Eco-Health Strategies- Pharmaceutical Waste Management in the SDG Era

[1]Sonia K, [2]Asmita Das, [2]Kanidha S, [2]R. Dhaniya Shree, [2]Sai Saravanan M, [2]Udayakumar S

[1]Associate Professor, Department of Pharmaceutical Chemistry. [2]3rd year B.Pharm student, Department of Pharmaceutical Chemistry,

Sri Ramachandra Faculty of Pharmacy, SRIHER(DU) Porur, Chennai- 600116, India

[1]soniapharm85@sriramachandra.edu.in, [2]asmita3672@gmail.com, [3]S.kanidha2006@gmail.com

Abstract

Pharmaceutical waste management has a vital role in drug industry. Unwanted waste are the substances that are not needed which are out of date, used in arrangements or is capable of possibly revolving into unsafe materials either to human or to the environment. Management of hazardous materials is the essential part of drug production. Medicine which are unwanted are found in varied forms like decayed materials, industrial scraps and many more. These are derived from numerous sections in the medical management sector including research scientists and producers, health center along with doctors with every section taking part in health service system. Several regulatory agencies are engaged in cessation of drug contamination, for instance environment security organizations, long arm of the law, waste disposal companies including civil services.[1,2] In this chapter, unwanted or undesired drugs, regulatory agency which are largely involved in waste disposal and theoretically the effective method for the management and discarding the unwanted drug materials has been discussed.

Index terms- Pharmaceutical waste management, industry, unwanted waste, drug, environment, medical, regulatory agency, management.

Introduction:

Pharmaceutical waste management has a vital role in drug industry. Unwanted waste are the substances that are not needed which are out of date, used in arrangements or is capable of possibly revolving into unsafe materials either to human or to the environment. Management of hazardous materials is the essential lump of drug production.

Advantages-

Public Health Protection: The most immediate advantage is safeguarding public health. Proper pharmaceutical waste management notably reduces the risk of contamination from expired medications, reducing potential health hazards.[2]

Environmental Preservation: Apart from human health, responsible waste management helps in preserving the environment [2]

Regulatory Compliance: Adhering to stringent waste disposal management is not just about avoiding legal consequences; it is also about promoting responsible corporate citizenship within the pharmaceutical sector and healthcare facilities.[2]

Resource Recovery: Some pharmaceutical waste can be reused, recycled, or transformed into valuable resources and reducing overall resource wastage. Compounds in water bodies have far-reaching issues on water quality, affecting aquatic life and ecosystems. [2]

Cost Reduction: Efficient pharmaceutical waste management can translate into significant cost savings over time, as improper disposal practices can lead to increased disposal expenses and regulatory fines.[2]

Disadvantages:

Complexity: The management of pharmaceutical waste is fundamentally complicated due to the wide range of waste kinds generated and the complexity of waste regulations that can differ by region. [2]

Costly Compliance: Maintaining and achieving compliance with ever-evolving disposal requirements can be a heavy financial responsibility, especially for smaller pharmaceutical companies and healthcare centers. [2]

Limited Awareness: A universal issue faced is the limited awareness among healthcare professionals and the public about proper pharmaceutical waste disposal practices, which can delay the adoption of responsible waste management. [2]

Environmental Contamination: Inadequate disposal processes, such as flushing pharmaceuticals down the toilet, can contribute to polluting water bodies, potentially causing harm to aquatic ecosystems. [2]

Resistance to Change: Institutional and cultural resistance to adopting eco-friendly practices can hinder progress in pharmaceutical waste management.[2]

Air pollution

Air pollution makes breathing difficult, with children and elderly people being the most vulnerable. Air pollution can lead to thousands of illnesses; in extreme cases, heart attack, stroke, and irregular heartbeat may occur, which could lead to death. Air pollution also damages the environment as toxic pollutants and chemicals could form acid rain as well as ground-level ozone that can damage trees, crops, wildlife, lakes, and water bodies.[3]

The pharmaceutical industry can affect air quality by releasing various pollutants into the atmosphere during the manufacturing process, including volatile organic compounds (VOCs), particulate matter, and other chemicals, which can contribute to air pollution and harm human health, particularly in areas surrounding pharmaceutical manufacturing plants; this is primarily due to the use of diverse organic solvents in drug production.[3]

The pharmaceutical industry's manufacturing processes can release pollutants into the air, contributing to air pollution. These hazardous pollutants include volatile organic compounds (VOCs), particulate matter, per- and polyfluoroalkyl substances (PFAS), methylene chloride, methanol, toluene, and hydrogen chloride, among others, adversely affecting air quality and human health.[3]

