Drowning risk and climate change: a state-of-the-art review

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ABSTRACT
Drowning and climate change are both significant global health threats, yet little research links climate change to drowning risk. Research into the epidemiology, risk factors and preventive strategies for unintentional drowning in high-income and in low-income and middle-income countries has expanded understanding, but understanding of disaster and extreme weather-related drowning needs research focus. As nation states and researchers call for action on climate change, its impact on drowning has been largely ignored. This state-of-the-art review considers existing literature on climate change as a contributor to changes in drowning risks globally. Using selected climate change-related risks identified by the World Meteorological Organization and key risks to the Sustainable Development Goals as a framework, we consider the drowning risks associated with heat waves, hydrometeorological hazards, drought and water scarcity, damaged infrastructure, marine ecosystem collapse, displacement, and rising poverty and inequality. Although the degree of atmospheric warming remains uncertain, the impact of climate change on drowning risk is already taking place and can no longer be ignored. Greater evidence characterising the links between drowning and climate change across both high-income and low-income and middle-income contexts is required, and the implementation and evaluation of drowning interventions must reflect climate change risks at a local level, accounting for both geographical variation and the consequences of inequality. Furthermore, collaboration between the injury prevention, disaster risk reduction and climate change mitigation sectors is crucial to both prevent climate change from stalling progress on preventing drowning and further advocate for climate change mitigation as a drowning risk reduction mechanism.

INTRODUCTION
Climate change threatens human health through a number of pathways. Of the immediate health impacts related to climate change, including injuries and deaths from extreme weather events, drowning poses a significant risk. The WHO describes drowning as an under-recognised threat to public health. Global estimates of the mortality burden of unintentional drowning are declining, with recent estimates ranging from 295 000 deaths in 2017 to 236 000 in 2019. However, these estimates exclude key components of the problem such as transport-related incidents (eg, boat capsize and ferry sinkings) and drowning related to extreme weather events, including flooding, tropical storms and storm surges, thus potentially underestimating the global burden.

Drowning risk is inextricably linked to environmental factors. The vast majority of drowning incidents occur in natural water bodies (such as rivers, lakes, ponds and oceans) in low-income and middle-income countries (LMICs). Varying climatic and environmental conditions, such as increasing temperatures and shifting rainfall patterns, can influence exposure to and behaviour around aquatic locations and increase drowning risk among already vulnerable communities.

Despite global efforts to secure commitments to limit global warming to 1.5°C, there is growing recognition that climate change is already the greatest risk facing human health. There is a need for greater consideration of the impact of climate change on injury risk, particularly drowning. Such impacts are likely to be many and wide-ranging, some obvious, such as drowning during more frequent flooding events, and some not, such as changes in drowning risk associated with longer-term shifts in seasonal patterns.

In this state-of-the-art review we consider existing literature on climate change as a contributor to variations in future drowning risks globally. The World Meteorological Organization (WMO) in their 2020 Statement on the State of the Global Climate identifies climate change-related risks to the achievement of the Sustainable Development Goals (SDGs). Figure 1 shows selected high-impact events connected to climate change, their relevance to the SDGs and the association with drowning risk, and is based on the WMO’s findings.

Using knowledge of the existing literature and expert opinion, we identified the causal mechanism of each of these risks and the underlying high-impact events that are likely to result in drowning. Based on this understanding the following categories were selected for further investigation:
- Heat and cold waves.
- Tropical cyclones and flooding (grouped as hydrometeorological hazards).
- Drought and water scarcity.
- Damaged infrastructure.
- Aquatic ecosystem collapse.
- Displacement.
- Rising poverty and rising inequality.

This selection process aimed to limit the risks and events addressed in this paper to those most closely connected to increased drowning risk, and as such the links between climate change and drowning discussed here are not all of the items proposed as...
High impact events connected to climate change...
Floods
There were 3254 floods globally between 2000 and 2019, compared with 1389 between 1980 and 1999. Between 2000 and 2019, floods resulted in 104 614 deaths. The WHO estimates that drowning accounts for 75% of deaths in flood disasters. As with cyclones, drowning risks due to flooding are particularly high in LMICs, where people live in flood-prone areas and warning, evacuation and community protection systems are weak.

