OPEN ACCESS

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

Rebecca Sindall [1,2], Thomas Mecrow [1,2], Ana Catarina Queiroga [2,3,4], Christopher Boyer [5], William Koon [2,6], Amy E Peden [2,4,7]

[1]International Department, Royal National Lifeboat Institution, Poole, UK
[2]International Drowning Prevention Researchers Alliance (IDRA), Kuna, Idaho, USA
[3]ITR Laboratory for Integrative and Translational Research in Population Health, Institute of Public Health University of Porto, Porto, Portugal
[4]Drowning Prevention Commission, International Lifesaving Federation, Leuven, Belgium
[5]Centre for Health and the Global Environment, University of Washington, Seattle, Washington, USA
[6]School of Biological, Earth and Environmental Sciences, University of New South Wales Faculty of Science, Sydney, New South Wales, Australia
[7]School of Population Health, University of New South Wales Faculty of Medicine, Sydney, New South Wales, Australia

Correspondence to
Dr Rebecca Sindall, Royal National Lifeboat Institution, Poole, Poole, UK; becky_sindall@rnli.org.uk

Received 16 November 2021
Accepted 1 February 2022
Published Online First 23 February 2022

To cite: Sindall R, Mecrow T, Queiroga AC, *et al*. *Inj Prev* 2022;**28**:185–191.

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.[1 2] 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.[3] Global estimates of the mortality burden of unintentional drowning are declining, with recent estimates ranging from 295 000 deaths in 2017[4] to 236 000 in 2019.[5] 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.[4]

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).[3] Varying climatic and environmental conditions, such as increasing temperatures and shifting rainfall patterns, can influence exposure to and behaviour around aquatic locations[6–10] and increase drowning risk among already vulnerable communities.[11 12]

Despite global efforts to secure commitments to limit global warming to 1.5°C,[13] there is growing recognition that climate change is already the greatest risk facing human health.[14–16] 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.[17]

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

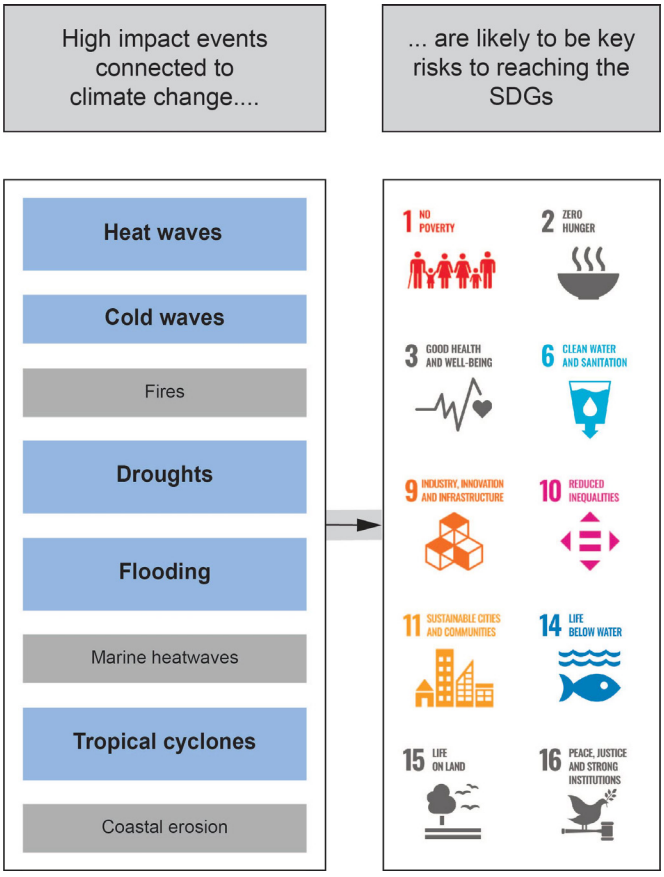

Figure 1 Selected climate change-related risks to the achievement of the Sustainable Development Goals (SDGs), adapted from the World Meteorological Organization State of the Global Climate report.[17] Greyed out high-impact events and SDGs are not considered further in this review.

high-impact events by the WMO but those related to increased drowning risk.

Our literature search comprised searches of Scopus, PubMed, Medline and Google Scholar databases for English-language papers published between 2005 and 2021, using terms including drown* AND climate OR disaster OR flood OR cyclone OR heat OR temperature OR drought OR infrastructure OR migration OR displace* OR fishing OR aquaculture OR poverty OR inequality. Due to the limited literature linking climate and drowning, expert elicitation was required to identify which papers had relevance to both drowning and one of the previously mentioned seven categories; these papers were included in the state-of-the-art review.

