Water Research 255 (2024) 121522

Contents lists available at ScienceDirect

Water Research

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

Making waves: Wastewater-based surveillance of cannabis use

Lubertus Bijlsma[a,*], Bradley Simpson[b], Cobus Gerber[b], Alexander L.N. van Nuijs[c], Dan Burgard[d]

[a] Environmental and Public Health Analytical Chemistry, Research Institute for Pesticides and Water, University Jaume I, E-12071, Castelló, Spain
[b] Clinical and Health Sciences, Health and Biomedical Innovation, University of South Australia, Adelaide 5000, South Australia, Australia
[c] Toxicological Centre, University of Antwerp, Universiteitsplein 1, 2610, Antwerp, Belgium
[d] Department of Chemistry and Biochemistry, University of Puget Sound, Tacoma, WA, USA

ARTICLE INFO

Keywords:
Wastewater surveillance
Drug use
Cannabis consumption
Tetrahydrocannabinol

ABSTRACT

Monitoring cannabis consumption holds great interest due to the increasing trend towards its legalization for both medicinal and recreational purposes, despite the potential risks and harms involved. Wastewater-based surveillance (WBS) offers a valuable tool for assessing shifts and patterns in drug consumption and to evaluate law enforcement strategies and harm reduction programs. However, WBS-derived cannabis use estimates have been linked to greater uncertainties compared to other drugs, in part due to the many different routes of administration and a substantial excretion of metabolites in faecal matter. Therefore, the usual approach for estimating consumed amounts and scaling consumption compared to other problem drugs requires a rethink. This viewpoint highlights the progress made in this area and describes the current existing barriers related to in-sewer and in-sample behaviour (e.g., adsorption/desorption mechanisms), analytical procedures used (e.g., sample preparation), and pharmacokinetic aspects (e.g., administration route) linked to cannabis biomarkers in influent wastewater. These need to be addressed to improve the estimation of cannabis use and reflect spatial and temporal trends in the same way as for other drugs. Until then, we recommend being cautious when interpreting wastewater-based cannabis consumption estimates.

1. Introduction

Cannabis remains the most widely used drug worldwide with the top three areas per capita being North America, Australia and New Zealand, and West Africa (UNODC, 2022). Frequent use of cannabis is associated with increased health issues such as depressive disorders, anxiety, interference with brain development, while also having social and legal consequences (Gobbi et al., 2019; Guerri and Pascual, 2019). Consequently, the consumption of cannabis imposes a strain on healthcare systems, treatment facilities, and legal frameworks (UNODC, 2022). Despite these potential harms and risks, there has been a growing trend towards the legalization of cannabis for both medicinal and recreational use. Preliminary signs and consequences of cannabis legalization indicates increased daily consumption and/or cannabis potency. However, it has also resulted in reduced arrest rates, increased tax revenues, and permits the implementation of more effective harm reduction strategies (UNODC, 2022). Therefore, it is crucial to continuously monitor cannabis use in this highly changing landscape to gain insight into spatial and temporal trends, as well as to evaluate the impact of new legal status, law enforcement measures, and harm reduction programs.

Wastewater-based epidemiology (WBE) and more recently, wastewater-based surveillance (WBS) have become increasingly popular for providing complementary data to public health monitoring. During the pandemic, WBS provided valuable complementary data to clinical data and helped alert health authorities to the presence of SARS CoV-2 in a community, as well as early prediction of surges in infection. WBE is a field that was established a decade before the COVID pandemic and is focused on monitoring spatial differences and changes in drug use over time, offering complementary information to established indicators, such as law enforcement seizures, surveys and arrests (González-Mariño et al., 2020). Therefore, different end-users, such as the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) and United Nations Office on Drugs and Crime (UNODC), have embraced WBE as a valuable source to obtain rapid additional and objective information on drug consumption in mass-based, as well as, dose-based patterns at the community level (EMCDDA, 2022; UNODC, 2022). However, higher

* Corresponding author.
E-mail address: bijlsma@uji.es (L. Bijlsma).

