**Using Monte Carlo simulation to assess uncertainty and variability of
methamphetamine use and prevalence from wastewater analysis**

Wei Pei¹, Qiu-Xia Zhan¹, Zhi-Yu Yan¹, Lin-Ke Ge², Peng Zhang², Zhuang Wang³,
De-Gao Wang^{1†*}

¹School of Environmental Science and Technology, Dalian Maritime University, 1
Linghai Road, Dalian, Liaoning, China, 116023

²Key Laboratory for Ecological Environment in Coastal Areas (SOA), National
Marine Environmental Monitoring Center, Dalian 116023, China

³Collaborative Innovation Center of Atmospheric Environment and Equipment
Technology (AEET), School of Environmental Science and Engineering, Nanjing
University of Information Science and Technology, Nanjing, China

*Corresponding author phone: 86-411 8472-3185; fax: 86-411 8472-3185

E-mail address: degaowang@dlmu.edu.cn (De-Gao Wang)

Abstract

Background In recent years, methamphetamine (METH) has increased dramatically in China. However, little is known regarding the prevalence of METH use among the general population in China.

Methods We provided a method to estimate the consumption and prevalence of METH in a city based on wastewater analysis. Monte Carlo simulations were employed to assess the uncertainty and variability of the consumption and prevalence rate in Beijing.

Results METH consumption in Beijing based on Monte Carlo simulation varied between 1.3 and 5.2 kg per day with a median of 2.6 kg per day. In 2013, the 12-month prevalence of METH use was 0.58% (95% confidential interval 0.08-3.16) among the general population aged 15-64 years. A population-weight consumption map displayed the geographical differences in Beijing.

Conclusions The proposed method dramatically improved the accuracy and reliability and can be used as a useful complementary tool to official methodologies for drug use monitoring. This report describes the first comprehensive study concerning the prevalence of METH among the general population in mainland China.

Keywords: sewage epidemiology; methamphetamine; prevalence; variability; uncertainty; dependence

Introduction

As a representative of amphetamine-type stimulants (ATS), methamphetamine (METH) abuse is a serious illicit drug problem in China and around the globe. Currently, the prevalence of ATS abuse is estimated at 52 million people aged 15-64 years worldwide and two-thirds of them reside in east and south-east Asia (Rawson, 2013). China has become one of the world's largest METH markets in recent years. One of the most notable trends in illicit drug use within China over the past decade is the dramatic growth and spread of METH use (Sun, Bao, Zhou, Meng, & Lu, 2014). Among government registered drug users in 2004, only 1.7% used amphetamines, but the proportion of METH use grew to 40.3% or 1.19 million by 2014 (CFDA, 2015).

Most important, the traditional drug occurrence methods, using questionnaires and socio-epidemiological surveys, are labor-intensive and time-consuming (Gartner, 2015). The reliability of these estimates depends on large representative samples of the population providing information on their drug use. In part to overcome these limitations, an alternative approach has been suggested based on sewage epidemiology. This method relies on measuring the concentrations of selected drugs or their metabolites in the influent of wastewater treatment plants (WWTPs), as a means of back-calculating the epidemiological prevalence and consumption. The chemical analysis of these compounds in urban wastewater produced by a population has recently been established as a complementary approach for monitoring consumption of illicit drugs (Thomas, et al.,

2012; Zuccato, et al., 2005), new psychoactive substances (Reid, Baz-Lomba, Ryu, & Thomas, 2014), licit drugs (Nieto, et al., 2010; Venhuis, de Voogt, Emke, Causanilles, & Keizers, 2014), tobacco (Castiglioni, Senta, Borsotti, Davoli, & Zuccato, 2015; Rodríguez-Álvarez, Rodil, Rico, Cela, & Quintana, 2014), and alcohol (Reid, Langford, Mørland, & Thomas, 2011; Rodriguez-Alvarez, Rodil, Cela, & Benito Quintana, 2014; Wang, et al., 2016). The main advantage of sewage analysis is that it provides evidence-based, objective, and real-time estimates of use in a defined population. However, this approach is also subjective to a number of uncertainties associated with the different steps involved (Chen, et al., 2011; Clouzot, et al., 2013; Lai, et al., 2011). The main uncertainties are those related to the sampling of wastewater, the stability of metabolites in wastewater, the chemical analysis, the method to back-calculate METH use, the estimation of the size of the population, and the human urinary excretion of metabolites (Castiglioni, et al., 2013; Lai, et al., 2011; Mathieu, Rieckermann, Berset, Schuerch, & Brenneisen, 2011). Gaussian error propagation has become widely used to calculate the uncertainty of estimation (Brewer, Ort, Banta-Green, Berset, & Field, 2012; Mathieu, et al., 2011). This approach obtains the relative standard deviation (RSD) of average values of estimation through the calculation the RSD of input parameters. This approach only analyzes the uncertainty of average values of estimation and cannot provide any information on the variability of estimation.

