Knowledge for Development and Diplomacy

Rapid Evidence Review

# The environmental impacts of illicit drug production

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**What are the environmental impacts of illicit drug production and associated waste products? What evidence is there of soil and water pollution from illicit drug production and waste, and what are the expected implications for overall ecosystem functioning?**

## Contents

# 1. Summary

This rapid evidence review summarises key findings emerging in the literature on the environmental damage caused by illicit drug production and associated waste products, and the risks for overall ecosystem health and function. A large body of evidence was found evaluating water pollution from licit pharmaceutical compounds due to widespread wastewater contamination, with some evidence of illicit pharmaceutical contaminants. In contrast there is limited evidence on the effects of these compounds on soil health due to comparative constraints in the identification and sampling of contamination sites. More evidence is available for pharmaceutical wastewater contamination in high- and middle- income countries, with relatively limited data for lower income countries. This review provides a broad overview of available evidence, prioritising recent academic papers and grey literature where available, supplemented with evidence of the environmental impacts of licit pharmaceuticals where research into the potential impacts and interactions of illicit compounds remains nascent. Overall evidence on the long-term effects of the introduction of biologically active drug compounds for overall ecosystem functioning is found to be severely limited.

This review is divided into two parts. The first section explores the environmental damage resulting from illicit drug production, including ecosystem impacts, land use change and environmental degradation, synthetic drug production and chemical waste, and waste management and disposal. The second section explores evidence for how prohibitionary drug policies may exacerbate environmental harms from illicit drug production.

The **key messages** emerging in the literature include:

- Distinct regional patterns of drug use and supply influence its environmental distribution. Opioids are the most frequent drug reported for users receiving drug treatment in Europe and sub-regions of Asia, while Latin America has a higher proportion of cocaine use, East and South-East Asia have higher prevalences of methamphetamine use, and in parts of Africa cannabis is the primary drug reported.
- Multiple pathways of environmental impact exist from illicit drug production depending on the crop being cultivated (or its chemical synthesis), its distribution channels, and the effects of its metabolites[1] in the environment from end use and direct waste disposal.
- An increase in the environmental load of parent drug compounds, their metabolites and precursor compounds is anticipated due to population growth.
- There is a paucity of disaggregated data on how socioeconomic inequalities (such as those shaped by poverty, gender, age, disability, race, ethnicity, sexuality, religion or belief, etc.) may differentiate experiences and vulnerabilities resulting from environmental damage from illicit drug production and waste.

### Ecosystem impacts

- The long-term effects of illicit drug compounds in the environment are not well understood, however waste chemical compounds which are not easily metabolised

[1] The compounds left over after a drug is broken down (metabolized) in the body. Metabolites in wastewater can be used to estimate the health of a population and its consumption of or exposure to defined substances (Gracia-Lor et al., 2017).

will accumulate through the food chain (bioaccumulation), with some indications of disruption to hormone chemical messaging, with implications for growth and reproduction among other factors (endocrine system disruption), and acute toxicity in limited studies on individual species.

- There is a significant gap in literature which uses an ecosystem-based approach[2] to assess and address the combined toxic effects of pharmaceutical compounds in the environment, resulting in a lack of understanding of the compound effects of complex mixtures of drugs in the environment over time and resultant environmental damage.
- Adverse effects on ecosystem health are expected for potent biologically active waste, including from cocaine, morphine, MDMA and amphetamine, with metabolites detected in low solutions (nanograms to micrograms per litre) in treated wastewater, with indications of impacts on the mortality, growth and reproduction of individual species.

**Land use change and environmental degradation**

- The relationships between land use change, illicit drug production and environmental degradation are complex. Literature focusing on coca cultivation in the Amazon basin emphases the indirect relationships between drug markets and deforestation, so-called "narco-deforestation".
- Patterns of land use change are characterised by the drug and its associated regional geographies of cultivation, trafficking and money laundering, with some evidence from participatory research conducted in Costa Rica, Honduras and Guatemala suggesting indirect environmental degradation is more likely to take place at logistical centres or hotspots of drug trafficking operations, typically along border regions.

**Synthetic drug production and chemical waste**

- Synthetic drugs require inputs from raw materials and precursor chemicals, and in general the more steps there are in the chemical production process for synthetic illicit pharmaceuticals, the more chemical waste is produced. Regulations restricting access to requisite precursor chemicals used as part of the synthetic drug production process may result in additional chemical waste produced to synthesis alternatives, or pre-precursors.

**Waste management and disposal**

- Illicit pharmaceutical compounds have pseudo-persistence[3] in surface water from continual use and supply, with inputs originating from wastewater following end use, and through direct dumping of waste chemicals used in the production process.
- Inadequate wastewater treatment and dilapidated or out-dated infrastructure is a primary source of environmental contamination from pharmaceutical waste, with high proportions of untreated sewage released directly into the environment globally, and with treated waste still containing biologically active chemical compounds.