https://doi.org/10.1016/j.watres.2024.121522
Received 14 November 2023; Received in revised form 6 March 2024; Accepted 24 March 2024
Available online 25 March 2024

uncertainties have been associated with WBE-derived cannabis use estimates than other drugs (e.g., cocaine, amphetamine, MDMA and methamphetamine). These uncertainties have been mostly related to the analytical determination of 11-nor-9-carboxy-Δ^9-tetrahydrocannabinol (THC-COOH) in influent wastewater, which is the primary urinary metabolite of the psychoactive constituent tetrahydrocannabinol (THC) metabolite (Causanilles et al., 2017; van Nuijs et al., 2018). The rate and extent of adsorption and desorption of THC and its metabolites between faeces and water i.e., partition between solid particulate matter and the liquid phase, has also recently been questioned (Pandopulos et al., 2022). Moreover, this raises questions to the proposed excretion correction factors for valid back-calculation of cannabis consumption (Gracia-Lor et al., 2016; Postigo et al., 2011). Hence, quantifying cannabis use in terms of population-normalised mass loads and especially by dose, within the WBS framework is a topic of debate (Burgard et al., 2019; Postigo et al., 2011; Zuccato et al., 2008). Therefore, as a research community, we should create more clarity, where it is pivotal to identify and evaluate: i) the latest advancements in the determination of THC and its metabolites in wastewater; ii) the current knowledge gaps that must be addressed to improve estimates of cannabis consumption; and iii) how to use, interpret and report the collected WBS data in its present state. Fig. 1 shows a roadmap of key issues for wastewater-based surveillance of cannabis use, which will be discussed in more detail in the following sections.

2. Barriers to provide accurate consumption estimates

2.1. Analytical barriers

The analytical methodologies applied in WBS studies for monitoring illicit drugs use typically involve the determination of a suite of biomarkers where THC-COOH is often just one of many compounds to be analysed. Although a single analysis of numerous analytes is more efficient, time-saving, and economical, a compromise of the experimental conditions is normally required (Bijlsma et al., 2020). It is generally accepted that some form of preservation is required to ensure analyte stability to estimate biomarker mass loads in influent wastewater. A critical parameter when analysing THC-COOH is the adjustment of sample pH. At acidic pH, the molecular, hydrophobic form of THC-COOH favours adsorption to particulate matter or sampling and processing material surfaces. Therefore, a best-practice protocol of the analytical procedure, avoiding acidification of samples was proposed, leading to more accurate estimations when measuring THC-COOH in the liquid phase of influent wastewater (Causanilles et al., 2017). However, the lipophilic characteristics of cannabinoids not only challenges the analytical determination (specifically for multi-residue methodologies), but it also highlights that important research questions have been widely overlooked or under-investigated, including the clearance pathways of THC and its metabolites in the human body (Campos-Mañas et al., 2022; Pandopulos et al., 2020). Accordingly, more specific methodologies have been developed to also measure the presence of THC and its metabolites in suspended solids of influent wastewater as a way to better understand the total THC metabolic loads. Consideration of urinary excretion of THC metabolites in the glucuronide form has been suggested (How and Gamal El-Din, 2021) but the congugated forms of THC metabolites have not been found in influent wastewater samples (Jacox et al., 2017). Results demonstrated that high percentages THC and its metabolites were present in faeces and in the solid phase of wastewater (Campos-Mañas et al., 2022; Pandopulos et al., 2022).

2.2. Sample and in-sewer dynamic barriers

Quantification of THC and its metabolites in both the aqueous phase and the suspended solids of influent wastewater allowed for the observation that they partition between the solid and liquid phase of influent wastewater (Fig. 2). Moreover, it has been speculated that faecal material from users and non-users may affect the total mass loads in the aqueous phase (Pandopulos et al., 2022). These recent insights give rise to new inquiries, unveiling a set of knowledge gaps that require further research (Fig. 2). These include: i) Obtaining more data concerning the partitioning and distribution of THC and its metabolites to support the findings from previous studies. ii) Investigating the impact of influent wastewater composition, which can differ in time and space i.e., geographical location, and potentially affect the adsorption or desorption on particulate matter. iii) Examining the partitioning dynamics during in-sewer transport and the potential sorption onto the biofilm of the sewer system (Ramin et al., 2017, 2016). iv) Assessing the sampling uncertainty associated with the collection of solids. By addressing these