Variability refers to the heterogeneity of a quantity over time, location, or members of a population. For example, the correction factors of excretion rates exhibit variability

due to individual variability. Variability is quantified by a distribution of frequencies of multiple instances of the quantity, derived from observed data. Uncertainty arises due to the lack of knowledge regarding the true value of a quantity. Uncertainty can be attributed to random sampling error, measurement error, lack of representativeness, and data gaps. For example, the concentration contains a degree of measurement uncertainty arising from measurement error. Unlike variability, uncertainty can be reduced with better data and/or better models. Uncertainty can be quantified as a probability distribution representing the likelihood that the unknown quantity falls within a given range of values.

As a representative of a probabilistic approach, Monte Carlo simulations can quantify model inputs in estimation models (Jones, et al., 2014; Wang, Aggarwal, et al., 2015; Wang, Alaei, Byer, Brimble, & Pacepavicius, 2013; Wang, Du, Pei, Liu, & Guo, 2015), and assess the variability and uncertainty of METH use. Li et al. (2014) reported that METH use through wastewater analysis collected from 13 WWTPs in Beijing, China. However, there is no uncertainty and variability of the estimation of the prevalence of METH use in Beijing. Hence, the major objectives of the present study are to estimate the uncertainty and variability associated with the estimation of METH use using the sampling and analytical data in Beijing, China (Li, et al., 2014). According to a newly developed model, the 12-month prevalence of METH use was estimated among the general population in Beijing.

Methods and models

Back-calculation of METH consumption

To estimate the amount of METH consumed, detected concentrations of METH were combined with wastewater flow rates, correction factors, and population served by WWTPs to calculate the daily METH consumed per capita ($J_{M,METH}$) for a WWTP. This value is summarized in the following equations:

$$J_{METH} = \frac{C_{METH,i} \times F_i \times f_{METH}}{P_i} \quad 1$$

where $C_{METH,i}$ is the concentration of METH in a WWTP of i , F_i is the flow rate of raw wastewater in a WWTP of i , P_i is the population served by a WWTP of i , and f_{METH} is the correction factor for METH.

To obtain a general view of consumption on a regional scale, more than one typical WWTP should be sampled to reflect the average consumption. Therefore, the average consumption for all 13 WWTPs ($J_{M,METH}$) should be calculated by the total mass load with their total population (Table 1).

$$J_{M,METH} = \frac{f_{METH}}{P_T} \sum_{i=1}^n C_{METH,i} \times F_i \quad 2$$

where n is the number of the WWTPs from 1 to 13 and P_T is the total population served by all 13 WWTPs.

The correction factor is related to the excretion rates and the mass fraction of METH for routes-of-administration. METH can be administered through four routes: smoking,

