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

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15. CLIMATE-FRIENDLY HEALTH-PROMOTING INFRASTRUCTURE

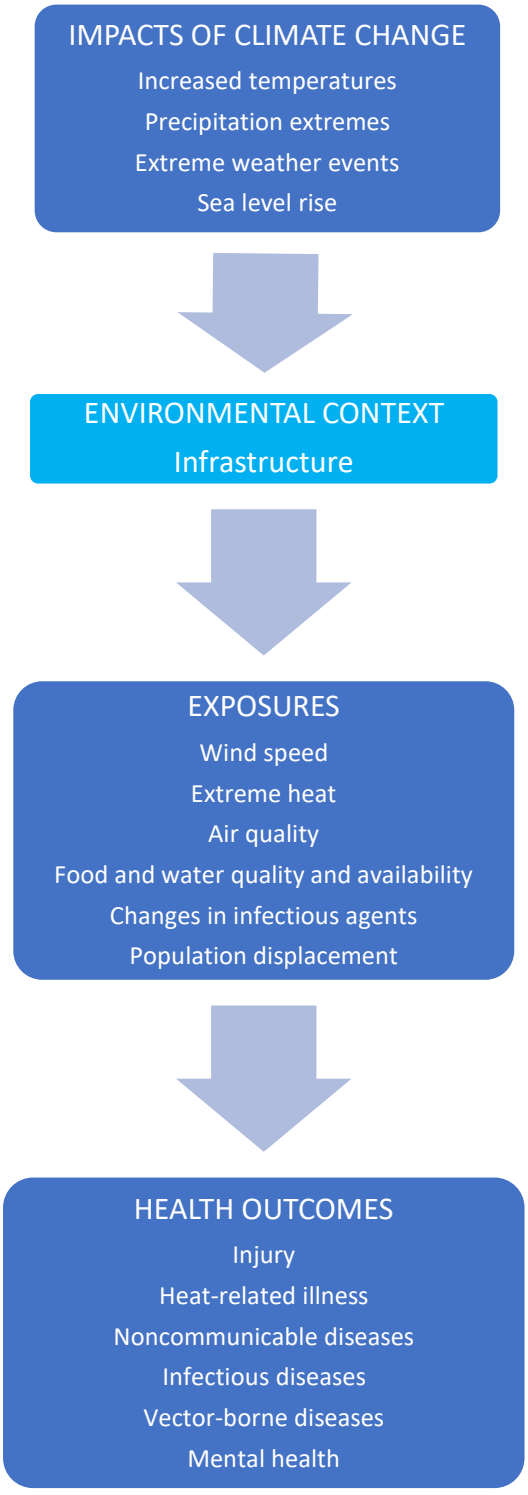
15.1. WHAT IS HAPPENING?

The condition and availability of infrastructure, such as buildings and physical structures for transport, water, sanitation, electricity, cooling and telecommunications systems, are critical determinants of public health. Climate change can cause infrastructural facilities to become severely damaged or be destroyed and fail to function, by driving extreme weather events, increased temperatures and sea level rise (Riley, 2021). Infrastructure is one of the major environmental mediating factors between climate drivers and exposure pathways that affect health outcomes, as illustrated in Figure 1. Infrastructure is generally constructed based on normative assumptions about weather, temperature and oceanic conditions, all of which are altered by climate change (Taylor, 2021).

The Intergovernmental Panel on Climate Change predicts with a high level of confidence that (1) the warming expected in small islands in the twenty-first century will further increase heat extremes and heat stress, (2) sea level will rise around small islands and, (3) coupled with storm surges and waves, sea level rise will exacerbate coastal inundation. Sea level rise likely will also cause shorelines to retreat on the sandy beaches of most small islands, and there are likely to be more intense, but generally fewer, tropical cyclones affecting small islands (Mycoo, 2021; Mycoo et al., 2022). For the Caribbean, a tendency towards a drier climate overall is expected but with more intense rainfall when it occurs (McLean et al., 2015). These impacts of climate change on small islands including those of the Caribbean should be considered in building and maintaining climate-resilient infrastructure in the interest of the health and well-being of Caribbean people. Unless infrastructure is suitably adapted, Caribbean people will suffer from the health consequences of heat stress (see Chapter 6, “Heat-related illness”) and various health consequences of damage to infrastructure associated with sea level rise, coastal inundation, saltwater intrusion into water supplies, flooding and extremely dry and extremely humid conditions (see Chapter 14, “Marine resources and health”; Chapter 12, “Agriculture and food safety and security”; and Chapter 3, “Water, sanitation and hygiene”). More intense tropical storms and hurricanes will cause additional injuries and deaths and will reduce access to health care, safe food and safe water (see Chapter 1, “Extreme weather events”).

Not only are infrastructural facilities vulnerable to climate change, but they also contribute substantially to it, since they consume vast amounts of energy in their construction and use. It has been estimated that infrastructure is responsible for 79% of all greenhouse gas emissions (UNOPS et al., 2021). Approximately one-quarter of CO_2 emissions come from the transport of people, goods and services (Gordon-Strachan, 2021), which is heavily dependent on road and other transport infrastructure.

Figure 1: The mediating role of infrastructure in pathways between climate change and health



Source: Adapted from USGCRP (2016).