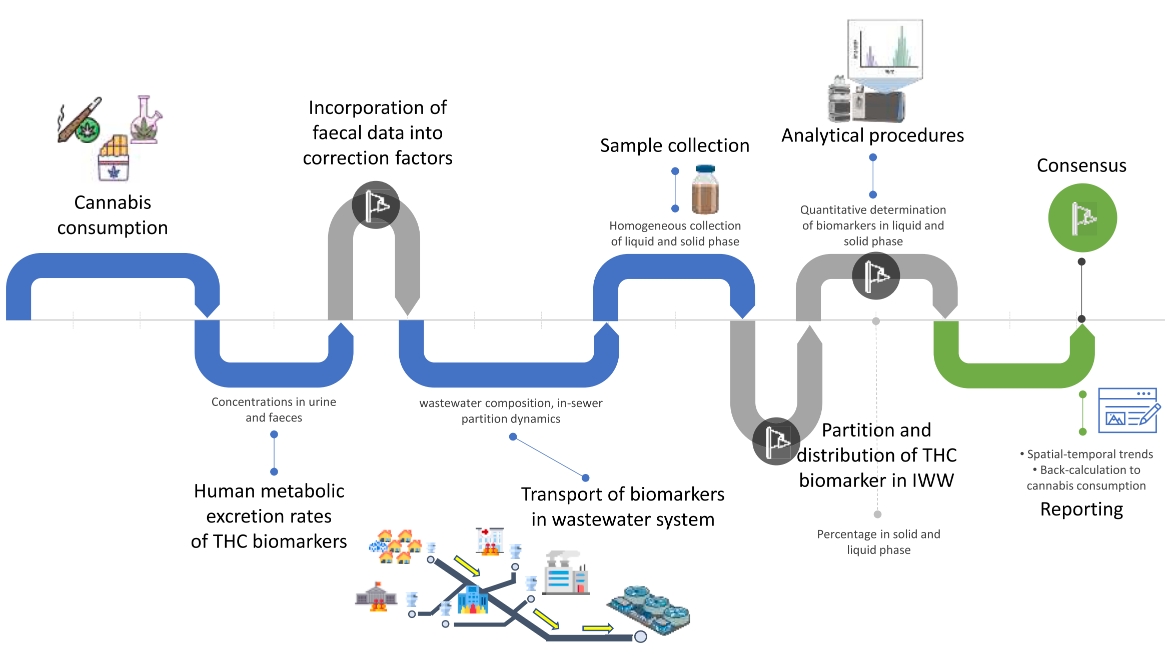

Fig. 1. Roadmap of wastewater-based surveillance of cannabis use (blue: barriers and research gaps; grey: milestones reached or to be reached; green: final objective). (For interpretation of the colours in this figure legend, the reader is referred to the web version of this article.)

