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Review of emerging contaminants in water: USA and African perspectives

Zamathula Queen Sikhakhane Nwokediegwu [1, *], Onyeka Henry Daraojimba [2], Johnson Sunday Oliha [3], Alexander Obaigbena [4], Michael Ayorinde Dada [5] and Michael Tega Majemite [6]

[1] *Independent Researcher, Durban South Africa.*
[2] *Department of Information Management, Ahmadu Bello University, Zaria, Nigeria.*
[3] *Independent Researcher, Lagos, Nigeria.*
[4] *Darey.io, United Kingdom.*
[5] *Sychar Water Technologies, Houston Texas, United States.*
[6] *Technical University Darmstadt, Germany.*

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Abstract

This research paper comprehensively reviews emerging contaminants in water, examining global trends and specific perspectives from the United States (USA) and Africa. Identifying contaminants originating from industrial, agricultural, and urban sources, the study explores regulatory frameworks, health, environmental impacts, and management strategies. Gaps and challenges are analyzed, including data limitations, regulatory gaps, and technological constraints. The paper recommends a holistic, adaptive approach, emphasizing research, regulatory adaptability, technological innovation, community empowerment, international collaboration, climate resilience, and equity. The proposed strategies aim to enhance water quality management, ensuring sustainable practices that safeguard human health, ecosystems, and equitable access to clean water on a global scale.

Keywords: Emerging Contaminants; Water Quality; Regulatory Frameworks; Environmental Health

1. Introduction

Water is an indispensable resource at the heart of sustainable development and public health. The quality of water, however, faces an escalating threat from a myriad of pollutants, including the insidious presence of emerging contaminants (Cohn, Sampou, & Verma; Connor, 2015; Gupta & Orbán, 2018). Emerging contaminants, often from industrial, agricultural, and urban activities, pose a growing concern globally, impacting both developed and developing regions. This paper undertakes a comprehensive review of the state of emerging contaminants in water, focusing on the perspectives of two distinct but interconnected regions—the United States of America (USA) and various nations across the African continent.

The significance of water quality cannot be overstated, as it directly influences human health, ecosystems, and economic activities. Emerging contaminants, a term encapsulating a diverse range of pollutants not traditionally monitored, present a contemporary challenge to water management (Alipoori et al., 2021; Rodriguez-Mozaz, de Alda, & Barceló, 2007; Sharma, Verma, Lugani, Kumar, & Asadnia, 2021). These contaminants include pharmaceuticals, personal care products, pesticides, industrial chemicals, and byproducts. Unlike conventional pollutants, identifying, assessing, and regulating emerging contaminants present unique challenges due to their dynamic nature and evolving sources (Dey, Bano, & Malik, 2019; Osuoha, Anyanwu, & Ejileugha, 2023).

* Corresponding author: Zamathula Queen Sikhakhane Nwokediegwu

This research seeks to achieve a dual objective. Firstly, it aims to provide a comprehensive understanding of the landscape of emerging contaminants in water globally, with a specific emphasis on the USA and Africa. Secondly, it endeavors to shed light on the divergent yet interconnected challenges these regions face in managing and mitigating the impacts of emerging contaminants. This study aims to contribute valuable insights for policymakers, researchers, and stakeholders involved in water quality management by comparing and contrasting the regulatory frameworks, prevalent contaminants, and management strategies.

The scope of this review encompasses an exploration of the current state of water contamination globally, focusing on the perspectives of the USA and Africa. While the USA represents a developed nation with established regulatory frameworks, Africa, comprising diverse countries at various stages of development, offers insights into the challenges faced by emerging economies in safeguarding water quality. Through an examination of the factors contributing to water contamination, the health and environmental consequences, regulatory frameworks, and management strategies, this paper aspires to contribute to the evolving discourse on mitigating the impacts of emerging contaminants in water. As the world grapples with the increasing complexity of water quality issues, this research aims to foster a deeper understanding of the challenges posed by emerging contaminants and provide a foundation for informed decision-making and collaborative efforts toward sustainable water management practices.

2. Concept of Emerging Contaminants

The term "emerging contaminants" refers to a diverse array of pollutants in water that have gained attention due to their presence, persistence, and potential adverse effects on human health and the environment (Pereira et al., 2015; Yadav et al., 2021). Unlike conventional pollutants, emerging contaminants are not routinely monitored or regulated, and their identification often requires ongoing research and surveillance. These contaminants encompass various chemical classes, including pharmaceuticals, personal care products, industrial chemicals, pesticides, and byproducts.

