Vol.1, Issue 3, October-December 2025, Page: 28-32

ISSN: 3107-4863

Global Journal of Science and Technology (GJST)

Effect of Pharmaceutical Residues on Aquatic Ecosystems

Avshesh Kumar

Department of Botany, T.D.P.G. College, Jaunpur (Affiliated to VBSPU, Jaunpur)

Abstract

Pharmaceutical residues have emerged as persistent organic micropollutants in aquatic ecosystems worldwide. These residues originate primarily from domestic sewage, hospital discharges, pharmaceutical manufacturing, and agricultural activities. Due to their chemical stability, bioactivity, and low biodegradability, pharmaceuticals persist in the environment, accumulating in sediments and biota. Their presence at even trace concentrations can lead to hormonal disruptions, behavioral alterations, and toxicity in aquatic organisms. This review highlights the pathways, persistence, ecotoxicological effects, and mitigation strategies of pharmaceutical residues in aquatic ecosystems. The findings emphasize the urgent need for sustainable management strategies and innovative wastewater treatment technologies to protect aquatic biodiversity and ecosystem health.

Keywords: Green roofs, Urban greening, Nature-based solutions, Stormwater, Urban heat island, Biodiversity, Air quality, Energy efficiency, Sustainability.

1.Introduction

Pharmaceutical residues are now recognized as contaminants of emerging concern in aquatic environments (Kümmerer, 2009). Global pharmaceutical production has increased dramatically over recent decades, driven by population growth, healthcare expansion, and veterinary use (Daughton & Ternes, 1999). These compounds, after human or animal administration, are often excreted unmetabolized or as active metabolites into sewage systems (Bound & Voulvoulis, 2005).

Traditional wastewater treatment plants (WWTPs) are inefficient in removing these microcontaminants because they were not designed to target bioactive molecules of pharmaceutical origin (Verlicchi et al., 2012). Consequently, trace quantities of antibiotics, analgesics, hormones, and antidepressants persist in surface waters, sediments, and even groundwater systems (Jones et al., 2002).

Pharmaceuticals differ from most pollutants because they are biologically active at low concentrations (ng/L–µg/L), stable, and often designed to resist degradation (Fent et al., 2006). Thus, even minute doses can elicit long-term physiological or genetic responses in aquatic species (Brooks et al., 2003). The continuous discharge of these residues results in pseudo-persistence—where new inputs compensate for degradation or removal (Aus der Beek et al., 2016).

Emerging evidence links pharmaceutical contamination with endocrine disruption in fish (Jobling et al., 1998), antibiotic resistance in bacteria (Martinez, 2009), and altered ecological balance in aquatic

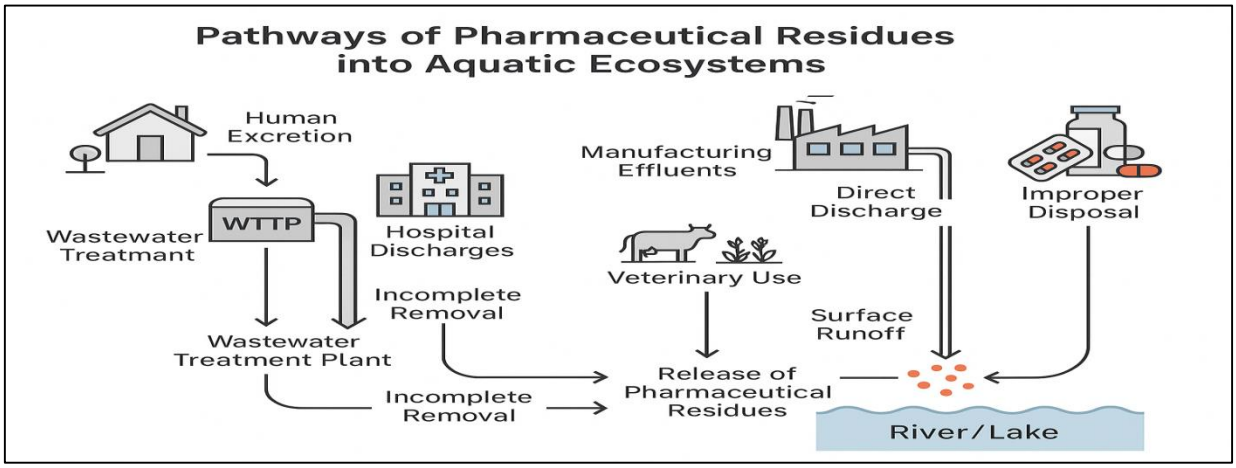
ecosystems (Corcoran et al., 2010). Therefore, understanding the environmental behavior and impacts of pharmaceuticals is essential to preserving aquatic ecosystem integrity.

2. Sources and Pathways of Pharmaceutical Residues

Pharmaceutical residues enter aquatic ecosystems through multiple anthropogenic activities, as shown in

Figure 1.

