REVIEW ARTICLE

Impact of pharmaceutical toxicity on the environment and its regulatory aspects

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Pharmaceutical-induced environmental contamination demands urgent attention, with around 43% of global rivers facing risks from active pharmaceutical ingredients (APIs). The entire spectrum of pharmaceutical products, including active and inactive components, requires serious consideration due to continuous emissions and potential hazards to the environment and human health. Discussions on chemical waste reduction face limitations due to incomplete knowledge about their toxicity to humans. Despite various initiatives, collaboration evidence is minimal, and environmental health disparities persist in socially disadvantaged communities, leading to higher disease rates. While awareness of ecotoxicity is growing, the European Union (EU), United States (US) and Canada have taken steps, including disposal procedures, prevention strategies, and focus on concerns like antimicrobial resistance. This article explores environmental pollution complexities and policies in US, EU and Canada to mitigate its impact within health disparities.

Keywords: Antimicrobial resistance, drug residues, environmental toxicity, green prescription, pharmaceutical pollutants.

PHARMACIES sometimes cannot filter all the chemicals used in pharmaceutical production (e.g. solvents, active pharmaceutical ingredients (APIs), excipients, additives, by-products, intermediates, etc.). These chemicals cause ecosystem imbalances that give rise to chemical pollution in the environment (air, water and soil.). Twenty years ago, economic depletion caused due to uncontrolled urbanization, population growth, fossil-fuel consumption and due to lack of appropriate national or international policies. Although household deaths from air and water pollution have decreased, air pollution still kills more than 9 million people worldwide each year. Since 2015, this number has not changed. In low- and middle-income countries, almost 90% of deaths are caused due to environmental pollution. The areas of focus include air pollution, lead poisoning and chemical poisoning. Air pollution kills more than 6.5 million people worldwide every year, and the number is growing. Lead and other pesticides kill 1.8 million people worldwide each year; this number may be lower now. Most countries have done little to combat this serious public health crisis. Although high-income countries manage the worst forms of pollution and link pollution control to climate change, only a handful of low- and middle-income countries have made pollution a priority, are committed to it, or have made progress regarding pollution control. Also, pollution control has received little attention from development or international aid. Pollution, climate change and biodiversity loss are interrelated, and solving any of them will benefit others. Thus environmental pollution cannot be ignored.

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Causes of pharmaceutical pollution

(1) Drug ingestion and excretion: When organisms consume pharmaceuticals, their bodies metabolize and excrete inactive metabolites as waste products, eventually finding their way into the environment through urine and faecal matter.

(2) Healthcare institutions disposal: Hospitals and healthcare facilities contribute significantly to pharmaceutical pollution due to inadequate disposal practices or contraventions in rules and regulations of standards[1].

(3) Drug manufacturing units: Some drug manufacturers dispose of excess drugs and other used chemicals/by-products in landfills or flush them, leading to pollution through wastewater run-off.

(4) Domestication of animals: Drugs fed to domestic animals are not always entirely metabolized, resulting in the excretion of excess pharmaceuticals. This leads to the settling of metabolites in the top layers of the soil (Figure 1).

(5) Agricultural usage: Insecticides and pesticides sprayed on agricultural products can contaminate the surrounding ecosystem.

(6) Domestic drug use and disposal: Improper disposal of pharmaceutical and personal care products by consumers results in the pollution of streams, groundwater, lakes and rivers. Pharmaceutical waste, chemical waste, personal care products and their waste results in pollution in household as well as in environment.

Types of pharmaceutical pollutants

Pharmaceutical pollutants are classified into six types (Figure 2).