Emerging contaminants reflect the dynamic nature of water pollution, where new substances continually enter aquatic environments and pose potential risks (Morin-Crini et al., 2021). The sources of these contaminants are multifaceted, originating from industrial discharges, agricultural runoff, improper disposal of pharmaceuticals, and urban activities. Understanding emerging contaminants requires a holistic approach, considering their fate and transport in water bodies, the potential for bioaccumulation, and their impacts on human and ecological health.

Examples of Common Emerging Contaminants

- Pharmaceuticals: Residual drugs from human and veterinary use.
- Personal Care Products: Ingredients from cosmetics and hygiene products.
- Pesticides and Herbicides: Agricultural chemicals that can leach into water sources.
- Industrial Chemicals: Including per- and polyfluoroalkyl substances (PFAS) and endocrine-disrupting compounds.
- Microplastics: Tiny plastic particles that accumulate in water bodies (de Oliveira et al., 2020; Gonsioroski, Mourikes, & Flaws, 2020; Jha et al., 2021).

Globally, the issue of emerging contaminants in water has garnered increasing attention in recent decades. Concerns revolve around the potential long-term impacts on ecosystems, the unknown consequences of chronic exposure on human health, and the challenges associated with regulating a diverse range of contaminants. Significant studies indicate a rising prevalence of emerging contaminants in developed and developing regions, emphasizing the need for collaborative efforts to address this complex issue (Agranoff & McGuire, 2003; Dulio et al., 2018; Papadopoulos et al., 2012; Thomas-Sharma et al., 2016). Landmark studies, such as the World Health Organization's Global Assessment of Water Quality, have underscored the ubiquitous presence of emerging contaminants in surface and groundwater. Research initiatives like the Global Emerging Pathogen Surveillance (GEPS) project have aimed to monitor contaminants of emerging concern, providing valuable data for understanding their distribution and potential risks (Farré, 2020; Raman et al., 2023).

The United States faces significant challenges in managing water quality due to a complex interplay of industrial, agricultural, and urban activities. Various water bodies, including rivers, lakes, and groundwater reservoirs, are affected by multiple emerging contaminants. Notable incidents, such as lead contamination in Flint, Michigan, have heightened public awareness of the vulnerabilities in water infrastructure. The USA has implemented regulatory frameworks to address emerging contaminants in response to the evolving water quality landscape. Agencies like the Environmental Protection Agency (EPA) are crucial in setting standards and guidelines. Initiatives like the Unregulated Contaminant Monitoring Rule (UCMR) aim to assess the occurrence of emerging contaminants in drinking water supplies, informing regulatory actions to protect public health (Bell, Horst, & Anderson, 2019; Levin et al., 2023; Tsaridou & Karabelas, 2021).

With its diverse ecosystems and socio-economic landscapes, Africa faces unique challenges in managing water quality. Many regions grapple with limited access to clean water, inadequate sanitation, and pollution from various sources. Although less studied than developed regions, emerging contaminants threaten water resources critical for human survival and agricultural activities. In Africa, challenges related to emerging contaminants include limited infrastructure, inadequate monitoring systems, and competing priorities for resource allocation. Regulatory frameworks vary across countries, with some nations actively working to strengthen water quality management. Initiatives like the African Water Facility (AWF) aim to support sustainable water resource management. However, the complex nature of emerging contaminants requires concerted efforts at regional and international levels (Nojiyeza, 2014; Said, Funke, Jacobs, Steyn, & Nienaber, 2011).

In summary, the global discourse on emerging contaminants in water underscores the need for a nuanced understanding of these pollutants. While the USA and Africa exhibit divergent contexts, a comprehensive review of their perspectives provides valuable insights into the complex challenges and potential solutions surrounding water quality management.

3. Factors Contributing to Water Contamination

Water contamination is a multifaceted challenge influenced by various anthropogenic and natural factors. Understanding the complexity of these contributors is crucial for formulating effective strategies to mitigate and prevent water pollution. The following sections explore vital factors contributing to water contamination, considering global trends and the specific contexts of the USA and Africa.

