European Monitoring Centre
for Drugs and Drug Addiction

Wastewater analysis and drugs — a European multi-city study

Introduction

The analysis of municipal wastewaters for drugs and their metabolic products to estimate community consumption is a developing field, involving scientists working in different research areas, including analytical chemistry, physiology, biochemistry, sewage engineering, spatial epidemiology and statistics, and conventional drug epidemiology. This page presents the findings from studies conducted since 2011. Data from all studies can be explored through an interactive tool, and a detailed analysis of the findings of the most recent study, in 2023, is presented.

See our wastewater analysis hub page for more resources on this topic.

*Page last updated: **20 March 2024***

Data explorer

Please note that due to the large amount of data involved processed on this page, it may take some moments before all content appears.

In this section you can explore the data from the most recent study in 2023, as well as from previous studies. Each study reveals a picture of distinct geographical and temporal patterns of drug use across European cities. Clicking on a symbol in the graph or the map will show more detailed information for a given wastewater treatment plant. You can also select a site from the drop-down menu.

Target drug (metabolite)

cocaine cannabis amphetamine methamphetamine MDMA ketamine

Study year

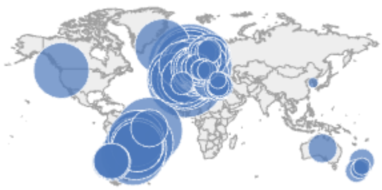
Mean

Daily mean Weekday mean Weekend mean

Select a city

World view Europe South America Oceania

Quantities detected (mg/1000p/day)



Notes

- **Cocaine** is detected through its metabolite benzoylecgonine (BE) and **cannabis** through its metabolite THC-COOH.
- Please see the notes in the Source data section, which include general notes, substance-specific notes, as well as city-specific remarks.
- Because of the size of the data-set, this data explorer may be slow or unresponsive. If this is the case, we recommend trying another browser such as FireFox, Safari or Chrome.

Analysis: results from a European multi-city study

The findings of the largest European project to date in the emerging science of wastewater analysis are presented in this section. The project analysed wastewater in around 90 European cities and towns (hereinafter referred to as 'cities') to explore the drug-taking habits of those who live in them. The results provide a valuable snapshot of the drug flow through the cities involved, revealing marked geographical variations.

Wastewater analysis is a rapidly developing scientific discipline with the potential for monitoring real-time data on geographical and temporal trends in illicit drug use. Originally used in the 1990s to monitor the environmental impact of liquid household waste, the method has since been used to estimate illicit drug consumption in different cities (Daughton, 2001; van Nuijs et al., 2011; Zuccato et al., 2008). It involves sampling a source of wastewater, such as a sewage influent to a wastewater treatment plant. This allows scientists to estimate the quantity of drugs consumed by a community by measuring the levels of illicit drugs and their metabolites excreted in urine (Zuccato et al., 2008).

Wastewater testing in European cities

In 2010, a Europe-wide network (Sewage analysis CORe group — Europe (SCORE)) was established with the aim of standardising the approaches used for wastewater analysis and coordinating international studies through the establishment of a common protocol of action. The first activity of the SCORE group was a Europe-wide investigation, performed in 2011 in 19 European cities, which allowed the first ever wastewater study of regional differences in illicit drug use in Europe (Thomas et al., 2012). That study included the first intercalibration exercise for the evaluation of the quality of the analytical data and allowed a comprehensive characterisation of the major uncertainties of the approach (Castiglioni et al., 2014). Following the success of this initial study, comparable studies were undertaken over the following years, covering 88 cities and 24 countries in the European Union and Türkiye in 2023. A standard protocol and a common quality control exercise were used in all locations, which made it possible to directly compare illicit drug loads in Europe over a one-week period during 10 consecutive years (van Nuijs et al., 2018). Raw 24-hour composite samples were collected during a single week between March and May 2023 in the majority of the cities. These samples were analysed for the urinary biomarkers (i.e. measurable characteristics) of the parent drug (i.e. primary substance) for amphetamine, methamphetamine, ketamine and MDMA. In addition, the samples were analysed for the main urinary metabolites (i.e. substances produced when the body breaks drugs down) of cocaine and cannabis, which are benzoylecgonine (BE) and THC-COOH (11-nor-9-carboxy-delta9-tetrahydrocannabinol).

The specific metabolite of heroin, 6-monoacetylmorphine, has been found to be unstable in wastewater. Consequently, the only alternative is to use morphine, although it is not a specific biomarker and can also be excreted as a result of therapeutic use. This underlines the importance of collecting the most accurate figure for morphine use from prescription and/or sales reports.

Patterns of illicit drug use: geographical and temporal variation

2023 key findings

The project findings revealed distinct geographical and temporal patterns of drug use across European cities (see the data explorer).

The annual SCORE wastewater sampling presented here, from 88 cities, showed that, overall, the loads of the different stimulant drugs detected in wastewater in 2023 varied considerably across study locations, although all illicit drugs investigated were found in almost every city that participated. For the first time, data from outside Europe is also shown and compared against European cities.

The BE loads observed in wastewater indicate that cocaine use remains highest in western and southern European cities, in particular in cities in Belgium, the Netherlands and Spain. Low levels were found in the majority of the eastern European cities, although the most recent data continues to show signs of increase.

The loads of amphetamine detected in wastewater varied considerably across study locations, with the highest levels being reported in cities in the north and east of Europe, as in previous years. Amphetamine was found at much lower levels in cities in the south of Europe, although with the most recent data showing some signs of increase.

The highest loads were found in cities in Sweden, Belgium, Germany, the Netherlands and Finland.

Methamphetamine use, generally low and historically concentrated in Czechia and Slovakia, was also present in Belgium, the east of Germany, Spain, the Netherlands and Türkiye. The observed methamphetamine loads in the other locations were very low, although most recent data show signals of increases in central European cities.

