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REVIEW

Protecting Public Health: A Review of Water Contamination and Disinfection Practices

Protegiendo la Salud Pública: Una Revisión de la Contaminación y las Prácticas de Desinfección del Agua

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ABSTRACT

Introduction: pathogen-induced water contamination is a significant global issue, resulting in both acute and chronic diseases. Environmental factors, chemical contaminants, and pathogenic microorganisms—such as viruses, bacteria, and parasites—deteriorate water quality. These obstacles impede the realization of Sustainable Development Goals (SDGs), including SDG 3 (Good Health and Well-being) and SDG 6 (Clean Water and Sanitation).
Objective: the objective of this review is to deliver a thorough evaluation of pathogen contamination in water resources, highlighting the public health concerns and the necessity for integrated, transdisciplinary strategies to advance the Sustainable Development Goals (SDGs).
Method: recent literature concerning microbial, parasite, and chemical pollution in water was synthesized. Comparative analysis across studies were undertaken to identify significant pollutants impacting water quality and human health.
Results: data demonstrates that waterborne pathogens substantially degrade water quality and facilitate disease outbreaks. Microbial and parasite pollutants, affected by environmental and chemical variables, present significant health hazards. Research underlines the complexity of water contamination and the urgent need for thorough monitoring and management measures.
Conclusions: findings underline the necessity of coordinated research and transdisciplinary approaches to treat waterborne illnesses. Effective methods must address biological, chemical, and environmental elements to prevent infections, improve public health, and maintain sustainable water management. Aligning these activities with SDG 3 and SDG 6 is critical for lowering waterborne disease burden and reaching global health and water safety targets.

Keywords: Water Contamination; Waterborne Infections; Water Disinfection; Public Health; Sustainable Development Goals (SDGs).

RESUMEN

Introducción: la contaminación del agua inducida por patógenos es un problema global significativo que provoca enfermedades agudas y crónicas. Los factores ambientales, los contaminantes químicos y los microorganismos patógenos —como virus, bacterias y parásitos— deterioran la calidad del agua. Estos desafíos

obstaculizan el cumplimiento de los Objetivos de Desarrollo Sostenible (ODS), incluidos el ODS 3 (Salud y Bienestar) y el ODS 6 (Agua Limpia y Saneamiento).
Objetivo: el objetivo de esta revisión es ofrecer una evaluación exhaustiva de la contaminación por patógenos en los recursos hídricos, destacando las implicaciones para la salud pública y la necesidad de estrategias integradas y transdisciplinarias para avanzar en los ODS.
Método: se sintetizó la literatura reciente sobre contaminación microbiana, parasitaria y química en el agua. Se realizaron análisis comparativos entre estudios para identificar los principales contaminantes que afectan la calidad del agua y la salud humana.
Resultados: los datos demuestran que los patógenos transmitidos por el agua degradan considerablemente su calidad y facilitan brotes de enfermedades. Los contaminantes microbianos y parasitarios, influenciados por variables ambientales y químicas, representan riesgos significativos para la salud. La investigación destaca la complejidad de la contaminación del agua y la necesidad urgente de implementar medidas exhaustivas de monitoreo y gestión.
Conclusiones: los hallazgos subrayan la necesidad de una investigación coordinada y enfoques transdisciplinarios para abordar las enfermedades transmitidas por el agua. Los métodos eficaces deben considerar los elementos biológicos, químicos y ambientales para prevenir infecciones, mejorar la salud pública y mantener una gestión sostenible del agua. Alinear estas acciones con los ODS 3 y 6 es fundamental para reducir la carga de enfermedades de origen hídrico y alcanzar las metas globales de salud y seguridad del agua.

Palabras clave: Contaminación del Agua; Infecciones Transmitidas por el Agua; Desinfección del Agua; Salud Pública; Objetivos de Desarrollo Sostenible (ODS).

