THE IMPACT OF PHARMACEUTICAL POLLUTION ON AQUATIC ECOSYSTEMS: CHALLENGES, PATHWAYS, AND REMEDIATION STRATAGIES

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ABSTRACT:

The issue of drugs being present in aquatic habitats presents a formidable challenge to modern research. The emergence of antibiotic resistance is one of the most important effects, which might trigger a worldwide health emergency. Beyond the resistance to antibiotics, drugs also affect aquatic species' behaviour and reproductive systems, upsetting entire ecosystems. Numerous studies have demonstrated how drugs end up in water bodies as a result of the careless dumping of tainted household, agricultural, and industrial wastewater. The dual nature of pharmaceuticals is examined in this work: although they are essential to human health, incorrect use and disposal of them poses serious and complicated problems for aquatic ecosystems. We look at the routes these materials take to get into water bodies and the dangers they bring to aquatic life. There is also discussion of practical remediation techniques that could be used to treat pharmaceutical compounds.

Keywords: pharmaceuticals, water pollution, effluents

I. INTRODUCTION:

If pharmaceuticals raw materials reaching the water and contaminating the water is known as pharmaceutical water pollution. Inappropriate distribution of wastage and effluents which are not properly treated lead to pollution. They generate large amount of waste during manufacturing, housekeeping activity which leads to accumulation of dust. The pharmaceuticals have also been detected in ground water, sea and ocean. [4] From last 15 years pharmaceuticals compounds are considered most important bioactive compounds. They have been considered as emerging pollutants and there is no solution yet has been identified for the detection of these compounds. The still research is undergoing to discover for permeant eradication of pharmaceutical pollutants from water and will take long term to develop techniques. [6]

The last century saw advances in medical science and the creation of new, more effective medications that made it possible to treat a variety of ailments, increasing life expectancy, lowering infant mortality, improving disease prevention, and improving the quality of health. As a result, pharmaceutical-containing human waste washes into freshwater bodies after washing off of the ground .The human body eventually excretes active pharmaceutical metabolites and unmetabolized components, endangering both human health and aquatic life.[1] Nonetheless, many pharmaceuticals are very mobile, soluble in water, and readily incorporated into the surrounding environment (plants, soils, and sediments), even at nanoscale levels, making it difficult to remove them from the environment.[2]

Wastewater from homes, cities, hospitals, and industries, as well as the effluents from sewage treatment facilities (STPs), aquaculture, and intensive livestock in farming, are the main sources of pharmaceutical pollution .(3) Some common causes of pharmaceutical pollution are left over active ingredients, parabens, plasticizers, beta blockers, antibiotic resistant drugs and antibiotic drugs. Some of the common pharmaceuticals are also classified as persistent organic pollutants such as polyfluro organic compunds. The most of the contamination is caused by sulfamethoxazole and carbamazepine is more compared to other source of pollutants. [5] Modifications to the product, improved selection of raw materials and processing technology, and organizational or procedural improvements can all help reduce waste. These replacements, process adjustments, and good manufacturing practices are covered in greater detail in this section.The pharmaceutical sector is a multifaceted, fiercely competitive, and highly private industry. Thus, it is challenging to give a broad overview of substitution and process change. In addition, it is necessary to consider the laws and rules that the pharmaceutical industry must abide by. As a result, processes cannot just be changed; instead, they must all adhere to meticulously planned and specified procedures (ISO standards; Good Manufacturing Practices). There are many methods in prevention of pharmaceutical water pollution such as materials substitution, process medication, waste stream aggregation, recycling and recovery and solvent waste recycling. [7]

There also many other electronic separation techniques for pollutants in water and help to decrease the effects caused by pharmaceutical pollutants and reduces the death of aquatic floraand fauna. Recently various methods are identified for detection of pollutants in water. The most common methods used are chromatography and spectroscopy. Nowadays electrochemical methods are also used for detecting pharmaceutical pollutants such as potentiometry. The enzyme immunosorbent assays, biosensors and enzyme strips are also used for detecting pharmaceutical pollutants. [9]