3.1. Industrial Activities

Industrial discharges, including effluents from manufacturing processes, contribute significantly to water pollution globally. Chemical contaminants such as heavy metals, solvents, and industrial byproducts find their way into water bodies, posing a threat to aquatic ecosystems and human health (Madhav et al., 2020; Mishra et al., 2019). In the USA, industrial discharges are regulated under frameworks like the Clean Water Act. However, challenges persist, with industrial spills and inadequate wastewater treatment systems impacting water quality in various regions. In Africa, rapid industrialization coupled with insufficient infrastructure often leads to unregulated discharge of pollutants into water bodies. Efforts to balance industrial development with environmental conservation are essential for sustainable water quality management (Perry & Vanderklein, 2009).

3.2. Agricultural Practices

Agricultural runoff, containing fertilizers, pesticides, and herbicides, significantly contributes to water contamination globally. Nutrient pollution from agricultural activities can lead to eutrophication, disrupting aquatic ecosystems. In the USA, agricultural runoff is a significant concern, particularly in regions with intensive farming. The use of fertilizers and pesticides contributes to nutrient and chemical contamination in surface and groundwater. Agriculture is a vital sector in Africa, and improper pesticide use and inadequate soil conservation contribute to water pollution. Balancing agricultural productivity with sustainable practices is essential for minimizing these impacts (Adomako & Ampadu, 2015; Zahoor & Mushtaq, 2023).

3.3. Urbanization

Rapid urbanization results in increased impervious surfaces, altering natural water flow patterns and leading to heightened levels of pollutants in urban runoff. Stormwater runoff from urban areas carries contaminants such as heavy metals, oils, and chemicals into water bodies. Urbanization in the USA has led to challenges such as combined sewer overflows and stormwater runoff, impacting water quality in urban water bodies. Sustainable urban planning and stormwater management strategies are critical for addressing these issues. As African urban populations grow, the lack of adequate infrastructure and urban planning often results in untreated wastewater discharge into water sources. The integration of sustainable urban development practices is essential for minimizing the environmental impact (Edokpayi, Odiyo, & Durowoju, 2017; Jacobsen, Webster, & Vairavamoorthy, 2012; Tariq & Mushtaq, 2023).

3.4. Mining Activities

Mining activities introduce a range of pollutants, including heavy metals and sediments, into water bodies. Acid mine drainage is particularly pervasive, threatening surface and groundwater quality. Historical and ongoing mining activities in the USA have left a legacy of contaminated sites, impacting water quality. Regulatory measures and remediation efforts aim to address these challenges. Mining is a crucial economic activity in many African countries, but inadequate environmental safeguards can contaminate water. Striking a balance between economic development and environmental protection is imperative (George, Ephrahim, & Onyeka, 2010; Mensah et al., 2015; Pretty & Odeku, 2017).

4. Health and Environmental Impacts

Water contamination, driven by various pollutants, has far-reaching consequences on human health and the environment. This section explores the interconnected impacts of emerging contaminants, considering the global perspective and specific contexts in the USA and Africa.

4.1. Human Health

The presence of emerging contaminants in water poses potential risks to human health. Exposure to pharmaceutical residues, industrial chemicals, and microbial contaminants can result in adverse health effects, including endocrine disruption, antibiotic resistance, and the spread of waterborne diseases. In the USA, concerns about human health arise from contaminants like lead, PFAS, and pharmaceuticals in drinking water. Prolonged exposure to these substances has been linked to developmental issues, reproductive problems, and chronic diseases. In Africa, where access to clean water is often limited, waterborne diseases like cholera and typhoid pose significant health risks. Emerging contaminants, when present, can exacerbate these challenges, emphasizing the urgent need for improved water quality management (Hemson, 2016; Kulshrestha & Mittal, 2003).

4.2. Environmental Consequences

Aquatic ecosystems bear the brunt of water contamination, experiencing a range of ecological disturbances. Chemical pollutants can harm aquatic organisms, disrupt food chains, and alter the biodiversity of rivers, lakes, and oceans. In the USA, oil spills and industrial discharges devastate aquatic ecosystems (Zhang et al., 2019). The contamination of water bodies has resulted in fish kills, habitat degradation, and long-term ecological imbalances. Africa's diverse ecosystems face threats from both traditional pollutants and emerging contaminants. The discharge of pollutants into rivers and lakes jeopardizes the health of aquatic life, affecting fisheries and the livelihoods of communities dependent on these resources (Ewim et al., 2023; K'oreje, Okoth, Van Langenhove, & Demeestere, 2020; Onukogu et al., 2023).

