CHAPTER 3

HEALTH IMPACT OF CLIMATE IN THE CARIBBEAN

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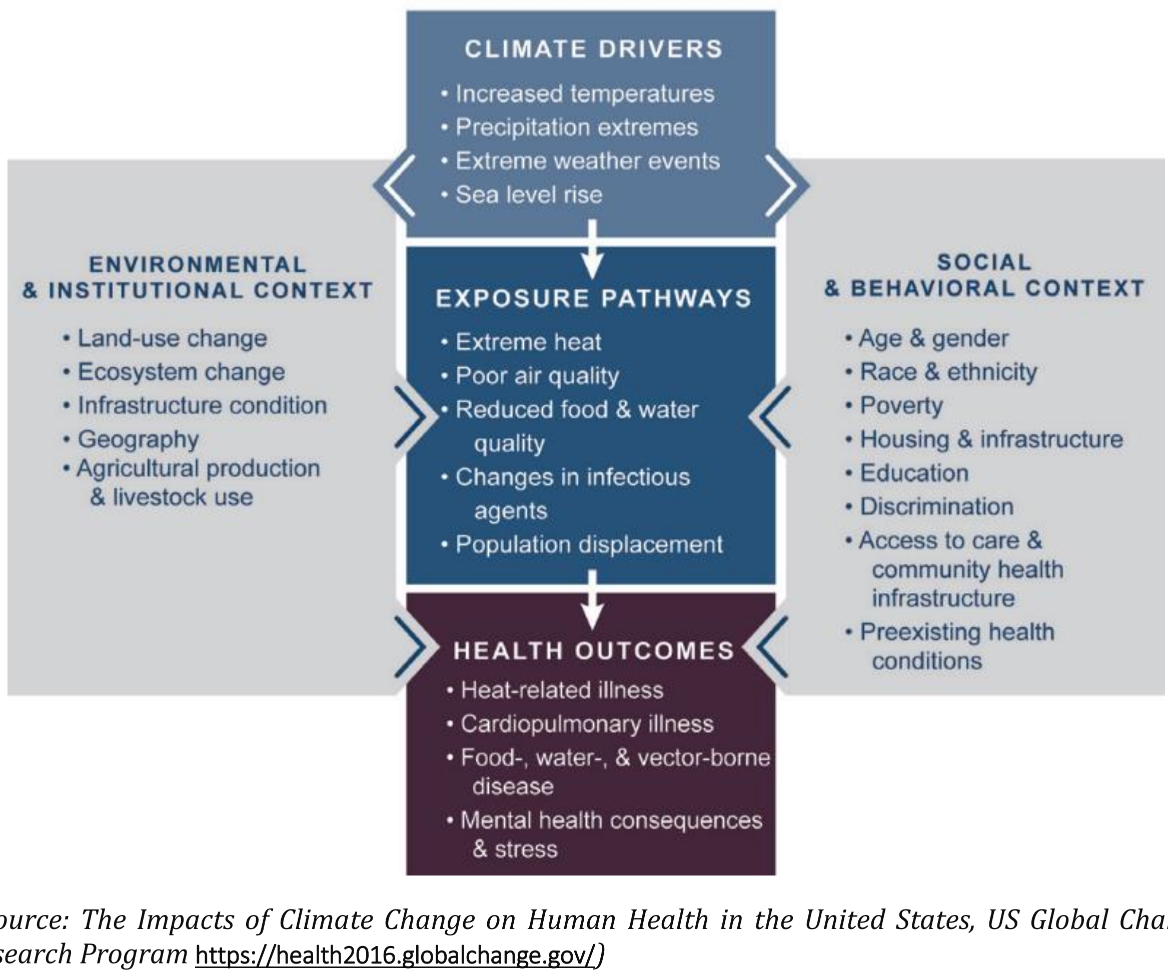
INTRODUCTION

In this chapter, we examine evidence specifically for the Caribbean of climate variability and change and health outcomes. The analyses are guided by the following framework, developed by the US Global Change Research Programme. We examine the evidence for the Caribbean on climate drivers, exposure pathways and health outcomes. The impact on health outcomes of climate drivers and exposure pathways is conditioned by contextual factors: environmental, institutional, social and behavioural. Policy strategies, institutional action and resources can also condition outcomes. Environmental, economic and social vulnerabilities of SIDS and vulnerable populations have been considered in chapter 2. Sea level rise is a climate driver that has a particularly serious impact on SIDS, so it is considered in chapter 2 rather than the current chapter. Chapter 4 is devoted to considering severe weather events, showing how the major hurricanes of 2017 affected health determinants and outcomes in the Caribbean. Institutions, behavioural and policy strategies and resources oriented to addressing climate and health are considered in Chapter 5.

Figure 1: Primary exposure pathways by which climate change affects health



(Source: The Impacts of Climate Change on Human Health in the United States, US Global Change Research Program https://health2016.globalchange.gov/*)*

An important feature of links between climate and health is that they are multiple and may occur simultaneously or in sequences of varying duration. Thus, there may be compounding or cascading health impacts (United States Global Change Research Program, 2016). This poses a difficulty for research on the links, since science seeks to isolate the impacts of individual factors, and complex multivariate models may be needed to capture interconnections and dynamics. The final section of this chapter analyses the status of research and surveillance on climate and health links and suggests some strategies for strengthening the evidence.

Interactions between exposure pathways are multiple, and contextual factors condition eventual health outcomes. Consider the example of heavy precipitation events, which may be interspersed with increasingly long hot, dry spells. According to climate predictions presented below, this is not an unrealistic scenario for most of the Caribbean. Mould and bacteria may proliferate in dwellings after floods. These may lead to infections among inhabitants of damp buildings, who may pass them on to others. There may also be increased risk of mosquito-borne diseases such as dengue as pools of water are left following the rains and infrastructural damage. The hot, dry spells following the wet events may aggravate symptoms such as fever, and lead to the release of mould spores, bacteria and small particulate matter into the air as buildings and furnishings dry out. Respiratory diseases, including infections and allergies, may result or be aggravated. Eventual health impact is mediated by contextual factors involving human action and characteristics. For instance, the choice of chemicals, such as bleach, used for cleaning dirt following a flood may itself lead to some negative health impacts, which must be weighed against the risk from the dirt itself. Government policies and actions can reduce the negative health impact, by for example speedily removing debris that can encourage mosquito-breeding, and educating and providing materials to the public for environmental clean-up. Impacts will vary depending on geography and social status, and it is important that actions to mitigate the consequences of climate change focus especially on vulnerable populations (as identified in Chapter 3).

The example above serves to illustrate the importance of cross-sectoral action, as it concerns more than one sector, including in this instance infrastructure/ public works, sanitation, health and education sectors. Chapter 1, section 1.3 discussed inter-sectoral linkages and cross sectoral strategies to address health outcomes of climate change and variability.

1. CLIMATE DRIVERS: PROJECTIONS OF CLIMATE VARIABILITY AND CHANGE IN THE CARIBBEAN

Human physiology is such that healthy individuals are able to function normally with temperature and humidity patterns and ranges that are usual where they live. Difficulties may arise when people move out of their usual surroundings to experience colder or hotter conditions (such as tourists from Northern countries experiencing the levels of heat and solar radiation of the tropics) or when climatic conditions vary from accustomed norms. Susceptibility to certain infectious diseases and to negative outcomes of chronic conditions also varies by season according to climatic conditions such as temperature and humidity. Thus, climate variability can affect health through natural seasonal fluctuations and through exposure to unaccustomed climatic conditions.

As noted in chapter 1, climate change constitutes sustained changes in average conditions. This alters the ecology and exposure pathways such as heat, air and water quality and infectious agents. It may lead to population displacement as people seek to move to locations which provide more favourable conditions for their health and livelihoods. Climate change can therefore affect human health in two main ways: first, by changing the severity or frequency of health problems that are already affected by climate or weather factors; and second, by creating unprecedented or unanticipated health problems or health threats in places where they have not previously occurred (United States Global Change Research Program, 2016).

Chapter 1, section 1.1 presented information on climate change with some comparisons between the global situation and that of the Caribbean. In summary, in the Caribbean, maximum and minimum temperatures have increased over the past fifty years and the temperature range per year (i.e. the diurnal range) is decreasing (Peterson et al., 2002; Stephenson et al., 2014). Since the 1950s, the number of very hot days has increased and the number of very cool nights has decreased (Stephenson et al., 2014). Global Climate Models (GCMs) indicate future temperature increases in the Caribbean to be between 1.0^{0}C and 3.2^{0}C by the 2100s, with a median of 2.0^{0}C: above the 1.5^{0}C that was the target of the Paris Agreement and the "1.5^0 to Stay Alive" campaign led by the Caribbean Community Climate Change Centre (CCCCC) (see Chapter 5 on this campaign). Global Climate Models (GCMs) project an overall tendency to a drier Caribbean climate, with changes in annual precipitation varying from -39 to +11% under a moderate emissions scenario, with a median of -12% (M.A. Taylor, Chen, & Bailey, 2010). This is likely to lead to increased water shortages and droughts over time. There also appears to be increased variability within each year, with evidence from 1961 to 2010 showing small increasing trends in annual daily intensity of precipitation, maximum number of consecutive dry days and heavy rainfall events (Stephenson et al., 2014). The period 1995 to date is one of above normal storm activity in the Caribbean (Bell, Blake, Landsea, Goldenberg, & Pasch, 2018), and this has been predicted to endure until around 2040 (Goldenberg, Landsea, Mestas-Nuñez, & Gray, 2001). Thus, the population of the Caribbean is increasingly exposed to precipitation extremes leading to drought and flooding, to increased temperatures, and to extreme weather events such as hurricanes. Sea levels are expected to rise between 0.21 and 0.48 m by the year 2100, with serious consequences for Caribbean people, most of whom live or work on or near coastlines (M.A. Taylor et al., 2010).[1]

