

## Tracing illicit and prescription drug use in a Spanish prison by combining wastewater analysis and pharmaceutical dispensing data

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### ABSTRACT

**Background and aim:** We combined wastewater-based epidemiology (WBE) and pharmaceutical dispensing records to distinguish between illicit and prescription drug use.

**Methods:** We collected 24-h composite wastewater samples during three one-week campaigns in a prison in northern Spain. Samples were analysed for pharmaceuticals, illicit drugs, nicotine and alcohol. Population-normalised daily loads (PNDLs) were converted to consumption estimates and compared with Spanish population WBE estimates and pharmacy dispensing data.

**Results:** Wastewater analysis showed high use of several pharmaceuticals, with the highest average PNDL for gabapentinoids. Pregabalin and gabapentin estimates from wastewater exceeded pharmacy dispensing, suggesting internal diversion. Cannabis consumption was about four times higher than community estimates and cocaine was also higher in all campaigns. Ketamine and MDMA use were above community medians during the February campaign and nicotine use was nearly ten times higher than community levels.

**Conclusion:** WBE identifies prescription drug diversion, illicit drug markets and quantifies licit substance use in prisons.

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## 1. Introduction

Prisoners experience high rates of substance use disorders involving alcohol, tobacco, illicit drugs and prescribed psychotropics, with important consequences for health, security and social reintegration (Enggist et al., 2014; Australian Institution of Health and Welfare, 2026; Dolan et al., 2007). Beyond illicit substances, prisons often report very high dispensing of benzodiazepines, opioids and other psychotropic medications through prison pharmacies, but it is frequently unclear to what extent these medicines are used as prescribed, diverted, or traded within the prison market (Franco-Mingarro et al., 2008; Roncero et al., 2025; Royal College of Psychiatrists, 2019). Reliable and comparable data on both illicit and prescribed drug use are therefore essential not only for clinical care, but also for designing, implementing and evaluating prison drug policies, including safer prescribing guidelines, diversion-prevention measures and harm-reduction strategies.

Traditionally, information on drug use in prisons has relied on self-report, clinical records and targeted urinalysis (Brewer et al., 2016; van Dyken et al., 2016). These indicators are vulnerable to under-reporting, selection bias and strategic avoidance of testing, and they usually focus on a limited group of controlled drugs. As a result, they provide only a partial picture of the overall burden of substance use, particularly for alcohol, nicotine, gabapentinoids or benzodiazepines, despite their recognised role in polydrug use, morbidity and diversion in prison settings (Royal College of Psychiatrists, 2019; Soni and Walters, 2019). This constrains the capacity of prison systems to monitor the real impact of prescribing practices, security measures and drug policy reforms.

Wastewater-based epidemiology (WBE) has emerged as a complementary, objective indicator that can provide near real-time, population-level estimates of drug consumption (Zuccato et al., 2008; González-Mariño et al., 2018; Bijlsma et al., 2021). Prisons are particularly suitable for WBE because they are enclosed environments with defined populations and dedicated sewer systems, allowing high-resolution monitoring of temporal changes (Postigo et al., 2011; Brewer et al., 2016; van Dyken et al., 2016). Previous WBE studies have shown that wastewater can reveal substances and patterns that routine urinalysis misses and have raised ethical questions that have led to specific guidelines for applications in small or vulnerable populations (Prichard et al., 2014; EMCDDA, 2016). However, a recent review of WBE in prisons concluded that the full potential of this approach remains underused: most studies have focused on a narrow set of illicit stimulants and opioids, with very limited data on gabapentinoids, synthetic cannabinoids, alcohol, nicotine or enantiomeric profiling to distinguish prescribed from illicit stimulant use (Egaña et al., 2025; Kannan et al., 2023; Estévez-Danta et al., 2021; Verovšek et al., 2022; Sharfudeen et al., 2023; Estévez-Danta et al., 2024).

In this context, our study applies WBE in a prison in northern Spain to quantify the consumption of a broad range of psychoactive substances, including gabapentinoids, benzodiazepines, ADHD medications, opioids, cannabis, cocaine, ketamine, MDMA, alcohol and nicotine. By comparing wastewater-derived consumption estimates with prison pharmacy dispensing data, with a particular focus on high-risk psychotropics such as pregabalin and gabapentin, and by situating prison consumption in relation to general-population WBE estimates, we aim to identify potential internal diversion or trafficking and to explore how WBE can support evidence-informed prescribing and drug-control policies in the prison setting (PNSD, 2024; Agencia Española, 2024).

## 2. Methods

### 2.1. Setting

The study was conducted in a prison in northern Spain served by a dedicated sewer collecting wastewater from incarcerated people, staff

and visitors. The exact location of this prison will not be disclosed due to confidentiality and ethical reasons. The daily population contributing to the wastewater was estimated by combining the number of imprisoned people (excluding those on leave) with staff and visitors weighted by time spent on site, and the proportion attributable to prisoners was calculated for each sampling day (Table S1).

### 2.2. Sampling

Three one-week sampling campaigns were carried out in June 2023, November 2023 and February 2024. For each campaign, 24-h time-proportional composite samples were collected over seven consecutive days using an automatic sampler programmed to collect 100 mL every 10 min. Samples were stored at  $-20^{\circ}\text{C}$  until received for analysis at the University of Santiago de Compostela laboratory. A portable NIVUS NFM-0550 flowmeter was installed in the manhole receiving all prison wastewater to obtain daily flow rates, which were used for back-calculation of mass loads.

