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A REVIEW ON ENVIRONMENTAL IMPACT OF PHARMACEUTICALS

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ABSTRACT

A growing area of concern in environmental science, the comprehensive review aimsto evaluate and synthesize the extensive literature on pharmaceuticals' effects on the environment. Due to their widespread use and incomplete removal during wastewater treatment processes, pharmaceuticals, including human and veterinary medicines, have been detected all over the environment. Due to their bioactive properties, these substances may pose ecological risks, but the scope and consequences of these impacts are still poorly understood. The most important aspects are covered in our review, including entry pathways into the environment, detection techniques, potential effects on animals and plants, and pharmaceutical contamination's potential effects on human health. We also looked into the efficacy of the technologies that are currently used for wastewater treatment to get rid of these substances and evaluated the potential of new technologies. The review comes to a close by talking about the implications for policy and the need for a global coordinated response. We hope that by summarizing the breadth of research in this area, more research and awareness of the environmental effects of pharmaceutical waste will be raised.

I. INTRODUCTION

In today's society, the use of pharmaceuticals, which include medicines for humans and animals, has become essential. They are essential to disease management, prevention, and control, significantly increasing life expectancy and quality of life. However, the environmental effects of these substances are becoming increasingly apparent and cannot be ignored any longer. The multifaceted nature of this growing problem is demonstrated by the intricate network of pathways through which pharmaceuticals enter the environment. The three main categories of these pathways are as follows: direct release in factories, indirect release through biological excretion, and improper disposal of unused medications are all forms of release. Despite strict regulations, pharmaceutical manufacturing facilities frequently discharge effluents loaded with active pharmaceutical ingredients (APIs) directly into wastewater streams. This results in the contamination of aquatic ecosystems due to the absence of effective treatment protocols**.** This problem is especially bad in places where pharmaceutical production is concentrated in large numbers. In parallel, the pharmaceuticals excreted by humans and animals, a more frequent route, significantly contributes to environmental burden. The body excretes unmetabolized pharmaceutical residues into sewage systems through urine or feces after consumption. Through the application of manure to agricultural fields, pharmaceuticals for animals enter the environment in additional ways. Inadvertently releasing treated eluents and biosolids—often used as fertilizers—laden with these compounds back into terrestrial and aquatic environments is the result of wastewater treatment plants (WWTPs) that were not intended to remove these wastes. Ferrari and other asserted that their high volume of production.

This review aims to raise awareness, encourage more research, and contribute to the creation of effective and informed policies. This review aims to establish a solid foundation for future efforts to combat the environmental pollution caused by pharmaceuticals that is becoming an increasingly pressing issue by focusing on both the issues and potential solutions.

1.1) Sources of Pharmaceutical Pollution

The problem of pharmaceutical residues contaminating our ecosystems is a complicated one that can largely be attributed to three primary sources:

1) Pharmaceutical Manufacturing
2) Human and Animal excretion
3) Improper disposal of Medication
4) Aquafarming

1) Pharmaceutical Manufacturing

The pharmaceutical industry itself, which is responsible for the massive production of these compounds, is the

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first significant source of pharmaceutical pollution. Manufacturing facilities frequently directly discharge effluents into wastewater streams, despite stringentregulations. When appropriate treatment protocols are not in place or are ineffective, theseeffluents, which are loaded with APIs, find their way into aquatic environments. This problem is made worse in areas where pharmaceutical production is concentrated, which causes severe localized pollution.

2) Human and Animal Excretion

The excretion of pharmaceutical residues by humans and animals is the second major source of pharmaceutical pollution. This source is much more dispersed and affects virtually every household. Some APIs are excreted in large quantities through urine and feces, which eventually make their way into the sewage system. The body does not fully metabolize all APIs that are consumed. This problem gets worse when veterinary medicines are used, because manure applied to agricultural land can directly introduce residues into the environment. Because of these contributions, pharmaceutical pollution from human and animal excrement is widespread and difficult to control.

