

## Wastewater analysis to assess new psychoactive substances and emerging drug use trends in Kenyan cities

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Date submitted: 28<sup>th</sup> March 2026

Date Published: 30<sup>th</sup> June 2026

### ABSTRACT

According to the United Nations Office on Drugs and Crime (UNODC), an estimated 292 million people aged 15-64 used drugs in 2022. Statistics from the UNODC indicate continued growth, especially synthetic drugs. Also, the emergence of new psychoactive substances (NPS) has recorded rapid growth over the last 20 years. This study attempted to assess NPS and illicit drug use in Kenya, through wastewater analysis (WWA). The study covered the five (5) Kenyan cities where wastewater samples were collected. Each collected sample was composited with 3 grab samples at each sampling point resulting to a total of 48 wastewater samples which were subjected to laboratory analysis and identification. Analytical findings confirmed the existence of three (3) NPS namely alpha-ethyltryptamine, benzofurans and synthetic cathinones. The study also identified methamphetamine, 3, 4-methylenedioxymethamphetamine (MDMA/ ecstasy), tryptamine-based psychedelics (psilocybine and N, N-Dimethyltryptamine (DMT)), diazepam and amitriptyline as the emerging psychoactive substances. The findings demonstrate that Kenya is at risk of NPS and with an equally rapidly evolving drug landscape. The study therefore recommends for review of the current scheduling framework to provide for rapid control of NPS and emerging psychoactive substances. Secondly, there is need for establishment of an Early Warning System (EWS) to inform timely and coordinated response to mitigate emerging threats of NPS and emerging psychoactive substances.

Finally, the Pharmacy and Poisons Board needs to strengthen the pharmaceutical regulation and prescription monitoring to mitigate diversion and misuse of these drugs as alternative psychoactive substances.

**Key words:** *Wastewater analysis (WWA), new psychoactive substances (NPS), illicit drug use, emerging drug use trends, drug surveillance, early warning system, synthetic drugs, and Kenya.*

## INTRODUCTION

The global drug use continues to grow, driven by increased availability, continued diversification of synthetic drugs, and emerging new markets. According to the United Nations Office on Drugs and Crime (UNODC), an estimated 292 million people aged 15-64 used drugs in 2022, marking a 20% increase over the past decade (UNODC, 2024). Statistics from UNODC indicate continued growth, especially synthetic drugs while traditional plant-based drugs like opiates derived from opium face supply related disruptions (UNODC, 2025).

Drug use in Africa points to a growing prevalence of synthetic drugs, cocaine, heroin, and pharmaceutical opioids, marking a significant shift from traditional use of cannabis. The World Drug Report estimates that Africa contributes significantly to the global burden reporting a regional annual prevalence of 5.5% among the population aged 15-64 (UNODC, 2025a).

Kenya's strategic location linking East Africa, maritime routes of the Indian Ocean, and global air destinations has positioned it as a major transit hub for illicit drugs like cocaine, heroin, methamphetamine, synthetic drugs and emerging NPS. While this facilitates trafficking to other African countries, North America, and Europe, it also imposes severe multi-dimensional challenges arising from spill-over into the domestic market making Kenya to transform from a pure transit hub to an emerging consumption country (UNODC, 2025; National Authority for the Campaign Against Alcohol and Drug Abuse (NACADA), 2025).

New psychoactive substances (NPS) are not controlled under the 1961 Single Convention on Narcotic Drugs, or the 1971 Convention on Psychotropic Substances. However, they may pose significant public health threats that are comparable to scheduled drugs (UNODC, 2024). These substances are mostly synthetic compounds "designed" to mimic the effects of the common traditional illicit drugs (UNODC, 2024). The emergence of NPS has recorded rapid growth over the last 20 years, driven by globalization, expansion of online markets, and access to simple synthetic chemistry. Over 1,000 substances have been reported globally by monitoring bodies like the UNODC and the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) (UNODC, 2024). The commonly reported NPS in the global drug market over the past five (5) years are synthetic cannabinoids followed

by synthetic cathinones, and phenethylamines. Analysis of seizure data also shows that ketamine continues to dominate synthetic NPS seizures globally (UNODC, 2025).

Detection and identification of NPS and emerging drug use trends has been a major challenge, especially in the African continent. Wastewater analysis (WWA) therefore offers hope, as an emerging and proven scientific method validated for overcoming these detections related hurdles. It analyzes metabolites and drug residues in untreated sewage. WWA provides objective and near-real-time population-level data (Causanilles et al., 2023). Since its entry in 2001, WWA has been conducted in over 100 cities globally, tracking illicit substances such as methamphetamine, cocaine, amphetamine, cannabis, MDMA/ ecstasy, and NPS (Gonzalez-Marino et al., 2020). WWA offers essential opportunities for policy making, public health, and law enforcement to address the growing challenges of emerging drug use trends (UNODC, 2025).

WWA has proven its potential to complement established surveillance and monitoring methods in the illicit drugs arena (Zuccato et al., 2008). The rapid emergence of NPS challenges traditional surveillance methods (EMCDDA, 2023). Similarly, WWA captures population-based data providing a more comprehensive picture compared to individual testing (González-Mariño et al., 2020). WWA is therefore designed to overcome the challenges of non-disclosure in the use of stigmatized or controlled substances (Peacock et al., 2019).

Recent drug seizures report and evidence from studies on drug use confirm that the country has become increasingly vulnerable to synthetic drugs and emerging psychoactive substances. The country is witnessing a growing availability and use of emerging substances especially methamphetamine, MDMA/ ecstasy, ketamine and prescription drugs. Kenya's strategic positioning as a key East African transit hub and its global air connectivity to major world destinations makes it an attractive illicit drug trafficking route. This geographic advantage increases the country's vulnerability to NPS and other emerging drug use trends as a result of spill-over effects related to illicit drug trafficking. Despite these imminent threats, traditional surveillance methods have largely been ineffective in providing real-time early warning to inform timely response measures. Therefore, WWA has the potential to overcome these inherent challenges facing conventional surveillance methods.