In a changing climate, exposure to river flooding will double for 323–570 million people (depending on emission and population forecasts), with South and East Asia being the most affected region. However, there are strong regional and subregional variations in such predictions, and the exposure of communities to flood risk, resulting in higher risk of drowning, will have the highest impact where resources and knowledge are low. Despite this, the majority of research into flood-related drowning deaths is from HICs. The drowning risks associated with flash flooding and slow-onset flooding are likely to vary geographically, as are the activities prior to drowning. In HICs, driving of non-aquatic vehicles into floodwater is a prevalent risk factor, but there is little literature to suggest that this risk is mirrored in LMICs. In the Solomon Islands, the most common cause of death during a 2014 flooding event was drowning combined with blunt force trauma when people (mostly under 14 years) were swept away.

Droughts can lead to riskier behaviour around water
While the link between drought or water scarcity and drowning is not as clear as for hydrometeorological disasters, these hazards can result in changes in behaviour, including increased exposure to more risky water sources and increased use of water storage containers in and around the home. There were 338 drought events globally between 2000 and 2019, compared with 263 between 1980 and 1999. Between 2000 and 2019, 40% of droughts occurred in Africa, with 70 happening in East Africa alone. Literature on drowning related to droughts remains extremely limited and focused on Australia. Byard records the drowning of 2-year-old twins in a rainwater tank in Australia and notes the risk of these types of tanks becoming more common for water storage in domestic settings. Depczynski et al showed that farm dams, which help to protect Australian farmers against periods of drought, pose a risk to children as they are rarely fenced off.

Drowning risks related to water access issues in non-drought settings have been identified in Bangladesh and India. A household survey in Barisal Division, Bangladesh showed that use of surface water rather than piped water was associated with an increased risk of fatal and non-fatal drowning. Furthermore, 66% of drownings in Bangladesh occur in ponds, the primary water source when piped water is not available, and 56% of drownings in Bangladesh occur when people are washing or bathing.

In the state of Bihar in India, Dandonna et al showed that bathing was the second most common activity prior to children drowning and the most common in urban areas. However, case reports showed that, where the activity was listed as playing (the most common activity prior to drowning), the water body in which drowning occurred was often linked to water insecurity, for example, buckets by water pumps for water storage at home. In the Sundarbans of West Bengal, India, Gupta et al similarly found that 78.4% of indoor drowning deaths occurred in household water storage reservoirs. These findings suggest that changes in water usage for daily activities would increase drowning risk during drought events.

Climate change impacts on infrastructure are complex with anecdotal links to drowning
Infrastructure, including buildings, roads, bridges, and power and water supplies, can be vulnerable to climate change, with resulting damage leading to increased drowning risk. Moreover, anecdotal evidence suggests that as infrastructure improves, exposure to drowning risk reduces, for example, using a bridge rather than a boat to cross a river, and climate change may slow such development progress. The direct impacts of climate change on infrastructure are increasingly well understood within relevant sectors, but the interconnectedness of infrastructure sectors (eg, reliance on power to treat wastewater or reliance on water sources to produce power) makes indirect climate risks to infrastructure more complex and links to drowning risk have not been considered in the literature. However, ageing infrastructure and lack of infrastructure maintenance were linked to increased flooding and drowning deaths following Hurricane Katrina in New Orleans (US). This demonstrates the role that infrastructure may play in exacerbating drowning risk during extreme weather events, particularly with the risk of damage to infrastructure increasing in a changing climate. (figure 1).

Staines and Ozanne-Smith demonstrated that drowning rate in Victoria, Australia, decreased from 12 per 100 000 in 1905 to 0.67 per 100 000 in 2014–2015. A substantial proportion of this reduction occurred at the end of the 19th century, with infrastructure development considered as a contributing factor, including the development of a piped water supply system which reduced reliance on hazardous water sources and water storage. Furthermore, safe bridges and roadways, street lighting, removal of water hazards, construction of safety barriers and improved waterway management were all expected to have contributed to reductions in drowning mortality.

Franklin et al highlighted that low and middle sociodemographic index (SDI) countries in Africa and Asia accounted for the vast majority of unintentional drowning deaths but that middle SDI countries also accounted for the greatest decline in drowning deaths (54%) between 1990 and 2017, suggesting that development is a driver of reduced drowning. Similar trends were found in Europe when considering the change in child drowning rates across European subregions between 1993 and 2008. Armour-Marshall et al found that, although child injury rates fell in all regions across the study period, the total number of deaths in former Soviet countries fell fastest as standard of living improved along with improved transport infrastructure and enhanced social environments.

This impact of economic development on reducing drowning risk is a slow process and not an effective intervention strategy. However, climate change is likely to further hinder economic development in LMICs. In the context of climate change, additional impacts or variations in injury risk should be considered by both injury prevention agencies and those developing infrastructure services.