oral ingestion, injection, and nasal insufflations (Courtney & Ray, 2014). Smoking is the dominant route-of-administration in China (Du, et al., 2014) and 98.6% of users in Beijing use METH through smoking (Wang, et al., 2008). Khan and Nicell (2012) summarized the urinary excretion profile of METH administered through various routes based on ten suitable studies. The analysis of compiled data suggests that the enantiomeric-composition and route-of-administration have little influence on the urinary residues. The major urinary residues are unchanged METH, the three metabolites of amphetamine, hydroxymethamphetamine, and hydroxyamphetamine. The unchanged METH is the best candidate among all of the various METH residues to calculate consumption of METH because it is the major urinary drug residue, is fairly stable and is able to adsorb negligibly onto solid phases in wastewater (Metcalf, Tindale, Li, Rodayan, & Yargeau, 2010). The meta-analysis of compiled data (Khan & Nicell, 2012) suggests that urinary excretion rate ($42 \pm 17\%$) is notably similar when METH is administered through oral ingestion, injection, or nasal insufflations; however, the urinary excretion rate ($27 \pm 8\%$) of smoking is significantly lower compared to other routes because significant amounts of METH initially placed in smoking devices end up not being delivered to users. If we do not consider the delivery yield of smoking devices, the four administration routes should have a similar urinary excretion rate ($42 \pm 17\%$).

Considering the different excretion ratios between smoking and other routes, the f_{METH} should be calculated based on the mass fraction of METH for routes-of-administration and their corresponding excretion rates.

$$f_{\text{METH}} = \frac{1}{x_{\text{Smoked}} R_{\text{Smoked}} + x_{\text{Non-smoked}} R_{\text{Non-smoked}}} \quad 3$$

where R_{Smoked} and $R_{\text{Non-smoked}}$ are the percentages of abuser using METH through smoking and non-smoking routes, and x_{Smoked} and $x_{\text{Non-smoked}}$ are the excretion percentages of unchanged METH through smoking and non-smoking routes. The values of R_{Smoked} and $R_{\text{Non-smoked}}$ were 98.6% and 1.4% based on the investigation of 139 people who abused METH in Beijing, respectively (Wang, et al., 2008).

The total consumption of METH per year in Beijing can be calculated based on the average METH consumed in the total population in Beijing ($P_{\text{Beijing}} = 21.15$ million).

$$m_{\text{METH}} = 365 f_{\text{METH}} \frac{P_{\text{Beijing}}}{P_{\text{T}}} \sum_{i=1}^n C_{\text{METH},i} \times F_i \quad 4$$

where P_{T} is total population (11.7 million) in the city investigated.

Back-calculation of the number of abusers and prevalence rate

From an epidemiological and public health perspective, a desirable goal would be to estimate the number of abusers of METH. Recognizing this goal, the estimated prevalence of METH use as the number of people (P_{Abuser}) having used METH in the last 12 months can be calculated based on the following equation:

$$P_{\text{Abuser}} = \frac{f_{\text{METH}}}{D \times n_{\text{D}}} \frac{P_{\text{Beijing}}}{P_{\text{T}}} \sum_{i=1}^n C_{\text{METH},i} \times F_i \quad 5$$

where D is the one-time dose of METH demanded, and n_D is the frequency of METH use. The size of the typical dose is estimated to be 135 ± 80 mg in this study, which is much higher than the typical value of 30 mg suggested by the United Nations Office on Drugs and Crime (UNODC) (UNODC, 2004). The low dose of METH (5-30 mg) was often used in the research of pharmacokinetics, and the high dose was used by the illicit users (> 50 mg) (Cruickshank & Dyer, 2009). All addictive drugs produce tolerance, and addicts compensate by increasing drug exposure. The quantity of illicit drug ingested is related to the severity of the addiction. METH has been known to cause death at an ingested dose as low as 1.5 mg per kg body weight, while long-time abusers developing a drug tolerance may use as much as 5,000 to 15,000 mg per day (Derlet & Heischouer, 1991).

The representative values for n_D was 0.31 ± 0.31 dose/d/capita, as reported from METH-experienced people in six provinces in China (Bao, et al., 2015). The 12-month prevalence rates of METH use were estimated among the general population (21.15 million), adult population aged 15-64 years (17.5 million) and young adult population aged 15-34 years (8.3 million) in Beijing in 2013.

