Research for Action on Climate Change and Health in the Caribbean:
A Public, Private, People's and Planetary Agenda

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3. WATER, SANITATION AND HYGIENE

3.1 WHAT IS HAPPENING?

Water, sanitation and hygiene (WASH) are essential for health. They are affected by all the main consequences of climate change: increased temperatures, extreme weather events and sea level rise. Water access and quality are determined by environmental and institutional factors such as geography, land and marine use, agricultural production and infrastructure (Trotman et al., 2017). Water distribution is also associated with social stratifiers such as gender, race, age, income and education. Preexisting conditions and access to health care influence health outcomes arising from WASH (Allen, 2021; USGCRP, 2016).

Water access and quality are interrelated in several ways. If water supplies are limited, then maintaining adequate hygiene may be challenging. At the same time, if the resource from which a water supply is sourced is "low" then the quality may also be poor, depending on how much the water is treated before it enters the distribution system. Lastly, intermittent flow associated with limited water supplies can affect the water chemistry within the pipe distribution system. The impacts of water insecurity and water quality on health are discussed separately in the subsections that follow, but it is important to recognise that they are linked.

Water security

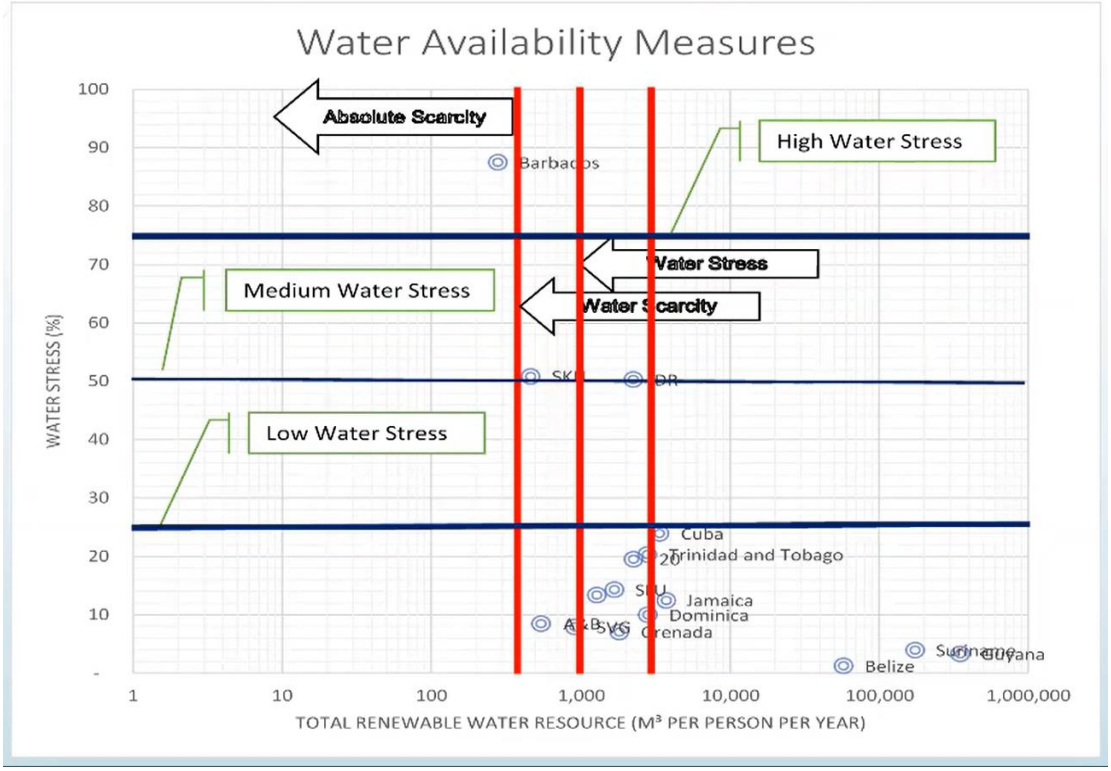
Hydration is fundamental to life. The body requires water for many essential functions, including balancing internal temperature and keeping cells alive. Survival time without water is generally estimated at under five days, depending on factors such as age, sex, weight, height, exercise patterns and external temperature. With climate change compounding hot conditions in the tropics, water needs are likely to increase in Caribbean Small Island Developing States (SIDS).

