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Environmental Impact and Sustainable Solutions for Pharmaceutical Waste Management: An Empirical Investigation

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Abstract

The expansion of the pharmaceutical industry has raised concerns about the environmental repercussions stemming from pharmaceutical waste. Inadequate management of waste and disposal have caused hazardous chemicals to be released into the environment, putting the wildlife and people in danger. This summary delves into the environmental consequences of pharmaceutical waste and highlights sustainable solutions for efficient waste management. Pharmaceutical waste encompasses expired or unused medications, packaging materials, and by-products from manufacturing processes. It contains biologically active compounds that can persist in the environment for extended periods. These materials have been found in lakes, soil, and animals, and can cause an imbalance in the ecology and can damage different marine species. To make matters worse, incorrect disposal of pharmaceutical drugs can pollute drinking water, thus posing a serious risk to people's health. Addressing these pressing issues necessitates the implementation of sustainable solutions for pharmaceutical waste management. This abstract explores various approaches, including source reduction, proper disposal practices, and the adoption of advanced treatment technologies. Source reduction involves minimizing the generation of pharmaceutical waste by implementing measures such as improved inventory management and the development of eco-friendly manufacturing processes. Less waste generated can help the environment. The right way to discard medicines is to drop them off at designated areas or take advantage of return programs. These initiatives aim to prevent inappropriate disposal of pharmaceuticals in household waste or by flushing them down the toilet. By establishing dedicated channels for disposal, the risks of environmental contamination can be significantly reduced. Additionally, the exploration of advanced treatment technologies, such as incineration, chemical treatment, and biodegradation, is crucial for effective pharmaceutical waste management. These technologies aim to eliminate or neutralize hazardous compounds present in pharmaceutical waste, thereby minimizing the environmental impact.

Keywords- Exploration of advanced treatment technologies, Generation of pharmaceutical waste.

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Introduction

Medical streams of waste are increasing in size and complexity in both advanced and impoverished countries. Without proper healthcare waste management systems, this can negatively affect human wellness and the natural world. According to Manga, Forton, Mofor, and Woodard (2011) in a typical healthcare institution in Buea, a medium-density town, the waste generated on an annual basis is highly extensive, reaching approximately 16 tonnes per day. The components of this garbage are 49% nonhazardous waste, 16% infectious waste, and 14% sharp objects. If a production and disposal process is executed properly, this waste can be regenerated for other uses. For example, the recovery of the non-contaminated waste components for the secondary market is an effective way to reduce our reliance on natural resources. In addition, healthcare-related waste from medical facilities can often be harmful and must be treated with caution. This approach presents a prototype for countries in the initial stages of development to battle the key obstacles of hospital waste disposal and put in place strategies for a lasting waste stream management plan. To help Cameroon better make use of sustainable medical waste management methods, it is essential to generate and execute sufficient Health Care Waste Management Plans that look into all parts of waste creation, collection, delivery, processing, and removal. Sufficient financial and human resources are required, notably for Sanitation Units and all workers involved in waste generation, handling, and disposal from generation through final disposal or recovery. With the right resources, It can be done to isolate the uncontaminated waste stream, which includes plastic and cardboard, with the purpose of utilizing them in certain secondary markets, thus keeping them from being dumped in rubbish dumps. Avoiding the disposal of any waste in landfills helps to make usage of resources more efficient and provides for lasting waste management options. Hospitals require a large amount of energy to provide adequate health services, and they use more than any other type of commercial building, apart from food service businesses. Eckelman & Sherman, (2016) institutions are vast structures operate ceaselessly, day in and day out. Within their walls, an energy-intensive activities take place, encompassing advanced heating, cooling, and ventilation systems, computational operations, utilization of medical and laboratory equipment, sterilization procedures, refrigeration, laundry services, and even the nourishment.

In addition to the energy consumed onsite for heating and electricity, the healthcare system relies on energy-intensive commodities and services, including pharmaceuticals and medical devices, the manufacturing of which entails significant energy inputs. Despite research has been conducted to quantitatively analyze or explore the consumption-based emissions originating from the U.S. healthcare sector, their temporal trends, or their overall impact on public health. While GHGs represent a critical facet concerning emissions and the potential detrimental effects of climate change on human well-being and livelihoods, it is crucial to acknowledge other emission categories within healthcare that yield adverse environmental and public health consequences. Beyond the direct emissions stemming from healthcare facilities, there are also indirect emissions arising from the generation of electricity and the production of materials employed in these establishments.

