Pharmaceutical Waste: Risks & Challenges Faced by Aquatic Ecosystem

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ABSTRACT

Pharmaceutical industries are experiencing a steady increase in both their numbers and demands, leading to a significant rise in the amount of waste they generate. This waste comprises various components such as organic compounds, excipients, and plastic containers. Unfortunately, a major portion of this waste is discharged into aquatic bodies through pipes, eventually reaching canal systems and ultimately the seas. This practice poses a severe threat to aquatic life, as it significantly impacts their habitat in a hazardous manner. One of the primary deleterious effects caused by pharmaceutical waste discharge is the elevation of the Biological Oxygen Demand (BOD) in the affected aquatic areas. This increase in BOD results in reduced oxygen availability for aquatic creatures, leading to mortality and ultimately causing a disruption in the natural balance of the ecosystem. Moreover, the accumulation of organic compounds from pharmaceutical waste leads to eutrophication, which accelerates the aging process of lakes, ultimately converting them into land. Another harmful consequence is biomagnification, wherein the concentration of toxicants increases as they move up the food chain through successive trophic levels. The continuous contamination of aquatic ecosystems by industrial waste is exacerbating the degradation of these fragile environments. However, the growing recognition of this issue has prompted research and implementation of various water treatment methods. These methods aim to mitigate the degradation rate and protect aquatic ecosystems from further harm. By employing advanced treatment techniques, it is possible to reduce the negative impact of pharmaceutical waste discharge and preserve the integrity of aquatic ecosystems. Efforts must be made to raise awareness among pharmaceutical industries about the importance of responsible waste management. By adopting sustainable practices and investing in environmentally friendly technologies, such as improved waste disposal systems and more efficient water treatment methods, the industry can significantly reduce its ecological footprint. Collaboration between regulatory bodies, environmental organizations, and pharmaceutical companies is essential to address this pressing issue effectively. With concerted efforts and a collective commitment to environmental stewardship, it is possible to mitigate the detrimental effects of pharmaceutical waste on aquatic ecosystems and safeguard the future of our planet's delicate aquatic habitats.

Keywords: BOD (Biochemical Oxygen Demand), Succession, Eutrophication, Biomagnification

1 Introduction

The increasing consumption of drugs for disease prevention, treatment, and cure has led to a rise in pharmaceutical waste, which has become a serious concern in environmental contamination [1]. There is a direct association between the use of medications and the generation of pharmaceutical waste as healthcare technology develops alongside pharmaceutical use. In addition to production leftovers such organic compounds, excipients, and plastic containers, this waste also contains unwanted and outdated medications. The environment and public health could be at risk from inappropriate disposal of pharmaceutical waste [2].

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This paper aims to discuss the risks and challenges posed by pharmaceutical waste in the aquatic ecosystem, its impact on the environment, and explore management practices to treat wastewater contaminated with pharmaceutical compounds unused or expired drugs and manufacturing waste [3]. Unused or expired drugs result from consumer behavior, improper disposal practices, or healthcare facilities discarding expired medications. Manufacturing waste comprises organic compounds, solvents, packaging materials, and excess active pharmaceutical ingredients (APIs) [4]. These categories encompass a wide range of substances that can have varying degrees of impact on the aquatic ecosystem. There are a number of reasons for the abrupt rise of pharmaceutical waste in the aquatic ecosystem. First off, there is more pharmaceutical waste due to the ongoing development and introduction of new treatments [5]. Second, these compounds can infiltrate wastewater treatment systems due to poor disposal techniques including emptying unwanted drugs into sinks or flushing them down toilets [6]. Pharmaceutical chemicals frequently accumulate in water bodies as a result of conventional wastewater treatment systems' inability to remove them effectively. Additionally, due to inadequate medication metabolism in both humans and animals, active drug metabolites are excreted, and these metabolites end up in water bodies [7]. These elements work together to increase the amount of pharmaceutical waste in the aquatic ecosystem.