The crucial factors contributing to pollution caused by pharmaceutical industries are the lack of awareness and adequate regulation. Recent studies have reported that the global pharmaceutical sector emits greenhouse gases at a rate 55 percent higher than the automotive industry. In spite of the pharmaceutical industry being smaller, it causes high rates of pollution.[3]

The pollution caused due to pharmaceutical industries is called drug pollution or pharmaceutical pollution. Going through history, you can find instances where high concentrations of pollutants were released from pharmaceutical industries.[3]

Air pollutants that are commonly found in pharmaceutical laboratories are bioaerosols and microbes. Air pollutants emitted by pharmaceutical industries are carbon monoxide, particulate matter, volatile organic compounds, and carbon dioxide. Carbon monoxide is one of the most poisonous gases, and it is known as the silent killer. When concentrated levels of carbon monoxide enter the body, it can lead to death. The harmful pollutants released by these laboratories affect all forms of life. Air pollution caused by pharmaceutical industries can be controlled by proper management of the air disposal system. The waste products which can be burnt are supposed to be burnt, and the ashes should be buried, or else they should be treated appropriately and then let out to the environment.[3]

Filtering the air

High-quality filters should be used in a pharmaceutical laboratory to ensure that the air is filtered correctly before being disposed of. In most pharmaceutical laboratories, high-efficiency particulate air (HEPA) filters are used; these filters can filter the microbes and particulate matter from the air. HEPA filters have an ultra-fine glass fiber medium that prevents the microbes and particulate matter in the air improving the air quality.[3]

Treating the air

In pharmaceutical laboratories, at temperatures above 1200 degrees Celsius, all microbes are destroyed. This is done to ensure that the air pollution is reduced.[3]

Disposal of the drug

Some pharmaceutical laboratories practice encapsulation, which is how pharmaceuticals are put into barrels and filled with concrete, and then landfilled. Encapsulation can be done with pills when they are in the PVC pack.[3]

Installation of ducts

HVAC (Heating, ventilation, and air conditioning) ducts with fiberglass can be installed for optimum conditions inside pharmaceutical laboratories. HVAC ducts can ensure that there are optimum conditions for the preparation of drugs. These ducts can control the number of microbes and dust particles in the air. The pharmaceutical sector alone is estimated to emit around 52 megatons of CO2 equivalents globally.[3]

It appears that pharmaceutical companies emit at least as many greenhouse gases as the automotive industry, for example. Drug manufacturers cause approximately 13% more CO2 emissions than cars. The pharmaceutical companies together form the sixth largest producer of carbon dioxide in the world in terms of manufacturers and electricity consumption. Pharmaceutical companies worldwide need to have stronger monitoring and regulation of greenhouse gas emissions.[3]

Water pollution

In the United States, Germany, Spain and the United Kingdom, over 101 distinct pharmaceuticals were existed in groundwater, surface water, tap water or drinking water. Between 30 and 100 different pharmaceuticals were found present in the previously mentioned waters in Canada, Thailand, Australia, China, India, Japan, South Korea, Sweden, France, Poland, Italy, Brazil and the Netherlands.[4]

In 2022, the most extensive study of drug pollution of the world's rivers found that it threatens the environmental and human health in more than a region of the studied locations". It inspected 1,052 sampling areas along 258 rivers in 104 countries, indicating the river pollution of 470 million people. It found that "the most adulterated sites were in low to middle income countries and were associated with areas with untreated wastewater and waste management infrastructure and drug manufacturing," and files the most frequently detected pharmaceuticals.[4]

Pharmaceuticals and their effects: The excretion of oral contraceptives into freshwater ecosystems has caused fish and amphibians to feminize. Antipsychotics were created about seventy years ago, and it was not until 2007 that it was reported that antipsychotics were present in the environment. They are used to treat a plethora of illnesses, including depression, schizophrenia, autism, attention deficit hyperactivity disorder, and bipolar disorder. Anti psychotics, once excreted by the patient by either feces or urine, travel to wastewater treatment plants, which do not remove the drugs and their metabolites. These drugs have been found in drinking water, all bodies of water, and hospital sewage.[4]

Once they reach the aquatic environment, they possibly undergo bioconcentration and bioaccumulation through the food web. Psychiatric drugs, such as fluoxetine, sertraline, citalopram, chlorpromazine, and oxazepam, were found to change fish behavior and cause disruption in the hormones of fish. In invertebrates, these drugs were found to cause reproductive toxicity and hormone disruption and alter their behavior.[4]