4.3. Bioaccumulation and Biomagnification

Specific contaminants have the potential to bioaccumulate and biomagnify through food chains. This process can lead to elevated pollutants in apex predators, threatening wildlife and human consumers. In the USA, concerns about bioaccumulation are evident in the case of mercury, which accumulates in fish. Consumption of contaminated fish can lead to mercury poisoning, especially in vulnerable populations. In Africa, where traditional reliance on fish for nutrition is common, the bioaccumulation of contaminants in fish is a significant concern. Balancing the nutritional needs of communities with the potential health risks poses a complex challenge (Ali & Khan, 2018; Rodríguez-Jorquera et al., 2017; Saidon, Szabó, Budai, & Lehel, 2024).

4.4. Eutrophication

Excessive nutrient runoff, often from agricultural activities, can lead to eutrophication—an overgrowth of algae in water bodies. This can deplete oxygen levels, harm aquatic life, and create "dead zones." Nutrient pollution is a prevalent issue in the USA, with agricultural runoff contributing to eutrophication in bodies of water like the Gulf of Mexico (Bailey, Meyer, Pettingell, Macie, & Korstad, 2020; Joyce, 2000). Efforts to reduce nutrient runoff are crucial for mitigating these impacts. Eutrophication is a growing concern in Africa as agricultural intensification increases nutrient runoff. Managing nutrient levels in water bodies is essential for preserving aquatic ecosystems and the services they provide (Whitaker, 2019).

5. Regulatory Frameworks and Management Strategies

Efficient regulatory frameworks and management strategies are essential to comprehensive water quality management. This section examines the regulatory approaches and management strategies employed globally, specifically in the USA and Africa, in response to the challenges posed by emerging contaminants.

5.1. USA Regulatory Framework

Clean Water Act (CWA): The cornerstone of water quality regulation in the USA, the Clean Water Act empowers the Environmental Protection Agency (EPA) to establish and enforce water quality standards. The National Pollutant Discharge Elimination System (NPDES) under the CWA regulates point source discharges, controlling the release of pollutants into navigable waters (Czarnezki, Lam, & Ahmad, 2015; Drelich, 2009).

Safe Drinking Water Act (SDWA): The SDWA focuses on ensuring the safety of drinking water. The EPA sets standards for contaminants in public water supplies, including emerging contaminants. The Unregulated Contaminant Monitoring Rule (UCMR) enables the EPA to evaluate contaminants that are not currently regulated (Act, 1974; Tiemann, 2014).

Emerging Contaminants Action Plan: The EPA addresses emerging contaminants, emphasizing research, risk assessment, and regulatory development. This plan enables the EPA to proactively respond to newly identified contaminants, ensuring a robust regulatory framework (Murray, Thomas, & Bodour, 2010).

5.2. African Regulatory Landscape

Regional and National Approaches: African regulatory frameworks vary across countries, reflecting diverse economic and developmental contexts. Regional bodies like the African Union (AU) provide guidelines, but implementation depends on individual nations.

Challenges and Opportunities: Many African countries face challenges enforcing water quality regulations due to limited resources, institutional capacities, and competing priorities. Opportunities lie in strengthening regional collaboration and leveraging international support for capacity building (Herrera, 2019; Saleth & Dinar, 2000).

National Water Quality Policies: Several African countries have established national water quality policies to address contamination issues. These policies encompass monitoring, regulation, and enforcement mechanisms. However, implementation gaps persist, requiring sustained efforts for effective enforcement (Abbaspour, 2011; Kreamer & Usher, 2010).

5.3. Best Practices and Management Strategies

Adopting a watershed management approach is critical for both the USA and Africa. Protecting source waters through land-use planning, riparian buffers, and sustainable agricultural practices helps prevent contaminants from entering water bodies. In both regions, investing in advanced water treatment technologies is crucial. Techniques such as advanced oxidation processes and membrane filtration can effectively remove emerging contaminants, ensuring the delivery of safe drinking water. Enhancing public awareness is a common strategy. In the USA, public water systems are mandated to provide Consumer Confidence Reports. In Africa, community-based education programs promote water conservation and pollution prevention. Both regions prioritize ongoing research to identify emerging contaminants and understand their effects. Collaborative research efforts contribute to the development of innovative solutions, such as the use of natural systems for water treatment (Andrews, Stevens, & Wise, 2002; Jeong & Koh, 2002).

Many African countries face limitations in monitoring, enforcing regulations, and implementing water quality management strategies. Insufficient data on emerging contaminants in the USA and Africa hinder comprehensive risk assessments. Rapid advancements in science and technology may outpace the ability of regulations to keep up. However, collaboration between nations and international organizations can enhance knowledge sharing, capacity building, and regulatory harmonization. Investing in research and technological innovation will pave the way for more efficient detection and removal of emerging contaminants. Empowering local communities through education and engagement fosters a shared responsibility for water quality.

