A Review on Pharmaceuticals Affect the Environment and Strategies to Minimise Pharmaceutical Pollutipon

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Abstract

Due to the widespread use of pharmaceuticals in human and veterinary medicine and their subsequent release into various environmental compartments, pharmaceutical contamination has emerged as a growing environmental concern. Manufacturing pharmaceuticals, human and animal excrement, improper disposal of unused medications, and aquaculture activities are major sources. These contaminants enter the environment through the discharge of wastewater, infiltration of soil and groundwater, contamination of surface water, and emissions into the air. Pharmaceuticals remain in the body and undergo physical, chemical, and biological transformations after they are released, affecting their mobility, bioavailability, and impact on the environment. Antimicrobial resistance, endocrine disruption, soil degradation, biodiversity loss, and global warming are just a few of the potential dangers posed by pharmaceutical residues that have been found in air, surface water, groundwater, and soil. Chronic contamination results from conventional wastewater treatment systems' inability to completely remove contaminants. Effective strategies like advanced treatment technologies, regulatory control, secure disposal methods, public awareness, and sustainable pharmacy approaches are necessary to address these issues. Strengthened frameworks for risk assessment and monitoring will be crucial to reducing pharmaceutical pollution and safeguarding human and environmental health.

Keywords: Pharmaceutical contamination, manufacturing, antimicrobial resistance, endocrine disruption, biodiversity, and monitoring.

1. INTRODUCTION

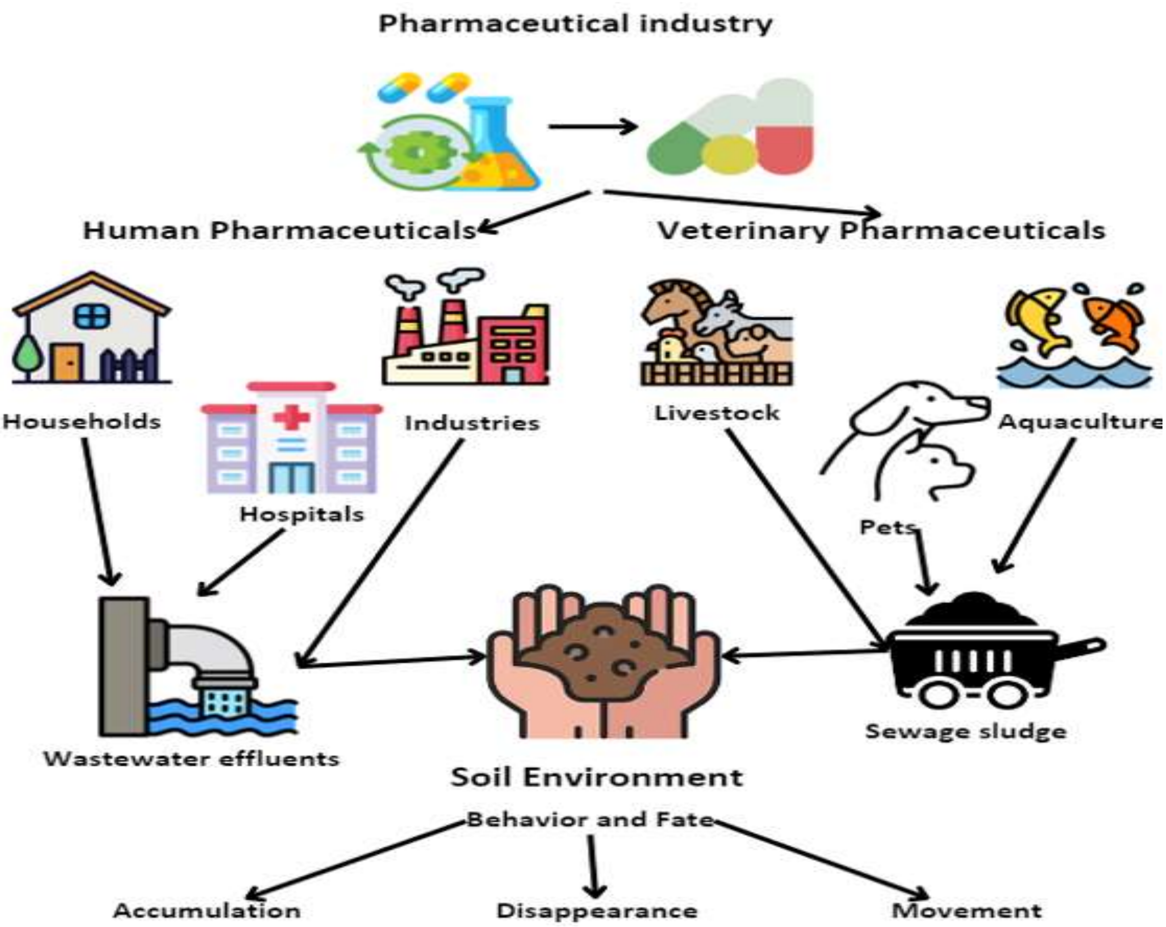
Due to their widespread use in human and veterinary medicine, pharmaceuticals have developed into significant environmental contaminants. Through sewage effluents, pharmaceutical manufacturing discharge, and improper disposal of unused medicines, unmetabolized drug residues and their metabolites are excreted into wastewater, soils, and surface waters following administration[1]. Pharmaceuticals, in contrast to conventional pollutants, are made to be biologically active even at low concentrations, which raises concerns regarding persistence, bioaccumulation, and ecological toxicity[2].