Literature review

The history of pharmaceutical sciences is a remarkable tale of success. Pharmaceutical products become ubiquitous in lives. According to Kümmerer (2010) products, known as pharmaceuticals, are chemicals utilized for their biological activities. They are supporting our modern lifestyle and contribute to our overall health and well-being. The “green pharmacy” development of pharmaceutical products and processes to eliminate or reduce the use and generation of hazardous substances. It focuses on preventing and minimizing the environmental, safety, and health impacts associated with pharmaceuticals at the term "green" primarily emphasizes the environmental aspects of pharmaceuticals. While this is a consideration, there are factors to take as well. For instance, a pharmaceutical deemed "green" based on the quality and quantity of waste generated during its synthesis, the utilization of renewable feedstock.

if the pharmaceutical persists in the environment after being excreted and gives environmental or health issues, its sustainability may be called into question. Similarly, if the production of renewable feedstock requires excessive water and fertilizer, competes with food production, or relies on endangered species, it may not be considered sustainable. Likewise, even if the compound itself is environmentally friendly or sustainable, if the material flows associated with its production, distribution, and usage are extensive in terms of quantity or quality or rely on non-renewable resources, it may not be truly sustainable. greener products or chemicals may lose their environmental benefits or even become

ISSN 2515-8260 Volume 05, Issue 01, 2018

problematic when produced and used in large volumes. Thus, while the packaging itself may be "green," it may not be sustainable. Taking a sustainable perspective entail considering a much broader range of factors. The active chemicals contained in PPCPs, those are primarily intended to trigger certain biological reactions, have been recognised as potentially dangerous to the aquatic ecology and are suspected of directly impacting some aquatic organisms. The growing use of pharmaceuticals, the ongoing introduction of new substances into the environment, and the lack of effective wastewater treatment equipment create significant problems for researchers and plant managers in mitigating their consequences. Additionally, the presence of pharmaceuticals in wastewater puts the potential of recycling treated wastewater, which might be a practical strategy to achieve sustainable water management, in jeopardy. Pharmaceutical-contaminated wastewater comes from a range of sources, including hospitals, veterinary clinics, homes, and pharmaceutical manufacturing sites, and eventually makes its way through wastewater treatment plants (WWTPs) before being released into natural aquatic environments.

However, medication removal in WWTPs has been reported to be poor. In Ulsan, South Korea, seventeen of twenty PPCPs were found in the influents of all five WWTPs. Most chemical concentrations in According to Behera et al. (2011), WWTPs showed lower influent and secondary effluent levels in comparison to those in the US and Europe. Chemical structuring, physical characteristics, and single WWTP treatment approaches were found to affect the clearance rates of medicines like acetaminophen, ibuprofen, ketoprofen, naproxen, gemfibrozil, caffeine, estrone, estriol, and estradiol. Although these drugs exhibited high removal efficiencies, more comprehensive research still needs to be conducted to fully understand the efficacy of modification in eliminating antibiotics and mefenamic acid and carbamazepine from wastewater. These investigations are critical for establishing a sustainable water cycle and resolving the problems that PPCPs cause in wastewater treatment.

Sustainability, as per its essence, entails the optimization of numerous variables. In the realm of the pharmaceutical industry, the driven by an amalgamation of theoretical reasoning and scientific advancements, has embraced Process Mass Intensity (PMI) as the foremost metric based on mass. PMI serves as a measure to assess the environmental impact of pharmaceutical processes. It diligently tracks the overall mass of materials employed relative to the mass of the end product manufactured. By eschewing a waste-centric alternative like

ISSN 2515-8260 Volume 05, Issue 01, 2018

the E factor, PMI stimulates ingenuity and excellence in the domains of pharmaceuticals and fine chemicals. This well-informed decision fosters an environment conducive to enhanced performance and unleashes innovative potential.

According to Jimenez-Gonzalez, Ponder, Broxterman, and Manley (2011), it is acknowledged that individual companies may employ a set of metrics that best suit their needs.As a result, rather than waste measures,The decision made by the ACS GCI Pharmaceutical Roundtable to prioritize the utilization of an input materials metric (PMI) as a measure of process sustainability, rather than focusing solely on waste management strategies such as the E factor or atom economy, showcases a well-supported and forward-thinking approach. This innovative strategy emphasizes the efficient use of resources and highlights the Roundtable's commitment to driving environmentally friendly practices within the pharmaceutical industry.

While acknowledging Despite the fact that PMI is not a perfect metric that provides a comprehensive life cycle appraisal (LCA) view or addresses specific environmental, health, and safety concerns about materials and waste, mass metrics such as PMI or its inverse, mass efficiency, are critical intermediate steps in estimating LCAs and footprints. Furthermore, scientists and engineers may directly evaluate these mass measurements in laboratory settings since they are trustworthy, simple to manufacture and compare. Facilitate communication and benchmarking, and allow for quick estimations of process or route greenness with minimal time and effort investment.

In past years, the presence of medications as environmental contaminants was disregarded. Advances in sensitive analytical technology, on the other hand, have made it feasible to detect trace quantities of prescription and over-the-counter medications in streams. Human and veterinary pharmaceutical residues enter the environment through several methods, the most common of which are wastewater treatment plant outflow and the application of sewage sludge and animal manure to land.