Figure 1. *Pathways of Pharmaceutical Residues into Aquatic EcosystemsPharmaceutical residues originate from human excretion, hospital discharges, manufacturing effluents, veterinary use, and improper disposal. These compounds enter aquatic systems via sewage networks, surface runoff, and direct industrial discharge. Conventional wastewater treatment plants only partially remove them, resulting in environmental accumulation.*



2.1 Domestic and Hospital Wastewater

Human and hospital discharges contribute substantially to pharmaceutical contamination. After ingestion, drugs are metabolized partially and excreted as parent compounds or metabolites through urine and feces (Bound & Voulvoulis, 2005). Hospitals add large loads of antibiotics, disinfectants, and contrast agents (Verlicchi et al., 2010).

2.2 Pharmaceutical Manufacturing Effluents

Industrial discharges are among the most concentrated sources. Larsson et al. (2007) reported effluent antibiotic concentrations up to 31 mg/L in Indian rivers—comparable to therapeutic doses.

2.3 Improper Disposal of Medicines

Inadequate disposal of expired or unused medicines through household waste or toilets contributes to environmental loading (Kümmerer, 2001).

2.4 Veterinary and Agricultural Runoff

Livestock treated with veterinary antibiotics release residues through manure and urine, which are transported to water bodies via runoff during rainfall (Sarmah et al., 2006).

3. Occurrence and Persistence in Aquatic Systems

Pharmaceutical residues have been detected in nearly all environmental compartments. Commonly detected compounds include diclofenac, carbamazepine, ibuprofen, sulfamethoxazole, ciprofloxacin, and ethinylestradiol (Michael et al., 2013; Zhou et al., 2019).

Their persistence depends on molecular structure, temperature, pH, and photodegradation potential. Carbamazepine and diclofenac are notably resistant to biodegradation, often serving as indicators of pharmaceutical pollution (Clara et al., 2004; Tixier et al., 2003).

Pharmaceuticals can bind to sediments or bioaccumulate in aquatic organisms. Hydrophobic drugs have higher partitioning coefficients, promoting accumulation in biota and magnification through food webs (García-Galán et al., 2010).

4. Ecotoxicological Effects on Aquatic Organisms

Pharmaceutical residues exert toxicological effects on various aquatic species, ranging from microorganisms to fish. A summary is presented in **Table 1.**

Table 1. Common Pharmaceutical Residues and Their Reported Effects on Aquatic Organisms

Pharmaceutical	Category	Detected Range (ng/L–µg/L)	Affected Organism	Reported Effect	Reference
Diclofenac	NSAID	10–400	*Fish, algae*	Gill damage, reduced photosynthesis	(Cleuvers, 2003; Fent et al., 2006)
Carbamazepine	Antiepileptic	20–1200	*Fish*	Bioaccumulation, behavioral changes	(Clara et al., 2004; Brooks et al., 2003)
Ethinylestradiol	Synthetic estrogen	1–50	*Fish*	Feminization of males, endocrine disruption	(Jobling et al., 1998)
Fluoxetine	Antidepressant	5–150	*Fish, crustaceans*	Altered feeding, reduced mobility	(Brooks et al., 2003)
Sulfamethoxazole	Antibiotic	100–5000	*Bacteria, algae*	Growth inhibition, antibiotic resistance	(Grenni et al., 2018)

4.1 Microbial Communities

Antibiotics disrupt microbial diversity and inhibit essential ecological processes like nitrogen fixation and organic matter decomposition (Grenni et al., 2018).

4.2 Algae and Aquatic Plants

Nonsteroidal anti-inflammatory drugs (NSAIDs) reduce algal chlorophyll synthesis and inhibit photosynthesis (Pomati et al., 2004).

4.3 Invertebrates

Crustaceans such as Daphnia magna exhibit mobility and reproductive impairments when exposed to fluoxetine and ibuprofen (Flaherty & Dodson, 2005).

4.4 Fish and Amphibians

Chronic exposure to estrogens like ethinylestradiol causes intersex conditions and reproductive failure (Jobling et al., 1998; Kidd et al., 2007).

5. Environmental and Human Health Implications

The ecological impact of pharmaceutical residues extends through trophic levels. Alterations in microbial communities disturb nutrient cycling, while reproductive anomalies in fish reduce biodiversity (Corcoran et al., 2010).

Antibiotic residues contribute to antimicrobial resistance, now a global public health concern (Martinez, 2009). Furthermore, bioaccumulation of pharmaceuticals in edible fish species may pose dietary risks to humans (García-Galán et al., 2010).

6. Treatment and Mitigation Strategies

6.1 Advanced Oxidation Processes (AOPs)

AOPs such as ozonation and photocatalysis degrade pharmaceuticals efficiently into harmless by-products (Michael et al., 2013).

6.2 Membrane Filtration

Nanofiltration and reverse osmosis are effective for removing micropollutants from wastewater (Bellona et al., 2004).

6.3 Constructed Wetlands

Constructed wetlands utilizing Phragmites australis and Typha latifolia remove pharmaceutical residues via adsorption and phytodegradation (Matamoros & Bayona, 2006).

6.4 Policy and Public Awareness

Environmental awareness campaigns, stricter regulations, and pharmaceutical take-back programs are essential to control source-level contamination (Heberer, 2002).

