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# Application of a sewage-based approach to assess the use of ten illicit drugs in four Chinese megacities

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## HIGHLIGHTS

- First study on sewage-based epidemiology in megacities from mainland China.
- Higher consumption of methamphetamine, ecstasy, ketamine and cocaine in South compared to North.
- Omnipresent use of methamphetamine among cities of mainland China.
- Prevalent use of ketamine in Southern China.
- Influent loads of most drugs were consistent with trends reported by the UNODC.

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## ABSTRACT

Sewage-based epidemiology was applied for the first time to a number of mainland Chinese megacities. The application monitored influents to 9 sewage treatment plants (STPs) to estimate the use of illicit drugs in Beijing, Guangzhou, Shenzhen, and Shanghai. Altogether, 11.4 million inhabitants were covered during September–October 2012. 24-h composite raw sewage samples were collected for 4 consecutive days at each STP. Each collected sample was analyzed for cocaine, benzoylecgonine, ecgonine methylester, methadone, 2-ethylidene-1,5-dimethyl-3,3-diphenylpyrrolidine, 6-monoacetylmorphine, amphetamine, methamphetamine, ecstasy, mephedrone, methylenedioxypyrovalerone, 11-nor-9-carboxy-delta-9-tetrahydrocannabinol, ketamine, and norketamine. Through the analysis of these chemical residues, the use of amphetamine, cannabis, cocaine, ecstasy, heroin, mephedrone, methadone, methamphetamine, methylenedioxypyrovalerone and ketamine among Chinese urban inhabitants was monitored. The results obtained demonstrated in a quantitative way that the drug use patterns of Chinese are different from their European counterparts. Abuse of methamphetamine and ketamine was particularly noteworthy in China, while consumption of cocaine and ecstasy, the most popular drugs in Europe, was very low among the sampled Chinese inhabitants. Further, the use of most drugs demonstrated a geographical trend, since their use was much higher in the southern cities of Shenzhen and Guangzhou than it was in Beijing and Shanghai. Interestingly, the exclusive, but minor, metabolite of heroin, 6-monoacetylmorphine, was detected only sporadically. This would suggest that the use of heroin among Chinese urban users sampled in the study was low. Further, the patterns of drug use observed during the study are largely consistent with trends reported by the United Nations Office on Drugs and Crime. Overall, our study suggests that sewage-based epidemiology can readily be used to monitor the use of illicit drugs in those countries/regions where traditional means to monitor drug use patterns have only yielded limited or information of questionable reliability.



## 1. Introduction

The presence of centralized sewage systems in most cities makes it a relatively easy task to monitor use of illicit drugs by its resident through the analysis of urban sewage (Daughton, 2011; van Nuijs et al., 2011a). In literature, such an approach is referred by some as "sewage epidemiology" (Zuccato et al., 2008). The clear advantage of a sewage driven

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approach, compared to traditional epidemiological studies, is that the use of illicit drugs by populations of various spatial scales can be readily and objectively quantified. The application of such an approach also makes it relatively easy to temporally track and hence grasp temporal trends with which an upstream population uses various illicit drugs (Mari et al., 2009; Metcalfe et al., 2010; van Nuijs et al., 2011b). Furthermore, trends in the use of various illicit drugs obtained through the application of a sewage-based approach appear to be in agreement with those obtained through the application of methodologies and/or approaches that have been traditionally used for such purposes (Reid et al., 2012). Since its first practical application 8 years ago (Zuccato et al., 2005), the use of a sewage-based approach to monitor use of illicit drugs of various urban populations has significantly expanded (van Nuijs et al., 2011a). In 2011, the use of illicit drugs by populations residing in nineteen European cities was simultaneously monitored over a number of days (Thomas et al., 2012). Outside Europe, where the approach has seen the widest application (some recent applications being Archer et al., 2013; Baker and Kasprzyk-Hordern, 2013; Nefau et al., 2013; Reid et al., 2014; van Nuijs et al., in press), sewage-based epidemiology has been used to understand trends with which various illicit drugs are used by urban populations residing in Australia (Chen et al., 2013a; Irvine et al., 2011; Lai et al., 2011), Brazil (Maldaner et al., 2012), Canada (Metcalfe et al., 2010), Hong Kong (Lai et al., 2013), Taiwan (Lin et al., 2010), and the United States (Banta-Green et al., 2009; Bisceglia et al., 2010; Chiaia-Hernandez et al., 2011; Kinyua and Anderson, 2012).