Much essential infrastructure in the Caribbean is not built to climate-resilience standards (R4ACCHC, 2022a,b). Access to climate-resilient housing is especially scarce in low-income communities, with residents of these communities losing their accommodation and possessions when hurricanes strike. For example, housing damage in Dominica following Hurricane Maria amounted to 38% of all costs inflicted by the hurricane (Government of Dominica, 2017). In Chapter 3, "Water, sanitation and hygiene", Box 1 details what happened to Dominica's water and sanitation infrastructure as a result of Hurricane Maria. For example, the construction of water and sewage pipes across bridges resulted in loss of water and sanitation services for extended periods, as water from the hurricane cascaded down hillsides and broke both the pipes and the bridges (Allen et al., 2019; CARPHA, 2018; Dubrow, 2021). Figure 2 illustrates the difficulties that can be experienced in obtaining safe water and with recovery in general when infrastructure is destroyed by a hurricane.

Figure 2: Waste and sanitation hazards in Dominica following Hurricane Maria, September 2017

Source: International Medical Corps
(https://internationalmedicalcorps.org/story/dominica-devastated-by-hurricane-maria-but-determined-to-rebuild).

In the Caribbean, 52% of the population lives in urban settings (World Bank, 2021), so it is important to consider how infrastructure in urban areas can affect health. An important risk factor for heat-related illness and illness related to poor air quality is the urban heat island effect. This is a phenomenon whereby urban areas experience higher air temperatures than the surrounding countryside and is due to urban construction and human activities. In urban areas, artificial surfaces such as roads and buildings absorb and re-emit more heat than the plants, soil and water they have replaced, which makes their surroundings warmer too. Dark-coloured roofs, for instance, absorb heat during the day and radiate it overnight. Heat from sunlight is compounded by heat from human activities such as power generation and the use of cars and air conditioning. The geometry of cities also contributes to heat island effects: narrow spaces between tall structures, known as urban canyons, can block wind and trap heat. The especially hot conditions during the day affect people's ability to work, both within and outside buildings, affect cognition and dispose people to heat-related illness. Built structures that become hot during the day retain heat throughout the night. The difference between urban and rural areas is even greater at night than during the day, preventing night-time relief from heat stress (Campbell-Lendrum and Corvalán, 2007; Gordon-Strachan, 2021; Gregory and Azarijafari, 2021; Yang et al., 2016). For more information, see Chapter 6, "Heat-related illness". The combination of buildings, dense populations and warm conditions in urban settings also provide ideal conditions for *Aedes aegypti*, the mosquito that is responsible for most cases of

vector-borne diseases in the Caribbean (Henry and Mendonça, 2020). For more information, see Chapter 2, “Vulnerability to vector-borne diseases”.

The negative effects on human health of air pollution caused by transport and other forms of fossil fuel use is aggravated under the hotter urban conditions (Gordon-Strachan, 2021). For example, ground-level ozone is formed when vehicle and other fossil fuel and chemical emissions react in the presence of heat and sunlight. Inhaling ozone can cause coughing, shortness of breath, increased severity of asthma, bronchitis and other lung diseases, irritation and damage to airways, and premature death from lung diseases (United States Environmental Protection Agency, 2022). See Chapter 5, “Air quality”, for more information.

Much infrastructure in the Caribbean is dedicated to the use of private vehicular transport and does not encourage physical exercise. Many roads do not have sidewalks and there are very few cycle lanes. Little consideration has been given to protection from heat in the design of public parks and outdoor sport and recreational facilities. Infrastructural design may thus contribute to sedentary lifestyles and to the burden of noncommunicable diseases in the region. See Chapter 4, “Noncommunicable diseases and risk factors”, for more information.

Poor sanitation is another infrastructure-related factor that increases vulnerability to the impacts of climate change in urban areas. In Small Island Developing States, such as those of the Caribbean, the coastal locations of most cities creates an additional vulnerability, from sea level rise and storm surges (Campbell-Lendrum and Corvalán, 2007). See Chapter 14, “Marine resources and health”, for more information.

The climate resilience of health service infrastructure is of special concern. In the face of hurricanes, floods, extreme heat, and other climate hazards, health facility factors that are critical for maintaining sanitary and safe conditions for patients include the quality of building construction, facilities for solid and liquid waste disposal, water supply, electricity and refrigeration. Health facilities also have the opportunity to contribute to climate change mitigation through their choices of construction materials and energy options. These issues are considered in Chapter 16, “Smart health facilities”.

Little research has been dedicated to examining the effects of infrastructural design on health in the context of climate change in the Caribbean. Much of the information on which the current chapter is based was extrapolated from evidence on climate change conditions in the Caribbean and from general information on how health is affected by infrastructure as an environmental determinant, based on studies elsewhere (Allen, 2021). Caribbean urban planning and geography experts are, however, starting to consider how climate-friendly infrastructural design can contribute to Caribbean health (Mycoo, 2021; Sarjeant, 2021), as discussed in Section 15.2, ″What should be done?” There is a need for the greater involvement of public health and medical experts in these research endeavours. A PhD study in Barbados is looking at community-level environmental features influencing walkability, individual walking behaviour and risk of noncommunicable diseases (Rocke, 2022). While monitoring and early warning systems are being developed for extreme temperatures, air quality, vector-borne diseases and extreme weather events, the data collected have not generally been used in combination with data on the presence of or condition of infrastructure to examine how these can moderate or aggravate impacts on health. Data are also lacking on how infrastructural risks to health are influenced by sociodemographic and socioeconomic status.

