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Current trends in Finnish drug abuse: Wastewater based epidemiology combined with other national indicators

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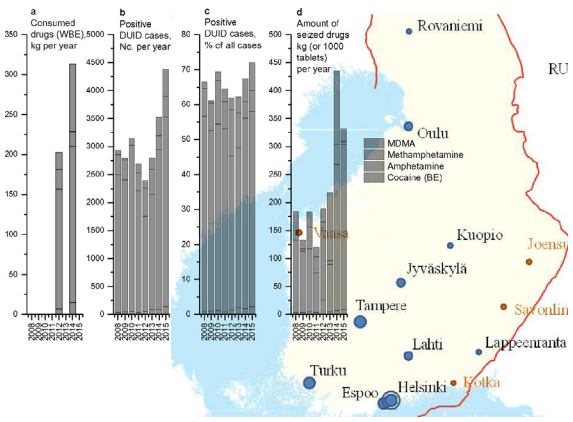
HIGHLIGHTS

- Wastewater-based epidemiology was combined with other indicators of drug use for joint interpretation of the data
- Regional drug use trends with extensive geographical coverage of 45% of the Finnish population
- The use of amphetamine, MDMA and cocaine has increased from 2012 to 2014 in Finland
- Amphetamine continues to dominate the Finnish stimulant-drug market in all parts of the country
- Market size estimates and estimates for a comparison of confiscated drugs to drugs consumed by users were performed

GRAPHICAL ABSTRACT



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ABSTRACT

No single measure is able to provide a complete picture of population- or community-level drug abuse and its current trends. Therefore, a multi-indicator approach is needed. The aim of this study was to combine wastewater-based epidemiology (WBE) with data from other national indicators, namely driving under the influence of drugs (DUID) statistics, drug seizures, and drug use surveys. Furthermore, drug market size estimates and a comparison of confiscated drugs to drugs actually consumed by users were performed using the WBE approach. Samples for wastewater analysis were collected during one-week sampling periods in 2012, 2014 and 2015, with a maximum of 14 cities participating. The samples were analysed with a validated ultra-high-performance liquid chromatography-mass spectrometric (UHPLC-MS/MS) methodology for various common drugs of abuse. The results were then compared with data from other national indicators available. Joint interpretation of the data shows that the use of amphetamine and MDMA has increased in Finland from 2012 to 2014. A similar trend was also observed for cocaine, although its use remains at a very low level compared to many other European countries. Heroin was practically absent from the Finnish drug market during the study period. The retail market for the most common stimulant drugs were estimated to have been worth EUR 70 million for amphetamine and around EUR 10 million for both methamphetamine and cocaine, in 2014 in Finland.

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1. Introduction

In 2001 Daughton first proposed the idea of untreated municipal wastewater as a highly diluted urine sample from the population residing in the area (Daughton, 2001). Despite its short history, wastewater-based epidemiology (WBE) has become an established discipline to monitor regional use trends of illegal drugs, with >40 publications in 2014 (Castiglioni and Vandam, 2016). In addition to the endeavors of the scientific community, a crucial factor in the rapid recognition of the concept in Europe has been the interest and support of the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA), which also hosts an interactive website presenting the results of an ongoing European multi-city study now covering 80 cities, including 14 Finnish cities today (EMCDDA, 2016).

Most of the earlier WBE studies were focused on drug use in major cities, but lately, more extensive studies that include both bigger and smaller cities have also been carried out, as exemplified by the study of Nefau et al. (2013) that included 25 cities in France. We started systematic, nationwide monitoring of the Finnish drug situation by means of wastewater analysis initially in 2012, with ten cities participating (Kankaanpää et al., 2014). In 2014, to further improve the geographical coverage of the study, four additional towns situated in previously uncovered parts of Finland were invited to participate. These 14 cities and neighbouring areas covered approximately 45% of the Finnish population. To the authors' knowledge, this is the widest coverage in national drug abuse studies based on WBE. However, a multi-indicator approach and joint interpretation of complementary data from various sources is still likely to give a better image of the current drug situation and its past development.

On the other hand, the WBE approach is completely different from various other methodologies for estimating drug prevalence and related issues, and therefore WBE can be used innovatively and complementary to other approaches. For example, estimates and calculations of the size of a drug market are challenging, since the nature of the drug market is largely hidden and criminal. For the first time EMCDDA and Europol estimated that the size of Europe's drug market is worth at least EUR 24 billion in 2013 (EMCDDA and Europol, 2016). Nevertheless, it was admitted that these new estimates were based on very limited data, with many gaps, which has necessitated some very broad assumptions. Wastewater analysis data was not used in these calculations and may at least complement other approaches.

