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The microbial ecology of wastewater treatment plants: Balancing efficiency and resistance.

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Introduction

Wastewater treatment plants (WWTPs) are critical infrastructures that safeguard public health and environmental integrity by removing contaminants from sewage and industrial effluents. At the heart of these systems lies a complex and dynamic microbial ecosystem that drives the biological degradation of organic matter, nutrients, and pollutants. Understanding and managing the microbial ecology of WWTPs is essential not only for optimizing treatment efficiency but also for mitigating the emergence and spread of antimicrobial resistance (AMR), a growing global concern [1].

bacteria, archaea, protozoa, and fungi. These microbes form structured communities in activated sludge, biofilms, and anaerobic digesters, each contributing to specific treatment functions. Key bacterial phyla include Proteobacteria, Bacteroidetes, Firmicutes, and Actinobacteria, with genera such as *Nitrosomonas*, *Pseudomonas*, and *Acinetobacter* playing pivotal roles in nitrification, denitrification, and organic matter degradation [2].

Microbial consortia are tailored to the physicochemical conditions of the treatment process. For instance, aerobic tanks favor nitrifiers and heterotrophs, while anaerobic digesters support methanogens and fermentative bacteria. The synergy among these microbes ensures the breakdown of complex pollutants into simpler, less harmful compounds. Recent advances in molecular biology have revolutionized the study of microbial ecology in WWTPs. Techniques such as 16S rRNA gene sequencing, metagenomics, and transcriptomics provide high-resolution insights into microbial composition, functional potential, and community dynamics. These tools enable the identification of core microbial communities and the detection of rare or emerging taxa, facilitating targeted interventions to enhance treatment performance [3].

Moreover, molecular methods help monitor shifts in microbial populations due to operational changes, environmental stressors, or the introduction of novel pollutants. This knowledge is crucial for maintaining system stability and resilience. Despite their effectiveness, WWTPs face challenges in maintaining consistent treatment efficiency. Fluctuations in influent composition, hydraulic loads, and temperature can disrupt microbial communities, leading to process failures such as sludge bulking, foaming, or incomplete nutrient removal [4].

To address these issues, strategies such as bioaugmentation, process control optimization, and the use of microbial indicators have been developed. Bioaugmentation involves the addition of specialized microbial strains to enhance specific functions, while real-time monitoring and control systems help maintain optimal conditions for microbial activity. WWTPs are increasingly recognized as hotspots for the emergence and dissemination of antimicrobial resistance. They receive a continuous influx of antibiotics, resistant bacteria, and resistance genes from hospitals, households, and agricultural sources. Within the microbial communities of WWTPs, horizontal gene transfer (HGT) facilitates the spread of resistance genes among diverse taxa, including pathogens and environmental bacteria. Studies have detected a wide range of resistance genes in WWTPs, including those conferring resistance to beta-lactams, tetracyclines, and sulfonamides. The presence of mobile genetic elements such as plasmids, transposons, and integrons further accelerates the dissemination of resistance traits [5].

Conclusion

The dual goals of maximizing treatment efficiency and minimizing resistance spread require a delicate balance. Operational practices that enhance microbial diversity and stability can reduce the selective pressure for resistance. For example, maintaining low antibiotic concentrations, optimizing sludge retention times, and avoiding over-aeration can help limit the proliferation of resistant strains. Advanced treatment technologies such as membrane bioreactors (MBRs), ozonation, and UV disinfection offer additional barriers to resistant bacteria and genes. However, these methods are energy-intensive and costly, necessitating careful cost-benefit analyses. To sustainably manage microbial ecology in WWTPs, interdisciplinary approaches are needed. Integrating microbial ecology with engineering, public health, and policy can foster holistic solutions. The microbial ecology of wastewater treatment plants is a cornerstone of environmental biotechnology. By harnessing the power of microbial communities, WWTPs achieve remarkable feats of pollutant removal and resource recovery. Yet, the same microbial dynamics pose risks of antimicrobial resistance, demanding vigilant management and innovation. Balancing efficiency and resistance is not merely a technical challenge—it is a societal imperative for safeguarding health and sustainability.

References

1. Culyba MJ, Mo CY, Kohli RM. Targets for combating the evolution of acquired antibiotic resistance. Biochemistry. 2015;54(23):3573-82.
2. Petakh P, Oksenych V, Kamyshnyi O. Exploring Leptospira interrogans FDAARGOS_203: Insights into AMR and Anti-Phage Defense. Microorganisms. 2024;12(3):546.
3. Wilson DN. Ribosome-targeting antibiotics and mechanisms of bacterial resistance. Nat Rev Microbiol. 2014;12(1):35-48.
4. Guttman DS, McHardy AC, Schulze-Lefert P. Microbial genome-enabled insights into plant–microorganism interactions. Nat Rev Genet. 2014;15(12):797-813.
5. Cox G, Wright GD. Intrinsic antibiotic resistance: mechanisms, origins, challenges and solutions. Int J Med Microbiol. 2013;303(6-7):287-92.

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