II. SOURCES OF PHARAMACEUTICAL WATER POLLUTION:

Hospital and residential sewage disposal is the primary source of pharmaceutical discharges into aquatic habitats since pharmaceuticals are widely used to treat human diseases. As active metabolites of drugs that can either remain unaltered or be coupled to polar molecules, most pharmaceuticals are actually only partially digested or maintained by the body and are mostly removed through urine. The wastewater from intensive animal farming sites and the effluents from intensive aquaculture systems, where the use of veterinary medication is prevalent and essential, represent another important, albeit geographically limited, supply of pharmaceuticals. Sludges used in agriculture to recover inorganic contaminants, wastewater from treatment plants used for irrigation, and wastewater from livestock agricultural sites applied to farmland are additional sources of pollution.[3]

Surface waters also contain remnants of several harmful chemical substances, including pharmaceutical drugs, as a result of poor removal in wastewater treatment plants. The most significant sources of human pharmaceutical compounds are hospital and municipal wastewaters, while manufacturers' wastewater, landfill leachates, and the release of leftover medication into the environment can also contribute.[4] By means of natural atmospheric and oceanic processes, persistent organic pollutants can travel great distances to regions of the world devoid of human activity. These pollutants are carried by primary and secondary sources, such as industry, agriculture, urbanized areas, and transportation, through the atmosphere.[5]

III. CAUSES OF WATER POLLUTION:

Pharmaceutical water pollution is caused by several factors that contribute to the presence of pharmaceutical residues. Pharmaceutical manufacturing plants produce wastewater containing active pharmaceutical ingredients (APIs), solvents, and other chemicals used in production, which can enter aquatic ecosystems through discharge from these facilities. Improper disposal methods, such as flushing unused medications down toilets or sinks, significantly contribute to pharmaceutical pollution by introducing APIs and other pharmaceutical compounds directly into wastewater systems, often bypassing adequate treatment before entering the environment. Pharmaceuticals ingested by humans and animals are typically excreted unchanged or as metabolites, and conventional wastewater treatment facilities are often insufficient to fully eliminate these substances, leading to their discharge into rivers, lakes, and groundwater. Additionally, veterinary pharmaceuticals administered to livestock can enter water systems via runoff from agricultural areas or through the distribution of manure, adding to the cumulative pharmaceutical burden in the environment. In aquaculture, pharmaceuticals such as antibiotics and antiparasitics can enter aquatic ecosystems through discharge from fish farms, further complicating the issue of pharmaceutical pollution. Conventional wastewater treatment plants may not be equipped to effectively remove pharmaceutical residues, as APIs and their metabolites can be chemically stable and resistant to degradation, persisting in the environment even after treatment.[8]

The increasing trends of globalization and urbanization contribute to higher pharmaceutical consumption and production, exacerbating the problem of pharmaceutical pollution by amplifying the quantities of pharmaceuticals entering water bodies through various pathways. Addressing pharmaceutical water pollution necessitates a multifaceted approach. This includes advancing wastewater treatment technologies, enhancing disposal practices, implementing regulatory measures to manage pharmaceutical waste, and educating the public on proper medication disposal. Globally, efforts are underway to mitigate these sources and minimize the environmental and health impacts of pharmaceutical contamination.[8]

IV. COMMON PHARMACEUTICAL DETECTED IN WATER SYSTEM:

Table 1: Common pharmaceuticals detected in water

S.NO	ANTIBIOTICS	ANALGESICS & ANTI-INFLAMMATORY DRUGS	ANTIDEPRESSANTS	LIPID REGULATORS
1	Amoxicillin	Ibuprofen	Fluoxetine	Gemfibrozil
2	Ciprofloxacin	Diclofenac	Sertraline	Atorvastatin
3	Tetracycline	Acetaminophen	Citalopram	Simvastatin

These drugs may or may not present in the water system, hence therefore there is a little chance of this drug which leads to the contamination.[10]

V. TECHNIQUES FOR CHEMICAL DETECTION IN WATER SYSTEMS:

There are several techniques available to detect chemicals in water systems, each suited for different types of analyses and contaminants. Spectroscopy methods, such as UV-Visible Spectroscopy and Infrared (IR) Spectroscopy, measure the absorbance of light by chemicals, identifying them based on their specific light absorption properties. Chromatography techniques, like Gas Chromatography (GC) and High-Performance Liquid Chromatography (HPLC), are used to separate and analyse volatile and non-volatile compounds, respectively, often coupled with mass spectrometry (GC-MS and HPLC-MS) for precise identification and quantification. Mass Spectrometry (MS) techniques, including GC-MS and LC-MS, measure the mass-to-charge ratios of ions, providing detailed chemical analysis.