Until 2003, what was known about climate change in the Caribbean relied on GCMs, which did not provide fine-scale projections enabling differences to be discerned between sub-regions and individual islands and territories. That year, a group of Caribbean climate scientists met in Havana, Cuba, with the intention of providing information more relevant to sub-regional and national policy-makers. They agreed to use dynamical downscaling methodology using a Regional Climate Model (RCM). The model chosen was the Providing Regional Climates for Impacts Studies (PRECIS) regional model, which had been released by the Hadley Centre of the United Kingdom and was being promoted as a tool to meet climate information needs of developing countries and SIDS. Arising from the workshop was a multi-country collaborative initiative that could generate high-resolution climate projections, using a subset of Special Report on Emission Scenarios.[2] The Caribbean institutions that

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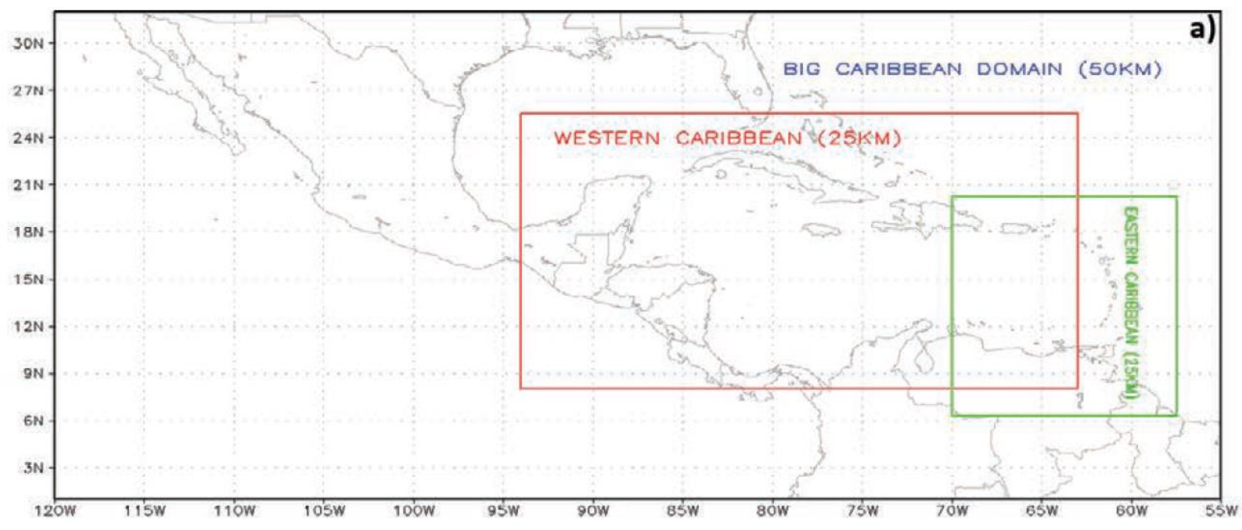
[1] SLR in the Caribbean is expected to be near the global mean, based on evidence from the 1950 to 2000 period for the region, which showed SLR near the global mean (M.A. Taylor et al., 2010).
[2] SRES refers to the *IPCC Special Report on Emission Scenarios* (2000). Each SRES is a plausible storyline quantifying how GHG emissions could change over the 21st century in the absence of policy interventions to

worked on the project were the campuses of the University of the West Indies in Barbados and Jamaica, the INSMET (Institute of Meteorology) in Cuba and the CCCCC in Belize. The RCMs simulated the present and end-of-century (2071-'99) climate for the A2 (Medium-High Emissions) and B2 (Medium-Low Emissions) SRES scenarios (see footnote 2). Two domains were defined to take advantage of PRECIS's two available resolutions – a Caribbean domain at 50 km resolution encompassing the area from the Bahamas to Guyana and Central America (UWI-Jamaica and INSMET to lead the research) and a smaller Eastern Caribbean domain at 25 km resolution to capture the smaller islands (UWI-Barbados to lead). A Western Caribbean domain at 25 km was later added. Validation by comparing RCM- and GCM-generated results with climate data covering the same period demonstrated that the RCMs were more accurate (M.A. Taylor et al., 2013).

Figure 2: Geographical domains for projections of climate change in the Caribbean by the PRECIS project



Note: The full area of this map is the big domain at 50 km resolution, which covers all the Caribbean plus parts of Central America, southern United States and northern South America. The two smaller domains are at a resolution of 25 km and cover the Western Caribbean (red) and the Eastern Caribbean (green).

Source: (M.A. Taylor et al., 2013)

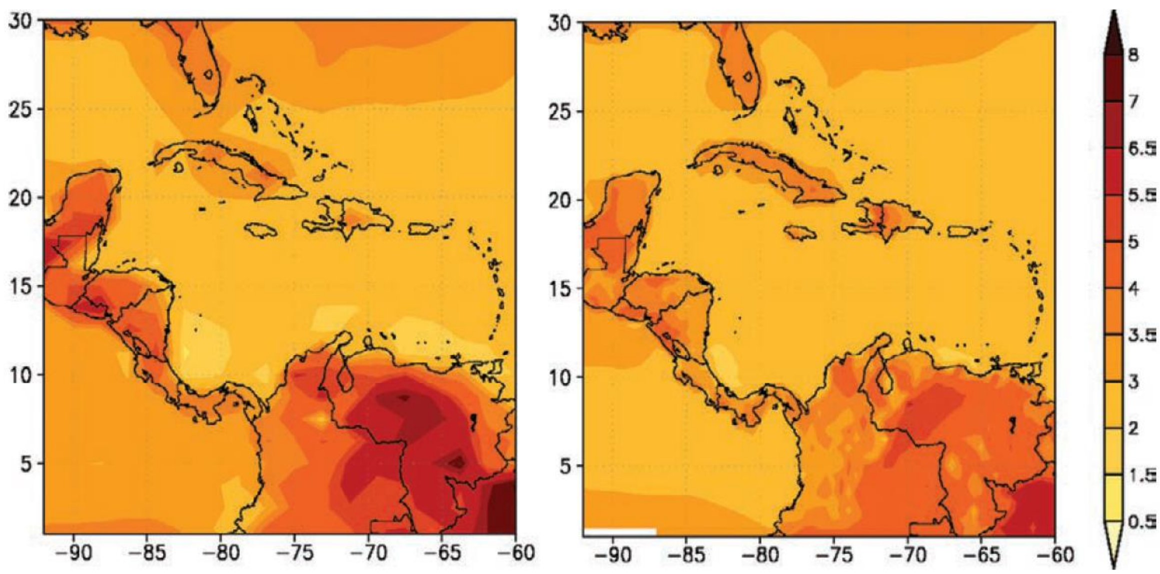
change the emissions. Each SRES describes the relationship between f2.uture GHG emissions and driving forces such as energy use, population growth, economic and technological development and other factors. Forty scenarios are grouped into four families according to the similarities in their storylines (M.A. Taylor et al., 2010). There are four main emissions scenario families. These are labelled B1 (Low Emissions), B2 (Medium-Low Emissions), A2 (Medium-High Emissions) and A1F1 (High Emissions) (M.A. Taylor et al., 2007)

The first round of climate projections from PRECIS showed warming of between 1^0 and 5^0C by the 2071-2100 period. The changes were characterized by:

- Greater warming in the northwest (Belize, Cuba, Hispaniola and Jamaica) in comparison to the Eastern Caribbean island chain, and
- Greater warming in the summer months than in the drier early months of the year.

PRECIS projections show temperature increases for the larger Caribbean islands (Jamaica, Cuba and Hispaniola) that are larger than in the corresponding GCM. In both the larger and smaller Caribbean islands, the RCM showed greater temperature changes on the land than over the sea, likely due to evaporative heat loss being less over the land and the greater thermal inertia of the sea (see figure below).

Figure 3: Mean changes in annual mean temperature for 2071-'99 with respect to 1961-'89 as simulated by the HasAM3P GCM (on the left) and the PRECIS RCM (on the right) for the SRES A2 scenario



Source: (M.A. Taylor et al., 2013)

The RCMs corroborate the predicted overall reduction in rainfall suggested by the GCMs but reveal sub-regional variation. In the A2 scenario, between 10^0 and 24^0N – that is, encompassing the Caribbean Sea and most of Central America - a significant drop in mean annual rainfall (10%-50%) is projected by the end of the century. Above 24^0 N, a 10%-30% increase in precipitation is predicted. For the B2 scenario, a difference is the wet area in the north extends southward to 21^0N, so that rainfall also increases over Cuba.

The PRECIS project is historically important as it enables the climate change picture for different parts of the Caribbean to be differentiated. The implementation of the project demonstrated notable challenges and successes. Challenges experienced during the project included:

- The necessity to upgrade available hardware and to acquire sufficient data storage;
- The lack of consistent and reliable weather observations, and
- Uneven funding for the respective institutions, being in most cases limited to money for the initial hardware and attendance at meetings.