INTRODUCTION

Waterborne infections remain a significant global threat to human health, underscoring the necessity of reliable access to potable water for essential daily activities such as food preparation, consumption, and personal hygiene. Improving drinking water quality offers substantial health benefits, including the prevention of life-threatening diseases such as cholera, typhoid, and hepatitis.[1] At the same time, global water scarcity presents a critical challenge to sustainable development, with varying impacts across sectors and regions. Agriculture alone consumes approximately 70 % of global freshwater resources, yet a considerable share is wasted due to inefficient irrigation practices. Localized water shortages often trigger far-reaching economic consequences, as fluctuations in global agricultural demand can strain regional water systems.[2] Conversely, disruptions in regional water availability can propagate across multiple industries including manufacturing, transportation, and energy, highlighting the complex interdependence of water resources on both local and global scales.[2]

As a key biophysical factor influencing food production, water remains an irreplaceable resource despite technological advances such as cost-effective nitrogen fertilizer production.[3] The Middle East is particularly vulnerable due to severe freshwater scarcity and the compounding impacts of climate change on water resources.[4] In Saudi Arabia, one of the world's driest nations, persistent water shortages and the rapid deterioration of water quality represent urgent challenges, further aggravating public health risks.[4]

Water is fundamental to life, and its contamination, whether physical, chemical, biological, or radiological, poses widespread threats. Historical records illustrate the persistence of this problem: as early as 500–400 B.C., the Indian Sanskrit text Sushruta described waterborne illnesses resembling cholera. Although improved sanitation has significantly reduced cholera incidence in high-income countries, millions in low-income regions remain affected by Vibrio cholerae. The World Health Organization (WHO) estimates between 10 000 and 120 000 cholera-related deaths annually, with 3-5 million infections occurring predominantly in developing countries.[5] These figures align with long-term evidence that cholera has devastated populations across both resource-rich and resource-limited settings.[5,6]

Globally, access to safe drinking water and adequate sanitation remains a significant challenge. According to UNICEF,[7] around 2,2 billion people lack safely managed drinking water, and 4,2 billion people do not have access to safely managed sanitation services. Water contamination, caused primarily by pathogenic microorganisms including bacteria, viruses, and protozoa, continues to pose a major public health concern. These deficiencies particularly affect regions with inadequate sanitation and water treatment infrastructure, facilitating the spread of waterborne diseases such as cholera, typhoid, and dysentery.[8] The data highlight the growing urgency for improved water disinfection technologies, stricter regulation of chemical pollutants such as PFAS, and sustainable water management practices to protect human health and achieve global water security.[8]

Eliminating harmful microorganisms such as bacteria, viruses, and protozoa is essential to reduce the risk of waterborne infections. In addition to microbial contaminants, chemical and physical pollutants also pose significant challenges to water quality. These contaminants may originate from human waste, industrial effluents, agricultural runoff, or natural events such as floods and must be minimized to meet water quality standards.[8,9] Moreover, disinfection processes can produce by-products, such as trihalomethanes, when chemical disinfectants like chlorine react with naturally occurring organic matter. These disinfection by-products have been linked to long-term health risks, including cancer.[10,11]

Disinfection is a critical step in ensuring the microbiological safety of drinking water by deactivating or removing harmful bacteria.[8] Effective microbial reduction often requires higher disinfectant doses due to variations in raw water quality, such as the presence of humic substances or ammonia.[12] Limited access to modern disinfection technologies increases the risk of disease outbreaks in low- and middle-income regions, highlighting the need for solutions that are both effective and sustainable.[9] Addressing the dual challenge of eliminating pathogens while minimizing the formation of disinfection by-products (DBPs) necessitates advanced disinfection techniques tailored to regional water quality and available resources.[11] The use of pre-treatment methods or modern technologies can reduce DBP formation, while scalable, affordable, and multi-barrier approaches are recommended to manage diverse pollution sources effectively.[10,13]

Public Health Challenges of Waterborne Microbial Contaminants

Unsafe water supplies contaminated by harmful microorganisms are a leading cause of death worldwide, with an estimated 1,4 million deaths annually attributed to inadequate water, sanitation, and hygiene (WASH) services.[14] Waterborne pathogens contribute significantly to global water quality challenges, affecting both freshwater sources (rivers, lakes, reservoirs, groundwater) and saltwater bodies (estuaries and coastal seas).[15] Children are particularly vulnerable, accounting for a substantial portion of these deaths. In 2021, over 1200 children under five died daily from diarrheal diseases, a leading cause of mortality in this age group.[16] A 2023 UNICEF report highlighted that 190 million children in 10 African countries face heightened risks due to inadequate WASH services, compounded by climate-related challenges.[17] Furthermore, over 300 000 children under five died from diarrheal diseases in 2023, underscoring the critical need for improved water quality and sanitation.