[2] An ecosystem-based approach (EBA) recognises the interdependencies of ecosystems as integrated systems. An EBA links the state of a natural resource or system within the context of overall ecosystem "services" (typified by the Millenium Ecosystem Assessment as provisioning, regulatory, cultural and supporting services) (Wentworth, 2011).

[3] A chemical is determined to be pseudo-persistent when it is replenished in the environment faster than it degrades. Chemicals' half-lives in the environment vary depending on environmental conditions and the inherent properties of the chemical (Bu et al., 2016).

- The persistence of biologically active compounds in the hydrological cycle, the closed nature of the water system and water recycling potentially has severe implications for overall environmental health, and food and water security, with research gaps identified over the long-term consequences of contamination.

**Environmental damage from illicit drug prohibition**

- Direct and indirect environmental impacts from drug prohibition policies may enhance environmental damages, for example: associated damaging economies which may be leveraged for money laundering, such as cattle ranching; the forced eradication of illicit crops and contamination risks from pesticides; the use of unregulated pesticides during illicit drug cultivation; use of additional pre-precursor chemicals in the synthesis of synthetic drugs; and some evidence from studies in Colombia and Mexico indicating that interdiction exercises have served to displace drug cultivation and trafficking into increasingly remote, ecologically valuable frontiers.
- Where environmental conservation and drug prohibition policies are typically conceived and implemented in isolation of one another, limited cross-agency collaboration and engagement may hinder the realisation of cross-cutting policy objectives.

# 2. Environmental damage from illicit drug production

**Multiple pathways of environmental impact exist from illicit drug production depending on the crop being cultivated (or its chemical synthesis), its geography of distribution, resultant trafficking networks, and the effects of its metabolites in the environment from end use and direct waste disposal. While the long-term effects of illicit drug compounds in the environment are not well understood, waste chemical compounds which are not easily metabolised accumulate through the food chain, with some indications of endocrine disruption and acute toxicity in limited studies on individual indicator species.**

## Definitions and pathways

Illicit drugs are typically restricted classes of chemical compounds[4] which are not widely administered as part of existing therapeutic practice due to their perceived risks to human health, including from addiction (Rosi-Marhsall et al., 2015). However, 'illicit' drug use also includes the (mis)use of licit prescription pharmaceuticals for their euphoric qualities (Krishnan et al., 2023). Licit pharmaceutical compounds may also be used as components in the production of illicit drugs, thereby complicating the identification and classification of residual chemical compounds in soil and water and defining the precise extent of environmental damage from illicit drug production, particularly where the scale of damage is significantly less

[4] For the purposes of this rapid review, 'illicit' drugs are determined according to the following five broad classifications: stimulants (such as cocaine, amphetamines and methamphetamines), depressants (including opioids such as morphine and structural analogues of morphine, such as heroin), hallucinogens (including entactogens such as methylenedioxymethamphetamine (MDMA), and lysergic acid diethylamide (LSD), psilocybin, dimethyltryptamine (DMT) and mescaline), cannabinoids (marijuana and synthetic cannabinoids) and dissociative anaesthetics (such as ketamine and phencyclidine (PCP)) (UNODC, 2023).

when compared with the waste products of legitimate pharmaceutical and agricultural industries (UNODC, 2023a).

In the United Nations Office on Drugs and Crime (UNODC, 2022) *World Drug Report* booklet on drugs and the environment, three routes of environmental impact from illicit drug production are identified:

- **Cultivation and production** (energy use, deforestation and biodiversity loss, soil and water pollution and depletion, effects on the food chain, and air pollution).
- **Drug use** (water pollution, soil pollution, food chain effects).
- **Drug responses** (alternative development, with possible impacts including deforestation or reforestation, and a higher or lower subsequent carbon footprint).

While not included in the UNODC routes of environmental impact, critics consider the pollutive impacts of prohibitionary policies a key oversight (Walsh & Salomón, 2022). Prohibition has been attributed to driving illicit drug cultivators to increasingly ecologically remote frontiers, and to the creation of profitable illegitimate markets and environmentally damaging, unregulated production practices and waste disposal (McSweeney, 2015; Walsh & Salomón, 2022, see section 3).

Ripanda et al. (2022), who evaluated evidence of the pharmaceutical load of illicit drugs on the environment in sub-Saharan Africa through wastewater epidemiology, typified primary and secondary effects of illicit drug exposure to the ecosystem through the food chain, where humans are seen to act as both sources and sinks of contaminants:

- **Primary effects (usage)** – diseases, toxic effect, acute effect, overdose, injury, dependence, addiction
- **Secondary effects (food chain)** - release and/or disposal into the environment, either directly or indirectly through wastewater treatment plants. The compounds interact with “lower” organisms and bioaccumulate to impact “higher” organisms in the food chain. Aquaculture is observed to be impacted through direct exposure. Agriculture is impacted through both direct exposure and irrigation.