## **METHODOLOGY**

### *Study design*

The study employed a cross-sectional design where wastewater samples were collected in the five (5) cities of Kenya - Nairobi, Mombasa, Kisumu, Nakuru and Uasin Gishu. The selection of these sampling sites was informed by the existence of well-established sewerage network, close proximity to the national reference laboratories for storage and

preservation of samples, cosmopolitan nature of the population, and large networks of vulnerable populations e.g. injecting drug users, female sex workers and concentration of institutions of higher learning. Also, these 5 cities are known hotspots for illicit drugs. Data was collected from 7th April to 30th May 2025.

### *Sampling procedure*

The sampling locations in each of the selected cities were identified prior to the study implementation. In four (4) of the sampled cities, the team mapped three (3) sampling sites (hot spots) through the use of key informants. The 5<sup>th</sup> city, Nairobi, which is the capital city, was allocated four (4) sampling sites. In each of the sampling site, three (3) composited wastewater samples were collected. Overall, this resulted to a total of 48 wastewater samples. The technical team from the collaborating water and sewerage companies guided on the identification of the most suitable points to sample from the existing sewerage networks. Venue-based wastewater sampling was adopted for the study where samples were collected near drug using sites, and alcohol drinking establishments.

### *Sample collection and storage*

The collection of wastewater samples was preceded by identification of a suitable sampling site. Three (3) grab wastewater samples were collected in each sampling site at intervals of one hour during peak hours and composited to create one representative sample. Therefore, in a period of three (3) hours, three (3) representative samples were collected in each sampling site.

This ensured the capture of temporal variations in drug residue levels. The peak hours considered in the study were 10:00 – 13:00 for drug using sites and 06:00 – 09:00 for mapped high-risk alcohol drinking establishments. Even though a 24-hour composite sample collection is the desired standard, the approach adopted by the study was reliable for screening and identifying the presence of NPS and illicit drug use.

The collected wastewater samples were then filtered to remove suspended solids. Using clean glass containers, a sample of one litre was collected in each sampling site. Each sample was labeled and given a sample number; date of sampling; the sampled city; sampling site; method of sampling; and the name of the handling officer. After labeling, the samples were kept in a portable cooler box with ice packs at temperatures of 4°C. These conditions were maintained to prevent the degradation of metabolites and drug residues (Baker & Kasprzyk-Hordern, 2011). The samples were transported within 12 hours to the nearest Government Chemist national reference laboratories in Nairobi, Kisumu and Mombasa for refrigeration.

After completion of the sample collection, the samples were delivered to the main Government Chemist national reference laboratory in Nairobi. The collected samples were frozen at  $-20^{\circ}\text{C}$  to preserve the stability of metabolites, compounds, and drug residues. The receiving officer ensured that each of the samples was securely sealed and labeled, and the risks of cross-contamination were minimized during storage. Also, to guarantee traceability of the samples, the sampling forms were also produced in triplicate and shared with the collaborating institutions (UNODC, 2009).

### *Sample preparation*

The first step was to homogenize wastewater samples to ensure consistency before further processing. This was followed by the pre-treatment of samples to reduce matrix complexity and eliminate interfering components. Suspended solids and particulate matter were removed using the standard physical separation methods, filtration and/or centrifugation, resulting in an aqueous phase that is clearer and suitable for extraction. This step was particularly important for improvement of analyte recovery and minimizing interference resulting from complex and variable composition of wastewater matrices (Baker & Kasprzyk-Hordern, 2013).

Target analytes, including residues of NPS and illicit drugs were isolated using solid-phase extraction (SPE). This method was preferred because of its effectiveness in concentrating trace levels of organic contaminants, and its suitability for handling a wide range of wastewater compounds. Wastewater aliquots were passed through pre-conditioned SPE cartridges designed to retain both polar and semi-polar psychoactive substances. After loading the samples, the cartridges were rinsed to remove undesirable matrix interferences. The retained analytes were then eluted using an appropriate organic solvent system. The resulting eluates were carefully concentrated under controlled laboratory conditions to improve the sensitivity for screening and confirmatory analyses.

The concentrated extracts were reconstituted using solvent systems chosen as per the requirements of subsequent analytical techniques and the chemical nature of the target compounds. For colorimetric screening, aqueous or buffered solutions were used to ensure appropriate interaction with chromogenic reagents and stable color formation.

For UV–Vis spectrophotometric screening, the extracts were prepared in optically clean solvents with minimal absorbance in the visible range, to allow accurate detection of chromophore development. In the case of confirmatory analysis using Gas Chromatography - Mass Spectrometry (GC-MS), the extracts were reconstituted in volatile and instrument-compatible organic solvents. In some instances, derivatization was carried out to improve thermal stability, volatility, and chromatographic separation of certain analytes prior to analysis.

### *Substance identification*

Identification of NPS and emerging drug use trends in wastewater followed a systematic process, utilizing Colorimetric tests, UV-Vis Spectrophotometry, and GC-MS. These integrated methods enabled robust detection and identification of NPS and emerging drug use trends.

Colorimetric analysis was used as a preliminary screening step to assess the presence of selected classes of illicit drugs and NPS in wastewater extracts from five Kenyan cities. Within wastewater analysis, such approaches are commonly used for identification of potential chemical signals prior to confirmatory analysis (Baker & Kasprzyk-Hordern, 2013; EMCDDA, 2016). Aliquots of each extract were reacted with class-specific chromogenic reagents (Marquis, Simon's, and Scott's), selected based on the functional groups of target analytes. Reactions were performed under controlled conditions, and color development was assessed against reference charts after a fixed incubation period (UNODC, 2009). In each batch, reagent blanks and positive controls were also included to account for verification of reagent performance, and background signal. Absorbance was measured using UV-Vis spectrophotometry, at wavelengths corresponding to chromophore maxima, to provide a semi-quantitative estimate of color intensity (Skoog et al., 2014). Analyses were conducted in replicate to evaluate reproducibility. Given the limitations of colorimetric methods, any detected signals were treated as presumptive indicators of compound classes rather than definitive identification. For this reason, all positive findings were further verified using GC-MS, following established multi-tier analytical frameworks in wastewater drug monitoring (Castiglioni et al., 2013; EMCDDA, 2016).

Measurements of UV-Vis spectrophotometry were carried out using a Shimadzu 1650 PC double-beam spectrophotometer, equipped with UV Probe software for data acquisition and processing. The UV-Visible Spectroscopy analyses focused on the ultraviolet region, with scans recorded from 200 to 400 nm, within the instrument's broader operational range of 190–1100 nm. A spectral bandwidth of approximately 2 nm was used to balance sensitivity and spectral definition. Spectra were collected at a data interval of 0.1 nm, although true optical resolution was governed by the instrument bandwidth. Wavelength accuracy was maintained at  $\pm 0.5$  nm, with reproducibility of approximately  $\pm 0.1$  nm.