Pharmaceutical active components, according to Kim and Aga (2007), are Current discourse revolves around the issue of micropollutants, which, after entering the human body, undergo only partial transformation and are subsequently released into sewage systems. They exist as a mixture of metabolites and bioactive forms. While wastewater treatment plants do remove a

ISSN 2515-8260 Volume 05, Issue 01, 2018

portion of these drugs during the treatment process, a significant number of micropollutants persist. To tackle this conundrum, future endeavors ought to prioritize the optimization of wastewater treatment plant designs and operations, aiming to achieve maximal efficiency in antibiotic removal. It is worth noting that existing designs fall short of eradicating micropollutants in their entirety. While certain drinking water treatment methods, such as activated carbon, ozonation, and membrane technologies, prove effective in reducing micropollutant concentrations, their implementation may be financially burdensome for many municipal wastewater treatment plants.

Through a comprehensive evaluation of multiple full-scale wastewater treatment facilities, it becomes apparent that a combination of physical and biological treatment, coupled with optimization of operating conditions, holds the potential to enhance pharmaceutical removal efficiencies. Additionally, the application of sand filtration, which effectively eliminates colloidal particles, offers another avenue for the removal of antibiotics that have adhered to such particles.

the pressing challenge of micropollutant persistence necessitates a proactive approach in the realm of wastewater treatment. By delving into the intricacies of design and operation optimization, we can strive towards maximum antibiotic removal efficiencies. This requires a careful balance between physical and biological treatment methods, along with meticulous fine-tuning of operating conditions. Only through such concerted efforts can we hope to address the lingering presence of micropollutants in our wastewater systems. Pharmaceuticals are formulated to engender biological effects. They are utilized by both humans and animals to treat medical problems, stem infections, and reduce symptoms. While some pharmaceuticals are completely metabolized in the body, According to Jones, Voulvoulis, and Lester (2005) others may exit through the sewage system. Unlike pesticides, pharmaceuticals are not expected such restrictions due to their need in improving human and animal health, and their great economic value. In fact, the use of pharmaceuticals is expected to augment due to the rise in average life expectancy and advances in comprehending the human genome. This means that pharmaceuticals and their derivatives are likely to be pervasive in the environment, particular in places where there is human activity.

Pharmaceutical contamination in surface and groundwater is becoming recognised as an environmental hazard in several nations. APIs, on the other hand, have a broad range of durability in aquatic conditions, with some being extremely durable.

However, conducting direct experimental studies on humans to assess the potential developmental impairments caused by a specific pharmaceutical can be challenging and time-consuming. Moreover, ethical considerations may impose constraints on such studies. This discussion does not imply that pharmaceutical sector must do more to safeguard the public from occurrences such as the thalidomide disaster. However, there is still much to learn about impairments that may only emerge once development is complete, or even later. The reason of this reduction, as well as its possible link to the increased use of medications in the United States, including PIE APIs ingested through drinking water, raise important questions. It is reasonable to explore such questions in various studies investigating observed human impairments, as society must be thorough in seeking answers.

According to Khetan and Collins (2007) it is firmly believed that the pharmaceutical industry's long-term interests lie in recognizing the necessity for independent studies to address these questions. Just like the many anthropogenic chemicals introduced into the environment, it would be unwise to completely ignore common sense and continue prioritizing "the prophecy of bliss" over the "prophecy of doom" When weighing the benefits and drawbacks of medications. The addition of a combination of trace medicines to water, molecules designed to demonstrate powerful physiological action, poses a critical growing water concern that needs thorough analysis and strategic planning to limit any harmful consequences. Considering these lessons and the difficult challenges they pose, our chemocentric society must reconcile the clashing objectives of short-term economic gain with the wisdom of sustainability, which needs a longer-term outlook.

To define the battle in which green chemists have a legitimate stake, we must work for a route towards a robust chemical economy that is compatible with the health of living creatures. focuses largely on the environmental implications of medicines, but it also has implied importance for chemistry, because chemicals play a critical role in the dynamic framework of our fast-growing civilization's technical component. According to Chartier (2014) effective guidance It is possible that the means for steering this growth towards more sustainable paths are inadequate. Green chemistry must satisfy its objective of decreasing or