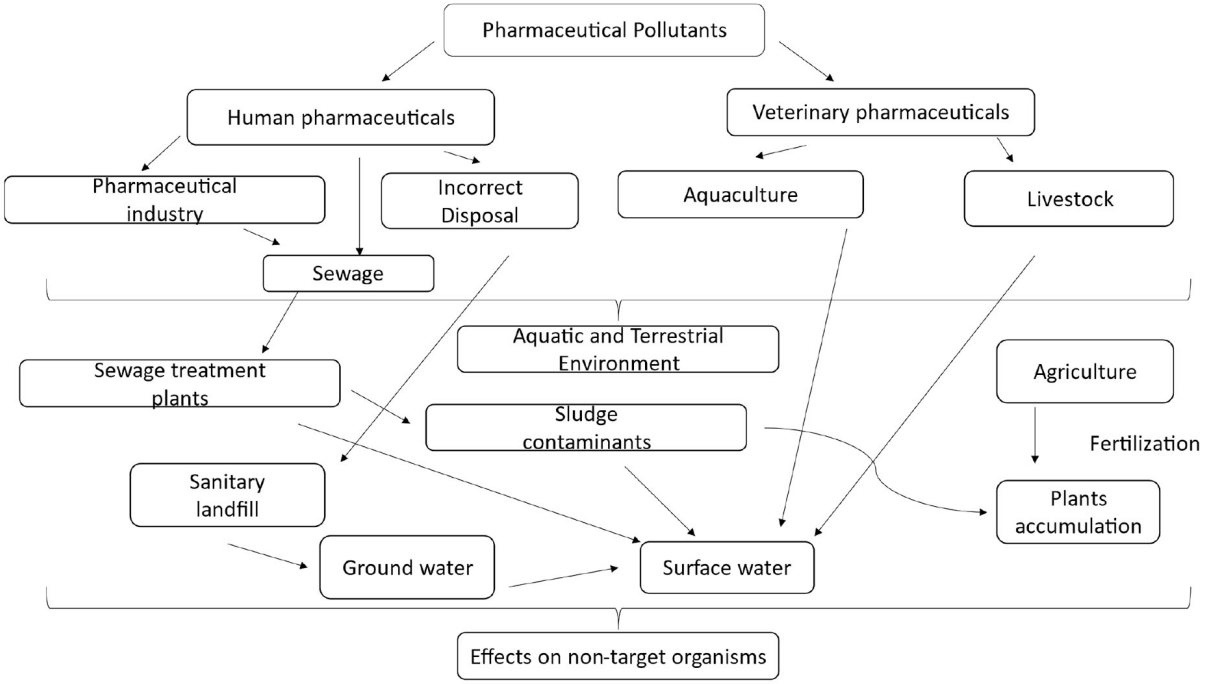

Figure 1. Pharmaceutical pollutants life cycle.

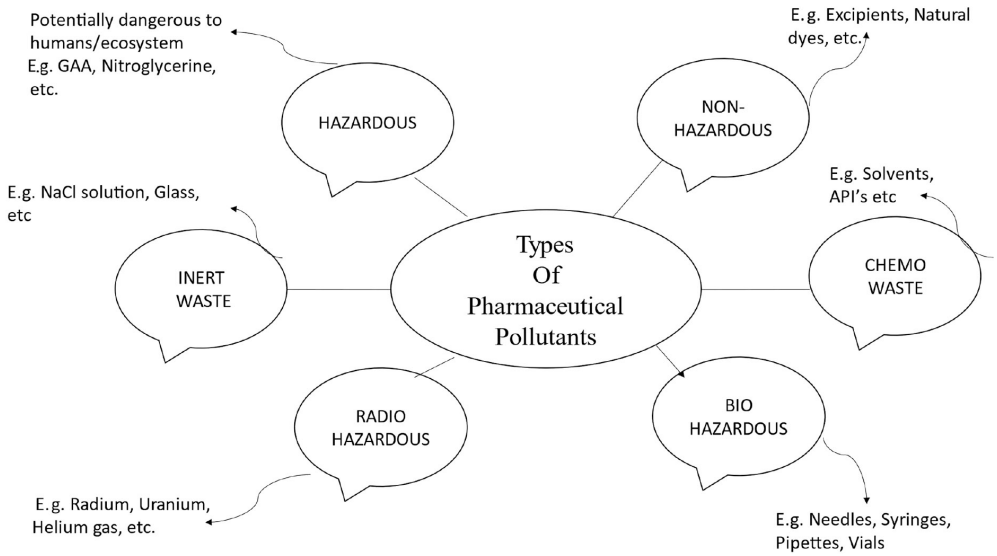

Figure 2. Types of pharmaceutical pollutants.

(1) Hazardous chemicals: These are chemical compounds or chemicals that cause serious harm. For example, gases such as hydrogen chloride, benzene and toluene, or compounds and metals such as asbestos, cadmium, mercury and chromium[2].

(2) Non-hazardous pollutants: These are substances found in the workplace that do not cause any harmful effects to the employees on exposure. These pollutants may not be immediately toxic in low concentrations, their cumulative effects can still have significant impacts on human health, ecosystems and the environment as a whole[3].

(3) Chemotherapy waste: Chemotherapy waste include chemicals from pharmaceutical medications and personal care products. It includes empty medicine bottles and other medications[4].

(4) Inert waste: This refers to waste that is not chemical or biological and does not react either with any other compounds leading to accumulation in environment. These compounds are not biodegradable. Examples are sand and

gravel, which are particularly relevant to landfills because inert waste generally requires lower disposal cost than biodegradable or compostable waste. It includes glass insulation, metal, wood, etc.[5].

(5) Radioactive hazardous pollutants: Radioactive (or nuclear) wastes are the products of nuclear power plants, power plants, hospitals and research facilities. Nuclear waste is also generated when nuclear reactors and other nuclear facilities are dismantled and destroyed. There are grouped into two broad categories: high-level radioactive waste and low-level radioactive waste[6]. Examples include I-125, F-18 and I-131.

(6) Biohazardous pollutants: Biohazardous wastes (such as blood, body fluids and human cells), also known as biological waste, are potentially infectious and considered to threaten public health and the environment[7].