Uncertainty analysis

This estimation is also subjective to a number of uncertainties associated with the different steps involved. The uncertainty and variability of input parameters induce the

uncertainty of estimations. The input parameters have some degree of uncertainty in the estimation consumption due to the use of average values. To this end, the Monte Carlo simulation (Oracle Crystal Ball software, Version 7.3.1) was used to conduct the uncertainty analysis. The Monte Carlo simulation was based on repeated random sampling ($n=100,000$ samples) of the probability distributions defined for the principal factors of variation and uncertainty of each assumed parameter. The Monte-Carlo approach allows the possibility of describing the uncertainty and variability associated with the parameters and incorporating them into the estimates of consumption and number of abusers. The final result was a distribution of the consumption with corresponding probabilities. For analyzing the results, the mean and median values, as well as the 2.5% and 97.5% percentiles [i.e., 95% confidence interval (CI)], were extracted and presented.

Selecting appropriate input distributions for uncertain and variable inputs is crucial to the integrity of probabilistic analysis results. A distribution is selected based on how well it represents a sample data set from the population, the judgments of experts, the characteristics of the underlying population, or some combination of these factors. The best representative distribution may be empirical, or any of a number of parametric distributions (e.g., normal, lognormal, uniform, triangular, weibull, etc.). All the parameters used in this study were assumed to be normal or lognormal distributions. When a quantity is affected by a large number of random variables together, the result will tend to take on the shape of a normal distribution. A theoretical criterion for selecting

the normal distribution is based on the central limit theorem (CLT). The normal distribution can be used to represent a quantity for which the underlying mechanism can be described by the CLT. The CLT can also be used as the basis for selecting a lognormal distribution to represent a quantity. The lognormal distribution has often been found to be a good representation of non-negative, positively skewed physical quantities, such as pollution concentrations and rates of elimination of toxicants (Hattis & Burmaster, 1994; Morgan & Henrion, 1990).

The parameter of C_{METH} , assumed to be lognormal distributions, was obtained from the average values and standard deviation analyzed in each WWTP. The values of P and F of each WWTP were assumed to be normal distributions that were obtained from the average values and 10% of the RSD. The value of P_{Beijing} was assumed to be normal distributions that were obtained from the average value and 2% of RSD. The standard deviation of concentrations and flow rates should include the natural variability of measure concentrations, flow rates in various sampling days, and the analytical and measurement errors.

The distributions of urinary unchanged METH as percentage of the total amount of METH excreted (mean and standard deviation) were assumed to be lognormal distributions. The parameters of x_{Smoked} and $x_{\text{Non-smoked}}$ were assumed to be lognormal distributions that were obtained from the average values and the standard deviation. The parameters of D and n_D were assumed to be lognormal distributions. Tables 1 and 2 show description of the Monte Carlo parameter distributions for estimation.

Sensitivity analysis

The sensitivity analysis shows how much each predictor variable contributes to the uncertainty or variability of the predictions. In turn, it adds information on which portion of the variability is from natural fluctuation versus how much is caused by lack of knowledge. The contribution of an assumption to the total variance of the forecast was obtained as the square of the correlation coefficient normalized to the sum of the squared correlation coefficients adjusted to 100%.

Results and discussion

Daily consumption of METH per capita

Due to the relation between the value of f_{METH} and the routes-of-administration, the value of f_{METH} used in this study is estimated to be 3.68, based on the investigation in Beijing. According the f_{METH} value and data listed in Table 1, the mean daily METH consumed in 13 WWTPs is estimated to be 122 $\mu\text{g/d/capita}$ in Beijing. The probability distribution density of daily METH consumed per capita using the Monte Carlo simulation showed that the median value is 125 μg (95% CI: 63-246)(Figure 1). These estimations imply that METH consumption per capita varied between 23 and 90 mg per year with a median value of 46 mg per year. Because the estimation is calculated as the product of several probability distributions, the distribution of METH is approximately lognormal as result of the CLT. The skewness value of 0.63 for the lognormal

distribution of consumption suggests that heavy users consumed more than half the METH than recreational users.