Confirmatory analysis was performed using GC-MS. Samples were analyzed on an Agilent Technologies 7890B gas chromatograph coupled to a 5977A mass selective detector. Separation was achieved on a DB-5MS UI capillary column (30 m  $\times$  0.25 mm i.d., 1.0  $\mu$ m film thickness) using helium ( $\geq 99.999\%$ ) as the carrier gas at a constant flow of 1.0 mL/min. Injections were performed in splitless mode and the injector was maintained at 250 °C. The oven temperature program was set at 40 °C (1 min), ramped at 10 °C/min to 280 °C, and

held for 3 min. The mass spectrometer (MS) operated in electron ionization mode (70 eV) with a solvent delay of 2.75 min, scanning from 40 to 500 m/z at 5.9 scans s<sup>-1</sup>.

The ion source, quadrupole, and transfer line temperatures were maintained at 230 °C, 150 °C, and 280 °C, respectively. MassHunter software was used for data acquisition and processing. This multi-tiered approach that combines rapid screening with selective instrumental confirmation is consistent with established practices in wastewater drug analysis (Castiglioni et al., 2013; EMCDDA, 2016).

### *Interpretation of results*

Interpretation of data integrated results from all three analytical methods was undertaken to confirm the presence of NPS and emerging drug use trends. Colorimetric tests assisted with the rapid presumptive results, UV-Vis Spectrophotometry which aided in screening, while GC-MS provided the confirmatory identification and quantification. This cross-validation across methods for identification of NPS and emerging drug use trends guaranteed the reliability of the analytical results (Hernández et al., 2014). For analytical accuracy, quality control measures that included blanks, duplicates, and spiked samples, were implemented to monitor matrix effects (Castiglioni et al., 2014).

### *Ethical considerations*

The study was guided by the ethical guidelines for sewage surveillance to monitor drug use (Prichard et al, 2004). These guidelines ensure that the risk of identifying individual drug users and communities is safeguarded. Generally, WWA studies raise limited ethical issues because data is aggregated without the identity of individual users.

## **RESULTS**

A total of 48 wastewater samples were collected and submitted to the Government Chemist national reference laboratory for analyses and identification. Laboratory analyses identified the following maker compounds: butylated hydroxytoluene; benzyl alcohol; pyridine; 3(1-methyl-2-pyrrolidinyl) -(s); 4-methylphenol; tolycaine; acetaminophen; amitriptyline; indole; pyrrolidine 1,5-dimethyl-3,3-diphenyl-2-ethylidene-; 3,4-methylenedioxyanisole; benzofuran 2,3-dihydro-; 1H-indole 3-methyl-; alpha-ethyltryptamine; methanone (2-amino-5-chlorophenyl) phenyl; propane 2-nitro; cocaine; and caffeine (Table 1).

**Table 1: Wastewater marker compounds and drug associations**

Marker compound	Drug class / association	Rationale	References
Pyridine	<ul style="list-style-type: none"><li>- Methadone</li><li>- Synthetic cathinones</li></ul>	<ul style="list-style-type: none"><li>- May appear as impurity in methadone synthesis;</li><li>- Used in synthetic cathinone production</li></ul>	(UNODC, 2019; Kelly, 2011)
Pyrrolidine, 1,5-dimethyl-3,3-diphenyl-2-ethylidene-	<ul style="list-style-type: none"><li>- Synthetic cathinones (<math>\alpha</math>-pyrrolidinophenones)</li></ul>	<ul style="list-style-type: none"><li>- Structural signature of pyrrolidinophenone stimulants</li><li>- Not from <i>khat</i> or methadone;</li></ul>	(Kelly, 2011; Capriola, 2013; Prosser & Nelson, 2012)
Methanone, (2-amino-5-chlorophenyl)phenyl-	<ul style="list-style-type: none"><li>- Synthetic cathinones</li><li>- Benzodiazepines especially diazepam</li></ul>	<ul style="list-style-type: none"><li>- Chlorinated <math>\beta</math>-keto amphetamine analog</li><li>- Degradation product (aminochlorobenzophenone)</li></ul>	(UNODC, 2019; Bijlsma et al., 2014; Prosser & Nelson, 2012)
Butylated hydroxytoluene (BHT)	<ul style="list-style-type: none"><li>- Methadone formulations</li></ul>	<ul style="list-style-type: none"><li>- Antioxidant excipient in pharmaceutical methadone</li><li>- Indicative of pharmaceutical use that may not be necessarily not illicit</li></ul>	(Capriola, 2013)
Benzyl alcohol	<ul style="list-style-type: none"><li>- Methadone formulations</li></ul>	<ul style="list-style-type: none"><li>- Excipient solvent;</li><li>- Suggests pharmaceutical ingestion of methadone</li></ul>	(Capriola, 2013)
3(1-methyl-2-pyrrolidinyl)-(s)	<ul style="list-style-type: none"><li>- Methamphetamine</li><li>- Cathinone analogues</li></ul>	<ul style="list-style-type: none"><li>- Pyrrolidine ring</li><li>- Synthetic cathinone signature</li><li>- Stimulant signature</li></ul>	(Prosser & Nelson, 2012; Kelly, 2011)
Tolycaine	<ul style="list-style-type: none"><li>- Tolycaine</li><li>- Adulterant in stimulants</li></ul>	<ul style="list-style-type: none"><li>- Local anaesthetic with psychoactive central nervous system (CNS) effects</li><li>- Marker for direct use</li><li>- Marker for drug adulteration</li></ul>	(Bade et al., 2020)
Acetaminophen	<ul style="list-style-type: none"><li>- OTC drugs</li><li>- Poly-drug use</li><li>- Co-formulations in opioids</li></ul>	<ul style="list-style-type: none"><li>- Suggests general drug excretion;</li><li>- Co-formulant in opioid related painkillers</li><li>- Proxy for opioid consumption</li></ul>	(González-Marino et al., 2020; Darke et al., 2020)