Anti-neoplastic drugs are employed during chemotherapy all over the world. They pollute water courses and have 'mutagenic, cytostatic, and ecotoxicological effects on the micro-organisms that are in the aquatic environment.' The wastewater treatment process is not able to remove antineoplastic drugs due to their intractable nature them. Bodies of water that are contaminated with antineoplastic drugs pose grave consequences on the aquatic environment and even human health. Chemotherapy drugs such as cyclophosphamide, fluorouracil, doxorubicin, cisplatin, and mitomycin C were discovered to cause genotoxicity in aquatic organisms. Antibiotics are widely produced and consumed to treat bacterial and fungal diseases. Since antibiotics are only partially metabolized, the non-metabolized antibiotics are released into the environment. Due to this, antibiotics are discovered in sludge, drinking water, wastewater, surface water, soil, groundwater, and sediments. Residual antibiotics are not easily degraded, so they can survive in environments for long periods of time.[4]

There are calls for an urgent push to eradicate antibiotics from the environment because they could cause the generation of antibiotic-resistant bacteria and antibiotic-resistant genes, which would pose an immense threat to the ecological system and human health. The excessive use and excretion of antibiotics to waterways makes the problem of antimicrobial resistance worse and will gradually affect the human population, possibly causing more deaths.[4]

Antibiotics were found to reduce growth in algae, aquatic plants, and environmental bacteria. Groundwater contamination by pharmaceuticals, which belong to the category of contaminants of emerging concern (CEC) or emerging organic pollutants (EOP), has been receiving increasing attention in the fields of environmental engineering, hydrology, and hydro geochemistry since the last decades of the twentieth century.[4]

Pharmaceuticals are suspected to provoke long-term effects in aquatic ecosystems even at low concentration ranges (trace concentrations) because of their bioactive and chemically stable nature, which leads to recalcitrant behaviors in the aqueous compartments, a feature that is typically associated with the difficulty in degrading these compounds to innocuous molecules, similarly with the behavior exhibited by persistent organic pollutants.[4]

Furthermore, continuous release of medical products in the water cycle poses concerns about bioaccumulation and biomagnification phenomena. As the vulnerability of groundwater systems is increasingly recognized even by the regulating authority (the European Medicines Agency, EMA), environmental risk assessment (ERA) procedures, which are required for pharmaceutical applications for marketing authorization, and preventive actions are urged to preserve these environments.[4]

In the last decades of the twentieth century, scientific research efforts have been fostered towards a deeper understanding of the interactions of groundwater transport and attenuation mechanisms with the chemical nature of polluting agents. Amongst the multiple mechanisms governing solute mobility in groundwater, biotransformation and biodegradation play a crucial role in determining the evolution of the system (as identified by developing concentration fields) in the presence of organic compounds, such as pharmaceuticals. Other processes that might impact pharmaceutical fate in groundwater include classical advective-dispersive mass transfer, as well as geochemical reactions, such as adsorption onto soils and dissolution/precipitation. One major goal in the field of environmental protection and risk mitigation is the development of mathematical formulations yielding reliable predictions of the fate of pharmaceuticals in aquifer systems, eventually followed by an appropriate quantification of predictive uncertainty and estimation of the risks associated with this kind of contamination.[4]

Energy use and carbon emissions

Caused by skyrocketing emissions of greenhouse gases, climate change, is one of the biggest if not the biggest global environmental problem in the current times. Attaining carbon neutrality is perceived as a very critical and essential goal right now in order to deal with and reduce the ill and adverse impacts of climate change, as carbon dioxide is one among the greenhouse gases that has a major contribution to global warming. Most countries and cities, most organizations and industries have made approaches to become carbon neutral.[5] One among these industries is the pharmaceutical industry as well. The pharma industries are one of the main contributors of carbon emissions (approximately 55% higher than the automobile industry). Hence, it needs to take steps and environmentally conscious strategies to reduce its carbon footprint. [7]

For instance, as one of the world's largest carbon dioxide producer, China's energy-related CO2 emission has indeed gotten worldwide research attention. With the intention of controlling the overall CO2 emission, the Chinese Government has set up a target for carbon emission reduction that is to reduce the intensity of the CO2 emissions by 60-65% by 2030 in relation to the levels in 2005. To ensure the success in attaining this goal, all the different sectors and industries have to share the responsibility of reducing the CO2 production together. Hence, each sector and industry would have to identify its own emission reduction possibility and potential by identifying the actual source of the CO2 emissions.[5]