### 2.3. Chemical analysis and quality assurance

Four validated analytical methods were applied to cover a wide range of substances of (potential) abuse (Table 1). Illicit drugs, pharmaceuticals and their metabolites were determined by solid-phase extraction followed by LC-MS/MS, using an adapted version of the González-Mariño et al. method, with morphine, pregabalin and gabapentin added and revalidated (method quantification limits  $<30\text{ ng/L}$ ; recoveries 71–113%; RSD  $<20\%$ ). Alcohol and nicotine use were assessed via ethyl sulfate, cotinine and hydroxy-cotinine, measured by direct injection LC-MS/MS after enzymatic deconjugation for nicotine metabolites (MQL 200–400 ng/L). The enantiomeric profile of amphetamine, MDMA and methamphetamine was obtained using a chiral LC-MS/MS method with a Lux AMP column, reporting the fraction of the R-isomer. Quality control included blanks and spiked controls in each batch, requiring recoveries between 60–140%.

### 2.4. Wastewater-based epidemiology back calculation

Daily mass loads were calculated by multiplying measured concentrations (ng/L) by the corresponding 24-h wastewater flow ( $\text{m}^3/\text{day}$ ). These loads were normalised by the estimated contributing population to obtain population-normalised daily loads (PNDL;  $\text{mg}/\text{day}/1000$  inhabitants). Drug consumption was estimated by applying literature-based correction factors that account for excretion fractions and molecular-weight ratios for each parent drug and metabolite. For benzodiazepines with complex overlapping metabolism (diazepam, temazepam, oxazepam), no consumption estimates were calculated. Nicotine consumption was derived from cotinine and hydroxy-cotinine estimates, and amphetamine and morphine were interpreted considering their multiple licit and illicit sources as detailed in the Results.

### 2.5. Prescription data and general-population comparators

Daily dispensing of gabapentinoids, benzodiazepines, ADHD medications, opioids and esketamine was extracted from the prison pharmacy system for each sampling week and converted into defined daily doses per 1000 inhabitants per day (DID) using WHO DDD values. Wastewater-derived consumption estimates were also expressed as DID to allow direct comparison with pharmacy data. Where available, Spanish general-population WBE estimates and national dispensing data were used as external comparators to situate prison consumption within the broader drug-policy context. (Table S3).

### 2.6. Statistics

Statistical analyses were performed to assess differences across the

**Table 1**  
Correction factors applied for the back-calculation of substance use.

	Biomarker	Drug/ Pharmaceutical	Correction factor	Reference	Category
Pharmaceuticals	Pregabalin	Pregabalin	1.39	Kannan et al., 2023	Gabapentinoids
	Gabapentin	Gabapentin	1.41		
	$\alpha$ -Hydroxyalprazolam	Alprazolam	5.59	Estévez-Danta et al., in preparation	Benzodiazepines
	Alprazolam	Alprazolam	5	Postigo et al., (2011)	
	Lorazepam	Lorazepam	1.33	Estévez-Danta et al., in preparation	
	Lormetazepam	Lormetazepam	1.25	Estévez-Danta et al., in preparation	
Illicit Drugs	Ritalinic acid	Methylphenidate	1.52	Ostman et al., (2014)	ADHD drugs
	Amphetamine	Lisdexamphetamine	4.35	Estévez-danta et al., (2021)	
	2-etiliden-1,5-dimetil-3,3-difenilpirrolidina (EDDP)	Methadone	3.4	Baker et al., (2012)	Opioids
	Amphetamine	Amphetamine	2.77	Gracia-Lor et al., (2016)	Stimulants
	Methamphetamine	Methamphetamine	2.44		
	MDMA	MDMA	4.4		
	Benzoylcegonine	Cocaine	3.59		
	11-Nor-9-carboxy- $\Delta$ 9-tetrahydrocannabinol ( $\Delta$ 9-THC-COOH)	Cannabis	182	Bijlsma et al., (2021)	Cannabis
	Ketamine	Ketamine	5	Du et al.,(2020)	Ketamine
	Morphine	Heroin	3.07	Zuccato et al., (2008)	Opioids
Alcohol & Nicotine	Cotinine	Nicotine	3.409	Montes et al., (2020)	Nicotine
	OH-Cotinine	Nicotine	1.896		
	Ethyl sulfate	Alcohol	3047	López-García et al., (2020)	Alcohol

three sampling campaigns (June 2023, November 2023, and February 2024) for each drug. A Kruskal–Wallis test was applied to the wastewater dataset to compare the DID values across the three campaigns. Dunn's multiple comparison test with Bonferroni correction was then used to detect significant differences between campaign pairs. Additionally, a Mann–Whitney  $U$  test (an unpaired Wilcoxon test) was employed to compare wastewater and prescription data. This test was performed for each sampling period and for all campaigns combined. The Mann–Whitney  $U$  test was also performed to determine whether median consumption differed between weekdays and weekends. The statistical significance level was set at  $p < 0.05$ . All analyses were conducted in R version 4.5.0 (R Core Team, 2024) using the tidyverse, rstatix, ggplot and grid packages.

### 2.7. Ethical issues

Formal permission to carry out the study was obtained from the prison director. Besides, the Basque Country Ethics Committee approved this study (ref. PI2022043). Wastewater samples were collected exclusively as pooled composite samples at the facility level, and no individual-level sampling or identification was performed. Therefore, no personal data were collected, processed, or stored, and results cannot be linked to specific individuals. To further strengthen ethical oversight and ensure proper communication with the institution, a designated spokesperson was appointed within the study to act as an official liaison between the research team and the prison authorities.

## 3. Results and discussion

The proportion of inmates with respect to the total prison population ranged from 91.0% in February 2024–93.7% in June 2023 (Table S1). With the exception of methamphetamine, which was only detected in June, all analytes were found in all sampling campaigns. (see Table S4). Detailed information about concentration data found in wastewater samples is available as supplementary material (Table S4). As expected, the highest concentrations correspond to nicotine metabolites (ranging from 18,894 to 43,978 ng/L), except for the surprisingly high pregabalin concentrations (ranging from 29,082 to 226,794 ng/L). Enantiomeric fractions for amphetamine-like substances are detailed in Table S5. Both the R and S enantiomers of amphetamine and MDMA were found in all samples. However, only the S isomer was identified in the case of

methamphetamine (Table S5).