In this typology, the extent of wastewater management and treatment can affect the concentration of damaging pharmaceutical compounds in the environment (Ripanda et al., 2022). However, the extent of wastewater treatment plants and their efficacy is hugely variable globally, and waste that is treated may still contain damaging pharmaceutical compounds which are then released into the environment (Archer et al., 2017; see section 2.5).

Wartenberg et al. (2021) also identify six pathways of impact in their categorisation of cannabis’ effects on the environment, which include:

- **Pesticide use** (its direct impacts on the environment when applied to crops, as well as its residues on the end product and the potential harms to consumers)
- **Air pollution**
- **Energy use** (which is particularly high for indoor cannabis cultivation)
- **Water use** (where cannabis is often cultivated in semi-arid and drought prone regions)

- **Land cover change**
- **Water pollution** (following end use from cannabis compounds which persist in treated wastewater).

In the absence of a standardised framework for assessing and quantifying the extent of environmental damages from illicit drug production, or for assessing effect concentrations on reproduction, growth inhibition, fertilisation and respiration rate of aquatic organisms (Fontes et al., 2020), multiple pathways of impact exist. These environmental impacts are highly variable depending on the crop being cultivated (or its chemical synthesis), its geography of distribution, resultant trafficking networks (Devine et al., 2021), and the effects of its metabolites in the environment from end use and direct waste disposal (Gwenzi et al., 2022).

Further, distinct regional patterns of drug use and supply influence its environmental distribution. For example, opioids are the most frequent drug reported for users receiving drug treatment in Europe and sub-regions of Asia, while Latin America has a higher proportion of cocaine use, East and South-East Asia have higher prevalences of methamphetamine use, and in parts of Africa cannabis is the primary drug reported (UNODC, 2023a). The biological activity, exposure and ecological effects of these parent compounds, metabolites and precursor compounds are still poorly understood (Ter Laak & Emke, 2023; Richmond et al., 2018), and individual studies have largely considered isolated ecologies (Rosi-Marshall & Royer, 2012). However, from these targeted studies there is a growing body of evidence examining the effects of exposure to different (il)licit pharmaceutical compounds on indicator species (see for example Gwenzi et al., 2022; Richmond et al., 2018; Burns-Edel, 2016).

## Ecosystem impacts

**There is a significant gap in literature which uses an ecosystem-based approach to assess and address the combined toxic effects of pharmaceutical compounds in the environment, resulting in a lack of understanding of the compound effects of complex mixtures of drugs in the environment over time and resultant environmental damage**. **Adverse effects on ecosystem health are expected for potent biologically active waste, including from cocaine, morphine, MDMA and amphetamine.**

(Il)licit chemical compounds have the ability to influence overall ecosystem functions, such as biodiversity, food web and nutrient dynamics, habitat structure and disease dynamics (Prichard & Granek, 2016), influenced by effects to primary production, microbial respiration and invertebrate secondary production (Rosi-Marshall & Royer, 2012). However, the extent of this influence and its ramifications remain unknown, with existing research typically detailing either the occurrence and concentration of particular compounds, or the negative effects of particular compounds on the mortality, growth and reproduction of single-species (Rosi-Marshall & Royer, 2012).

There is more evidence for the disruption of food chains and webs (trophic interactions) in aquatic ecosystems for licit compounds, with overall risks including emergent antimicrobial resistance, and endocrine disruption and acute and chronic toxicity in aquatic organisms (Gwenzi et al., 2022). However, for many substances their degradation mechanisms in the environment and the toxicity of their metabolites are not well known (Gwenzi et al., 2022). Prichard and Granek (2016, p. 22377) review existing research into the effects of pharmaceuticals and personal care products (PPCPs) on marine environments, classifying habitat types to develop a conceptual model of ecosystem-level effects. Where documented dynamics in response to PPCP contaminants are observed to affect individual organisms' reproduction, metabolism, behaviour and stress responses, these are extrapolated to determine an influence over the following overall ecosystem-level dynamics:

- **Biodiversity/community composition** (functional bacterial/microalgal diversity, algal cell density, activity in the presence of a predator, time taken to find shelter)
- **Food web and nutrient cycles** (bioluminescence inhibition, community gross production, respiration, and total levels of nitrogen and phosphorous)
- **Habitat structure** (coral bleaching, the ability of molluscs to secrete filaments to attach to a solid surface (Byssus thread strength))
- **Disease dynamics** (coral viral infection, parasitic infection).

