the TEQ and ICR comparisons between male and female. It shows that the mean value of TEQ for male (220.35 ng/d) is higher than that of female (121.50 ng/d). The mean value of ICR for male (147.41) is a slightly higher than that of female (143.33). Also, the ICR distribution poles in Fig.3c showed that the ICR in low probability (i.e., $0 < ICR < 100$) for male is less than that of female. In other words, the other ICR for male is higher than that of female. This information about TEQ and ICR suggests that male is a slightly more sensitive than female.

3 Conclusions

A hybrid uncertainty analysis method was applied to assess the human health risk from inhalation of ambient air PAHs. The result shows that: (1) ambient air PAH pollution is a contributor to human health risk; (2) at least 67.8% of adults are safe from daily PAH carcinogenic inhalation. The daily inhalation totality for male and for children at 10 years old is relatively higher than that of female and children at 6 years old; (3) for Beijing's inhabitants, by far about 1.73% cancer sufferers of this year were related to ambient air PAHs inhalation. At 95% confidence interval, there are 272–309 personal cancers could be traced back to ambient air PAHs pollution. The possibility of more than 500 sufferers is 15.3%. While the inhalation of ambient air PAHs does contribute to increasing the cancer risk of the residents in Beijing, however, the contribution might not be the most significant one.

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