The main aim of the study was to assess community-level drug abuse by combining WBE with driving under the influence of drugs (DUID) statistics, drug seizure data from the Police and Finnish Customs authorities, and drug use survey data. Furthermore, since the WBE approach allows unique possibilities for estimating the size of the drug market, in terms of quantity and value, we combined data from different sources to perform these novel types of estimates for a few main drugs. The WBE approach was also applied for comparing confiscated drugs to drugs actually consumed by users.

Wastewater samples were collected during two one-week sampling campaigns in 2012 and again in 2014, with 10 and 14 cities participating per year respectively. The sampling campaign of 2015 was more limited, with the four biggest cities participating only. The analytes included in this part of the study were amphetamine, methamphetamine, 3.4-methylenedioxymethamphetamine (MDMA, 'Ecstasy'), cocaine and its metabolite benzoylecgonine (BE), and the heroin marker 6-monoacetylmorphine (6-MAM), as well as methadone and its metabolite EDDP. Cannabis was not included in the study, since its biomarker carboxytetrahydrocannabinol may suffer from some sampling and analytical challenges, and therefore the authors do not consider its results adequately accurate in wastewater.

2. Material and methods

2.1. Chemicals, reagents and materials

Amphetamine sulphate, cocaine hydrochloride and MDMA hydrochloride were purchased from Sigma-Aldrich (St. Louis, MO, USA). Methamphetamine hydrochloride and methylenedioxyamphetamine (MDA) hydrochloride, and 6-MAM were donated by the UN Narcotics Laboratory (Vienna, Austria). The cocaine metabolite BE and the methadone metabolite EDDP, as well as the deuterated drug analogues amphetamine-d_6, cocaine-d_3, MDMA-d_5, methamphetamine-d_{14} and benzoylecgonine-d_3, were purchased from Cerilliant (Round Rock, TX, USA) at concentrations of 1 mg/mL, or 100 μg/mL in methanol or acetonitrile. Carbon 13-labelled internal standards $^{13}C_6$-amphetamine sulphate, $^{13}C_6$-methamphetamine hydrochloride and $^{13}C_6$-MDMA hydrochloride were purchased from Chiron AS (Trondheim, Norway). All of the reagents used were of the highest quality. Water was purified to a UHQ grade using a Millipore Direct-Q system from EMD Millipore Corporation (Billerica, MA, USA) equipped with an LC-Pak™ (Millipore), C_{18} reverse-phase silica cartridge to minimize interference from organic impurities in the mobile phase. The Oasis MCX Vac RC (60 mg) SPE cartridges were from Waters (Milford, MA, USA).

2.2. Sample collection and storage conditions

For the nation-wide studies of 2012 and 2014, composite 24-h samples of untreated wastewater were collected twice a year during one-week sampling periods from the inlets of fourteen wastewater treatment plants (WWTPs) located in the cities of Espoo, Helsinki, Joensuu (since 2014), Jyväskylä, Kotka (since 2014), Kuopio, Lahti, Lappeenranta, Oulu, Rovaniemi, Savonlinna (since 2014), Tampere, Turku, and Vaasa (since 2014). The geographical locations of the cities are shown in Fig. 1, with cities participating since 2014 printed in yellow. The number of inhabitants served by each WWTP ranged from 800,000 to <30.000, and they are listed in detail in the left panel of Fig. 4. In addition, a more limited sample collection was carried out in 2015, with the biggest WWTPs of Helsinki, Espoo, Turku and Tampere participating only.

Using the equipment available at each WWTP, five to seven consecutive 24-h composite raw wastewater samples were collected in either a volume- or time-proportional mode. A volume-proportional sampling mode was used in all WWTPs except Lappeenranta, Savonlinna, Joensuu, Oulu and Rovaniemi, where samples were collected in a time-proportional mode. From the sampling device, samples were immediately transferred to glass bottles and acidified (pH 2 with hydrochloric acid) to prevent the degradation of compounds prior to analyses (Gheorghe et al., 2008; Baker and Kasprzyk-Hordern, 2011). The samples were stored in a refrigerator until dispatched in coolers to the National Institute for Health and Welfare (THL), Helsinki, where they were stored in a deep-freeze state (at −18 °C) until analysed. The sampling campaigns were carried out as follows: 1) May 19 to 28, 2012; 2) November 25 to December 1, 2012; 3) March 11 to 17, 2014; 4) November 25 to December 1, 2014, and 5) March 11 to 17, 2015.

2.3. Sample pre-treatment, instrumentation, and analytical conditions

Sample pre-treatment was carried out with Oasis MCX cartridges, and instrumental analyses with a triple quadrupole UHPLC-MS/MS system as described earlier (Kankaanpää et al., 2014). However, in 2013 deuterated drug analogues were replaced as internal standards by ^{13}C analogues where available prior to the analysis of the national samples from 2014 and 2015.

The analytical methodology was validated prior to the first sample collection periods in 2012. A detailed description of the validation

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