Total consumption and geographical pattern of METH

In order to assess the consumption of METH in Beijing, we calculated the consumption of METH based on the mean mass load and total population of the city. The total consumption was 940 kg based on a population of 21.15 million in Beijing. The Monte Carlo simulation analyzed the uncertainty and variability of METH consumption in Beijing. The cumulative distribution for consumption (Figure 2) indicates that the total consumption of METH was 963 kg (95% CI: 492-2007) in 2013. These estimated results indicate that almost one thousand kg of METH were consumed in one year in Beijing. It should be noted that there are some limitations on the estimated consumption. In this study, we used the resident population to calculate the consumption of METH and did not take the floating population for consideration. In fact, Beijing is the capital of China; therefore, the floating population for touring was 0.4 million per day in 2013 (Xia, 2014), which estimates a gap of 18 kg, ignoring the floating population. Therefore, the consumption of METH of 963 kg per year is underestimated. However, we used the average consumption of the population living in the center of Beijing, which may be higher than the average consumption of the population living in the suburban areas. From this viewpoint, the total consumption in Beijing may be overestimated. Considering all factors in this estimation, the final result predicted in our study may be reliable.

To understand the overall consumption in densely populated areas, the population-weighted METH consumption was calculated as the products of the estimated METH consumption per capita and average population density in 18 districts in Beijing (Figure 3). The calculated population-weighted consumption shows the low-high-low trend from urban center to suburban spaces. The consumption of Dongcheng and Xicheng districts are about tens of kg per year. Consumption then increases to over 100 kg per year in the Chaoyang, Haidian and Fengtai districts and then declines to tens of kg per year. The high population-weighted consumption is mostly concentrated in the Chaoyang, Haidian and Fengtai districts, with the highest population in Beijing. The geographical differences may be related with the socio-economical factors, such as residential income, housing price, crime rate, transportation convenience, and business prosperity. However, we cannot determine a significant relationship between these socio-economical factors and METH consumption. Further study should be performed to identify a potential socio-economic indicator of drug consumption.

Number of abusers and prevalence of METH

Based on Equation 5, the number of people having potentially used METH in the last 12 months and according prevalence of METH use was estimated in Beijing. Figure 4 illustrates the cumulative probability distribution of density of the abuser and the 12-month prevalence in Beijing. The number of METH abusers in Beijing was estimated to be 101,000 (95% CI: 14,000-554,000). The 12-month prevalence of METH use was

estimated to be 0.48% (95% CI: 0.06-2.65) in the general population, corresponding to a 12-month prevalence of 0.58% (95% CI: 0.08-3.16) of the adult population aged 15-64 years. To the best of our knowledge, there is not any information on the prevalence of METH use in general population in China (Sun, Chen, Yang, Lu, & Kosten, 2013). This report is the first to describe the prevalence of METH among general population in the mainland of China. The estimated results in this study cannot be compared with any other studies. The UNODC has reported the use of ATS in the world based on annual report questionnaire data and other official sources. The value in this study agrees well with the 12-month prevalence (best estimate = 0.6%, range of 0.2-1.3%) of the use of ATS in East and South-East Asia (UNODC, 2015). Beijing shows a similar prevalence rate to the United States of America (U.S.A.). METH use in the U.S.A. displays a stable trend, with an annual prevalence of METH use among the general population aged 15-64 having remained in the range of 0.5% to 0.6% between 2010 and 2013 (Courtney & Ray, 2014). Compared to other countries and regions, Beijing shows a relative high prevalence rate of METH use. Estimated prevalence of METH use based on sewage epidemiology suggested that the METH use was 0.45% in three Canadian cities (Metcalf, et al., 2010) and 0.23% (0.04-0.42%) in five cities from South Korea (Kim, et al., 2015).

According to government registered drug users in Beijing, 80% of registered METH abusers' age are lower than 35 years (Wang, et al., 2008). Assuming only young adults aged 15-34 years use METH, the 12-month prevalence rate can be estimated to be 1.5%

(95% CI: 0.2-6.8). The estimated use reaches 1.5% among young adults, which indicated that 1 out of 67 people between the ages of 15 and 34 years used METH. The reasons for the high prevalence of METH are probably linked to high levels of METH availability, peer pressure, and cheap prices. Therefore, this high prevalence of METH use is a serious social problem that needs to be solved by increased drug-control programs and initiatives.