ISSN 2515-8260 Volume 05, Issue 01, 2018

eliminating dangers in all sectors of chemical products and processes, including medicines, at this point. The industry has already made significant strides towards greening its synthetic processes. It can improve its ability to improve the health of current generations while consciously avoiding the environmental and transgenerational injustices that PIE problems already represent or may pose in the future by redirecting its intellectual and economic resources towards promoting internal and independent studies on PIE issues. Human activities, as well as changes in lifestyle and consumer patterns, have resulted in huge volumes of waste of various types being produced. These wastes jeopardise people's lives, the lives of other living species, and the natural resources needed for human survival. Extensive research has been conducted to evaluate appropriate waste treatment methods with the goal of reducing environmental pollution and maximising resource recovery. There has been an increase in global concern in recent years about the solid waste generated by healthcare facilities (HCFs) such as hospitals, clinics, pathological laboratories, pharmacies, and other healthcare services. Existing waste management practises, particularly in developing nations, are deemed insufficient. According to Hossain, Santhanam, Norulaini, and Omar (2011), healthcare facilities are unable to separate clinical solid waste prior to disposal, resulting in worsened health consequences and excessive disposal costs. There is an urgent need to implement effective sterilisation technologies for controlling clinical solid waste prior to final disposal. As a result, it is strongly advised to implement supercritical fluid carbon dioxide (SF-CO2) sterilisation at the time of initial rubbish collection. This approach would eliminate infection and contamination, ensuring that the rubbish posed no infectious risks. Non-skilled healthcare staff may be responsible for clinical solid waste collection, sorting, and recycling/reuse initiatives. As a result, hospitals would be able to establish a safe environment for patients, healthcare professionals, and waste handlers. Moreover, the adoption of SF-CO2 sterilization technology for managing clinical solid waste would reduce the exposure to infectious waste, decrease labor requirements, minimize management costs, and ensure better compliance with regulatory standards.

Objective

To investigate the environmental impact and sustainable solutions for pharmaceutical waste management

Methodology

This research is a descriptive type that collected data from 181 participants, including representatives from different pharmaceutical companies, healthcare professionals, administrators, and waste management personnel from hospitals, clinics, pharmacies, and

ISSN 2515-8260 Volume 05, Issue 01, 2018

other healthcare facilities. The data were analyzed using a checklist question, which required respondents to answer with either a "Yes" or a "No" for each question.

Data Analysis and Interpretations:

Table 1 Environmental Impact and sustainable solutions for pharmaceutical waste management

SL No.	Environmental Impact and sustainable solutions	Yes	% Yes	No	% No	Total
1	Improper disposal of pharmaceuticals can contribute to the development of drug-resistant bacteria and pathogens.	163	90.06	18	9.94	181
2	Implementing proper disposal methods for pharmaceutical waste is crucial.	145	80.11	36	19.89	181
3	Educating the public about the importance of responsible pharmaceutical waste disposal can help raise awareness and encourage proper practices.	157	86.74	24	13.26	181
4	Recycling unused or expired medications can be an effective sustainable solution.	169	93.37	12	6.63	181
5	Improper disposal of pharmaceuticals can lead to water pollution.	150	82.87	31	17.13	181
6	Continued research and innovation may be essential to finding sustainable solutions for pharmaceutical waste management.	131	72.38	50	27.62	181

Table 1 shows the environmental impact and sustainable solutions for pharmaceutical waste management. It was found that around 93.3% respondents accept that recycling unused or expired medications can be an effective sustainable solution. Additionally, improper disposal of pharmaceuticals can contribute to the development of drug-resistant bacteria and pathogens (90.0%). Moreover, educating the public about the importance of responsible

ISSN 2515-8260 Volume 05, Issue 01, 2018

pharmaceutical waste disposal can help raise awareness and encourage proper practices (86.7%). Improper disposal of pharmaceuticals can lead to water pollution (82.8%). However, implementing proper disposal methods for pharmaceutical waste is crucial (80.1%). Lastly, continued research and innovation may be essential to finding sustainable solutions for pharmaceutical waste management. (72.3%).

Conclusion

The research conducted shows the damaging effects of pharmaceutical waste on the environment, aquatic life, and people's health. The research findings also point to the lack of knowledge of the environmental consequences of pharmaceutical waste and the inadequate disposal being implemented globally. This brings about a danger to both biological diversity and the health of people, since certain components of pharmaceutical waste can linger in the surroundings for long periods of time and can produce unfavorable outcomes for ecosystems and wildlife.

Despite this, the research also brings up realistic sustainable solutions for managing pharmaceutical waste which are of high importance.The suggested measures involve the enforcement of more stringent rules and directions for waste removal, motivating pharmaceutical enterprises to execute eco-friendly production methods, and spreading awareness amongst the public regarding proper disposal techniques. Moreover, the research underscores the significance of cooperation between interested parties such as regulatory agencies, healthcare providers, pharmaceutical producers, and the general public, to effectively solve this concern. By implementing such sustainable resolutions, we can minimize the negative effects of medicine debris on the ecosystem and human health. It's essential for all parties concerned to realize their responsibility in minimizing the production of pharmaceutical garbage, encouraging recycling, and reusing, and putting their efforts into innovative techniques for waste management. Ultimately, a collective attempt is necessary to address the obstacles linked with medicine waste management and progress towards a more stable future.

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