The pharmaceutical industry is an energy intensive sector. With the increasing concerns in environmental sustainability, the pharmaceutical industries also must become aware and take strong steps to reduce their energy consumption and reduce the CO2 emissions by either using alternative sources of energy or by using energy- saving schemes and strategies. Despite the many steps taken towards sustainability goals, researchers say that there is further potential in order to have cleaner and greener production in terms of green chemistry, waste management, etc.[6]

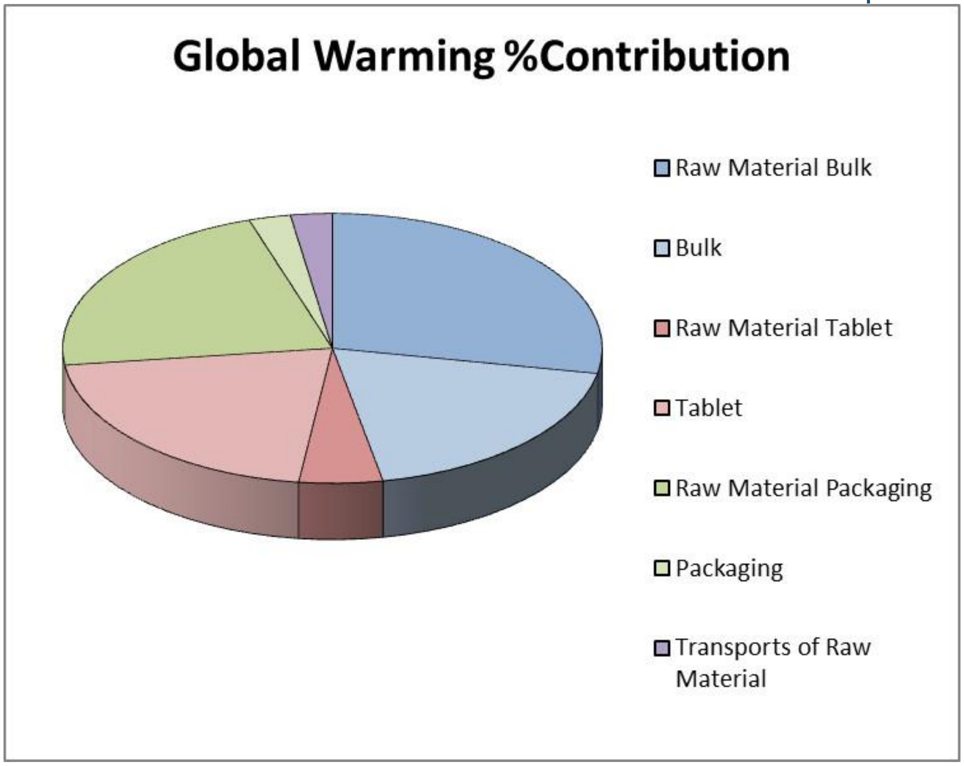

Fig.1- Contribution of the pharmaceutical industry to global warming

Carbon footprint of pharmaceutical industries

In the pharmaceutical sector, 3D printing is one among the widely used technologies. 3D printing involves the production of 3d structures by various means and methods.)[8] (An example would be the production of fused deposition modelling (FDM- In FDM the hot melt extruded filament is used as primer for printing where drug loaded filament is passed through the nozzle).[9]

However, in spite of having several applications, 3D printing also has its set of disadvantages that effect the environment with a negative impact. Being a digital technology, 3D printing is solely dependent on electricity to operate, and electricity being one the major contributors to CO_2 emissions leads to 3D printers having a major drawback. The main drawback is its emissions produced during the printing process. Plastic polymers are used as the primary material in most 3D printers. Polyvinyl alcohol, polylactic acid and acrylonitrile butane styrene (ABS)are thermoplastic polymers that are used but they are all non-biodegradable polymers. The emissions are produced due to the melting of these plastic polymers to create structures which in turn release a wide range of harmful chemicals into the environment.[9]

Beside the emission of harmful toxics into the air, another major drawback of 3D printers is the energy consumption.[9] A large amount of energy in the form of electricity is consumed for the operation of 3D printers and the source of this energy is non-renewable sources. Hence, though 3D printers have a large variety of uses and applications in the pharmaceutical industries, its energy consumption and toxic emissions contribute to climate change and leave a carbon footprint.[8]

In order to reduce the CO2 emissions, the industry needs to aim for carbon neutrality. Carbon neutrality can be defined as "net-zero carbon". It refers to a state of balance and equilibrium in the environment where in the amount of carbon dioxide released into the atmosphere is balanced by the amount removed from it.[8]