As a significant sink for pharmaceutical residues, soil receives inputs from livestock manure, biosolid application, and wastewater irrigation[3]. These substances undergo adsorption, degradation, and leaching when introduced, affecting their fate and mobility. These processes have an impact on the diversity of microbes in the soil as well as the health of the soil's health and contribute to the spread of genes that are resistant to antibiotics[4]. Trace-level detection of pharmaceuticals and their transformation products has been made possible by analytical methods like high-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC–MS), and liquid chromatography–mass spectrometry (LC–MS) [5].

Pharmaceutical manufacturing effluents, animal and human excrement, improper drug disposal, and aquaculture practices are the main sources of contamination [6]. These routes collectively contribute to the entry of active pharmaceutical ingredients (APIs) into terrestrial and aquatic systems[7]. Pharmaceuticals undergo physical, chemical, and biological processes in the environment that determine their persistence and transformation, including photolysis, hydrolysis, and biodegradation. However, many are constructed to withstand degradation, allowing for their environmental presence over time [8].

Antimicrobials, antiparasitics, and anti-inflammatory medications used in animals enter the soil through runoff and manure, whereas human medications enter the soil through sewage and solid waste [9]. Additionally, improperly managed household waste that contains pharmaceutical residues may leach into groundwater. Recycling, safe pharmaceutical disposal, sustainable waste management practices like segregation at the source, and proper treatment are essential for reducing contamination risks and ensuring environmental safety[10].

fig:1



AIM: A Review on pharmaceuticals affect the environment and strategies to minimise pharmaceutical pollution.

Objectives:

1. To determine the most significant environmental sources of pharmaceutical contamination (human excrement, wastewater, industry, improper disposal, and veterinary use).
2. To classify the kinds of pharmaceutical contaminants that are frequently found, such as drugs used to treat pain, hormones, cancer, and so on.
3. To comprehend the pharmaceuticals' environmental fate and pathways in water, soil, and biota.
4. To look at how pharmaceutical residues affect the environment and human health.
5. To draw attention to the analytical methods used to detect and track pharmaceutical contaminants.
6. To talk about strategies for control, remediation, and regulation.