Marker compound	Drug class / association	Rationale	References
Amitriptyline	- Amitriptyline	<ul style="list-style-type: none"> <li>- Excreted un-metabolized</li> <li>- Indicates antidepressant use</li> <li>- Indicates sedative use</li> <li>- Suggests poly-drug use trends</li> </ul>	(Darke et al., 2020; Bijlsma et al., 2014)
Indole	- Plant-based tryptamines e.g. <i>khat</i>	- Indicates natural psychoactive plant metabolites e.g. <i>khat</i>	(Kelly, 2011)
3,4-methylenedioxyanisole	<ul style="list-style-type: none"> <li>- MDMA</li> <li>- Synthetic analogues</li> </ul>	<ul style="list-style-type: none"> <li>- Methylenedioxy ring</li> <li>- Strong stimulant indicator</li> <li>- Piperonal-derived precursor</li> <li>- By-product in the production of MDMA</li> </ul>	(Kinyua et al., 2015; Prosser & Nelson, 2012)
Benzofuran 2,3-dihydro-	- Benzofuran NPS e.g. 5/6-APB	- Marker for “benzofury” entactogen NPS	(Bade et al., 2020)
1H-indole 3-methyl-	<ul style="list-style-type: none"> <li>- Tryptamine-based psychedelics</li> <li>- NPS e.g. psilocybin and DMT</li> </ul>	<ul style="list-style-type: none"> <li>- Plant-derived tryptamines</li> <li>- NPS tryptamines</li> <li>- Core indole from tryptamine synthesis or metabolism</li> </ul>	(Bade et al., 2020; Kelly, 2011)
Alpha-ethyltryptamine	- Synthetic tryptamines (alpha-ethyltryptamine)	<ul style="list-style-type: none"> <li>- Direct indicator for synthetic hallucinogenic NPS</li> <li>- Not from natural plant-based sources</li> </ul>	(Zuccato et al., 2011; Prosser & Nelson, 2012)
Propane 2-nitro (2-nitropropane)	- Synthesis of methamphetamine	<ul style="list-style-type: none"> <li>- By-product of reductive amination synthesis</li> <li>- Indicates illicit production</li> </ul>	(Kinyua et al., 2015; Nicol & Quinn, 2012; UNODC, 2006)
Cocaine	- Cocaine	- Gold-standard excretion marker for cocaine use	(Darke et al., 2020; Postigo et al., 2010)

Marker compound	Drug class / association	Rationale	References
Caffeine	<ul style="list-style-type: none"> <li>- Caffeine</li> <li>- Adulterant for heroin, cocaine or amphetamines</li> </ul>	<ul style="list-style-type: none"> <li>- Stimulant cut to enhance or bulk drugs</li> <li>- Suggests adulteration</li> <li>- Alone may not be indicate illicit drug use</li> </ul>	(Darke et al., 2020; González-Marino et al., 2020)

*Source: Literature review*

With reference to Table 1, identification of these marker compounds in wastewater suggests the presence of psychoactive substance use. Similarly, these marker compounds are suggestive of widespread use of stimulants, opioids, NPS, prescript drugs, and existence of small scale clandestine laboratory activity (Daughton, 2018).

Specifically, analytical results identified benzofurans; alpha-ethyltryptamine; and synthetic cathinones as the emerging NPS in Kenya. In addition, methamphetamine; MDMA/ ecstasy; tryptamine-based psychedelics (e.g., psilocybin and DMT); diazepam; and amitriptyline were identified as emerging psychoactive substances. The study also detected *khat* and cocaine, even though the two psychoactive substances have traditionally existed in the Kenyan drug market. Besides, the study was indicative of small scale clandestine laboratory activity related to illicit drug production of synthetic stimulants particularly methamphetamine.

## DISCUSSION

With reference to the study results, it is evident that WWA has the potential for a reliable surveillance toolkit in the detection of NPS and emerging psychoactive substances. Analytical report confirmed the presence of NPS and emerging drug use trends.

The analytical report suggests the existence of NPS in Kenya, namely alpha-ethyltryptamine ( $\alpha$ -ET); benzofurans; and synthetic cathinones. Alpha-ethyltryptamine ( $\alpha$ -ET) is often classified as NPS having emerged in the recreational drug markets and initially they were not regulated in many jurisdictions (Corkery et al., 2012). These substances are designed to mimic the effects of controlled psychedelics especially LSD or DMT. Tryptamine-based NPS have been associated with severe adverse effects, including psychosis, serotonin syndrome, and fatalities (Corkery et al., 2012). As a result of these risks, many countries have scheduled these substances. For example,  $\alpha$ -ET are now Schedule I substances in the US, and currently a banned substance in the UK (Drug Enforcement Administration, 2020; Corkery et al., 2012). However, there are limited comparable studies reporting detection of  $\alpha$ -ET.

Benzofurans are classified as a category of NPS. Benzofurans are synthetic stimulants with empathy-enhancing and hallucinogenic effects, similar to amphetamines and MDMA, and belong to the phenethylamine family (Galindo et al., 2019; Negus et al., 2022). Benzofurans are the third most commonly reported NPS after synthetic cannabinoids and cathinones. Over 20 benzofuran variants have been reported worldwide by the UNODC (Negus et al., 2021; UNODC, 2024). Benzofurans produce euphoria, increase empathy, and mild hallucinations that are similar to MDMA (Monte et al., 2018). Similar detections of benzofurans have been reported in the UK and European countries (Acher et al., 2020; Salgueiro-Gonzalez et al., 2024)

Synthetic cathinones, marketed as “bath salts”, are a group of NPS mimicking effects of stimulants such as amphetamine, MDMA (ecstasy), methamphetamine, and cocaine (Bailey et al., 2020). They are chemically  $\beta$ -keto analogs of amphetamine, derived structurally from cathinone, the natural stimulant in the *khat* plant (*Catha edulis*) (Kelly, 2011). The UNODC Early Warning Advisory tracks 209 synthetic cathinones worldwide as of 2024 (UNODC, 2024), while the EU Early Warning System monitors 162 (EMCDDA, 2024). Synthetic cathinone inhibit/reverse the re-uptake of dopamine, norepinephrine, and serotonin transporters. They produce intense psycho-stimulation, comparable to or exceeding that of cocaine or methamphetamine (Baumann et al., 2018; Simmler et al., 2013). Synthetic cathinones have been reported in wastewater samples in South Africa and most European countries (Lawrence et al., 2023; Acher et al., 2018; González-Mariño et al., 2016; Salgueiro-Gonzalez et al., 2024; Bade et al., 2023).