The following environmentally conscious steps are to be taken in order to reduce emissions and removing the carbon footprint

a) designing efficient energy-saving strategies and coming up with strategic answers

b) administration and expedition of the strategies and schemes

c) the comparison of designed and actual performance as a post-implementation control. While seeking for encouraging strategies, a multi-objective criterion should be adopted where in the comprehensive decision-making does not just consider energy saving, but also focusses on other aspects and fields like good manufacturing practices (GMP), and workers' safety.[9]

Antibiotic resistance

Antibiotic resistance is a global threat arising from the overuse and misuse of antibiotics. Microbial populations adapt to the presence of antibiotics, developing mechanisms to hold out and thrive even in the presence of antimicrobial drugs. Environmental factors, including pharmaceutical waste and agricultural runoff exacerbate the spread of resistance. Antibiotics enter the environment through various pathways, including wastewater treatment plants, industrial discharges, and livestock farming.[10]

Overview of Antibiotic Resistance as a Global Health Challenge:

Antibiotic resistance is a complex and multifaceted issue that has become a major global health concern. The overutilization and misapplication of antibiotics in human and animal medication, as well as the presence of antibiotics in the environment, have contributed to the emergence and increase of drug-resistant bacteria. These bacteria are capable of evading the effects of antibiotics, making infections harder to treat and increasing the risk of mortality, prolonged hospital stays, and higher healthcare costs. The World Health Organization (WHO) has proclaimed antibiotic resistance a global health emergency, spotlighting the urgent need for coordinated efforts to address this challenge. The threat of untreatable infections is a stark reminder of the importance of accountable antibiotic use and the need to prevent further spread of resistant bacteria. Failure to address this issue could lead to a return to a pre-antibiotic era, where common infections could once again become life-threatening.[12]

Impact of Pharmaceutical Wastewater and Effluents on the Environment:

The pharmaceutical industry plays a notable role in the production and release of antibiotics into the environment. Wastewater generated during pharmaceutical manufacturing processes often contains significant amounts of antibiotics and their byproducts. This wastewater can be discharged into sewage systems or directly into rivers and lakes, leading to antibiotic contamination of water bodies. Antibiotics present in pharmaceutical wastewater can exert selective pressure on bacterial populations in the environment, promoting the emergence and spread of resistant strains. These resistant bacteria can then spread to humans and animals through various pathways, including contaminated water, food, and soil. The presence of antibiotics in the environment also disrupts the natural balance of microbial communities, affecting ecosystem health and biodiversity.[10]

Fig.3- microbial communities, affecting ecosystem health and biodiversity

Emergence of Superbugs Due to Antibiotic Pollution:

Antibiotic pollution in the environment is a major driver of the emergence of "superbugs," highly resistant bacteria that are strenuous or not possible to treat with current antibiotics. These superbugs pose a serious commination to public health, as they can cause infections that are resistant to multiple antibiotic classes. The rise of superbugs is a direct consequence of the extensive use and misuse of antibiotics, coupled with the release of these drugs into the environment. The selection and growth of resistant bacteria in the environment is a significant concern. These bacteria can transfer resistance genes to other bacteria, causing amplification of resistance across diverse microbial bodies. The contamination of water bodies with antibiotic-resistant bacteria causes a particular threat to human health, as drinking water and food sources can become contaminated.[11]

Inadequate Treatment and Disposal of Pharmaceutical Waste:

The disposal of pharmaceutical waste, including expired or unused antibiotics, is another critical aspect of antibiotic pollution. Inadequate waste management practices can lead to the leakage of antibiotics into the environment, contributing to the spread of resistance. In many developing countries, pharmaceutical waste is often disposed of improperly, either by dumping it directly into landfills or into sewage systems. Landfills are not designed to contain antibiotic residues, and these drugs can leach into the surrounding soil and groundwater. Sewerage systems are often not equipped to remove antibiotics effectively, and these drugs can pass through wastewater treatment plants and end up in rivers and lakes. The lack of adequate treatment and disposal facilities for pharmaceutical waste exacerbates the problem of antibiotic pollution and the emergence of resistant bacteria.