The potential of waste products from pharmaceuticals and personal care products to influence overall ecosystem productivity and functioning is consequently well established (Rosi-Marshall et al., 2015). Yet for illicit drugs, these effects have been historically considered to be at concentrations below lethal levels and consequently of low environmental concern (Richmond et al., 2018). Seasonal variation, including water temperature, river flow, ultraviolet exposure, and rainfall, may also affect the concentrations of drugs in water systems (Zhang et al., 2017). However, due to the persistence of supply of these compounds to the environment, even at low solutions, through wastewater, dumping and other activities (Ter Laak & Emke, 2023), many illicit drug compounds are now considered to be pseudo-persistent or highly persistent (depending on the type of compound and its degradation characteristics) in the environment (Rosi-Marshall et al., 2015; Ripanda et al., 2022). The impacts of this on plant and animal life (biota) over time, including accounting for complex and variable mixtures of chemical compounds, are still poorly understood (Richmond et al., 2018). Where research remains nascent into the affects and interactions of drug and metabolite residues in the environment, there are also no guidelines available for what would constitute a 'safe' or permissible concentration of these chemicals (Pall et al., 2013). Where some opioids have been observed to be contaminated with heavy metals and microorganisms, this may also be difficult to quantify (Ripanda et al., 2022).

How these chemical compounds will impact an organism, its stimulatory or inhibitory effects, depends on the characteristics of both elements (Ripanda et al., 2022). This underscores urgent questions to answer to understand the effects on overall ecosystem health (Rosi et al., 2023). There is comparatively more research available for the effects of licit compounds on the environment. For example, Rosi et al. (2023) examined spatial data on pharmaceutical waste concentrations, cross-referenced with the global occurrence of bat species, to model the epidemiological risks of antiviral pharmaceutical pollution in freshwater habitats. The model data suggested insects affected by anti-viral drug compounds, which are then consumed by bats, risk the evolution of anti-viral resistant viruses in bats. While this study draws conclusions based on observations of licit compound interactions, it signposts some key issues which are poorly understood when considering the health risks of pseudo-persistent illicit drug compounds, particularly due to the constraints limiting the detection of contamination sites and neutralisation of chemical waste (Pardal et al., 2021).

Richmond et al. (2018) argue there is a risk of the biomagnification of illicit compounds upwards in the food chain, citing evidence from limited controlled studies investigating the effects of targeted compounds on specific species. For example:

- Amphetamines and LSD may affect the web-building ability of spiders (Richmond et al, 2018).
- The emergence of aquatic insects may be disrupted by amphetamines (in addition to some pesticides and antidepressants) in stream water (Richmond et al., 2018), in turn affecting their mortality, behaviour and reproduction (Lee et al., 2016).
- Various pharmaceuticals have been shown to decrease algal biomass and structure (Lee et al., 2016).
- Prolonged exposure to waterborne cocaine particles may affect the dopamine receptors and reproductive cycle of endangered European Aguilla Eels, and may also impact catfish species in the Amazon basin (Burns-Edel, 2016).

Pal et al. (2013) also document the toxic effects of amphetamines on rainbow trout, cocaine sensitivity in zebrafish, resulting in mutations to dopamine signalling, while zebra mussels exhibit DNA damage and enhanced cell death when exposed to cocaine. Morphine has also been observed to reduce the cell function of freshwater mussels, while the overall metabolism of morphine among fish is slower than mammals due to cardiac output differences (Pal et al., 2013). Addiction has also been observed in fish who have been exposed to methamphetamine, which Ripanda et al. (2022) argue indicates the possibility of the development of addiction through exposure to illicit drug compounds in the food chain. Observed pollutants in the environment are expected to accumulate in the fat tissues of riparian predators, including potentially humans who eat fish (Richmond et al., 2018).

Further, patterns of predation and migration distribute the impacts of chemical pollutants far from the initial pollution sites where waste may have been introduced. In a study of six streams in Melbourne, Australia, Richmond et al. (2018) found evidence of over 60 pharmaceutical compounds in aquatic invertebrates and riparian spiders, suggesting direct trophic transfer via emerging adult insects to their predators, such as frogs, bats and birds, and to platypus and brown trout, with unknown consequences for wildlife. Lee et al. (2016), in surveys of six streams across a rural to urban gradient in Baltimore, Maryland, USA, also detected evidence of multiple drugs, including amphetamines, at all sites. The toxification of watersheds in Brazil due to the disposal of cocaine or chemicals used in its production was also revealed in a waterway purity study, which revealed cocaine at a higher concentration than any other pharmaceutical compound detected (Burns-Edel, 2016). While these studies are regionally limited, they indicate the presence of biologically active pharmaceuticals in the environment above levels and in wider distributions than initially expected by researchers (Richmond et al., 2018).