These challenges demonstrate Caribbean resource-capacity constraints with respect to research and surveillance. Some such constraints were ameliorated by collaboration between institutions, which enabled parallel runs of the models to be conducted in multiple institutions, mutual exchange to troubleshoot and encourage, and shared commitment to the importance of the task promoting timely delivery of downscaled climate information. Collaboration also avoided replication in individual territories. Legacies of the project include:

- A significant amount of future climate data at scales closer to Caribbean island scales, available through the PRECIS-Caribbean website hosted by INSMET;
- Increased capacity to do modelling work in the region and apply downscaling techniques at the collaborating centres and by passing on skills to graduate students and other technical staff;
- The addition of a modelling centre at the Anton De Kom University of Suriname, using expertise garnered under the PRECIS-Caribbean initiative and concentrating on climate change scenarios for the Caribbean states in northern South America. The Anton De Kom University has joined a Caribbean modellers group with the four institutions that carried out the original PRECIS-Caribbean research;
- The use of the data in cross-disciplinary research and policy planning documents, such as was done in at least eight countries in their Second National Communication reporting requirements for the UNFCCC; studies of the economic costs of climate change in selected Caribbean countries (ECLAC, 2011a, 2011b, 2011c, 2011d, 2011e, 2011f, 2011g, 2011h, 2013); and in examinations of the impact of climate change on water resources (A. Cashman, Nurse, & Charlery, 2010) and fisheries (Nurse, 2011)
- Facilitation of downscaling to enable results specific to smaller areas, coastlines and topography.
- Commencement of Phase 2 of the PRECIS project involving an ensemble of perturbation models and simulations with other regional models. (M.A. Taylor et al., 2013)

To date, however, the use of PRECIS findings in health research, or collaboration of the modelling group with health researchers and policy-makers, has received little attention. An important exception has been the production of a review, *Health Effects of Climate Variability and Change in the Caribbean*, by the Climate Studies Group at Mona, Jamaica Campus of the UWI, which was involved in the PRECIS research (M.A. Taylor et al., 2010).

2. EXPOSURE PATHWAYS

2.1 Extreme heat

High temperatures and humidity stress the body's ability to cool itself. When heat is combined with physical activity, the loss of fluids, fatigue and other conditions can lead to a number of heat-related illnesses and injuries e.g. heat rash, heat cramps, heat exhaustion, heat syncope (fainting or dizziness), and heat stroke. The latter two are potentially fatal if not recognized and the victims given immediate emergency therapy. Heat exhaustion usually develops over several days and primarily involves electrolyte and water imbalance. That is, it is the prolonged duration of heat stress and the consequent cardiovascular strain as the body attempts to maintain normal range of temperature which is the predominant cause of classic heat illness (M.A. Taylor et al., 2010).

The temperature impact is often greater in urban areas that in rural areas. This is attributed to the "urban heat island" effect, i.e. heat storage in built structures allowing for radiant energy to reduce night time cooling, (Campbell-Lendrum & Corvalán, 2007) and the absence of night time relief. Typically, air pollution episodes are also frequently associated with heat waves.

Whereas all people can acclimatize to heat, the ability to do so varies with age, sex and other physiological and economic factors. In tropical and sub-tropical areas, adaptation to heat is usually effective among healthy individuals; however, heat stress remains a concern, with higher temperatures, for tourists, outdoor workers, pregnant women and children (M.A. Taylor et al., 2010). In the Caribbean, specific population groups may be especially vulnerable: this will be explored in section 3.1.

As shown below, extreme heat is also associated with other exposure pathways, exerting health influence through effects on air and water quality, drought, food availability, changes in infectious agents and population displacement.

2.2 Air quality

Weather conditions influence the transportation and concentration of air-borne pollutants including dust, pollen, levels of fossil fuel pollutants and smoke. The mechanisms, then, by which climate change would affect human exposure to air pollutants include by:

- Changes in weather patterns that influence local and regional pollution concentrations.
- Changes in human-caused emissions, including adaptive responses involving increased fuel combustion for power generation (e.g. for air conditioning).
- Its effect on natural sources of air pollutant emissions.
- Changing the distribution and types of airborne allergens (M.A. Taylor et al., 2010).

The relationship between some specific pollutants and health are explored below as well as the likely impact of climate change.

Suspended particulate matter

Suspended particulate matter includes dust, soot and other solid and liquid materials released into the air. They are produced in many different processes, such as the burning of fuels in engines, furnaces and power plants, the incineration of waste, the mixing and application of fertilizers, road construction, industrial processes such as steel making, wood processing, mining, cement production, land burning in agriculture (e.g. sugarcane fields after harvest), bush and forest fires, and cooking on open fireplaces and woodstoves (M.A. Taylor et al., 2010).

Some of these behavioural processes may themselves be influenced by climate change, leading to reinforcement of negative impacts on health. For example, in the Caribbean fossil fuel consumption may increase due to increased use of air conditioning for cooling, and bush and forest fires may also increase due to increased temperatures. Following Hurricanes Irma and Maria in 2017, there was an increase in incineration of waste due to the massive amount of debris resulting from damage to property and vegetation, and delays in removal of organic waste from homes due to damage to roadways and garbage disposal vehicles. In Dominica, disposal of downed trees by chopping and shredding released wood dust into the air (see Chapter 4). Dust may also increase as a result of construction to re-build infrastructure damaged by severe weather events.

WHO's climate and health country profile for Jamaica also shows that 11% of the population uses solid fuels for cooking, with higher usage in rural than urban areas. This practice pollutes the air and is associated with chronic obstructive pulmonary disease, acute lower respiratory infections, ischaemic heart disease, stroke and lung cancer. The health problems associated with indoor air pollution are more prevalent among women than men, because women generally spend more time at home. Small children left at home with their mothers as they cook are also at risk (World Health Organisation, 2017).

Once released, a particulate's residence time in the atmosphere is determined by weather conditions and the properties of the particles. In general, the residence time of particles in the atmosphere is short - 5 days on average. The health effects of particulates are strongly linked to particle size. Small particles, such as those from fossil fuel combustion, are likely to be most dangerous as they can be inhaled deeply into the lungs and can settle in areas where the body's natural clearance mechanisms cannot remove them. The constituents in small particulates also tend to be more chemically active and can also be acidic. Studies associate particulate pollution with acute changes in lung function and respiratory illness, resulting in increased hospital admissions for respiratory disease and heart disease, or the aggravation of chronic conditions such as asthma and bronchitis (M.A. Taylor et al., 2010).

Allergens

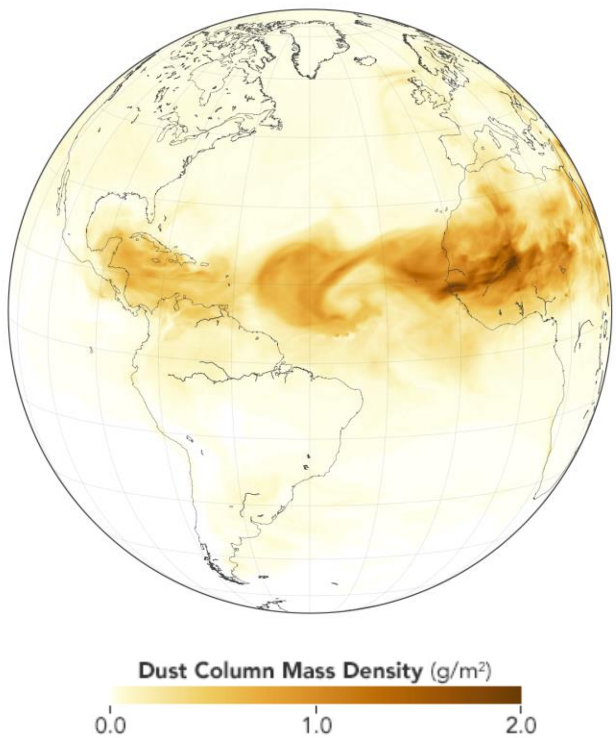
It is forecast that under a climate-changed future there will be higher concentrations of airborne allergens, such as pollen and moulds, causing increased incidences of asthma and allergies. Increased aridity and eventual desertification from increasing temperatures may increase particulate-carried fungal spores, multiplying the potential for endemic and epidemic pulmonary and systemic fungal infection. This is documented most extensively for coccidiomycosis, which is spread by dust, often preceded by increased rain (M.A. Taylor et al., 2010). The climate projections of the PRECIS-Caribbean project suggest that there will be increased dry spells with risk of drought as well as episodes of heavy rain with flood risk. The combination of increased episodes of flood and drought is likely to increase air pollution, as mould and other pathogens that gathered on walls and other materials in the aftermath of floods are dried and carried in the air.

Experimental research has also shown that doubling CO_2 levels from about 300 to 600ppm induces a four-fold increase in the production of ragweed pollen. This suggests that the incidence of hay fever and related respiratory diseases may increase due to global warming (M.A. Taylor et al., 2010).

Dust

The influx of Sahara dust, also known as Saharan or African dust, to the Caribbean and US has increased dramatically since 1970 due to drought in North Africa caused by fluctuations in the North Atlantic Oscillation (NAO), in turn a possible manifestation of anthropogenic climate change. The season of maximum dust transport is the summer. Dust of Asian and African origin is thought to affect ecological and human health in the United States and Caribbean nations. Saharan dust plays an important role in the biogeochemistry of soils and waters and in air quality (Bozlaker, Prospero, Price, & Chellam, 2017).

Figure 4: Dust crossing the Atlantic on June 28, 2018



Source: https://earthobservatory.nasa.gov/images/92358/here-comes-the-saharan-dust

Long-term dust monitoring in Barbados shows that fluctuating but increasing concentrations have been impacting the Caribbean since 1973 and that the dusts serve as a carrier for, among other substances, viable bacteria and fungi, pollen, insects and other organic debris. The incidence of asthma in Barbados and nearby Trinidad, as documented by the Caribbean Allergy and Respiratory

Association (CARA), is among the highest in the world, and has increased 17-fold since 1973 (M.A. Taylor et al., 2010).