Making water available to all who need it is hindered by two main types of challenges (Cashman, 2021):

- Challenges with regard to the availability of water resource;
- Challenges in making water resources accessible for those who need them.

Having a safe, reliable and sustainable source of drinking water has always been a challenge for SIDS, with fresh water being from surface water (rivers, springs, ponds) and groundwater sources, and increasingly from desalination plants. In 2013, Antigua and Barbuda, Barbados, Dominica, Jamaica, Saint Lucia, Saint Vincent and the Grenadines, and Trinidad and Tobago were among the top 36 water-stressed (based on demand for water relative to supply) countries in the world (Dubrow, 2021; Reig et al., 2013). The availability of water varies from island to island and even within islands (CIMH and Land and Water Division of FAO, 2016). For instance, in Jamaica, the capital city of Kingston is located in a region of the country where water is relatively scarce, which poses health and other challenges to residents of this metropolitan area. In the Caribbean, Barbados has the lowest total water resource volume per person and the highest level of water stress (Figure 1). The challenges are likely to worsen, since climate models for the Caribbean predict an overall drying trend, with more frequent dry spells, as climate change advances this century, although with some geographical variation (Cashman, 2021; Taylor, 2021; Taylor et al., 2018).

Figure 1: Water availability by Caribbean country



Source: Cashman (2021).

Water availability varies over time, and one of the consequences of climate change is increased seasonal variability and unpredictability, posing problems for farmers (Gamble et al., 2010) and for the sustained provision of water to the population. Both slow-onset extreme weather events (such as drought) and rapid-onset conditions (such as hurricanes) affect the availability of water. Pollution with harmful microorganisms and chemicals can make existing water supplies unusable. Saline intrusion and other pollution resulting from sea level rise, over abstraction and flooding can also reduce the availability of fresh water.

Governance factors affecting the ability to make water available include uncertain finances, ageing infrastructure (resulting in burst pipes and loss from pipelines), inadequate planning, lack of data, poor service coverage and human resource constraints. Combined, these result in inadequate water services, eroding political support and finances and increasing the challenges. In some Caribbean countries, up to 75% of the water supplied by national water companies is lost through leakage. Across the Caribbean, people experience water outages and many pay for trucks to bring water to meet their water supply needs, for instance by filling their water tanks. This creates inequity, as many people cannot afford to pay for truck-borne water (R4ACCHC, 2022a). Attempts to address food insecurity by increasing local production may increase water stress because of competition for water resources (Cashman, 2021).

The impacts of these scenarios include increased competition for water resources, higher cost of provision, disruption in supply due to extreme events and deterioration in water quality. These all point to the likelihood of increasing water insecurity as climate change advances (Cashman, 2021; UNFCCC, 2008). Droughts often give rise to an increased need to store water. If water is stored in uncovered containers, this may result in increased mosquito breeding and increased incidence of vector-borne diseases (Clauzel and Forbes-Robertson, 2017; Dominica Ministry of Health and the Environment, 2016).