1.1 Pharmaceutical Waste and the Aquatic Ecosystem

One of the most serious types of pollution is pharmaceutical waste, which has a considerable effect on the aquatic ecosystem. The delicate balance of aquatic life can be upset by pharmaceuticals because they have been designed to be physiologically active and potent [8]. Aquatic species' behavior, growth, and reproduction may be negatively impacted by the presence of drugs such as hormones, steroids, and antibiotics [9]. The disturbance of the endocrine systems of aquatic organisms is one of the main issues with pharmaceutical waste. Pharmaceutical hormones and steroids can mimic or interact with the natural hormones of aquatic species, resulting in aberrant reproduction and changed growth patterns [10], [11]. Changes in the population dynamics of one species can have an impact on other species that are dependent on it, which can have cascade consequences on the entire ecosystem. Pharmaceuticals in bodies of water can also encourage the development of bacteria that are resistant to antibiotics [12]. Bacteria may become resistant to antibiotics as a result of selective pressure brought on by environmental antibiotics. Since these antibiotic-resistant bacteria can transmit to people through contaminated water or eating infected aquatic species, this poses a serious concern to the general public's health. The microbial ecosystems in water bodies can be disturbed by pharmaceutical waste as well. These substances have the potential to alter the diversity and composition of bacteria and other microorganisms that are crucial to the health of aquatic environments [13], [14]. Alterations in microbial populations can have far-reaching effects on ecosystem stability, nutrient cycling, and organic matter decomposition. Ineffective removal during traditional wastewater treatment methods is the main cause of the buildup of pharmaceutical waste in the aquatic ecosystem. Pharmaceutical chemicals remain in treated effluents that are discharged into rivers, lakes, and coastal areas because many treatment plants are not specially constructed to remove them [15]. As a result, hospitals, pharmaceutical production sites, and residential wastewater discharges all have the potential to release medicines into the aquatic ecosystem. Pharmaceutical manufacturing, healthcare facilities, households, veterinary clinics, agriculture, research institutes, and illicit drug production are just a few of the sources of pharmaceutical waste [16]. The general makeup of pharmaceutical waste, which can include a variety of chemicals and compounds, is influenced by each source. Table 1 represents the sources and composition of pharmaceutical waste.

Table 1: *Sources and composition of pharmaceutical waste*

S. No	Source	Compositions
1.	Pharmaceutical Manufacturing	Unused and expired drugs, manufacturing byproducts, packaging materials
2.	Healthcare Facilities	Expired medications, unused prescriptions, medical supplies
3.	Household	Expired or unwanted medications, over-the-counter drugs, personal care products
4.	Veterinary Pharmaceuticals	Medications used in animal healthcare, veterinary drugs
5.	Agriculture and Aquaculture	Veterinary medications for livestock, aquaculture pharmaceuticals
6.	Research and Laboratory Waste	Unused chemicals, experimental compounds, pharmaceutical samples
7.	Consumer and Environmental Routes	APIs excreted by humans, disposal of pharmaceuticals through sewage systems and landfills
8.	Illicit Drug Production	Chemicals, solvents, drug paraphernalia
9.	Contaminated Water and Effluents	Pharmaceuticals discharged into water bodies, contaminated effluents
10.	Challenges in Monitoring	Lack of standardized reporting and data collection, difficulties in tracking and quantifying waste

1.2 Environmental Risks Posed by Pharmaceutical Waste

The harmful effects of pharmaceutical waste on the aquatic ecosystem are many, there are several ways through which it affects the lifestyle of the aquatic ecosystem.