7. Conclusion

Pharmaceutical residues are an insidious but escalating environmental threat. Their continual introduction into aquatic ecosystems, coupled with inadequate treatment and monitoring, disrupts ecological balance and poses health risks. The persistence, bioaccumulation, and bioactivity of these residues highlight the need for integrating advanced treatment technologies, environmental legislation, and public awareness initiatives.

Future efforts should focus on green pharmacy approaches—designing biodegradable drugs, upgrading treatment infrastructure, and enforcing stringent discharge standards. Preserving aquatic biodiversity requires an integrated framework linking scientific innovation, policy implementation, and societal responsibility. Only through collective global action can we mitigate the growing pharmaceutical footprint on aquatic ecosystems.

References

1. Aus der Beek, T., Weber, F. A., Bergmann, A., Hickmann, S., Ebert, I., Hein, A., & Küster, A. (2016). Environmental Science Europe, 28(2), 1–17.
2. Bellona, C., Drewes, J. E., Oelker, G., Luna, J., Filteau, G., & Amy, G. (2004). Journal of Membrane Science, 249(1–2), 227–232.
3. Bound, J. P., & Voulvoulis, N. (2005). Chemosphere, 56(11), 1143–1155.

4. Brooks, B. W., Chambliss, C. K., Stanley, J. K., Ramirez, A. J., Banks, K. E., Johnson, R. D., & Lewis, R. J. (2003). Environmental Toxicology and Chemistry, 22(9), 2077–2084.
5. Clara, M., Strenn, B., & Kreuzinger, N. (2004). Water Research, 38(4), 947–954.
6. Cleuvers, M. (2003). Ecotoxicology and Environmental Safety, 54(3), 375–381.
7. Corcoran, J., Winter, M. J., & Tyler, C. R. (2010). Critical Reviews in Environmental Science and Technology, 40(4), 287–304.
8. Daughton, C. G., & Ternes, T. A. (1999). Environmental Health Perspectives, 107(Suppl 6), 907–938.
9. Fent, K., Weston, A. A., & Caminada, D. (2006). Aquatic Toxicology, 76(2), 122–159.
10. Flaherty, C. M., & Dodson, S. I. (2005). Ecotoxicology, 14(8), 653–660.
11. García-Galán, M. J., Díaz-Cruz, M. S., & Barceló, D. (2010). Analytical and Bioanalytical Chemistry, 397(3), 1173–1183.
12. Grenni, P., Ancona, V., & Barra Caracciolo, A. (2018). Microchemical Journal, 136, 25–39.
13. Halling-Sørensen, B., et al. (1998). Chemosphere, 36(2), 357–393.
14. Heberer, T. (2002). Toxicology Letters, 131(1–2), 5–17.
15. Jobling, S., Nolan, M., Tyler, C. R., Brighty, G., & Sumpter, J. P. (1998). Environmental Science & Technology, 32(17), 2498–2506.
16. Jones, O. A. H., Voulvoulis, N., & Lester, J. N. (2002). Environmental Pollution, 117(1), 97–108.
17. Kidd, K. A., Blanchfield, P. J., Mills, K. H., et al. (2007). PNAS, 104(21), 8897–8901.
18. Kristiansson, E., Fick, J., Janzon, A., et al. (2011). PLoS ONE, 6(2), e17038.
19. Kümmerer, K. (2001). Chemosphere, 45(6–7), 957–969.
20. Kümmerer, K. (2009). Chemosphere, 75(4), 417–434.
21. Larsson, D. G. J., de Pedro, C., & Paxeus, N. (2007). Journal of Hazardous Materials, 148(3), 751–755.
22. Martinez, J. L. (2009). Environmental Pollution, 157(11), 2893–2902.
23. Matamoros, V., & Bayona, J. M. (2006). Environmental Science & Technology, 40(18), 5811–5816.
24. Michael, I., Rizzo, L., McArdell, C. S., et al. (2013). Water Research, 47(3), 957–995.
25. Patel, M., Kumar, R., Kishor, K., et al. (2019). Chemosphere, 228, 755–768.
26. Pomati, F., Netting, A. G., Calamari, D., & Neilan, B. A. (2004). Environmental Toxicology and Chemistry, 23(1), 134–141.
27. Sarmah, A. K., Meyer, M. T., & Boxall, A. B. A. (2006). Chemosphere, 65(5), 725–759.
28. Tixier, C., Singer, H. P., Oellers, S., & Müller, S. R. (2003). Environmental Science & Technology, 37(6), 1061–1068.
29. Verlicchi, P., Galletti, A., Petrovic, M., & Barceló, D. (2010). Science of the Total Environment, 407(10), 3674–3692.
30. Verlicchi, P., Al Aukidy, M., & Zambello, E. (2012). Science of the Total Environment, 429, 123–155.
31. Vulliet, E., & Cren-Olivé, C. (2011). Chemosphere, 84(8), 1075–1081.
32. Zhou, L. J., Ying, G. G., Liu, S., et al. (2019). Environment International, 125, 542–559.