A study in Grenada investigated the relationships among dust, climatic variables, and asthma-related visits to the emergency room. All asthma visits to the emergency room (n = 4411) over the years 2001–2005 were compared to the dust cover and climatic variables for the corresponding period. Risk of asthma was positively associated with dust concentration and rainfall, and rainfall was correlated with dust. The authors concluded that Sahara dust in conjunction with seasonal humidity allows for inhalable particulate matter that exacerbates asthma among residents in Grenada (Akpinar-Elci, Martin, Behr, & Diaz, 2015).

A study in Guadeloupe examined the association between the presence of Sahara dust pollution and attendance for asthma by children at the emergency department. The Saharan dust affected 15% of the 337 days of the study in 2011 and involved an increase in the average daily concentrations of PM10 (particulate matter <10 micrometres) and PM 2.5–10 (particulate matter >2.5 micrometres and <10 micrometres) compared to days without dust. The visits for asthma concerned 836 children including 514 boys and 322 girls. The excess risk percentages (IR%) for visits related to asthma in children aged between 5 and 15 years on days with dust compared to days without dust were, for PM10, IR 9.1% versus 1.1%; and for PM2.5–10 IR4.5% versus 1.6%. The authors concluded that the PM10 and PM2.5–10 pollutants contained in the Sahara dust increased the risk of visiting the health emergency department for children with asthma in Guadeloupe during the study period (Cadelis, Tourres, & Molinie, 2014).

A study in Barbados provides contrasting findings to those in the Grenada and Guadeloupe studies. This study also looked at the association between Sahara dust and paediatric asthma admissions, in this case over a longer time period (1996-2005). The study also looked at other climatic and air quality variables. The strongest climate effect was maximum relative humidity and the strongest environmental effect was grass pollen, and both were positively associated with asthma admissions. Sahara dust was not found to be positively associated with paediatric asthma admissions. These findings suggest the need to control for other climatic and air quality variables when studying the impact of Sahara dust on health (Hambleton, 2008). Another study looking at associations between Sahara dust and paediatric asthma admissions in Barbados similarly found no significant associations. The authors point out, however that the concentration of dust in the size range under 2.5 micrometres diameter is sufficiently high as to challenge United States Environmental Protection Agency air quality standards for respirable particles. Thus, African dust may constitute a health threat of a different nature, producing symptoms less obvious than those of asthma (Monteil & Antoine, 2009; J.M. Prospero, Blades, Naidu, & Lavoie, 2009; J. M. Prospero et al., 2008). As noted above, very small particles are especially dangerous to health.

Sahara dust may also be a risk factor for meningococcal meningitis, which is caused by air-borne bacteria. One important theory of meningococcal transmission focuses on the damage caused to the mucus membranes of the upper respiratory by the dust that abounds in the African meningitis belt during the driest months of the year. This theory may have relevance in the Caribbean, since the region has a distinctly dry season and the climate is expected to get drier, and it also receives significant quantities of the same dust implicated in the initiation of African meningococcal meningitis epidemics. However, it has been noted that, while meningococcal meningitis epidemiology varies globally in relation to environmental variables, no study has presented transferable dose-response relationships, and there may also be associations with other climate variables such as wind speed, humidity, land cover, precipitation, cold cloud duration, and soil type (Baulcomb & Moran, 2011a, 2011b).

Ozone

Ground-level ozone is naturally occurring and, at other times especially as a major constituent of urban smog, is also formed chemically through photochemical reactions involving nitrogen oxides and volatile organic compounds in the presence of bright sunshine with high temperatures. Climate change may increase the concentration of ground level ozone, which has been found to be increasing in most regions. In urban areas, transport vehicles are the key sources of nitrogen oxides and volatile organic compounds. Temperature, wind, solar radiation, atmospheric moisture, venting and mixing affect both the emissions of ozone precursors and the production of ozone.

Exposure to elevated concentrations of ozone is associated with increased hospital admissions for pneumonia, chronic obstructive pulmonary disease, asthma, allergic rhinitis and other respiratory diseases, and with premature mortality. Those mainly at risk from ozone pollution are persons who spend time outdoors during hot weather, particularly children, exercisers, and outdoor workers. Although a considerable amount is known about the health effects of ozone in Europe and North America, few studies have been conducted in other regions.

In the Caribbean, ozone is likely to be a health factor mostly in and near the few large cities of the region (M.A. Taylor et al., 2010). It is notable that six Jamaican cities have been shown to have levels of air pollution above the WHO's mean guideline value, suggesting that potential ozone and other air pollution may be greater than generally thought (World Health Organisation, 2017).

2.3 Food availability and quality

In Jamaica, it has been shown that vegetative growth and thus domestic food production decline during the drier summer months. The implication is that the increased dryness over most of the Caribbean predicted by the PRECIS-Caribbean climate model will negatively affect food supply(T. L. Allen, Curtis, & Gamble, 2010). This is corroborated by a further study in Jamaica which aimed to understand drought and climate change in southwestern Jamaica through an integration of local knowledge and perception of drought and its physical characteristics manifested in remotely sensed precipitation and vegetation data. Local knowledge and perception were investigated through a survey of 60 farmers in St. Elizabeth Parish and physical characteristics of drought were examined through statistical analysis of satellite precipitation and vegetation vigour time series. The survey indicated that most farmers were concerned about an increase in drought occurrence. Satellite estimates of rainfall and vegetation vigour for St. Elizabeth Parish supported this perception, suggesting that severe drought events were becoming more frequent. The satellite precipitation time series also suggested that the early growing season was becoming drier as compared to the primary growing season, especially since 1991. Consequently, Jamaican farmers perceptions of drought are not driven by magnitude and frequency of dry months alone but rather by the difference between growing seasons. The authors recommend that development of drought adaption and mitigation plans must not focus solely on drought; they must also compare moisture conditions between months and seasons to be effective (Gamble et al., 2010). It is also important to consider the impact of climate variability and change on agricultural pests such as insects and other animals that consume crops (Baulcomb & Moran, 2011a, 2011b).

There is also likely to be impact on Caribbean fisheries. Increasing CO_2 emissions are leading to observed and projected change in the level of acidity of the world's oceans. Research has shown that the world's oceans have become approximately 30% more acidic (i.e. a reduction in pH from 8.2 to 8.1 units) since 1750 – the start of the Industrial Revolution. Ocean acidification is expected to be a limiting factor in the development of corals and other organisms, which use carbonate ions in sea water to build calcium carbonate shells and exoskeletons. The threat to reef habitats and associated fauna, including fish, will become more pronounced. Since reef fishery constitutes a vital component of small-scale activity, this sector of the industry is likely to be most affected. Fishery production is also massively affected tsunamis and severe weather events such as storm surges (Nurse, 2011).

Potential results of climate change thus include reduced local food supply and especially fresh farm produce and fish. The PRECIS- Caribbean modelling exercise predicted predicted a trend towards a drier climate for most of the Caribbean, with heavier rain and more frequent severe weather events. These prospects are not promising for Caribbean agriculture, since dryness reduces growth, flooding can also destroy crops and storms and hurricanes can destroy produce and infrastructure. Heavier rains trigger greater runoff rather than infiltrating the agricultural soils, making fields drier. Already highly dependent on food from outside the region, the Caribbean's dependency is likely to increase.

Most Caribbean countries already have food supplies with more calories and fat per capita than needed for health, contributing to diabetes and other NCDs. This largely results from over-consumption of processed and fast food containing high amounts of sugar, salt and fat, much of which is imported (Caribbean Public Health Agency, Allen, & West, 2017). For some isolated and poor communities, especially indigenous communities such as the Kalinago who rely to a large extent on subsistence agriculture, the impacts of climate change may include hunger and under-nutrition.

2.4 Water availability and quality

Water in Caribbean SIDS comes primarily from surface (rivers, springs, ponds) and ground water sources, although there are variations from island to island in the proportions of ground-to-surface water abstraction and utilisation. Rainwater is harvested in some of the smaller islands and in islands where topographic constraints limit access to the public distribution systems in some locations. Desalination technologies are seeing increased application in Caribbean islands where the demand for fresh water substantially surpasses the supply from natural sources (UNEP, 2012). The likelihood of drier conditions in the Caribbean will pose challenges to traditional supplies of water and may necessitate increasing desalination.

Drought may affect health through lack of water for drinking and sanitation. Combined with hot weather, dehydration and heat stroke are important risks of drought. Drought also affects health indirectly through the loss of food production and subsequent necessity to import, which, as discussed above, may affect the quality as well as the quantity of food.

Drought can lead to spread of disease as people use water that may be contaminated with pathogens or harmful chemicals. A reduction in rainfall leads to low river flow, reduced effluent dilution and increased pathogen loading. Droughts may be associated with storing water in uncovered containers, which are sites for mosquito breeding (Clauzel & Forbes-Robertson, 2017; Dominica Ministry of Health and the Environment, 2016). It has been found that some Caribbean vector-borne disease outbreaks, such as the Chikungunya epidemic, were associated with water storage, linked to coping with dry climatic conditions. Rising temperatures may also increase the altitudinal range of a number of disease-carrying mosquitoes thereby transmitting the health risk to communities in upland areas that are now outside the range of these mosquitoes (M.A. Taylor et al., 2010). This is especially relevant to those Caribbean territories with mountainous terrain.