15.2. WHAT SHOULD BE DONE?

> As we seek to bridge the infrastructure gap and improve the quality of life of people everywhere, it is critical that we invest in sustainable infrastructure that adapts to future uncertain climate conditions; contributes to the decarbonization of the economy; protects biodiversity and minimizes pollution. Sustainable infrastructure is the only way we can ensure that people, nature and the environment thrive together.
>
> Inger Andersen, Executive Director of United Nations Environment Programme (UNEP), in UNOPS et al. (2021)

This quote from the Executive Director of UNEP highlights that, if appropriately designed, infrastructure can contribute to achieving the major environmental goals of climate change adaptation and mitigation, conservation of biodiversity and minimisation of pollution. All of these goals relate to health, so infrastructure has the potential to be a major contributor to improving public health, by creating health co-benefits. Moreover, infrastructure can prevent and reduce illness if health is considered in its design, i.e. if facilities are purposely built to prevent and reduce illness and promote health. Infrastructure can also contribute to health if the mitigation of climate change is considered in its design, i.e. by using sustainable materials and sources of energy. Studies calculating the cost savings from considering climate change adaptation and mitigation in infrastructural design have consistently shown that the benefits far outweigh the costs of such design (Campbell-Lendrum et al., 2009; Gordon-Strachan, 2021; Patterson-Waterston, 2021).

While the mitigation of and adaptation to climate change have become major considerations in infrastructural design globally, issues of health and equity are not so often factored into design. This means that, even when projects address environmental sustainability, opportunities to improve health are missed, and some people are left behind or disadvantaged. Health and equity should be considered alongside climate change adaptation and mitigation in cost–benefit analyses of different infrastructural options (Patterson-Waterston, 2021; R4ACCHC, 2022c). Many people in the Caribbean live in substandard housing with limited access to basic utilities. This must be addressed as part of overall infrastructural mitigation and adaptation strategies (Bouillon, 2012).

Individual and community actions and how to support them

Move decision-making on infrastructural projects closer to the communities affected

Since infrastructure is responsible for around 79% of all greenhouse gas emissions and around 88% of the costs of adaptation to climate change (UNOPS et al., 2021), decisions about infrastructure are both highly important and highly political. Moving towards environmental justice, health and equity requires involving affected communities in decision-making about where to place infrastructure and the characteristics of the infrastructure to be installed. Too often, corporate and narrow political interests are served by infrastructure projects, which line the pockets of a few, displacing and inflicting losses on vulnerable communities. Not only would the democratisation of decision-making improve environmental justice, but local, traditional and indigenous expertise may also be very useful in ensuring that appropriate technologies are used and applied to optimise conservation of the environment and health (Mycoo, 2021; Scobie et al., 2021). Technical experts and local community members should engage in mutual education and dialogue to optimise solutions.

A further advantage of sharing decision-making more equitably is that it can help to achieve national goals. While national policymakers set goals and targets relating to climate change, such as time-bound, specific targets for fossil fuel emission reductions, it is the people “on the ground” who make the millions of decisions on consumption and production that determine whether or not these goals and targets are achieved. If local stakeholders have a say in decisions about infrastructure, it is more likely to be designed and built in harmony with their own goals and objectives, and their actions are likely to support the overall goals of the infrastructural project (Scobie et al., 2021). If environmental goals are accepted by all sides, a virtual cycle of mutually supportive action is created. Better communication by and coordinated education and support between the national and local levels of government can help to multiply achievements at both levels (Patterson-Waterston,

2021). In health systems, involvement of front-line service providers and patient advocates can assist in designing health infrastructure to optimise human and planetary health. In the words of Caribbean urban planner, Renelle Sarjeant, "People already seem to want green environments. They need to decide how and be supported" (Sarjeant, 2021).

Mechanisms for community consultation and involvement need to be established and supported by government, especially local authorities, given that they are responsible for local infrastructural development. "Town hall" meetings and committees can involve experts and developers in presenting information to local stakeholders and in receiving their feedback on local impacts and solutions. Environmental impact assessments should involve local stakeholders in highlighting potential challenges and solutions. Environmental laws should be strictly enforced. See Chapter 9, "Distribution, equity and justice in climate change and health", for further information on methods for involving communities.

Involve communities in developing "blue–green" infrastructure in the public realm

The public realm consists of the shared outdoor spaces that are open and accessible to the public. Increasing the numbers of plants (green) and water features (blue) in the public realm combats the urban heat island effect, reduces CO_2 emissions and pollution, and provides a pleasant environment, improving physical and mental health. Including greenery in children's play areas, for instance, has been shown to improve their immunity (Mycoo, 2021). Plants and access to green spaces can be incorporated into the design of buildings (e.g. through rooftop gardens, green walls), transport hubs, schools, health centres, etc. Further blue–green options include urban agriculture; permeable pavements, to improve drainage and water conservation; the use of aquatic plants in water channels; and the creation of detention ponds, to control flood and stormwater (Sarjeant, 2021). The numbers of blue–green parks and other recreational facilities in urban environments can be increased (R4ACCHC, 2022d). Maintaining and planting trees on hillsides are important measures for preventing landslides and infrastructural damage. Preventing the increasing numbers of bush/forest fires is also important for stabilising slopes and preventing landslides.