In recent years, the use of illicit drugs has seen a rapid increase in mainland China (Lu et al., 2008; Zhang, 2012). Unofficial estimates alluded to in interviews of local drug enforcement personnel, suggested that the number of illicit drug users in mainland China circa 2004/2005 was at least 10 to 12 million individuals (Swanstrom, 2006; Devaney et al., 2006), of these, however, only 1.2 million users were officially registered as drug addicts (Swanstrom, 2006). In seven years since, the number of officially registered drug addicts within mainland China has almost doubled to 2.1 million individuals (Zhang, 2012; Xinhua News Agency, 2013), while the unofficial estimate for the actual number of drug users in the country has not been updated. Therefore, the actual number of drug users within mainland China, nationally or regionally, largely remains unknown. More uncertain yet is the accurate number of users for each illicit drug. However, annually updated indirect measures such as the number of officially registered drug addicts and the quantity/mass of drug seized (UNODC, 2012) can be used to establish trends and levels with which various drugs are used in mainland China. These lines of evidence suggest that, while HER has been reported as the most widely used drug in China, the use of METH and KET has rapidly been expanding (UNODC, 2012). Consider that the use of these illicit drugs has increased from minor levels in 2007 to such levels in 2011 that METH and KET users were suggested to only be outnumbered by the number of HER users in the country (UNODC, 2012). COC, though globally important, is only of minor importance in China (UNODC, 2012). Use of MDMA and cannabis is also reported in China, but these drugs have been suggested to be used by far fewer Chinese inhabitants than the extent with which these drugs are used by inhabitants of Europe, North America or Australia (UNODC, 2012, 2013a, 2013b). Limited information is available as to the use of MEPH and MDPV among Chinese inhabitants (Hammond, 2012). However, illegal manufacturing facilities in China have been suggested to be an important source of these synthetic drugs internationally (DEA, 2011).

Overall, only limited information of questionable reliability is available through traditional routes for the trends with which Chinese inhabitants use various illicit drugs. Therefore, the overall objectives of the current investigation were to apply for the first time a sewage-based approach to assess the level with which a number of classical and emerging illicit drugs are used in megacities of mainland China and to assess geographical patterns of these drugs.

## 2. Materials and methods

### 2.1. Illicit drugs assessed

The use of the following illicit drugs among Chinese urban inhabitants was monitored in this study: amphetamine (AMP), cocaine (COC), ecstasy (MDMA), heroin (HER), ketamine (KET), methadone (MTD), methamphetamine (METH), mephedrone (MEPH), methylenedioxypyrovalerone (MDPV), and delta-9-tetrahydrocannabinol (THC, the primary active compound in cannabis).

### 2.2. Choice of metabolites for the selected illicit drugs used in sewage-based epidemiology

The accuracy and applicability of sewage-based epidemiology hinges on selecting suitable chemical residues to be monitored in raw sewage, so that the use of parent illicit drug by the upstream population can be assessed. Rather than the illicit drug itself, chemical residues that arise from human metabolism are more suitable for tracking use since their presence in raw sewage can be directly ascribed to human use (van Nuijs et al., 2011a). However, in certain cases, one needs to use the presence of the parent illicit drug in raw sewage samples to track the drug's use in the upstream population.

COC use was monitored by measuring the influent concentrations of its metabolites benzoylecgonine (BE) and ecgonine methyl ester (EME) (van Nuijs et al., 2011b). Dependent on the route with which it is administered, between 15 to 32% and 18 to 22% of an administered dose of COC is excreted as BE and EME, respectively (Khan and Nicell, 2011). COC itself was also monitored in this study so that its accidental or deliberate dumping could also be tracked. MTD use was tracked by monitoring wastewater influent concentrations of its major metabolite, ethylidene-1,5-dimethyl-3,3-diphenylpyrrolidine (EDDP). On average 27% of an administered dose of MTD is eliminated in human excreta (urine and feces) as EDDP (Verebely et al., 1975). Influent concentrations of MTD itself were also monitored in this study to track the accidental or deliberate disposal of the drug. Use of MDMA was tracked by measuring MDMA itself (van Nuijs et al., 2011b). Approximately, 20% of an administered dose of MDMA is excreted as parent compound (Abraham et al., 2009). Unchanged METH is the most suitable chemical residue to track its use; dependent on the route with which it is administered 27 to 43% of the administered dose of METH is excreted unchanged (Khan and Nicell, 2012). Similarly, unchanged AMP is the most suitable chemical residue to track its use (Khan and Nicell, 2012), 34–40% of an administered dose of AMP is eliminated unchanged. It is worth noting that in populations where there is significant use of illicit METH, unchanged AMP cannot be used to track its use since METH is also metabolized to AMP (Khan and Nicell, 2012). Approximately, 4 to 9% of an administered dose of METH is eliminated as AMP (Khan and Nicell, 2012). 11-Nor-9-carboxy-delta-9-tetrahydrocannabinol (THC-COOH) is the most suitable chemical residue to track an upstream population's use of THC (Khan and Nicell, 2012; Zuccato et al., 2008). However, the exact fraction of a smoked dose of THC that is eliminated as THC-COOH is very low and remains to be established (Khan and Nicell, 2012). Norketamine (NK) and KET itself were used to track an upstream population's use of ketamine (Baker and Kasprzyk-Hordern, 2011; van Nuijs et al., in press). 1.6% and 2.3% of an injected dose of ketamine are eliminated via the urinary route as NK and unchanged KET, respectively (Wieber et al., 1975). Thus far, largely incomplete data has been reported for the metabolic disposition of the new psychoactive substances MEPH and MDPV in humans (Meyer et al., 2010a, 2010b). Hence, preliminarily, the use, the manufacture and the accidental or deliberate disposal of these drugs within China was monitored by tracking the presence of parent MEPH and MDPV in raw sewage samples. The use of HER was tracked by monitoring its exclusive, but minor, metabolite 6-monoacetylmorphine (6-MAM) (Postigo et al., 2010; van Nuijs et al., 2011b). The major metabolite of heroin use, morphine, was

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