How do pharmaceuticals enter into the environment?

Patient usage

The utilization of medications by patients, whether prescribed or over-the-counter, represents a significant contributor to chemical pollution. Essentially, a portion of the medications consumed by patients is naturally excreted, potentially entering the water systems after undergoing treatment in wastewater treatment plants. Additionally, pharmaceuticals can find their way into the environment through various means, such as inappropriate disposal of medications and discharge from manufacturing wastewater units. The release of drug compounds into the environment stems from multiple sources, including direct disposal from pharmaceutical manufacturing facilities, patient usage, animal excretion, aquafarming practices and the improper disposal of unused or expired medications (Figure 3).

Medical institutions

Medical institutions must return unused medications to the manufacturers or pharmaceutical waste recycling facilities. However, they are simply recycled or flushed. Thus, the lack of proper management leads to pharmaceutical waste in healthcare facilities.

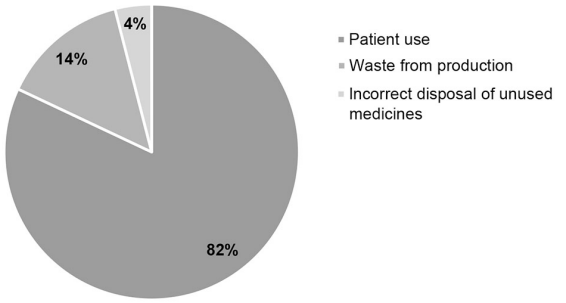

Figure 3. Routes of entry of pollutants into the environment.

Water treatment facilities

Inefficient removal of pharmaceutical residues occurs in water treatment plants, primarily attributed to inadequate design. Similar to the measures taken in water treatment plants, major efforts are taken to prevent the migration of these wastes into groundwater sources. Emphasis is laid on waste removal, employing various methods to impede waste entry into groundwater and other water bodies. Consequently, this waste is directed to landfills[8–10].

Pharmaceutical waste processing facilities

These specialized facilities manage substantial quantities of pharmaceutical chemical waste, producing residual waste even after undergoing processing. Waste from hospitals and various outlets is transported to these plants, undergoing efficient processing.

Human and animal usage

Both humans and animals utilize medications for immediate disease prevention post-consumption. However, excretion of these drugs from the body occurs through processes such as urination, defecation and sweating. Over time, these pharmaceutical remnants are expelled from the body, subsequently entering into the environment[11,12].

Unused drugs

Unused medications are usually discarded or flushed down the toilet. These medications eventually permeate the environment and water bodies, integrating into the ecosystem[13].

Essential products

Medications serve purposes beyond disease treatment. Some formulations are used in cosmetics, beauty products and aromatherapy sprays. When applied to the skin, not all the components are fully absorbed into the body; some are eliminated during bathing. Consequently, remnants are left in the environment, contributing to the accumulation of pharmaceutical waste[14,15].

Residences and agricultural lands

Crops cultivated in residential areas or on farms often undergo applications of pesticides, insecticides and fungicides. These substances safeguard crops from bacterial infections, insect infestations, viral threats and fungal diseases. Additionally, the spray is formulated to enhance crop growth and overall productivity. However the usage of sprays lead to mixture of chemicals into groundwater, contributing to the generation of pharmaceutical waste.

Table 1. Various drugs and their effects on the environment

Therapeutic class	Drug	Reported effects
Antibacterials	Tetracyclines, macrolides and streptomycin	Antibacterial resistance measured in soil bacteria obtained from sites treated with pig slurry.
	Tylosin	Impacts on the structure of soil microbial communities.
	Erythromycin	Inhibition of growth of cyanobacteria and aquatic plants.
	Tetracycline	Inhibition of growth of cyanobacteria and aquatic plants.
	Sulphamethazole	Inhibition of basal ethoxyresorufin-O-deethylase (EROD) activity in cultures of rainbow trout hepatocytes.
Analgesics	Carbamazepine	Inhibition of basal EROD activity in cultures of rainbow trout hepatocytes. Inhibition of emergence of *Chironomus riparius*.
	Diclofenac	Inhibition of basal EROD activity in cultures of rainbow trout hepatocytes.
Parasiticide	Avermectins	Adults insects: Loss of water balance, disruption of feeding and reduced fat accumulation, delayed ovarian development, decreased fecundity and impaired mating. Juvenile insects: Delayed development, reduced growth rate, development of physical abnormalities, impairment of pupariation or emergence, and a loss of developmental symmetry.
	Fenbendazole	Impact on drug decomposition.
Ectoparasiticide	Cypermethrin	Impact on drug decomposition.
Synthetic steroids	17a-Ethylestradiol	Endocrine-disrupting effects on fish, reptiles and invertebrates.
	Methyltestosterone	Impersex, reduced fecundity, oogenesis, spermatogenesis in snails.
Anti-inflammatory	Ibuprofen	Stimulation of growth of cyanobacteria and inhibition of growth of aquatic plants.
Lipid regulator	Clofibrate	Inhibition of basal EROD activity in cultures of rainbow trout hepatocytes.
	Fenofibrate	Inhibition of basal EROD activity in cultures of rainbow trout hepatocytes.
Cardiac glycoside	Digoxin	Inhibition in the ability of dissected polyps from the cnidarian *Hydra vulgaris* to regenerate a hypostome, tentacles and a foot.
Beta blocker	Propanalol	Weak EROD inducer in cultures of rainbow trout hepatocytes.
Calcium channel blocker	Amlodipine	Inhibition in the ability of dissected polyps from the cnidarian *Hydra vulgaris* to regenerate a hypostome, tentacles and a foot.
Antianxiety drugs	Diazepam	Inhibition in the ability of dissected polyps from the cnidarian *Hydra vulgaris* to regenerate a hypostome, tentacles and a foot.