4. Types of pharmaceutical pollution:

1. Water pollution

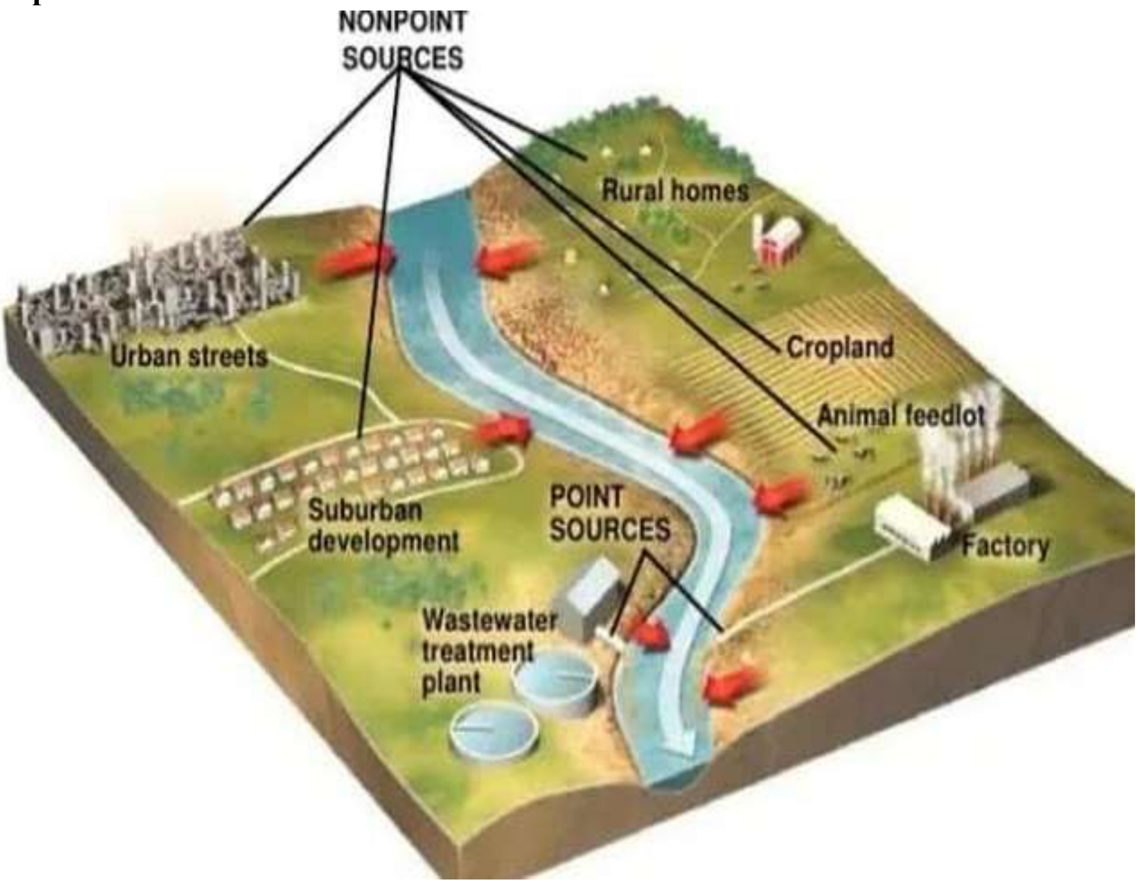


Fig:4

Industrial effluents and organic and inorganic wastes that are disposed of in rivers contribute to water pollution. Paper, pulp, chemical, textile, dyeing, petroleum refineries, tanneries, and electroplating industries are the primary culprits in this regard[11]. These industries release dyes, detergents, acids, salts, and heavy metals like lead and mercury pesticides, fertilizers, synthetic chemicals with carbon, plastics, and rubber, among other things, into the water bodies [12].

2. Soil pollution

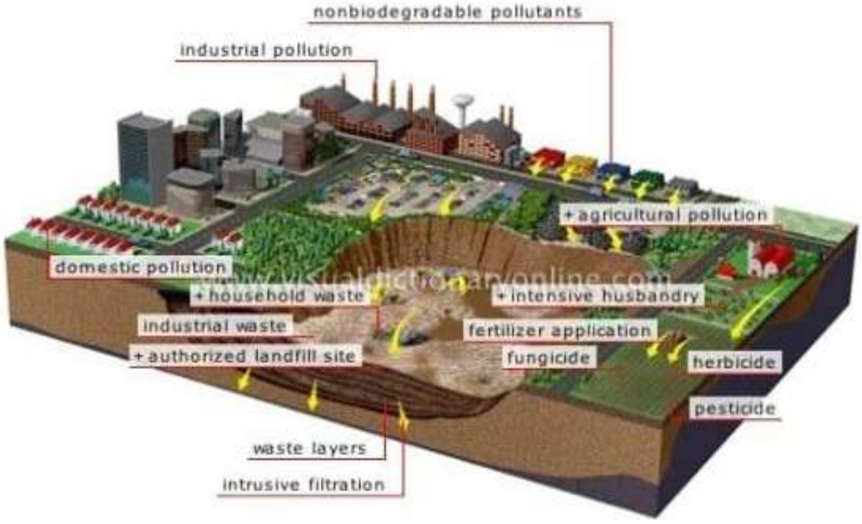


Fig:5

World Journal of Pharmaceutical Research Industries dump their liquid and solid wastes over the soil's surface. They include radioactive waste, sludge, flyash, scrap, effluents, and other wastes that release a lot of toxic chemicals into the soil [13]. Agriculture is being hampered by soil pollution, which is also destroying the local vegetation. People who regularly come into contact with this soil also suffer from long-term health problems as a result [14].