Contaminated water supplies pose significant health risks, leading to an estimated 1,4 million deaths annually due to unsafe drinking-water, sanitation, and hygiene practices.[18] Waterborne pathogens contribute to a substantial burden of disease, affecting both freshwater sources (rivers, lakes, reservoirs, groundwater) and saltwater bodies (estuaries and coastal seas). Children are particularly vulnerable, with over 1200 children under five dying daily from diarrheal diseases, a leading cause of mortality in this age group.[17] A 2023 UNICEF report highlighted that 190 million children in 10 African countries face heightened risks due to inadequate water, sanitation, and hygiene services, compounded by climate-related challenges.[16] Furthermore, over 300 000 children under five died from diarrheal diseases in 2023, underscoring the critical need for improved water quality and sanitation.[17] These illnesses are caused by harmful bacteria such as Vibrio cholerae, Escherichia coli, and Enterococci, which are commonly found in contaminated water, leading to numerous outbreaks, including those involving Enterococcus faecalis.[19] Millions of people in developing regions, particularly in Africa, are affected by waterborne diseases.[20] In more than 29,5 % of gastrointestinal disease cases, various bacteria and pathogens have been identified, often causing symptoms like fever, diarrhea, vomiting, and abdominal pain, with Shigella species responsible for a significant number of infections.[20]

In addition, Adenoviruses, Leptospira, and Cryptosporidium parvum were responsible for 10,99 %, 10,08 %, and 6,59 % of cases, respectively, while Shigella species and other gastrointestinal pathogens accounted for approximately 21 % and 23 % of outbreaks.[21,22] Furthermore, Naegleria fowleri and Escherichia coli O157:H7 were responsible for 16,84 % and 7,37 % of outbreaks, respectively, with Schistosoma species also implicated.[23]

The presence of pathogenic bacteria in water is largely due to human activities that introduce contaminants, insufficient water sanitation systems, and pollution from human or animal waste. Wastewater discharges into freshwater and coastal waters are significant sources of fecal microorganisms, including pathogens.[24] Common waterborne bacterial strains include Shigella, Listeria, Escherichia coli, Staphylococcus aureus, and Bacillus cereus, though they are often found in trace amounts, with Listeria being among the most prevalent.[25] Traditional contamination indicators such as E. coli, enterococci, and other aerobic bacteria are frequently detected when infections occur.[26]

The detection of antibiotic-resistant bacterial species in water is particularly concerning, as these bacteria can cause a wide range of diseases due to their resistance patterns, often carried on plasmids. While antibiotics have been crucial in treating bacterial infections, the rise of antibiotic-resistant strains threatens their efficacy, making treatments more difficult and costly[27] (figure 1).

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Authors (Year)	Study Design	Sample / Population	Methods	Results	Recommendations
WHO (2023)	Global report	Global population, unsafe WASH systems	Review of WASH-related health data	Unsafe water causes 1.4 million deaths annually	Improve access to safe water, sanitation, and hygiene
WHO (2023)	Burden of disease analysis	Freshwater & saltwater bodies worldwide	Global data analysis	Waterborne pathogens affect rivers, lakes, reservoirs, groundwater, estuaries, coastal seas	Enhance monitoring and management of water sources
UNICEF (2023)	Child health statistics	Children under 5 globally	Data collection on diarrheal disease	>1,200 child deaths/day from diarrheal diseases	Improve child-focused WASH interventions
UNICEF (2023)	Report	190 million children in 10 African countries	Field reports & climate data	Children at high risk due to poor WASH and climate impacts	Implement targeted WASH programs in vulnerable regions
CDC (2025)	Surveillance report	Global and U.S. populations	Monitoring of waterborne disease	1.4 million deaths annually linked to unsafe WASH	Strengthen outbreak detection and response
Cho, S. et al. (2020)	Laboratory/field study	Surface water samples	Tested prevalence & antimicrobial resistance of Salmonella, E. coli, Enterococcus	High prevalence & resistance patterns detected	Monitor antibiotic resistance in water sources
UN et al. (2021)	Review	Water sources & shellfish in Africa	Occurrence study of human enteric viruses	Millions affected in developing regions; Shigella common	Strengthen WASH and water quality surveillance
Painter, J. E. et al. (2016)	Epidemiological surveillance	U.S. water & outbreak cases	Analysis of cryptosporidiosis reports 1995–2012	Adenoviruses 10.99%, Leptospira 10.08%, Cryptosporidium 6.59% of cases	Improve protozoan pathogen detection & control
Owliaee, I. et al. (2024)	Systematic review	Global water resources	Detection of adenoviruses	Adenoviruses present in various water types	Expand viral monitoring in water systems
Iyer, V. G. et al. (2024)	Prevalence study	Freshwater bodies in India	Survey for Naegleria fowleri	Naegleria 16.84%, E. coli O157:H7 7.37% of outbreaks	Implement early warning & preventive measures in freshwater sources