The highest average PNDL for any substance were obtained for pregabalin (29,091 mg/day/1000 inhab) and gabapentin (11,115 mg/day/1000 inhab). Among illicit drugs, the highest mean PNDL was obtained for benzoylcegonine (1513 mg/day/1000 inhab). The complete PNDL dataset is available in Table S6.

The results of WBE-derived use are presented below in subsections, beginning with pharmaceuticals, whose use can be contrasted against pharmacy dispensation, followed by illicit drugs, and finishing with the two most popular (and licit) substances of abuse in the community (alcohol and tobacco) (Table S7). It is worth noting that amphetamine use, though being an illicit drug, is discussed with pharmaceuticals as it can also originate from the prescription of lisdexamphetamine, which is used in the treatment of attention-deficit/hyperactivity disorder (ADHD). Similarly, morphine is discussed under the illicit drugs subsection because very low dispensing of this substance, which can also reflect illegal heroin or codeine consumption.

### 3.1. Pharmaceuticals

The amounts of pharmaceuticals dispensed by the pharmacy staff are summarized in Table 2 (further detailed in Table S3).

### 3.2. Gabapentinoids

The use of gabapentinoids has increased in recent years. In Spain, pregabalin use has almost doubled over the past decade, rising from 3.87 DID in 2013–6.44 DID in 2023, while gabapentin use has increased from 1.78 to 2.54 DID in the same period (Agencia Española, 2024). This study found that the amount of pregabalin and gabapentin dispensed by the prison's pharmacy (and thus prescribed) is higher than that reported for the general population in Spain (Table S3). On average, pregabalin was dispensed at a rate 10 times higher in prison (61.3 DID), while gabapentin was dispensed at a rate twice as high (5 DID vs. 2.54 DID) (Table S3). We did not collect data about the prevalence of neuropathic pain, epilepsy or generalized anxiety disorder (pregabalin labelled indications) in the prisoners' population. Some studies have shown that anxiety disorders (Gómez-Figueroa and Camino-Proaño, 2022) and epilepsy (Stawinska-Witoszynska et al., 2021) are more prevalent among inmates than in the general population. Nevertheless, the "Safer Prescribing in Prisons" guidance for clinicians recommends avoiding

**Table 2**  
Mean pharmacy dispensation as DID (DDD/day/1000 inhab).

Type	Pharmaceutical	Sampling campaign			Mean
		June 2023	November 2023	February 2024	
Gabapentinoids	Pregabalin	42.9	50.8	90.4	61.4
	Gabapentin	8.2	3.7	3.2	5.0
Benzodiazepines	Alprazolam	122.9	164.6	278.3	188.6
	Bromazepam	1.7	1.1	1.1	1.3
	Clonazepam	15.7	16.5	23.8	18.7
	Clorazepate	490.5	457.4	714.9	554.3
	Diazepam	132.7	140.9	195.1	156.2
	Lorazepam	199.4	234.1	270.6	234.7
	Lormetazepam	91.4	90.5	84.6	88.8
	ADHD	Methylphenidate	1.0	3.9	1.1
Opioids	Lisdexamphetamine	14.9	19.8	49.0	27.9
	Methadone	47.0	42.5	36.8	42.1
Antidepressant	Morphine	0.0	0.5	0.5	0.4
	Codeine	0.0	0.0	0.0	0.0
	Esketamine	0.0	1.8	0.0	0.6

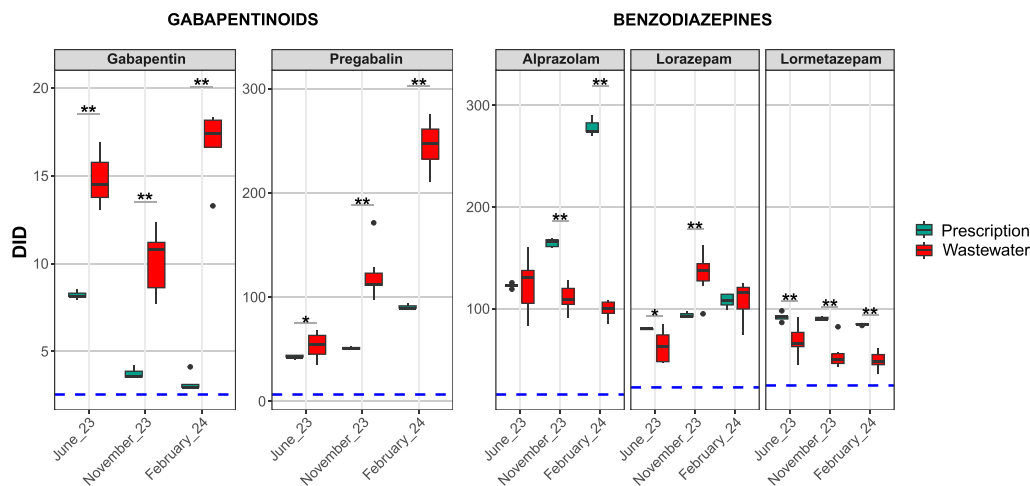
gabapentinoids because of their high risk for trading and diversion, especially in patients with opioid use disorder (Royal College of Psychiatrists, 2019).