3) Improper disposal of Medication

Last but not least, putting expired or unused medicines in the wrong place can have a big impact on the health of the environment. Pharmaceuticals that haven't been used are frequently dumped in the trash of homes or flushed down sinks and toilets. This practice prevents these compounds from being removed or degraded before they enter environmental matrices by allowing them to enter landfill leachate or domestic wastewater directly. When multiplied by the magnitude of global medication use, this seemingly insignificant act reveals a significant and widespread source of pharmaceutical pollution. Recognizing these sources is the first step in developing efficient strategies to reduce pharmaceuticals' negative effects on the environment. As a result, coch calls for an in-depthinvestigation and sustainable solutions.

4) Aquafarming

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1.2) Pathways of the Environment

Understanding the diverse ways through which pharmaceuticals make ther way into the environment a enicial step m grappling with this complex problem. These pathways are asvaried as they are numerous, but four key conduits stand out for their pervasive influence. WWII's, direct release into water bodies, soud contamination via fertilizers, and lenching and runoff.

A. Wastewater Treatment Plant

Our wastewater management relies heavily on wastewater treatment plants (WWTPs), but their design did not include pharmaceutical removal in mind. As a result, pharmaceutical residues can easily enter the environment through these facilities. A significant amount of pharmaceuticals that animals and humans consume are not completely metabolized, and the compounds that result, including the original substances and various metabolites, are eliminated through urine or feces. Although they are quite effective at removing conventional pollutants, these processes are ill-equipped to deal with the complex chemical structures and resilient nature of many pharmaceuticals. These waste products enter the sewage system and end up in WWTP. However, conventional treatment processes in WWTP, primarily biological degradation and physicochemical separation, fail to completely eliminate pharmaceutical compound. As a result, these compounds remain in the treated wastewater. This treated wastewater is either dumped into rivers, lakes, or acas or used as irrigation water in agriculture, thereby contaminating both terrestrialand aquatic ecosystems. It is essential to emphasize that this path is not simply a linear progression from consumption to environmental redistribution; It is an ongoing issue. Demonstrating the pervasive and self-perpetuating nature of this problem, these pharmaceuticals can

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enter the human food chain through seafood from polluted water bodies or crops irrigated with contaminated water.

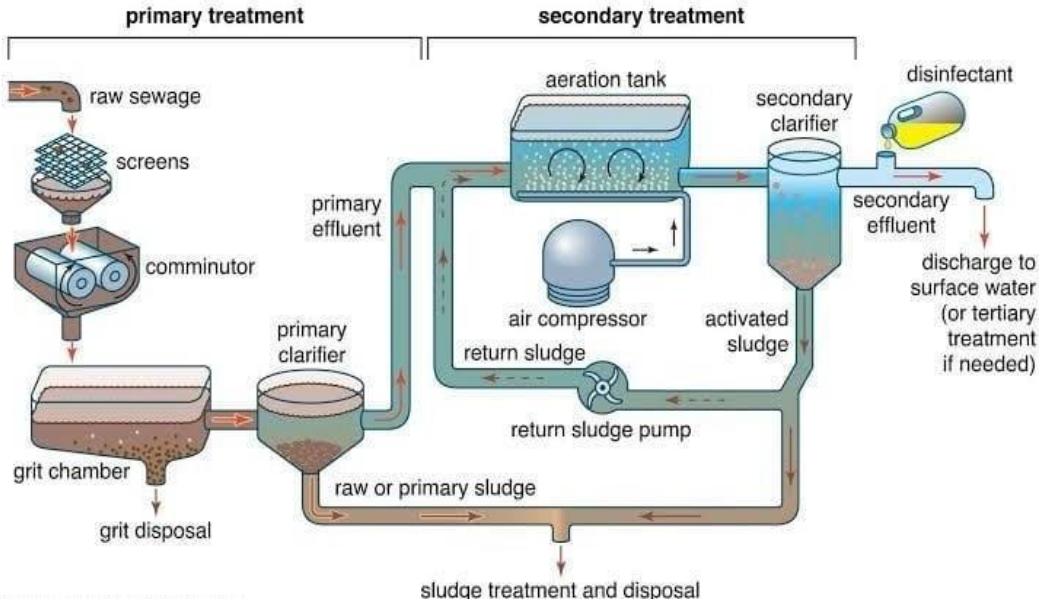

Fig No:1 Waste Water Treatment

B. Direct Release into Water Bodies

Direct release into water bodies Although WWTPs are a significant indirect source,pharmaceuticals can also be released directly into ecosystems. Stormwater runoff,untreated or inadequately treated sewage, and industrial influence all contribute tothis release. Particularly in countries with less stringent environmental regulations, pharmaceutical manufacturing plants can be a significant source of this direct release. In areas with inadequate wastewater treatment infrastructure or regulatory overnight, the direct release of pharmaceuticals into water bodies becomes the primary pathway. The aquatic organisms in these ecosystems bear the immediate brunt of this pollution, resulting in a variety of sub-lethal effects, changes in biodiversity, and a possible shift in the balance of the ecosystem. Long-term effects of this pollution on these ecosystems' structure and function are difficult to predictand even harder to reverse.