Pharmaceutical pollution and its effects

(1) Impact on fish and aquatic life: Numerous studies have demonstrated that oestrogen and similar chemicals feminise male fish, altering the male–female ratio. These substances, commonly found in birth-control pills and postmenopausal hormonal treatments, have led to the presence of hermaphrodite fish species with both male and female characteristics in the Potomac River, USA. Elevated estrogenic levels in river water contribute to the prevalence of female fish near pollution sources, and popular antidepressants have been detected in the brain tissue of fish downstream of wastewater treatment plants (Table 1).

(2) Influence on wastewater treatment systems: Antibiotics, frequently employed in disease treatment, possess properties that can impact sewage systems and the microbiological alterations of water. The presence of antibiotics in sewage treatment inhibits the activity of sewage bacteria and disrupts the decomposition of organic matter. Additionally, antibiotics can hinder nitrifying bacteria in the process of treating wastewater[16].

(3) Effects on drinking water: Chemicals in pharmaceuticals may mix with water or be flushed in the toilets after exiting the body. Mostly, municipal wastewater treatment plants do not fully eliminate these chemicals and impurities from drinking water, necessitating a combination of treatment methods. Although the levels of these chemicals in rivers and streams are relatively low compared to standard doses, there is a growing concern that prolonged exposure could result in health problems. The potential synergistic effects of these compounds, particularly endocrine disruptors, pose risks to biological processes such as growth, development, reproduction and hormonal control. Studies have raised alarms about the presence of these chemicals in surface water and groundwater since the 1990s.

(4) Prolonged environmental impact: Certain chemical compounds persist in the environment and water bodies for an extended duration. When concentrations reach a specific threshold, typically 1 part per million, these chemicals begin to impact the environment. Some drugs, like antiepileptic medications, have prolonged effects, while others are pseudo-persistent, breaking down only after an extended period. This persistence continuously impacts the environment, with some substances having about 30% fat solubility, enabling bioaccumulation and potential entry into the food chain. Studies in Europe and the US have identified hundreds of these compounds in groundwater, sewage, treated wastewater and tap water, underscoring the widespread presence of these contaminants in various water sources[17].

(5) Antibiotics: Long associated with irresponsible use in human medicine and agriculture, antibiotics have also

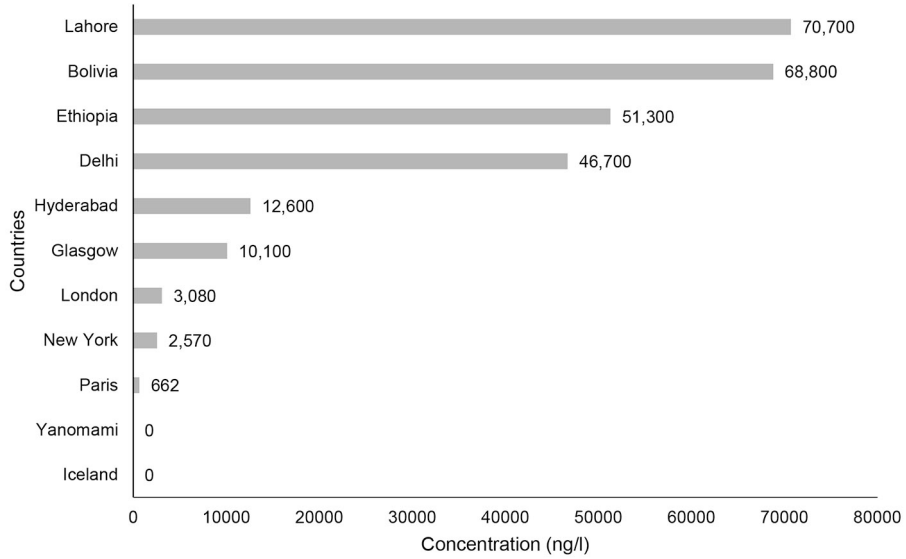

Figure 4. Cumulative concentration of various drugs around the globe.

been linked to contamination from drug production. Studies conducted in India and China on antibiotic pollution during 2016 and 2017 support this conclusion (Table 1).