Water quality, sanitation and hygiene

Anthropogenic and natural threats to the quality of the water supply that are not related to climate change include poorly designed or malfunctioning sanitation infrastructure and services; contamination by human, animal and agricultural wastes; deforestation leading to greater exposure of water sources to contamination; pollution due to chemical contaminants; over abstraction; sand and gravel mining from freshwater sources; and deposition of airborne contaminants (IPCC, 2014; Itoewaki, 2021; UNEP, 2012; UN-OHRLLS, 2015). Over 80% of wastewater going into the ocean is untreated, threatening marine water quality and marine life. Humans who have direct contact with ocean water (e.g. fisher people, swimmers) can be exposed to contaminants from untreated wastewater. Human health can also be threatened via consumption of contaminated fish and other seafood (see Chapter 14, "Marine resources and health"). In water-stressed countries, wastewater should be recycled, so dumping wastewater into the ocean represents a lost opportunity for sustainable water supplies (Buenfil, 2021; Dubrow, 2021). The impacts of all of these threats to water quality on health are aggravated by climate change.

Drought can lead to the spread of disease, as people use scarce water that may be contaminated with pathogens or harmful chemicals. A reduction in rainfall reduces river flow and effluent dilution and increases pathogen loading. Health impacts are likely to include an increase in waterborne diseases with diarrhoeal and other symptoms and an increased burden on health services.

Flooding can lead to a variety of diseases, as pathogens and chemicals are spread by floodwater (Dubrow, 2021; Wells et al., 2015). Exposure to floodwater most commonly causes diarrhoeal disease, while prolonged exposure leads to skin diseases. *Leptospira*, the genus of bacteria that causes leptospirosis, is spread through the urine of infected animals, and can get into water or soil and survive there for weeks to months. The bacteria can then be carried by floodwater that humans can be exposed to. Leptospirosis can lead to kidney damage, meningitis (inflammation of the membrane around the brain and spinal cord), liver failure, respiratory distress and even death (Dubrow, 2021; CDC, 2017). Mosquitoes, the vector that spreads the most disease in the Caribbean, breed in standing water. Several other vectors also require water as part of their life cycles. Flooding tends to provide additional breeding sites for vectors that spread diseases (see Chapter 2, "Vulnerability to vector-borne diseases").

Warming oceans and freshwater lakes, combined with elevated phosphorus and nitrogen from agricultural run-off (promoted by extreme precipitation events), increase the risk of harmful algal blooms. These blooms, which represent overgrowth of microalgae in either salt or fresh water, produce an array of phycotoxins. Depending on the species, phycotoxins produced by these algae have a range of toxicities, including liver, gastrointestinal, kidney, neurological, skin and respiratory toxicities. Fish, shellfish and drinking water can become contaminated with phycotoxins, which cause a variety of human diseases (Dubrow, 2021). Further detail is provided in Chapter 14, "Marine resources and health".

The effects of flooding on water quality depend on sanitation systems and practices. Large portions of the populations of Caribbean countries are not serviced by public sewage collection systems but rather depend on individual systems such as septic tanks, soakaways and pit latrines. In times of high rainfall, run-off and floodwater may become contaminated with faecal waste from these systems and pose health risks. The practice of dumping solid waste into rivers, streams, ravines and drains is widespread. This waste can clog waterways, exacerbating the effects of flooding and leading to human exposure to pathogens (Ebi et al., 2006).

Extreme events such as hurricanes can cause major disruption to water hygiene, sanitation and distribution systems, increasing vulnerability to waterborne diseases, including schistosomiasis, cryptosporidiosis and cholera, and dehydration and malnutrition resulting from disturbance in food production or distribution (Taylor et al., 2010). Box 1 provides a case study from Dominica.

Box 1: Case study – the impact of Hurricane Maria on water, sanitation and hygiene in Dominica

Hurricane Maria caused extensive damage to the water and sewage infrastructure in Dominica (18 September 2017) as water cascaded down hills and mountains and broke pipes, some of which were built into bridges. The main sewage treatment facility in Roseau was compromised because its electrical panel flooded. Pump stations were also damaged, and a major sewage pipeline under one of the bridges in Roseau was broken. Much of Roseau was covered in mud and silt, and sewage in places, for a few days following the hurricane. Throughout the island, there were cuts in the water supply and risks of exposure to sewage.