Key parameters affecting the estimations

The parameters of concentrations, wastewater flow, population size, excretion rate of unchanged METH, dose and frequency of METH use have potential influences on the estimation of drug consumption and number of abusers. In this study, we presented these parameters for the sensitivity of the distributions for METH consumption and number of abusers in Beijing (Figure 5). The sensitivity analysis for METH consumption shows that the excretion percentage of unchanged METH through the smoking route contributed to 66% of the variance, while the concentrations in WWTP of GBD and in WWTP of SHM contributed to 14% and 11%, respectively (Figure 5a). The excretion rate plays the most important role in the uncertainty and variability of the estimation of METH consumption. Due to inter-individual heterogeneity of the excretion rate, the variability in excretion rates was the main factor which affected the final uncertainty of the consumption estimation. The parameters of concentration also have influences on the uncertainty and variability of estimation. The uncertainty of concentration may originate from many sources, such as the measurement error, stability of METH, and representativeness of

sampling. In addition, we estimated the average consumption in one year over a six-day sampling in 2013; therefore, the temporal variation in concentrations could be considered in this study.

The parameters of frequency of METH use and dose have high influences on the estimation of corresponding number of abusers, which accounted for 63% and 26%, respectively. The parameter of excretion rate is also an important contributor (7%) to overall variance to the number of abusers. The contribution of the other input parameters was lower than 4% (Figure 5b). In this study, the frequency of METH use can be affected by the drug use characteristics of METH users. The proportion of heavy or recreational use among these people determined the frequency of METH use. The high proportion of heavy users means high use frequency. In this study, the frequency of METH use (0.31 ± 0.31 dose/d/capita, median: 0.22 dose/d/capita) was estimated from the participants recruited from the compulsory detoxification and rehabilitation centers in six provinces of China. The recreational users (fewer than five times per month) and heavy users (over 20 times per month) contributed to 59% and 14% of total METH users. The remaining 27% METH users reported using the drug between five and 19 times per month. Therefore, the wide distribution of frequency may induce high uncertainty of prevalence rate in this study.

In addition, the average content of pure active drug in a typical dose taken by the most common route was approximately 30 mg (UNODC, 2004). However, the actual dose demanded by abusers can be affected by many factors, such as purity of METH and

route-of-administration. The purity of street products (crystals or tables) fluctuates unpredictably with time and in different locations (Wang, Yu, Shi, & Xiang, 2015), leading to possible miscalculation of the actual average amounts of active drug taken as a dose (Zuccato, Chiabrando, Castiglioni, Bagnati, & Fanelli, 2008). In fact, the dose of METH use reported by the abusers in Beijing (Bao, et al., 2013), due to the purity in street products, is far greater than the typical dose recommended by the UNODC. Drug intake routes have an effect on the dose of METH use. The bioavailability (90.3%) of smoked METH is greater than that (67.2%) of the oral route (Cook, et al., 1993) which, in turn, may affect the dose. Furthermore, the drug use habit is another important factor controlling the dose, which is dependent on the abuser ratios of recreational and heavy use.

Conclusions

The probabilistic analysis is a good tool to assess the uncertainty and variability of estimation for drug consumption and prevalence. The Monte Carlo simulation indicated that the total METH consumption was 963 kg per year based on a population of 21.2 million in Beijing. It is estimated that a total of 101,000 people between the ages of 15 and 64 years used METH. This study is the first to report the prevalence of METH use among the general population in Chinese cities. Our research provides the evidence of consumption, which is of great importance to help the administration strengthen evidence-based prevention and treatment of illicit drugs. Further research should focus on

the development of mathematical modeling to account for dose and frequency of use based on local drug use habits.

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Figure captions

Figure 1. Probability distribution of estimated mass load of METH ($\mu\text{g/d/capita}$) in Beijing: mean, median, 2.5th, and 97.5th percentiles.

Figure 2. Cumulative probability distribution of estimated consumption of METH (kg per year) in Beijing: mean, median, 2.5th, and 97.5th percentiles.

Figure 3. Spatial pattern of population-weighted METH consumption in Beijing.

Figure 4. Cumulative probability distribution of estimated population ($\times 10^3$) of abusers and prevalence of METH in Beijing: mean, median, 2.5th, and 97.5th percentiles.