Further, while the available literature indicates targeted environmental damage from illicit drug compounds in water systems, with widespread evidence of the persistent availability of pharmaceutical compounds in surface water (Thomas et al., 2014; Lee et al., 2016), there is limited data on the influence of illicit drugs on soil quality and structure due to collection constraints and the nature of the clandestine disposal of illicit drug waste (Ter Laak & Emke, 2023). However, there is some evidence to suggest impacts on soil microbial quality and the possible stimulation of increased enzyme activity in soils through the introduction of methamphetamine, with implications for nutrient cycling and interactions with plants and mycorrhizal relationships that are themselves not well understood (Pal et al., 2013).

The use of anti-“pest” rodenticides by growers of coca and marijuana also present risks to the ecosystem, including through leaching, poisoning, and direct and indirect mortality risks to wildlife (Burns-Edel, 2016). While rodenticides are also used in regulated crop production, illegal second-generation anticoagulant formulas typically employed for illegitimate drug crop production lead to acute environmental damage and harms to wildlife, with mammals and birds affected by the poison suffering severe internal bleeding over a number of days prior to death (Fisher et al., 2019).

## Land use change and environmental degradation

**The relationships between land use change, illicit drug production and environmental degradation are complex, with growing emphasis in the literature on the evidence of the indirect relationships between drug markets and deforestation, labelled “narco-deforestation”, and associated “narco-degradation” through cultivation, trafficking, and money laundering activities.**

While the impacts of drug crop cultivation are associated with the clearing of areas for planting and mono-cropping practices (Buxton, 2015), the global environmental impact of illicit crop cultivation and drug manufacture is relatively small compared with that of the legal agricultural or pharmaceutical sector (UNODC, 2023a). However, the localised effects of deforestation for illicit drug crop production at a community and individual level can be acute (UNODC, 2022), particularly when accounting for associated socioeconomic impacts and risks of violence (UNODC, 2023b).

The evidence exploring the links between land use change and illicit drug production typically focuses on coca production in the Amazon (UNODC, 2023b). In this context, climate change has also been seen to be a risk factor for expanding cultivation where cocaine cartels may seek to find new land to cultivate coca, both in response to changing temperature and precipitation patterns, as well as to evade law enforcement, with the potential for increased competition in already contested hyperborder regions (Argomedo, 2020). For example, a high incidence of convergent crimes have been documented in tri-border areas in the Amazon basin, with organised criminal groups simultaneously engaging in natural resource exploitation in addition to cocaine production and trafficking (UNODC, 2023b). However, coca is also seen to be a particularly resilient crop to climate change, and how cultivation patterns may change with climate change is uncertain (Smith & The Daily Climate, 2014).

Coca bush cultivation is persistent and has been increasing in line with overall increasing demand (total cocaine production reached 2,304 tons in 2021, the seventh consecutive year-on-year increase, with the global population of cocaine users estimated to be 22 million) (UNODC, 2023a), However the relationships between coca production and environmental degradation in the Amazon basin are complex, with growing emphasis in the literature on the evidence of the indirect relationships between drug markets and deforestation, labelled “narco-deforestation” (UNODC, 2023b). Drug trafficking and associated money-laundering are often classified as catalysts for deforestation through their inter-relationships with local extractive sectors associated with the loss of forest cover, including land speculation and agricultural expansion, cattle ranching, mining, roads, urban and energy development schemes, displacement and migration (UNODC, 2023b). However, the assertion that coca farming typically precedes cattle ranching has been contested in the literature (Murrillo-Sandoval et al., 2023).

Devine et al. (2021) conducted interviews and participatory mapping exercises between 2017-2018 with actors working in three protected areas in Guatemala, Honduras and Costa Rica to understand patterns of narco-degradation. Despite an extensive network of protected areas, Central America has one of the highest deforestation rates in the world. In all three protected areas, narco-degradation was found to be concentrated in and around transportation-logistical hotspots, with narcotrafficking observed to accelerate the conversion of natural resources into commodities.

- In Guatemala, narco-degradation was associated with cattle ranching and land speculation in illicit land markets.
- In Honduras narco-degradation was associated with cattle ranching, but also oil palm plantations and fishing.
- In Costa Rica, degradation was associated principally with maritime and mangrove ecosystem damage, with anecdotal evidence from a local protected area manager observing that “the narcos did incredible destruction to the mangroves to make canals so they could unload boats!” (Devine et al., 2021, p. 11).

Therefore, while there is an overall focus on deforestation and an emphasis in the contemporary literature on the indirect environmental impacts of illicit drug cultivation, how this is characterised will depend on the drug and its associated regional geographies of trafficking and money laundering (Devine et al., 2021).