The highest mass loads of MDMA were found in the wastewater in cities in Belgium, France, Germany, the Netherlands and Spain.

The highest mass loads of the cannabis metabolite THC-COOH were found in wastewater in cities in Czechia, Spain, the Netherlands and Slovenia.

For the second time, ketamine loads are being published. The highest mass loads were found in the wastewater in cities in Belgium, France, the Netherlands, and Spain.

Seventeen countries participating in the 2023 monitoring campaign included two or more study locations (Austria, Belgium, Cyprus, Czechia, Germany, Estonia, Finland, Italy, Lithuania, Luxembourg, Netherlands, Portugal, Spain, Slovakia, Slovenia, Sweden and Türkiye). The study highlighted differences between these cities within the same country, which may be explained in part by the different social and demographic characteristics of the cities (universities, nightlife areas and age distribution of the population). Interestingly, in the majority of countries with multiple study locations, no marked differences were found when comparing large cities to smaller locations for all substances.

In addition to geographical patterns, wastewater analysis can detect fluctuations in weekly patterns of illicit drug use. More than three quarters of cities show higher loads of amphetamine, BE, ketamine and MDMA in wastewater during the weekend (Friday to Monday) than during weekdays. In contrast, cannabis (THC-COOH) and methamphetamine use was found to be distributed more evenly over the whole week.

Seventy-three cities have participated in at least five of the annual wastewater monitoring campaigns since 2011. This allows for time trend analysis of drug consumption based on wastewater testing.

Cannabis

Cannabis is Europe's most commonly used illicit drug, with an estimated 22.6 million last year users. National surveys of cannabis use would suggest that overall, around 8 % of European adults (22.6 million aged 15 to 64) are estimated to have used cannabis in the last year. However, both the level of use and trends in use reported in recent national data appear heterogeneous.

In wastewater, cannabis use is estimated by measuring its main metabolite, THC-COOH, which is the only suitable biomarker found so far. Although it is excreted in a low percentage and more research is still needed (Causanilles et al., 2017a), it is commonly used to report on cannabis use in the literature

(Zucatto et al., 2016; Bijlsma et al., 2020).

The THC-COOH loads observed in wastewater indicate that cannabis use was highest in western and southern European cities, in particular in cities in Czechia, Spain, the Netherlands and Slovenia. In 2023, there were diverging trends with 20 cities out of 51 reporting an increase in THC-COOH loads in wastewater samples, and 15 a decrease.

Figure 1. Relative geographical distribution of cannabis metabolite as detected in European cities, 2023 (daily mean)

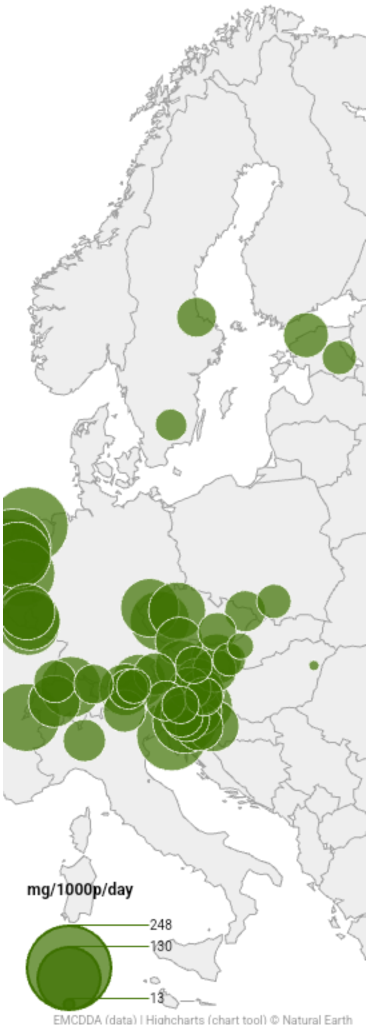
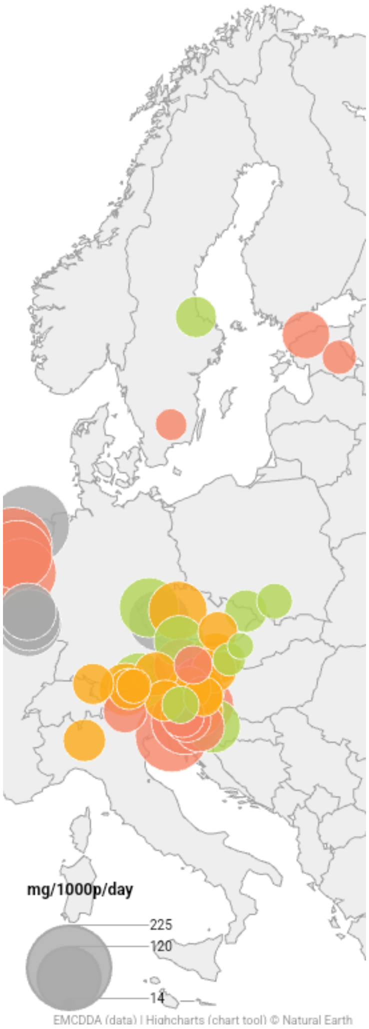


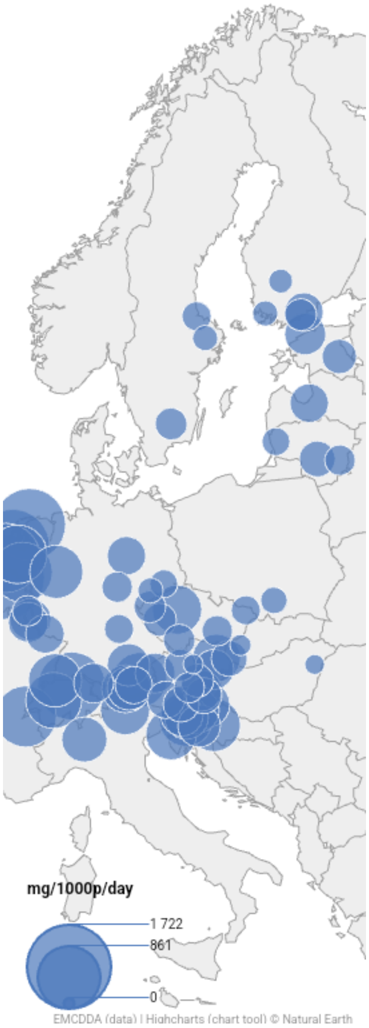
Figure 2: Changes in the mean weekly cannabis metabolites from wastewater analyses in selected European cities between 2022 and 2023Red = increase | Green = decrease | Yellow = stable, with respect to previous year