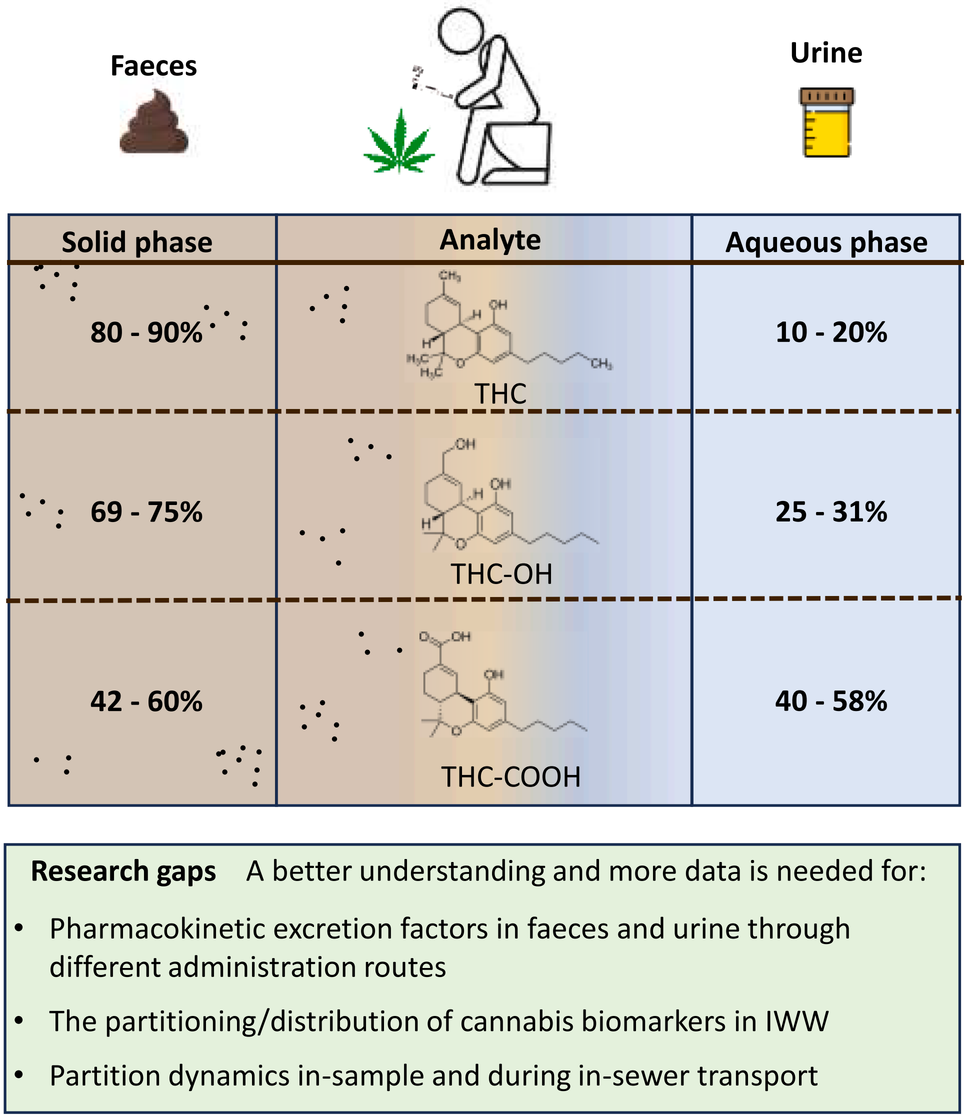

Fig. 2. Reported partition of cannabis biomarkers between the solid and aqueous phase of IWW (Campos-Mañas et al., 2022; Pandopulos et al., 2022) and main research gaps identified.

barriers, we can enhance our understanding of the topic and generate more comprehensive and accurate research outcomes.

2.3. Pharmacokinetic barriers

An interesting feature of the WBS approach lies in its ability to estimate the consumption of drugs by employing a back-calculation using influent wastewater mass loads, parent/metabolite molar mass ratio and pharmacokinetic excretion factors (Zuccato et al., 2008). For cannabis, different excretion correction factors, mainly derived from urinary THC-COOH levels from smoked cannabis, were proposed i.e., 182 (Gracia-Lor et al., 2016) and 36.4 (Postigo et al., 2011). The latter assumed that the other major THC metabolite, 11-hydroxy-THC (THC-OH), completely oxidizes into THC-COOH during the process of in-sewer transport. However, this has not been demonstrated and will depend on the particular characteristics of each catchment. In this context, both correction factors have been considered to account for uncertainty (Bijlsma et al., 2021). Nevertheless, neither correction factor takes into account any of the metabolites that might be excreted in and then partition from the faeces. Additional pharmacokinetic studies are needed to validate, confirm, or improve knowledge of both the urinary excretion of THC-COOH as well as the faecal excretion. These values are needed to further refine these excretion correction factors. Additionally, it is relevant to consider the glucuronide form, which is currently reported as the most abundant metabolite in urine (but likely deconjugates in influent wastewater) when calculating the 'effective' concentration of THC-COOH (D'Ascenzo et al., 2003; Khan and Nicell, 2012; van Nuijs et al., 2011). Given the aforementioned new insights, the consideration of faecal data into these factors has become imperative.