C. Soil Contamination via fertilizers

Fertile soil is the lifeblood of terrestrial ecosystems and our agricultural practices. However, it also serves as a significant sink for pharmaceutical residues. The application of treated wastewater and biosolids from WWTP's in agriculture introduces a complex cocktail of pharmaceuticals into our soils Although these substances are intended to influence and fertility and crop growth, they also carry the unintended consequence of soal contamination. Pharmaceuticals present in the soil I can be taken up by plants, potentially entering the food chain. They can also leach into groundwater or runoff into nearby water bodies, contaminating these vital sources of freshwater. Moreover, the soil acts as a complex chemical reactor, where pharmaceuticals cat undergo various transformations due to biological, chemical, and physical processes. These transformations can lead to the formation of new compounds, whose environmental behavior and toxicological effects are often unknown.

Fig No.2 Soil Contamination

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D. Leaching and Renoff

In the context of pharmaceutical pollution, leaching and runoff serve as crucial links that connect terrestrial and aquatic ecosystems. The process of water percolating through the soil dissolves and transports a variety of substances, including pharmaceutical residues, known as leaching. Pharmaceuticals leached from the snil can contaminate the groundwater, a crucial source of drinking water, which is why this procedure is especially important in agricultural fields where pharmaceutical- containing biosolids or manure are used. Then again, most, advanced quickly by precipitation occasions, transports surface bound drugs into nearby streams, waterways, or lakes. These pathways, with all of their complexity and interconnectedness, serve as a stark reminder of the omnipresence of pharmaceuticals in our environment. This pathway is especially troubling becauseit can lead to sudden, episodic surges in pharmaceutical concentrations in aquatic ecosystems, posing a serious threat to the organisms that live in these habitats. We open the door to the development of targeted, effective strategies to monitor, regulate, and mitigate this broad issue by recognizing these pathways. The development of infirmed regulatory policies, as well as advancements in waste management practices and treatment technologies, are based on this understanding.

1.3) Persistence and Transformation of Pharmaceutical in the Environment

Pharmaceuticals' persistence and transformation in the environment Pharmaceuticals released into the environment are not inert; rather, they undergo a series of physical transformations. chemical and biological processes These changes have the potential toalter the pharmaceuticals' properties, behavior, and potential effects on the environment.However, it is essential to keep in mind that. In order to carry out their therapeutic functions, many pharmaceuticals are constructed to resist rapid breakdown, which contributes to their persistence in the environment.

- **Physical Processes (Photolysis and hydrolysis)**

When it comes to pharmaceuticals' fate in the environment, physical processes play a crucial role. The most important transformation mechanisms are hydrolysis and photolysis among these. Compounds that are broken down by sunlight are referred to as photolysis. This process is significantly influenced by the environmental medium's optical properties, as well as the intensity and wavelength of light. Pharmaceuticals in shallow or surface waters are particularly susceptible to photolysis. Hydrolysis, on the other hand, involves adding water to a molecule and cleaving chemical bonds in the molecule, which alters the molecule's structure and properties. In aquatic environments, it is a crucial process that is highly dependenton factors such as pl. temperature, as well as the presence of catalytic substances. However, the effects of these physical processes on various pharmaceuticals varygreatly based on their chemical makeup and environmental conditions.

- **Biological processes (Biotransformation & biodegradation)**

The way pharmaceuticals end up in the environment is also significantly influenced by biological processes, particularly biotransformation and biodegradation. The process by which animals, plants, or microorganisms alter a substance's chemical structure, altering its properties and behavior, is referred to as biotransformation. Biodegradation, a specific type of biotransformation, involves the complete breakdown of a substance by microorganisms into simpler,harmless substances like carbon dioxide, water, and basic nutrients. This process can either detoxify the substance or, in some instances, transform it into a form that is more harmful. Biodegradation can act as a natural attenuation mechanism for pharmaceuticals. However, the specific microbial communities that are presentin the environment and the surrounding environment have a significant impact on this process's efficiency. In addition, pharmaceuticals' diverse and complex structures frequently pose a significant obstacle to their complete biodegradation.