Figure 5. The results of sensitivity analysis for estimated consumption (a) and number of abusers (b) of METH in Beijing.

Tables

Table 1. Monte Carlo parameter distribution for population, flow rate, and concentrations in 13 WWTP for estimation of METH use in Beijing. The original data of concentration, flow rate and population was cited from Li et al. (2014).

WWTP	Concentrations (ng/L)			Flow rate ($\times 10^4$ m ³ /d)			Served population of WWTP ($\times 10^6$)		
	Symbol	Type	Distribution	Symbol	Type	Distribution	Symbol	Type	Distribution
GBD	Cgbd	lognormal	128 $\pm$ 63	Fgbd	normal	950 $\pm$ 95	Pgbd	normal	3.45 $\pm$ 0.35
QH	Cqh	lognormal	64.1 $\pm$ 36.5	Fqh	normal	550 $\pm$ 55	Pqh	normal	1.52 $\pm$ 0.15
XHM	Cxhm	lognormal	170 $\pm$ 103	Fxhm	normal	600 $\pm$ 60	Pxhm	normal	3.33 $\pm$ 0.33
BXH	Cbxh	lognormal	158 $\pm$ 61	Fbxh	normal	100 $\pm$ 10	Pbxh	normal	0.285 $\pm$ 0.029
JXQ	Cjxq	lognormal	168 $\pm$ 64	Fjxq	normal	350 $\pm$ 35	Pjxq	normal	0.685 $\pm$ 0.068
FZ	Cfz	lognormal	191 $\pm$ 80	Ffz	normal	43.1 $\pm$ 0.4	Pfz	normal	0.180 $\pm$ 0.018
WJC	Cwjc	lognormal	166 $\pm$ 62	Fwjc	normal	80.0 $\pm$ 8.0	Pwjc	normal	0.257 $\pm$ 0.026
LGQ	Clgq	lognormal	129 $\pm$ 59	Flgq	normal	80.0 $\pm$ 8.0	Plgq	normal	0.519 $\pm$ 0.052
TZ	Ctz	lognormal	135 $\pm$ 37	Ftz	normal	100 $\pm$ 10	Ptz	normal	0.571 $\pm$ 0.057
XJH	Cxjh	lognormal	37.0 $\pm$ 23.0	Fxjh	normal	20.6 $\pm$ 2.1	Pxjh	normal	0.186 $\pm$ 0.019
BY	Cby	lognormal	88.8 $\pm$ 25.2	Fby	normal	40.0 $\pm$ 4.0	Pby	normal	0.457 $\pm$ 0.046
YF	Cyf	lognormal	35.0 $\pm$ 20.1	Fyf	normal	20.0 $\pm$ 2.0	Pyf	normal	0.087 $\pm$ 0.009
WQ	Cwq	lognormal	13.1 $\pm$ 8.9	Fwq	normal	20.0 $\pm$ 2.0	Pwq	normal	0.060 $\pm$ 0.006

Table 2. Monte Carlo parameter distribution of other input parameters for estimation of METH use in Beijing

Parameter	Symbol	Units	Type	Distribution
Excretion percentage of unchanged METH through smoking route	X_{Smoked}	unitless	lognormal	$27\% \pm 8\%$
Excretion percentage of unchanged METH through non-smoking route	$X_{\text{Non-Smoked}}$	unitless	lognormal	$42\% \pm 17\%$
Percentage of abuser using METH through smoking route	R_{Smoked}	unitless	point	98.6%
Percentage of abuser using METH through non-smoking route	$R_{\text{Non-Smoked}}$	unitless	point	1.4%
Population of Beijing in 2013	P	million	normal	21.15 ± 0.42
Percentage of population aged 15-64 in Beijing	R_{15-64}	unitless	point	82.7%
Percentage of population aged 15-34 in Beijing	R_{15-34}	unitless	point	39%
One-time dose of METH demanded	D	mg	lognormal	135 ± 80
Number of dose a abuser use METH per day	n_D	dose/d/capita	lognormal	0.31 ± 0.31

Figure

Figure 1

Figure 2

Figure 3

Figure 4

a

b

Figure 5