WBE-derived consumption estimation data for pregabalin was significantly higher in February than in June (Fig. 1 & Table S8). Meanwhile, gabapentin estimated consumption was significantly higher in February and June than in November (Fig. 1 & Table S8). In addition, this study is the first to show that wastewater-derived consumption estimates for both gabapentinoids, gabapentin and pregabalin, exceed the amounts dispensed by the prison pharmacy in every sampling campaign (Fig. 1 & Table S9). The difference was particularly evident for pregabalin during the third sampling period (245.5 vs 90.4 DID). These data support the hypothesis of diversion or drug trafficking of these psychotropic drugs in the prison setting. Even when both gabapentinoids are mainly excreted unchanged in urine and a drug dumping cannot be completely discarded, no clear daily peaks were detected in any of the sampling campaigns, which argues against this hypothesis. Nevertheless, the high degree of inter-individual variability in renal excretion and in-sewer stability warrants caution due to the uncertainty surrounding the correction factors and further pharmacokinetic data would be required to improve the back-calculations.

### 3.2.1. Benzodiazepines

According to pharmacy dispensing data between 1054 and 1568 DID were dispensed in the three sampling periods by prison staff (Table S3). Around 40% of the benzodiazepine dispensed DIDs were of clorazepate. In comparison, the use of benzodiazepines in the community in Spain, which is already considered as one of the highest in the world (Roncero et al., 2025), was approximately 79.7 DID in 2023 (Agencia Española, 2024). Thus, the use of benzodiazepines in the prison is far higher than by the general population, which is in line with other studies that have compared psychotropic drug use between prisoners and the community in Spain (Franco-Migarro et al., 2008).

For many benzodiazepines it was not possible to compare pharmacy data with wastewater data, because of overlapping metabolic pathways within this drug class, particularly for diazepam, oxazepam and related drugs (Quireyans et al., 2025). Yet, alprazolam,  $\alpha$ -hydroxyalprazolam, lorazepam and lormetazepam can be considered direct wastewater biomarkers, as no other benzodiazepines are transformed into these drugs. Although lorazepam has been identified as a lormetazepam metabolite, it has been estimated that only 5% of the lormetazepam dose administered orally is excreted as lorazepam conjugate. Therefore, it can be concluded that almost all of the administered lormetazepam is excreted in the urine as a lormetazepam conjugate (Hümpel et al., 1979).



**Fig. 1.** Drug consumption estimation (DID) of prescription drugs (gabapentinoids and benzodiazepines), comparing WBE (red) and pharmacy data (green). The blue dashed line (- -) indicates drug use in the community in Spain. The Kruskal-Wallis test results comparing sampling campaigns are represented (\*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ ). Statistically differences between pharmacy data and wastewater analysed by U Mann-Whitney are represented (\*  $p < 0.05$ ; #  $p < 0.01$ ; ##  $p < 0.001$ ).

According to pharmacy data, lorazepam use was 234.7 DID on average, followed by alprazolam (188.6 DID), and diazepam with 156.2 DID (Table 2). The average consumption of these benzodiazepines by the general population in Spain was 15.5 DID for alprazolam, 22.5 DID for lorazepam and 24.4 DID for lormetazepam (Agencia Española, 2024). So, the use of these drugs in the prison setting was higher than the average reported use in Spain but comparable to that reported by Postigo et al. in a prison in Girona (Spain) ca. 15 years ago (Postigo et al., 2011). This was especially evident for alprazolam, a drug that has been the subject of much debate among addiction specialists due to its perceived high addictive potential (Ait-Daoud et al., 2018). In fact, the “Safer Prescribing in Prisons” guidance for clinicians recommends avoiding benzodiazepines due to clinical safety and diversion risk (Royal College of Psychiatrists, 2019).

The benzodiazepine that presented higher PNDL was oxazepam, with an average of 1714 mg/day/1000 inhab. This substance is not available as a marketed drug in Spain. Therefore, its presence in wastewater in our study is likely due to the consumption and metabolism of two benzodiazepines: diazepam and clorazepate. Comparison between sampling campaigns showed higher PNDLs in June for oxazepam ( $p = 0.004$ ) and temazepam ( $p = 0.023$ ) (Fig. 2 & Table S8). As mentioned, no WBE-derived use was calculated, given the cross-metabolism of these substances, and, consequently, no comparison with pharmacy dispensing could be carried out.

For substances for which WBE-derived use could be calculated, the amount of benzodiazepines consumed did not exceed the amount dispensed by the pharmacy (in some cases, it was lower), which contrasts with the findings observed for gabapentinoids. (Fig. 1 & Table S8).

### 3.2.2. Attention-deficit/hyperactivity disorder (ADHD) treatment drugs (stimulants)

Both methylphenidate and lisdexamfetamine are used to treat ADHD, which is highly prevalent among incarcerated populations (Young et al., 2015).

On average  $2.0 \pm 1.5$  DID of methylphenidate were dispensed during the three sampling campaigns by the prison's pharmacy staff. This is higher than previous reports in the general population in Spain, although recent data are lacking (Criado Alvarez and Romo Barrientos, 2003). WBE data did not suggest drug trafficking with methylphenidate ( $1.8 \text{ DID} \pm 1.1$  on average, Fig. 3). When comparing sampling campaigns, the highest consumption was observed during November ( $p < 0.001$ ).

Lisdexamfetamine was the most frequently prescribed ADHD drug in

our study, with  $27.9 \pm 15.4$  DID dispensed. This pharmaceutical is mostly excreted as amphetamine (S-isomer only) in urine, thus the detection of amphetamine in wastewater could derive from consumption of both lisdexamfetamine and amphetamine. WBE data (consumption estimations were made with lisdexamfetamine) did not suggest any drug trafficking with the prescribed drug, with an average estimation consumption of  $32.8 \pm 11.3$  DID ( $p = 1.00$ ) (Fig. 3). The enantiomeric fraction (average 0.28, indicating a higher presence of the S-isomer than the R-isomer; see the detailed data in Table S5) revealed a mixed pattern, with an important contribution from the prescription of lisdexamfetamine. Findings from locations where the illicit use of amphetamine is highly prevalent typically render EFR values in the range of 0.50–0.55. (Estévez-Danta et al., 2021, 2024). Still, this EFR value also suggests some contribution of illegal amphetamine use. Consumption was higher during February (1310 mg/day/1000 inhab) than in November (936.6 mg/day/1000 inhab) ( $p < 0.001$ , Table S8).