Involving the public in designing, constructing and maintaining these spaces enhances community engagement, sustainability, responsiveness to needs and access to environmental justice (Sarjeant, 2021). To enable this, community outreach is needed, along with information, education and communication on ways that community members can become involved, providing details on the practical steps they can take and tools they can use. Participatory processes can enhance effectiveness and efficiency of actions by communities, but investment is needed in equipment and materials for communities to use. The engagement of influencers such as faith leaders, community leaders and celebrities is important in motivating communities to get involved (R4ACCHC, 2023). Governments and the private sector should involve local communities in environmental planning and in the development of health- and well-being-oriented solutions. At times, action by government against property developers may be needed to achieve equitable and sustainable infrastructure. The value added by developing sustainable infrastructure should be emphasised in communication by civil society to the government and private sector (R4ACCHC, 2023). Tools such as Greenkeeper, an online tool that estimates the economic value of the ecosystem services provided by existing and potential urban green spaces (Patterson-Waterston, 2021), can help in motivating change.

It is also important to build on existing good practices in the Caribbean. Some Caribbean cities, such as Havana, Cuba, have multiple green spaces, such as squares and parks, in which plants are well maintained and continuously planted, and which people attend when they have opportunities for relaxation and leisure time. These spaces provide carbon sequestration services, improve local air quality, provide shade from the sun, help to manage groundwater infiltration and reduce flooding (Mycoo, 2021).

The development of blue–green infrastructure is one of several nature-based solutions that can complement and reinforce each other in facilitating climate change mitigation and adaptation, thereby improving health (Mycoo, 2021). Other nature-based solutions include ecosystem protection, support for rebuilding ecosystems and the restoration of natural resources (Sarjeant, 2021). Installing infrastructure for rainwater harvesting is also a nature-based solution (Gordon-Strachan, 2021; R4ACCHC, 2022c). Individuals and communities can become involved and take leadership roles in implementing all of these solutions. Governments and the private sector should collaborate to support these efforts.

Individuals and communities also need to desist from actions that worsen climate change risks, e.g. dumping litter, plastic waste and even old appliances into rivers and drains, which can become blocked, exacerbating flooding and providing mosquito-breeding sites (see Chapter 2, "Vulnerability to vector-borne diseases", and Chapter 3, "Water, sanitation and hygiene").

Strengthen the climate resilience of homes

Homeowners can contribute to their own safety and health by constructing, maintaining, retrofitting and repairing their homes, to ensure that they meet climate-resilience standards. This includes using special materials and building techniques to hurricane-proof homes. The capacity of water pipes and electricity wires to withstand hurricanes, floods, drought and extreme heat should also be addressed. The installation of solar panels and rainwater-harvesting facilities can help to mitigate climate change and its effects. Painting roofs white or with heat-reflective paints can increase the reflection of the sun's heat, reducing indoor air temperatures on hot days and reducing the load on air-conditioning systems (Pearce, 2018). Houses and surrounding land should be designed to minimise pools of stagnant water where mosquitoes can breed. To facilitate the implementation of these measures, education, information and advice should be provided using various information tools, media and face-to-face interaction, to enable people to contribute to making infrastructural changes, monetarily and in kind. It would also be helpful to have a checklist for the safety and greenness of homes/houses, adapted to the Caribbean situation, that people can refer to. For example, the "Climate change preparedness and resiliency checklist" (U.S. Climate Resilience Toolkit, 2021) developed in the United States of America could be adapted for use in the Caribbean.

It would be useful to provide information on traditional Caribbean construction methods designed to cool indoor environments, which consume less energy than some conventional methods (R4ACCHC, 2023). Consumers and homeowners should be educated on the importance of demanding more climate-friendly products and services from the private sector. Suppliers such as hardware and paint stores can be encouraged to learn about and stock heat-reflective paints.

These solutions are not available – or are available only minimally – to those who do not own their homes or cannot afford the expenses involved in converting their homes. Governments and landlords have responsibilities to climate-proof buildings or to provide the resources and expertise needed for this to be done. Building codes and their enforcement should be reviewed and will need to be adjusted to ensure compliance with evolving climate-resilience standards.

Structural/governmental and private sector actions

Form multisectoral partnerships for sustainable infrastructural development, including with the health sector

This recommendation is complementary to those above concerning community involvement and moving decision-making closer to affected communities. Governments should actively form partnerships with affected communities as well as with a range of different types of agencies that have a critical influence on infrastructural

development and health. Stakeholders include central government, local government, property owners, planners and designers, private developers, small and medium-sized enterprises, community groups, healthcare providers and health researchers (Sarjeant, 2021). Within government, the agencies responsible for environmental management, health, transport, urban and coastal development and planning, marine resources and agriculture should be involved in such partnerships (Gordon-Strachan, 2021). Partners should work together to identify funding streams, including existing climate change-related financing, to support the development of infrastructure that supports both health and climate resilience (R4ACCHC, 2023).