(6) Consequences on wildlife: The clean-up of sewage, whether by humans or chemicals, may affect wildlife as animals consume water containing these substances or swim in it. Research on the effects of chemicals on wildlife, while limited and uncertain, suggests potential significant impacts. Preliminary findings indicate that antidepressants may adversely affect their health, while reproductive suppressants may reduce fish populations in ponds[18].

Global status of pharmaceutical pollution

The cumulative drug concentration for each sample was calculated as the average of all chemicals measured at different locations. An average value was determined, which is the sum of the average values for all locations over the sample period. API was identified at each of the three research locations, except for sites in Iceland (a total of 17 sites) and Yanomami village in Venezuela (three sites). Samples with the highest average concentration and highest cumulative concentration were collected from Lahore, Pakistan. This was followed by La Paz in Bolivia and Addis Ababa in Ethiopia. The main testing facility is in Rio Seka, La Paz, Bolivia, and is closely associated with the untreated sewage and waste in the rivers. The selection of diagnostic specimens primarily relied on competitive sampling across diverse regions, with a particular emphasis on Africa (including Ethiopia, Tunisia, Democratic Republic of Congo, Kenya, Nigeria) and Asia (encompassing Pakistan, India, Armenia, Palestine, and China). Notably, in North America the most contaminated sample originated from San Jose, Costa Rica, ranking ninth out of 137. In Europe, the highest level of contamination was observed in Madrid, Spain, securing the 14th position out of 137. Simultaneously, Oceania's most contaminated sample could be traced back to Adelaide, Australia, attaining the 93rd position out of 137. Metformin and caffeine have been identified in more than half of the laboratories globally[19,20] (Figure 4).

Chemical pollution status in India

India is recognized as the third largest pharmaceutical producer on a global scale, with a substantial presence comprising about 3000 pharmaceutical plants and an extensive range of around 10,500 products. The pharmaceutical manufacturing sector in India is acknowledged for its significant environmental impact, standing out as one of the most influential industries in the country. Hyderabad, commonly known as the 'API capital of India', is the hub of the country's major pharmaceutical industry. Studies have shown that local residents consider the groundwater in industrial areas to be highly polluted with multidrug-resistant bacteria. It is estimated that about 60,000 infants die every year in India due to high doses of antibiotics. Antimicrobial resistance is caused by contamination of water containing antibiotics[21–23] (Figure 5).

Case study on various drug concentrations in water across India

Chemicals are widely distributed in ecosystems, including water, land and air. Table 2 shows the concentrations of chemical residues in water samples collected from water bodies in Hyderabad and Delhi. This study shows that

chemical residues remain in water for several reasons and cause environmental toxicity. Anti-diabetic drug residues are widely found in India. The country was found to have the highest metformin and caffeine residual contents after Bolivia[24,25] (Tables 2 and 3).

Global policies for regulating pharmaceutical pollution

Numerous countries typically formulate and enforce waste management and environmental protection laws. Most developed nations establish regulations to mitigate environmental impacts, focusing on the management, control and monitoring of activities to reduce the risk of environmental instability. In the US, several agencies like the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration and the Food and Drug Administration address environmental pollution within their respective domains. EPA, the Drug Enforcement Administration (DEA), the Department of Transportation, Fish and Wildlife Service, the Environmental Protection and Occupational Safety and Health Administration, and the Joint Commission regulate chemical waste. Similarly, the European Commission sets the environmental pollution policy for the European Union, while the Canadian Council of Ministry of the Environment establishes policies for environmental waste.

United States of America

The EPA prioritizes drugs initially as pharmaceuticals and subsequently as treatments. Both the EPA and DEA advocate for the incineration of medical waste. However, there are no formal, standardized regulations for the management of pharmaceuticals and personal care products (PPCPs) in the country. Each state retains the authority to decide the method of waste disposal. Typically, household chemicals are disposed of in the trash or down the drain. It is considered that proper disposal can reduce the transmission of PPCPs. Nevertheless, it is crucial to address the broader usage of medications and restrict them by adhering to waste monitoring programmes and established practices that curtail waste and contamination. While various aspects of PPCP management are still being developed, making incremental improvements is essential. In 2008, the US-EPA recommended includes chemicals as hazardous waste and their management could be used to manage solid waste. The agency currently has a rule for PPCPs (nicotine) called the 'Good Drug Control and Nicotine P075 Amendment', which was signed in 2018 and published in 2019. EPA and US states are back on the drug crackdown list to reduce abuse of drugs and PPCPs restrictions thereby lowering misuse[26,27].