## Synthetic drug production and chemical waste

**Synthetic chemicals require inputs from raw materials and precursor chemicals, and in general the more steps there are in the chemical production process for synthetic illicit pharmaceuticals, the more chemical waste is produced. While the composition and volume of chemical waste varies, waste products from synthetic drug production are primarily highly acidic, affecting the chemistry of soil and water, with wider environmental health implications and expected impacts on overall ecosystem functioning.**

Ter Laak and Emke (2023, p. 7) document five stages of waste in synthetic drug production: in the production of base chemicals (waste of synthesis or extraction), in the reaction mixtures and by-products of the synthesis and extraction of pre-precursor and precursor chemicals, the production additives and end product of the drug for the market, and the final consumption and metabolites of the drug in human waste. Knowledge on the composition and emissions of synthetic drug production waste is limited. However, there is significant evidence to suggest the environmental risks of the disposal of this chemical waste into soil and surface water (Rosi-Marshall & Royer, 2012; Ter Laak & Emke, 2023). Common acids found in waste following amphetamine and MDMA production include formic acid, hydrochloric acid and acetic acid (Ter Laak & Emke, 2023). The regulation of precursor chemicals may also result in additional chemical waste produced to synthesise alternatives (Ter Laak & Emke, 2023).

In coca production in the Amazon basin, farmers also often use chemical fertilisers and herbicides which leach into the surrounding environment, while coca leaves are soaked in gasoline and other chemicals to extract the coca base, with more than 300 litres of gasoline used to produce one kilogram of cocaine (UNODC, 2023a). In studies of MDMA and amphetamine production in Belgium, 6-10kg of chemical waste are generated for every 1kg of MDMA, whereas for amphetamine, 20-30kg of waste are produced per kg (Pardal et al., 2021). For the production of methamphetamine, which uses readily available ingredients, including common cold medicines, ammonia fertiliser and hydrochloric acid, the cooking process generates a variety of harmful solvents and gases, including hydrogen chloride and phosphine (NDIC, 2004). The waste products from these processes and the persistence of biologically active compounds in the environment have legacy impacts for both human and animal health which are poorly understood and have been identified as an area of necessary research (UNODC, 2023a).

All synthetic drug production processes require raw materials (precursor chemicals, often synthesised with pre-precursor chemicals due to legal restrictions on supply), reagents (often readily available organic solvents, acids and bases) and excipients (inactive substances used for dilution and binding) (Ter Laak & Emke, 2023). In response to regulation and restrictions, the illicit drug market is constantly evolving, and the precursor chemicals, dilutants and adulterants added to chemical compounds are consequently highly variable. Aghababaei et al. (2018) assessed the levels of toxic metals and bacterial contaminants in seized packages of opium, heroin and crack compounds in Iran, identifying lead, cadmium and chromium contamination. This has environmental health implications as both lead and cadmium are nephrotoxic heavy metals which can cause severe renal damage, while lead poisoning has also been associated with reproductive issues. Chromium is also a known carcinogen based on available data from animal and human epidemiological studies (Aghababaei et al., 2018). However, improved data collection and analysis on the fate of illicit drug compounds and associated waste chemicals in the environment are necessary to understand the true extent of their environmental impact (Ter Laak & Emke, 2023).

## Waste management and disposal

**Illicit pharmaceutical compounds have pseudo-persistence in surface water from continual use and supply, with inputs originating from wastewater following end use, and through direct dumping of waste chemicals used in the production process. Inadequate wastewater treatment and dilapidated or out-dated infrastructure is a primary source of environmental contamination from pharmaceutical waste, with high proportions of untreated sewage released directly into the environment globally, and with treated waste still containing biologically active chemical compounds.**

Illicit chemical compounds are generally observed to be ubiquitous in the environment, with contamination taking place primarily through inputs of treated and untreated wastewater (Thomas et al., 2014; Lee et al., 2016). Sampling from wastewater treatment plants (WWTPs) is a prevailing mechanism to quantify solutions of hazardous chemicals in sewage, providing an indicative profile of population use, although presence in wastewater is also determined by the differential metabolism of specific drugs (Rosi et al., 2023). There is a high probability that waste will not be detected when discharged into sewers or groundwater (Pardal et al., 2021).

Chemical waste from illicit drug production may also enter the environment through direct dumping of barrels in ditches, on the street and in nature, and in vehicles and trailers, in addition to leaching from and abandonment of production sites (Ter Laak & Emke, 2023). Due to the clandestine nature of illicit drug production, including fly tipping of waste, many such sites are not easily discovered or documented, while remediating pollutants in the sewer system is practically very difficult due to the continuous nature of wastewater treatment (Ter Laak & Emke, 2023; Pardal et al., 2021).