A strong framework of regulation is needed for new developments, and this can be better implemented if strong collaboration and planning mechanisms are in place (Campbell-Lendrum and Corvalán, 2007; Sarjent, 2021). More active input is needed from the health sector, to ensure that development and health policies contribute to following a preventive approach to local and global environmental sustainability, urban population health and health equity (Campbell-Lendrum and Corvalán, 2007).

There is also a need to develop alliances to focus on the maintenance and upgrading of existing infrastructure in the Caribbean, much of which is old and therefore requires considerable investment. The health and economic benefits of this investment must be stressed to government agencies, the private sector and civil society.

It is important to network internationally. Given the high level of urbanisation in the Caribbean, it would be helpful for local and national governments to connect with people involved in the global movement to create greener and healthier cities. For example, the C40 Cities organisation is a global network of mayors taking action to confront climate change and thereby enhance well-being (C40 Cities, 2022). The Caribbean Association of Local Government Authorities involves mayors in global initiatives such as the Compact of Mayors, a cooperative effort among mayors and city officials to pledge to reduce greenhouse gas emissions, track progress and prepare for the impacts of climate change (R4ACCHC, 2022a).

Adapt infrastructure and building codes to the characteristics of climate change in the Caribbean

As mentioned earlier in this chapter in Section 15.1, “What is happening?”, the predicted characteristics of climate change in the Caribbean include increased warming, an overall drier climate interspersed with more intense rainfall, more intense tropical cyclones and sea level rise. Adapting to each of these characteristics requires engineering and infrastructural solutions (Mycoo, 2021; Mycoo et al., 2022). Cooling services are needed as part of infrastructural design, to prevent heat-related illness. See Chapter 6, “Heat-related illness”, for details about heat-related illness and recommendations for addressing it. Buildings and other infrastructure must be constructed to withstand ever hotter and drier conditions without cracking, melting or crumbling. Risks of landslides resulting from successive droughts and extremely wet conditions must be considered. Much critical infrastructure is found around coastlines, and this infrastructure must be strengthened and/or relocated to address the risks associated with sea level rise, coastal inundation and saltwater intrusion into water supplies (see Chapter 14, “Marine resources and health”, and Chapter 3, “Water, sanitation and hygiene”, for more information on the health consequences of these risks and recommendations for addressing them). Infrastructure in general must be constructed to withstand more intense tropical storms and hurricanes (see Chapter 1, “Extreme weather events”).

All these considerations should form the basis of revising building codes and other requirements for obtaining permission to install or make major modifications to infrastructure (Gordon-Strachan, 2021; R4ACCHC, 2023). Insurance companies can get involved by providing incentives to build infrastructure that meets climate-resilience standards by adjusting their premium levels according to adherence to building codes, as has been done in Dominica (R4ACCHC, 2023). Building contractors should be targeted with information, education and communication products (R4ACCHC, 2023). The Pan American Health Organization recently concluded its “Smart Health Care Facilities in the Caribbean” project. As part of this project, a toolkit was developed for retrofitting

and/or building health facilities that are both green and safe, thus making them "smart". This toolkit can be adapted to ensure that buildings are environmentally resilient to climate disasters. See Chapter 16, "Smart health facilities", for more information.

Governments and the private sector need access to scientific information on how to construct and maintain climate-resilient infrastructure. The Caribbean needs to strengthen its research capacity, and particularly its research in engineering and related fields, and to develop appropriate means of communicating the information collected from such research (R4ACCHC, 2023).

Draw inspiration from traditional Caribbean infrastructural design for climate resilience

In the past, Caribbean people have developed infrastructure appropriate to the tropical climate, but there appears to have been a move away from appropriate architecture over the course of the twentieth century and into the current century. This has coincided with an acceleration of climate change and has aggravated the negative effects of climate change on public health (Mycoo, 2021).

Figure 3 provides some examples of traditional and new housing features in the Caribbean. Traditional features to address the hot climate prioritised methods to maximise ventilation and shade. Traditional housing in flood plains, especially in Guyana and Trinidad and Tobago, was often constructed on stilts, so that water could flow underneath without damage to property. Outside the rainy season, the area under the house provided additional shade and living space.

Some of the newer housing developments in the Caribbean are inappropriate for the local climate, since they are based on designs and have used materials imported from more temperate countries, often contributing to the urban heat island effect (R4ACCHC, 2022d). Current designs favour enclosed spaces and the use of fossil fuel-powered air conditioning for cooling (Gordon-Strachan, 2021). Such developments in lower income communities sometimes render inhabitants extremely vulnerable to flooding and are maladapted to the increasingly hot conditions being experienced (R4ACCHC, 2023). The role of property developers and politicians in constructing and allowing such developments to be constructed, respectively, must be challenged. There is a need to widen drains and adopt other flood mitigation measures, especially given the slower run-off of floodwaters because of sea level rise. The health consequences of flooding are presented in Chapter 3, "Water, sanitation and hygiene", and those of increased temperatures are presented in Chapter 6, "Heat-related illness".