- **Chemical processes (Oxidation and reduction)**

Pharmaceuticals' environmental fate is also influenced by a variety of chemical reactions, in addition to biological and physical processes. Among these chemical processes, oxidation and reduction, collectively known as rodos reactions, are among the most influential. Oxidation involves the loss of electrons, which typically results in the formation of products that are more polar and possibly more soluble in water. Reduction, on the other hand, involves gaining electrons and frequently results in products that are less polar and possibly less water-soluble. The complexity of these transformation processes highlights the difficulty in predicting pharmaceuticals' environmental fate and impacts. These reactions can

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significantly alter pharmaceuticals' behavior in the environment, affecting their mobility, bioavailability, and toxicity. In addition, these processes may occasionally result in the formation of transformation products that may be more stable or long-lasting than the parent compounds. As a result, understanding thesetransformation processes and their interactions is essential for determining the environmental risk posed by pharmaceuticals and formulating the most effective strategies for their mitigation.

1.4) Detection and Monitoring of Pharmaceuticals in the Environment

Understanding pharmaceuticals' supply, distribution, and impact on the environment begins with their detection and monitoring in the environment. Methodologies havechanged a lot over the years, moving away from more traditional approaches and toward more cutting-edge, emerging ones. Despite these significant advancements, there are still a lot of obstacles and limitations, highlighting the need for ongoing research and innovation in this field.

- **Conventional Method**

Methods that have always been used to detect pharmaceuticals in environmental matrices include mass spectrometry (MS) and techniques like gas chromatography(GC) and liquid chromatography (LC). Due to their ability to detect and quantify a wide range of compounds in a variety of sample matrices, these methods have served as the foundation for pharmaceutical environmental monitoring. LC-MS is particularly suited for pharmaceuticals due to its sensitivity and selectivity for polar and ionic compounds. which are typical characteristics of these materials. In contrast, more volatile and thermally stable compounds typically benefit from OC MS. Additionally, methods of sample preparation such as liquid-liquid extraction and solid phase extraction are frequently used to concentrate pharmaceuticals andeliminate potential matrix interferences. The understanding of the occurrence environment has significantly improved as a result of these conventional methods.

- **Emerging Techniques**

Trace level detection, a wide range of pharmaceuticals, and complex environmental matrices all present significant analytical challenges, despite their usefulness. High-resolution M5, such as time-of-flight and orbitrap-based systems,is increasingly being used by researchers as a result of these advances in detectionand quantification methods. These methods allow for the detection and identification of not only parem pharmaceuticals but also their metabolites and transformation products due to their exceptional resolution, accuracy,and sensitivity.

- **Challenges and limitations**

The detection and monitoring of pharmaceuticals in the environment remains constrained by a number of obstacles and limitations despite advancements. These include problems with sample preparation, like the possibility of sample contamination and the loss of analytics during the extraction and I concentration step. The complexity of environmental matrices also makes it hard to use the selectivity and sensitivity method. It can be difficult to identify and quantify low- level pharmaceuticals among many other substances because of the potential for detection to be hampered by diverse and variable matrices. In addition, a significant amount of expertise and expensive, specialized equipment are required for many emerging and advanced techniques. restricting their application and accessibility. Additionally, the detection of pharmaceuticals alone does not providea complete picture of environmental risk because of the sheer variety of pharmaceuticals, each of which has distinct chemical properties and behavior. Reflecting on the key insights from this section, while progress has been made in the detection and monitoring of pharmaceuticals in the environment, numerous challenges and limitations necessitate ongoing research and technological innovation. The presence of transformation products and mixtures of multiple pharmaceuticals, as well as their potential effects that are either synergistic or antagonistic, adds another layer of complexity to risk. An integrated, holistic approach to risk assessment and advancements in analytical methods will be crucial in addressing pharmaceuticals' impact on the environment.