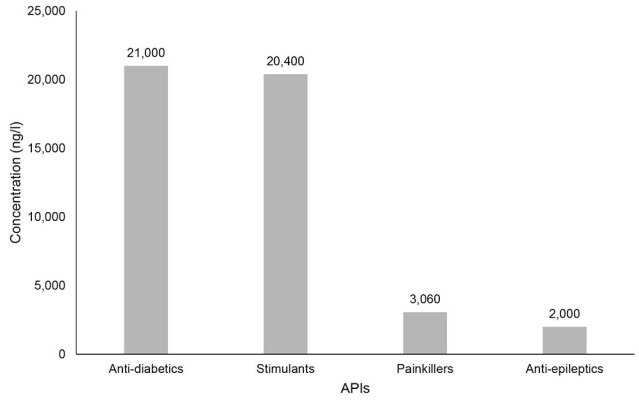

Figure 5. Concentration of drug residues in India.

Canada

Certain Provinces in Canada lack specific laws or regulations pertaining to PPCPs. The regulations for pharmaceuticals and medical waste are comparatively less stringent

Table 2. Concentration of drug residues in water across India

Pharmaceutical	Site number	Highest concentration (ng/l)	
		Delhi	Hyderabad
Sulphamethoxazole	3	973	–
	5	–	350.2
Trimethoprim	3	137	–
	5	–	30.0
Sitagliptin	3	545	864.9
Salbutamol	2	92.7	–
Ranitidine	2	113	–
Propranolol	2	20.6	–
Pregabalin	3	1,280	–
Paracetamol	2	5,880	–
Nicotine	3	9,760	–
	4	–	1,434.6
Nevirapine	5	–	853.5
Naproxen	3	896	–
Metformin	3	35,600	–
	5	–	40,175.6
Lidocaine	3	224	–
	5	–	112.3
Gabapentin	4	1,850	1,224.9
Fexofenadine	2	813	–
	5	–	3,091.2
Erythromycin	3	90.1	–
Diltiazem	8	–	30.7
Diazepam	5	–	59.5
Desvenlafaxine	3	77.1	–
Cotinine	3	5,020	3,116.0
Codeine	2	95.1	–
Ciprofloxacin	6	–	506.1
Cetirizine	4	1,230	–
	5	–	2,479.9
Caffeine	3	30,600	11,694.4
Carbamazepine	4	206	–
Atenolol	3	919	–
	4	–	1,160.8

Table 3. Site number and location of samples collected in the case study conducted in India

Place	Site no.	Location
Delhi	1	Y1, Wazirabad
	2	Y2, ITO
	3	Y3, Nizamuddin
	4	Y4, Ohkla
	5	Y5, Kalindi Kunj
Hyderabad	1	Reservoir, upstream of Hyderabad urban area
	2	Reservoir, upstream of Hyderabad urban area
	3	Confluence points of streams from the above two reservoirs, influenced by light urban area
	4	Musi river, region influenced by urban area, laundry services
	5	Musi river, upstream of waste water treatment plant (WWTP), heavily influenced by urban and industrial discharges
	6	Musi river, downstream of WWTP, influenced by industry and rural agricultural activities
	7	Musi river, influenced by industry and rural agricultural activities
	8	Musi river, influenced by rural agricultural activities
	9	Musi river, influenced by rural agricultural activities
	10	Reservoir on Musi River, downstream of the city

than those in the US. Similar to the US, guidelines and current recommendations for waste disposal are determined by each state or municipality. In 1992, the Canadian Council of Ministers of the Environment set the country's objective of meeting minimum national standards for medical waste management. To minimize drug waste, Canada actively engages in drug take-back programmes, allowing individuals to return unused medications. The Northwest Territories Biomedical Waste Management Guidelines from 2005 advocate for the separation of pharmaceuticals from general waste, recommending disposal through incineration or neutralization of chemical compounds. While these regulations continue to be adhered to and serve as the primary guidelines for chemical waste in the country, the extent of their impact[28] on reducing environmental pollution remains uncertain[12].

European Union

In 2013, the European Commission decided to mitigate water pollution caused by pharmaceuticals and their by-products. It conducted a 12-week consultation programme to formulate a framework to restrict the release of chemical waste into the environment. The set deadline for implementing this approach was 2018, but subsequent monitoring and enforcement seem to be lacking. The EU later introduced the European Green Deal, succeeding prior efforts by the European Commission to combat environmental pollution. The Green New Deal, launched in 2021, strives to execute the Zero Pollution Action Plan. It is noteworthy that comprehensive discussions on this matter took place only once. An illustration of a suggested initiative within this novel strategy can be found in ref. 29. The recommendation entails active participation in the Pharmaceutical Waste Reduction Committee, involving the formulation of policies to diminish waste by reducing the size of pharmaceutical packaging. Like the approaches in the US and Canada, the EU deems disinfection as the most appropriate method for handling medical waste. Overall, the EU collaborates in shaping policies and regulations that all member countries adhere to, ensuring a collective approach to waste disposal rather than allowing individual nations to dictate procedures[30].