Cocaine

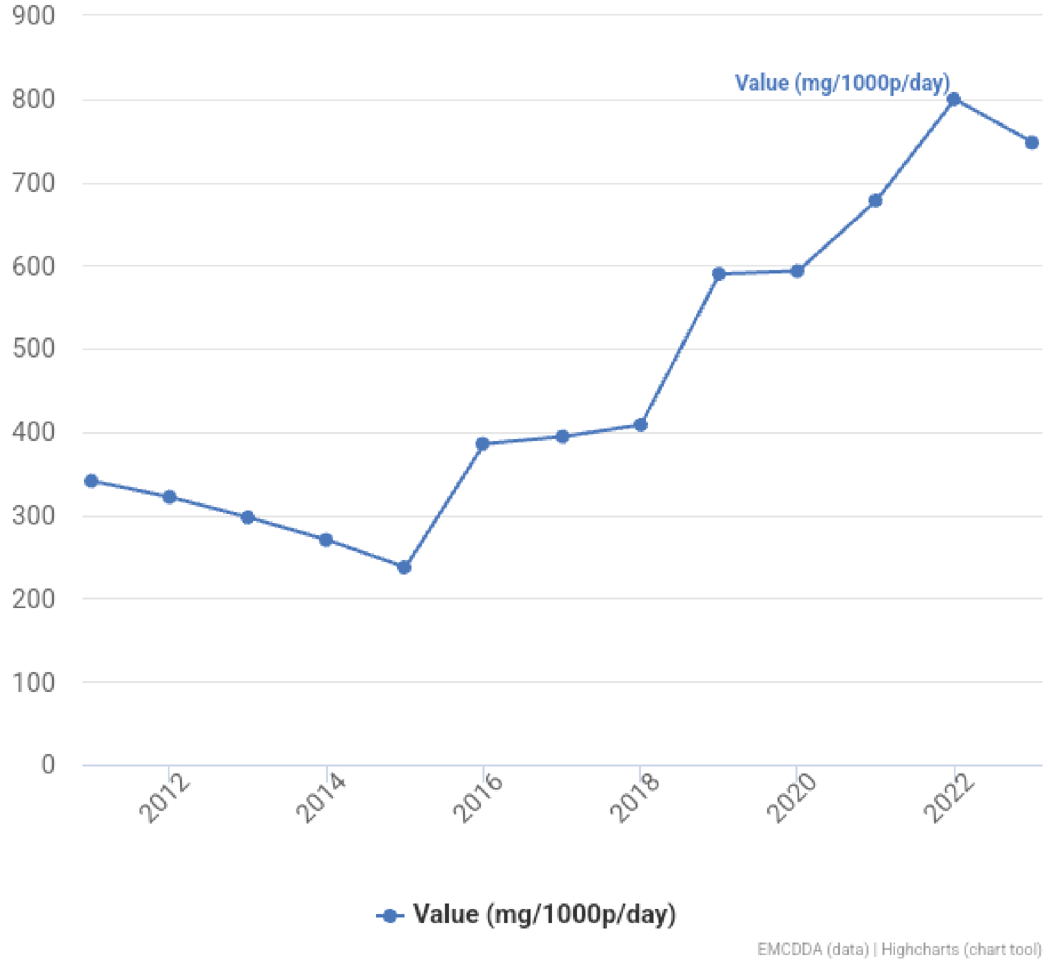
The BE loads observed in wastewater indicate that cocaine use remains highest in western and southern European cities, in particular in cities in Belgium, the Netherlands and Spain. Low levels were found in the majority of the eastern European cities, but the most recent data continues to show signs of increases. When comparing to study locations outside the European Union, cities in Brazil, Switzerland and in the United States show similar levels of use as the cities in Europe with the highest loads.

Figure 3: Relative geographical distribution of cocaine metabolite as detected in European cities, 2023 (daily mean)



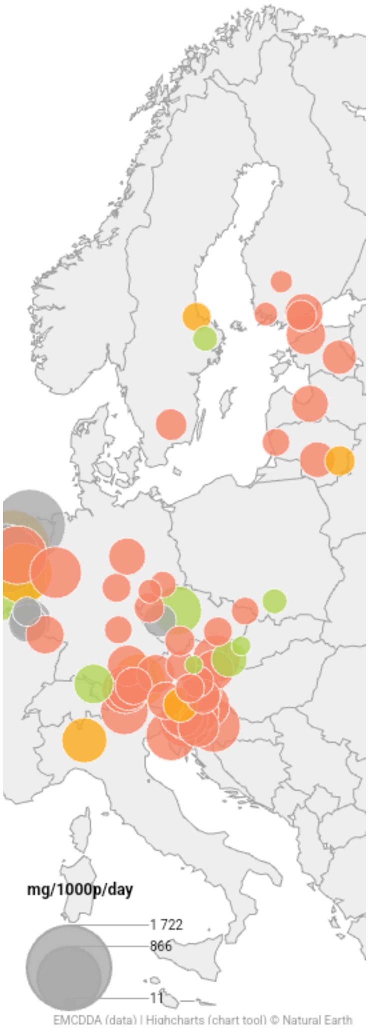
A relatively stable picture of cocaine use was observed between 2011 and 2015 in most cities. 2016 marked a turning point, with increases observed in the majority of cities each year since then. The 2023 data revealed further increases in cocaine residues in most cities when compared to 2022 data, with 49 out of 72 cities reporting an increase, while 13 cities reported no change and 10 cities reported a decrease. An overall increase is seen for all 10 cities with data for both 2011 and 2023.