3. Air pollution

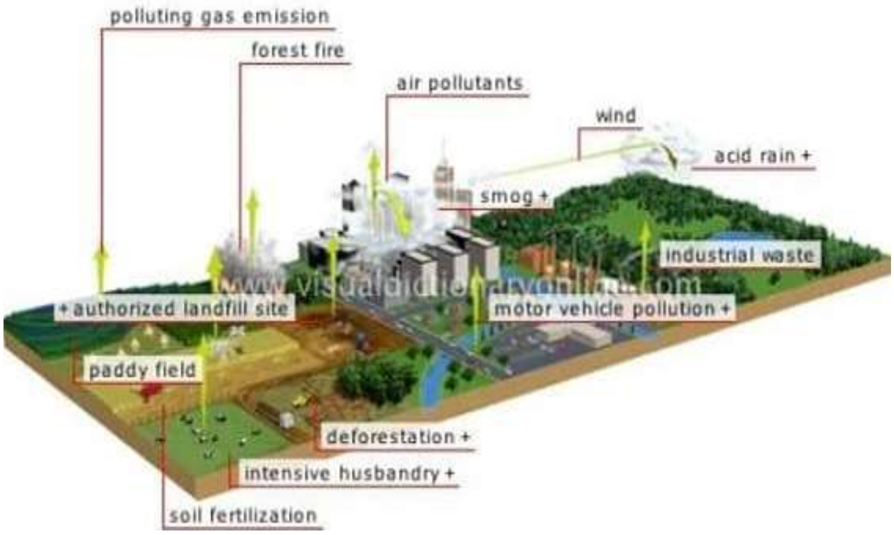


Fig:6

A high concentration of harmful gases, like carbon monoxide and sulfur dioxide, contribute to air pollution. Dust, smoke, and other airborne particulate materials include both solid and liquid particles [15]. Chemical and paper factories, brick kilns, refineries, and smelting plants all produce smoke, as do large and small factories that burn fossil fuels in violation of pollution regulations. Leaks of toxic gas can be extremely dangerous and have long-term effects. The health of people, animals, plants, buildings, and the atmosphere as a whole are all negatively impacted by air pollution [16].

4. Wildlife extinction

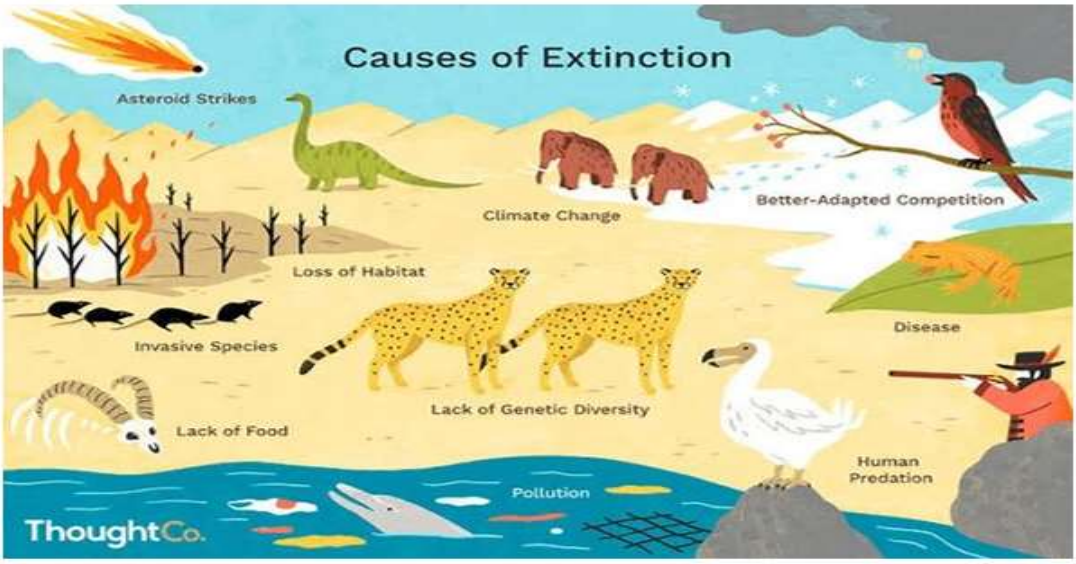


Fig:7

World Journal of Pharmaceutical Research The issue of industrial pollution generally demonstrates that it disrupts natural rhythms and patterns, resulting in severe effects on wildlife. As a result, habitats are disappearing, species are disappearing, and the environment is finding it harder to recover from each natural disaster[17]. Oil spills, fires, radioactive material leaks, and property damage are all examples of major industrial accidents that are more difficult to clean up because they have a greater impact in a shorter amount of time[18].