Droughts took place in several Caribbean countries in 2009-’10 and 2014-’16. Record low rainfall was experienced between September 2009 and May 2010 (Farrell, Trotman, & Cox, 2010). Impacts from the 2009-’10 event included reduced crop yields, low reservoir levels and significant increases in bushfires and acreage burned. With the return of rains, there were landslides on over-exposed slopes (Trotman et al., 2017). In 2009-’10 in Jamaica, where the island’s largest dams had been operating at less than 40% capacity, inmates at a maximum-security prison protesting the lack of water started a riot that left 23 injured. The National Water Commission in Jamaica was bedevilled with an upsurge in incidents of water theft; illegal connections and vandalism; and death threats to employees (UNEP, 2012).

At the end of 2014, Jamaica and Antigua and Barbuda were reporting significant impacts due to the onset of drought conditions. The year 2015 was the driest on record at rainfall stations in many Caribbean islands, including Antigua, Tobago, Barbados, Jamaica and Saint Lucia, and drought conditions with some short periods of relief persisted until August 2016. The 2014-’16 drought periods led to decreases in agricultural production reported in Anguilla, Antigua and Barbuda, Barbados, Belize, Dominica, Haiti, St. Kitts and Nevis, St. Lucia and Trinidad and Tobago, with destructive bush fires reported in Jamaica, St. Kitts and Nevis and Trinidad and Tobago. These events led to extreme heat, poor air quality and reduced local food supply, which are aspects of climate variability and change discussed in previous sections.

Water shortages were reported in 2014-’16 in Antigua and Barbuda, Barbados, Grenada, Guyana, St. Kitts and Nevis, St. Vincent and the Grenadines and Trinidad and Tobago, forcing water rationing. The Potswork Dam in Antigua was only 10% full by the end of 2014, and by the end of 2015, consumption of desalinated water was greater than 90%, compared with the normal 60% (Trotman et al., 2017). The Dominica climate and health assessment cited poor storage and treatment of water to mitigate drought as contributors to the proliferation of *Aedes Aegypti* mosquitoes, the vector responsible for dengue, chikungunya and Zika (Dominica Ministry of Health and the Environment, 2016). In Barbados, a gastroenteritis outbreak was found to be a result of improper water storage practices. Also in Barbados, the Water Authority indicated that increases in irrigation contributed to severe water shortages in some communities across the island in 2015. In Belize, decreases in crop yields, especially for sugar cane and fruits, led to export losses estimated in the millions of dollars (Trotman et al., 2017).

Figure 5: Cattle affected by drought and heat in Union Island, St. Vincent and the Grenadines, 2015

Source: http://www.ipsnews.net/2015/06/prolonged-drought-leaves-caribbean-farmers-broke-and-worried/

It has been noted that Caribbean disaster risk management efforts have focused mainly on floods and storms (see Chapter 5), and so drought issues tend to lack effective governance, human resource capacity, and finance, and there is relatively poor national coordination, policy-making, and planning in place to deal effectively with droughts (CIMH & FAO, 2016). Drought is one of the issues that should be addressed by Integrated Water Resources Management planning and policy (Adrian Cashman, 2014; A. Cashman et al., 2010; UNEP, 2012).

Water quality is affected by chemical and environmental pollution. Chemicals which, in large quantities, could be damaging to health, such as chlorine bleach, may be added to water to disinfect it and be used in the process of cleaning up after disasters. Sustained public education is necessary to enable households to use amounts of disinfectants that are not themselves damaging to health, differentiating the amounts to be used in drinking water from amounts to be used in cleaning. Mass distribution of potable water and sanitation tablets is an important aspect of Water, Sanitation and Hygiene responses to natural disasters, discussed in Chapter 4. After disasters, normal water supply may be cut off and household appliances destroyed, resulting in practices such as use of rivers to bathe and wash clothes, using detergents that may enter the water supply if these water courses are also used as sources of drinking water.

Figure 6: Laundry drying on ruins of a house destroyed by Hurricane Ivan in Grenada, 2004

Source: (UNEP, 2012)

Climate change can also lead to the growth of algal blooms in water. Harmful algal blooms can occur in fresh, marine (salt), and brackish (a mixture of fresh and salt) water bodies around the world. Various factors can cause rapid growth, or blooming of these organisms, including:

- Increases in nutrient levels (for example phosphorus and nitrates) from fertilizer run-off from residences and agricultural lands, sewage discharges, and run-off from urban areas and industrial facilities;
- Changes in nutrient levels associated with ocean upwelling (El Niño, El Niña);
- Upwelling of nutrients from the sea floor from massive storms;
- Low water flows, such as those associated with drought;
- Changes in water temperature, particularly increases in temperature;
- Changes in chemical factors such as pH or turbidity;
- Changes in ocean currents, and
- Changes in the local ecology (how organisms interact with each other) (CDC, 2018a).

The main routes of exposure to harmful algal bloom toxins are:

- Skin contact (through activities like swimming);
- Inhalation (by breathing in tiny airborne droplets or mist contaminated with HAB toxins), and
- Ingestion (by eating or drinking food or water contaminated with HAB toxins) (CDC, 2018c).

Thus, algal blooms can have effects on various health exposure pathways, such as water-sports, air quality, food and water quality.

Figure 7: Harmful algal blooms

Source: https://www.cdc.gov/habs/index.html

Dinoflagellates, a type of phytoplankton, are the most common cause of harmful algal bloom in marine waters. Ciguatera is a toxin that is produced by a harmful alga, *Gambierdiscus toxicus* of the dinoflagellate type, that can lead to poisoning of people who eat fish that have been exposed to it. Ciguatera toxin can accumulate in carnivorous reef fish when they eat other fish that consume algae that live in coral reef waters. The ciguatera toxin may be found in large tropical reef fish, such as barracuda, grouper, red snapper, eel, amberjack, sea bass, and Spanish mackerel. An increase in ciguatera fish poisoning in the Caribbean is one of the possible outcomes of sea surface temperature rise and other climate-related ocean hazards such as increasing upswells during storms and El Niño/ El Niña. Symptoms include nausea, vomiting, diarrhoea, muscle pain, numbness, tingling, abdominal pain, dizziness, and vertigo. Hot and cold sensation may be reversed. Severe cases of ciguatera poisoning may result in tearing of the eyes, chills, skin rash, itching, shortness of breath, drooling, and paralysis. Death due to heart or respiratory failure occurs in rare cases (CDC, 2018b).

Effective surveillance and public education are needed to identify the presence of ciguatera and provide warnings and education when the algal blooms or outbreaks occur. The public may be advised, for example, to avoid consuming large carnivorous fish at these times. A scientific review paper on harmful algal blooms states that there is a lack of time-series data in most regions experiencing outbreaks, and a need for more research on the relationship between specific climatic effects and the biological responses of specific algae (Wells et al., 2015). It has been noted that there are gaps in knowledge on specific dose-response relationships between climate variables and algal bloom varieties, in part because of the difficulty in controlling for non-climate factors (Baulcomb & Moran, 2011a, 2011b). High resolution climate projections, such as those produced by the PRECIS-RCMs, are needed to understand how the distribution of harmful algae may change. Projections suggest that the habitat of most species will shift further north and south within and beyond the tropical belt as a consequence of global warming (Townhill et al., 2018).

Water quality and flooding are also affected by sanitation systems and practices. Large portions of the Caribbean population are not serviced by sewage-collection systems but rather depend on individual systems such as septic tanks, soakaways, and pit latrines. In times of high rainfall and flooding, storm-water runoff and floodwaters may become contaminated with faecal waste from these systems and can pose serious health risks. The practice of dumping solid waste in rivers, streams, and ravines is widespread. This waste can also exacerbate the effects of flooding. One of the reasons often advanced, by laypersons and experts alike, for repeated flooding in several Caribbean countries, is the clogging of waterways with solid waste (Ebi, Lewis, & Corvalan, 2006).

2.5 Changes in infectious agents

Climate variability and change affect the ecological balance and thus the survival and lifecycle of infectious agents, as illustrated in the discussion of harmful algal blooms above. New pathogens may be introduced, or pathogens may proliferate, for example via Sahara dust or through climate-related population movement. The extent to which climate variability and change affect infectious disease agents depends on interaction with other influences, such as human migration and transport, drug effectiveness/ resistance, adequacy of nutrition, land use practices, sanitation infrastructure and practices, clean water supply and urbanization.

Infectious diseases may be classified by their natural reservoirs as anthroponoses (human reservoir) or zoonoses (animal reservoir). Vector-borne diseases are transmitted from animals to humans. Some of these animal vectors, such as mammals in the case of leptospirosis, are able to regulate their own temperature. Insect vectors and infectious agents (protozoa, bacteria and viruses) are small and devoid of thermostatic mechanisms. Their temperature and fluid levels are therefore determined directly by the local climate. There is a limited range of climatic conditions within which these infective or vector species can survive and reproduce. Temperature, water availability, wind and duration of sunlight can affect the health of these organisms directly. The lifecycle and reproductive cycle of *Aedes Aegypti* mosquito speeds up at higher temperatures, for example (M.A. Taylor et al., 2010). Specific effects will be considered in the sections on food- and water- and vector-borne diseases below.

2.5 Population displacement

Climate science predicts that the Caribbean people are increasingly exposed to tropical storms and hurricanes, floods, droughts, rising sea levels as well as the slower-onset impacts of increased temperatures and declining air and water quality. Impacts on Caribbean migration have received little focussed attention. The human resource base in each Caribbean country is small, resulting from small to extremely small population sizes and traditional patterns of movement of Caribbean people between their home countries and countries within and outside the region for education and employment. The 2017 hurricanes have contributed to and highlighted existing human resource capacity constraints, as illustrated in Chapter 4. For instance, the hurricanes exposed existing shortages of health care workers. The hurricanes led many people to leave the countries affected temporarily or permanently, to seek medical care, education, employment and to find somewhere they feel more secure. Some families have experienced separation and loss, affecting mental health, as a result of these severe climate events. We can expect further displacement of people whose livelihoods are especially sensitive to climate change, such as farmers, fisherfolk and people in the tourist sector. Their unemployment could lead to aggravation of crime within countries, or further migration.