Indian regulations for the control of pharmaceutical pollution

The government of India (GoI) has implemented several initiatives to manage environmental pollution. The establishment of the Central Pollution Control Board (CPCB) under the Ministry of Environment, Forests, and Climate Change (MoEFCC), GoI is a key regulatory measure. Enacted on 22 September 1974, under the Water (Prevention and Control of Pollution) Act, 1974, CPCB oversees various measures (Table 4). One notable measure is the Zero Liquid Discharge Policy, for which CPCB has provided guidelines to pharmaceutical industries to achieve zero liquid discharge. Among the 220 API manufacturers in Hyderabad, approximately 86 have implemented facilities with zero waste[31], indicating their ability to utilize almost any type of wastewater. Additionally, MoEFCC has mandated that companies install equipment for continuous monitoring of wastewater to ensure regular oversight.

Possible ways for reduction of pharmaceutical waste

- Exploring antibiotic use is a crucial research focus for prominent entities dedicated to safeguarding public and environmental health, such as the World Health Organization (WHO) and the European Commission.

Table 4. Effluent standards

Industry	Parameters	Standards
Pharmaceutical (manufacturing and formulation industry)	Effluent standards	
	Compulsory parameters	
		Limiting concentration (mg/l)
	pH	6.0–8.5
	Oil and grease	10
	Biological oxygen demand (BOD) (3 days, 27°C)	30
	Bioassay test	90% survival of fish after first 96 h in 100% effluent
	Chemical oxygen demand	250
	Additional parameters	
	Mercury	0.01
	Arsenic	0.20
	Chromium (Cr^{6+})	0.10
	Lead	0.10
	Cyanide	0.10
	Phenol (C_6H_5OH)	1.0
	Sulphides	2.0
	Phosphates	5.0
	Particulate matter	50 (mg/Nm^3)
	Total organic carbon	20 (mg/Nm^3)

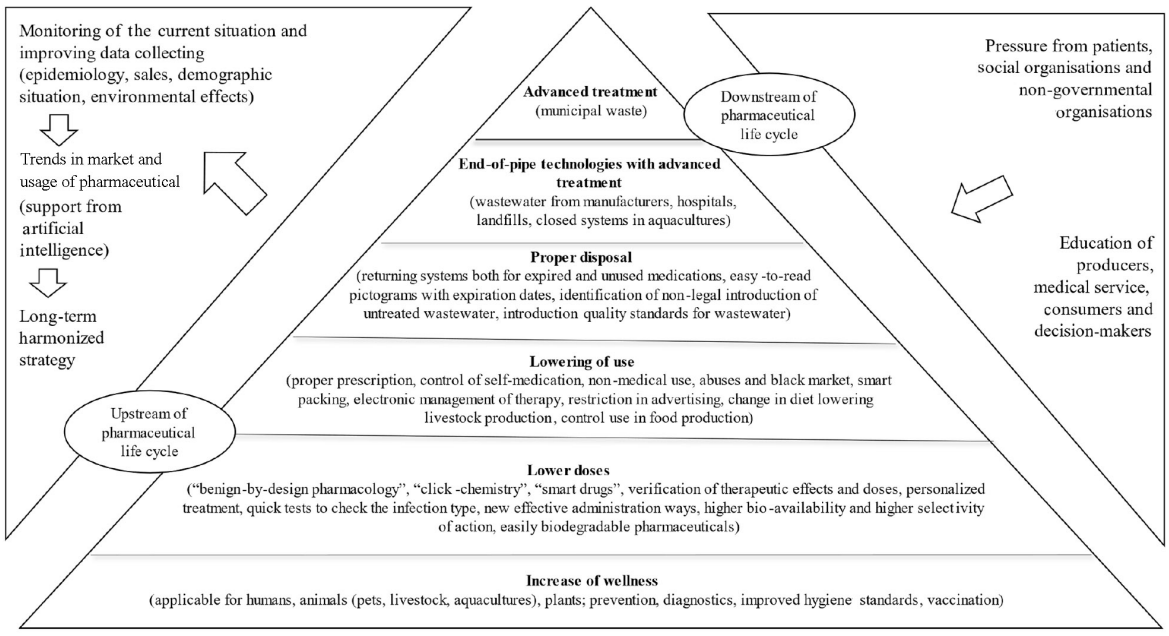

Figure 6. Possible solutions to control pharmaceutical pollution.

- The environmental contamination from pharmaceuticals presents an intricate and contentious challenge marked by unclear research, conflicting conclusions, diverse stakeholder interests and a high degree of complexity[32].
- Allocate resources to public education initiatives concerning the appropriate disposal of medications, integrating them into drug recovery programmes.
- Implement more stringent regulations to curb drug usage in numerous healthcare settings, including hospitals, nursing homes and other medical facilities.
- Urgently conduct further research to assess the potential impacts of these chemicals on human health.
- Implement measures to restrict bulk purchases of medicines, ensuring that only the necessary quantity is available and potentially mitigating excessive purchases.
- Emphasize proper disposal methods for water, advocating against indiscriminate disposal and instead promoting safe options such as burning or burying (Figure 6).