Watersheds were also compromised. Forest coverage and shade of these bodies of water was reduced as the hurricane removed leaves and branches of trees. It was estimated that 80–90% of trees were defoliated by Hurricane Maria (Government of the Commonwealth of Dominica, 2017). This led to increased evaporation of water and risks of contamination. In some water sources, new colourful blooms of algae and traces of sulphur and iron were identified by environmental health officers. Analyses of the risks to human health were hampered by damage to the national laboratory at the Princess Margaret Hospital. Laboratory staff at the Dominica Water and Sewage Company, assisted by a senior member of staff from the national laboratory, therefore monitored water quality, conducting chemical, physical and bacterial analyses.

In the first few days after Hurricane Maria, hygiene in shelters for displaced people was poor, with no potable or stored water and very little food. Few had toilet facilities and shelters were overcrowded. This combination of factors produced a high-risk public health situation, as unsafe water and food supplies were being used by occupants in the interim, and there was high risk of transmission of disease among the shelter population.

Many of the immediate water supply needs were addressed by importing millions of plastic water bottles with assistance from aid agencies and neighbouring countries. This added to the solid waste management challenges of the country. It was also ecologically unsustainable, since plastic water bottles are petrochemical products and release greenhouse gases as they slowly break down in hot weather (World Economic Forum, 2022).

Sources: Allen et al. (2019a); CARPHA (2018); Dubrow (2021).

Pathogenic *Vibrio* species, which cause diarrhoeal disease, including *Vibrio cholerae*, grow best in warm brackish water along coastlines. Although cholera is not found in most of the Caribbean, it has become endemic in Haiti (Eisenberg et al., 2013) and remains a threat wherever and whenever sanitation systems fail in the Caribbean. With warming waters, infection by noncholera *Vibrio* species is of increasing concern (Dubrow, 2021).

Primary research on the health outcomes of changes in WASH owing to climate change is rare in the Caribbean (Rise et al., 2022). The information in Box 1 arose from key informant interviews in Dominica conducted approximately seven months after Hurricane Maria. Post-disaster needs assessments are often conducted in the immediate aftermath and identify challenges for the WASH infrastructure, but we did not identify longitudinal studies in the Caribbean that tracked the effects on health systems, the disease outcomes that emerge and the responses that arise from various sectors. A major challenge is the lack of monitoring data on the WASH systems themselves, such as the location, type, frequency and duration of leaks and damage to the infrastructure (Cashman, 2021). The impact of hurricanes in particular on WASH and associated health outcomes is an important area for further research.

A few Caribbean studies have looked at the impact of climate change on gastrointestinal (GI) illnesses. For instance, the relationship between extreme rainfall, ecosystem services offering flood protection and the occurrence of Medicare claims for GI illnesses was studied in Puerto Rico. The study found that claims for GI illnesses increased following extreme rainfall events. However, the effect was reduced for people living in areas with ecosystem services such as karst soils and increased for people living in flood-prone areas (De Jesus Crespo

et al., 2019). In Haiti, where cholera has become endemic since the 2010 earthquake, increased rainfall was found to be significantly correlated with increased cholera incidence four to seven days later. The relationship between rainfall and cholera was found to be significant for all spatial scales and locations examined (Eisenberg et al., 2013). In Cuba, significant associations were found between the Oceanic Niño Index and giardiasis cases. However, in two out of three study locations the relationship was positive, while in the other study location it was negative (Escobedo et al., 2015). One study used weekly syndromic surveillance data on gastroenteritis cases collected by the Caribbean Public Health Agency to examine the impact of the 2017 hurricanes. Countries hit by Hurricanes Irma and Maria at Category 4 or 5 strength were compared with other Caribbean countries. It was found that, in the three months following the hurricanes, the numbers of gastroenteritis cases increased more rapidly in the countries that were struck by the hurricanes at Category 4 or 5 than in the countries that were not (Allen et al., 2019b; CARPHA, 2018).