Globally, climate-induced migration is provoking security concerns. The devastating civil war that began in Syria in March 2011 is the result of complex interrelated factors, one of which is the reduced availability of fresh water, which has played a direct role in the deterioration of Syria's economic conditions. Starting in 2006 and lasting into 2011, Syria experienced a multi-season, multi-year period of extreme drought that contributed to agricultural failures, economic dislocations, and population displacement. More than 1.5 million people - mostly agricultural workers and family farmers - moved from rural land to cities and camps on the outskirts of Syria's major cities of Aleppo, Damascus, Dara'a, Deir ez-Zour, Hama, and Homs. The government's failure to put in place economic measures to alleviate the effects of drought was said to be a critical driver in propelling massive mobilizations of dissent, including the growth of the Islamic State movement and the violence they have inflicted in Syria and around the world (Gleick, 2014). Climate-induced food shortages and destruction of economic opportunities are likewise said to be major factors behind large-scale migrations, such as from some Latin American countries to the US and from some African countries to Europe. The increasingly protectionist and unwelcoming rhetoric by politicians in the destination countries may be viewed as attempts at defence from some of the consequences of climate change (Klein, 2014; Parenti, 2011).

Caribbean people may likewise be exposed to new risks as they seek to improve their health and other conditions from the impacts of climate change by moving between countries. Caribbean policy-makers will need to develop strategies to address the potential influx of migrants from within and outside the region, while enabling adaptations to climate change and thus attracting citizens to remain in their countries. The implications for health systems that are already under strain must be squarely confronted.

An important point to note is that migrants may move *to* places of environmental vulnerability as well as *away from* such places. For example, people whose livelihood is diminished in rural areas may move towards urbanised areas. In much of the Caribbean, urban areas are crowded and have little capacity for expansion, for example because of surrounding hills and sea. Their infrastructure, already challenged by climate issues such as flooding and sea level rise, can be put under further strain by influx of people (Campbell-Lendrum & Corvalán, 2007). Displacement of people by climate variability and change must therefore be managed operationally as well as politically. Informal settlements, often occupied by migrants, are especially vulnerable to health impacts of climate change (Heslop-Thomas & Bailey, 2006b).

A further issue is that of poverty and inequality. Those left behind as people migrate may be especially vulnerable, comprising people who cannot afford to migrate, or have health conditions that prevent them from doing so. Climate change may aggravate existing inequalities and patterns of marginalisation (Foresight, 2011).

3. HEALTH OUTCOMES

3.1 Heat-related illness

Heat-related illness, including sunstroke, sunburn, heat stress, heat exhaustion, and dehydration, may affect some populations more than others. There is evidence that women are less heat-tolerant than men. Exertional Heat Stress may be followed by heat intolerance. A study with Israeli Defence Force soldiers who reported for treatment for Exertional Heat Stress found that 67% of the women developed heat intolerance as against 26% of the men. The higher heat intolerance rate in women may stem from their lower aerobic fitness, slower sweat rates, different hormonal profile, and different morphology. The authors note that further studies of gender differences should consider menstrual cycle phase, use of contraceptive pills, physical fitness, cardiovascular function, and anthropometric measurements together with the physiological results (Druyan et al., 2012).

A case-control study showed that, among elderly people presenting to emergency departments during a heat wave, use of psychotropic drugs (anticholinergic,[3] antipsychotic or anxiolytic[4] drugs) was independently associated with their presentation for treatment. This suggests that users of psychotropic drugs, for medical or recreational reasons, may be at special risk of heat stress.

Should heat waves continue to increase in frequency and intensity under climate change, the risk of death and serious illness would increase, principally in older age groups, amongst those with pre-existing cardio-respiratory diseases, and amongst the urban poor (Ebi et al., 2006; M.A. Taylor et al., 2010). Thus, vulnerability to extreme heat is conditioned by demographic factors (age, gender and race/ ethnicity) and social factors (e.g. usual place of residence which affects accustomed levels of heat exposure, housing and infrastructure, discrimination, access to health care and pre-existing conditions) – see Figure 1 above. The implication is that policy responses to climate change and health should factor in the vulnerabilities to extreme heat of populations such as older persons, women, children, tourists, people working outside in both formal and informal income-generating activities, the homeless and those living in housing without adequate cooling mechanisms, those marginalised by racism, people with pre-existing conditions such as NCDs and people with lower levels of access to health care and facilities. The combined impact of heat stress and drug treatment or among illicit drug users should also be considered.

A study in Grenada and Trinidad and Tobago used focus group discussions to explore perceptions of health impacts of increasing temperatures among Caribbean health-care providers including physicians and nurses, and at least one veterinarian and technician in each group. Participants in both groups perceived air temperatures as hotter than usual and as contributing to more heat-related illness and hospital admissions. Participants in Grenada described an increase in hospitalizations for dehydration and sunburn. Trinidad and Tobago participants talked extensively about heat stress, chronic obstructive pulmonary disease and increasing deaths of working and domestic animals. A veterinarian described experience of putting dogs on fluids to save their lives after they have collapsed from heat stress (Macpherson & Akpinar-Elci, 2015).

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[3] Anticholinergic drugs are used to treat a variety of medical conditions that affect the contraction and relaxation of muscles.
[4] Anxiolytic drugs are used in the treatment of anxiety.

Heat waves and global warming can also impact eco-systems and the normal balance and synergies between species. In Alaska, a number of eco-system and health consequences of warming and the heatwave that occurred in 2016 were identified using a community-based surveillance system established by the Alaska Native Tribal Health Consortium. This used cellphones to record incidents of environmental change via photos and text, validated through expert investigation and commentary (http://leonetwork.org). The warming conditions favoured some phytoplankton species, and one of the largest harmful algal blooms on record reached the Alaska coast in 2015. There were uncommon paralytic shellfish poisoning events and oyster farm closures in 2015 and 2016. Dramatic mortality events in seabird species such as common murres in 2015/16 (tens of thousands of dead birds counted) were attributed to starvation and presumed to be a result of warming-induced effects on food supply. Increased occurrences of diseases were also observed, including sea star wasting disease. Human communities, especially native communities, were affected by changes in the acquisition, preservation, quality, and quantity of wild foods (Walsh et al., 2018). The leonetwork community-based surveillance system has potential for adaptation to the Caribbean, to utilise local observations and knowledge to enhance responses and adaptation to climate change.

