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Temporal trends in drug use in Adelaide, South Australia by wastewater analysis

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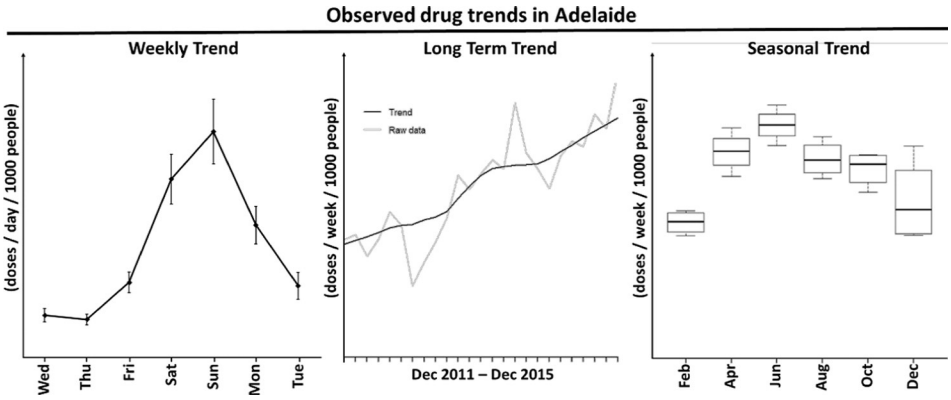
HIGHLIGHTS

- Wastewater was analysed bimonthly over four years to assess trends in drug use.
- Strongest long-term trends were increasing use of oxycodone and methamphetamine.
- Drugs such as MDMA, cannabis, morphine and heroin were either stable or decreasing.
- Use peaked on weekends for some drugs while others were constant over the week.
- Cannabis use was seasonal, in a manner consistent with the plant maturation cycle.

GRAPHICAL ABSTRACT



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ABSTRACT

Analysis of municipal wastewater for drug metabolites can reveal the scale of drug use within communities. An Australian city with a population of 1.2 million inhabitants was assessed for 4 stimulants: cocaine, methamphetamine, 3.4-methylenedioxymethamphetamine (MDMA) and amphetamine; 6 opioids: codeine, morphine, heroin, fentanyl, oxycodone and methadone; 11 new psychoactive substances (NPS); benzylpiperazine (BZP), trifluoromethylphenylpiperazine (TFMPP), methcathinone, methylone, mephedrone, methylenedioxypyrovalerone (MDPV), alpha pyrrolidinopentiophenone (alpha-PVP), paramethoxyamphetamine (PMA), 25C-NBOMe, 25B-NBOMe, 25I-NBOMe; and cannabis, for up to four years between December 2011 and December 2015. Temporal trends revealed increasing usage rates of methamphetamine, cocaine, oxycodone, and fentanyl, while decreasing rates of use were observed for MDMA, BZP and methylone. Use of other opioids and cannabis was generally stable across years, while use of new psychoactive substances fluctuated without an apparent direction. Opioids and cannabis were used at a consistent level through the course of the week, while use of stimulants and some NPS increased on the weekend. Seasonal differences in use were observed for MDMA and cannabis ($p $_amp_$lt; 0.05) where, on average, MDMA use was approximately 90% higher in December than in other months and cannabis use was approximately 45% lower in each February. Residual month-to-month variability measures on trend-free data showed NPS use had higher variability than the stimulants and opioids. Frequent wastewater sampling and analysis over prolonged periods has yielded valuable insights into long-term drug use trends, in some instances revealed important within-year trends, and demonstrated the differing patterns of use of drugs on weekends compared to weekdays.

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1. Introduction

Illicit drug use is of global concern, posing significant and challenging problems in every country. The direct and indirect effects of substance abuse, such as crime, disease, addiction and other social impacts put considerable pressure on many government, law enforcement and health departments. Due, in part, to the large proportion of drug-related overdoses involving prescribed substances, pharmaceutical opioids are also of concern (United Nations Office on Drugs and Crime, 2013). Therefore, it is imperative for governments to implement strategies to reduce harmful consumption of illicit substances and ensure proper use of pharmaceuticals in order to improve social and physical wellbeing.

In recent times, drugs of abuse and pharmaceuticals have been monitored through the analysis of municipal wastewater (Kasprzyk-Hordern et al., 2008; Zuccato et al., 2008) (for an extensive review, see (European Monitoring Centre for Drugs and Drug Addiction, 2016)). This technique provides timely and accurate information of population drug use without incriminating illicit drug users, while also capturing valuable data on pharmaceuticals that exhibit abuse potential. Monitoring drug use over time contributes meaningful information about underlying health concerns in the community and can quantify what might otherwise be anecdotal perceptions of changing patterns of drug use. A range of stakeholders, including health authorities, police and policy makers require such data to enable local and international comparisons, to identify differences, compare problems, and share possible solutions.

Consequently, wastewater analyses can be used to glean useful information about patterns of drug use over time: (1) Long-term trends can reveal whether use of drugs is stable, fluctuating, rising or on the decline; (2) Seasonal patterns can identify differences in use between months of the year, and between the same months in different years; (3) Patterns between days of the week can reveal levels of recreational versus habitual use, and (4) residual variability in month-to-month use can be assessed through subtraction of modelled trends. Particularly when used in conjunction with data from population surveys, wastewater data can give deeper insights into the health of communities under study.