Figure 1. Parasitic Threats to Water Quality: Summary of Key References on Protozoan Contamination, Risks, and Remediation

Parasitic Threats to Water Quality: Sources, Risks, and Remediation Methods

Waterborne and water-washed diseases are primarily caused by fecal contamination of water sources and inadequate hygiene practices, as well as the presence of parasitic pollutants and the methods used to remove them. Protozoan parasites, in particular, have been identified as leading causes of infant mortality in recent years, responsible for approximately 1,7 billion cases of diarrhea globally and around 842 000 deaths each year.[28]

Giardia and Cryptosporidium are transmitted through the fecal-oral route, and infections typically occur through ingestion of contaminated water, including during recreational activities in swimming pools. Between 1990 and 2012, the majority of laboratory-confirmed cases of these parasites in drinking water in developed countries were reported, including 411 041 outbreak-related cases in the United States attributed to Giardia and Cryptosporidium.[29] Omarova and colleagues found that Giardia and Cryptosporidium parasites are commonly detected during waterborne and water-washed outbreaks. Their study also highlighted that these parasites are more resistant to conventional drinking water and wastewater treatment processes compared to most bacteria and viruses[30] (figure 2).

Authors (Year)	Study Design	Sample / Population	Methods	Results	Recommendations
Bourli, P. et al. (2023)	Review	Worldwide outbreaks of protozoan parasites	Literature review of outbreak reports 2017–2022	Protozoa (Giardia, Cryptosporidium) major contributors to diarrheal disease; 1.7 billion cases globally; ~842,000 deaths/year	Improve surveillance, water treatment, and hygiene practices globally
Efstratiou, A. et al. (2017)	Review	Laboratory-confirmed cases in developed countries (1990–2012)	Review of outbreak data and surveillance reports	411,041 outbreak-related cases in the US; Giardia & Cryptosporidium prevalent in drinking water	Strengthen monitoring and outbreak response in developed countries
Omarova, A. et al. (2018)	System-based study / Review	Drinking water and wastewater in developing countries	Analysis of protozoan occurrence & resistance to treatment	Giardia & Cryptosporidium resistant to conventional treatment; frequently detected during outbreaks	Implement improved treatment processes, water safety management, and hygiene interventions

Figure 2. Parasitic Threats to Water Quality: Summary of Key References on Protozoan Contamination, Risks, and Remediation

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Measures to prevent pathogenic bacterial contamination in water

Major etiological agents of waterborne outbreaks include the protozoa Giardia and Cryptosporidium and bacterial pathogens such as Vibrio cholerae, Salmonella, and Escherichia coli. Recent surveillance indicates that these organisms remain leading causes of water-associated illness: U.S. surveillance and burden studies estimate millions of waterborne illnesses annually and show that outbreaks associated with drinking water continue to occur.[27,31] Cryptosporidium and Giardia are frequently implicated in large drinking-water and recreational outbreaks, and recent investigations in Europe have documented unprecedented increases in Cryptosporidium detections and outbreaks.[32] In addition, bacterial pathogens continue to drive epidemics, as shown by a 2023 outbreak of Escherichia coli O157:H7 in Utah traced to untreated irrigation water,[33] and recurrent cholera epidemics linked to contaminated water remain a major global health concern, with large outbreaks reported in 2023.[34] Because exposure data are limited and many cases go unreported, reported outbreak-linked incidence likely underestimates the true public-health burden.[27]