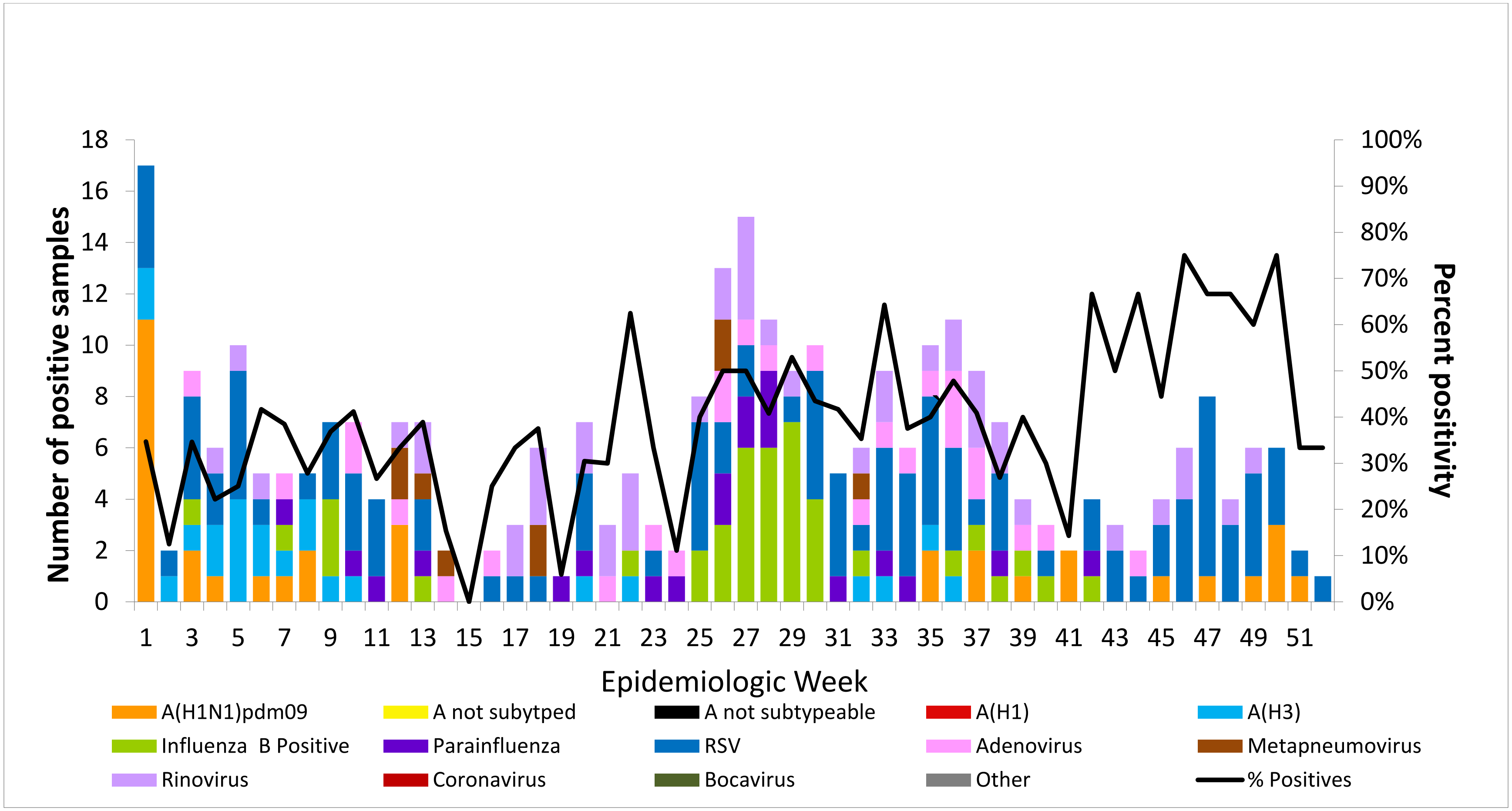
3.2 Cardiopulmonary illness

The human cardiovascular and respiratory systems are sensitive to temperature change. Increase in temperature increases blood viscosity and can lead to high blood pressure and heart rate: risk factors for cardio-vascular disease. Thus, it can trigger heart attacks, strokes, and other vascular events. Temperature changes can also cause constriction of the bronchial tubes, and exacerbate both concurrent acute and chronic respiratory conditions (Ebi et al., 2006; McMichael et al., 2003). Global warming thus has important effects on these NCDs. Adults who suffer from pre-existing cardiovascular and respiratory diseases, the elderly, children and outdoor labourers are most vulnerable to this category of impact. Additionally, individuals who lack access to air conditioning are more at risk, as are those individuals who reside in cities and are exposed to the "urban heat island effect," as both these factors exacerbate the effects of temperature increases (Baulcomb & Moran, 2011b; Campbell-Lendrum & Corvalán, 2007).

Section 2.2 considers the impact of climate drivers on pulmonary diseases such as asthma in the Caribbean. The possible association between Sahara dust and asthma has been the subject of several research projects in the region (Akpinar-Elci et al., 2015; Cadelis et al., 2014; Hambleton, 2008; J. M. Prospero et al., 2008). Associations have been found between days of hospitalisation with asthma symptoms and days of Sahara dust. However, the inclusion of other climate variables in examining Sahara dust and asthma associations led to the conclusion that other variables may have greater explanatory power than Sahara dust (Hambleton, 2008). This highlights the complexity of links between climate and health, and the difficulties of isolating specific risk factors. Pulmonary diseases other than asthma and potential climate risk factors other than Sahara dust have received little attention in the Caribbean research.

CARPHA collects weekly reports of respiratory viruses in CMS and conducts laboratory testing to determine virus types (see Figure 8). There is potential for mapping respiratory virus against climate data to identify patterns of association. Seasonal trends can be identified by looking at multiple years, enabling the identification of events and outbreaks that fall outside the normal patterns and the exploration of climate-related risk factors.

Figure 8: Distribution of influenza virus and other respiratory viruses by epidemiological week, 2017



Source: CARPHA

3.3 Food- and water-borne disease

Exposure to water-borne infection can occur as a result of contact with contaminated drinking water, recreational water, coastal water or food. Behavioural factors such as sewage disposal processes combine with climate factors to influence patterns of infection. Temperature can affect growth and survival while rainfall patterns can influence the transport and dissemination of infectious agents (McMichael et al., 2003). The following table shows some direct and indirect weather effects in bacteria, protozoa and viruses.

Table 1: Water and food-borne agents: connection to climate

Pathogen groups	Pathogenic agent	Food-borne agents	Water-borne agents	Indirect weather effect	Direct weather effect
Viruses	Enteric viruses (e.g. hepatitis A virus, Coxsackie B virus)	Shellfish	Groundwater	Storms can increase transport from faecal and waste water sources	Survival increases at reduced temperatures and sunlight (ultraviolet)[a]
Bacteria Cyanobacteria Dinoflagellates	Vibrio (e.g. *V. vulnificus*, *V. Parahaemolyticus*, *V. cholerae* non-01; Anabaena spp., Gymnodinium Pseydibutzschia spp.)	Shellfish	Recreational, Wound infections	Enhanced zooplankton blooms	Salinity and temperature associated with growth in marine environment
Protozoa	Enteric protozoa (e.g. Cyclospora, Crytosporidium)	Fruit and vegetables	Recreational and drinking water	Storms can increase transport from faecal and waste water sources.	Temperature associated with maturation and infectivity of Cyclospora

[a] Also applies to bacteria and protozoa.

Source: Rose, 2001, quoted in (McMichael et al., 2003), p110.

Water- and food-hygiene and distribution systems can be hugely disrupted by severe weather events such as hurricanes, increasing vulnerability to water-borne diseases, including schistosomiasis, cryptosporidium, and cholera; food-borne diseases, including diarrheal diseases, food poisoning, salmonellosis, and typhoid; and malnutrition resulting from disturbance in food production or distribution (Baulcomb & Moran, 2011a, 2011b). Appendix A in Taylor et al (2010) provides description of climate associations with specific diseases (M.A. Taylor et al., 2010). A 2002 study by the Caribbean Epidemiology Centre and the Water and Sewage Authority of Trinidad and Tobago found that 18.6% of samples of potable water taken after heavy rainfall events were positive for cryptosporidium (Ebi et al., 2006). In Chapter 4, we present results of analysis of the impact of Hurricanes Irma and Maria on reported gastro-enteritis symptoms, comparing Caribbean countries affected by Category-4 or -5 hurricanes with countries that were not. For Dominica, which was severely affected by Tropical Storm Erika in 2015, and Hurricane Maria in 2017, we also compare reports of gastro-enteritis symptoms in 2015 and 2017 with such reports in years unaffected by severe weather events. According to both analyses, severe weather events were associated with increases in reported symptoms.

Globally, *Salmonella, Norovirus, Clostridium botulinum, Shigella, pathogenic Escherichia coli (E-coli), Campthylobacter, Vibrio cholera* and parasites are the most important human food-borne illnesses, among more than 250 food-borne diseases (FBDs) that have been described. Reported cases and outbreaks of acute gastroenteritis and FBD pathogens have been reported to CAREC, then CARPHA, since 1990. A Foodborne Disease Programme was established at CAREC in 2003. The purpose was to strengthen national and regional capacity to develop and sustain integrated surveillance, prevention and control systems. This integrated the epidemiological, laboratory, environmental and veterinary aspects of FBD surveillance into a coordinated programmatic approach.

Challenges to information on FBDs include variation in national surveillance systems in CMS, and in laboratory capacity. There are almost no CMS with a fully integrated FBD surveillance system that integrates human, food and animal surveillance data. Reporting frequency and completeness vary by country. Stool specimens are also not commonly collected from patients with acute gastroenteritis, significantly affecting the determination of the aetiology and prevalent FBD that cause human illness. This is perhaps the single most limiting factor for FBD surveillance in the Caribbean. Bearing in mind these limitations, it is nevertheless possible to see trends in the data reported to CARPHA, presented below.

Food-borne disease trends

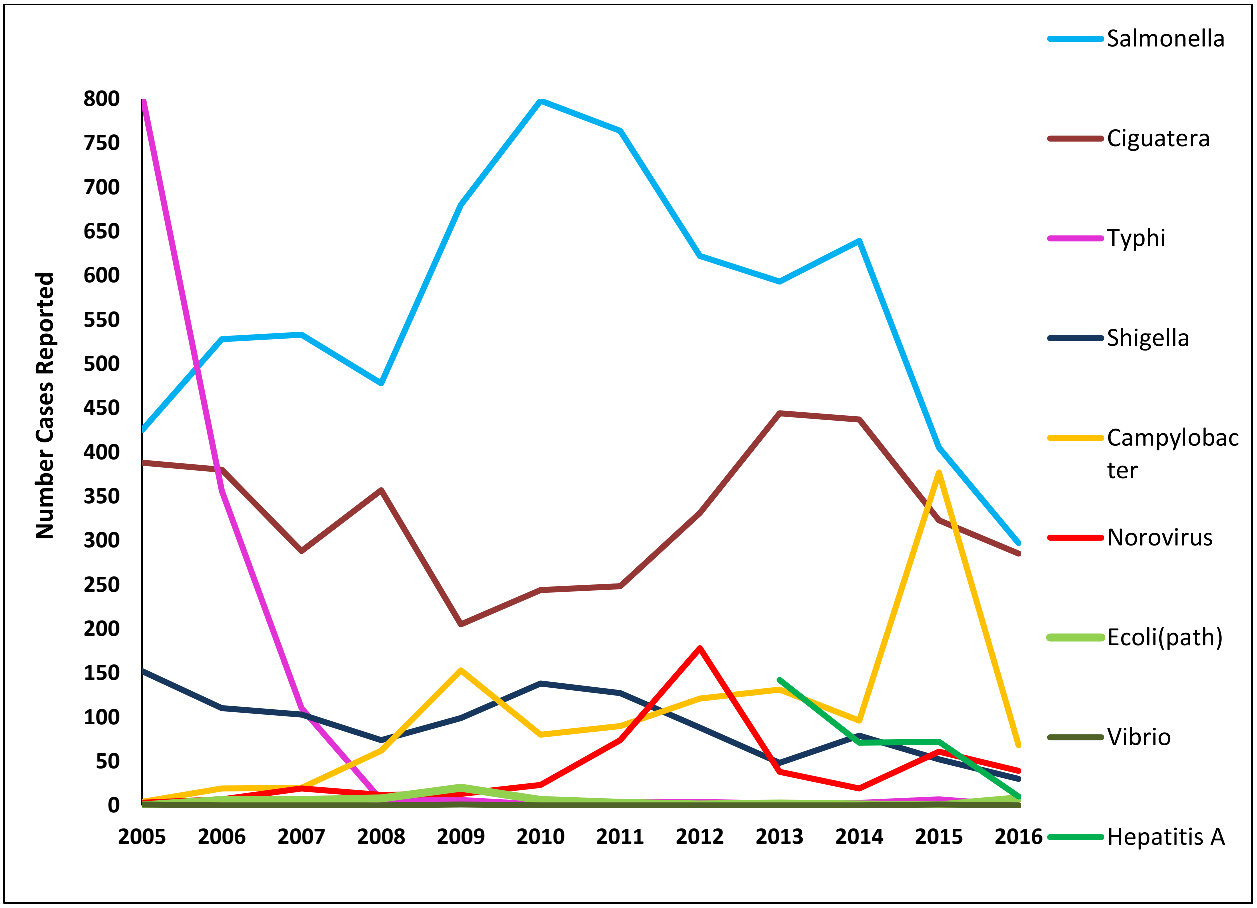
The following chart show a fluctuating picture of lab-confirmed food-borne diseases reported to CARPHA since 2005. There is no suggestion from these data of overall increase in numbers of cases, which might be anticipated over a longer term given gradual warming of the climate. Long-term monitoring is advised. Some notable findings are as follows:[5]