5. Global Warming

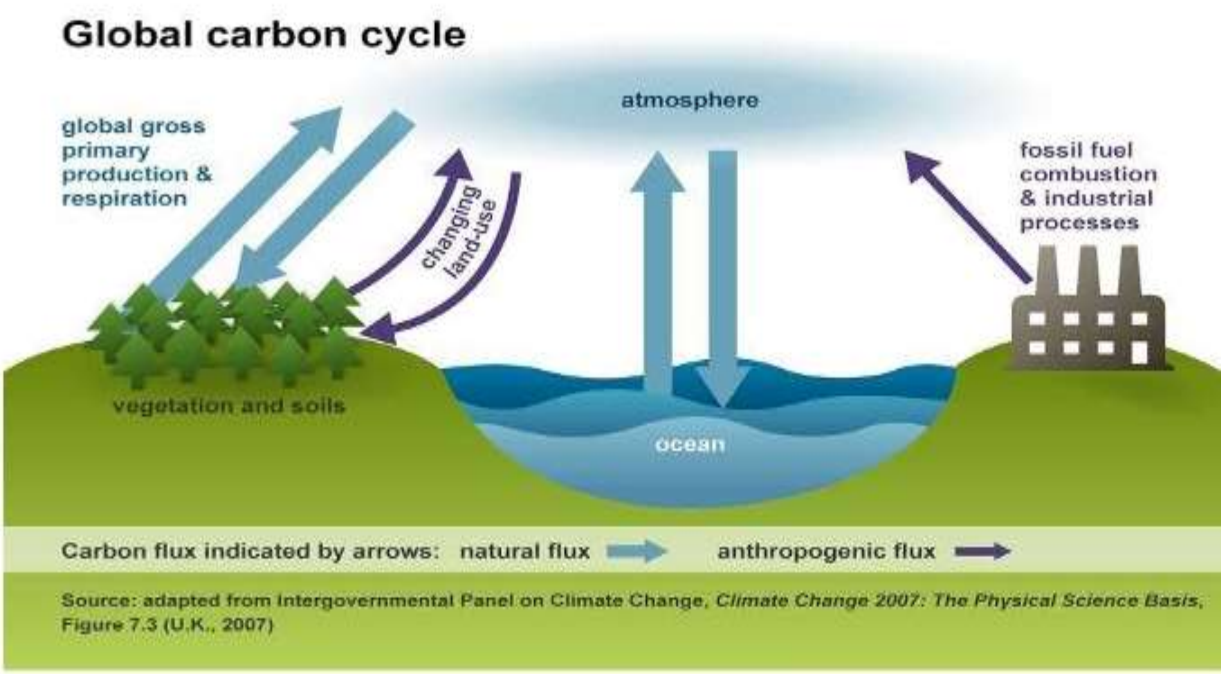


Fig:8

Global warming has been steadily rising as industrial pollution has increased. Industries are putting smoke and greenhouse gases into the air, which makes global warming worse. A few of the effects of global warming include the melting of glaciers, the extinction of polar bears, floods, tsunamis, and hurricanes.

6. Biodiversity loss

Fig:9

Chemical waste, pesticides, radioactive materials, and other industrial pollutants continue to wreak havoc on the planet and its inhabitants[19]. Wildlife and ecosystems are impacted, and natural habitats are disrupted. Habitats are being destroyed and animals are disappearing. The rising amount of hazardous, liquid, and other waste threatens the health of the ecosystem and has an effect on food, water, and health security. The cleanup of disasters caused by industrial pollution, such as oil spills and radioactive leaks, can take years or decades[20].

5 . Pathways of Pharmaceutical Contamination into the Environment

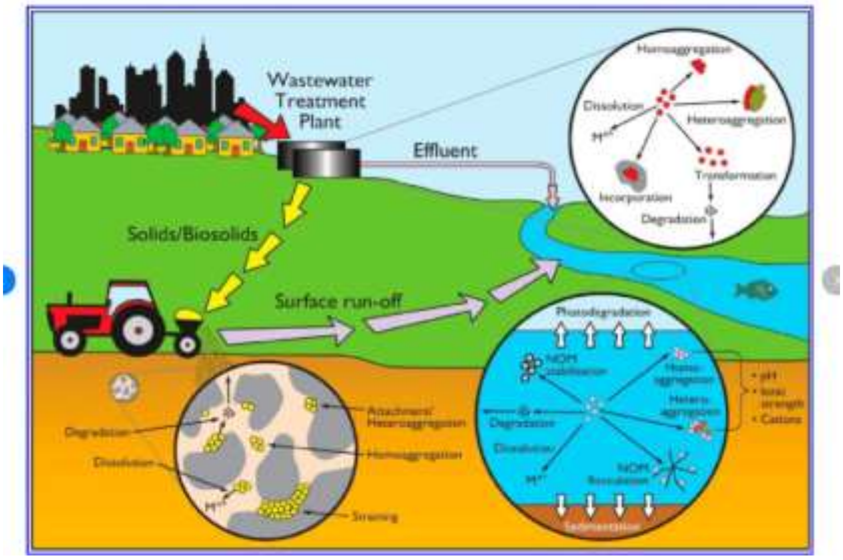


Fig:10

a. Wastewater Discharge

The majority of pharmaceuticals enter the environment through wastewater from hospitals and municipalities. Unmetabolized drugs and active metabolites are excreted in urine and feces following consumption by humans and animals[21]. These leftovers end up in wastewater treatment plants (WWTPs), which aren't made to get rid of pharmaceuticals. The effluent contains significant concentrations of psychiatric drugs, hormones, analgesics, and antibiotics even after treatment. Over time, these compounds end up in lakes and rivers, causing ongoing contamination. Antimicrobial resistance and long-term exposure to aquatic organisms result from continuous discharge[22].