6. Gaps and Challenges

Addressing emerging contaminants in water presents a set of complex challenges. It reveals critical gaps in current research, regulations, and resource allocation. This section examines the critical gaps and challenges faced globally and within the specific contexts of the USA and Africa.

Many regions lack comprehensive monitoring systems for emerging contaminants, resulting in a dearth of data on their prevalence and distribution. The dynamic nature of emerging contaminants poses challenges in conducting robust risk assessments, leading to uncertainties in understanding potential impacts. Rapid advancements in analytical techniques continually reveal new contaminants, outpacing the development of regulatory standards and risk assessments. Limited understanding of multiple contaminants' cumulative and synergistic effects hinders accurate risk assessments. Many African countries face data collection, monitoring, and research challenges, leading to a lack of comprehensive information on emerging contaminants. Limited institutional capacities hinder conducting thorough risk assessments and implementing effective water quality management strategies (Organization, 2004; Qadir et al., 2010).

Regulatory frameworks vary globally, leading to inconsistencies in identifying and managing emerging contaminants. Rapidly evolving contaminants necessitate regulatory frameworks that can adapt swiftly, which is often challenging for existing systems. The pace of regulatory development struggles to identify new contaminants, potentially leaving gaps in protection. Some emerging contaminants lack regulatory standards, leaving water supplies vulnerable to potential health risks. Varied regulatory capacities and approaches among African countries result in challenges in harmonizing and implementing effective water quality standards. Weak enforcement mechanisms undermine the effectiveness of existing regulations, allowing pollution to persist.

Implementing advanced treatment technologies for emerging contaminants can be financially prohibitive, especially in resource-constrained regions. Aging water infrastructure in the USA requires substantial investment to upgrade treatment facilities and address contamination issues effectively. Many African nations face financial constraints, limiting their ability to invest in advanced water treatment technologies and infrastructure upgrades (Briscoe, 1999; Rosnes & Shkaratan, 2011). Public understanding of emerging contaminants and their potential health and environmental impacts remains relatively low in many regions. Communicating complex scientific information to the public poses challenges, affecting public awareness and cooperation with water quality initiatives. Limited community engagement and awareness hinder efforts to mobilize local support for sustainable water management practices.

The lack of a unified global approach hampers information sharing, collaborative research, and the development of standardized solutions. Enhanced collaboration with international partners could contribute to shared knowledge and resources addressing global water quality challenges. Strengthening regional cooperation can facilitate knowledge exchange and resource sharing to address common water quality concerns. Climate change influences the transport and fate of contaminants, adding complexity to the understanding and management of emerging contaminants. The increased frequency of extreme weather events in the USA poses challenges in managing water quality, with events like floods impacting contaminant dispersion. African nations are particularly vulnerable to climate change, exacerbating existing water quality challenges and increasing the risks associated with emerging contaminants.

Vulnerable communities often bear a disproportionate burden of water contamination, highlighting environmental justice concerns that need targeted interventions. Certain populations, especially marginalized communities, may face higher exposure to emerging contaminants, emphasizing the need for equitable water quality measures (Balazs & Ray, 2014; Vanderwarker, 2012). Disparities between rural and urban areas in access to clean water and sanitation contribute to differential exposure to water contaminants. Disparities in research capabilities and access to information can lead to uneven understanding and responses to emerging contaminants. Bridging the gap between scientific research and public understanding is crucial for fostering informed decision-making and community engagement. Strengthening research capacities in African nations is essential for generating localized data and developing context-specific water quality management strategies.

7. Future Directions and Recommendations

As we confront the evolving challenges of emerging contaminants in water, we must chart a course toward sustainable and resilient water quality management. Future directions should encompass research priorities, regulatory enhancements, technological innovations, and community engagement. The following recommendations offer a roadmap for policymakers, researchers, and stakeholders to address the gaps and challenges identified in the previous sections.

Allocate resources for research focusing on identifying emerging contaminants, understanding their fate and transport, and assessing their health and environmental impacts. Establish comprehensive and long-term monitoring programs to track the occurrence and trends of emerging contaminants globally, regionally, and locally. Foster international collaboration to share data, expertise, and resources for a more holistic understanding of emerging contaminants. Promote interdisciplinary research that combines expertise from environmental science, public health, engineering, and other relevant fields.