Figure 4: Aggregated trends in cocaine residues in 7 EU cities, 2011 to 2023



NB: Trends in mean daily amounts of benzoylecgonine in milligrams per 1 000 head of population in Antwerp Zuid (Belgium) Zagreb (Croatia), Milan (Italy), Eindhoven and Utrecht (Netherlands), Castellon and Santiago (Spain). These 7 cities were selected owing to the availability of annual data from 2011 to 2023.

Figure 5: Changes in the mean weekly cocaine metabolites from wastewater analyses in selected European cities between 2022 and 2023Red = increase | Green = decrease | Yellow = stable, with respect to previous year



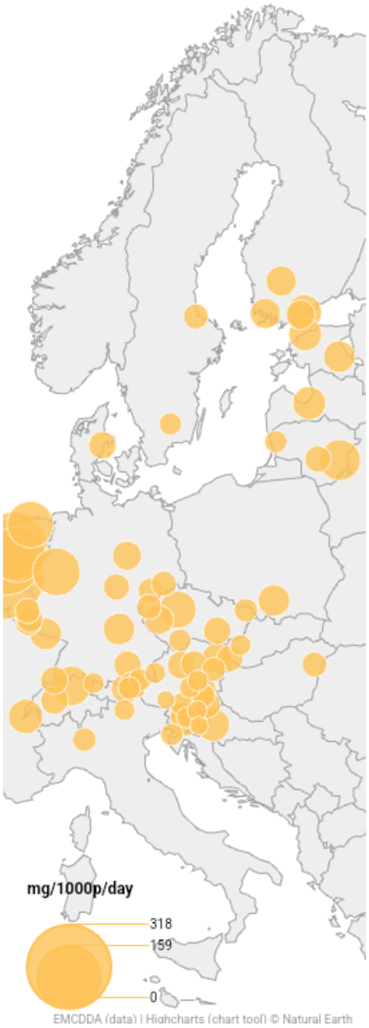
Contrary to previous years, in most countries with multiple study locations, no marked differences were found when comparing large cities to smaller locations. In addition to geographical patterns, wastewater analysis can detect fluctuations in weekly patterns of illicit drug use. More than three quarters of cities show higher loads of BE in wastewater during the weekend (Friday to Monday) than during weekdays, which may reflect a pattern of more recreational use.

A recent European project on wastewater found crack cocaine residues in all 13 participating cities and for all sampling days, with the highest loads reported in Amsterdam and Antwerp.

MDMA

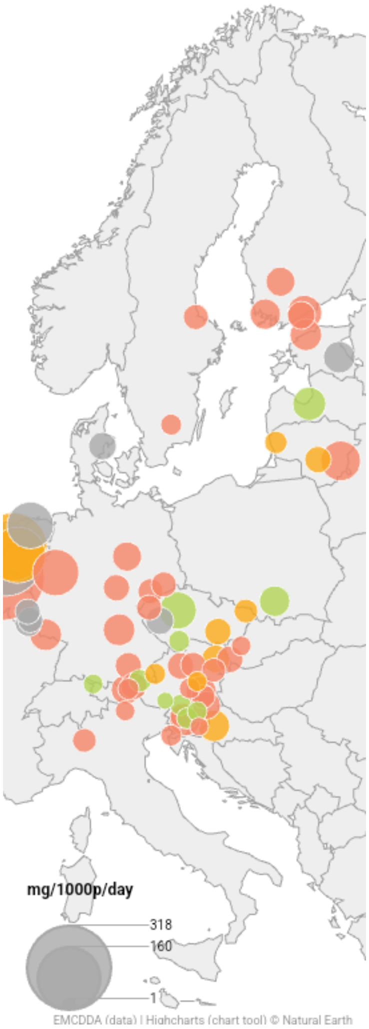
The highest mass loads of MDMA were found in the wastewater in cities in Belgium, France, Germany the Netherlands and Spain. Where data is available, when comparing to study locations outside the European Union, only cities in Switzerland show similar levels of use as the cities in Europe with the highest loads, while all the other location show low levels of MDMA use.

Figure 6. Relative geographical distribution of MDMA residues as detected in European cities, 2023 (daily mean)



General population surveys in many countries showed that MDMA prevalence was declining from peak levels attained in the early to mid-2000s. In recent years, however, the picture has remained mixed with no clear trends. Where prevalence is high, this may reflect MDMA no longer being a niche or subcultural drug limited to dance clubs and parties, but now being used by a broader range of young people in mainstream nightlife settings, including bars and house parties.

Figure 7: Changes in the mean weekly MDMA metabolites from wastewater analyses in selected European cities between 2022 and 2023Red = increase | Green = decrease | Yellow = stable, with respect to previous year



Looking at longer-term trends in wastewater analysis, in most cases the loads increased between 2011-16, and have fluctuated after this. In 2020, possibly due to the fact that in the majority of countries nightlife was largely closed for long periods, almost half of the cities (24 of 49) reported a decrease with 18 reporting an increase. In 2021, 38 out of 58 cities, reported a decrease. In 2022, 28 out of 62 cities reported an increase and 27 a decrease. Of the 69 cities that have data on MDMA residues in municipal wastewater for 2022 and 2023, 42 reported an increase (mostly in northern Europe), 11 a stable situation and 16 a decrease (mostly in cities in southern and central Europe). Of the 9 cities with data for both 2011 and 2023, 9 had higher MDMA loads in 2023 than in 2011.