Promote blue–green infrastructural policies and plans

To achieve the health outcomes of blue–green infrastructure outlined above, governments should integrate the creation of blue–green infrastructure into spatial and sectoral plans and policies. Public–private partnerships are critical, along with the allocation of finance and incentivisation mechanisms. A variety of agents should be made aware of the importance of blue–green infrastructure and become involved in these partnerships, including sectoral agencies, line ministries, physical and urban planners, architects, engineers, landscape architects, mayors, communities and neighbourhoods (Sarjeant, 2021). Dominica has made climate resilience a central goal of national development policy, aiming to become a climate-resilient nation (Government of Dominica, 2012). For this purpose, it has established a coordinating agency, the Climate Resilience Execution Agency for Dominica (CREAD, 2019). Moreover, Saint Lucia's National Adaptation Plan 2018–2028 includes plans for green roofs, urban afforestation, natural buffers and green spaces (Mycoo, 2021).

Figure 3: Climate change adaptation features of old and new architectural styles in the Caribbean

Traditional architectural features

Adaptation to heat

– Jalousie windows
– Verandahs
– Porticos
– Gable windows
– Short piers for air flow

Source: Photo of a house in Trinidad and Tobago by James Hospedales.

Adaptation to flooding

Elevation of the house on stilts

Source: Photo of a house in Trinidad and Tobago by James Hospedales.

Typical housing construction in the twenty-first century for low-income neighbourhoods in the Caribbean

– Bungalows built on flat land, including floodplains
– Small windows with little natural ventilation

Source: Trinidad Express Newspapers (2018) (https://trinidadexpress.com/news/local/national-disaster-declared/article_16ff68d4-d47a-11e8-9e2f-e3a80bd3c43c.html).

Provide infrastructural support for green mobility and exercise

Green mobility refers to options for movement or transport that do not damage the natural environment, such as walking or cycling. Green mobility options can also reduce the environmental damage and decline in air quality associated with transport, for example by shifting towards sustainable energy sources and providing shaded bus stops and sustainably cooled transport hubs to encourage public transport use. Green mobility that involves a physical exercise component is often termed "active transport". This mitigates climate change by reducing the use of automobiles and has health co-benefits such as reducing the incidence of and morbidity associated with noncommunicable diseases (Campbell-Lendrum and Corvalán, 2007; Gordon-Strachan, 2021; R4ACCHC, 2022e).

Green mobility should be supported and the benefits to health therefore promoted by infrastructural design. The number, and blue–green characteristics, of parks and other recreational facilities enabling exercise should be increased. The number of footpaths and cycle lanes should be increased, and they should be provided with shade, ideally using plants, to help prevent heat-related illness (R4ACCHC, 2022e; Rocke, 2022). Duties and taxes should be removed from bicycles and e-bikes to provide an incentive for their use. Compact urban design can reduce travel distances and commuting times, contributing to green mobility. The number of electric vehicle charging stations, of which there are few in the Caribbean, should be increased (Sarjeant, 2021). The availability of exercise equipment and number of sports fields should continue to be increased, with attention being paid to their installation in low-income and marginalised communities. Moreover, these facilities must be properly maintained and repaired on an ongoing basis.

Invest in sustainable energy infrastructure

Since infrastructure itself is responsible for over three-quarters of greenhouse gas emissions, it is critically important for new infrastructural developments to include means of manufacturing energy from sustainable, renewable, nonpolluting sources. These forms of energy should be used to power other forms of infrastructure (Campbell-Lendrum and Corvalán, 2007).

The Eastern Caribbean Central Bank provides a model, having established a solar farm on its premises (R4ACCHC, 2022b). The project involved installing solar panels in a series of canopies over the bank's car park at its headquarters in Basseterre, Saint Kitts and Nevis, resulting in the largest solar-powered generator on the island. It is also thought to be the largest solar-powered system in the Eastern Caribbean operated by any entity other than a power company (Eastern Caribbean Central Bank, 2022). Chapter 5, "Air quality", and Chapter 14, "Marine resources and health", provide further details of options related to energy infrastructure for mitigating climate change with health co-benefits.

To encourage the greater adoption of sustainable energy infrastructure by households and businesses, governments should offer more incentives such as tax breaks, and cost–benefit analysis and other relevant data should be provided to consumers (R4ACCHC, 2022d,g). Utility companies can assist by providing easily accessible information to consumers, to enable them to monitor their energy use, and by communicating with consumers about the importance of conservation in the context of climate change.

Reduce, reuse, recycle

Infrastructure should support a reduction in environment-damaging production and consumption in the Caribbean. New developments should incorporate facilities for collecting and processing materials for recycling. Facilities should be properly maintained and repaired rather than replaced, once they can meet environmental standards. Compact design should be a principle for designing infrastructure.

Requirements on water-harvesting facilities are included in the building codes of countries such as Antigua and Barbuda. Other Caribbean countries should include these requirements too, as climate change continues to

exacerbate water stress in this region. The management and recycling of wastewater should also be included as part of the greening of urban spaces. The regional adoption of integrated water resource management (IWRM) plans is actively being discussed by Caribbean stakeholders and is at the nexus of climate change and water security. Several Caribbean countries, including the Bahamas, Barbados, Guyana, Jamaica, and Trinidad and Tobago, have drafted/developed IWRM plans. However, IWRM has not been fully integrated into legal and policy frameworks (Gordon-Strachan, 2021).