1.5) Impact of Pharmaceutical in the Environment on ecology and Human health

The widespread presence of pharmaceuticals in the environment raises serious concerns for both human health and the environment as a whole. Although these substances were initially made to precisely interact with biological systems, they have the potential to haveunintended effects on systems and organisms that are not

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intended targets when they are present in the environment. The effects on aquatic life and the crucial connection to AMRwill be examined in this section.

- **Effects on Aquatic and terrestrial Wildlife**

Biological future and ecotoxicological effects of pharmaceuticals and their byproducts on aquatic and terrestrial organisms, as well as other wildlife within their habitats, are still poorly understood, according to scientists. It is established that aquatic organisms are susceptible to a variety of chemicals contained in wastewater residues when exposed to significant quantities over their lifetimes. Due to their bioactive nature, pharmaceuticals can pose significant threats to aquatic and terrestrial ecosystems. Numerous pharmaceutical residues frequently end up in water bodies like rivers, lakes, and oceans, posing significant threats to aquatic biota like fish, amphibians, invertebrates, and phytoplankton. Pharmaceuticals can cause acute or chronic toxic effects on organisms at a variety of biological levels, from the molecular to the population level. According to Paut Kusturica et al., for instance, the feminization of male fish caused by synthetic estrogens in contraceptives has been linked to reproductive problems and skewed sex ratios. reported that the use of birth control pills alone causes the human population worldwide to release approximately 30,000 kilograms of natural steroidal estrogens and 700 kilograms of synthetic estrogens each year. Diclofenac and other nonsteroidal anti-inflammatory medications have been linked to renal failure and the near extinction of several Asian vulture species. Antidepressants like fluoxetine can alter the behavior of marine and freshwater organisms by affecting feeding habits, growth rates, and interactions between predators and prey.In a similar vein, terrestrial wildlife is not shielded from the effects, particularly those that are closely associated with bodies of water or that make use of irrigated fields. Herbivores could be exposed to pharmaceuticals that are present in the soil because plants can absorb them. Pharmaceuticals for animals, like antibiotics and hormones used in livestock production, are one example. can persist in manure and, when applied as fertilizer, can contaminate terrestrial environments, posing a threat to the health of plant organisms and soil organisms. The ecological effects of pharmaceuticals on the environment are complex and can have an impact on all ecosystems. The prediction and evaluation of risks are further complicated by these compounds' potential interactions with one another and other environmental contaminants, which can have additive, antagonistic, or synergistic effects.

- **Potential Human Exposure pathways**

There is currently no research that identifies any long-term effects on human health from low-dose exposure to pharmaceuticals in the water supply. However, the quantitative methods used to calculate the predicted and actual environmental concentrations of APIs have their uncertainties and discrepancies. Pharmaceuticals in the environment can also have an effect on human health, primarily through food and water contamination. sources. Pharmaceuticals can contaminate drinking water, including groundwater and surface water. While pharmaceutical residues can be removed from wastewater through treatment processes, some compounds resist degradation and may end up in treated water that is then released back into the environment. Although typically in low concentrations, pharmaceuticals have been found in both source and treated drinking water. Pharmaceuticals can also enter the human food chain through the consumption of contaminated plants and animals. For instance, pharmaceuticals can be absorbed by plants grown in contaminated soils or irrigated with contaminated water. In a similar vein, certainpharmaceuticals can bioaccumulate in the tissues of fish and other aquatic organisms, offering yet another potential route of human exposure. Although the concentrations of pharmaceuticals in food and drinking water are generally regarded as low, the possibility of long-term chronic exposure raises concerns. It is difficult to assess potential risks to human health because of the unknown effects of long-term exposure to low levels of pharmaceutical mixtures. Mackulak et al. () also echoed this sentiment. 2019), who asserted in their study that it is difficult to ascertain whether elevated concentrations of particular drug metabolites in agricultural plants ultimately pose a health risk to hurnans. However, they did pointout that a plant's growth and development could be adversely affected by pharmaceuticals or their metabolites just being present.

- **Link To Antimicrobial Resistance.**

The global AMR epidemic is becoming increasingly linked to the environment's presence of antimicrobial compounds, including antibiotics. These compounds can selectively pressurize microbial communities, encouraging the survival of resistant strains and facilitating horizontal gene transfer of resistance mechanisms.