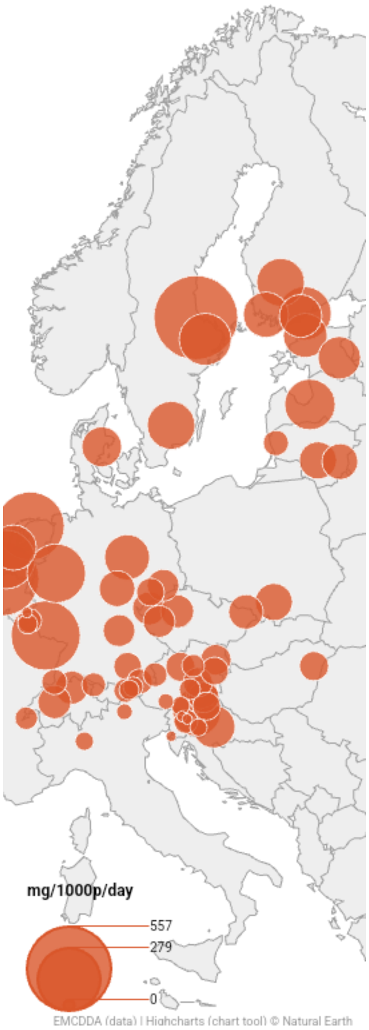
As for cocaine, and contrary to previous years, in most countries with multiple study locations, no marked differences were found when comparing large cities to smaller locations. More than three quarters of cities showed higher loads of MDMA in wastewater during the weekend (Friday to Monday) than during weekdays, reflecting the predominant use of ecstasy in recreational settings.

Amphetamine and methamphetamine

Amphetamine and methamphetamine, two closely related stimulants, are both consumed in Europe, although amphetamine is much more commonly used. Methamphetamine consumption has historically been restricted to Czechia and, more recently, Slovakia, although recent years have seen increases in use in other countries.

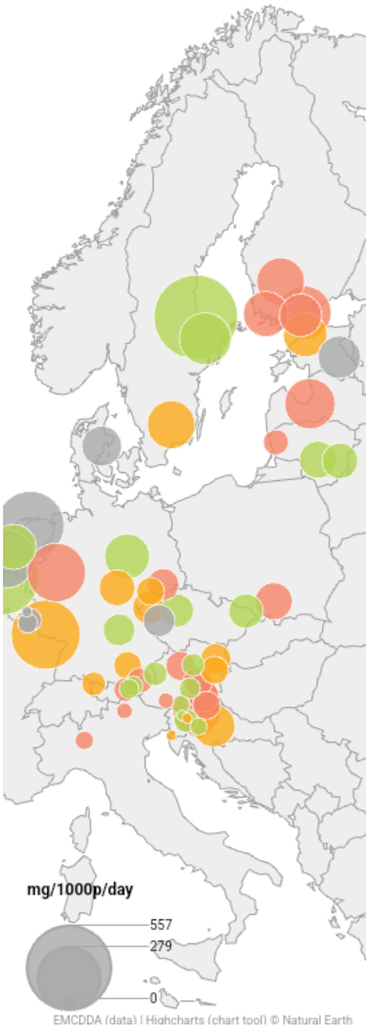
The loads of amphetamine detected in wastewater varied considerably across study locations, with the highest levels reported in cities in the north and east of Europe. The highest loads were found in cities in Sweden, Belgium, Germany, the Netherlands and Finland. Amphetamine was found at much lower levels in cities in the south of Europe, although the most recent data shows some signs of increase.

Figure 8. Relative geographical distribution of amphetamine residues as detected in European cities, 2023 (daily mean)



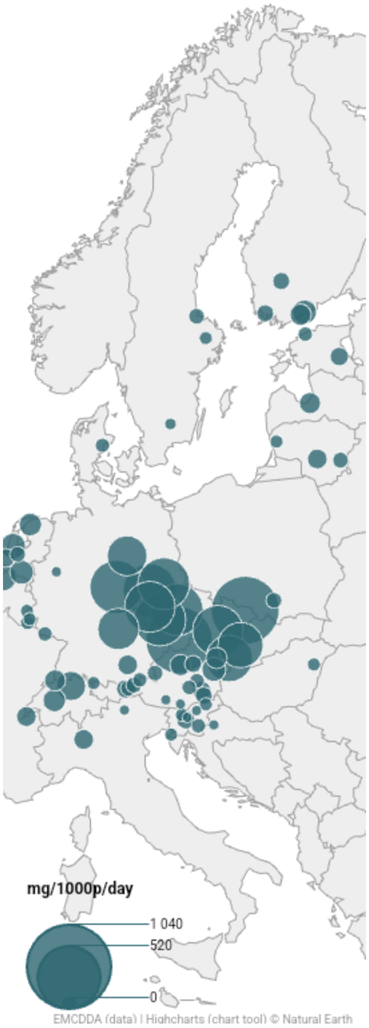
To examine the data, use the data explorer, also available on this page. Underlying data is available in source data.

Figure 9: Changes in the mean weekly amphetamine metabolites from wastewater analyses in selected European cities between 2022 and 2023Red = increase | Green = decrease | Yellow = stable, with respect to previous year



In contrast, methamphetamine use, generally low and historically concentrated in Czechia and Slovakia, now appears to be present also in Belgium, Cyprus, the east of Germany, Spain, the Netherlands, Türkiye and several northern European countries (Denmark, Finland, Lithuania, Norway). The observed methamphetamine loads in the other locations were very low to negligible, although most recent data show signals of increases in central European cities.