This small body of Caribbean research, then, focuses mainly on water quality and waterborne disease. A few studies also examined the effect of drought and floods on Caribbean agriculture and thus on food security (see Chapter 12, “Agriculture and food safety and security”). We did not identify studies that looked at how the construction and management of utilities and infrastructure contribute to the health outcomes of climate change.

3.2. WHAT SHOULD BE DONE?

Individual and community actions and how to support them

Encourage water demand management, water conservation and the use of alternative water sources

While water availability is largely out of the hands of individuals and communities, they can be encouraged to moderate water demand and engage in conservation practices. Communication strategies and tools should be developed to enable consumers to reduce water wastage. Similarly to elsewhere, Caribbean governments periodically impose hosepipe bans in times of drought. More can be done to encourage turning off taps when they are not needed in the home (Cashman, 2021).

Potable drinking water is often used in situations that do not require a high level of water cleanliness (e.g. for washing the car). As water becomes scarcer, it will become increasingly necessary to recycle water and adapt to using water of the appropriate quality for a given task. Water should be used at the quality level needed (Buenfil, 2021). Desalination technologies are seeing increased application in those Caribbean islands where the demand for freshwater substantially exceeds the supply from natural sources (UNEP, 2012). Rainwater harvesting schemes are being developed across the Caribbean, and their use by the general population should be facilitated (R4ACCHC, 2022b). Rainwater harvesting should be included in building codes, policies and laws. For example, in Antigua and Barbuda, a water harvesting system is a requirement in the building code for residential buildings.

It is important to note that rainwater harvesting can increase the risk of disease if water receptacles and storage containers are uncovered and mosquitoes that transmit diseases can breed in them. Rainwater harvesting should be accompanied by measures to cover water containers and otherwise prevent mosquitoes from breeding in them. Guidance on managing water storage should be developed.

Involve communities in integrated water resource management

The Global Water Partnership defines integrated water resources management (IWRM) as “a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (Hassing et al., 2009). Local communities and nongovernmental organisations (NGOs) can play a critical role in developing systems that manage water resources in tandem with land and other resources that sustain livelihoods and health in a manner that leaves no one behind. They should be involved in recommending, lobbying for, working on and developing appropriate local solutions to water shortages, making use of alternative sources and technologies as needed (Cashman, 2021). This may help make the most efficient use of scarce water resources. Communities are unlikely to achieve this alone, however. IWRM also requires a structure of policies and legislation along with an institutional framework for implementing and enforcing them. Information and monitoring and evaluation systems are also necessary (Hassing et al., 2009). These points highlight the need for structural/governmental and private sector actions, as detailed below.

Structural/governmental and private sector actions

Fulfil government responsibilities on the human right to water and sanitation for all

As it is essential for life, access to clean water has been recognised as a human right. The human right to safe drinking water was first recognised by the United Nations General Assembly and the Human Rights Council as part of binding international law in 2010 (United Nations, 2010). The human right to sanitation was explicitly recognised as a distinct right by the United Nations General Assembly in 2015 (UN-Water, n.d.; United Nations, 2016). These rights were also asserted in United Nations Sustainable Development Goal 6: “Ensure availability and sustainable management of water and sanitation for all” (see https://sdgs.un.org/goals/goal6). Thus, governments are obliged by international law to ensure that their citizens have access to water and sanitation.

They must be available to all communities, regardless of circumstances. This is becoming increasingly challenging because of climate change, with low-income and other vulnerable communities facing disproportionate challenges in accessing water and sanitation. Policymakers must listen to the concerns of vulnerable communities in different types of circumstances, so that they can address the needs of these communities. Information about water safety and access must be issued regularly, along with early warnings for floods and droughts. A multisectoral approach is needed for IWRM, which includes the private sector, to prevent risks associated with industrial processes (R4ACCHC, 2023).