### 3.2.3. Methadone

In this study, the average amount of methadone dispensed by the prison pharmacy, an opioid used to treat opioid use disorder, was  $42.1 \pm 4.3$  DID, which is in line with previous reported data of opioid use disorder in prisons (Egaña et al., 2025). Wastewater did not show diversion or abuse with this drug, with an estimated consumption of  $39 \text{ DID} \pm 12.1$  ( $p = 0.322$ , Fig. 2). Consumption was higher in June compared with November ( $p = 0.001$ ). Although differences were small in two of the sampling campaigns (no statistical differences), pharmacy dispensation was higher than wastewater consumption estimation in November (42.5 vs 27.4 DID,  $p = 0.004$ ) (Table S9).

In summary, prison prescription data revealed a higher prevalence of benzodiazepine and gabapentinoid use compared to the general population. Furthermore, WBE estimation data strongly suggest gabapentin and pregabalin diversion.

## 3.3. Illicit drugs

### 3.3.1. Cannabis

The estimated average daily consumption of tetrahydrocannabinol (THC) did not significantly vary between sampling campaigns:  $54.4 \text{ g/day/1000 inhab}$  (ranging from 44 g in June 2023–67.9 g in February 2024) (Fig. 4 & Table S8). This aligns with the findings of a similar study conducted in France which described a “massive or, indeed, endemic cannabis use in the prison setting” (Néfau et al., 2017), and largely surpasses reports from other prisons worldwide (Egaña et al., 2025). The

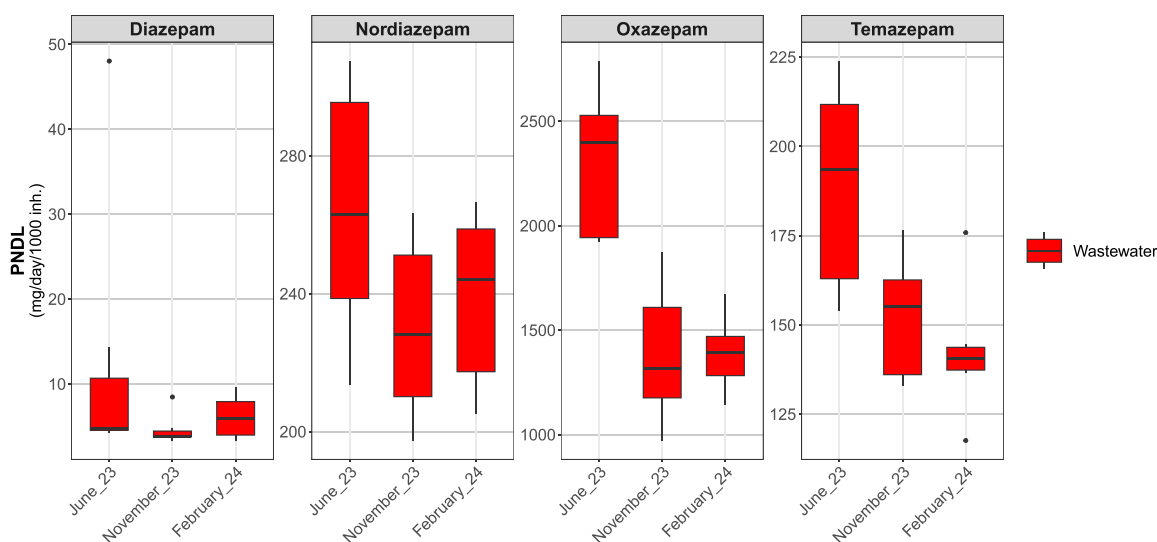
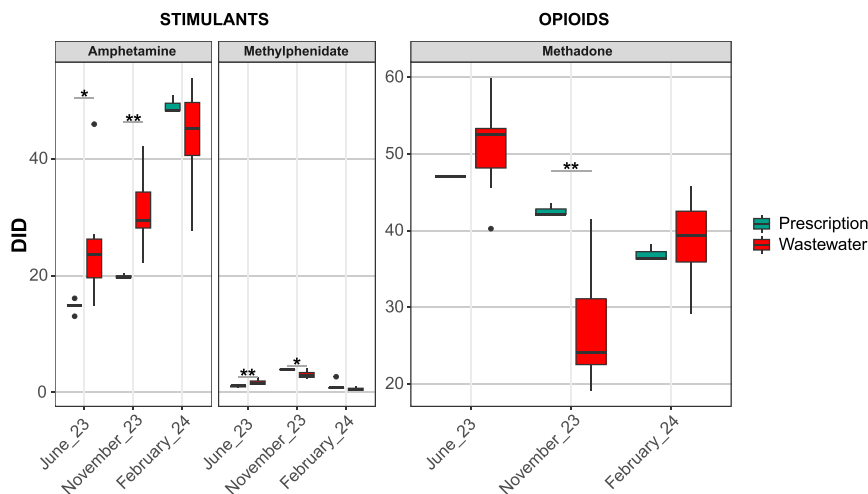
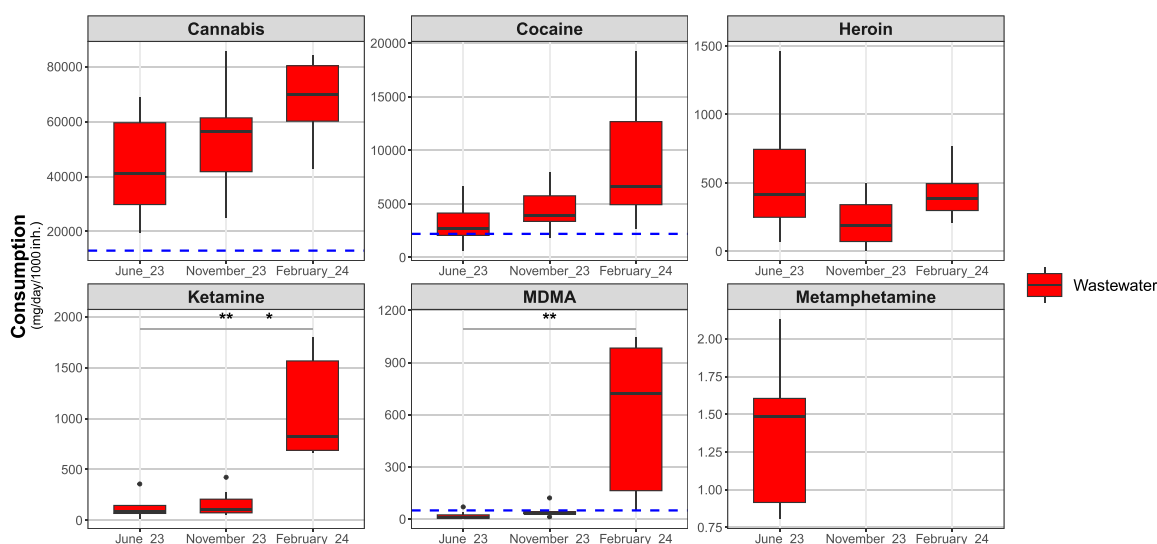