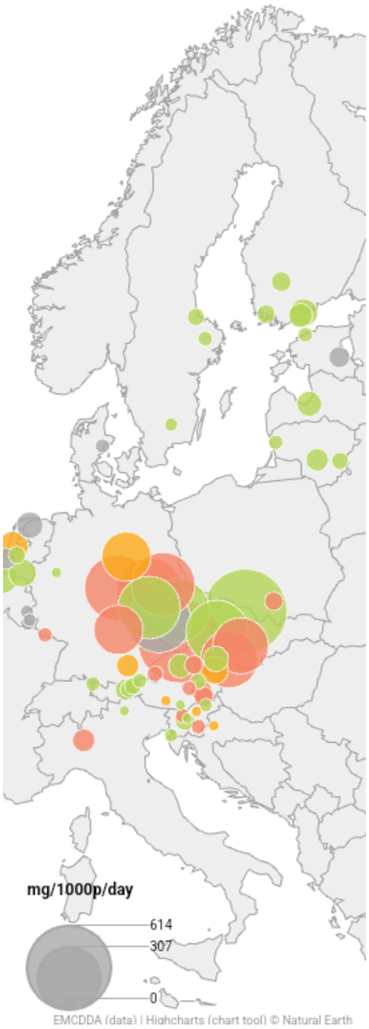
Figure 10. Relative geographical distribution of methamphetamine residues as detected in European cities, 2023 (daily mean)



Overall, the data related to amphetamine and methamphetamine from the 11 monitoring campaigns showed no major changes in the general patterns of use observed, although since 2021 increases were observed in several cities for both substances in regions where use has traditionally been low to negligible. Of the 65 cities with data on amphetamine residues in municipal wastewater for 2022 and 2023, 26 reported an increase, 13 a stable situation and 26 a decrease.

Of the 67 cities that have data on methamphetamine residues in municipal wastewater for 2022 and 2023, 15 reported an increase, 13 a stable situation and 39 a decrease. The 2 cities with the highest loads are situated in Czechia, followed by cities in Germany, Slovakia and Türkiye.

Figure 11: Changes in the mean weekly methamphetamine metabolites from wastewater analyses in selected European cities between 2022 and 2023Red = increase | Green = decrease | Yellow = stable, with respect to previous year

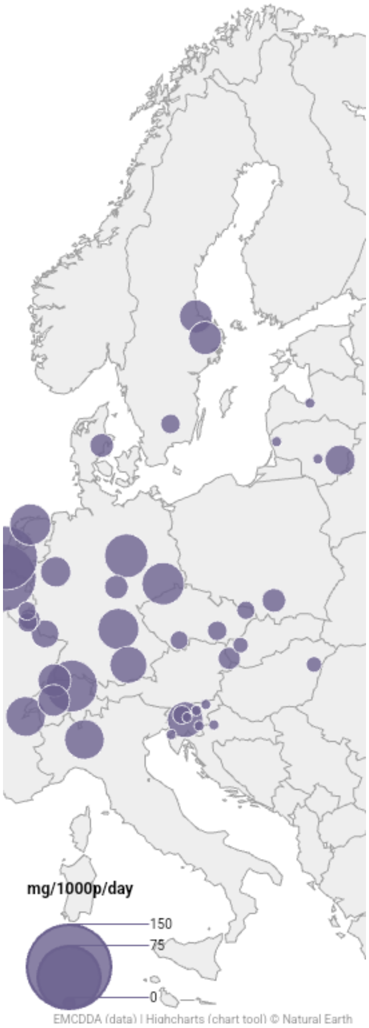


In 2023, methamphetamine use was found to be distributed more evenly over the whole week than in previous years, possibly reflecting the use of these drugs being associated with more regular consumption by a cohort of high-risk users. For amphetamine, more than three quarters of cities show higher loads during the weekend (Friday to Monday) than during weekdays.

Ketamine

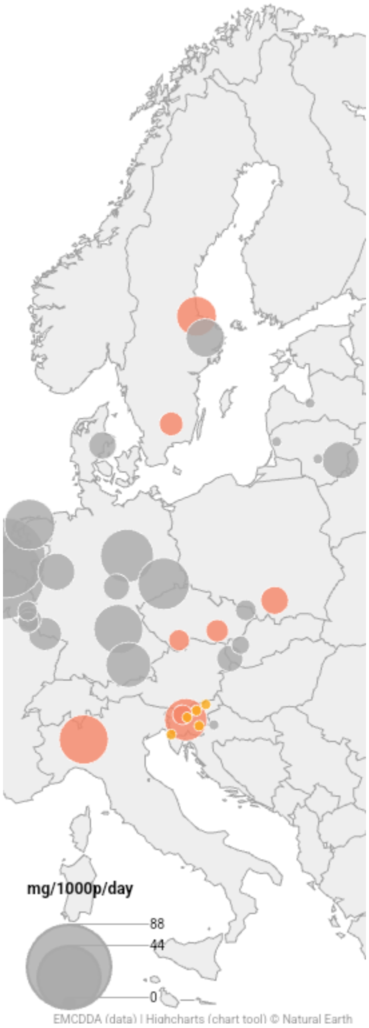
In 2023, low levels of ketamine residues in municipal wastewater were reported by 49 cities, although with signals of increases. Of the 22 cities that have data on ketamine residues for 2022 and 2023, 12 reported an increase, 8 a stable situation and 2 a decrease. The highest mass loads were detected in cities in Belgium, France, the Netherlands, and Spain.

Figure 12. Relative geographical distribution of ketamine residues as detected in European cities, 2023 (daily mean)



More than three quarters of cities showed higher loads of ketamine in wastewater during the weekend (Friday to Monday) than during weekdays, reflecting the predominant use of ketamine in recreational settings.

Figure 13: Changes in the mean weekly ketamine metabolites from wastewater analyses in selected European cities between 2022 and 2023Red = increase | Green = decrease | Yellow = stable, with respect to previous year



Limitations of this method

Wastewater analysis offers an interesting complementary data source for monitoring the quantities of illicit drugs used at the population level, but it cannot provide information on prevalence and frequency of use, main classes of users and purity of the drugs. Additional challenges arise from uncertainties associated with the behaviour of the selected biomarkers in the sewer, different back-calculation methods and different approaches to estimate the size of the population being tested (Castiglioni et al., 2013, 2016; EMCDDA, 2016b; Lai et al., 2014). The caveats in selecting the analytical targets for heroin, for example, make monitoring this drug in wastewater more complicated compared to other substances (Been et al., 2015). Also, the purity of street products fluctuates unpredictably over time and in different locations. Furthermore, translating the total consumed amounts into the corresponding number of average doses is complicated, as drugs can be taken by different routes and in amounts that vary widely, and purity levels fluctuate (Zuccato et al., 2008).