Facilitate access to water from recycled and alternative sources

Since water is a public good, local and national governments must be involved in providing households with access to water from various sources, while keeping the population adequately informed about the level of safety of each source. The provision of safe drinking water to all must remain a government priority, and the general population should be kept informed of ways to sanitise water from sources other than government pipes as necessary. Recycled water can be shared between sectors to be used in production processes, with adequate safety measures in place. Technical assistance may be needed to help governments optimise their adaptation strategies. The Food and Agriculture Organization of the United Nations has developed a tool to help governments establish where to locate structures for rainwater harvesting. It is also exploring the possibility of developing urban agriculture, including vertical gardens, which will use less land and water than conventional agriculture. Aquaculture can also reduce the need for land and irrigation (Buenfil, 2021). The Pan American Health Organization (PAHO) has included water conservation and rainwater harvesting strategies in its Smart Health Facilities initiative (Hassan, 2021; PAHO, n.d., 2013).

Develop disaster preparedness strategies for droughts

Caribbean disaster risk management efforts have focused mainly on floods and storms, so drought strategies tend to lack effective governance and adequate human resources and funds, and the national coordination, policymaking and planning in place are relatively poor and unable to deal with droughts effectively (CIMH and Land and Water Division of FAO, 2016). Drought is one of the issues that should be addressed by IWRM planning and policy (Cashman, 2014; Cashman et al., 2010; UNEP, 2012).

Strengthen waste management in advance of extreme weather events

Waste management before the wet or hurricane season is a key intervention for disaster resilience (R4ACCHC, 2023). If potential water receptacles are covered or adequately disposed of (e.g. plastic bottles, tires), the potential for mosquito proliferation in the event of flooding or a hurricane will be lower (Medlock, 2021). Community clean-up drives can assist in removing waste that may become hazardous by presenting an injury or sanitation risk. Drains, rivers and other waterways should be cleaned regularly, especially given the practice of dumping major solid waste items, such as fridges, into river courses.

Develop climate-resilient water and sanitation infrastructure

Existing infrastructure is very vulnerable to hurricanes. In mountainous terrain, vital pipelines are often built into bridges, making them vulnerable to damage from raging torrents that damage the bridges themselves. Caribbean governments are facing increasing costs of using stronger materials to construct pipes and reinforce them. In Dominica, the main water pipeline for the capital city of Roseau was rebuilt underground after it was damaged during Hurricane Maria.

It is clear that much of the existing water and sanitation infrastructure is not fit for purpose, since in several Caribbean countries more than half of piped water leaks away before reaching consumers. Routine maintenance **and** breakage repair are needed at a bare minimum (R4ACCHC, 2023). Going beyond these, extra funds and technical expertise are needed to make the most of existing and new technologies. The process of upgrading

WASH infrastructure can take considerable time and is hampered by lack of adequate monitoring systems to pinpoint the problems. Development partners and the private sector can make useful contributions to efforts to strengthen WASH infrastructure and information systems. The Green Climate Fund is contributing to some water infrastructure development projects (Cashman, 2021).

Infrastructure such as roadside and pipe drainage should be expanded to accommodate greater volumes of water. There is also a need to control the sources of flooding to slow the flow of water (such as increasing the capacity of rivers to contain high discharge [heavy rainfall] events). Furthermore, nature-based solutions, such as improving soil cover with plants to reduce water pollution and run-off, and diverting high water flows into natural water storage areas, can reduce the volume of floodwater (Asian Development Bank, 2022; Environment Agency, 2023). Guidelines on nature-based solutions should be developed for the Caribbean. Guidelines on vector control should be expanded to include potential breeding sites underground (such as cisterns and pipes) and brackish water (Mavian et al., 2018). Public health regulations on water storage should be developed and reinforced (Lowe et al., 2020).

Insurance providers should subsidise the development of infrastructure to ensure that it can be repaired in the event of disaster (CARPHA, 2018; Harewood, 2021).