1.2.1 Eutrophication

The process of eutrophication involves the gradual enrichment of a body of water, or portions of it, with minerals and nutrients, especially nitrogen and phosphorus [17]. Eutrophication is a relatively gradual process when it happens naturally. It is brought on by nutrient pollution, a type of water pollution. Untreated industrial runoff that contains significant levels of organic waste is released into the aquatic environment, which is a major contributor to the eutrophication of surface waters by encouraging the growth of algae and aquatic plants [18]. Nutrients like nitrogen and phosphorus progressively accumulate in a body of water due to the natural process known as eutrophication, which takes place over an extended period of time. Aquatic plants and algae depend on these nutrients to develop and survive [19]. But human endeavor's, particularly pollution, have the ability to quicken this process and damage aquatic ecosystems. Nutrient contamination, which frequently results from the release of untreated industrial or agricultural runoff into water bodies, is one of the main causes of eutrophication. High quantities of organic waste, such as fertilisers, sewage, and animal dung, are present in these sources of pollution. These contaminants cause an excess of nutrients to enter the water, which encourages the rapid growth of aquatic plants and algae. Increasing nutrient concentrations can lead to algal blooms. These blooms are made up of tightly clustered algae that frequently appear as green or brown scum on the water's surface [20]. Excessive algae development prevents sunlight from entering the water column, denying submerged aquatic vegetation the light it needs for photosynthesis. The ecosystem's balance may be thrown off if plants buried in water die due to a lack of light. Aquatic plants and algae decay and sink to the bottom of the body of water [21]. This organic debris is broken down by bacteria and other microbes, which require oxygen. The demand for oxygen rises as the breakdown process progresses, causing the amount of dissolved oxygen in the water to drop. Because aquatic plants produce less oxygen at night because of diminished photosynthesis, this oxygen depletion can be extremely severe. Hypoxia, or the lack of oxygen in the water, can have detrimental effects on aquatic life. Fish and other aquatic creatures who depend on oxygen risk suffocation and death. Other creatures, such as benthic invertebrates, which are essential to the decomposition of organic matter and nutrient recycling, are adversely impacted by the absence of oxygen [22]. Normal eutrophication is the gradual natural enrichment of lakes with nutrients like nitrogen and phosphorus, fostering gradual aquatic plant and algae growth over centuries. Anthropogenic eutrophication, driven by human activities like industrial waste, sewage, agriculture runoff, and excessive fertilizer use, accelerates this process, leading to rapid nutrient influx, algal blooms, and more severe environmental impacts compared to the natural process.