Risky behaviour among fishers will increase if aquatic ecosystems collapse
In 2018, 59.51 million people were engaged in the primary sector of fisheries (65.5% of the workforce) and aquaculture (34.5% of the workforce). Most of this workforce is employed in LMICs and the majority are small-scale artisanal fishers and aquaculture workers working in Asia (85%) and Africa (9%). Aquatic
Migration is associated with transport-related drowning risk and increased drowning risk in unfamiliar destinations

From 2011 to 2020, weather-related events triggered an average of 21.5 million new displacements each year, more than twice the number of displacements caused by conflict and violence. Migration is a complex issue with economic, social, environmental and political factors all playing a part in an individual’s migration decisions. There is no consensus on the current number of climate migrants globally, but it is generally acknowledged that the rate of climate migration is increasing and that this trend is set to continue and accelerate in the coming decades. Most people displaced by disaster remain in their home countries in areas that are highly exposed to floods and storms, amplifying the drowning risks associated with hydrometeorological hazards. Displacement can increase the threat of drowning through individuals taking transportation risks (such as the highly publicised drowning of migrants in the Mediterranean) through individuals taking transportation risks (such as the highly publicised drowning of migrants in the Mediterranean) and that most workplace deaths happen by drowning, particularly when small vessels are unsuited to the prevailing hazardous weather conditions.

Mortality rates for fishers in LMICs could be higher still. A study of fishers on Lake Victoria in Uganda estimated a drowning fatality rate of 502 per 100,000 person-years, with 51.7% of drowning deaths related to boat transport and 39.0% related to fishing. A similar study of fishing communities on the Tanzanian shores of Lake Victoria resulted in a drowning fatality rate of 217 per 100,000 person-years, with 87% of adult deaths occurring while they were fishing from boats. Of these, 69% of deaths occurred when the boat sank or capsized in bad weather. This mirrors the risks associated with fishing in adverse weather conditions seen in HICs. Anecdotal evidence from the Tanzanian study suggests that many fishers routinely fish in bad weather as not fishing results in loss of income. Roberts similarly found that in British waters, economic pressures led fishers to overload vessels or go out in boats that were unsuitable for the prevailing weather conditions, particularly when exhaustion of previously lucrative fishing grounds forced them to go further out to sea in small and unsuitable vessels. Similar dynamics have been documented globally. The combination of climate change impacts, including rising sea temperatures and the degradation of fish stocks, may drive risk-taking behaviours in fishing communities worldwide.

Rising poverty and vulnerabilities will exacerbate inequalities in drowning risk

Many of the world’s most vulnerable people already live in climate ‘hotspots’ and lack the resources to adapt to an increasingly inhospitable environment. It is predicted that unless significant efforts are made to address climate change and disaster risk, the number of people needing humanitarian assistance due to disasters could reach 200 million annually by 2050. Drowning has the greatest impact among the world’s poorest people, with 91% of drowning deaths occurring in LMICs and drowning rates in LMICs being 3.4 times higher than in HICs. An expected increase in global inequality will likely lead to a sharp distinction between those communities worst affected by drowning and those who are rarely exposed to drowning risks. Inequality in drowning risk between socioeconomic groups appears to exist in all countries. In Denmark, Müller and Laursen showed that there was a strong association between lower social groups and higher drowning rates. Those employed in high skill level jobs have a drowning rate of 0.34 per 100,000 compared with a rate of 0.87 per 100,000 for those employed in basic level jobs and 6.38 per 100,000 for those receiving social benefits. In Bangladesh, Gashuddin et al. demonstrated that children in the poorest quintile were seven times more likely to die by drowning than children in the richest quintile. The impacts of climate change on inequality are well documented and a greater localisation of drowning prevention interventions will be required to prevent the intersection of water-related risks and the vulnerabilities of poverty from producing ‘drowning hotspots’ due to a changing climate.
Franklin et al.\(^4\) argue that a much greater focus is needed on drowning in Africa, in part due to the heterogeneity of drowning on the continent. Saunders et al.\(^70\) noted that high levels of inequality, poverty, poor infrastructure and ineffective service delivery all contribute to high rates of fatal drowning in Sub-Saharan Africa, with inequality affecting both exposure to injury as well as outcome following injury. A recent review of literature on drowning from the African continent has highlighted the need to address the region’s high drowning rate, including the impact of weather and heat on drowning risk.\(^71\)

Furthermore, drowning has the ability to exacerbate poverty and inequality, with Whitworth et al.\(^72\) demonstrating that the families of drowned fishers on Lake Victoria suffer a range of consequences from loss of income to family break-up as a result.