Decentralise sanitation services to ensure post-disaster access

As experienced in Dominica following Hurricane Maria, roads and bridges can be destroyed by hurricanes, making it impossible for garbage trucks and other vehicles and equipment to reach communities. Thus, regular refuse collection services are disrupted at a time of great need, and it is very difficult to remove the debris. It is important to station equipment, vehicles and dumps strategically in various parts of the country, while observing measures to avoid contamination of water sources and agricultural sites with waste (Allen et al., 2019a; Harewood, 2021). The Dominica Solid Waste Management Company introduced measures to station garbage trucks and establish dumps in various parts of the island, following the experience of roads and bridges being damaged by Hurricane Maria and vehicles being prevented from reaching areas outside the capital, where they were stationed at that time (Allen et al., 2019a; CARPHA, 2018). Water, solid waste and debris management plans should be integral parts of disaster preparedness and response plans (Harewood, 2021). Adaptation measures include locating vehicles and equipment in areas less prone to flooding and other sorts of damage from extreme events.

Provide water, sanitation and hygiene infrastructure and services to all populations

Efforts must be made to provide adequate water and sanitation infrastructure and services (such as refuse removal and water pipes) to all types of accommodation and surrounding roads and landscapes. Support should be provided for the maintenance of water storage and sewage systems. When developing policies and interventions, the need for these services among the following vulnerable populations should be at the forefront of considerations: poorer communities, urban populations, squatter communities, indigenous communities, and women, children and people with disabilities (Medlock, 2021).

Develop human resources and access to technologies to improve water, sanitation and hygiene

There is a need to increase expertise in the Caribbean population in areas such as plumbing, hydroengineering and water quality assessment. Members of the public could be trained in basic plumbing skills, which could assist in reducing leakage and increasing the efficiency of water systems at the household level. However, the emphasis must be on improving public works and addressing deficiencies in infrastructure and water safety (R4ACCHC, 2023).

Research gaps and how to address them

Conduct research on how climate change is affecting the biological and chemical composition of water sources

Environmental research and monitoring should be conducted to assess how climate change factors such as increased ambient temperatures and coastal and other flooding affect the biological and chemical composition of water sources. This includes assessing the microorganism profile of water and chemicals, such as antibiotics, that may enter the water supply. There is also a need for better understanding of how ingesting water that is polluted as a result of climate change can affect health via its impact on the body's microbiome, chemical balance and immunity (R4ACCHC, 2022b, 2023).

Conduct research on how floods and droughts are affecting the agriculture sector and food safety and security

Scarcity, unpredictability and safety of water supplies can have major impacts on the agriculture sector and on food safety and security. Governments should be partners in research to identify and track the impacts of water-related hazards on the local agriculture sector (R4ACCHC, 2023).

Improve prediction models for waterborne infections

Research is needed on how meteorological and climatic factors interact with nonclimate drivers in the spread, distribution and incidence of waterborne infections, including leptospirosis, a range of diarrhoeal diseases (including cholera) and noncholera *Vibrio*. Nonclimate drivers include pathogen evolution, human susceptibility to infection, ecosystem change, level of economic development, water and land use (e.g. dams, deforestation), urbanisation, human behavioural factors, level of public health infrastructure and level of WASH infrastructure. This research can inform national and regional prevention and control policies, adaptation measures, the targeting of resources and the development of early warning systems (EWSs).

Conduct research on community and industrial water and waste management practices

It is important to study water management (including wastewater management, water safety practices, use of water for produce irrigation, rainwater harvesting and desalination) and sanitation and conservation practices (Allen, 2021). Research should be conducted at the local community level and within industries, including agriculture, extraction, processing, manufacturing and tourism. Water use should be appraised to identify wasteful and polluting practices and develop solutions.

