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Climate Change and Emerging Waterborne Diseases: A Review

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Abstract

Climate change is significantly altering global hydrological systems, creating favourable conditions for the emergence and spread of waterborne diseases. Rising temperatures, increased flooding, prolonged droughts and extreme weather events are disrupting water quality and availability, exacerbating the transmission of pathogens through contaminated water sources. The sudden shifts in climatic factors influence the survival, reproduction, and distribution of infectious agents, including bacteria (e.g., *Vibrio cholerae*, *Leptospira* sp.), viruses (e.g., norovirus, hepatitis E) and parasites (e.g., *Cryptosporidium* sp., *Giardia* sp.). The warming of aquatic environments enhances the growth of harmful algal blooms and expands the geographic range of vector-borne diseases with water-related transmission cycles, such as those caused by Aedes and Culex mosquitoes. In addition to environmental drivers, human factors including urbanization, inadequate sanitation infrastructure and population displacement intensify vulnerability to waterborne disease outbreaks. Flood-prone regions and drought-affected areas illustrate how extreme weather events compromise water safety, leading to waterborne disease outbreaks. Furthermore, antimicrobial resistance (AMR) in waterborne pathogens is an emerging growing concern, as climate stress and pollution accelerate the evolution of drug-resistant strains in aquatic ecosystems. Thus, this review examines the complex relationship between climate change and the rising incidence of waterborne diseases, focusing on emerging pathogens. By synthesizing current knowledge, the world can craft strategies that enhance global resilience against the converging crises of climate change and waterborne disease emergence.

Keywords: Emerging Waterborne Diseases, Climate Change, Global Warming

Introduction

Climate change represents one of the most significant global challenges of the 21st century, influencing every facet of environmental and anthropogenic realm. Among its wide-ranging effects is the increased prevalence and spread of waterborne diseases with crippling impacts on vulnerable populations worldwide (Levy *et al.,* 2018). These diseases, caused by pathogenic microorganisms such as bacteria, viruses and protozoa, are typically transmitted through contaminated drinking water, food prepared with contaminated water or recreational exposure to unsafe water sources (Ashbolt, 2004; Lanrewaju *et al.,* 2022). Climate variability, characterized by rising temperatures, altered precipitation patterns, sea-level rise and increased frequency of extreme weather events, directly and indirectly facilitates the emergence, transmission and persistence of waterborne pathogens. As a result, climate change is altering the global distribution and seasonality of waterborne diseases, posing new risks to public health, particularly in vulnerable regions with inadequate water management and sanitation infrastructure. Thus, the review explores the multifaceted relationship between climate change and emerging waterborne diseases.

Climate change and aquatic system

An essential part of the global environment are aquatic ecosystems which are vital contributors to ecological production and biodiversity and they also offer a range of services to humans such as recreational activities, habitat for economically significant fisheries and water for drinking and irrigation. However, human activity has been posing a growing direct and indirect hazard to aquatic systems and the situation become more worse due to global climate change (Priya *et al.,* 2023). Changes in rainfall patterns can cause both prolonged droughts and intense flooding, each of which influences water quality in different ways. Intense rainfall events often lead to surface runoff, overwhelming sanitation infrastructure and leading to the contamination of drinking water supplies with faecal material, pathogens and chemical pollutants. Floodwaters, particularly in urban areas, can mix with untreated sewage, providing ideal conditions for outbreaks of diseases such as cholera, typhoid and leptospirosis (Lau *et al.,* 2010; James *et al.,* 2018; Nelson *et al.,* 2022). Conversely, droughts reduce the availability of clean water, forcing populations to rely on stagnant or compromised water sources. Reduced water levels can concentrate pollutants and pathogens, while also promoting the proliferation of harmful algal blooms, many of which produce toxins that threaten both human and aquatic life. Furthermore, rising global temperatures favour the survival and reproduction of many waterborne pathogens, extending their active seasons and enabling their spread to previously unaffected regions. The major impacts of climate change on water resources are portrayed by Poff *et al.* (2002) are given below,

- The spatial distribution of aquatic species and basic biological processes will shift as a result of climate change-induced increases in water temperatures. However, human modification of possible migratory routes, however, may restrict a species' capacity to migrate, raising the risk of biodiversity loss and species extinction.
- Seasonal variations in runoff and precipitation patterns will modify aquatic systems' hydrologic properties, impacting ecosystem productivity and species composition. Climate change is likely to further stress sensitive freshwater and coastal wetlands, which are already negatively impacted by an array of other human impacts. Changes in the seasonal timing of snowmelt will alter stream flows, potentially interfering with the reproduction of many aquatic species.