CRITICAL ISSUES

Interaction with water increases during hotter weather

High ambient temperatures and excess humidity increase the risk of drowning in outdoor settings.[8–10] Parks *et al*[18] used a Bayesian spatiotemporal model to demonstrate that a 1.5°C anomalously warm year would be associated with drowning deaths in men aged 15–24 years, increasing by 13.7% in the US. Among all injury types, drowning was the injury type most affected by increased temperatures. Warmer temperatures lead people to spend longer in the water,[7] and evidence from Australia highlights increased alcohol consumption on days with hotter temperatures.[19] Extreme heat events increased from 130 events between 1980 and 1999 to 432 between 2000 and 2019,[20] with a concerning predominance outside the summer season.[21] Warmer global temperatures are also impacting ice stability, with increased drowning events seen in ice-covered regions with warmer winters across Canada.[6] As temperatures increase, water-related behaviours and thus exposure to drowning risk are also likely to change, with more people seeking the water for heat relief and extreme heat pushing people to visit aquatic locations earlier in the morning and later in the evening, potentially triggering a need to reconsider traditional supervised bathing periods.

Preparedness can prevent hydrometeorological hazards leading to drowning deaths

Floods and tropical cyclones accounted for 44% and 28% of all disasters between 2000 and 2019, and in both cases drowning is a leading cause of death.[20] An increase in the frequency and severity of these hazards has clear potential to increase drowning risk for the communities that experience them.

Tropical cyclones

Tropical cyclones (called hurricanes, typhoons or cyclones in different parts of the world) consist of destructive winds, inundating rain and storm surges, which frequently lead to flooding and landslides. There were 2043 such events between 2000 and 2019, compared with 1457 between 1980 and 1999.[20] The number of deaths associated with these events has reduced with an average of 9980 people killed per year between 2000 and 2019[20] compared with an average of 11 800 deaths per year between 1980 and 2000.[22] In LMICs with limited implementation of warning, evacuation and shelter systems, drowning from storm surge accounts for an estimated 90% of deaths attributed to cyclones.[23] High-density settlements in low-lying areas with poor housing construction amplify the risk of death. In high-income countries (HICs), cyclone mortality has declined significantly as warning, evacuation and shelter systems are implemented, and most deaths now occur in the postimpact phase of the cyclone.[24] However, even in HICs, drowning accounts for substantial numbers of cyclone deaths, although the proportion varies from event to event.[25 26]

There is limited evidence on the impact of cyclones on drowning in LMICs, with most data coming from Bangladesh, with particular focus on a small number of high-mortality events including the 1991 cyclone. An evaluation of mortality during this event showed that almost all deaths were caused by the storm surge and the highest risk of mortality was for children under 10 (26% mortality) and women over 40 (31% mortality).[27] Although 95% of the people surveyed had received warnings 4 or more hours before the cyclone struck, existing shelters had space for less than 10% of the five million people affected.[27] Furthermore, only two out of five shelters were usable due to flooding.[28] This cyclone acted as a catalyst for the government to improve cyclone preparedness systems, with subsequent cyclones causing far lower mortality due to the adoption of early warning systems, cyclone shelters, evacuation plans, coastal embankments, reforestation schemes, and increased awareness and communication. However, evacuation remains a challenge, with lack of awareness, poor communication and illiteracy all posing major obstacles.[28] Keim[23] highlights that very few drowning victims would be expected to survive inundations related to cyclones and therefore preparedness is key to preserving life, with other approaches including emergency response being less effective and much more expensive.

Floods

There were 3254 floods globally between 2000 and 2019, compared with 1389 between 1980 and 1999.[20] Between 2000 and 2019, floods resulted in 104 614 deaths.[20] 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.[5]

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.[29] However, there are strong regional and subregional variations in such predictions,[30] 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,[31–34] as are the activities prior to drowning. In HICs, driving of non-aquatic vehicles into floodwater is a prevalent risk factor,[31] but there is little literature to suggest that this risk is mirrored in LMIC settings. 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.[35]

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.[20] 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[36] 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*[37] 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[38] 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.[39]

In the state of Bihar in India, Dandona *et al*[40] 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*[41] 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[42] and links to drowning risk have not been considered in the literature. However, ageing infrastructure and a lack of infrastructure maintenance were linked to increased flooding and drowning deaths following Hurricane Katrina in New Orleans (US).[43] 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[44] 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*[4] 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*[45] 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 general standards 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).[46] 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%).[46] Aquatic

ecosystem collapse is already impacting how these industries operate. For example, Sarker *et al*[47] estimate that climate change will reduce the potential marine fish production for Bangladesh by 10%, and Jasparro[48] notes that if atmospheric carbon dioxide doubles, South Africa's fisheries could experience a 50%–60% decrease in productivity.

