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Combating Antimicrobial Resistance: A Review of Wastewater Treatment Methods for ARB and ARGs

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Abstract

The global rise of antimicrobial resistance (AMR) poses a significant threat to public health, driven in part by the proliferation of antimicrobial-resistant bacteria (ARB) and antimicrobial resistance genes (ARGs) in environmental systems. Wastewater treatment plants (WWTPs) are critical control points for limiting the spread of ARB and ARGs, yet conventional treatment methods often fall short in effectively eliminating these contaminants. This review provides a comprehensive analysis of current wastewater treatment methods, including physical, chemical, and biological approaches, in their capacity to mitigate ARB and ARGs. The mechanisms, advantages, and limitations of processes such as membrane filtration, advanced oxidation processes, and bioaugmentation are critically evaluated. Additionally, the role of novel and hybrid technologies in enhancing treatment efficacy is explored. By synthesizing recent research, this review highlights the need for optimized, multi-barrier approaches to effectively reduce the dissemination of ARB and ARGs from wastewater into the environment. The findings underscore the urgency for innovation and policy development in wastewater management to combat the escalating challenge of antimicrobial resistance.

Keywords: Antimicrobial resistance (AMR): Antimicrobial-resistant bacteria (ARB): Antimicrobial resistance genes (ARGs): Wastewater treatment.

Introduction

The emergence and rapid spread of antimicrobial resistance (AMR) have become a global health crisis, threatening the effectiveness of antibiotics and other antimicrobial agents [1]. A significant contributor to this problem is the dissemination of antimicrobial-resistant bacteria (ARB) and antimicrobial resistance genes (ARGs) into the environment, particularly through wastewater systems. Wastewater treatment plants (WWTPs) serve as critical interfaces between human activities and natural water bodies, making them key players in either curbing or exacerbating the spread of AMR. Conventional wastewater treatment methods, while effective in reducing organic pollutants and pathogens, are often inadequate in fully removing ARB and ARGs [2]. These resistant entities can persist through various stages of treatment and be released into the environment, where they may proliferate and transfer resistance genes to other microorganisms, compounding the challenge of AMR. This review aims to critically assess the efficacy of existing wastewater treatment methods in mitigating the presence of ARB and ARGs. By examining a range of physical, chemical, and biological treatment processes, the review seeks to identify gaps in current practices and explore innovative solutions that could enhance the removal of these resistant contaminants. Understanding the strengths and limitations of each approach is essential for developing comprehensive strategies that can effectively combat AMR at the environmental level. The review will also highlight the importance of integrated, multi-barrier approaches and the need for ongoing research and policy interventions to address this pressing issue. As AMR continues to evolve, so too must our methods for controlling its spread, particularly through the critical juncture of wastewater treatment [3].

Discussion

The review of wastewater treatment methods for addressing antimicrobial-resistant bacteria (ARB) and antimicrobial resistance genes (ARGs) reveals both promising advancements and significant challenges. The persistence of ARB and ARGs in treated wastewater highlights the complexity of effectively mitigating antimicrobial resistance (AMR) through conventional treatment processes [4]. This discussion explores the effectiveness of various methods, the need for innovation, and the broader implications for public health and environmental safety. Effectiveness of Conventional Treatment Methods: Conventional wastewater treatment processes, such as primary sedimentation, activated sludge, and secondary treatment, have demonstrated limited success in fully eliminating ARB and ARGs. While these methods efficiently reduce organic loads and pathogens, their inability to target ARB and ARGs raises concerns about the potential for environmental dissemination. The review underscores that even advanced processes, such as membrane filtration and advanced oxidation, though more effective, do not guarantee complete removal. This limitation necessitates a critical reevaluation of current practices, emphasizing the need for enhancements or supplementary treatments [5].

Emerging and Hybrid Technologies: Emerging technologies, including advanced oxidation processes (AOPs), bioaugmentation, and hybrid systems, offer promising avenues for more effectively targeting ARB and ARGs. AOPs, which generate reactive species capable of degrading resistant genes, have shown considerable potential in laboratory settings. However, scalability, cost, and operational challenges remain barriers to widespread implementation. Similarly, bioaugmentation, which involves introducing specialized microbial communities to outcompete or degrade ARB and ARGs, presents a

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novel approach but requires further research to optimize its application in diverse wastewater environments [6]. Hybrid systems that combine multiple treatment processes such as integrating AOPs with membrane filtration or coupling biological and chemical treatments are emerging as potentially more effective solutions. These systems capitalize on the strengths of individual processes while mitigating their weaknesses, providing a more robust defense against ARB and ARGs. The discussion highlights the importance of continued innovation in developing and refining these hybrid approaches to address the multifaceted nature of AMR [7].

Multi-Barrier Approaches and Policy Implications: The findings of this review support the adoption of multi-barrier approaches that incorporate a combination of physical, chemical, and biological treatments to maximize the removal of ARB and ARGs [8]. This strategy aligns with the growing recognition that no single treatment method is sufficient to address the complexity of AMR. By employing multiple barriers, wastewater treatment plants can enhance their overall effectiveness and reduce the risk of releasing resistant contaminants into the environment [9]. Policy and regulatory frameworks play a crucial role in driving the adoption of these advanced treatment methods. The discussion calls for stronger regulations that mandate the implementation of multi-barrier approaches, particularly in regions where AMR poses a significant public health risk. Additionally, there is a need for increased investment in research and development to accelerate the transition from experimental to practical applications of emerging technologies [10].

Conclusion

Broader Implications for Public Health and Environmental Safety: The persistence of ARB and ARGs in treated wastewater has far-reaching implications for public health and environmental safety. The potential for these resistant entities to enter natural water bodies, agricultural systems, and even drinking water supplies underscores the urgency of addressing this issue at its source. The discussion emphasizes that effective wastewater treatment is not just a technical challenge but a critical component of global efforts to combat AMR. By improving wastewater treatment practices, we can reduce the environmental reservoir of ARB and ARGs, thereby limiting their spread and the consequent impact on human health. However, this requires a concerted effort involving technological innovation, policy reform, and public awareness. The discussion concludes by reiterating the importance of continued collaboration between scientists, engineers, policymakers, and the public to develop and implement effective solutions to this growing global challenge.

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