For discovered dumping or production sites, the UNODC (2020) identifies the following disposal methods for seized chemicals: open-air burning of volatile solvents; combustible and semi-combustible liquids; open-air pit burning; evaporation; composting or bioremediation[5]; remote burial; landfill burial; infiltration of non-hazardous liquids (into soils); encapsulation in cement; rendering a substance inert; and neutralisation of acids and bases. However, given that both illicit crop cultivation and synthetic drug manufacture generally take place in remote areas, the opportunities for waste remediation may be limited where there is direct dumping or discharge of drug-related waste in forests, rivers and sewage systems (UNODC, 2022).

Poor wastewater treatment systems also determine the concentration of these compounds in the environment (UNODC, 2022), particularly in regions where high precipitation and a lack of surface drainage lead to regular flooding of urban streams (Thomas et al., 2014). In a study of the Rio Negro and two of its tributaries in Manaus, Brazil, which receive large amounts of untreated sewage, Thomas et al. (2014) detected cocaine and its principal metabolite, benzolecognine. Also detected in surface water were low concentration solutions of propranolol, diclofenac, amitriptyline, carbamazepine, carbamazepine-epoxide, metoprolol, carisoprolol, citalopram and sertraline. There is some evidence to suggest that licit pharmaceutical waste from selective serotonin reuptake inhibitors (SSRIs) commonly used to treat depression, such as sertraline and citalopram, can also affect the size, behaviour, biomass, emergence, community structure and reproduction of some organisms, including aquatic insects, amphibians and fish (Thomas et al., 2014).

However, where infrastructure for waste treatment is present, WWTPs do not necessarily remove all compounds which may be damaging to the environment, and wastewater treatment processes, including advanced oxidation processes such as ultraviolet radiation, are insufficient to remove many drug compounds (Fontes et al., 2020; Mohan et al., 2021; Zhang et al., 2017). Data from WWTP effluent analysis of European countries (Spain, Belgium, Switzerland, Italy, Croatia, France and Germany), the UK, USA, Canada and Australia indicates 'benzoylecgonine, ecgonine methyl ester, MDMA, methamphetamine, amphetamine and morphine are the most abundant residues in effluents' (Pall et al., 2013, p. 1090).

However, while the evidence for the impacts of illicit compounds and their associated chemical precursors and waste is less well documented (Reymond et al., 2022), there is significant comparative evidence on the effects of licit pharmaceutical compounds and personal care products on the environment (Rosi-Marshall & Royer, 2012). For example, the per/polyfluoroalkyl (PFAS) group of synthetic "forever" chemicals, which are introduced to aqua- and agriculture through pesticides, direct waste disposal into freshwater bodies and through WWTPs, ultimately finding their way into the food system through organic waste used

5 The use of microorganisms to consume and break down environmental pollutants (Lorenzo, 2008).

as fertiliser and crop irrigation (Dhore & Murthy, 2021). PPCPs (such as hormones, fragrances, chemotherapy drugs, antibiotics, antihistamines, analgesics, stimulants, and antimicrobials) are commonly found in surface waters globally (Rosi-Marshall & Royer, 2012). Pharmaceuticals also occur widely in drinking water, including hormones, steroids, antibiotics and antidepressants (Mohan et al., 2021).

The limited evidence of the extent and effects of illicit drugs and associated waste compounds in the environment leads to an evidence gap for calculations of the distribution and loads of pharmaceuticals which influence ecosystem degradation (Fork et al., 2021). Fork et al. (2021) argue addressing this data barrier is significant in order to drive appropriate regulation and provide metrics for the compound loading which damages aquatic ecosystems, and to understand how this may be mitigated through improved wastewater treatment. This is particularly significant where globally, over 80 percent of sewage is released to the environment without adequate treatment, with infrastructure often dilapidated and leaking untreated sewage directly into the environment, with additional pressures on existing infrastructure due to population growth (Fork et al., 2021).

Further, the illegal disposal of chemical waste from the production of illicit drugs is difficult to measure due to its very nature; clandestine disposal is often in remote locations, such as the fly-tipping of chemical waste in barrels in ditches (Ter Laak & Emke, 2023). Discharging waste directly into soil and surface waters has a direct impact on the environment, while mixing with other waste streams (for examples in sewers) is less frequently detected, and thus its indirect environmental impacts are not as well understood or quantified (Ter Laak & Emke, 2023). Where direct dumping sites are discovered where hazardous levels of chemicals have leached into the environment, advanced water treatment processes, such as reverse osmosis and ozonation, may be necessitated (Reynold et al., 2022). Where waste disposal is a principal pathway for contaminants to enter the environment (Ter Laak & Emke, 2023), there is a need to install, maintain and upgrade sewage infrastructure and wastewater treatment technologies to address the risk of environmental damage from biologically active pharmaceutical compounds (Fork et al., 2021).