Develop adaptive regulatory frameworks that can swiftly respond to identifying new contaminants and evolving scientific knowledge. Work towards harmonizing water quality standards globally and regionally to ensure consistency in identifying and managing emerging contaminants. Involve the public in regulatory decision-making processes, ensuring transparency and accountability in setting and updating standards. Implement regular reviews of regulatory frameworks to incorporate the latest scientific advancements and address emerging challenges.

Invest in developing and deploying cost-effective advanced treatment technologies capable of removing a broad spectrum of emerging contaminants. Leverage remote sensing technologies and real-time monitoring systems to enhance the detection and tracking of pollutants. Encourage collaboration between government agencies, private sector entities, and research institutions to accelerate the adoption of innovative technologies. Prioritize investments in upgrading water infrastructure to accommodate advanced treatment technologies.

Develop and implement community-based programs that empower residents to participate actively in water quality monitoring and conservation efforts. Enhance public awareness through educational campaigns, emphasizing the importance of water conservation and pollution prevention. Tailor education and engagement programs to be culturally sensitive, recognizing different communities' diverse needs and perspectives. Ensure that community members, especially those disproportionately affected, are included in decision-making processes related to water quality management.

Facilitate international collaboration platforms to share knowledge, best practices, and lessons learned in addressing emerging contaminants. Support capacity-building initiatives in developing regions, fostering local expertise in monitoring and managing water quality. Create international research networks to pool resources and expertise for collaborative studies on emerging contaminants. Encourage joint initiatives between developed and developing nations to address common challenges and share technological solutions.

Develop adaptation strategies that consider the impact of climate change on the transport, fate, and toxicity of emerging contaminants. Integrate water quality management into broader climate change adaptation and mitigation plans. To develop integrated strategies and promote collaboration between water management authorities and climate change agencies. Allocate resources for research on the specific impacts of climate change on water quality and emerging contaminants.

Prioritize policies that ensure equitable access to clean water and sanitation, addressing environmental justice concerns. Conduct health assessments in communities affected by water contamination, considering social and economic disparities. Prioritize community consultation in developing water quality regulations to address the needs and concerns of diverse populations. Integrate equity impact assessments into water quality management policies to identify and mitigate potential disparities.

8. Conclusion

Examining emerging contaminants in water from global, USA and African perspectives underscores the urgency of addressing the multifaceted challenges associated with water quality management. The intricate interplay between industrial activities, agricultural practices, urbanization, and climate change necessitates a holistic and adaptive approach to safeguarding water resources. As we navigate the complex landscape of contaminants, gaps, and regulatory frameworks, several vital takeaways emerge:

The concept of emerging contaminants demands a holistic understanding that transcends conventional regulatory frameworks. Current and future research should focus on identifying emerging contaminants, understanding their fate and transport, and assessing the cumulative impacts on human health and the environment. Regulatory frameworks must evolve at a pace commensurate with identifying new contaminants. Adaptive regulations that incorporate the latest scientific knowledge and technologies are essential. Harmonizing standards globally and regionally can foster consistency and enhance the effectiveness of water quality management efforts.

Investing in advanced treatment technologies and remote sensing capabilities is imperative for staying ahead of the dynamic nature of emerging contaminants. Public-private partnerships and infrastructure upgrades are vital to effectively deploying these innovations and ensuring the resilience of water treatment systems. Engaging and empowering local communities are central to sustainable water quality management. Community-based programs, education initiatives, and inclusive decision-making processes contribute to a sense of shared responsibility, fostering long-term commitment to water conservation.

The challenges of emerging contaminants transcend borders, emphasizing the need for robust international collaboration. Knowledge exchange, capacity building, and joint initiatives can accelerate progress in addressing shared concerns and achieving global water security. The intersection of emerging contaminants and climate change necessitates adaptive strategies that consider the evolving dynamics of water quality. Integrating water quality management into broader climate change plans and researching climate impacts is critical for building resilient systems. Equity and environmental justice must be at the forefront of water quality management efforts. Prioritizing equitable access, conducting community health assessments, and incorporating equity impact assessments into policies can help address disparities and ensure just outcomes.

In conclusion, the path forward requires a collaborative and multidisciplinary approach integrating scientific innovation, regulatory foresight, and community engagement. By embracing these principles, stakeholders can work towards a future where water resources are protected, communities are empowered, and the impacts of emerging contaminants are mitigated, ensuring a sustainable and resilient water future for all.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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