Water Research 84 (2015) 76–84

Contents lists available at ScienceDirect

Water Research

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

Methamphetamine and ketamine use in major Chinese cities, a nationwide reconnaissance through sewage-based epidemiology

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ARTICLE INFO

Article history:
Received 28 April 2015
Received in revised form
13 July 2015
Accepted 15 July 2015
Available online 17 July 2015

Keywords:
Methamphetamine
Ketamine
Sewage-based epidemiology
Use
China

ABSTRACT

Sewage-based epidemiology was applied to examine geographic variations in methamphetamine (METH) and ketamine (KET) use in China. Influent and effluent wastewater samples were collected from 36 sewage treatment plants (STPs) in 18 major cities that cover all the geographic regions of the country. Mean METH loads of the cities ranged from 12.5 ± 14.9 to 181.2 ± 6.5 mg/1000 inh/d, whereas mean KET loads ranged from <0.2 to 89.6 ± 27.4 mg/1000 inh/d. No clear geographical pattern was observed in METH use, although slightly lower use in north and east China relative to other regions can be suggested. In contrast, an overall increasing trend from the north to the south was evident for KET loads. Apparent METH removal was greater than 80% at most STPs, whereas KET removal was less than 50% at most STPs and was even negative (i.e., measured effluent concentrations were greater than influent concentrations) at a significant number of STPs. Results in Beijing, Shanghai, and Shenzhen indicate that METH use in China may have increased substantially since 2012, whereas KET use did not significantly change, if not decreased. Comparison between seizures and estimated consumptions reveals that seizures in most Chinese provinces are far less than consumptions. In several provinces (e.g., Guangdong and Yunan), however, seizures were found to exceed consumptions, indicating that a significant fraction of METH and KET seized in these provinces is destined for consumption in other places.

1. Introduction

China is a country that has witnessed rapid increases in illicit drug use in the past quarter of a century. The number of registered drug users has increased at an annual rate of at least 15% in the past decade (in some years over 18%), much greater than the annual growth rates of gross domestic production in the same period (Office of China National Narcotic Control Commission, 2014). The number of registered users has amounted to nearly 2.5 million by the end of 2013, which is more than twice the number of 2008. In addition, the registered users only account for a small fraction of the entire population of drug abuse, as only drug users caught by police are registered in China. However, the exact number of drug users in the country cannot be estimated at this point.

Drug seizures have also increased rapidly in China. The total seizure of common illicit drugs (heroin, opium, cannabis and cannabis resin, amphetamine-like drugs, ketamine, ecstasy, and cocaine) has nearly doubled from 2011 (28.8 tons, without correction by purity) to 2014 (52.3 tons) (Office of China National Narcotic Control Commission, 2012, 2015). The increase in total seizure arose primarily from the seizures of synthetic drugs: the increase of methamphetamine and ketamine seizures accounted for nearly 80% of the total increase. While drug seizure increases in the past few years concur with the significant increase in registered drug users, drug seizure by no means reflects the actual drug consumption in China. Thus, even rough estimates on prevalence and consumption of illicit drugs in China are lacking.

In the past decade, a novel approach called sewage-based epidemiology was developed to estimate drug consumption by a particular population. This approach collects influent wastewater samples from sewage treatment plants (STPs) and measures the concentrations of drug residues or its metabolites in the samples. The drug loads and consumptions of the communities served by the

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http://dx.doi.org/10.1016/j.watres.2015.07.025
0043-1354/

sampled STPs are then back calculated by applying flow rates of STPs, populations of the communities, as well as correction factors that account for excretion rates and in-sewer stabilities of the drugs (Zuccato et al., 2008). This approach can yield results in near real time as sample collection and analysis can be completed within one or two days. It holds the promise to serve as a good complement to the existing drug monitoring approaches.

Due to the strong interest to monitor drug abuse and measure the effectiveness of drug control efforts, as well as the relative easiness to implement sewage-based epidemiology, dozens of research groups worldwide have started to apply and refine this methodology. Since its first application in Italy by Zuccato et al. (2005), 135 articles related to sewage-based epidemiology and illicit drug use were identified on PUBMED, among which 122 were published between 2008 and 2013 (Prichard et al., 2014). Sewage-based epidemiology studies were predominantly carried out in Europe. It has been applied in Italy (Zuccato et al., 2005, 2008; Castiglioni et al., 2013; Repice et al., 2013), England(Bones et al., 2007; Kasprzyk-Hordern et al., 2009; Baker et al., 2014), Belgium(van Nuijs et al., 2009a; van Nuijs et al., 2011a,b), France(-Karolak et al., 2010), Spain(Postigo et al., 2008; Boleda et al., 2009; Postigo et al., 2010; Martínez Bueno et al., 2011; Andrés-Costa et al., 2014), Norway(Harman et al., 2011; Bramness et al., 2015), Finland(Kankaanpää et al., 2014; Vuori et al., 2014), Sweden(Östman et al., 2014), Slovakia(Mackul'ak et al., 2014), Croatia(Terzic et al., 2010), and across Europe (Thomas et al., 2012; Ort et al., 2014). Sewage-based epidemiology was also extensively applied in US (Chiaia et al., 2008; Loganathan et al., 2009; Bartelt-Hunt et al., 2009; Bisceglia et al., 2010; Banta-Green et al., 2009; Chiaia-Hernandez et al., 2011; Brewer et al., 2012; Heuett et al., 2015) and Canada(Metcalfe et al., 2010; Yargeau et al., 2014). In contrast, sewage-based epidemiology studies were scarce in regions other than Europe and North America. Australia is the country that first saw application of this methodology outside these regions (Irvine et al., 2011; Lai et al., 2013a).