Analytical findings of this study were also indicative of the presence of other emerging psychoactive substances - methamphetamine; MDMA/ ecstasy; tryptamine-based psychedelics (e.g., psilocybin and DMT); diazepam; and amitriptyline. Methamphetamine is listed as a Schedule II substance under the 1971 UN Convention and in the US Controlled Substances Act, an indication of its strict national and international control (Drug Enforcement Administration, 2023). Methamphetamine is a potent CNS stimulant, characterized by euphoria, increased energy, and potential for addiction (Negus et al., 2021). Methamphetamine has also been detected in wastewater samples in European countries and Taiwan (Salgueiro-Gonzalez et al., 2024; Chen et al., 2023)

MDMA is listed as a Schedule I substance under the 1971 UN Convention on Psychotropic Substances. MDMA is controlled in many jurisdictions. For example, in America MDMA is regulated under the US Controlled Substances Act (Drug Enforcement Administration, 2023). In the UK, it is a Class A drug under the Misuse of Drugs Act (Home Office, 2023). MDMA is a synthetic drug with both stimulant and empathogenic effects. It produces increased empathy, euphoria, and mild hallucinogenic effects (National Institute on Drug Abuse, 2020). Similarly, MDMA has been detected in the European multi-city study in 12 European countries (Salgueiro-Gonzalez et al., 2024).

Tryptamine-based psychedelics e.g. psilocybin (found in magic mushrooms), and DMT (found in ayahuasca), are regulated under international drug control frameworks (UNODC, 2013). These substances are listed in the schedules of 1971 UN Convention. Tryptamine-based psychedelics have also been reported in 12 European cities (Salgueiro-Gonzalez et al., 2024).

The study also suggests non-medical misuse of prescription drugs, namely diazepam and amitriptyline. These findings corroborate with evidence from a previous study conducted in Kenya showing use of prescription drugs among the drug users (Kamenderi et al., 2021). The most commonly reported prescription drugs were diazepam, amitriptyline, benzhexol, flunitrazepam, tramadol and carbamazepine (Kamenderi et al., 2021). Diazepam and amitriptyline are misused by drug users often in combination with other substances like heroin to enhance euphoria or sedation (Prah et al., 2020; Griffin et al., 2013; UNODC, 2020; Kamenderi et al., 2021). Poly-drug use of diazepam and amitriptyline is also a common phenomenon among drug users exposed to low purity heroin (Kamenderi et al., 2021).

Even though the use of *khat* and cocaine has traditionally been profiled in the Kenyan drug market, their detection in the study is worth noting. *Khat* is one of the most widely used substances in Kenya after alcohol and tobacco (NACADA, 2022). Studies show that detection of *khat* (*Catha edulis*) in wastewater is extremely rare. However, detection of natural cathinone (*khat*) in wastewater has also been reported in Oslo, Norway (Harman et

al., 2011). However, for cocaine, comparative studies confirm that it is the most commonly detected illicit drug in WWA. A Kenyan study detected cocaine in wastewater samples in Eldoret (Ochieng et al., 2025). In Africa, cocaine has been detected in Durban, South Africa and it was identified as the dominant illicit drug (Lawrence et al., 2023). European cities have also routinely detected cocaine with Belgium, Netherlands and Spain recording the highest loads (European Union Drugs Agency [EUDA], 2025). Similar observations have been made in the United States and Australia (Huizer et al., 2021).

The analytical report was also suggestive of small scale clandestine laboratory activity related to illicit drug production of synthetic stimulants. This finding corroborates with the discovery of clandestine methamphetamine production activity in Namanga, Kajiado County, Kenya (Directorate of Criminal Investigation (DCI), 2024). Studies have shown that WWA may be useful in the discovery of illicit drug production and clandestine laboratory activities through detection of specific chemical markers in sewage systems. This approach leverages on the detectable chemical signatures generated by clandestine labs (Emke et al., 2018; UNODC, 2020). These markers are so specific and can differentiate residues from drug consumption, and production-related waste. This information may aid law enforcement agencies to locate clandestine labs. This foundation is mostly applicable for monitoring synthetic drugs, especially methamphetamine, amphetamines, MDMA, and synthetic cathinones (Emke et al., 2018; UNODC, 2020). For example, the study analysis detected a byproduct of reductive amination synthesis, referring to chemical compounds that are produced as secondary/unintended products during the synthesis of synthetic drugs, through the reductive amination process. These by-products are distinct from the target drug or its precursors, and their presence in wastewater may serve as markers specific for detection of clandestine drug production (Postigo et al., 2021; Bade et al., 2020).

## CONCLUSION

The findings of this study point to a rapidly evolving and increasingly complex drug use landscape in Kenya, with significant implications for national drug policy architecture, response strategies and surveillance systems. Evidence suggests a dynamic market shaped by multiple substances, including emerging psychoactive substances, and indications of local synthetic drug production. This therefore confirms that these substances are also being used at community level.

This emerging shift raises important public health concerns. Many of the newly identified substances, particularly NPS, are poorly understood, both in terms of their toxicity and health effects. This makes clinical management and emergency response even more difficult. The situation is further complicated by the growing pattern of poly-substance use increasing the risk of overdose and mental health problems, underscoring the need for integrated and

comprehensive harm reduction and treatment approaches.

The study equally underscores the value of wastewater analysis in detecting real-time drug use trends that are more often missed by traditional surveillance systems. The detection of emerging substances and synthetic drugs reveals undeniable limitations in the current monitoring strategies and reinforces the need for a national Early Warning System capable of identifying and responding to NPS and other emerging threats.

Besides, evidence suggesting local small-scale synthetic drug production points leads to a worrying shift in Kenya's illicit drug ecosystem. This development challenges existing law enforcement approaches, largely designed to deal with trafficking and seizures of plant-based drugs. This observation calls for strengthening of forensic capacity, intelligence-led policing, and regional cooperation.

Detection of the non-medical misuse of prescription medications such as diazepam and amitriptyline further illustrates weaknesses in pharmaceutical regulation, pointing to a possible risk of diversion from legitimate medical supply chains. This underscores the need for tightening the current prescription monitoring regime coupled with a robust public awareness intervention on the risks associated with the non-medical use of these drugs.