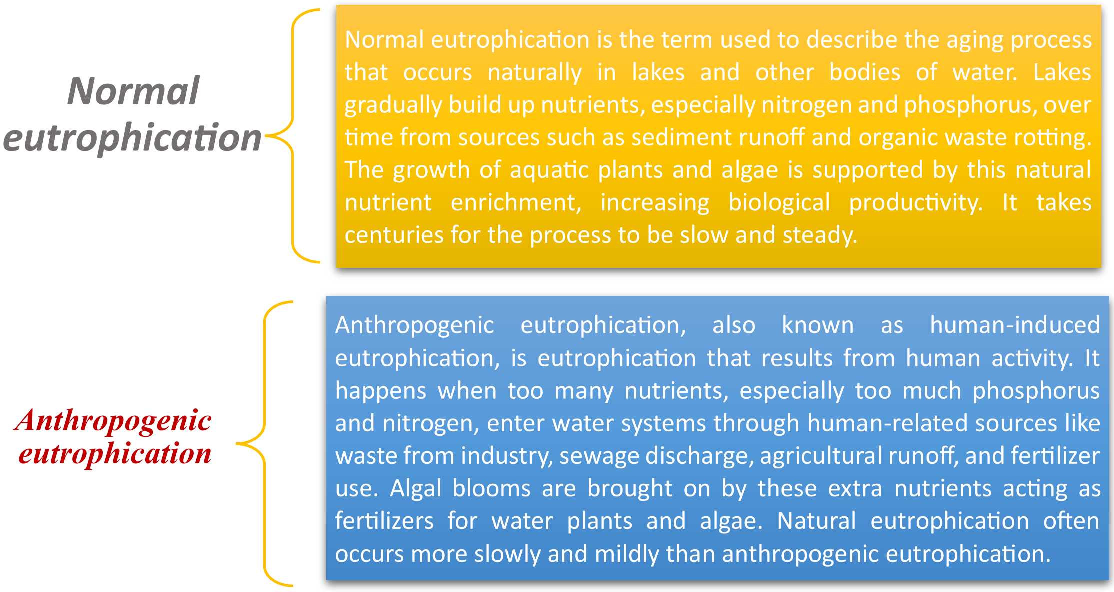

Figure 1: *Type of Eutrophication*

Figure 1 represents the normal eutrophication is the gradual natural enrichment of lake nutrients like nitrogen and phosphorus, fostering algae and plant growth over centuries. Anthropogenic eutrophication, accelerated by human activities such as industrial waste, sewage, agriculture runoff, and excessive fertilizer use, rapidly increases nutrient levels, causing harmful algal blooms and disrupting water ecosystems. Natural eutrophication progresses slowly, while human-induced eutrophication occurs swiftly and severely, posing environmental challenges. Lake Erie, the 12th largest lake in the world, serves as a clear example of the significance of phosphorus as a nutrient pollutant. During the 1950s and 1960s, the lake experienced a massive proliferation of blue-green algae, also known as cyanobacteria, largely due to high phosphorus levels entering the water from agricultural runoff, sewage, and industrial discharges. This sudden increase in algae had detrimental effects on the lake's ecosystem. By the 1970s, the central basin of Lake Erie became severely oxygen-depleted, leading to the label of the "dead sea" of North America. Decaying algae during the late summer months contributed to this anoxic condition [23]. The lack of oxygen caused fish kills and impacted commercial and sport fisheries, posing economic and ecological challenges. Municipal water supplies drawn from the lake also faced taste and odor issues due to the presence of excessive algae To address the issue, collaborative efforts have been undertaken to reduce phosphorus pollution in Lake Erie [24]. These initiatives involve implementing best management practices in agriculture to control fertilizer use, enhancing sewage treatment processes to remove phosphorus, and implementing conservation measures to protect water quality. While progress has been made, ongoing monitoring and collaboration are necessary to ensure the long-term health and sustainability of the lake.

1.2.2 Biomagnification

Biomagnification is the process through which the concentration of toxic substances increases as they move up the food chain. It occurs when organisms consume harmful substances that are not metabolized or excreted, resulting in the substances building up in their tissues. As these organisms are consumed by other organisms, the concentration of the toxic substances continues to rise [25]. Top predators end up with the highest concentration of toxic substances due to this ongoing process up the food chain. One example of such contaminants is mercury accumulation in aquatic ecosystems, which is highly harmful and has severe neurological and reproductive effects on organisms. Mercury is discharged into the environment through various human activities such as fossil fuel combustion and mining. Once in the aquatic ecosystem, bacteria and algae convert mercury into methylmercury, which is then ingested by tiny organisms like plankton. Larger organisms consume these small organisms, resulting in an increase in the toxicant as it moves up the food chain [26]. Biomagnification can have a severe impact on the aquatic ecosystem, leading to the decline or even extinction of certain species. A notable example is the decline in the population of vultures in India during the 1990s and 2000s. The primary reason behind the near extinction of vultures was the drug Diclofenac, which was found in the carcasses of cattle on which the vultures fed. The bioaccumulation of Diclofenac caused kidney failure in vultures, leading to their death. Even a small amount of Diclofenac in a carcass could kill a vulture shortly after consuming it [27]. In response to this threat, Diclofenac was banned for cattle use in India in 2006, and alternative drugs such as aceclofenac, ketoprofen, and nimesulide were introduced. Biomagnification can also pose risks to human health, particularly for communities that rely heavily on fishing and consume seafood. Consuming tainted seafood can expose humans to high levels of toxins [28]. This is of particular concern for certain communities, including indigenous cultures, that heavily rely on fishing and may consume foods that are high in toxins. To combat the negative consequences of biomagnification, it is crucial to reduce the discharge of hazardous compounds into the environment. This can be achieved through various measures, such as reducing the use of pesticides and other harmful chemicals, improving waste management practices, and promoting sustainable practices in industries like mining and energy production [29]. By implementing these strategies and raising awareness about the impacts of biomagnification, we can work towards minimizing the risks to both the aquatic ecosystem and human health.