Electrochemical methods, such as Potentiometry and Voltammetry, detect ion concentrations and analyse trace metals and organic compounds by measuring voltage and current. Spectrometry techniques, including Atomic Absorption Spectrometry (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS), detect metals and trace elements by measuring light absorption and ionized sample ions, respectively. Biosensors utilize biological materials, like enzymes or antibodies, to detect specific chemicals through biochemical reactions.

Fluorescence Spectroscopy detects chemicals that emit light upon excitation, useful for tracing organic compounds. Ion Chromatography (IC) is specifically used for detecting and quantifying ions such as nitrates, phosphates, and heavy metals. Nuclear Magnetic Resonance (NMR) Spectroscopy identifies organic compounds by analysing the magnetic properties of atomic nuclei. Colorimetry uses colour changes in a solution to indicate the presence and concentration of specific chemicals.

Field kits and test strips offer rapid, on-site detection of contaminants like chlorine, nitrates, and heavy metals. Enzyme-Linked Immunosorbent Assay (ELISA) employs antibodies and colour change to detect specific chemicals, commonly used for pesticides and herbicides. These methods can be employed individually or in combination to provide a comprehensive analysis and detection of chemicals in water systems. These methods can be used individually or in combination to provide comprehensive analysis and detection of chemicals in water.[9]