Include infrastructure in disaster preparedness and response, and build back better following extreme events

As part of disaster preparedness and response, and in the aftermath of extreme events, it is critically important to ensure the resilience of infrastructure. This means ensuring that structural integrity and strength are sufficient to withstand more intense wind and hydraulic forces. This is especially important for health facilities; storage facilities for emergency medical, food and water supplies; and hurricane shelters. See Chapter 16, "Smart health facilities", for further details. Water, sewage and solid waste infrastructure should receive special attention in disaster preparedness and response. Safeguarding infrastructure is one of the five pillars of the Caribbean Resilience Framework, developed by the Caribbean Disaster and Emergency Management Agency and its partners in 2018 (Riley, 2021). Design should also be sensitive to important social vulnerabilities that arise from disasters. For instance, shelters should be designed with separate areas and entrances for men and women, to prevent violence against women from occurring.

Research gaps and how to address them

Build the Caribbean body of knowledge on the role of infrastructure in reducing or amplifying the impacts of climate change on health

Developing science-driven policy on infrastructure, climate change and health is critical. Robust research is needed to measure the effect of different types of infrastructure in mediating the impacts of climate change on health. Such empirical evidence can provide cogent arguments for investment and the allocation of resources (Allen, 2021; Mycoo, 2021).

There is a need to identify the health impacts of the various types of infrastructural projects implemented in the Caribbean, and how these impacts vary according to climatic conditions (Allen, 2021). Longitudinal studies are needed, including those that map environmental, climatic and health conditions before and after project implementation and at determined intervals thereafter. Impacts should be disaggregated according to the sociodemographic characteristics of affected communities and geographical areas. Projects with varying levels of incorporation of "blue–green" features can be compared with each other in terms of performance and with the performance of "baseline" or status quo infrastructure (Sarjeant, 2021).

Health impact assessments and environmental impact assessments should be systematically conducted for infrastructure projects. Data from these should be collated in repositories to enable systematic learning from the limitations of previous projects and how these were resolved.

The geographical vulnerabilities of each Caribbean state should be measured and monitored, such as the percentage of the population living along coastlines; the topography (e.g. percentages of flat and mountainous terrain); geographical distances from other land masses and commercial centres (degree of isolation); and the availability of transport, communication infrastructure, healthcare equipment, supplies and specialised healthcare workers (Allen et al., 2021; Holdschlag and Ratter, 2012). This would provide important contextual information to inform the development of climate-resilient infrastructure (Allen, 2021).

Results from such studies should be combined with economic data to conduct cost–benefit analyses that incorporate subpopulation impacts (Gordon-Strachan, 2021; Patterson-Waterston, 2021; Sarjeant, 2021). Such cost–benefit analyses are critical to inform decisions to enhance health equity and environmental justice.

Identify health hazard hotspots and opportunities for infrastructural adaptation

Researchers in disciplines including medicine, public health, geography and meteorology can help to identify geographical areas with concentrations of people living with health conditions associated with climate change and to examine the infrastructural and other environmental conditions under which people are living in these areas. The environmental conditions identified can be compared with those in areas with lower levels of ill health, to identify infrastructural risk factors and make recommendations for adaptation (Sarjeant, 2021). The use of geographic information system technology can assist with this. Location-specific economic values of health and the social and environmental costs and benefits of different infrastructural options can be calculated (Patterson-Waterston, 2021). Opportunities for transforming/retrofitting Caribbean urban, rural and coastal spaces should be identified with the assistance of engineers, architects and environmental health specialists. An important area to focus on is possibilities for IWRM. See Chapter 3, "Water, sanitation and hygiene", for further information on IWRM (Gordon-Strachan, 2021; Mycoo et al., 2022).

Identify financial mechanisms to support climate- and health-friendly infrastructural development

Given that it has been estimated that 88% of all climate change adaptation costs involve infrastructural adaptation (UNOPS et al., 2021), it is critical to consider how the costs of climate- and health-friendly infrastructure will be met (Sarjeant, 2021). Economists and public health experts should collaborate to quantify the costs of climate-friendly investment options and seek sources of funding for these. Economic research can also help in the design of appropriate financial mechanisms for Caribbean conditions. Chapter 17, "Funding streams for climate and health action", provides a further analysis of this.

Critically examine the framework of laws and regulations concerning infrastructure through a climate and health lens

Lawyers, structural and mechanical engineers, and public health specialists should examine environmental and building codes, laws and regulations to assess the extent to which they promote climate change mitigation and adaptation and prevent further climate change-related damage (Gordon-Strachan, 2021). Health considerations should be foremost in recommending changes to the legislation and enforcement mechanisms.

Examine the climate resilience of infrastructural solutions developed by Caribbean people

As outlined above, there may be things to learn from traditional Caribbean architecture in terms of climate adaptation. Research should be conducted on how traditional infrastructural solutions to climate challenges affect health and how they can be updated to benefit health, for example by reducing indoor air temperatures or the impact of recurrent floods in some areas. Resources should be dedicated to research and development by Caribbean engineers and designers, to enable them to adapt infrastructure to local conditions (R4ACCHC, 2022b). Using renewable energy for air conditioning, in instances where it must be used to mitigate the effects of heat on health, is also an important topic for research (Allen, 2021; Gordon-Strachan, 2021).