Fig. 2. Population-normalized daily loads (PNDLs) for benzodiazepines. The Kruskal-Wallis test results comparing sampling campaigns are represented (\*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ ).



**Fig. 3.** Drug consumption estimation (DID) of prescription drugs (stimulants and opioids), comparing wastewater (red) and pharmacy data (green). The blue dashed line (- -) indicates drug use in the community in Spain. The Kruskal-Wallis test results comparing sampling campaigns are represented (\*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ ). Statistically differences between pharmacy data and wastewater analysed by U Mann-Whitney are represented (#  $p < 0.05$ ; ##  $p < 0.01$ ; ###  $p < 0.001$ ).



**Fig. 4.** Illicit drug use estimation (mg/day/1000 inhab.). The blue dashed line (- -) indicates median illicit drug consumption estimation by general population in Spain estimated in the period 2021–2023 in 27–28 WWTPs (PNSD, 2024). The Kruskal-Wallis test results comparing sampling campaigns are represented (\*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ ).

median consumption by the general population in Spain is around four times lower; median consumption was around 13 g/day/1000 inhab. However, it should be noted that there is a high degree of uncertainty associated with estimating cannabis use based on THC-COOH as a biomarker, as this non-polar biomarker can potentially adsorb to and desorb from suspended particulate matter, and other metabolites in sewage can potentially transform into THC-COOH (Bijlsma et al., 2024; van Wichelen et al., 2024).

### 3.3.2. Cocaine

The estimated average daily use of cocaine across sampling campaigns was not statistically different (Fig. 4 & Table S8): 3201 mg/day/1000 inhabitants in June 2023, rising to 9049 mg/day/1000 inhabitants in February 2024. This data is higher than those reported in previous WBE studies (Egaña et al., 2025), in which the highest cocaine consumption was observed in a prison in Girona, Spain, at 371 mg/day/1000 inhabitants over ten years ago (Postigo et al., 2011). Even considering that the use of cocaine use has steadily increased since then in Europe (EUDA, 2026a) cocaine consumption in our study was

higher than the median consumption in the community in Spain, which was estimated in the period 2021–2023 in ca. 28 wastewater treatment plant (WWTP) from across Spain (2200 mg/day/1000 inhab) (Observatorio Español de las Drogas y las Adicciones, 2024).

### 3.3.3. MDMA

MDMA use was detected in all three campaigns (Fig. 4 & Table S7). The average use was low in the first two campaigns (ca. 20–45 mg/day/1000 inhab) but reached 598 mg/day/1000 inhab in February 2024 ( $p = 0.002$ , Table S8), pointing to a more irregular use of this substance, unlike the former two. In fact, when the estimated MDMA use in February 2024 is examined in more detail, it can be seen that it remained low for the first two days and then suddenly rose for the remaining days of the week (Table S7). The median consumption in the community in Spain for the period 2021–2023 was 50 mg/day/1000 inhab (PNSD, 2024). The enantiomeric fraction (average of 0.57 considering the three sampling campaigns, including all February 2024 days, Table S5) suggests that MDMA was indeed consumed rather than discarded in the sewer due to any dumping event (Estévez-Danta et al., 2024).

### 3.3.4. Methamphetamine

Methamphetamine was only detected in the first sampling (Table S4), in June 2023, with a very low estimated use (1.4 mg/day/100 inhab) (Fig. 4 & Table S7). This is an order of magnitude lower than what has been reported in prisons in the USA or Australia (Brewer et al., 2016; van Dyken et al., 2014; van Dyken et al., 2016), where this drug is also more prevalent among the community. In fact, methamphetamine use by the general population in Spain is also low (PNSD, 2024). The analysis of the enantiomeric factor showed that this drug is exclusively consumed as the S(+)-enantiomer in our setting, in line with the results obtained in previous studies carried out in the community and by analyzing drug doses (Estévez-Danta et al., 2021). No selegiline, an antiparkinsonian drug that can be partly metabolized to methamphetamine (Lertxundi et al., 2021), was dispensed during any of the sampling campaigns.