1.3 Risks and Challenges

Pharmaceuticals are a serious concern to aquatic animals because they can have negative effects at even low levels. Aquatic species may experience stunted growth, aberrant development, and reproductive issues as a result of exposure to certain toxins [30]. Additionally, the presence of medicines in bodies of water encourages the growth of bacteria that are resistant to antibiotics, making it difficult to cure diseases that can affect both humans and animals. Pharmaceutical waste difficulties require a variety of issues to be resolved. The difficulty of detecting and measuring the presence of drugs in aquatic environments is a significant obstacle. Drug monitoring and control is a difficult undertaking due to infrequent inspections, a large number of pharmaceuticals on the market, and other factors [31]. The issue is made worse by the lack of appropriate pharmaceutical waste disposal techniques. Drugs are released into the environment when pharmaceutical trash is dumped alongside typical household waste in several nations. Water bodies are further contaminated by landfills' inadequate leachate collection systems [32]. Enhancing pharmaceutical monitoring and regulation in aquatic settings is essential to addressing these issues. The creation of effective and focused testing techniques can help to detect the presence of drugs. The release of medicines into water bodies can also be avoided by adopting specialised disposal systems for pharmaceutical waste, separate from typical household garbage. To educate the public about the environmental concerns linked with pharmaceutical waste, education and awareness programmes are also required. Promote the usage of take-back programmes for leftover drugs and encourage safe disposal practises to assist stop their introduction into the aquatic ecosystem [33], [34].

1.4 The conventional method of pharmaceutical waste management

Protecting the environment and public health depends on the safe and effective treatment of pharmaceutical waste. To ensure the proper processing and disposal of pharmaceutical waste, healthcare facilities are required to follow certain rules and regulations [35]. These rules are intended to prevent or reduce the damaging effects of waste on the environment and to reduce any dangers to human health. Pharmaceutical waste is managed using various common practices, yet these practices have some negative effects on aquatic life.

1.4.1 Landfill

Landfills are a common way for managing pharmaceutical waste, especially when substantial amounts of garbage need to be disposed of. With this technique, a sizable pit is made in a wide, open, low-lying area that is normally far from residential areas [36]. These pits are filled with waste that has been gathered in large trucks. The pits are fully filled, then covered with dirt and allowed to deteriorate naturally over time. While landfills provide an easy way to dispose of waste, they seriously endanger aquatic ecosystems and water bodies. The contaminating of surface water and groundwater resources is one of the main issues. Leachate is a fluid that is produced in the landfill as organic garbage breaks down. Leachate can contaminate adjacent to water sources if it is not properly contained since it can seep into the groundwater and saturate the local soil [37]. Water quality may suffer as a result, and aquatic life may be put at risk. The health and survival of aquatic organisms can be impacted by the presence of toxins in the water, which can disturb the ecosystems' natural equilibrium. Additionally, the discharge of contaminants from the landfill may alter the course of surface water by upsetting the normal water cycles. This change in water flow patterns has the potential to cause erosion, flooding, and changes to the aquatic species' habitats [38].

1.4.2 Incineration

The traditional way for getting rid of organic pharmaceutical waste is incinerating it. It entails burning dangerous substances at high temperatures (over 1200 °C) in incinerators that have been specifically constructed for the purpose. While incineration offers a practical method for getting rid of waste, it has various negative consequences on the environment, especially on aquatic bodies [39]. Water contamination is a major concern. Heavy metals and other harmful pollutants are emitted into the air during the combustion process. Through air deposition or runoff, these contaminants may eventually find their way into water bodies, contaminating them and perhaps harming aquatic life. The process of bioaccumulation is another effect of incineration. When pollutants are burned, they can eventually build up in the bodies of aquatic species [40]. The organisms themselves may experience health problems as a result of this bioaccumulation, and humans who consume them may be at risk. These pollutants can have toxic effects and disrupt the normal functioning of organisms' physiological systems. Furthermore, the presence of pollutants from incineration can disrupt the natural balance of aquatic ecosystems. The introduction of contaminants can lead to changes in the composition and abundance of species, potentially causing a decline in biodiversity and ecological imbalance [41].

