MANTECH Publications
Journal of Water Resource Engineering and Pollution Studies
Volume 5, Issue 2, May- August, 2020

Invisible Dangers: Pharmaceutical Contaminants in Aquatic Environments

Dr. Radhika V. Iyer
Assistant Professor
Department of Environmental Science
Meridian College of Engineering
Email: *r.iyer@meridiancollege.edu.in*

Aarav N. Choudhury
M.Sc Research Scholar
Department of Environmental Technology
Meridian College of Engineering
Email: *aarav.ch@meridiancollege.edu.in*

Abstract

Pharmaceutical contaminants have emerged as an invisible threat in global water bodies due to their continuous release from multiple sources. These include improper drug disposal, industrial effluents, excretion from medicated humans and animals, and agricultural runoff. Even at trace concentrations, these contaminants may have profound ecotoxicological effects such as endocrine disruption, behavioral changes in aquatic fauna, and the development of antibiotic-resistant pathogens. This paper explores the principal sources, pathways, and detection methodologies of pharmaceutical pollutants and critically evaluates current and emerging treatment technologies. Furthermore, it discusses regulatory gaps and proposes sustainable mitigation strategies that encompass green chemistry, public awareness, and policy reinforcement. The paper emphasizes that a multi-pronged approach is vital for protecting aquatic ecosystems from pharmaceutical contamination.

Keywords: *Pharmaceutical residues, Wastewater treatment, Endocrine disruptors, Antibiotic resistance, Ecotoxicology, Water pollution*

INTRODUCTION

Pharmaceutical compounds have revolutionized medicine and improved the quality of human life. However, their widespread and often unregulated usage has led to the contamination of aquatic ecosystems. Unlike conventional pollutants, pharmaceutical compounds are biologically active at low concentrations, persistent in the environment, and capable of interacting with a wide range of aquatic organisms. The presence of compounds such as antibiotics, antidepressants, anti-inflammatory drugs, and hormones in water bodies is a growing environmental concern.

The increasing detection of pharmaceutical residues in rivers, lakes, and groundwater systems worldwide has raised questions about their long-term impacts on aquatic biodiversity and public health. A comprehensive understanding of their sources, environmental behavior, ecological effects, and mitigation techniques is crucial for sustainable water management.

SOURCES OF PHARMACEUTICAL CONTAMINANTS

Pharmaceuticals enter aquatic environments through various anthropogenic activities. Some of the major sources include:

1. Domestic Sewage

Drugs consumed by humans are often excreted as active metabolites that pass through sewage systems. Conventional wastewater treatment plants (WWTPs) are not specifically designed to remove pharmaceuticals, leading to their accumulation in receiving water bodies.

2. Hospital and Industrial Wastewater

Hospitals and pharmaceutical manufacturing units discharge untreated or partially treated wastewater containing high concentrations of pharmaceutical compounds.

3. Agricultural Runoff

Livestock treated with veterinary drugs contribute significantly to water contamination through manure application and field runoff.

4. Improper Disposal

Expired or unused medicines often end up in landfills or are flushed down toilets, eventually leaching into water systems.

COMMON PHARMACEUTICALS DETECTED IN WATER

Drug Class	Example Compounds	Environmental Impact
Antibiotics	Ciprofloxacin, Amoxicillin	Promotes antibiotic resistance in microbes
Analgesics	Ibuprofen, Diclofenac	Toxic to fish and invertebrates
Hormones	Ethinylestradiol, Estrone	Causes endocrine disruption in aquatic species
Antidepressants	Fluoxetine, Sertraline	Alters fish behavior and reproduction
Beta-blockers	Atenolol, Propranolol	Affects cardiac function in aquatic fauna

Table 1: Common pharmaceutical classes found in aquatic environments and their impacts

ENVIRONMENTAL AND HEALTH EFFECTS

1. Endocrine Disruption

Hormonal drugs like estrogens mimic natural hormones and interfere with endocrine systems in aquatic fauna, leading to feminization of male fish and reproductive failures.

2. Antibiotic Resistance

One of the most alarming effects is the development of antibiotic-resistant bacteria due to the continuous exposure of microbial populations to sub-lethal antibiotic concentrations.