b. Soil and Groundwater Infiltration

Infiltration into soil and groundwater is another important route. Pharmaceuticals enter agricultural soils through improper disposal of unused medications, landfill leachates, and the application of biosolids (sewage sludge) as fertilizers. Manure spreads veterinary drugs that have been given to livestock, which further contaminates fields [23]. These residues reach groundwater aquifers, which are frequently utilized for drinking purposes, through percolation and leaching. Long-term pollution can be caused by persistent compounds like macrolides, tetracyclines, and sulfonamides that can remain in soil for months [24].

c. Surface Water Contamination

Surface waters like rivers, ponds, and reservoirs accumulate pharmaceuticals in wastewater effluents and agricultural runoff. Carbamazepine, diclofenac, and ethinylestradiol are examples of persistent and mobile compounds that are resistant to degradation and continue to accumulate[25]. Due to bioaccumulation in the food chain, these substances have been linked to hormonal disruption in fish, reproductive toxicity in aquatic species, and population declines in birds. Microorganisms' resistance genes may also be promoted by long-term exposure in aquatic systems, which can spread to human pathogens [26].

d. Airborne Contamination from Manufacturing Sites

Sites for pharmaceutical manufacturing are significant, albeit local, sources of contamination. Aerosols, dust particles, and volatile compounds are released into the atmosphere by waste handling and production processes that contain APIs [27]. People and animals can either inhale these airborne particles or deposit them on nearby soils and water surfaces. Surface waters close to manufacturing facilities have been found to contain extremely high concentrations of drugs, particularly antibiotics like ciprofloxacin, in heavily industrialized regions. In addition to causing harm to aquatic ecosystems, this also raises the likelihood of resistant bacteria spreading to communities nearby [28].

6.Types of pharmaceuticals found in the environment

Remains from pharmaceuticals are becoming more and more recognized as environmental pollutants[29]. They mostly get into the environment through excrement, wastewater discharge, improper disposal, agriculture, and pharmaceutical production. Antibiotics, analgesics/NSAIDs, hormones, and cancer drugs are among a number of groups that should be considered because of their persistence, biological activity, and potential effects on the environment[30].

a. Antibiotics

In wastewater, surface water, and sediments, antibiotics like ciprofloxacin, tetracycline, erythromycin, and sulfamethoxazole are among the most frequently detected pharmaceuticals. They mostly enter the environment through the feces of humans and animals, hospital discharges, and factories[31]. Many antibiotics can persist in the environment and are resistant to conventional treatment methods. Antibiotic-resistant bacteria and genes that can spread through environmental pathways and pose health risks to humans and animals are aided by their presence. For instance, Larsson et al. (2007) discovered extremely high antibiotic concentrations in the effluents of manufacturing units in India, indicating a significant point source [32].

b. Analgesics / NSAIDs

Ibuprofen, diclofenac, naproxen, and paracetamol are examples of non-steroidal anti-inflammatory drugs (NSAIDs) that are commonly used and make up a significant portion of municipal wastewater. Some are easily broken down, but others, like diclofenac, remain and are frequently found in lakes and rivers. The decline of vulture populations in South Asia, which was linked to diclofenac exposure through treated livestock carcasses, is a well-known example. Even at low concentrations, NSAIDs can affect the physiology of fish and aquatic invertebrates[33].

c. Hormones and Endocrine Disruptors

Natural hormones like estrone, 17-estradiol, and synthetic hormones like ethinylestradiol from contraceptives are included in this category. When wastewater is treated, these compounds are only partially removed because they are excreted in their active forms. The endocrine systems of aquatic organisms can be disrupted by hormones even at nanograms per liter levels, resulting in feminization of male fish, induction of vitellogenin, and impaired reproduction[34].

d. Anticancer (Cytotoxic) Drugs

Patients excrete unchanged or as active metabolites of anticancer medications like cyclophosphamide, ifosfamide, and methotrexate, which can enter the environment through hospital effluents and municipal wastewater. Concerns about their long-term effects on health and the environment are raised by the fact that many of these compounds are potent, highly mutagenic, or can cause cancer. Although their biological activity at trace levels makes them significant contaminants of emerging concern, their detected concentrations are typically low[35].

TABLE:1

TYPES	EXAMPLES	MAIN SOURCES	KEY ENVIRONMENTAL CONCERNS
Antibiotics	Ciprofloxacin, sulfamethoxazole	Excretion ,agriculture manufacturing	Antimicrobial Resistance,persistence
Analgesics/NSAIDS	Diclofenac ,ibuprofen	Municipal wastewater	Wildlife toxicity,persistence
Hormones	Estradiol, ethinylestradiol	Human/livestock Excretion	Endocrine disruption in a quatic species
Anticancer	Cyclophosphamide , methotrexate	Hospital effluents	Genotoxicity , long term ecological risk

7. Effects of Pharmaceutical Pollution

Pharmaceuticals are emerging contaminants that pose a significant threat to the environment because of their bioactivity, persistence, and widespread presence in a variety of environmental matrices. The majority of these substances enter the environment via household wastewater, industrial discharges, hospital effluents, and improper drug disposal. Pharmaceuticals can build up in soil, surface water, and groundwater after they are released, causing long-term effects on the environment and human health[36].