Currently, most data on drowning of fishers come from HIC settings, but it is widely acknowledged that fishing is a high-risk profession globally, with mortality rates in HICs over 100 per 100 000 fisher-years, and that most workplace deaths happen by drowning, particularly when small vessels are unsuited to the prevailing hazardous weather conditions.[49 50]

Mortality rates for fishers in LMICs could be higher still. A study of fishers on Lake Victoria in Uganda[51] 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[52] 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[49] 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.[53 54] 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.

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.[55] 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.[55–57]

Most people displaced by disaster remain in their home countries in areas that are highly exposed to floods and storms,[55] 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) or through displaced people encountering unfamiliar drowning risks while on the move or in new locations.[58]

There are several challenges with calculating mortality rates in migration settings, including the lack of reliable and complete data on migrant deaths and disappearances, the lack of reliable data on migration flows, and the lack of disaggregation even when accurate data are available. However, a small number of studies consider drowning risks relating to migration. It should be noted that these do not relate directly to climate migration, but it is likely that climate migrants will face similar challenges to migrants moving for other reasons. A 2020 International Organization for Migration report attempted to estimate the mortality rate of migrants crossing the Mediterranean.[59] Over 20 000 deaths have been recorded as migrants attempted to cross the Mediterranean since the beginning of 2014. Although the estimated number of migrant deaths has dropped since 2016,[60] the rates of drowning on the Central Mediterranean route had increased from an average of 208 deaths per 10 000 attempted crossings in 2015–2017 to 478 deaths per 10 000 attempted crossings in 2019.

River crossings for undocumented migrants or refugees can also prove fatal. Eschbach *et al*[61] showed that between 1993 and 1997, there were approximately 600 migrant fatalities from drowning in the Rio Grande. It is almost certain that other drowning deaths occur but are not recorded. Similarly, for Rohingya people crossing the Naf River between Myanmar and Bangladesh in August to October 2017, Hossain *et al*[62] identified 167 fatal drownings from a population of approximately 500 000 migrants. Most victims were children, women and elderly people, crossing the river in small fishing boats or rafts made of bamboo poles and empty jerry cans.

Earle *et al*[63] highlighted that internally displaced people often choose to move to urban areas. McMichael and Lindgren[64] further demonstrated that poor urban communities (including displaced people) tend to be situated in informal settlements and parts of cities that are at high risk from natural hazards including floods, storms and landslides. The combination of these factors suggests that displaced people in LMICs are likely to encounter higher or unfamiliar drowning risks once they settle in new locations as well as during the migration process. Willcox-Pidgeon *et al*[65] found similar challenges for settled migrants in HICs, with unique trends in drowning among migrant communities, that were not well addressed by existing drowning prevention interventions.[66]

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.[55]

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.[3] 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[67] showed that there was a strong association between lower social groups and higher drowning rates. Those employed in high or medium skill level jobs had a drowning rate of 0.34 per 100 000 compared with 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, Giashuddin *et al*[68] 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[69] 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 South 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*[52] 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.[72–74] 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 69] 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.[75] 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.

What is already known on the subject

- Climate change is a major, multifaceted threat to human health.
- Drowning is a significant cause of preventable death and injury, with an overwhelming burden in low-income and middle-income countries.
- The links between the many facets of climate change and drowning risk have not previously been comprehensively considered.

What this study adds

- We review the literature to consider the link between climate change-driven, high-impact events and the Sustainable Development Goals with a drowning prevention lens.
- Drowning risk for climatic events such as flooding is clear, but we highlight drowning risk associated with other impacts of climate change, including heat waves, drought and water scarcity, aquatic ecosystem collapse, and displacement.
- There is an urgent need for both the drowning prevention and climate change and health communities to act on the impacts of climate change-driven events on drowning risk.

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.

Contributors RS conceived the project and designed the manuscript and developed the first draft. All other authors drafted the original content and provided critical revision of the manuscript. All authors approved the submitted version.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors. Open access publication costs were supported by the Royal National Lifeboat Institution.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study does not involve human participants.

Provenance and peer review Not commissioned; externally peer reviewed.