- In addition to being vital parts of coastal and marine fisheries, wetlands offer an essential home for many species that are not well suited to other environmental conditions.
- The capacity of aquatic ecosystems to adjust to climate change is restricted and steps to lower the probability of major impacts include keeping riparian forests intact, lowering nutrient loading, repairing ecosystems that have been harmed, minimizing groundwater removal and carefully locating any new reservoirs to reduce negative consequences.

Emerging waterborne diseases

Waterborne diseases have long been a significant public health concern, but the emergence of new pathogens and the re-emergence of known pathogens in novel contexts are creating unprecedented challenges. Climate change, urbanization, globalization and environmental degradation are key drivers reshaping the landscape of waterborne illnesses, exposing vulnerable populations to heightened risks (Latendresse, 2023). As traditional pathogens like *Vibrio cholerae* and *Salmonella* sp. adapt to changing conditions, previously unrecognized or rare microbes are increasingly being linked to waterborne outbreaks, complicating prevention and treatment efforts. The warming of aquatic environments due to climate change is particularly concerning, as it expands the geographic range of waterborne pathogens (Semenza and Ko, 2023). Warmer waters enhance the growth and survival of bacteria which thrives in warmer temperatures and proliferates in poorly maintained water systems. Similarly, harmful algal blooms, fuelled by rising temperatures and nutrient pollution, produce toxins that contaminate drinking water and seafood, leading to illnesses like ciguatera poisoning and paralytic shellfish poisoning (Rolton *et al.,* 2022). Extreme weather events, including floods and heavy rainfall, further exacerbate the problem by overwhelming sanitation infrastructure and flushing pathogens into water supplies. Flood-related outbreaks of leptospirosis, hepatitis E and cryptosporidiosis have been documented in tropical and temperate regions alike, demonstrating the global nature of this threat.

Urbanization and population growth are additional factors contributing to the emergence of waterborne diseases. Rapid urban expansion often outpaces the development of adequate water and sanitation systems, leading to overcrowded slums where contaminated water and poor hygiene facilitate disease transmission. In these settings, even previously controlled pathogens can resurge with devastating consequences. For example, antibiotic-resistant strains of *Escherichia coli* and *Shigella* sp. are increasingly detected in urban water sources, posing treatment challenges in outbreaks (Larson *et al.,* 2019). Migration and displacement due to conflict or climate-related disasters further strain water infrastructure, creating ideal conditions for epidemics. Refugee camps and informal settlements frequently experience diarrheal disease outbreaks, with children and immunocompromised individuals at greatest risk.

In addition, international travel and trade can introduce pathogens to new regions where local populations lack immunity or where environmental conditions favour their persistence. The emergence of Naegleria fowleri, a brain-eating amoeba, in previously unaffected areas has been linked to climate warming and human activity (Maciver *et al.,* 2020). Similarly, the spread of drug-resistant *Aeromonas* sp. (Skwor *et al.,* 2020) and *Pseudomonas* sp. (Hafiane *et al.,* 2019) through contaminated water highlights the intersection of antimicrobial resistance and waterborne disease emergence. The World Economic Forum (2021) reiterated that antimicrobial resistance from water pollution has grown into a major global public health concern. The rise of emerging waterborne diseases underscores the urgent need for global cooperation as it is a cornerstone of global equity and security in an era of rapid

environmental change. The key pathways and climate change drivers of waterborne diseases are given in Table 1.

Key climate change drivers	Key climate hazards	Climate-sensitive pathways
Fossil fuels Deforestation Agriculture Land use	Increased ambient temperature	Mobilization and dispersion Environmental Fate Exposure Pathway Disease Burden Pathogen replication, survival, and virulence Low water availability and elevated pathogen concentrations
	Extreme precipitation and floods	Contact with floodwater and sewage Lack of clean water for hygiene Ingestion of contaminated water and food
	Increased droughts sea-level rise	Disrupted public health surveillance, emergency responses, and prevention Disrupted access to health care Food insecurity, malnutrition, and disease susceptibility

Table 1: Pathways and climate change drivers of waterborne diseases
(Modified from Semenza and Ko, 2023)

Impact of extreme weather events

Extreme weather events, exacerbated by climate change, are major drivers of waterborne disease outbreaks. Hurricanes, cyclones and typhoons often destroy critical infrastructure, including water treatment facilities and sewage systems, creating ideal conditions for the spread of diseases (Cann *et al.,* 2013). In the aftermath of Hurricane Katrina in 2005, for example, thousands of cases of gastrointestinal disease cases were reported due to contaminated water (Yee *et al.,* 2007). Similarly, recurrent flooding in South Asia frequently leads to outbreaks of cholera and leptospirosis (Liang and Messenger, 2018; Shafii *et al.,* 2023). The 2017 hurricane season provided tragic examples of this phenomenon, with multiple Caribbean islands experiencing disease outbreaks (Shultz *et al.,* 2019). Thus, floods, droughts, hurricanes and heatwaves are not just temporary inconveniences - they are fundamentally altering the landscape of public health by compromising water quality and accessibility on a global scale.