Overall, these findings suggest an evolving and rapidly changing drug environment in Kenya requiring an adaptive and evidence-driven response that integrates real-time surveillance with strengthened harm reduction services, improved coordination across sectors and enhanced regional collaboration.

### **Limitations of the study**

Even though WWA offers complementary data source for monitoring NPS and emerging drug use trends, this surveillance method may be prone to the risk of missing metabolites or the parent compounds due to their low concentrations in wastewater samples. To minimize these limitations inherent with WWA, this study ensured that the identified sampling points were closest to the known drug hotspots e.g. drug dens and entertainment venues.

## REFERENCES

- Archer, E., Castrignanò, E., Kasprzyk-Hordern, B., & Wolfaardt, G. M. (2018). Wastewater-based epidemiology and enantiomeric profiling for drugs of abuse in South African wastewaters. *Science of the Total Environment*, 625, 792–800. <https://doi.org/10.1016/j.scitotenv.2017.12.269>
- Archer, J. R. H., Mendes, F., Hudson, S., Layne, K., Dargan, P. I., & Wood, D. M. (2020). Evaluation of long-term detection trends of new psychoactive substances in pooled urine from city street portable urinals (London, UK). *British Journal of Clinical Pharmacology*, 86(3), 517–527. <https://doi.org/10.1111/bcp.14239>
- Bade, R., Rousis, N. I., Adhikari, S., Ort, C., Wang, L., Castiglioni, S., ... & Mueller, J. F. (2023). Three years of wastewater surveillance for new psychoactive substances from 16 countries. *Water Research X*, 19, Article 100179. <https://doi.org/10.1016/j.wroa.2023.100179>
- Bade, R., Thai, P., & Mueller, J. F. (2020). A review of wastewater-based epidemiology for new psychoactive substances: The quest for better data. *Trends in Analytical Chemistry*, 132, 116041. <https://doi.org/10.1016/j.trac.2020.116041>
- Bailey, D. N., Barrueto, F., & Hoffman, R. S. (2020). *Synthetic cathinones (“bath salts”): Pharmacology and toxicology of a new class of designer drugs*. *Clinical Toxicology*, 58(5), 345–359. <https://doi.org/10.1080/15563650.2020.1713407>
- Baker, D. R., & Kasprzyk-Hordern, B. (2013). Critical evaluation of methodology commonly used in sample collection, storage and preparation for the analysis of pharmaceuticals and illicit drugs in surface water and wastewater. *Journal of Chromatography A*, 1290, 1–18.
- Baker, D. R., & Kasprzyk-Hordern, B. (2011). Multi-residue analysis of drugs of abuse in wastewater and surface water by solid-phase extraction and liquid chromatography–tandem mass spectrometry. *Journal of Chromatography A*, 1218(44), 7901–7913. <https://doi.org/10.1016/j.chroma.2011.08.092>
- Baumann, M. H., Bukhari, M. O., Lehner, K. R., Anizan, S., Rice, K. C., Concheiro, M., & Huestis, M. A. (2018). Neuropharmacology of synthetic cathinones. *Handbook of Experimental Pharmacology*, 252, 123–147. [https://doi.org/10.1007/164\\_2018\\_159](https://doi.org/10.1007/164_2018_159)
- Bijlsma, L., Salgueiro-González, N., Celis, E., López de Alda, M., & Barceló, D. (2014). Consuming pharmaceuticals as emerging adult lifestyles in modern wastewater-based epidemiology. *Current Opinion in Environmental Science & Health*, 2, 100021. <https://doi.org/10.1016/j.coesh.2021.100021>
- Capriola, M. (2013). *Synthetic cathinone abuse*. *Clinics in Pharmacology: Advances &*

*Applications*, 5, 109–115. <https://doi.org/10.2147/CPAA.S42832>

Castiglioni, S., Bijlsma, L., Covaci, A., Emke, E., Hernández, F., Reid, M., Zuccato, P. & Thomas, K. V. (2013). Evaluation of uncertainties associated with the determination of community drug use through the measurement of sewage drug biomarkers. *Environmental Science & Technology*, 47(3), 1452–1460.

Castiglioni, S., Thomas, K. V., & Zuccato, E. (2014). Testing wastewater to detect illicit drugs: State of the art, potential and critical issues. *Science of The Total Environment*, 487, 613–620. <https://doi.org/10.1016/j.scitotenv.2014.03.133>

Causanilles, A., Krizman-Matasic, I., Burgard, D., Emke, E., Hernandez, F., Castiglioni, S., Bijlsma, L., Celma, A., Chappell, A., Covaci, A., de Voogt, P., Gonzalez-Marino, I., Gracia-Lor, E., Kasprzyk-Hordern, B., Matias, J., Meirinhos, A., McCall, A. K., Postigo, C., Sancho, J. V., ... Ort, C. (2023). Wastewater-based epidemiology: Assessing illicit drug usage and impact through an innovative approach. *Water*, 15(23), 4192. <https://www.mdpi.com/2073-4441/15/23/4192>

Chen, Y.-C., Hsu, J.-Y., Chang, C.-W., Chen, P.-Y., Lin, Y.-C., Hsu, I.-L., Chu, C.-J., Lin, Y.-P., & Liao, P.-C. (2023). Investigation of New Psychoactive Substances (NPS), Other Illicit Drugs, and Drug-Related Compounds in a Taiwanese Wastewater Sample Using High-Resolution Mass-Spectrometry-Based Targeted and Suspect Screening. *Molecules*, 28(13), Article 5040. <https://doi.org/10.3390/molecules28135040>

Corkery, J. M., Durkin, E., Elliott, S., Schifano, F., & Ghodse, A. H. (2012). The recreational tryptamine 5-MeO-DALT (N, N-diallyl-5-methoxytryptamine): A brief review. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 39(2), 259–262. <https://doi.org/10.1016/j.pnpbp.2012.05.022>

Darke, S., Lappin, J. M., & Farrell, M. (2020). *The clinician's guide to illicit drugs and health*. Cambridge University Press.

Daughton, C. G. (2001). Illicit drugs in municipal sewage: Proposed new nonintrusive tool to heighten public awareness of societal use of illicit drugs and their potential for ecological consequences. *Environmental Science & Technology*, 35(23), 469A–476A.