ORCID iDs
Rebecca Sindall http://orcid.org/0000-0002-1731-7042
Thomas Mecrow http://orcid.org/0000-0001-7392-0172
Ana Catarina Queiroga http://orcid.org/0000-0001-8395-1837
Christopher Boyer http://orcid.org/0000-0002-2247-7446
William Koon http://orcid.org/0000-0003-4708-4347
Amy E Peden http://orcid.org/0000-0002-6424-1511

REFERENCES

1 Haines A, Ebi K. The imperative for climate action to protect health. *N Engl J Med Overseas Ed* 2019;380:263–73.
2 Romanello M, McGushin A, Di Napoli C, *et al*. The 2021 report of the Lancet countdown on health and climate change: code red for a healthy future. *Lancet* 2021;398:1619–62.
3 World Health Organization. *Global report on drowning: preventing a leading killer*. Geneva: World Health Organization, 2014.
4 Franklin RC, Peden AE, Hamilton EB, *et al*. The burden of unintentional drowning: global, regional and national estimates of mortality from the global burden of disease 2017 study. *Inj Prev* 2020;26:i83–95.
5 World Health Organization. *Drowning*. Geneva: World Health Organization, 2021. https://www.who.int/news-room/fact-sheets/detail/drowning
6 Sharma S, Blagrave K, Watson SR, *et al*. Increased winter drownings in ice-covered regions with warmer Winters. *PLoS One* 2020;15:e0241222.
7 Peden A, Franklin RC, Leggat PA. Observing patterns of river usage. *Safety* 2019;5:66.
8 Chauvin M, Kosatsky T, Bilodeau-Bertrand M, *et al*. Hot weather and risk of drowning in children: opportunity for prevention. *Prev Med* 2020;130:105885.
9 Real Á Del, Sanchez-Lorenzo A, Lopez-Bustins J-A, *et al*. Atmospheric circulation and mortality by unintentional drowning in Spain: from 1999 to 2018. *Perspect Public Health* 2021:17579139211007181.
10 Fralick M, Denny CJ, Redelmeier DA. Drowning and the influence of hot weather. *PLoS One* 2013;8:e71689.
11 World Health Organization. *Regional office for the Western Pacific. regional status report on drowning in the Western Pacific*, 2021.
12 World Health Organization. *Regional office for south-east Asia. regional status report on drowning in south-east Asia*, 2021.
13 COP26 Goals - Mitigation. Un climate change conference UK 2021, 2021. Available: https://ukcop26.org/cop26-goals/mitigation/
14 Atwoli L, Baqui AH, Benfield T, *et al*. Call for emergency action to limit global temperature increases, restore biodiversity, and protect health. *N Engl J Med Overseas Ed* 2021;385:1134–7.
15 Vicedo-Cabrera AM, Scovronick N, Sera F, *et al*. The burden of heat-related mortality attributable to recent human-induced climate change. *Nat Clim Chang* 2021;11:492–500.
16 National Geographic. Why climate change is still the greatest threat to human health: national geographic, 2021. Available: https://www.nationalgeographic.com/science/article/why-climate-change-is-still-the-greatest-threat-to-human-health
17 World Meteorological Organization. *State of the global climate 2020*. Geneva, 2020.
18 Parks RM, Bennett JE, Tamura-Wicks H, *et al*. Anomalously warm temperatures are associated with increased injury deaths. *Nat Med* 2020;26:65–70.
19 Peden AE, Franklin RC, Leggat PA. Breathalysing and surveying river users in Australia to understand alcohol consumption and attitudes toward drowning risk. *BMC Public Health* 2018;18:1393.
20 Centre for Research on the Epidemiology of Disasters (CRED) and the United Nations Office for Disaster Risk Reduction. Human cost of disasters: an overview of the last 20 years 2000-2019. centre for research on the epidemiology of disasters (CRED) and the United nations office for disaster risk reduction 2020.