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Because they combine high densities of diverse microbial communities, residual antimicrobials, and mobile genetic elements, WWTPs are especially conducive to the emergence and spread of antimicrobial-resistant bacteria. Through biosolids and treated effluent, antimicrobial-resistant bacteria and their resistance genes can be released into the environment. Resistance can spread through water, sediment,and soil, affecting human and environmental health. Resistant bacteria can infect humans if they come into direct contact with contaminated environments or eat ordrink contaminated water or food. By means of vectors like insects. A major concern for public health is AMR, which poses a significant threat to the effectiveness of our current antimicrobial treatments. All in all, the effects of pharmaceuticals in the environment on human health and the environment as a whole are extensive and complicated. We need more research to learn more aboutthese effects and come up with ways to reduce potential dangers. A multidisciplinary approach that integrates environmental science, toxicology, microbiology, epidemiology, and risk assessment is essential moving forward, given the issue's global scope and complexity.

1.6) Policy Implication and Future Direction in Managing Pharmaceutical in the Environment Current Regulation and their Effectiveness.

Although the presence of pharmaceuticals in the environment is not a new concern, policymakers face a relatively novel and complex challenge due to the contamination's implications and the required response. This section will discuss the effectiveness of current regulations, offer suggestions for policymakers, and provide an outline. areas for future investigation into this multifaceted problem.

- **Current regulations and their Effectiveness**

The issue's complexity is exacerbated by the fact that environmental pharmaceutical regulatory frameworks are inconsistent and national. The approval process for new drugs, drug safety and efficacy in use, and manufacturing practices are the primary areas of pharmaceutical regulation at the moment; environmental fate and effects of these substances are rarely taken into account.

Environmental Risk Assessments (ERAs), according to Enick and Moore, are scientifically based, methodical processes in which risk is best defined by the objective likelihood of a dangerous occurrence. Based on the drug's characteristics,Deblonde and Hartemann explained that ERA systems classify environmental hazards into three primary categories: Bioaccumulation, the drug's potential to accumulate in the adipose tissue of aquatic organisms, and toxicity, the drug's potential to pose toxic risks to aquatic life, all refer to the drug's resistance to degradation in the aquatic environment. Jones and co. stated that it is unlikely thatthese legislative measures will have a significant impact on the environmental levels of the numerous pharmaceutical products that have already been approved for use, despite the introduction of guidelines for new pharmaceuticals in the United States and proposed drafts for ERA of new pharmaceuticals in the European Union. For the approval of new pharmaceuticals, an ERA is required in the European Union.4 However, this is not the case in many other regions, including the United States. Even when ERAs are required, they frequently come with restrictions. For instance, they typically do not take into account the dynamic and complex nature of environmental systems because they are based on the predicted environmental concentration (PEC). Additionally, they fail to take into account the effects of pharmaceutical mixtures, which are more relevant to the actual situation. For instance, Giunchi et al.'s study based solely on the ratio between the PEC and the predicted no-effect concentration, identified a significant environmental risk for several pharmaceuticals in Italy, including levonorgestrel, ciprofloxacin, amoxicillin, azithromycin, venlafaxine, sertraline, and diclofenac. On the waste management side, current wastewater treatment regulations do not mandate the removal of pharmaceuticals, with existing standards focusing more on traditional pollutants. Consequently, pharmaceuticals are frequently released into the environment as a result of conventional wastewater treatment procedures that are not intended to remove them. As a result, more targeted and robust regulatory frameworks are needed to address pharmaceutical pollution, despite the fact that current regulations have been effective in addressing traditional environmental contaminants.

II. AREA'S FOR FUTURE RESEARCH

To address the issue of pharmaceuticals in the environment, extensive research is required to fill in knowledge gaps and provide the evidence base for policymaking. The occurrence, fate, and effects of pharmaceuticals in various environmental compartments, including air, which has received less attention than water and soil,