- Many countries lack the infrastructure and resources to effectively manage pharmaceutical waste, leading to uncontrolled disposal.
- Inadequate wastewater treatment and improper disposal of pharmaceutical waste contribute to the accumulation of antibiotics in the environment.
- The global community must prioritize investments in waste management infrastructure to address the challenge of antibiotic pollution.[10]

Spread of Antibiotic-Resistant Genes and Bacteria in the Environment:

Antibiotic resistance genes can spread through the environment via various mechanisms. Horizontal gene transfer, a process by which bacteria interchange genetic material, plays a significant part in the dissemination of resistance genes. This can occur in the presence of antibiotics, as bacteria are under selective pressure to develop resistance mechanisms. Resistant bacteria can also spread through contaminated water, soil, and food, posing a risk of infection to humans and animals. The widespread presence of antibiotic-resistant bacteria in the environment is a concerning trend, indicating the need for effective strategies to mitigate this threat. The potential for these bacteria to spread to humans and animals through various pathways focus on the importance of addressing the root causes of antibiotic resistance, including the overutilization and misuse of antibiotics and the release of these drugs into the environment.[12]

Fig.4 Antibiotic-Resistant Horizontal gene transfer

Regulatory and Policy Initiatives to Curb Antibiotic Pollution:

Several regulatory and policy initiatives have been implemented to curb antibiotic pollution and promote responsible antibiotic use. These initiatives focus on different aspects of the problem, including the reduction of antibiotic practice in agriculture, the development of new antibiotics, and the improvement of wastewater treatment technologies. The goal of these initiatives is to reduce the release of antibiotics into the environment and to slow the springing up and spread of resistance. The WHO has issued guidelines on the appropriate use of antibiotics and has called for a global effort to combat antibiotic resistance. Many countries have implemented policies to restrict the usage of antibiotics in agriculture, aiming to reduce the overall consumption of these drugs and to minimize their release into the environment. In addition, research and development efforts are ongoing to develop new antibiotics and to find alternative therapies to combat infections.[10]

Strategies for Sustainable Pharmaceutical Manufacturing and Waste Management:

Moving towards sustainable pharmaceutical manufacturing and waste management practices is crucial to addressing antibiotic resistance. This involves reducing antibiotic use, improving wastewater treatment, and implementing responsible waste disposal methods. Sustainable practices in the pharmaceutical industry require a holistic approach that considers the entire life cycle of antibiotics, from production to disposal. Pharmaceutical companies can adopt various strategies to minimize antibiotic release into the environment. This includes optimizing manufacturing processes to reduce waste generation, investing in advanced wastewater treatment technologies, and implementing robust waste management systems for expired or unused antibiotics. In addition, promoting responsible antibiotic use in human and animal medicine is essential to slow the emergence and spread of resistance.[12]

Fig.5- Strategies for Sustainable Pharmaceutical Manufacturing and Waste Management

Call to Action: Addressing Antibiotic Resistance through Environmental Stewardship:

1. REDUCE: Minimize antibiotic use and promote responsible prescribing practices.
2. RECYCLE: Implement effective pharmaceutical waste management systems.
3. REUSE: Develop innovative technologies for treating pharmaceutical waste.
4. RESEARCH: Invest in research to understand and address antibiotic resistance.[10]

Packaging waste

With the increase in the global demand for more and more pharmaceutical products, pharmaceutical packaging waste has also been seeing a steep increase. A large variety of materials and substances are used to deliver medicines in the right form and structure, including, paper, glass, plastics, polymers, metals which are all regularly used. For example, blister packs for tablets, injectables, aerosol containers, spray containers etc. However, even though all these materials play a vital role in ensuring the delivery of the medicines and providing healthcare, the challenge lies in the fact that not all of these materials can be recycled and hence pose a problem when it comes to global sustainability.[13]

Medicines require packaging. This packaging is required to protect the drug, to maintain its integrity and efficacy from the point of manufacturing, all throughout transportation as well as storage. Packaging also helps to keep the medicine safe from any external factors like light, heat, moisture, temperature and pressure fluctuations and sustain the effective shelf-life. Also, for creating an aesthetic appeal. The packaging must also abide by the robust regulatory requirements to maintain the safety of the drug.[15]

Through the already existing concern over plastic pollution and the increasing plastic waste, the pharmaceutical companies are facing a serious challenge considering their heavy dependency on plastic and plastic polymers for fulfilling various packaging requirements.[15]

Fig.6- Plastic packaging in pharmaceutical industry

Being highly versatile, sterile, chemically inert, physically stable, economical, corrosion resistant, plastic is favored by most manufacturers.[13] However, the global plastic waste problem has come to a highly detrimental point. Sadly enough, due to its reliance on plastic, the pharmaceutical sector is responsible for 300 million tons of plastic waste production per year, more than half of which is composed of single-use plastics disposable plastic components used in the manufacturing process, like containers, tubing, bags, and filters.[16]