21 Perkins SE, Alexander LV, Nairn JR. Increasing frequency, intensity and duration of observed global heatwaves and warm spells. *Geophys Res Lett* 2012;39.
22 Pelling M, Maskrey A, Ruiz P. *Reducing disaster risk: a challenge for development: a global report*. New York, 2014.
23 Keim M. Cyclones, Tsunamis, and human health: the key role of preparedness. *Oceanography* 2006;19:40–9.
24 Shultz JM, Russell J, Espinel Z. Epidemiology of tropical cyclones: the dynamics of disaster, disease, and development. *Epidemiol Rev* 2005;27:21–35.
25 Rappaport EN. Fatalities in the United States from Atlantic tropical Cyclones: new data and interpretation. *Bull Am Meteorol Soc* 2014;95:341–6.
26 Rob DM, Peter A, Richard CF. The physical health impacts of tropical cyclones. *Annals of the Australasian College of Tropical Medicine* 2014;15:2–8.
27 Bern C, Sniezek J, Mathbor GM, *et al*. Risk factors for mortality in the Bangladesh cyclone of 1991. *Bull World Health Organ* 1993;71:73–8.
28 Haque U, Hashizume M, Kolivras KN, *et al*. Reduced death rates from cyclones in Bangladesh: what more needs to be done? *Bull World Health Organ* 2012;90:150–6.
29 Arnell NW, Gosling SN. The impacts of climate change on river flood risk at the global scale. *Clim Change* 2016;134:387–401.
30 Kundzewicz ZW, Kanae S, Seneviratne SI, *et al*. Flood risk and climate change: global and regional perspectives. *Hydrological Sciences Journal* 2014;59:1–28.
31 Jonkman SN, Kelman I. An analysis of the causes and circumstances of flood disaster deaths. *Disasters* 2005;29:75–97.
32 French J, Ing R, Von Allmen S, *et al*. Mortality from flash floods: a review of national weather service reports, 1969-81. *Public Health Rep* 1983;98:584–8.
33 Peden AE, Franklin RC, Leggat P, *et al*. Causal pathways of flood related river drowning deaths in Australia. *PLoS Curr* 2017.
34 Peden AE, Franklin RC. Exploring Flood-Related unintentional fatal drowning of children and adolescents aged 0–19 years in Australia. *Safety* 2019;5:46.
35 Natuzzi ES, Joshua C, Shortus M, *et al*. Defining population health vulnerability following an extreme weather event in an urban Pacific island environment: Honiara, Solomon Islands. *Am J Trop Med Hyg* 2016;95:307–14.
36 Byard RW. Rainwater tank drowning. *J Forensic Leg Med* 2008;15:533–4.
37 Depczynski J, Fragar L, Hawkins A, *et al*. Safe play areas for prevention of young children drowning in farm dams. *Australasian Journal of Early Childhood* 2009;34:50–7.
38 Jagnoor J, Gupta M, Ul Baset K, *et al*. The association between water, sanitation and hygiene (wash) conditions and drowning in Bangladesh. *J Water Health* 2019;17:172–8.
39 Rahman A, Alonge O, Bhuiyan A-A, *et al*. Epidemiology of drowning in Bangladesh: an update. *Int J Environ Res Public Health* 2017;14:488.
40 Dandona R, Kumar GA, George S, *et al*. Risk profile for drowning deaths in children in the Indian state of Bihar: results from a population-based study. *Inj Prev* 2019;25:364–71.
41 Gupta M, Bhaumik S, Roy S, *et al*. Determining child drowning mortality in the Sundarbans, India: applying the community knowledge approach. *Inj Prev* 2021;27:injurypre v-2020-043911.
42 Dawson R, Johns D, Gosling S. *Uk climate change risk assessment evidence report: chapter 4, infrastructure*. London, 2016.