VI. REMEDIATION STRATEGIES:

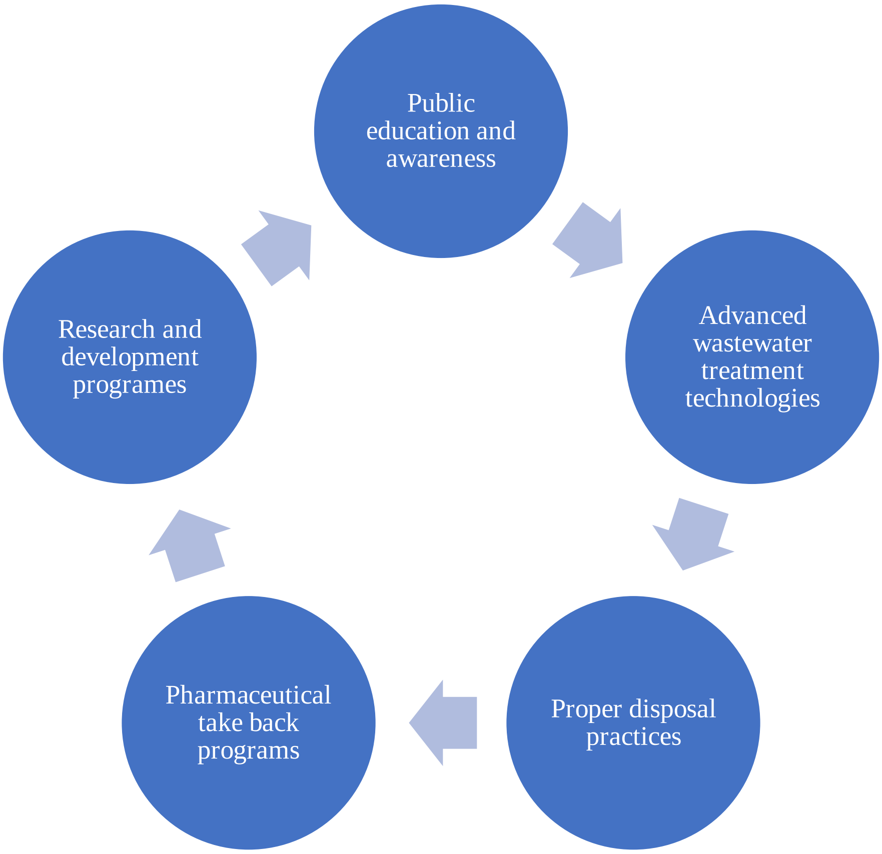

Fig:1 Example of Remediation Strategies

- Advanced wastewater treatment technologies :- Utilizing advanced treatment methods like activated carbon, ozonation, and advanced oxidation processes to efficiently eliminate pharmaceutical residues from wastewater.
- Regulatory Measures: Creating strict regulations and guidelines for pharmaceutical waste management, including disposal protocols for manufacturers, healthcare facilities, and households. Ensuring adherence to these regulations through regular monitoring and imposing penalties for non-compliance.
- Proper Disposal Practices: Encouraging the safe disposal of unused medications via take-back programs and designated drop-off locations. Raising awareness among the public and healthcare professionals about the significance of proper disposal methods to prevent pharmaceuticals from contaminating water bodies.
- Pharmaceutical Take-Back Programs: Implementing nationwide or regional take-back programs to provide convenient and safe options for disposing of unused or expired medications.
- Research and Development: Allocating resources to research for the development of environmentally friendly pharmaceuticals with reduced ecological impact. Performing studies to gain a deeper understanding of the environmental fate and effects of pharmaceutical residues.
- Public Education and Awareness: Initiating awareness campaigns to educate the public about the environmental consequences of improper medication disposal. Instructing healthcare providers on best practices for prescribing and disposing of pharmaceuticals.[5

VII. CONCLUSION:

There are possible negative effects on both individuals and the ecosystem from pharmaceutical environment, which is a major global concern. Evaluation and effects of the widespread release of pharmaceutical waste into the environment on humans and the ecosystem is necessary, and research should be promoted. Annually, thousands of tons of medicinally active substances are utilized worldwide for both human and animal usage. These drugs are expelled as parent compounds or active metabolites, which manage to avoid degradation in sedimentation tanks and end up in freshwater environments. Prior to recently, little was known about pharmaceuticals released into the environment; nevertheless, a number of global studies have measured pharmaceuticals in surface and ground water, STP effluents, and other wastewaters. Though there is a tremendous increase in knowledge, there is still much to learn about risk assessment and management, and the problem is not entirely clear. To strengthen abatement measures, reduce subtle environmental repercussions, and gain a better understanding of this recent ecological concern, we still need to increase our knowledge of the causes, occurrence, and effects of drugs as environmental pollutants.

REFERENCE:

1. Mezzelani, Marica, Stefania Gorbi, and Francesco Regoli. "Pharmaceuticals in the aquatic environments: evidence of emerged threat and future challenges for marine organisms." *Marine environmental research* 140 (2018): 41-60.
2. Mompelat, Sophie, Barbara Le Bot, and O. Thomas. "Occurrence and fate of pharmaceutical products and by-products, from resource to drinking water." *Environment international* 35.5 (2009): 803-814.
3. Bottoni, Paola, Sergio Caroli, and A. Barra Caracciolo. "Pharmaceuticals as priority water contaminants." *Toxicological & Environmental Chemistry* 92.3 (2010): 549-565.
4. Nikolaou, Anastasia, Sureyya Meric, and Despo Fatta. "Occurrence patterns of pharmaceuticals in water and wastewater environments." *Analytical and bioanalytical chemistry* 387 (2007): 1225-1234.
5. de Jesus Gaffney, Vanessa, et al. "Occurrence of pharmaceuticals in a water supply system and related human health risk assessment." *Water research* 72 (2015): 199-208.
6. Alipoori, Saeideh, et al. "Polymer-based devices and remediation strategies for emerging contaminants in water." *ACS Applied Polymer Materials* 3.2 (2021): 549-577.
7. Deo, Randhir P., and Rolf U. Halden. "Pharmaceuticals in the built and natural water environment of the United States." *Water* 5.3 (2013): 1346-1365.
8. Katsoyiannis, Ioannis A., et al. "Enhanced As (III) oxidation and removal by combined use of zero valent iron and hydrogen peroxide in aerated waters at neutral pH values." *Journal of Hazardous Materials* 297 (2015): 1-7.
9. An, Hyung Jun, et al. "Adsorptive removal of wide range of pharmaceutical and personal care products from water by using metal azolate framework-6-derived porous carbon." *Chemical Engineering Journal* 343 (2018): 447-454.
10. Dalahmeh, Sahar, et al. "Pharmaceutical pollution of water resources in Nakivubo wetlands and Lake Victoria, Kampala, Uganda." *Science of The Total Environment* 710 (2020): 136347.