Since, the global plastic problem can no longer be ignored, pharmaceutical industries must adopt a much more holistic and versatile approach that considers all the various aspects of the field to produce a sustainable packaging.[8] In order to address the waste production, many pharmaceutical industries are making responsible approaches towards minimizing plastic in the primary as well as secondary packaging, and making more environmentally conscious choices with their packaging supplies.[13]

One such responsible approach is the adoption of "**Pre-consumer or post-consumer recycled materials" or PCR**. As the name suggests, it involves recycling and repurposing plastics sourced from the users' end or repurposing the waste produced during the manufacturing and production process to generate packaging systems. Adopting PCR has aided pharma industries to achieve their sustainability goals in addressing the global plastic pollution by offering concrete solutions to limiting the single-use plastic production.[13]

Besides PCR, there are also other alternatives to improving the environmental impact of plastic packaging including innovative **bio-based plastics**. A major advantage of using bioplastics is the significant reduction in the negative impact it has on the environment meaning that they do not contribute as much to the build-up the plastic garbage and waste production. Bioplastics are of two major types- **biodegradable** and **non-biodegradable**. The former are easily broken down and decomposed by microorganisms including fungi and bacteria. The biodegradable plastics are further classified into 2 types of bioplastics that are compostable and oxo-biodegradable. As the name suggests, compostable bioplastics are degraded by composting while the oxo-biodegradable plastics undergo decomposition by oxygen exposure in the environment. The latter, non-biodegradable bioplastics cannot undergo degradation as they are made up of renewable material that do not biodegrade. However, they can be recycled and repurposed or even used to generate energy by incineration**.** These bio-based plastics are sourced from renewable source and hence can be highly effective to reduce the environmental footprint of the pharmaceutical industries. Nevertheless, even though these bio-based plastics are derived renewable sources, this does not assure us that the material is completely biodegradable and capable of 100% decomposition.[14,15] Bioplastics are ordinarily plastics that are produced from polymers that are bio-based, that provide to a more reasonable and sustainable commercial plastic life cycle, the virgin polymers are made up of renewable and recyclable raw materials. In comparison with fossil-based polymers, bio-based polymers have a much lower carbon footprint and show benefits due to its materialistic characteristics. Moreover, they are more compatible with the current recycling streams. Although, plastic is non-biodegradable, it does offer certain advantages like reusability through recycling processes, compared to which, the bio-based packaging materials may not be as sustainable overall. Hence, an approach towards sustainability in packaging models means, the manufacturers should take into consideration the environmental aspects at every stage and point of manufacture and production, from design all the way to disposal.[16,17]

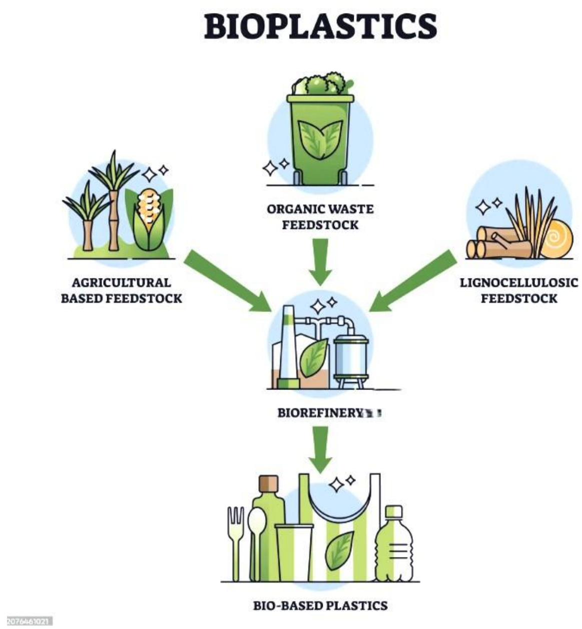

Fig.7- Production of bio-based plastics

By adopting these conventions that set an example for environmentally conscious practices for the packaging industry, pharmaceutical industries and manufacturers can make an appreciable progress to creating a more sustainable future in packaging. It also agrees with the global focus on sustainability.