### 3.3.5. Ketamine

No prescription of ketamine occurred in the prison except one 84 mg intranasal esketamine dose used by a patient during the November 2023 sampling campaign for refractory depression. However, ketamine was detected in all wastewater samples (Table S4). Mean consumption estimations significantly varied from 127.1 mg/day/1000 inhab in June and November 2023–1095 mg/day/1000 inhab in February 2024 ( $p = 0.005$  and  $p = 0.010$  respectively) (Fig. 4 & Table S8). We hypothesize that the high level of ketamine consumption in February is most likely due to the fact that drug consumption in prisons is driven by different factors, such as drug availability. In a WBE study carried out in six Spanish cities during different periods of the COVID-19 pandemic, around 5 mg/day/1000 inhab were recorded (Gracia-Lor et al., 2024). The highest ever recorded consumption in a prison was 60 mg/day/1000 inhab in an Australian study almost 10 years ago (van Dyken et al., 2014). The official report about drug use in Spain derived from WBE data mentions that ketamine was present in most of the samples, although no consumption estimation was performed (PNSD, 2024). However, the use of illicit ketamine seems to have been rising in the last 5 years and becoming a drug of much concern, e.g. for the EUDA (EUDA, 2026b).

### 3.3.6. Opioids

The results obtained for methadone have been mentioned previously. From this class, morphine has also been considered. According to pharmacy dispensation data, morphine use in prison is similar than prescribed in general population (around 0.5 DID) (Agencia Española, 2024) (Table S3). It must be taken into account that other opiates, such as heroin and codeine, produce morphine when metabolised. Therefore, the morphine detected in wastewater could be derived from morphine itself, or from the consumption of these other opiates. Considering that morphine loads were higher (average load 147.6 mg/day/1000 inhab, Table S6) than the amount of dispensed morphine (average 35.5 mg/day/1000 inhab), and that no codeine was dispensed by the pharmacy staff in any of the three-sampling periods, illegal consumption of heroin, and/or drug trafficking with morphine/codeine seems the most likely explanation.

We then estimated heroin consumption following the method proposed by Zuccato et al. (Zuccato et al., 2008). We calculated the estimated amount of excreted therapeutic morphine (excretion factor 85%) and we subtract that amount from the total morphine in the wastewater. Then we back-calculated heroin consumption from that “heroin derived morphine”. The latter resulted in an average heroin use roughly in the 330–560 mg/day/1000 inhab. Yet, these values need to be considered with caution as they could also originate from trafficking of morphine itself or even codeine.

To sum up, wastewater confirms illicit drug use in prison. Cannabis consumption was roughly four times higher than Spanish community estimates, while cocaine use estimates ranged from 3201 to 9049 mg/day/1000 inhabitants, compared with 2200 mg/day/1000 inhabitants

in the community. Ketamine and MDMA use peaked in February, both clearly above Spanish community medians.

## 3.4. Alcohol and nicotine

This is, as far as we are concerned, the first study to measure alcohol and nicotine consumption using WBE in a prison setting.

### 3.4.1. Alcohol

Unlike most of the abovementioned drugs, the average daily alcohol consumption did not significantly vary across sampling campaigns (2.6–2.7 L/day/1000 inhab, Fig. 5 & Table S7). This consumption is lower than what was reported for the general population in Spain in 2024 using WBE (overall median of 7.6 L/day/1000 inhab) (PNSD, 2024). As visitors and staff very likely contribute, it is not possible to discern if this alcohol was illegally consumed by prisoners or not. However, this is likely to happen, since otherwise and considering that the non-inmate equivalent population is lower than 10% (see above and Table S1) that would mean visitors/prison staff would have an average alcohol use rate 3–4 times higher than the regularly found in the community.

Although alcohol consumption is prohibited in prisons, there are reports in the literature of illicit alcohol (“pruno”, “moonshine”) being produced in prisons from fermented fruit (Walters et al., 2015; CDC, 2011).

### 3.4.2. Nicotine

The average daily nicotine use did not significantly vary across sampling campaigns (13,966–17,705 mg/day/1000 inhab, Fig. 5 & Table S7). The average intake of nicotine in our study (15,159 mg/day/1000 inhab) is almost 10 times higher than the overall median consumption in Spain, according to WBE data: 1641 mg/day/1000 inhab (PNSD 2024). However, it has to be considered that 74.0% of the Spanish prison population declared having smoked tobacco in the last 30 days, which is higher than the community population average (ESDIP, 2022). As no nicotine products to treat tobacco dependence were dispensed during any of the sampling periods, we can assume that this was the result of tobacco smoking or vaping. It would be interesting to analyze new biomarkers like anabasine (indicator of the exposure to tobacco-containing products) and 2-cyanoethyl-mercaptopuric acid (2CyEMA, indicator for the exposure to acrylonitrile, a combustion product mainly originating from the use of cigarettes) in future studies (Scherer et al., 2025).

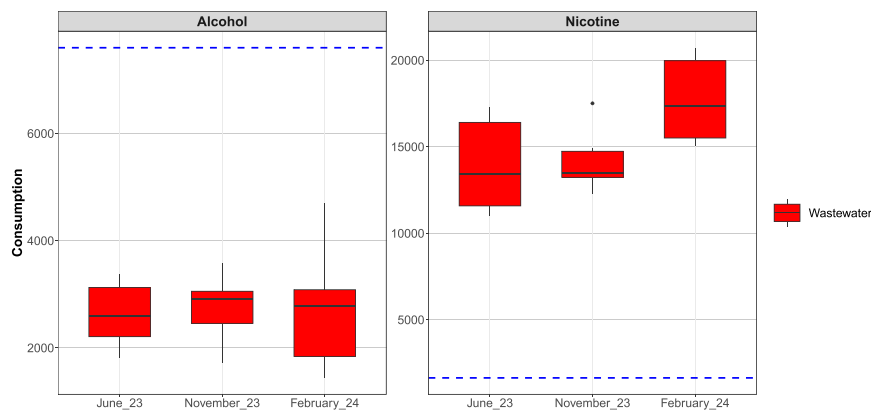
In brief, alcohol consumption remained stable below the community median of 7.6 L/day/1000 inhabitants, whereas nicotine use was almost ten times higher than community levels.