# 3. Environmental damage from illicit drug prohibition

**The global prohibitionist regime and counter-narcotic approaches have been linked to enhanced environmental degradation and may work in opposition to sustainable development policies and programming. Direct and indirect environmental impacts include spraying of illicit crops, displacement of drug cultivation and trafficking into increasingly remote, ecologically valuable frontiers, and laundering profits through environmentally damaging enterprises.**

There is some evidence to suggest that counter-narcotic approaches commonly applied may work, directly and indirectly, in opposition to policies intending to protect the environment (Walsh & Salomón, 2022), while also exacerbating existing vulnerabilities which lead to entrapment in illicit drug crop cultivation, production, and trafficking (UNODC, 2023a). Intersecting vulnerabilities may also be enhanced by climate change; for example, many farmers in Mexico have opted to cultivate opium poppies instead of legal crops due to their high relative yields and lower water inputs (Olivera-Villarroel & Celis, 2020).

The reactive and proactive responses of those directly exposed to, or seeking to limit, environmental damage may manifest in crime if an ecologically informed approach which recognises the dependencies between humans and nature is lacking (Potter, 2016). This may be observed where drug control and environmental policy have been developed and managed independently of one another, with reactive cooperation between agencies after environmental damage has already taken place, rather than pre-emptive collaboration (Burns-Edel, 2016). These policy siloes are also reflected in the blind spots in the monitoring of environmental hazards by law enforcement agencies and limited information sharing among relevant actors (Pardal et al., 2021).

Further, counter-narcotic operations have been observed to displace drug production and trafficking into more ecologically vulnerable areas, such as into protected areas, national parks and tropical rainforests (Pardal et al., 2021). The interception of drug shipments can incentivize traffickers to seek out new routes through biodiverse frontier regions (McSweeney, 2015). When interdiction activities displaced cocaine trafficking routes between Colombia and Mexico, and between Afghanistan, Iran and Turkey, trafficking operations responded by engaging new actors and moving deeper into forests, or exploiting sites further along the river and coastline (McSweeny, 2015).

The eradication of drug crops also risks driving cultivation into more remote environments, accelerating deforestation and biodiversity loss (McSweeney, 2015). Drug crop eradication programmes, such as the aerial fumigation of coca and cannabis plantations using pesticides, may affect and displace alternative livelihoods and populations, such as those engaged with agriculture and alternative crop cultivation and husbandry, due to residual ecological damage (Pardal et al., 2021; Buxton, 2015). Glyphosate, a broad spectrum non-selective herbicide typically used in forced crop eradication, may have negative health implications and contribute to population displacement and migration, introducing new pressures on forested areas (Kanissery et al., 2019; UNODC, 2023a).

The recent UNODC reports reviewed for this report (2022, 2023a, 2023b) have begun exploring the links between illicit drug production and environmental damage, with a particular focus on deforestation (UNODC, 2022) and links to how drug production and trafficking exacerbate other environmentally destructive criminal economies, such as illegal logging and wildlife trades in the Amazon basin (UNODC, 2023b). However, no evidence was found exploring how these activities may be exacerbated by the prohibitionist drug regime itself (UNODC 2022, 2023a, 2023b; Walsh & Salomón, 2022). In Central America, Devine et al. (2021, p. 14) argue that 'the violence, economic power and impunity' of the operations of drug trafficking organisations can't be overstated, and the far-reaching effects of illicit drug production on the environment necessitates coordination between conservation, wildlife trafficking and drug control policies often implemented in isolation. Prohibitionist policies have also been critiqued for eroding public trust in authorities, particularly where existing institutions are weak in contexts of insecurity and conflict and susceptible to coercion by traffickers (McSweeney, 2015).

Walsh and Salomón (2022) argue that the UNODC "misses the forest for the trees" in its focus on the impacts of specific drug production and trafficking activities at the expense of attention to how drug prohibition generates the profitable black market which enables subsequent environmental damage. The incentives of an illicit market are argued to lead to the massive profits which enable the circumvention of systems of state environmental governance, leading to the intimidation, corruption and co-option of state institutions, and the ultimate undermining of their efficacy. Further indirect environmental harms also result from activities used to launder drug profits through legitimate destructive industries, such as agribusiness (Walsh and Salomón, 2022), in addition to subsidiary companion illegal economies in logging, mining, and trafficking in wildlife (UNODC, 2023b).

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## Review overview

This review is based on 6 days of desk-based research. The K4DD research helpdesk provides rapid syntheses of a selection of recent relevant literature and international expert thinking in response to specific questions relating to international development.

K4DD services are provided by a consortium of leading organisations working in international development, led by the Institute of Development Studies (IDS), with the University of Birmingham, Liverpool School of Tropical Medicine (LSTM), the University of Manchester Humanitarian and Conflict Response Institute (HCRI), Association of Commonwealth Universities, and Royal United Service Institute (RUSI).



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