2.4. Routes of administration barriers

Finally, different routes of administration of cannabis products yields different excretion rates (Wall et al., 1983), which can highly affect WBS back-calculations (Burgard et al., 2019; Khan and Nicell, 2012). While smoked cannabis remains the most prevalent route of administration, there has been a noticeable shift towards the use of edible and vaped cannabis in the United States and Australia (Davenport, 2021; Penington Institute, 2022). In 2020, more than 20 % of 12th grade students had tried vaping cannabis, more than doubling the rate from five years before (Miech et al., 2022). These changes can vary in time and from country to country and may be related by the legalization of cannabis for both medicinal and recreational purposes. This can also cause a change in type of cannabis, for example an interest in Δ^8-THC has been observed, and the popularity of cannabidiol (CBD) has also increased. Although the contribution of these alternatives to recreational THC use is currently uncertain and appears to be minor, it is essential for researchers to develop analytical methods that can differentiate between these analytes in the event that these types of cannabis become more prevalent (Bijlsma et al., 2020).

3. The current state and potential value of monitoring cannabis use through wastewater-based surveillance

Monitoring cannabis use is of significant relevance and interest, given it is the most used drug and has the most dynamic policy landscape. WBS provides a tool to measure changes and trends in high resolution. Spatial and temporal patterns are perhaps of main overall interest to end-users. These are affected differently by the complications highlighted in the previous section. However, they still provide the potential to show trends from within a single wastewater catchment area. Future research plays a pivotal role in extracting the maximum amount of information from WBS data. In its current state, careful interpretation is necessary when evaluating WBS data on cannabis consumption and, in the authors' opinion, the data could be best utilized in the following manner:

Spatial comparisons of excreted amounts of THC and its metabolites in influent wastewater should be conducted with caution. Sewer catchments and the characteristics of influent wastewater can exhibit significant variations across different locations due to factors such as the type of sewer system, industrial discharges, weather conditions. Hence, monitoring spatial trends can be prone to increased uncertainty. Nevertheless, spatial scale of use among areas has been deemed useful by some agencies and in instances where triangulation has been done, spatial patterns of cannabis use largely agreed with surveys (https://www150.statcan.gc.ca/n1/daily-quotidien/210726/dq210726a-eng.htm).

WBS derived trends in cannabis use *within* a catchment has temporal inherent value when the catchment demographics remain largely unchanged. Intra-catchment uncertainties amount to a potential systematic error and therefore temporal trends remain valid. Temporal trends are a real strength of WBS, including cannabis use monitoring.

The relative scale of use of drugs is often important for end-users when it comes to identifying problem areas and making policy decisions. An example includes the Australian National Wastewater Drug Monitoring Program reports, in which the scale of drug use is a central theme. This type of dose-based consumption dataset is sometimes favoured by end-users (Freeman and Lorenzetti, 2020). Yet from our perspective, consensus is first required to ensure a common approach and a common set of values for correction factors and doses are used across the WBS community. In general, it is recommended to maintain close communication with end-users, engage in discussions regarding the findings, evaluate uncertainties, and triangulate data with other consumption indicators. Such collaborative efforts contribute to a more comprehensive understanding of the subject matter.

4. Conclusions

Cannabis is very different from the usual suite of substances measured by wastewater analysis due to the primary route of excretion and the chemistry of its metabolites. This viewpoint highlighted different barriers (i.e., analytical, sample and in-sewer dynamic, pharmacokinetic and routes of administration) that restrain accurate consumption estimates. Therefore, we believe that research should primarily address the following:

- Assess the partitioning and distribution of THC and its metabolites between the solid and liquid phase of influent wastewater;
- A better understanding of route of administration and clearance;
- Incorporate faecal data into excretion correction factors;
- Reach a consensus within the WBS community to ensure a common approach as to how best report cannabis estimations from WBS data.