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2 Alternative methods used for the pharmaceutical waste disposal

2.1 Membrane Filtration Techniques

A semi-permeable membrane is used in the separation technique known as membrane filtration to separate materials according to their sizes. It functions by applying pressure to a fluid that is passed over the membrane, enabling tiny particles to flow through while trapping larger ones [42]. The permeate (filtered fluid) and the retentate (concentrated particles) are effectively separated into two streams by this method. The use of membrane filtration, particularly with pore sizes ranging from 0.22 to 0.45 micrometers, has shown promise in the retention of small-sized organic waste and microorganisms. By preventing their release into water bodies, membrane filtration can help mitigate eutrophication and reduce the increase in biochemical oxygen demand (BOD), which can have detrimental effects on aquatic organisms [43]. Ongoing studies have demonstrated the effectiveness of membrane-based filtration for wastewater treatment and water purification. Various research efforts have highlighted the high efficiency of polymeric membranes in effectively separating contaminants from water sources. This indicates the potential of membrane filtration as a viable method for reducing the presence of pharmaceutical waste and other pollutants in water bodies, thereby protecting aquatic ecosystems and human health. While further research is still being conducted to optimize membrane filtration techniques and improve their application in pharmaceutical waste management, the current findings indicate its effectiveness in retaining and removing harmful substances. Incorporating membrane filtration into wastewater treatment processes can contribute to the preservation of water quality and the overall health of aquatic ecosystems [44].

2.2 Vermicomposting of herbal pharmaceutical industry solid waste

Vermicomposting is a technique for managing organic waste that uses earthworms to break down organic materials and create nutrient-rich compost. It can be applied to the solid waste produced by the herbal medicine business and is a sustainable and ecologically beneficial method [45]. Vermicomposting is an efficient way to handle the organic byproducts, plant matter, and other solid waste from the herbal medicine sector. To speed up the decomposition process, the waste materials are first shredded or broken down into smaller bits. Then, earthworms are added to the trash heap, more especially, species like Eisenia fetida and Lumbricus rubellus. A strategy that is both effective and environmentally benign that can be used for the solid waste produced by the herbal medicine sector [46]. The organic waste materials are consumed by the earthworms, who then break them down into simpler molecules during their digestive process. They also excrete vermicompost, which is a very beneficial soil amendment and contains castings that are rich in nutrients. This process creates vermicompost, which is full of vital minerals, healthy bacteria, and enzymes that can boost soil fertility and plant growth. Solid waste from the herbal medicine sector can be composted with worms for numerous benefits. First off, it transforms organic waste into a useful resource to offer a sustainable waste management solution [47]. Waste disposal has a smaller negative influence on the environment when it is diverted from landfills. Second, vermicompost can be utilised in agricultural and horticultural practices as an organic fertiliser or soil amendment to promote healthy plant growth without the need for synthetic chemicals. This lessens the need for artificial fertilizers and is consistent with the principles of sustainable agriculture [48].

2.3 Oxidation Process for Pharmaceutical Compounds Removal

Pharmaceutical chemicals are frequently eliminated from wastewater and other aqueous systems via the oxidation method. It entails a chemical reaction involving an oxidizing agent and pharmaceutical chemicals that degrades or transforms the pharmaceutical compounds into less dangerous ones [49]. This can be accomplished via a variety of oxidation methods, including chemical oxidation processes and advanced oxidation processes (AOPs). The process of ozonation, which uses ozone (O_3) as the oxidizing agent, is one often used AOP. Ozone is a potent oxidant that can efficiently oxidize medicinal substances to break them down. Hydroxyl radicals (OH•), which are very reactive and can further oxidize the medicines, are created when it combines with the chemicals [50]. Antibiotics, hormones, and painkillers are just a few of the pharmacological substances that have been successfully removed from water by ozonation. The employment of hydrogen peroxide (H_2O_2) with ultraviolet (UV) light in combination is another frequently used oxidation technique. This process is known as UV/ H_2O_2 oxidation. In this procedure, the hydroxyl radicals produced when the hydrogen peroxide is activated by UV light combine with the medicinal molecules to accelerate their breakdown [51]. Pharmaceutical component elimination techniques other than AOPs include chemical oxidation procedures like Fenton's reagent (a mixture of hydrogen peroxide and an iron catalyst) and permanganate oxidation. In these procedures, wastewater is treated with a chemical oxidant that starts oxidation reactions and converts pharmaceutical chemicals into simpler, less dangerous byproducts [52].