a. Ecotoxicological Effects

Even in trace amounts, pharmaceutical residues can have long-term toxic effects on aquatic and terrestrial organisms. Antibiotics alter microbial diversity and ecosystem balance by encouraging resistance to antibiotics. Reproductive disorders, feminization of male fish, and population decline are brought on by hormones and endocrine-disrupting compounds (EDCs) interfering with hormonal systems. Diclofenac, an NSAID, has been linked to renal failure in vultures and fish toxicity, while psychiatric and anticancer medications may have genotoxic or mutagenic effects on aquatic life. The widespread mortality of vultures (Gyps spp.) caused by diclofenac in India is a notable illustration of the far-reaching ecological impact of pharmaceutical pollution across trophic levels [37].

b. Human Health Impacts

Even though pharmaceuticals are usually found in low concentrations in the environment, prolonged exposure to them through food chains, drinking water, or direct contact could be harmful to health and the environment. The emergence of antibiotic-resistant pathogens, which pose a significant threat to global public health, is one of the most pressing concerns. Additionally, the presence of endocrine-disrupting substances has the potential to disrupt hormonal balance, which could have an impact on human fertility, growth, and immune function. Additionally, long-term exposure to pharmaceutical mixtures may result in toxic effects that are additive or synergistic, although the full extent of these effects is still poorly understood and requires additional research [38].

c. Effects on Soil and Groundwater Ecosystems

Pharmaceuticals that enter the soil through biosolid application, manure, or wastewater irrigation can significantly impact soil health and ecosystem balance. These contaminants can disrupt soil microbial communities, leading to altered nutrient cycling and reduced soil fertility. Certain pharmaceutical compounds are highly persistent, allowing them to leach into groundwater and contaminate drinking water sources. Antibiotics present in soil can promote the selection of resistant bacteria within the rhizosphere, potentially influencing plant growth and diminishing ecosystem resilience. Additionally, hormones may persist and migrate through soil layers, further threatening groundwater quality and posing long-term environmental risks [39].

d. Bioaccumulation and Food Chain Impacts

Many pharmaceuticals are not fully metabolized and can bioaccumulate in plants, invertebrates, and fish, allowing residues to move through trophic levels and eventually reach humans. For instance, fish exposed to psychiatric drugs often exhibit altered behavior, disrupting natural predator–prey dynamics. Similarly, plants irrigated with contaminated water can absorb drugs such as carbamazepine and diclofenac, leading to indirect human exposure through the food chain [40].

e. Environmental Resistance and Genetic Transfer

Antibiotics exert selective pressure on antimicrobial resistance (AMR) in aquatic and soil environments. Through horizontal gene transfer, resistant genes can be transferred between microorganisms, spreading resistance across ecosystems and into clinical settings. The World Health Organization lists this as one of the biggest threats to global health.

8. Strategies to Minimise Pharmaceutical Pollution

The continuous release of active pharmaceutical ingredients (APIs) from human, veterinary, and industrial sources contributes to pharmaceutical pollution, which poses a significant threat to the environment. A multi-tiered strategy involving source reduction, proper waste management, treatment technologies, regulatory enforcement, and public participation is required to reduce this pollution[41].

Source Reduction and Green Pharmacy: The best way to stop pollution is right where it starts. Pharmaceutical waste can be reduced through rational prescribing, appropriate dosage, and avoiding unnecessary medications. The design of biodegradable drugs that break down into harmless compounds after use, reducing their environmental persistence, is promoted by the green pharmacy concept.

Proper Disposal and Take-Back Programs: Solitue and water contamination result from improper disposal of unused or expired medications, whether through flushing or household waste. Supported by public education, take-back initiatives and pharmacy-based collection systems guarantee safe disposal.

Wastewater Treatment Upgradation: Pharmaceuticals are difficult to remove from wastewater in conventional treatment facilities. Activated carbon adsorption, advanced oxidation processes (ozonation, UV/H2O2), membrane filtration, and constructed wetlands are all examples of advanced technologies that can significantly boost removal efficiency. Particularly efficient are hybrid systems like membrane bioreactors (MBRs) and post-treatment polishing (ozonation plus carbon).

Industrial Effluent Control: The pharmaceutical industry relies heavily on Effluent Treatment Plants (ETPs), Zero Liquid Discharge (ZLD) systems, and cleaner production methods. Transparency in effluent management and strict regulatory monitoring are essential for avoiding localized contamination.