Disposal of waste medicine

Responsible drug ejection is necessary. Unsuitable ejection of unwanted medicine could lead to pharmaceutical pollutions inquire environment. Actually, medication product has unwanted waste in body of water worldwide. Until, investigation have found that slightest adverse effects living being. Therefore assessment, learning and doing are necessary. It requires safeguarding action from manufactures, patients together with prescribers alike to assure that undesired medication is disposed properly.[18]

Intrusion of medicines into habitat

nevertheless, flushing unwanted medicines down the toilet are not the accurate way of disposing the medications. medications that penetrate our physique, treatment provided to animals within raw material(antibiotic) and dump from production process valid into habitat. accurate disposal of unsafe or unused drugs is necessary to prevent the pollution caused by medications.[18]

Role of patients with leftover medications

It's necessary to administer the medicine as prescribed by Health care professional and carryout to correct disposal of unused and undesired medicines. To the unused/unsafe medications, local gathering scheme will give an accurate method for disposal of medicines that defend pollution in habitat. The FDA (Food Drug Administration) provides a checklist of fixed control of disposal of medicines.[18]

Fig.8- Lack of disposal of pharmaceutical waste

Role of prescribers

Prescribers as well play a major role in achieving the effective use of prescriptions. Occasionally, by prescribing a suitable quantity of drugs which is required for a current treatment together with evaluate treatment of long-lasting on a structured basis which may give less chance of patients remaining drugs on the end of the treatment. Prescribers as well being an instructor who gives an aid for patients' knowledge about unsafe and unused drugs.[18]

Discoveries of the drug companies

As regards the industrial level, drug companies and so on partners rise mass-producing effective to diminish waste, instruct circle on the correct way of disposing medications and control to promote the technical assessment of pharmaceutical in the society. As testing increases regarding the disposal of unused medicine companies like Pfizer monitor the scientific originator and inquire them into daily practices up to date.[18]

Conclusion

Pharmaceuticals play a vital role in improving human health, but their production and disposal can have significant environmental consequences.

importance of addressing pharmaceutical pollution:

Rising pollution: pharmaceutical pollution is a growing concern. residual drugs and their byproducts are found in water, soil, and air, affecting ecosystems and human health.

Environmental impact: these chemicals can disrupt wildlife populations, contaminate drinking water, and contribute to antibiotic resistance.

Pharmaceutical waste disposal and aquatic ecosystem impacts:

1. Improper disposal of pharmaceuticals can lead to their release into wastewater treatment plants, where they may not be fully removed.
2. These chemicals can then enter rivers, lakes, and oceans, impact aquatic life and plausibly contaminating drinking water sources.
3. The existence of pharmaceuticals in the environment can disrupt the delicate balance of ecosystems, affecting reproduction, growth, and behavior of aquatic organisms.[19]

Fig. 9- Existence of pharmaceuticals waste plastic in aquatic environment

Strategies for Reducing Unused Pharmaceuticals in the Environment:

Take-back programs: Pharmacies and healthcare providers often offer take-back programs to collect unused medications for safe disposal.

Proper disposal instructions: Educating consumers about safe disposal methods, such as flushing or discarding medications in secure containers.

Prescription optimization: Healthcare professionals can minimize unnecessary prescriptions and work with patients to manage medications effectively.[20]

Green Manufacturing Practices in the Pharmaceutical Industry:

Renewable energy: Embracing renewable energy sources, such as wind and solar power, to cut down the dependence on fossil fuels.

Water conservation: Implementing water-efficient processes and reducing water usage during production and cleaning.

Waste reduction: Minimizing waste generation by optimizing production processes and using recycled materials whenever possible. [21]

Fig.10- Minimizing waste generation by optimizing production processes

Challenges in Managing Healthcare Waste and Plastic Pollution:

1. Disposal costs: Proper disposal of pharmaceutical waste can be expensive and logistically challenging, especially in developing countries.
2. Plastic packaging: The pharmaceutical industry depends heavily on plastic packaging, which can contribute to plastic pollution and environmental degradation.

3. Regulation and enforcement: Ensuring effective regulation and enforcement of environmental standards is crucial for minimizing pharmaceutical pollution.[21]

Emerging Technologies and Innovations for Sustainable Pharma:

1. Bio-based materials: Exploring sustainable alternatives to plastic packaging, such as biodegradable materials and bioplastics.
2. Closed-loop manufacturing: Developing closed-loop manufacturing systems that minimize waste and optimize resource utilization.
3. Advanced waste treatment: Investing in advanced wastewater treatment technologies to remove pharmaceuticals and other contaminants from wastewater.
4. Bioremediation: Using microorganisms to break down pharmaceutical pollutants in the environment.
5. *Green chemistry*: Developing sustainable and environmentally friendly chemical processes for drug production.[20]

Fig.11- Green chemistry

Conclusion and Call to Action for Stakeholders:

Addressing pharmaceutical pollution requires a collective effort from all stakeholders, including pharma companies, health maintenance professionals, policymakers, and consumers.

Hence, this is about the effective methods for the management and discarding the unwanted drug materials and pharmaceutical waste management.

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