Conduct practical research projects to explore integrated water resource management solutions for local communities

Communities and NGOs should be supported in developing IWRM plans that follow good-practice guidelines, and in implementing, monitoring and evaluating them. They also should be supported in disseminating the results of their research so that other communities can learn from their experiences. Experts in IWRM and civil society organisations should collaborate in this research and establish links with government water and sewage agencies to develop and implement solutions.

Conduct research on water wastage, recycling and technologies to reduce water scarcity/insecurity

The following three topics should be researched to enable more sustainable water solutions (Dubrow, 2021):

- The impact of water wastage on water scarcity/insecurity;
- Technical and behavioural issues with rainwater harvesting and wastewater reuse;
- Technologies to address water scarcity/insecurity.

Civil society organisations and WASH experts should collaborate on the first two of these. WASH experts should collaborate with other scientists and higher education institutions in the Caribbean to address the third. Research on these topics should be supplemented by operational research, involving governments among the stakeholders and economists among the experts, to work out feasible and cost-effective ways to roll out the recommendations.

Include water, sanitation and hygiene in research to develop disaster preparedness and response strategies

Water and sanitation are critical utilities and should be included in integrated risk management research to develop strategies to bolster their resilience in the face of extreme weather events and other disasters (Harewood, 2021). Existing strategies to maintain and bolster the resilience of infrastructure must be critically examined to identify weaknesses and gaps in existing services and how they are affected during extreme events. WASH experts, including civil engineers and public health inspectors, should be involved in this research. Again, operational research is needed to identify feasible and cost-effective ways to roll out the recommendations. A useful component of disaster preparedness research would be to explore atmospheric water generation technologies for the provision of potable water at shelters.

Surveillance gaps and how to address them

Develop water and sanitation infrastructure monitoring systems and data

Caribbean governments struggle to maintain and develop water and sanitation systems that are fit for purpose, partly because they lack diagnostic and monitoring capacity (Cashman, 2021). Major investments should be made in developing an information system in each country that clearly identifies the locations and causes of leaks, contamination and other issues, and records how and when they were addressed. Records should be kept of issues raised in public complaints and how they were addressed. Resources and skills in managing information systems should be developed, so that information can be shared regularly with all stakeholders to enable evidence-based policy decisions. Electronic information systems should be developed to facilitate data-sharing.

The development of such information systems is essential for providing data that can be used in research projects that explore associations between WASH infrastructure availability and quality and health outcomes.

Monitor waterborne and vector-borne disease outbreaks and water pollution, with a focus on the outcomes of extreme events

There is a critical need to strengthen the reporting of waterborne and vector-borne diseases and to establish systems to monitor pollution of water sources, including harmful algal blooms. This need will increase as water becomes scarcer and temperatures increase further. Temporally and spatially granular data are needed to establish EWSs, pinpoint areas and communities at risk, and respond to outbreaks on a timely basis.

Research and surveillance capacity-strengthening needs

To address the profound infrastructural and societal issues surrounding WASH, a stakeholder analysis is needed at the beginning of each research project and surveillance-strengthening initiative, listing those most affected and the range of experts and government agencies that need to be involved in developing and rolling out the solutions. Technical expertise alone will not address the challenges, since cooperation and collaboration with civil society, national governments and regional agencies are essential. Regional agencies that should be involved include the Caribbean Disaster Emergency Management Agency, the Caribbean Public Health Agency, PAHO and the University of the West Indies. National universities should also be involved. Data-sharing agreements should be developed.

Caribbean expertise may be supplemented and enhanced by technical support, training and research collaboration with international agencies and universities in areas such as (Harewood, 2021):

- Information systems;
- Epidemiology;
- Gastroenterology;
- Toxicology;
- Parasitology;
- Behavioural science;
- Civil engineering;
- Land surveying;
- IWRM;
- Integrated risk management;
- Emergency management;
- Mixed methods approaches to quantify and document the extent of waterborne and vector-borne diseases.

Investment in information technology infrastructure is very important for enabling the necessary information flows and level of detail needed for epidemiological and environmental reporting.

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