Daughton, C. G. (2018). Monitoring emerging chemicals and human exposure using wastewater-based epidemiology. *Water Research*, 145, 1-21. <https://doi.org/10.1016/j.watres.2018.07.054>

Directorate of Criminal Investigations (DCI). (2024). *Press statements on Namanga drug laboratory investigation*. Nairobi, Kenya.

Drug Enforcement Administration. (2023). *Controlled Substances - Alphabetical Order*. U.S. Department of Justice. <https://www.deadiversion.usdoj.gov/schedules/>

European Monitoring Centre for Drugs and Drug Addiction (EMCDDA). (2016). *Assessing illicit drugs in wastewater: Advances in wastewater-based drug epidemiology*. Publications Office of the European Union.

EMCDDA. (2023). *European drug report 2023: Trends and developments*. European Monitoring Centre for Drugs and Drug Addiction. [https://www.emcdda.europa.eu/publications/edr/trends-developments/2023\\_en](https://www.emcdda.europa.eu/publications/edr/trends-developments/2023_en)

Emke, E., Evans, S., Kasprzyk-Hordern, B., & de Voogt, P. (2018). Enantiomer profiling of amphetamine and methamphetamine in wastewater: A review of stereoselective versus non-stereoselective analyses. *Science of the Total Environment*, 610-611, 987-997. <https://doi.org/10.1016/j.scitotenv.2017.08.143>

European Union Drugs Agency. (2025). *Wastewater analysis and drugs — a European multi-city study*. [https://www.euda.europa.eu/publications/pods/waste-water-analysis\\_en](https://www.euda.europa.eu/publications/pods/waste-water-analysis_en)

Galindo, L., Grifell, M., Palma, A., Ventura, M., Carbó, M., Quintana, P., & Torrens, M. (2019). Benzo fury: A new trend in the drug misuse scene. *Current Neuropharmacology*, 17(8), 719–726. <https://doi.org/10.2174/1570159X17666190219161421>

Gonzalez-Marino, I., Baz-Lomba, J. A., Alygizakis, N. A., Andres-Costa, M. J., Bade, R., Bannwarth, A., Barron, L. P., Been, F., Berset, J. D., Bijlsma, L., Bodik, I., Brenner, A., Brock, A. L., Burgard, D. A., Castrignanò, E., Celma, A., Christophoridis, C. E., Covaci, A., de Voogt, P., ... Ort, C. (2020). Spatio-temporal assessment of illicit drug use at large scale: Evidence from 7 years of international wastewater monitoring. *Addiction*, 115(1), 109-120. <https://onlinelibrary.wiley.com/doi/10.1111/add.14767>

González-Mariño, I., Gracia-Lor, E., Rousis, N. I., Castrignanò, E., Thomas, K. V., Kasprzyk-Hordern, B., ... & Castiglioni, S. (2016). Wastewater-based epidemiology to monitor synthetic cathinones use in different European countries. *Environmental Science & Technology*, 50(18), 10089–10096. <https://doi.org/10.1021/acs.est.6b02644>

Griffin, C. E., Kaye, A. M., Bueno, F. R., & Kaye, A. D. (2013). Benzodiazepine pharmacology and central nervous system-mediated effects. *Ochsner Journal*, 13(2), 214-223. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3684331/>

Harman, C., Reid, M., & Thomas, K. V. (2011). In situ calibration of a passive sampling device for selected illicit drugs and their metabolites in wastewater, and subsequent year-long assessment of community drug usage. *Environmental Science & Technology*, 45(13), 5676–5682. <https://doi.org/10.1021/es201124j>

Hernández, F., Castiglioni, S., Covaci, A., de Voogt, P., Emke, E., Kasprzyk-Hordern, B., Ort, C., Reid, M., Sancho, J. V., Thomas, K. V., van Nuijs, A. L. N., Zuccato, E., & Bijlsma, L. (2014). Mass spectrometric strategies for the investigation of biomarkers of illicit drug use in wastewater. *Mass Spectrometry Reviews*, 35(3), 265–301. <https://doi.org/10.1002/mas.21476>

Home Office. (2023). *Misuse of Drugs Act 1971*. UK Government. <https://www.gov.uk/government/collections/misuse-of-drugs-act>

Huizer, M., Ter Laak, T. L., & de Voogt, P. (2021). Wastewater-based epidemiology for illicit drugs: A critical review on global data. *Water Research*, 207, Article 117789. <https://doi.org/10.1016/j.watres.2021.117789>

Kamenderi, M., Muteti, J., Okioma, V., Kandie, J., Munyoki, W., Lelei, K. and Kimani, S. (2021). Emerging trends on non-medical use of prescription drugs in Kenya. *African Journal of Alcohol and Drug Abuse*, 5(41-55).

Kelly, J. P. (2011). Cathinone derivatives: A review of their chemistry, pharmacology and toxicology. *Drug Testing and Analysis*, 3(7–8), 439–453. <https://doi.org/10.1002/dta.313>

Kinyua, J., Covaci, A., & van Nuijs, A. L. N. (2015). A multi-analyte approach to monitor the consumption of new psychoactive substances and classic drugs in wastewater. *Talanta*, 132, 110-116. <https://doi.org/10.1016/j.talanta.2014.08.049>

Lawrence, T. I., Archer, E., Wolfaardt, G. M., & Kasprzyk-Hordern, B. (2023). Wastewater profiling of illicit drugs and new psychoactive substances in the eThekweni Metropolitan Municipality, South Africa. *Environmental Pollution*, 326, 121433.

Monte, A. P., Marona-Lewicka, D., Cozzi, N. V., & Nichols, D. E. (2018). Pharmacokinetics, pharmacodynamics, and toxicology of new psychoactive substances (NPS): 2C-B, 4-fluoroamphetamine, and benzofurans. *Drug and Alcohol Dependence*, 192, 242–256. <https://doi.org/10.1016/j.drugalcdep.2018.07.033>

NACADA (2022). *Status of Drugs and Substance Use in Kenya*. NACADA.

NACADA (2025). *22<sup>nd</sup> Edition of Biannual Report on the Status of Alcohol and Drug Control in Kenya*. NACADA.