**GAPS IN THE LITERATURE**

Climate change is already reshaping the nature of drowning globally. Nevertheless, there is little literature that considers the direct and indirect links between climate change and drowning risk, despite the inextricable links between drowning and the environment and the well-documented environmental impacts of climate change. In addition, no published work has attempted to characterise the risks that climate change may pose to existing interventions and the impact this may have on the current rate of decline in drowning deaths.

Opportunity for analysis of drowning risk during extreme weather events is limited due to poor data collection systems. Data collection systems in LMICs often rely on media reporting to estimate deaths only during large-scale events, and drowning is rarely disaggregated from other causes of injury. Where data sets are available, they are not usually cross-referenced with other health reporting systems.

**RECOMMENDATIONS**

As the multisectoral global drowning prevention agenda advances, planning for, addressing and incorporating the evolving impacts of climate change into existing evidence-based interventions to achieve flexible and adaptive drowning prevention programmes and policy are essential. In the first instance, drowning prevention practitioners and researchers must acknowledge the sector’s intrinsic link to a changing climate.

The most visible impact of climate change on drowning risk is an increase in weather-related disasters, including cyclones and flooding, in which high numbers of deaths are attributable to drowning.\(^20\) The best intervention to prevent these deaths is preparedness in terms of warning systems, evacuation plans and shelters.\(^2\) Education-based drowning prevention programmes could incorporate some of these messages in hazard-prone areas, and it may be possible for proven drowning prevention interventions such as community day-care facilities to double as safe shelter locations if venues are purpose-built with that use in mind.

Many of the factors associated with increased drowning rates relating to climate change come from risk-taking behaviour when people’s access to resources becomes limited (eg, fishers who cannot catch sufficient fish to sustain their livelihoods, or people forced to use alternative water sources due to drought or damage to infrastructure) or when they are forced to move (eg, unsafe river or sea crossing when migrating, or settling in flood-prone areas as safer areas are already occupied). Some specific unsafe behaviours may be addressed by existing drowning prevention interventions, such as the provision and use of life jackets and boating safety standards. Other climate-driven drowning risks, such as exposure to flooding, require systems-level approaches traditionally outside the scope of the drowning prevention sector, such as the provision of safe housing and agricultural land, improved infrastructure to limit vulnerable dwellings, and enhanced early warning systems.

On a larger scale, climate change will slow the economic development of some countries, which may slow the rate of decline of drowning linked to development.\(^4\)\(^6\)\(^9\) Collaboration between injury prevention agencies and other development agencies can support the integration of drowning prevention into general development programmes and fast-track the adoption of safer infrastructure and services.\(^76\) Furthermore, the increased drowning risk associated with climate change should encourage drowning prevention specialists to advocate and act in support of climate change mitigation, adaptation and resilience.

With all these issues, there is greater evidence of the links between drowning and climate change in HIC settings than in LMICs, and many of the predictions here need to be further explored and validated in LMIC contexts. As climate change progresses, it will be increasingly important for drowning prevention interventions to reflect the drowning risks at a local scale so that they consider geographical variation and the impacts of inequality within countries and regions. This includes the expansion of traditional drowning estimates to include disaster-related drowning. Partnership with the groups most vulnerable to climate change and drowning risk will be vital to ensure that interventions do not exacerbate existing inequalities.

**FUTURE DIRECTIONS**

There are a range of research priorities associated with advancing the drowning and climate change discussion. An overarching need is that of a broader evidence base regarding the epidemiology, risk factors and strategies for the prevention of drowning in LMICs, which is currently lacking. Such data will help advance understanding of the global burden of drowning and support the identification of trends in drowning risk in a changing climate.
An essential component of this is ensuring suitable centralised data collection systems are in place to capture disaggregated drowning data (fatal and non-fatal) during disasters and integrating these data into global drowning estimates.

Local climate change predictions should be considered during all stages of the design, implementation and evaluation of drowning prevention interventions through interaction with climate experts and communities who may recognise changes to their environment and the impacts that they have on drowning risk. Similarly, research and policy collaboration across sectors such as public health, disaster and development is required to develop systemic changes that support drowning prevention within key national, regional and international frameworks. This may include local disaster management plans, regional strategies for climate change adaptation, and global agendas such as the SDGs and the Sendai Framework.

Across the injury prevention sector, there is a clear need to recognise and quantify the injury risks associated with climate change and to collaborate with communities and development agencies to prevent climate change from stalling progress on drowning prevention and numerous related public health agendas.

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