43 Comfort LK. Cities at risk: Hurricane Katrina and the drowning of new Orleans. *Urban Affairs Review* 2006;41:501–16.
44 Staines C, Ozanne-Smith J. Drowning deaths between 1861 and 2000 in Victoria, Australia. *Bull World Health Organ* 2017;95:174–81.
45 Armour-Marshall J, Wolfe I, Richardson E, *et al*. Childhood deaths from injuries: trends and inequalities in Europe. *Eur J Public Health* 2012;22:61–5.
46 Food and Argiculture Organisation of the United Nations (FAO). *The state of World fisheries and aquaculture: sustainability in action*. Rome, 2020.
47 Sarker S, Ara Hussain F, Assaduzzaman M, *et al*. Blue economy and climate change: Bangladesh perspective. *J Ocean Coast Econ* 2019;6:6.
48 Jasparro C. *Environmental threats to security, stability and US interests in southern Africa: opportunity knocks – time for a comprehensive region defense environmental international cooperation and environmental security assistance strategy. research paper for the*. Colorado: US Air Force Institute for National Security Studies, 2009.
49 Roberts SE. Occupational mortality in British commercial fishing, 1976-95. *Occup Environ Med* 2004;61:16.
50 Lincoln JM, Conway GA. Preventing commercial fishing deaths in Alaska. *Occup Environ Med* 1999;56:691–5.
51 Kobusingye O, Tumwesigye NM, Magoola J, *et al*. Drowning among the lakeside fishing communities in Uganda: results of a community survey. *Int J Inj Contr Saf Promot* 2017;24:363–70.
52 Whitworth HS, Pando J, Hansen C, *et al*. Drowning among fishing communities on the Tanzanian shore of Lake Victoria: a mixed-methods study to examine incidence, risk factors and socioeconomic impact. *BMJ Open* 2019;9:e032428.
53 Rogers LA, Griffin R, Young T, *et al*. Shifting habitats expose fishing communities to risk under climate change. *Nat Clim Chang* 2019;9:512–6.
54 Galappaththi EK, Ford JD, Bennett EM, *et al*. Climate change and community fisheries in the Arctic: a case study from Pangnirtung, Canada. *J Environ Manage* 2019;250:109534.
55 UNHCR. Data reveals impacts of climate emergency on displacement, 2021. Available: https://www.unhcr.org/en-us/news/stories/2021/4/60806d124/data-reveals-impacts-climate-emergency-displacement.html
56 McLeman R, Opatowski M, Borova B, eds. *Environmental migration and displacement: What we know and don't know. Laurier Environmental Migration Workshop*, 2016.
57 Rigaud KK, De Sherbinin A, Jones B. *Groundswell: preparing for an internal climate migration*. Washington DC: The World Bank, 2018.
58 Beerman S, Bean E, Byers B. *Vancouver Declaration on drowning risk reduction of migrants and refugees*, 2017.
59 International Organization for Migration (IOM). *Calculating "death rates" in the context of migration journeys: Focus on the Central Mediterranean, GMDAC Briefing Series: Towards safer migration in Africa*. Migration and Data in Northern and Western Africa, 2020.
60 Statistica. Deaths of migrants in the Mediterranean sea 2014-2021, 2020. Available: https://www.statista.com/statistics/1082077/deaths-of-migrants-in-the-mediterranean-sea/
61 Eschbach K, Hagan J, Rodriguez N, *et al*. Death at the border. *Int Migr Rev* 1999;33:430–54.
62 Hossain MJ, Ashrafi R, Rahman A. Pw 2015 drowning disaster during Rohingya migration in Bangladesh in the 2017 year. *Injury Prevention* 2018;24:A157–8.
63 Earle L, Aubrey D, Ferrera N I. When internal displacement meets urbanisation: making cities work for internally displaced people. *Refugee Survey Quarterly* 2020;39:494–506.
64 McMichael AJ, Lindgren E. Climate change: present and future risks to health, and necessary responses. *J Intern Med* 2011;270:401–13.
65 Willcox-Pidgeon S, Franklin RC, Leggat PA, *et al*. Epidemiology of unintentional fatal drowning among migrants in Australia. *Aust N Z J Public Health* 2021;45:255–62.
66 Giles AR, Brooks Cleator L, McGuire-Adams T, *et al*. Drowning in the social determinants of health: understanding policy's role in high rates of drowning in aboriginal communities in Canada. *aboriginal policy studies* 2014;3.
67 Müller H, Laursen B. Social inequality in accidental drowning in Denmark 2001-2006. *Injury Prevention* 2010;16:A121.
68 Giashuddin SM, Rahman A, Rahman F, *et al*. Socioeconomic inequality in child injury in Bangladesh - implication for developing countries. *Int J Equity Health* 2009;8:7.
69 Bank W. *Poverty and shared prosperity 2020: reversals of fortune*. Washington DC, 2020.
70 Saunders CJ, Adriaanse R, Simons A, *et al*. Fatal drowning in the Western Cape, South Africa: a 7-year retrospective, epidemiological study. *Inj Prev* 2019;25:529–34.
71 Miller L, Alele FO, Emeto TI, *et al*. Epidemiology, risk factors and measures for preventing drowning in Africa: a systematic review. *Medicina* 2019;55:637.
72 Grasso VF, Singh A. *Early warning systems: state-of-art analysis and future directions*, 2011.
73 Guha-Sapir D, Parry L, Degomme O. *Risk factors for mortality and injury: post-tsunami epidemiological findings from Tamil Nadu*. Brussels, 2006.
74 Rogers D, Tsirkunov V. *Global assessment report on disaster risk reduction: costs and benefits of early warning systems*, 2011.
75 Staines C. *History of drowning deaths in a developing Community-the Victorian experience*. Monash University, 2013.