## 3.5. Weekly variations

When the three sampling campaigns were considered together, no apparent variations in wastewater consumption estimations were observed between weekends and working days for any of the analysed substances (Table S10), in contrast with what has been described in the community in Spain, especially for MDMA, cocaine (Bijlsma et al., 2021) and alcohol (López-García et al., 2020), whose consumption tends to be higher during weekends. However, in the case of MDMA, very high levels of consumption were observed over four days in February, as mentioned above and as previously discussed. We hypothesize that this is most likely due to the fact that drug consumption in prisons is driven by different factors, such as drug availability, and differs from that of the general population, where the weekend is markedly a period of recreational use.

## 3.6. Limitations

Like any other drug use indicator, WBE provides aggregate



**Fig. 5.** Alcohol (mL/day/1000 inhab) and nicotine (mg/day/1000 inhab) consumption estimation. The blue dashed line (- -) indicates median licit drug consumption estimation in the community in Spain estimated in the period 2021–2023 in 27–28 WWTPs (PNSD, 2024). The Kruskal-Wallis test results comparing sampling campaigns are represented (\*  $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\*  $p < 0.001$ ).

consumption information rather than insights into individual use patterns. In this prison context, the sewer system design prevented discrimination between prisoner, staff and visitor contributions (91–94% attributable to inmates; [Table S1](#)), so data interpretation requires caution. This is particularly true of alcohol and nicotine, which are widely consumed by the general population. However, the high level of nicotine consumption is unlikely to be affected by staff and visitor use. If prisoners did not consume alcohol (it is forbidden in this setting), the average alcohol consumption rate of visitors and prison staff would be 3–4 times higher than that typically observed in the general population.

Obtaining representative composite samples was challenging without a WWTP, but this was mitigated through a custom flow meter installation, frequent subsampling and three separate weekly campaigns.

Ethical considerations also apply, particularly when studying smaller or vulnerable populations such as prisons ([EMCDDA, 2016](#); [Prichard et al., 2014](#)). Although WBE avoids many privacy concerns of urine testing or cell searches, data reporting must consider potential stigmatization risks. Despite these limitations, our findings demonstrate that WBE can still provide actionable policy insights when combined with pharmacy dispensing data and interpreted within appropriate methodological and ethical frameworks.

#### 4. Conclusions and implications from a policy and interventions perspective

This study shows that wastewater analysis can provide a detailed and objective picture of both illicit and prescribed drug use in a prison, complementing traditional indicators such as urinalysis and self-report ([Bijlsma et al., 2021](#); [Zuccato et al., 2008](#); [González-Mariño et al., 2020](#)). By integrating WBE with pharmacy dispensing data, we identified substantial gaps between dispensed and actually consumed gabapentinoids—particularly pregabalin—and documented extremely high benzodiazepine prescribing compared with the general population, as well as intense use of cocaine, cannabis, ketamine and MDMA despite existing control measures ([Agencia Española, 2024](#); [Egaña et al., 2025](#)).

Situating prison drug consumption in relation to national WBE estimates and dispensing data confirmed that prisons concentrate a disproportionate burden of high-risk substance use for both illicit and prescribed drugs, while also revealing very high nicotine use and detectable alcohol consumption that rarely enter routine, security-focused monitoring (PNSD, 2024; ESDIP, 2022). These findings support the inclusion of prisons as sentinel settings within national drug-monitoring and harm-reduction strategies and are consistent with calls from international agencies to address the health and human-rights dimensions of drug use in custody ([EMCDDA, 2016](#)).

From a policy perspective, our data argue for stricter and better-monitored prescribing of high-risk psychotropic medicines—especially gabapentinoids and benzodiazepines—through clearer indications, deprescribing where appropriate and supervised dosing, in line with existing “Safer Prescribing in Prisons” guidance ([Royal College of Psychiatrists, 2019](#); [Soni and Walters, 2019](#)). They also highlight the need to combine supply-reduction efforts with expanded evidence-based treatment and harm-reduction interventions for illicit drugs, and with robust tobacco-control and cessation programs ([Néfaud et al., 2017](#); [Walters et al., 2015](#)). Repeated WBE campaigns, combined with pharmacy and clinical data and conducted under appropriate ethical safeguards for small and vulnerable populations, could become a pragmatic tool to evaluate the impact of prison drug policies and to detect emerging substances or shifts in prison drug markets that require rapid responses ([Prichard et al., 2014](#); [EMCDDA, 2016](#)).

#### CRedit authorship contribution statement

**Rosario Rodil:** Writing – review & editing, Conceptualization. **Rosa Montes:** Writing – review & editing, Conceptualization. **Vladimir Akhrimenko:** Writing – review & editing, Investigation. **Xiana González-Gómez:** Writing – original draft, Supervision, Investigation. **Iker Egaña:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Maite Nogales-García:** Supervision, Investigation. **Gorka Orive:** Writing – review & editing, Investigation, Conceptualization. **Juan Ignacio Mestre-Pintó:** Writing – review & editing, Conceptualization. **Unax Lertxundi:** Writing – review & editing, Conceptualization. **José Benito Quintana:** Writing – review & editing, Visualization, Conceptualization.

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#### 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

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.etap.2026.105021](https://doi.org/10.1016/j.etap.2026.105021).

## Data availability

Data will be made available on request.

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