3. Toxicity to Aquatic Organisms

Drugs can bioaccumulate in fish and invertebrates, causing liver damage, behavioral anomalies, and mortality.

4. Human Health Risks

Though conventional water treatment reduces some pharmaceuticals, traces may still persist in drinking water sources, posing chronic exposure risks to humans.

MONITORING AND DETECTION TECHNIQUES

Advances in analytical chemistry have made it possible to detect pharmaceuticals at nanogram levels in water.

Method	Description	Limitation
High-Performance Liquid Chromatography (HPLC)	Separates and quantifies pharmaceuticals	Time-consuming and costly
Gas Chromatography–Mass	Highly sensitive detection	Requires complex sample

Method	Description	Limitation
Spectrometry (GC-MS)	method	preparation
Enzyme-Linked Immunosorbent Assay (ELISA)	Quick screening method	Less specific and prone to cross-reactivity
Liquid Chromatography–Tandem Mass Spectrometry (LC-MS/MS)	Gold standard for trace detection	High operational costs

Table 2: Analytical methods for detection of pharmaceutical contaminants

TREATMENT AND REMOVAL STRATEGIES

1. Conventional Treatments

Standard WWTPs using activated sludge are ineffective against most pharmaceutical compounds due to their low biodegradability.

2. Advanced Oxidation Processes (AOPs)

Techniques like ozonation, photocatalysis, and Fenton reactions break down complex drug molecules into harmless compounds.

3. Membrane Filtration

Reverse osmosis and nanofiltration can physically remove pharmaceuticals, though at a high operational cost and energy demand.

4. Bioremediation

Emerging eco-friendly techniques utilize bacteria, algae, and fungi to metabolize pharmaceutical compounds.

5. Adsorption

Activated carbon is widely used for removing residual pharmaceuticals due to its high adsorption capacity.

SOLUTIONS AND POLICY INTERVENTIONS

The solution to pharmaceutical pollution lies in a combination of technological, behavioral, and regulatory strategies.

- **Public Awareness**: Educating people on responsible medication usage and disposal practices.

- **Drug Take-Back Programs**: Establishing return policies for unused or expired medications.
- **Green Pharmacy**: Designing biodegradable and environmentally safe pharmaceuticals.
- **Legislation**: Enforcing stricter effluent standards for hospitals and pharmaceutical industries.
- **Extended Producer Responsibility (EPR)**: Holding manufacturers accountable for post-consumer waste.

CONCLUSION

Pharmaceutical contaminants represent a growing yet often overlooked threat to aquatic ecosystems. Their presence—even in minute concentrations—can have far-reaching ecological and health consequences. This paper has detailed the primary sources, detection methods, environmental effects, and removal technologies associated with pharmaceutical pollution. While scientific advancements provide promising tools for remediation, the real challenge lies in policy enforcement, public behavior, and global cooperation. Addressing this issue requires an integrated approach involving environmental scientists, policymakers, healthcare professionals, and the general public to protect the planet's vital freshwater resources.

REFERENCES

1. Kümmerer, K. (2009). *Pharmaceuticals in the Environment: Sources, Fate, Effects and Risks.* Springer-Verlag, Berlin Heidelberg.
2. Fatta-Kassinos, D., Vasquez, M. I., & Manaia, C. M. (2011). *Removal of pharmaceuticals from effluents of sewage treatment plants*. Water Research, 45(3), 1155-1171.
3. aus der Beek, T. et al. (2016). *Pharmaceuticals in the environment—Global occurrences and perspectives*. Environmental Toxicology and Chemistry, 35(4), 823-835.
4. Rivera-Utrilla, J., et al. (2013). *Pharmaceuticals as emerging contaminants and their removal from water*. Chemical Engineering Journal, 227, 425–443.
5. Boxall, A. B. A. (2004). *The environmental side effects of medication*. EMBO Reports, 5(12), 1110–1116.
6. Joss, A., et al. (2006). *Biological degradation of pharmaceuticals in municipal wastewater treatment: Proposing a classification scheme*. Water Research, 40(8), 1686–1696.
7. WHO (2012). *Pharmaceuticals in Drinking Water.* World Health Organization, Geneva.
8. US EPA (2020). *Contaminants of Emerging Concern including Pharmaceuticals and Personal Care Products.*