Efforts are being made to enhance wastewater monitoring approaches. For example, work has been undertaken on overcoming a major source of uncertainty related to estimating the number of people present in a sewer catchment at the time of sample collection. This involved using data from mobile devices to better estimate the dynamic population size for wastewater-based epidemiology (Thomas et al., 2017).

New developments and the future

Wastewater-based epidemiology has established itself as an important tool for monitoring illicit drug use and future directions for wastewater research have been explored (EMCDDA, 2016).

First, wastewater analysis has been proposed as a tool to address some of the challenges related to the dynamic new psychoactive substances (NPS) market. This includes the large number of individual NPS, the relatively low prevalence of use and the fact that many of the users are actually unaware of exactly which substances they are using. A technique has been established to identify NPS that involves the collection and analysis of pooled urine from stand-alone portable urinals from nightclubs, city centres and music festivals, thereby providing timely data on exactly which NPS are currently in use at a particular location (Archer et al., 2013a, 2013b, 2015; Causanilles et al., 2017b; Kinyua et al., 2016; Mackuľak et al., 2019; Mardal et al., 2017; Reid et al., 2014). The European project 'NPS euronet' aimed to improve the capacity to identify and assess the NPS being used in Europe. The project applied innovative analytical chemical and epidemiological methods and a robust risk-assessment procedure to improve the identification of NPS, to assess risks, and to estimate the extent and patterns of use in specific groups (e.g. at music festivals) and among the general population (Bade et al., 2017; González-Mariño et al., 2016).

Second, in addition to estimating illicit drug use, wastewater-based epidemiology has been successfully applied in recent years to providing detailed information on the use and misuse of alcohol (Boogaerts et al., 2016; Mastroianni et al., 2017; Rodríguez-Álvarez et al., 2015), tobacco (Senta et al., 2015; van Wel et al., 2016) and medicines in a specific population (Baz-Lomba et al., 2016, 2017; Been et al., 2015; Krizman-Matasic et al., 2018). Furthermore, wastewater analysis can potentially provide information on health and illness indicators within a community (Kasprzyk-Hordern et al., 2014; Thomaidis et al., 2016; Yang et al., 2015).

Third, the potential for wastewater-based epidemiology to be used as an outcome measurement tool, in particular in the evaluation of the effectiveness of interventions that target drug supply (e.g. law enforcement) or drug demand (e.g. public health campaigns) has not yet been fully explored. Close collaboration between the different stakeholders involved, including epidemiologists, wastewater experts and legal authorities, is highly recommended in order to start examining these potential wastewater-based epidemiology applications (EMCDDA, 2016). The WATCH project included a 30-day synthetic drug production monitoring campaign in three cities in Belgium and the Netherlands. High levels of MDMA were recorded during the whole monitoring period in one city in the Netherlands, suggesting continuous discharges of unconsumed MDMA from sources within the wastewater catchment area, indicating drug production was taking place in this region.

Fourth, by back-calculating the daily sewer loads of target residues, wastewater analysis can provide total consumption estimates, and specific efforts are now being directed towards finding the best procedures for estimating annual averages. In 2016, the EMCDDA presented, for the first time, illicit drug retail market size estimates in terms of quantity and value for the main substances used (EMCDDA and Europol, 2016). It is envisaged that findings from wastewater analysis can help to further develop work in this area.

Finally, new methods such as enantiomeric profiling have been developed to determine if mass loads of drugs in wastewater originated from consumption or from the disposal of unused drugs or production waste. It is now important to assess the possible utility of wastewater analysis to report on drug supply dynamics, including synthetic drug production (Emke et al., 2014). For example, recent malfunctioning of a small wastewater treatment plant in the Netherlands was caused by direct discharges in the sewage system of chemical waste from a drug production site. Further analysis revealed the actual synthesis process used to manufacture the corresponding drugs. The study confirmed that the chemical waste from the illegal manufacturing of stimulants will result in a specific chemical fingerprint that can be tracked in wastewater and used for forensic purposes. Such profiles can be used to identify drug production or synthesis waste disposal in the wastewater catchment area (Emke et al., 2018).

Wastewater analysis has demonstrated its potential as a useful complement to established monitoring tools in the drugs area. It has some clear advantages over other approaches as it is not subject to response and non-response bias and can better identify the true spectrum of drugs being consumed, as users are often unaware of the actual mix of substances they take. This tool also has the potential to provide timely information in short timeframes on geographical and temporal trends. In order to check the quality and accuracy of data, further comparisons between wastewater analysis and data obtained through other indicators are needed.

As a method, wastewater analysis has moved from being an experimental technique to being a new method in the epidemiological toolkit. Its rapid ability to detect new trends can help target public health programmes and policy initiatives at specific groups of people and the different drugs they are using.

Terms and definitions

In addition to the glossary below, see also Frequently-asked questions on wastewater-based epidemiology and drugs.

Back-calculation

Back-calculation is the process whereby researchers calculate/estimate the consumption of illicit drugs in the population based on the amounts of the target drug residue entering the wastewater treatment plant.

LC-MS/MS

Liquid chromatography–tandem mass spectrometry (LC-MS/MS) is the analytical method most commonly used to quantify drug residues in wastewater. LC-MS/MS is an analytical chemistry technique that combines the separation techniques of liquid chromatography with the analysis capabilities of mass spectrometry. Considering the complexity and the low concentrations expected in wastewater, LC-MS/MS is one of the most powerful techniques for this analysis, because of its sensitivity and selectivity.