Hence, a more developed approach for accurately determining the population-scale excretion and consumption of cannabis is required. Until these challenges have been met, a cautionary approach is recommended for drawing conclusions from WBS estimates of cannabis consumption.

CRediT authorship contribution statement

Lubertus Bijlsma: Writing – original draft, Writing – review & editing, Conceptualization. **Bradley Simpson:** Writing – review & editing, Conceptualization. **Cobus Gerber:** Writing – review & editing, Conceptualization. **Alexander L.N. van Nuijs:** Writing – review & editing, Conceptualization. **Dan Burgard:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

L. Bijlsma acknowledges grant RYC2020-028936-I funded by MCIN/AEI/ 10.13039/501100011033 and by "ESF Investing in your future".

References

Bijlsma, L., Burgard, D.A., Been, F., Ort, C., Matias, J., Yargeau, V., 2020. The estimation of cannabis consumption through wastewater analysis. Comprehensive Analytical Chemistry. Elsevier, pp. 453–482. https://doi.org/10.1016/bs.coac.2020.04.005.

Bijlsma, L., Picó, Y., Andreu, V., Celma, A., Estévez-Danta, A., González-Mariño, I., Hernández, F., López de Alda, M., López-García, E., Marcé, R.M., Miró, M., Montes, R., Pérez de San Román-Landa, U., Pitarch, E., Pocurull, E., Postigo, C., Prieto, A., Rico, A., Rodil, R., Valcárcel, Y., Ventura, M., Quintana, J.B., 2021. The embodiment of wastewater data for the estimation of illicit drug consumption in Spain. Sci. Total Environ. 772, 144794 https://doi.org/10.1016/j.scitotenv.2020.144794.

Burgard, D.A., Williams, J., Westerman, D., Rushing, R., Carpenter, R., LaRock, A., Sadetsky, J., Clarke, J., Fryhle, H., Pellman, M., Banta-Green, C.J., 2019. Using wastewater-based analysis to monitor the effects of legalized retail sales on cannabis consumption in Washington State, USA. Addiction 114, 1582–1590. https://doi.org/10.1111/add.14641.

Campos-Mañas, M.C., Van Wichelen, N., Covaci, A., van Nuijs, A.L.N., Ort, C., Béen, F., Castiglioni, S., Hernández, F., Bijlsma, L., 2022. Analytical investigation of cannabis biomarkers in raw urban wastewater to refine consumption estimates. Water Res. 223 https://doi.org/10.1016/j.watres.2022.119020.

Causanilles, A., Baz-Lomba, J.A., Burgard, D.A., Emke, E., Gonzalez-Marino, I., Krizman-Matasic, I., Li, A., Love, A.S.C., McCall, A.K., Montes, R., van Nuijs, A.L.N., Ort, C., Quintana, J.E.B., Senta, I., Terzic, S., Hernandez, F., de Voogt, P., Bijlsma, L., 2017. Improving wastewater-based epidemiology to estimate cannabis use: focus on the initial aspects of the analytical procedure. Anal. Chim. Acta 988, 27–33.

https://www150.statcan.gc.ca/n1/daily-quotidien/210726/dq210726a-eng.htm, n.d. Wastewater analysis suggests that consumption of fentanyl, cannabis and methamphetamine increased in the early pandemic period [WWW Document]. URL https://www150.statcan.gc.ca/n1/daily-quotidien/210726/dq210726a-eng.htm (accessed 11.13.23).

D'Ascenzo, G., Di Corcia, A., Gentili, A., Mancini, R., Mastropasqua, R., Nazzari, M., Samperi, R., 2003. Fate of natural estrogen conjugates in municipal sewage transport and treatment facilities. Sci. Total Environ. 302, 199–209.

Davenport, S., 2021. Price and product variation in Washington's recreational cannabis market. Int. J. Drug Policy 91, 102547. https://doi.org/10.1016/j.drugpo.2019.08.004.

EMCDDA, 2022. European Drug Report 2022: Trends and Developments. Publications Office of the European Union, pp. 1–60.