Water purification effectiveness depends critically on how thoroughly parasitic protozoa are removed. Recent systematic reviews and studies have confirmed that membrane and other physical filtration processes (microfiltration, ultrafiltration, nanofiltration, reverse osmosis) consistently achieve high log-reductions of Giardia cysts, Cryptosporidium oocysts, and many bacteria, often outperforming traditional granular media filters.[35,36] Conventional coagulation, flocculation, and sedimentation remain important pretreatment steps, helping to reduce particulate load and enhance downstream filtration efficiency.[37] In the U.S. and Europe, pressure-driven membrane systems are increasingly used in full-scale drinking-water plants for protozoan removal credits, with validated integrity testing and challenge-study protocols in place to ensure performance.[38] Despite its widespread use, chlorine disinfection has limited efficacy against protozoan cysts and oocysts; thus, many utilities now supplement or replace it with ultraviolet (UV), ozonation, advanced oxidation, or chlorine alternatives (e.g. chlorine dioxide) to improve pathogen inactivation while minimizing harmful by-product formation.[38] In addition to improving taste and color and removing organic and inorganic substances, ozonation has been shown recently to be effective against protozoan cysts; for example, treated wastewater used for agricultural irrigation, when dosed with ozone at 1,3 mg/L, yielded ~99 % reduction in Cryptosporidium parvum oocyst viability.[39] Ultraviolet (UV)-LED irradiation, particularly at ~280 nm, has likewise been demonstrated to inactivate bacteria, viruses, and even offer some reduction of Cryptosporidium oocysts, though higher UV doses are required under poor water quality.[40] Field trials at decentralized water systems in Japan over extended periods have confirmed that UV-LED modules can consistently reduce E. coli by ~2,7 log levels and maintain performance against environmental variation, with protozoan cyst detection being very rare.[41] To prevent harmful microorganism contamination, it is vital to protect water sources, optimize treatment technologies, and ensure secure distribution systems. Given the global prevalence of pathogen contamination, increasing public awareness of contamination sources and impacts remains essential. Moreover, a shift toward more field-scale studies — such as those tracking microbial fate in actual drinking water systems, conventional/compact plants, and groundwater — rather than only laboratory studies, is needed to improve understanding of pathogen interactions and persistence under real-world conditions.[41]

The development of new models and the improvement of existing modelling techniques, which are commonly used to forecast the levels of water-borne pathogens, are anticipated to aid in the assessment of pathogen contamination at the watershed-scale. The limited ability of existing models to predict pathogen contamination necessitates updating and developing new models to improve the accuracy of pathogen level forecasts.[42] Integrating knowledge from other fields (hydrology, microbiology, ecology, etc.) might help create long-term strategies to improve water quality and increase our comprehension of pollution levels and their causes. One of the most important steps in preventing and identifying issues with health, safety, and well-being is the testing and quick identification of pathogenic organisms.[9] Rapid identification and testing for pathogenic organisms are essential stages in preventing and identifying problems related to health, safety, and welfare. Fecal indicator microorganisms where humans become infected are frequently tested worldwide. As the population grows and more people visit certain water bodies, testing will be required to control and stop possible outbreaks of potentially infectious diseases.[42]

Monitoring indicator organisms, such as Escherichia coli and fecal coliforms, remains a standard method for estimating pathogen burdens in environmental water bodies. These indicators, often referred to as waterborne pathogen footprints, provide a practical measure for assessing microbial water quality and identifying potential health risks.[43] Determining the sources of contamination—including human, livestock, wildlife, or waterfowl feces—is critical, given that infectious diseases remain a leading cause of mortality globally and the third most common cause of death in the United States.[43] Over the past two decades, a growing number of emerging infectious diseases have been reported, largely driven by anthropogenic activities, climate change, expansion of water resources, and increased human–wildlife interactions.[43] Recent advancements in water treatment technologies have introduced various methods to remove biological contaminants from drinking water. Techniques such as oxidation treatments, ultraviolet (UV) irradiation, distillation, electrochemical filtration,