Regulatory, Monitoring, and Public Measures: It is essential to have solid policy frameworks that enforce Extended Producer Responsibility (EPR) schemes, prioritize high-risk compounds, and require Environmental Risk Assessments (ERAs). Advanced analytical tools like LC–MS/MS are used for continuous monitoring to track pollutants and evaluate ecological risks.[42]

Public Awareness and Integrated Management: It is essential to educate communities about drug disposal and responsible use. Sustainable management of is ensured by a coordinated, integrated strategy involving the public, healthcare professionals, the government, and industry. Pharmaceutical contamination

9. Control and Remediation Strategies for Pharmaceutical Pollution

Due to the ongoing release of active pharmaceutical ingredients (APIs) through domestic wastewater, improper disposal, and industrial effluents, pharmaceutical pollution has emerged as a significant environmental problem. At the source and treatment levels, effective control and remediation strategies are necessary to mitigate these effects.

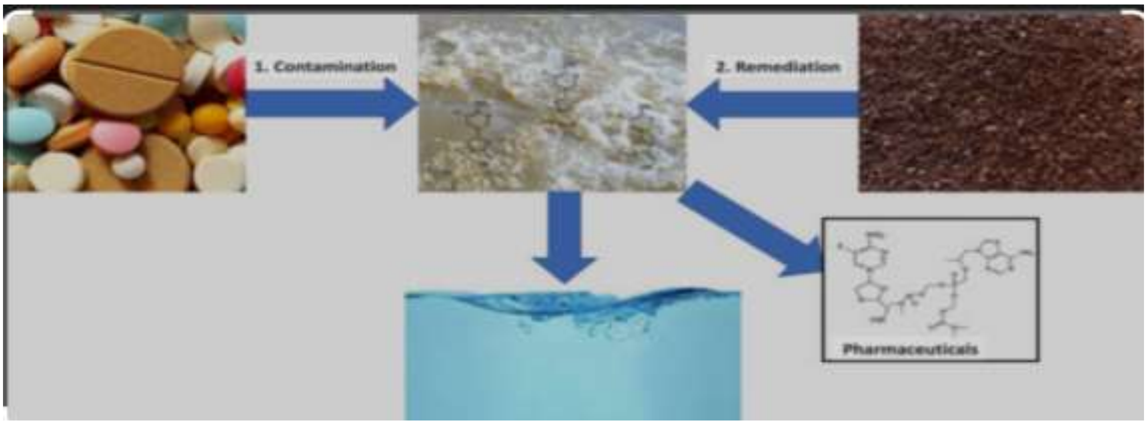


Fig:12

a. Source Control Measures

The first step is to reduce the amount of pharmaceuticals that enter the environment. This includes judicious drug use, improved prescription procedures, and eco-friendly pharmacy practices in which medications are made to be more biodegradable and less long-lasting after use. Take-back programs at pharmacies and public education about safe disposal practices can significantly reduce the amount of unused medicines that end up in sewage and landfills.

b. Industrial and Regulatory Control

High concentrations of APIs are frequently found in pharmaceutical manufacturing effluents. Industrial discharges can be reduced through the use of Zero Liquid Discharge (ZLD) systems, regular monitoring, and the installation of effluent treatment plants (ETPs). Emission standards for manufacturing units and regulatory frameworks like Environmental Risk Assessments (ERAs) during drug approval aid in controlling releases at the source.

c. Wastewater Treatment Technologies

Pharmaceuticals are frequently removed inefficiently by conventional wastewater treatment plants. For a variety of pharmaceutical compounds, advanced treatment methods like ozonation, activated carbon adsorption, membrane bioreactors, and advanced oxidation processes (AOPs) have demonstrated high removal efficiency. Particularly in decentralized settings, constructed wetlands and biofiltration offer low-cost alternatives[43].

d. Remediation Approaches

Pharmaceuticals that are already in the water and soil are the primary focus of environmental remediation. Effective methods include phytoremediation with aquatic or terrestrial plants, bioremediation with microbial degradation, and adsorption with natural or engineered materials. Better pollutant reduction can be achieved by combining multiple methods, such as biological treatment followed by ozonation[44].

10.Conclusion

Due to the widespread use of pharmaceuticals and their improper management, pharmaceutical contamination has emerged as a significant global environmental problem. Manufacturing pharmaceuticals, human and animal excrement, improper disposal, and aquafarming are major sources. These contaminants enter the environment through wastewater discharge, infiltration of soil and groundwater, contamination of surface water, and industrial emissions into the air. Physical, chemical, and biological transformations alter the mobility, bioavailability, and toxicity of pharmaceuticals as they persist in the environment. Antimicrobial resistance, endocrine disruption, soil degradation, biodiversity loss, and global warming are just a few of the serious effects that their presence has on the environment. Advanced treatment technologies, regulations, safe disposal practices, public awareness, and sustainable pharmacy practices are all necessary for effective management. Enhancing risk assessment and monitoring will aid in reducing pharmaceutical pollution and safeguarding human and environmental health.

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