3 Future scope for waste disposal management

Proper management of pharmaceutical waste is crucial to mitigate its impact on aquatic ecosystems. While conventional methods like landfills and incineration have their drawbacks, alternative approaches can help address these concerns [53]. Firstly, education and awareness campaigns play a vital role in informing the public about the environmental consequences of pharmaceutical waste and the significance of proper disposal. By increasing knowledge and promoting responsible practices, individuals can actively contribute to safeguarding aquatic ecosystems. One alternative method is the use of membrane filtration techniques. Membrane filtration involves passing wastewater through semi-permeable membranes that selectively allow certain particles to pass through while retaining others. This process can effectively remove small-sized organic waste and microorganisms, preventing eutrophication and reducing the mortality rate of aquatic organisms. The implementation of membrane filtration systems in wastewater treatment plants can significantly reduce the release of pharmaceutical compounds into water bodies [54]. Vermicomposting, another alternative method, offers a sustainable approach to managing herbal pharmaceutical waste. It involves the decomposition of waste through the activity of earthworms, leading to the production of nutrient-rich compost. By diverting waste from landfills, vermicomposting reduces the potential contamination caused by pharmaceutical waste and provides a valuable resource for soil enrichment [55]. This approach promotes circular economy principles by converting waste into a useful product. Proper disposal of unused or expired medications is crucial to prevent their entry into water bodies. Establishing designated collection sites or take-back programs encourages individuals to dispose of medications safely instead of flushing them down the toilet or sink. By promoting responsible disposal practices, the risk of pharmaceutical compounds contaminating aquatic ecosystems can be minimized. To address the root causes of pharmaceutical waste, efforts should focus on reducing overprescribing and overuse of medications [56]. Healthcare providers can play a key role in prescribing and dispensing only the necessary amount of medication required for effective treatment. This practice reduces the quantity of pharmaceutical waste generated and subsequently decreases its impact on water bodies. Implementing treatment processes specifically designed for pharmaceutical waste is vital in healthcare facilities and wastewater treatment plants [57]. Technologies such as oxidation processes or activated carbon adsorption can effectively remove pharmaceutical compounds from wastewater before it is discharged into water bodies. By incorporating these treatment methods, the concentration of pharmaceuticals in effluent can be significantly reduced, safeguarding aquatic ecosystems. Exploring alternative drug delivery methods can help minimize the release of drugs into the environment. Transdermal patches or injection systems, for instance, offer efficient drug administration while minimizing the quantity of pharmaceutical waste generated. By adopting such alternatives, the overall impact of pharmaceuticals on water bodies can be reduced [58].

4 Conclusion

Pharmaceutical waste poses a significant threat to the aquatic ecosystem and public health, necessitating proper management to mitigate its negative effects on the environment. Effective measures include improving pharmaceutical monitoring, establishing efficient waste disposal systems, and promoting strategies to minimize unnecessary pharmaceutical use. Collaborative efforts involving governments, healthcare organizations, and the pharmaceutical industry are crucial to addressing this issue. Conventional methods like incineration and landfill deposits have drawbacks such as disrupting natural water cycles, water pollution, bioaccumulation, acidification, and air pollution. Therefore, thorough research on waste disposal methods and the implementation of sustainable alternatives are essential. Emerging methods like membrane filtration, vermicomposting, and oxidation processes show promise in waste management. The increasing production of pharmaceutical waste necessitates immediate attention and action to ensure proper disposal and treatment. Implementing effective water treatment methods can mitigate the harmful effects of pharmaceutical waste, safeguarding both human health and the environment. Public awareness campaigns, strengthened regulations, and efficient waste treatment techniques are crucial for protecting the aquatic ecosystem and the communities that rely on it. By reducing the environmental impact of pharmaceutical waste, we can preserve the health and well-being of our ecosystems.

5 Publisher's Note

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