Freeman, T.P., Lorenzetti, V., 2020. Standard THC units': a proposal to standardize dose across all cannabis products and methods of administration. Addiction 115, 1207–1216. https://doi.org/10.1111/add.14842.

Gobbi, G., Atkin, T., Zytynski, T., Wang, S., Askari, S., Boruff, J., Ware, M., Marmorstein, N., Cipriani, A., Dendukuri, N., Mayo, N., 2019. Association of cannabis use in adolescence and risk of depression, anxiety, and suicidality in young adulthood: a systematic review and meta-analysis. JAMA Psychiatry 76, 426–434. https://doi.org/10.1001/jamapsychiatry.2018.4500.

González-Mariño, I., Baz-Lomba, J.A., Alygizakis, N.A., Andrés-Costa, M.J., Bade, R., Bannwarth, A., Barron, L.P., Been, F., Benaglia, L., Berset, J.D., Bijlsma, L., Bodík, I., Brenner, A., Brock, A.L., Burgard, D.A., Castrignanò, E., Celma, A., Christophoridis, C.E., Covaci, A., Delémont, O., Devoogt, P., Devault, D.A., Dias, M. J., Emke, E., Esseiva, P., Fatta-Kassinos, D., Fedorova, G., Fytianos, K., Gerber, C., Grabic, R., Gracia-Lor, E., Grüner, S., Gunnar, T., Hapeshi, E., Heath, E., Helm, B., Hernández, F., Kankaanpaa, A., Karolak, S., Kasprzyk-Hordern, B., Krizman-Matasic, I., Lai, F.Y., Lechowicz, W., Lopes, A., de Alda, M.L., López-García, E., Löve, A.S.C., Mastroianni, N., McEneff, G.L., Montes, R., Munro, K., Nefau, T., Oberacher, H., O'brien, J.W., Oertel, R., Olafsdottir, K., Picó, Y., Plósz, B.G., Polesel, F., Postigo, C., Quintana, J.B., Ramin, P., Reid, M.J., Rice, J., Rodil, R., Salgueiro-Gonzàlez, N., Schubert, S., Senta, I., Simões, S.M., Sremacki, M.M., Styszko, K., Terzic, S., Thomaidis, N.S., Thomas, K.V., Tscharke, B.J., Udrisard, R., van Nuijs, A.L.N., Yargeau, V., Zuccato, E., Castiglioni, S., Ort, C., 2020. Spatio-temporal assessment of illicit drug use at large scale: evidence from 7 years of international wastewater monitoring. Addiction 115, 109–120. https://doi.org/10.1111/add.14767.

Gracia-Lor, E., Zuccato, E., Castiglioni, S., 2016. Refining correction factors for back-calculation of illicit drug use. Sci. Total Environ. 573, 1648–1659. https://doi.org/10.1016/j.scitotenv.2016.09.179.

Guerri, C., Pascual, M., 2019. Impact of neuroimmune activation induced by alcohol or drug abuse on adolescent brain development. Int. J. Dev. Neurosci. 77, 89–98. https://doi.org/10.1016/j.ijdevneu.2018.11.006.

How, Z.T., Gamal El-Din, M, 2021. A critical review on the detection, occurrence, fate, toxicity, and removal of cannabinoids in the water system and the environment. Environ. Pollut. 268, 115642 https://doi.org/10.1016/j.envpol.2020.115642.

Jacox, A., Wetzel, J., Cheng, S.Y., Concheiro, M., 2017. Quantitative analysis of opioids and cannabinoids in wastewater samples. Forensic Sci. Res. 2, 18–25. https://doi.org/10.1080/20961790.2016.1270812.

Khan, U., Nicell, J.A., 2012. Sewer epidemiology mass balances for assessing the illicit use of methamphetamine, amphetamine and tetrahydrocannabinol. Sci. Total Environ. 421–422, 144–162. https://doi.org/10.1016/j.scitotenv.2012.01.020.

Miech, R.A., Johnston, L.D., Patrick, M.E., O'Malley, P.M., Bachman, J.G., Schulenberg, J.E., 2022. Monitoring the future national survey results on drug use, 1975–2022: secondary school students.