On the other hand, during droughts freshwater sources diminish, the remaining water supplies become concentrated with pollutants and pathogens, while water scarcity forces populations to rely on potentially contaminated alternatives. The resulting health impacts are particularly severe in regions already struggling with water infrastructure challenges, where children and immunocompromised

individuals bear the brunt of waterborne diseases. Charnley *et al.* (2021) critically reviewed the traits and risk factors of post-disaster infectious disease outbreaks and reiterated that understanding the risk factors and cascades, could help improve future region-specific disaster risk reduction. It should be noted that, the intersection of extreme weather events, water insecurity and infectious disease creates a feedback loop that threatens to undo decades of progress in global health. The window for effective action is narrowing, but the tools for meaningful intervention - from advanced water treatment technologies to nature-based solutions - are increasingly within reach if the world can muster the political will and resources to deploy them at scale.

Socioeconomic and public health implications

The socioeconomic and public health implications of climate change and emerging waterborne diseases present one of the most pressing challenges today with far-reaching consequences. The dangerous synergy between climate change and waterborne diseases threatens to reverse decades of progress in public health, particularly in low- and middle-income countries where access to clean water and medical resources is already limited (Semenza, 2020). The economic costs are staggering, with waterborne disease outbreaks draining national budgets through healthcare expenditures, lost productivity and emergency response measures, while also deterring investment and tourism in affected regions. The public health burden of climate-sensitive waterborne diseases manifests most acutely among marginalized communities that lack resilient infrastructure and social safety nets (Parry *et al.,* 2019; WHO, 2023). The dynamics of climate change and emerging waterborne diseases create a vicious cycle wherein climate change exacerbates disease transmission, which in turn deepens poverty and inequality by reducing workforce participation, overwhelming public health capacity and diverting resources from long-term development to crisis management.

From a socioeconomic perspective, the ripple effects of waterborne disease outbreaks extend far beyond immediate health impacts. Agricultural communities dependent on reliable water sources face crop losses and livestock deaths when droughts or floods contaminate irrigation supplies, threatening food security and livelihoods. Small-scale fisheries are equally vulnerable to toxic algal blooms fuelled by warmer waters. In urban areas, outbreaks disrupt labour markets and education when workers and students fall ill, while the stigma of disease can isolate affected communities and depress local economies. Poor water quality and sanitation already cost billions annually in lost GDP across developing nations and the figure poised to grow as climate impacts intensify. Furthermore, the spectre of waterborne pandemics looms larger as climate and land-use changes bring humans into closer contact with novel zoonotic pathogens harboured in aquatic animal reservoirs.

Conclusion

The nexus between climate change and emerging waterborne diseases is an urgent public health challenge that requires immediate and sustained global attention. As climatic shifts continue to disrupt hydrological cycles and create new ecological niches for waterborne pathogens, proactive adaptation strategies are essential to safeguard public health. Strengthening infrastructure, enhancing surveillance systems, promoting climate-resilient sanitation and fostering international cooperation are the key pillars in building resilience against these threats. The convergence of climate stressors with factors like urbanization, antimicrobial resistance, and fragile water infrastructure has created a perfect storm for disease emergence, disproportionately affecting vulnerable populations with the least capacity to adapt.

Current evidence reveals disturbing trends: the reactivation of ancient pathogens from thawing permafrost, the spread of vibrio infections into previously temperate waters and the increased frequency of diarrheal outbreaks following climate disasters. These challenges are compounded by the alarming speed at which waterborne pathogens are developing antimicrobial resistance in polluted aquatic environments. It is unlikely that disasters will decline in the near future, hence a concerted effort is required to reduce risk by boosting capacity through preparedness measures and decreasing susceptibility through preventive and mitigation. Furthermore, the reality that catastrophes are human tragedies that necessitate an international effort to pinpoint the best practices and shortcomings of current responses should not be overshadowed by the economic and political aspects of disasters. As the climate crisis continues to evolve, so too must the approaches to monitoring, predicting, and preventing waterborne disease outbreaks. By treating water security as both a public health imperative and climate justice issue, the world can build defences against the coming waves of climate-amplified waterborne threats while working toward the more fundamental solution of climate change mitigation itself. The alternative - a world where safe drinking water becomes increasingly scarce and waterborne diseases more virulent - is a future that cannot afford to accept.

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