Previous studies have employed wastewater analysis to monitor use at either very high frequency (every day assessed for the year) (Ort et al., 2014a), or at low frequency between years (the same one-week period compared between years) (Chen et al., 2013; Ort et al., 2014b; Thomas et al., 2012). We have utilised wastewater analysis techniques to monitor drugs in Adelaide, South Australia at an intermediate frequency. Cities in Australia lend themselves to wastewater analysis for several reasons: state capital cities are highly populated, have relatively stable populations, and are generally geographically isolated such that large-scale commuting between cities is negligible. Additionally, wastewater systems are sealed and kept separate from surface water runoff (storm water) systems, while rigorous census questionnaires enable demographics of regions under study to be accurately known.

Previously, we compared the scale of use of three popular stimulants to survey results from 2010 to 2013 (Tscharke et al., 2015). The present work reveals the trends in use of 22 drugs using moderate frequency of analysis (six weeks per year) over the course of up to four years of sampling between December 2011 and December 2015. Substances that were analysed were commonly used drugs or their metabolites, including cannabis and four established stimulants: cocaine, methamphetamine, amphetamine and 3,4-methylenedioxymethamphetamine (MDMA). Eleven new psychoactive substances (NPS) were assessed due to increased perceptions of use in the media and possible inclusion in "legal high" formulations; these included: benzylpiperazine (BZP), trifluoromethylphenylpiperazine (TFMPP), methcathinone, methylone, mephedrone, methylenedioxypyrovalerone (MDPV), alpha pyrrolidinopentiophenone (alpha-PVP), paramethoxyamphetamine (PMA), 25C-NBOMe, 25I-NBOMe and 25B-NBOMe. Six opioids were evaluated owing to their abuse potential and concerns of overdose, comprising of codeine, morphine, methadone, heroin, fentanyl and oxycodone.

2. Methods

2.1. Wastewater analysis

2.1.1. Materials

Deuterated isotopes and reference standards of each drug were purchased as certified solutions or powdered salts from Cerilliant (Round Rock, USA) and Toronto Research Chemicals (Toronto, Canada). The three NBOMe derivatives were gifted from Forensic Science South Australia.

2.1.2. Sample collection and analysis

Continuous flow-proportional composite wastewater samples (8 am–8 am) were collected over one-week periods in every second month, December, February, April, June, August and October from December 2011 to December 2015. Samples were collected at four treatment plants consistent with previously reported methodologies, including the addition of 2 g/L sodium metabisulphite to stabilise the heroin metabolite, 6-monoacetylmorphine (MAM) (Chen et al., 2012). Overall, a total of 25 weeks, or 175 individual samples at each of four treatment plants were assessed for this study (grand total of 700 daily samples). Immediately after collection, samples were stored at 4 °C for up to seven days prior to solid phase extraction (SPE) and analysis by LC-MS-MS. LC-MS-MS equipment and methodologies are described in detail in the Supplementary materials.

All cationic compounds were extracted using a solid phase extraction (SPE) methodology as reported previously (Irvine et al., 2011). Anionic THC COOH was extracted using liquid-liquid extraction (LLE) as described in the Supplementary materials.

2.1.3. Quantification and calculation

Analyte concentration in wastewater was determined using standard addition isotope dilution calibration curves (analyte/internal standard ratio vs concentration ratio). Calibration curve samples consisted of an equal mixture of wastewater from each day at each plant within each batch. Deuterium labelled standards of each analyte served as internal standards, outlined in Table S1 of the supplementary materials, to account for analyte loss during extraction procedures.

Analyte concentration in wastewater was determined and converted to estimates of community use. Briefly, the back-calculated use load was calculated by multiplying the analyte concentration by the daily flow volume to yield total excreted mass load (mg/day). Dividing the mass load by population in 1000′s gave the excreted population mass load (mg/day/1000 people). One way to normalise for population change is to apply a population biomarker to analyses (Chen et al., 2014). However, this approach was not yet reported at the commencement of this study. The greater Adelaide region had a slow growth rate of 1.0% per year (2011–2015) according to the Australian Bureau of Statistics (2015), which we considered a negligible change. For the NPS, no further back-calculation was attempted as reliable human excretion data is lacking. Applying an excretion back-calculation factor for benzoylecgonine, methamphetamine, MDMA, amphetamine (minus contributions from methamphetamine excretion), noroxycodone, norfentanyl, 6-monoacetyl morphine, codeine, morphine, methadone and THC COOH converted the daily excretion load to the back-calculated use (mg used/day/1000 people) of cocaine, methamphetamine, MDMA, amphetamine, oxycodone, fentanyl, heroin, codeine, morphine, methadone and THC (cannabis), respectively. Where dosages are known, this can be represented as doses/day/1000 people if the consumed amount is divided by the known dosage (mg). Back-calculation factors and dosages are listed in the Supplementary materials, Table S2.