should be the primary focus of future research. The effects of long-term, low- concentration exposure to pharmaceutical mixtures on humans and wildlife should be the subject of studies. This includes studies on sublethal effects, microbiome effects, and possible connections to human chronic diseases. Additionally, it is necessary to conduct research on the environment's contribution to the emergence and spread of AMR as well as risk mitigation strategies. In terms of detection and monitoring, the goal of research ought to be the creation of sensitive, cost- effective, and able-to-be-used in the field methods for detecting pharmaceuticals in the environment. Additionally, research on the cost-effectiveness of various policy options and the social and economic aspects of pharmaceutical pollution, such as public perceptions, behaviors, and willingness to pay for solutions, is required. Another important area for future research is the creation and evaluation of advanced wastewater treatment technologies, green pharmacy approaches, and pollution prevention strategies. Bringing together the main arguments presented thus far, addressing the issue of pharmaceuticals in the environment presents a significant challenge that necessitates an integrated, comprehensive approach. and novel strategies. Although significant progress has been made, there is still a lot of work to be done. To ensure the sustainable management of pharmaceuticals and the protection of human health and the environment, it is absolutely necessary for policymakers, researchers, industry, and the general public to collaborate on solutions.

III. RECOMMENDATION

During manufacturing, storage, and transportation, pharmaceutical packaging ought to be designed to prevent contamination. Carbamazepine and other pharmaceutical compounds can be broken down through bioremediation. To reduce the amount of medical waste that pollutes the environment, healthcare facilities should follow all applicable regulations and policies. A crucial criterion for determining the environmental danger posed by chemicals is bioaccumulation. If pharmaceutical sludge is used as fertilizer, it may pollute the soil. Antibiotics in the environment have contributed to the development of antibiotic resistance, a major threat to public health. More research is required to comprehend the environment's stability of anticancer drugs, according to studies. A comprehensive approach, such as the Dutch chain approach proposed by Moermond and de Rooy, that involves a variety of stakeholders, from consumers to policymakers, is necessary to address the growing problem of pharmaceutical pollution. Public education and awareness campaigns are the first step toward managing this issue. These programs have the potential to effectively draw attention to the health and environmental dangers posed by improper drug disposal. We can significantly reduce the amount of pharmaceutical pollutants that enter our water systems by informing the public about the importance of returning unwanted drugs to pharmacies or designated collection points rather than flushing them down the toilet or sink. The implementation of drug take-back programs by governments and pharmacies, for instance, can provide consumers with a secure and eco-friendly method for disposing of their expired or no longer needed medicines. This is in addition to the role that the individual plays in the problem.

IV. CONCLUSION

The journey through this comprehensive review has brought to light the issue of pharmaceuticals' effects on the environment's complexity and significance. It is evident that the scope of the problem is vast and multifaceted from the in-depth explanation of the numerous pathways through which pharmaceuticals enter the environment to the intricate processes that facilitate their persistence and transformation. The issue's global and far-reaching impact is demonstrated by the fact that these pharmaceutical residues have been found in a variety of environmental compartments. A growing body of evidence suggests significant potential risks as we investigate the effects of these pharmaceuticals on human health and the environment. There are compelling reasons for immediate attention and action, including the documented effects on aquatic and terrestrial wildlife, the potential routes of human exposure, and the connection to AMR. However, the review also reveals significant inconsistencies in our comprehension of the issue. The environmental fate and effects of pharmaceuticals are poorly understood in many ways, and even though detection and monitoring methods are getting better, they still face significant obstacles. In addition, we do not yet fully comprehend the social and economic aspects of pharmaceutical pollution. The inadequacy of current regulations to address pharmaceutical pollution has been highlighted by this review. Despite the existence of regulations, their efficacy is limited by their focus on conventional contaminants and their inability to fully take into account the particular difficulties posed by pharmaceuticals. Nonetheless, this review provides a clear blueprint for the necessary regulatory responses, and the potential for policymakers to drive change is substantial.

There are numerous opportunities for additional research and innovation based on our assessmentof the future directions. From the investigation of public perceptions and the cost-effectiveness ofvarious policy options to the development of advanced wastewater treatment technologies and green pharmacy strategies, options, it is evident that there is a fascinating and significant investigation. agenda to follow. In the end, this review gives a complicated picture of a big globalproblem. Pharmaceuticals' effects on the environment are a growing concern that necessitates immediate and coordinated action. However, it also presents an opportunity to rethink our relationship with pharmaceuticals, drive innovation in pharmaceutical design, and place environmental health at the center of our health care systems. One thing is certain: our actions nowwill shape the legacy we leave for future generations as we continue to confront this challenge.

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