Metabolite

Traces of drugs consumed will end up in the sewer network either unchanged or as a mixture of metabolites. Metabolites, the end products of metabolism, are the substances produced when the body breaks drugs down.

Residue

Wastewater analysis is based on the fact that we excrete traces in our urine of almost everything we consume, including illicit drugs. The target drug residue is what remains in the wastewater after excretion and is used to quantify the consumption of illicit drugs in the population.

Urinary biomarkers

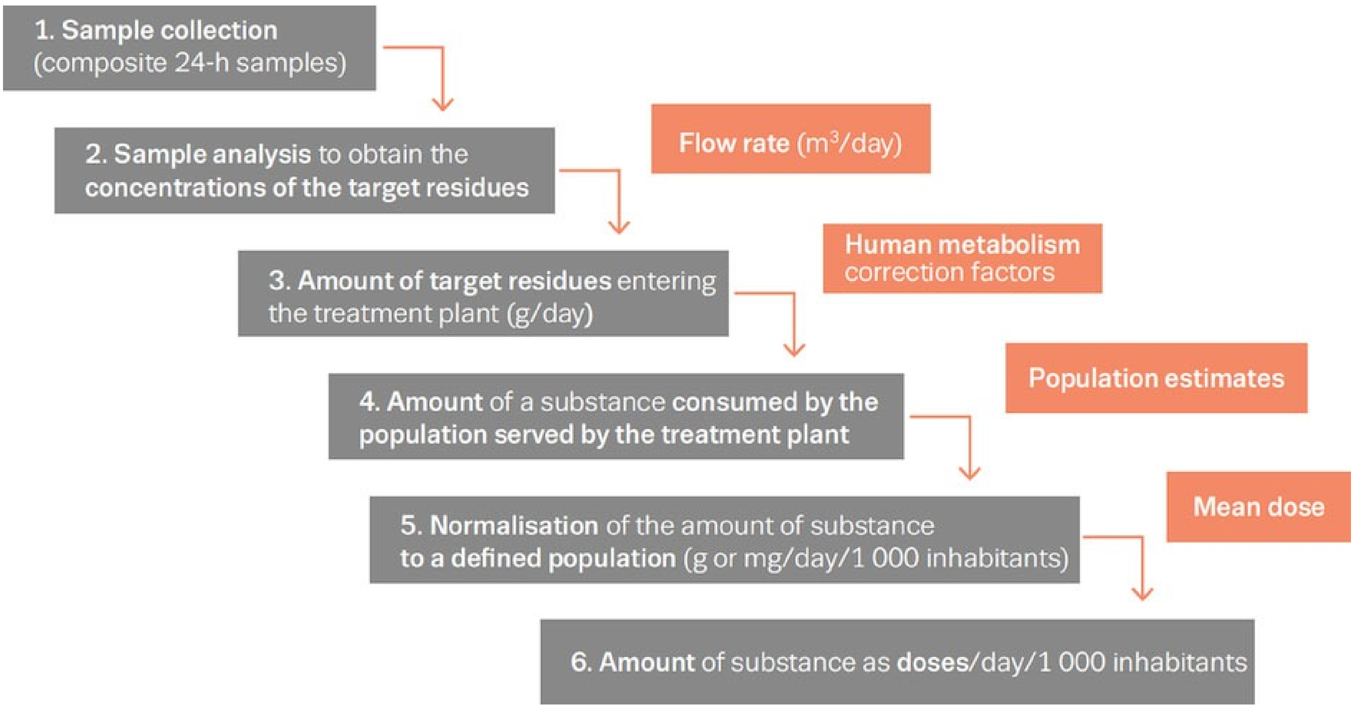
Analytical chemists look for urinary biomarkers (measurable characteristics to calculate population drug use) in wastewater samples, which can be the parent drug (i.e. the primary substance) or its urinary metabolites.

Enantiomeric profiling

Enantiomeric profiling is an analytical chemistry technique used to determine if studied drugs in wastewater originate from consumption or direct disposal (eq. production waste). It is based on the fact that chiral molecules (if only one chiral centre is present) exist as two enantiomers (opposite forms) which are non-superimposable mirror images of each other. As the enantiomeric ratio will change after human metabolism, the enantiomeric fraction can be used to determine whether the studied drugs in wastewater originate from consumption.

Methods and ethical considerations

In order to estimate levels of drug use from wastewater, researchers attempt first to identify and quantify drug residues, and then to back-calculate the amount of the illicit drugs used by the population served by the sewage treatment plants (Castiglioni et al., 2014). This approach involves several steps (see figure). Initially, composite samples of untreated wastewater are collected from the sewers in a defined geographical area. The samples are then analysed to determine the concentrations of the target drug residues. Following this, the drug use is estimated through back-calculation by multiplying the concentration of each target drug residue (nanogram/litre) with the corresponding flow of sewage (litre/day). A correction factor for each drug is taken into account as part of the calculation. In a last step, the result is divided by the population served by the wastewater treatment plant, which shows the amount of a substance consumed per day per 1 000 inhabitants. Population estimates can be calculated using different biological parameters, census data, number of house connections, or the design capacity, but the overall variability of different estimates is generally very high.



Although primarily used to study trends in illicit drug consumption in the general population, wastewater analysis has also been applied to small communities, including workplaces, schools (Zuccato et al., 2017), music festivals, prisons (Nefau et al., 2017) and specific neighbourhoods (Hall et al., 2012).

Using this method in small communities can involve ethical risks (Prichard et al., 2014), such as possible identification of a particular group within the community.

In 2016 the SCORE group published ethical guidelines for wastewater-based epidemiology and related fields (Prichard et al., 2016). The objective of these guidelines is to outline the main potential ethical risks for wastewater research and to propose strategies to mitigate those risks. Mitigating risks means reducing the likelihood of negative events and/or minimising the consequences of negative events.

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