Most of the sewage-based epidemiology studies so far were performed in/during specific settings or events, such as prisons (e.g., van Dyken et al., 2014), schools (Panawennage et al., 2011), and music festivals (Lai et al., 2013a), or at local community and city level (e.g., van Nuijs et al., 2011b; Terzic et al., 2010; Yargeau et al., 2014). Nationwide studies have been very limited. van Nuijs et al. (2009b) estimated cocaine consumption across Belgium by sampling 37 STPs that in total served about 40% of the Belgium population. Mackul'ak et al. (2014) collected wastewater samples from seven major cities in Slovakia and estimated drug consumption rates in these cities. In these nationwide studies, only use of traditional drugs (amphetamine, methamphetamine, cocaine, 3,4-methylenedioxymethamphetamine, heroin, and cannabis) was estimated. Occurrence and consumption of new psychoactive substances such as ketamine was not examined.

Sewage-based epidemiology studies have been scarce in Asia (Kim et al., 2015). China is the first Asian country to carry out such studies. Lai et al. (2013b) applied sewage-based epidemiology for the first time in China to estimate drug use in Hong Kong. They found that ketamine is the predominant drug of abuse, followed by methamphetamine and cocaine. Khan et al. (2014) performed a snapshot study by collecting and analyzing wastewater samples from four megacities, Beijing, Shanghai, Guangzhou, and Shenzhen. Methamphetamine and ketamine were found to be the major drugs of abuse in China. This finding is consistent with the fact that seizures of these two drugs ranked first and second, respectively, in the country (Office of China National Narcotic Control Commission, 2014). Li et al. (2014) sampled all the STPs in the urban area of Beijing to examine the consumption pattern of methamphetamine and amphetamine in the city. While these studies yielded useful insights on drug abuse in China, they did not provide information on drug use at the national level.

The objective of this work was to examine the geographic pattern of methamphetamine and ketamine use by urban inhabitants across China. Influent wastewater samples were collected from 36 STPs of 18 provincial capitals or equivalent cities that cover all the geographic regions of the country. Effluent samples were also collected from selected STPs to derive removal rates during wastewater treatment. Temporal variations in the use of these two drugs in a few megacities were examined by comparing drug loads obtained in 2014 (this study) and by Khan et al. (2014) in 2012. Comparing estimated drug consumptions and seizures in the sampled cities and provinces yielded interesting insights on drug abuse and trafficking in the country.

2. Materials and methods

2.1. Sample collection

Wastewater samples were collected from Beijing (BJ), Guiyang (GY), Haerbin (HRB), Hangzhou (HZ), Jinan (JN), Kunming (KM), Lanzhou (LZ), Luoyang (LY), Nanjing (NJ), Nanning (NN), Shanghai (SH), Shenyang (SY), Shenzhen (SZ), Shijiazhuang (SJZ),Wuhan (WH), Xi'an (XA), Xiamen (XM), Yinchuan (YC). These eighteen cities belong to all the eight geographic regions of the nation: northeast (HRB and SY); north China (BJ and SJZ); northwest (LZ, XA, and YC); central China (LY and WH), east China (JN, NJ, and SH); southeast (XM, HZ), southwest (KM and GY), south China (NN and SZ) (Fig. 1). The majority (15 of total 18) of the cities are provincial capitals or are under direct administration by the central government (BJ and SH). The other three cities (LY, XM, and SZ) are equivalent to provincial capitals in terms of economic development and population sizes. According to the recent census data, the population sizes of the cities range from 2.08 million of YC to 25 million of SH. The sum of the population of all the cities is 163.3 million, representing about 12% of entire population of China.

In total, wastewater samples were collected from 36 STPs in the above mentioned cities. In most cities, two or more STPs were selected for wastewater sample collection. In HRB, JN, LZ, and NN, however, only one STP in each city was sampled. Most sampled STPs treat wastewater from the urban centers of the cities. All the STPs are secondary types and involve activated sludge processes. The population served by the STPs totals 34.1 million, representing about 21% of the total population of the cities and 2.5% of the population of the entire country. The STPs are named as BJ-1 (first STP of Beijing), KM-2 (second STP of Kunming), etc.

The sampling campaign started in early July and ended in early October of 2014, with the majority of the sampling carried out between early August and mid-September. Each STP was sampled for two days (one weekend day and one weekday) by collecting 24-h composite samples at the sewage inlets using autosamplers, such as FC-9624 (GRASP Science & Technology Co., Ltd, Beijing), ISCO 3000, 3700, 4700 (Teledyne Technologies Inc., Lincoln, NE, USA), and GD-24A (Jinpeng Huanyi Technology Co., Ltd, Beijing). Heavy precipitation days were avoided for sampling. STPs were asked to program the autosamplers to imbibe 100 mL of influent at an interval of 1 h. A few STPs (SY-2, LZ-1, LY-1 and 2, XA-1 and 2) did not have autosamplers and denied entry of our own autosampler. For these STPs, 200 mL of wastewater was collected manually every 2 or 4 h throughout the day and was combined to form a composite sample. Effluent samples were also collected at about half of the STPs, in the same manner and at the same time as for the influents. Following collection, the samples were