Pandopulos, A.J., Bade, R., O'Brien, J.W., Tscharke, B.J., Mueller, J.F., Thomas, K., White, J.M., Gerber, C., 2020. Towards an efficient method for the extraction and analysis of cannabinoids in wastewater. Talanta 217, 121034. https://doi.org/10.1016/j.talanta.2020.121034.

Pandopulos, A.J., Simpson, B.S., White, J.M., Bade, R., Gerber, C., 2022. Partitioning of phytocannabinoids between faeces and water – Implications for wastewater-based epidemiology. Sci. Total Environ. 805, 150269 https://doi.org/10.1016/j.scitotenv.2021.150269.

Penington Institute, 2022. Cannabis in Australia 2022: Technical Report. Melbourne.

Postigo, C., de Alda, M.L., Barceló, D., 2011. Evaluation of drugs of abuse use and trends in a prison through wastewater analysis. Environ. Int. 37, 49–55. https://doi.org/10.1016/j.envint.2010.06.012.

Ramin, P., Brock, A.L., Causanilles, A., Valverde-Pérez, B., Emke, E., De Voogt, P., Polesel, F., Plósz, B.G., 2017. Transformation and sorption of illicit drug biomarkers in sewer biofilms. Environ. Sci. Technol. 51, 10572–10584. https://doi.org/10.1021/acs.est.6b06277.

Ramin, P., Brock, A.L., Polesel, F., Causanilles, A., Emke, E., De Voogt, P., Plosz, B.G., 2016. Transformation and sorption of illicit drug biomarkers in sewer systems: understanding the role of suspended solids in raw wastewater. Environ. Sci. Technol. 50, 13397–13408. https://doi.org/10.1021/acs.est.6b03049.

UNODC, 2022. World Drug Report 2022. United Nations Publication, p. 102.

van Nuijs, A.L.N., Castiglioni, S., Tarcomnicu, I., Postigo, C., de Alda, M.L., Neels, H., Zuccato, E., Barcelo, D., Covaci, A., 2011. Illicit drug consumption estimations derived from wastewater analysis: a critical review. Sci. Total Environ. 409, 3564–3577. https://doi.org/10.1016/j.scitotenv.2010.05.030.

van Nuijs, A.L.N., Lai, F.Y., Been, F., Andres-Costa, M.J., Barron, L., Baz-Lomba, J.A., Berset, J.D., Benaglia, L., Bijlsma, L., Burgard, D., Castiglioni, S., Christophoridis, C., Covaci, A., de Voogt, P., Emke, E., Fatta-Kassinos, D., Fick, J., Hernandez, F., Gerber, C., González-Mariño, I., Grabic, R., Gunnar, T., Kannan, K., Karolak, S., Kasprzyk-Hordern, B., Kokot, Z., Krizman-Matasic, I., Li, A., Li, X., Löve, A.S.C., Lopez de Alda, M., McCall, A.K., Meyer, M.R., Oberacher, H., O'Brien, J., Quintana, J.B., Reid, M., Schneider, S., Simoes, S.S., Thomaidis, N.S., Thomas, K., Yargeau, V., Ort, C., 2018. Multi-year inter-laboratory exercises for the analysis of illicit drugs and metabolites in wastewater: development of a quality control system. TrAC - Trends Anal. Chem. 103, 34–43. https://doi.org/10.1016/j.trac.2018.03.009.

Wall, M.E., Sadler, B.M., Brine, D., Taylor, H., Perez-Reyes, M., 1983. Metabolism, disposition, and kinetics of delta-9-tetrahydrocannabinol in men and women. Clin. Pharmacol. Ther. 34, 352–363. https://doi.org/10.1038/clpt.1983.179.

Zuccato, E., Chiabrando, C., Castiglioni, S., Bagnati, R., Fanelli, R., 2008. Estimating community drug abuse by wastewater analysis. Environ. Health Perspect. 116, 1027–1032. https://doi.org/10.1289/ehp.11022.