Effective use of medicine, ecological medicine or 'green medicine'

The concept of 'Effective use of medicine' introduced by WHO experts in 1985 has traditionally revolved around patients taking appropriate medication doses based on clinical needs for a sufficient duration and at the lowest cost, tailored to their specific requirements. Over the years, this concept has evolved into a pivotal framework guiding actions and strategies aimed at improving the well-being of countless patients, addressing concerns such as drug overdose and polypharmacy. However, we propose a contextual modification to incorporate the 'One Health' concept, emphasizing interconnected relationships to achieve holistic health for humans, animals and the environment. While this concept is predominantly applied to antibiotics, we advocate for its broader implementation. The reduction of unnecessary consumption of chemicals not only promotes human health but also contributes to environmental well-being by minimizing releases into the ecosystem. Five years ago, Christian Dawton (formerly EPA) introduced the term 'green recipe'. This underscores the significance of doctors considering a drug's properties and environmental behaviour when prescribing. For example, oxazepam, a metabolite of many benzodiazepines, is deemed suitable for adults due to its pharmacokinetic properties but poses environmental risks, being harmful to fish and non-biodegradable. The integration of environmental considerations into drug use has the potential to revolutionize drug treatment. The distribution report by the Swedish Environmental Research Institute, Stockholm, Sweden developed through collaboration between the Stockholm City Council and the pharmaceutical industry, classifies chemicals based on environmental properties. Doctors can use this information, including scores for environmental risk, bioaccumulation and toxicity, when prescribing medication to individual patients. The Kloca Listan (Wise List), currently the only method combining approved drugs for topical treatment, directly addresses environmental concerns. Additionally, the Dutch government's Psychotropic Drug Task Force aims to reduce psychoactive substances in water, signalling a crucial area deserving further research[33]. This comprehensive approach recognizes the intricate connections between medicine, the environment and public health, laying the foundation for a more sustainable and integrated healthcare paradigm.

Eco-friendly design

Enhancing the sustainability of chemical design is an intriguing aspect of 'Green Design' for the future. One promising idea involves the development of chemicals that are not only green but also more biodegradable, aligning with the concept of 'good design'. Currently, many psychoactive drugs lack a design focused on biodegradability, but there are emerging examples of efforts to create more environment-friendly drugs, such as glucophosphamide and herbal alternatives[34]. It is crucial to adopt a positive approach when evaluating the environmental impact of drugs, considering factors beyond biodegradability. The overall ecological footprint, as well as other properties of the drug, should be taken into account in the design process. There is a clear opportunity for improvement in this area. For instance, some existing drugs, like inhaled loxapine, an antipsychotic used to treat anxiety and depression, require a lithium battery for each dose. Another case is Abilify MyCite, where each capsule releases an electric current. These examples highlight the need for a re-evaluation of the design and manufacturing processes to make pharmaceuticals more sustainable and environment-friendly. Addressing such concerns is crucial for the development of pharmaceuticals that not only serve medical needs but also align with broader ecological goals[35].

Conclusion

The key findings of this study underscore a critical aspect: the presence of drugs in the environment is not limited to industrialized nations but extends to regions adhering to international standards. This highlights that the issue of drug residuals in the environment is a matter of global significance. Considering the substantial societal benefits of pharmaceuticals, strategies to reduce their environmental impact should prioritize efforts to minimize, control and prevent these substances from compromising their outcomes, effectiveness and efficacy, particularly in nations with regulatory constraints. The recent International Conference on Chemical Management 4th Session of ICCM, Geneva, Switzerland emphasized the discussion of 'environmentally persistent pharmaceutical contaminants' as a newly emerging global concern in chemical management. This initiative seeks to address the challenges posed by pharmaceutical contamination worldwide. Many individuals have volunteered to engage in diverse tasks to address this issue collaboratively and globally. This collaborative effort extends beyond national boundaries, aiming to find solutions to challenges related to drug contamination and establish a shared approach to environmental stewardship. Currently, various initiatives, including appropriate offices and activities, focus on mitigation, information dissemination, management, capacity building, and international collaboration and action. The discussion has identified international illicit trade as a focal point for global objectives. The primary objective of this collaborative endeavour is to comprehend and implement measures addressing the issue, conduct a comprehensive review and share essential information to bridge existing knowledge gaps. The proposal for the best ways to administer medication is a pivotal step forward, especially in developing countries where information may be uncertain. The International Conference on Chemicals Management aims to provide a platform for advancing effective approaches and strategies to administer medications globally, aligning with international standards

and fostering collaboration to deal with the uncertainties regarding the use of pharmaceuticals and their environmental impact.

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