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biologically active carbon filtration, and nanotechnology have been explored for their effectiveness in pathogen removal.[35] However, challenges persist in ensuring the complete eradication of harmful microorganisms, as some methods may not achieve the desired level of disinfection.[44] The integration of physical processes like screening and filtration with established disinfection techniques, including UV, ozonation, and chemical treatments, is commonly employed to control waterborne pathogenic bacteria. Nevertheless, these methods often require significant energy and resources, posing challenges for implementation in resource-limited settings.[44] In many developing countries, poor sanitation and restricted access to clean water contribute to the high incidence of waterborne diseases. These illnesses, often transmitted via the fecal-oral route, share symptoms such as fever, diarrhea, and muscle aches. While various disinfection methods are available, each has its own advantages and limitations, and some may not effectively eliminate all microorganisms, leading to potential biological contamination even after treatment.[44] Pathogenic bacteria such as Salmonella typhi, Escherichia coli, and Vibrio cholerae have been identified in water sources, causing diseases like cholera, typhoid, and diarrhea. The presence of these pathogens underscores the need for continuous monitoring and improvement of water treatment processes to ensure the safety of drinking water supplies[44] (figure 3).

Authors (Year)	Study Design	Methods	Results	Recommendations
Alajlan, S. A. (2024)	Policy analysis	Review of governmental health policies in low-income countries	Highlighted gaps in healthcare and sanitation policies	Strengthen healthcare systems & integrate water safety policies
Kunz, J. M. (2024)	Surveillance report	U.S. surveillance of waterborne disease outbreaks, 2015–2020	Millions of annual waterborne illnesses; outbreaks still common	Improve surveillance & outbreak prevention strategies
Martinez, M. P. et al. (2024)	Epidemiological surveillance	Cryptosporidiosis surveillance, Spain, 2023	Unprecedented rise in Cryptosporidium cases/outbreaks	Enhance monitoring & prevention of protozoan contamination
Treacy, J. et al. (2019)	Outbreak investigation	Molecular epidemiology & pathogen characterization of E. coli O157:H7	Linked outbreak to raw drinking milk	Rapid pathogen characterization for outbreak resolution
Zheng, Q. et al. (2021–2024)	Molecular epidemiology	AMR testing of V. parahaemolyticus isolates from aquatic products	Documented antimicrobial resistance & molecular profiles	Strengthen monitoring of aquatic products & AMR control
Obayomi, O. V. et al. (2024)	Review of technologies	Review of emerging water treatment technologies	Identified effectiveness of nanotechnology, UV, oxidation	Adopt innovative technologies for pathogen removal
Burke, M. et al. (2025)	Systematic review	Review of microorganism removal by physicochemical methods	Membrane filtration superior to traditional methods	Expand use of advanced membranes in treatment plants
Moussa, A. S. et al. (2023)	Experimental study	Tracked Giardia/Cryptosporidium fate in treatment plants	Conventional + compact plants reduce protozoa, but not fully	Optimize pretreatment & combine with disinfection
Lanrewaju, A. A. et al. (2022)	Literature review	Review of disinfection methods for viruses	Chlorine limited against protozoa; UV/ozone more effective	Integrate advanced disinfection into standard practice
Contreras-Soto, M. B. et al. (2025)	Experimental study	Ozonation of wastewater (1.3 mg/L dose)	~99% reduction in Cryptosporidium parvum viability	Recommend ozone for agricultural reuse water
Freitas, B. L. S. et	Experimental lab	Tested UVC-LED (280 nm) under	Effective against	Use UV-LED but consider

Figure 3. Summary of Key References on Waterborne Pathogens, Treatment Methods, and Public Health Recommendations

CONCLUSIONS

Water is a critical resource, yet only a small fraction of global freshwater is usable, and over a billion people lack access to safe drinking water. Human activities are depleting and polluting water supplies, increasing the need for effective monitoring of biological pollutants. Traditional culture-based methods for detecting pathogens are slow and may not distinguish pathogenic from non-pathogenic microorganisms, highlighting the need for rapid, precise detection technologies. With freshwater scarcity projected to worsen, recent advances in water treatment—including carbon-based purification, advanced oxidation processes (AOPs), UV-C LED disinfection, membrane nanotechnology, electrochemical methods, AI-driven optimization, energy-efficient desalination, and enhanced biological treatments—offer sustainable, efficient, and adaptable solutions to meet the growing demand for safe water.

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CONFLICT OF INTEREST
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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