National Institute on Drug Abuse. (2020). *MDMA (Ecstasy/Molly) DrugFacts*. National Institutes of Health. <https://www.drugabuse.gov/publications/drugfacts/mdma-ecstasymolly>

Negus, S. S., Banks, M. L., & Brandt, M. R. (2022). The toll of benzofurans in the context of drug abuse. In V. R. Preedy (Ed.), *Handbook of substance misuse and addictions: From biology to public health* (pp. 3045–3060). Springer. <https://doi.org/10.1007/978-3-030->

[92392-1\\_168](#)

Nicol, J. J., & Quinn, C. P. (2012). *Illicit methamphetamine manufacture: Chemical aspects and forensic implications. Forensic Science Review, 24(2)*, 97–120.

Ochieng, J. K., Olal, F. O., & Anino, E. (2025). Presence of illicit drug metabolites in the influent of a wastewater treatment plant in Eldoret, Kenya. *International Research Journal of Rongo University, 3(2)*. <https://doi.org/10.64535/ijoru.v3i2.120>

Peacock, A., Bruno, R., Gisev, N., Degenhardt, L., Hall, W., Sedefov, R., White, J., Thomas, K. V., Farrell, M., & Griffiths, P. (2019). New psychoactive substances: Challenges for drug surveillance, control, and public health responses. *The Lancet, 394(10209)*, 1668–1684. [https://doi.org/10.1016/S0140-6736\(19\)32231-7](https://doi.org/10.1016/S0140-6736(19)32231-7)

Postigo, C., de Alda, M. J. L., & Barceló, D. (2008). Analysis of drugs of abuse and their human metabolites in water by LC-MS/MS: A non-intrusive tool for drug abuse estimation at the community level. *Trends in Analytical Chemistry, 27(11)*, 1053–1069. <https://doi.org/10.1016/j.trac.2008.09.011>

Postigo, C., de Alda, M. J. L., & Barceló, D. (2021). Wastewater-based epidemiology to monitor synthetic cathinones and other new psychoactive substances. *Environmental Science & Technology, 55(8)*, 4567–4576. <https://doi.org/10.1021/acs.est.0c07685>

Postigo, C., de Alda, M. L., & Barceló, D. (2010). Analysis of drugs of abuse and their metabolites in water by ultra-high-performance liquid chromatography–tandem mass spectrometry. *Analytical and Bioanalytical Chemistry, 397(7)*, 2559–2572. <https://doi.org/10.1007/s00216-010-3784-9>

Prah, A., Purg, M., & Stare, J. (2020). Fatal poisoning with new psychoactive substances and classic drugs of abuse: Case reports. *Forensic Science International, 316*, 110468. <https://doi.org/10.1016/j.forsciint.2020.110468>

Prichard J, Hall W, de Voogt P, Zuccato E. Sewage epidemiology and illicit drug research: the development of ethical research guidelines. *Sci Total Environ* 2014; 472:550-555 doi: 10.1016/j.scitotenv.2013.11.039

Prosser, J. M., & Nelson, L. S. (2012). The toxicology of bath salts: A review of synthetic cathinones. *Journal of Medical Toxicology, 8(1)*, 33–42. <https://doi.org/10.1007/s13181-011-0194-z>

Salgueiro-Gonzalez, N., Béen, F., Bijlsma, L., Boogaerts, T., Covaci, A., Baz-Lomba, J. A., Kasprzyk-Hordern, B., Matias, J., Ort, C., Bodík, I., Heath, E., Styszko, K., Emke, E., Hernández, F., van Nuijs, A. L. N., & Castiglioni, S. (2024). Influent wastewater analysis to

investigate emerging trends of new psychoactive substances use in Europe. *Water Research*, 254, Article 121390. <https://doi.org/10.1016/j.watres.2024.121390>

Simmler, L. D., Buser, T. A., Donzelli, M., Schramm, Y., Dieu, L. H., Huwyler, J., Chaboz, S., Hoener, M. C., & Liechti, M. E. (2013). Pharmacological characterization of designer cathinones in vitro. *British Journal of Pharmacology*, 168(2), 458–470. <https://doi.org/10.1111/j.1476-5381.2012.02185.x>

Skoog, D. A., Holler, F. J., & Crouch, S. R. (2014). *Principles of Instrumental Analysis* (6th ed.). Cengage Learning.

United Nations Office on Drugs and Crime (UNODC). (2019). *Global synthetic drugs assessment 2019*. <https://www.unodc.org/unodc/en/data-and-analysis/global-synthetic-drugs-assessment.html>

UNODC. (2009). Guidelines on representative drug sampling. *United Nations Office on Drugs and Crime*. [https://www.unodc.org/documents/scientific/Drug\\_Sampling.pdf](https://www.unodc.org/documents/scientific/Drug_Sampling.pdf)

UNODC. (2006). Methods for the identification and analysis of amphetamine, methamphetamine and their ring-substituted analogues in seized materials (ST/NAR/34). United Nations. <https://www.unodc.org/pdf/scientific/stnar34.pdf>

UNODC. (2013). *The challenge of new psychoactive substances*. *United Nations Office on Drugs and Crime*. [https://www.unodc.org/documents/scientific/NPS\\_Report.pdf](https://www.unodc.org/documents/scientific/NPS_Report.pdf)

UNODC. (2020). World Drug Report 2020: Drug Supply. *United Nations Office on Drugs and Crime*. <https://wdr.unodc.org/wdr2020/en/drug-supply.html>

UNODC. (2024). *World Drug Report 2024: Synthetic drugs*. *United Nations Office on Drugs and Crime*. <https://www.unodc.org/unodc/en/data-and-analysis/world-drug-report-2024.html>

UNODC. (2025). *World Drug Report 2025*. *United Nations Office on Drugs and Crime*. <https://www.unodc.org/unodc/en/data-and-analysis/world-drug-report-2025.html>

Zuccato, E., Castiglioni, S., & Tettamanti, M. (2011). Changes in illicit drug consumption patterns in a small European city: Wastewater analysis as a new monitoring tool. *Science of the Total Environment*, 409(19), 3990–3997. <https://doi.org/10.1016/j.scitotenv.2011.07.041>

Zuccato, E., Chiabrando, C., Castiglioni, S., Bagnati, R., & Fanelli, R. (2008). Estimating community drug abuse by wastewater analysis. *Environmental Health Perspectives*, 116(8), 1027–1032. <https://doi.org/10.1289/ehp.11022>