Conduct research on infrastructural options for promoting green mobility and exercise

Replacing vehicular with active transport such as walking and cycling may not be straightforward in the Caribbean, as the hot conditions create risks of heat-related illness and there are concerns about security and safety and harassment, especially among women and girls. Research should be conducted into the efficacy of infrastructural solutions (Gordon-Strachan, 2021) such as walkways and cycle paths shaded by greenery or

artificial canopies, ventilation and cooling options. A current PhD project is looking at the walkability of public spaces in Barbados to promote exercise and prevent noncommunicable diseases (Rocke, 2022).

Conduct research on how to connect health specialists with other experts and officials to build a multisectoral approach

Research on institutional structures and processes for infrastructural projects should be conducted to assess ways in which public health and medical experts can contribute to infrastructural design. Once ways of engaging health workers are established, they can be communicated to students undertaking health-related tertiary education courses, hospital rotations, etc. A suggested research question is: "How can we connect the health sector with the planning departments and authorities in Caribbean countries with respect to urban greening, including promoting walking paths and biking lanes?" (Gordon-Strachan, 2021).

Surveillance gaps and how to address them

Develop and use measures of equity and health impact for infrastructural assessment and monitoring

The benefits and costs of infrastructural projects are not evenly distributed. Methodologies should be developed to measure differential impacts, according to demographic and socioeconomic factors, and the extent to which these impacts are concentrated in certain communities. Impacts on groups known to be vulnerable to the health effects of climate change should be assessed and monitored. For example, a scoring system was developed to assess the impact of Belize's nationally determined contributions on vulnerable groups, including women, indigenous people and people with disabilities (Patterson-Waterston, 2021). Various indicators of benefits and costs could be measured, including new employment and skills, as well as health status.

To integrate health data into such assessments, special efforts to strengthen health surveillance will need to be made. Electronic information systems should be strengthened to facilitate these kinds of surveillance approaches.

Strengthen information systems that monitor energy and water consumption and promote the use of the information generated

Utility companies should continue to strengthen information systems to monitor the consumption of energy and water. Communication campaigns should promote the use of the information collected to guide consumption decisions and promote conservation among individual consumers, businesses and government agencies. The information should be made available and readily accessible, for example via smartphone apps.

Develop integrated surveillance systems that monitor weather, health and emissions of greenhouse gases and other air pollutants

In evaluating the health dimensions of infrastructure, it is necessary to have access to weather, health and emissions data simultaneously. Strengthening and integrating these types of data is very important (Gordon-Strachan, 2021).

Develop and use tools to assess the environmental and health benefits of infrastructure

Metrics for the assessment of the health and social impacts of climate change-responsive projects are being developed globally. These can be adopted and possibly adapted to the Caribbean context (Gordon-Strachan, 2021). These metrics include:

- The Health Economic Assessment Tool (HEAT) for walking and cycling (WHO, 2021);
- The GreenUr green urban spaces and health tool, which uses geographic information systems to measure the availability and accessibility of green space and its health effects (WHO, 2022);

- Greenkeeper, an online tool that estimates the economic value of the ecosystem services provided by existing and potential urban green spaces (Patterson-Waterston, 2021).

The Caribbean Public Health Agency has developed an innovative framework for the monitoring and surveillance of integrated solid waste management in the Caribbean, with the aim of building resilience to climate change. Poor solid waste management in the context of climate change can exacerbate health challenges related to dust, bioaerosols, vermin and contaminated water or food, including infections, chronic diseases, acute poisoning and injuries. The monitoring and surveillance framework was designed for solid waste disposal facilities. It includes indicators under the broad headings of planning, implementation, evaluation and improvement, to assess whether or not key steps have been taken in the project management cycle that are consistent with the achievement of public health objectives. Assessments of environmental and social impacts are included among the planning indicators (Newton-James and Ivanova, 2021).

Research and surveillance capacity-strengthening needs

Developing suitable infrastructure to help address climate and health requires a wide range of scientific and creative skills, including in disciplines such as engineering, architecture, physics, chemistry, biology, medical science and public health. Social scientists, including economists and urban planners, are needed to plan projects and assess social and economic challenges, and to help develop social inclusion strategies and resource mobilisation. Experts in information technology, remote sensing and geographic information systems are also needed (Allen, 2021; Gordon-Strachan, 2021).

Intergovernmental agencies make an important contribution to operational research, complementing that of academic institutions. For instance, the health subcommittee of the Caribbean Disaster and Emergency Management Agency's Coordination and Harmonization Council has the key function of identifying challenges and gaps in the health sector regarding the implementation of health disaster risk reduction actions (Riley, 2021).

Major challenges in strengthening research and surveillance capacity in the Caribbean are the scale and cost of infrastructural projects and therefore the power of governments and large corporations in determining whether or not they go ahead. Resources are needed from donors to scale up research and make use of all available datasets and technologies, to establish infrastructure that truly serves the interest of Caribbean health. Public–private partnerships can assist considerably if they are truly oriented towards achieving better health outcomes by strengthening infrastructural responses to climate change in the region.

15.3. REFERENCES

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