- Salmonella accounted for the largest number of cases, with average 564 cases per year, peaking at 798 in 2010, and falling to a low of 297 cases in 2016. The highest numbers of salmonella cases reported 2013-'16 were in Guyana, Bermuda, Barbados and Belize (data not shown).
- Ciguatera cases[6] (resulting from fish poisoning) averaged 328 cases per year, ranging from 205 cases in 2009 to 444 in 2013, with 427 cases in 2014, 323 cases in 2014, and 285 in 2016.
- Cases of typhi fell dramatically from 805 in 2005 to 6 in 2008, and thereafter did not exceed 7 in any year.
- Shigella and camphylobacter accounted for similar number of cases per year. Shigella showed a downward trend while camphylobacter showed an upward trend.

[5] For further detailed analysis, see (Caribbean Public Health Agency et al., 2017)
[6] Ciguatera poisoning results from consumption of fish contaminated by ingestion of harmful algae, which are responsive to changes in marine environmental conditions – see section 2.4 above.

- Around a yearly average of 41 cases, there was a rise in the number of norovirus cases until 2012 when 178 cases were confirmed. Figures for norovirus were 19, 61 and 39 in 2014, 2015 and 2016 respectively.
- There was an average of 5 laboratory-confirmed cases of E-coli every year, ranging from 0 to 20.

Figure 9: Reported lab-confirmed cases of foodborne diseases pathogens, CARPHA Member States, 2005-2016



Source: CARPHA

Measures taken by CARPHA's Environmental Health and Sustainable Development department and other agencies to monitor and address risks from food- and water-borne diseases are presented in Chapter 5 and via the case study of the impact of Hurricane Maria on Dominica in Chapter 4.

3.4 Vector-borne disease

Vectors are living organisms that can transmit infectious diseases between humans or from animals to humans. Both the vectors and the infectious micro-organisms are susceptible to climate influences such as temperature, precipitation, humidity, surface water and wind, and biotic factors such as vegetation, host species, predators, competitors, parasites and human interventions (McMichael et al., 2003).

Vector-borne diseases (VBDs) with major health impacts in the Caribbean are listed below, with their vectors and means of transmission. Each of these diseases is described, and data on incidence presented, in the chapter on VBDs in CARPHA's *State of Public Health in the Caribbean Report 2014-'16. Building Resilience to Immediate and Increasing Threats: Vector-Borne Diseases and Childhood Obesity*. That chapter also presents information on policies and health promotion approaches to prevent VBDs in the region. The public health consequences of the major chikungunya and Zika epidemics in the 2014-'16 period are described (Caribbean Public Health Agency et al., 2017).

Table 2: Important Vector-Borne Diseases and means of transmission in the Caribbean

Disease	Vector	Transmitted by
Chikungunya	*Aedes aegypti* mosquito	Mosquito bite
Zika	*Aedes aegypti* mosquito	Mosquito bite
Dengue	*Aedes aegypti* mosquito	Mosquito bite
Malaria	*Anopheles* mosquito	Mosquito bite
Yellow Fever	*Aedes* or *Haemagogus*[1] mosquito	Mosquito bite
Leptospirosis	Domestic and wild animals	Urine of infected animal
Lymphatic filariasis	*Culex* mosquitoes	Mosquito bite
Schistosomiasis	Freshwater snails	Water infested by a parasitic worm
Leishmaniasis	Sandfly	Sandfly bite

1. *Haemogogus* is not an important source of infection in the Caribbean.

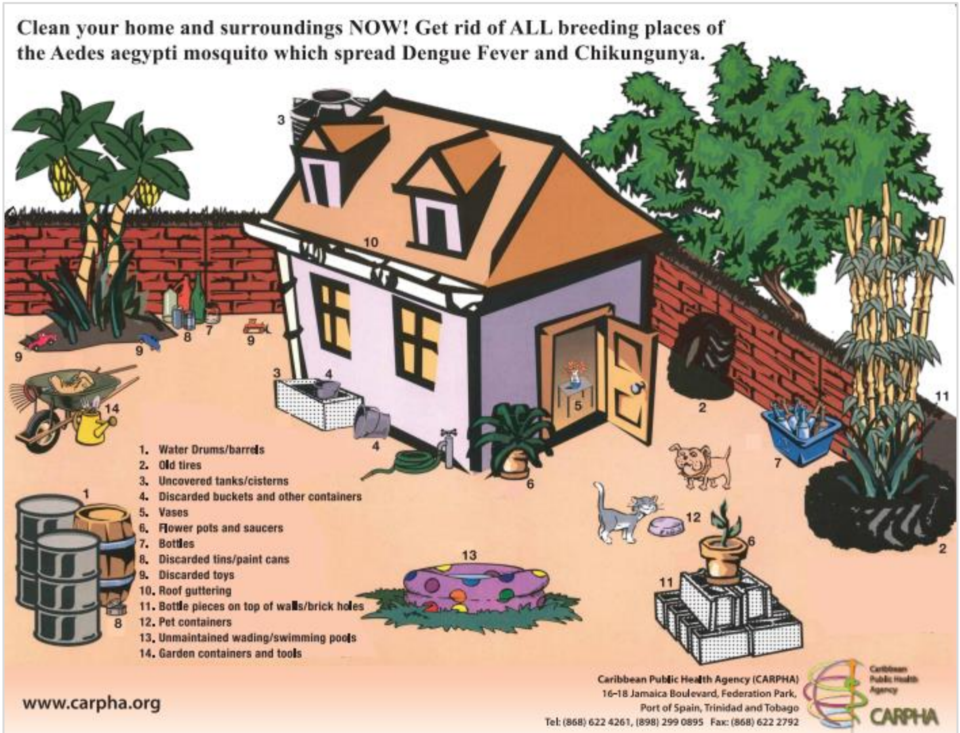
Source: (Caribbean Public Health Agency et al., 2017)

It is notable that water is a very important environmental determinant of VBD in the Caribbean. Standing water is the site for mosquito-breeding. Ground water and wet or previously dampened objects can transmit the bacteria present in the urine of animals with leptospirosis, so contact with water and objects touched by flood waters can lead to rapid spread. Contact with water habitats of freshwater snails can expose people to schistosomiasis. Addressing the major threats of these diseases requires attention to reducing the number and extent of water bodies where vectors breed or live and bacteria proliferate. The likely increases in heavy rains and severe storms and hurricanes are likely to increase population exposure to infected water and the number of breeding sites in debris and other vessels containing water. Water and sanitation management, and involvement of communities in reducing mosquito-breeding sites, are critical. CARPHA has produced guidelines for community mobilisation to reduce mosquito breeding sites (CARPHA, 2017). Sanitation management is also critical to reduce the population of rodents, especially rats, that are vectors for leptospirosis.

Mosquitoes are responsible for most cases of VBD transmission in the Caribbean. Higher temperatures have been found to shorten the period of the dengue virus incubation inside the *Aedes Aegypti* mosquito, speeding up onward transmission when the mosquito bites. Mosquitoes also tend to feed more frequently in warmer weather. This is because moderately high temperatures hasten the larval stage, leading to smaller mosquitoes, which then require more frequent blood meals, while increased temperatures also enhance metabolism (M.A. Taylor et al., 2010). Higher levels of rainfall increase breeding sites, but there is also evidence of mosquito-borne disease outbreaks in the dry season or during drought, as uncovered water containers provide sites for mosquitoes to breed (Clauzel & Forbes-Robertson, 2017). It has been observed that dengue cases rise during and up to two to three months after the rainy season in Caribbean countries (Campione-Piccardo, Ruben, Vaughan, & Morris-Glasgow, 2003).

There is also need for attention to social determinants of health, such as poverty, urbanisation, and gender inequalities. For instance, *Aedes aegypti* tend to inhabit densely populated human habitats with discarded items and water containers where water gathers. People in areas with inadequate or sporadic sanitation or water supply, which are associated with poverty and unplanned urbanisation, are especially vulnerable (Campione-Piccardo et al., 2003; Guzman & Kouri, 2003; Sommerfeld & Kroeger, 2015). Labour force participation is lower among women than men in the Caribbean, and women's traditional role in domestic chores and caring for children and elderly people means that they spend more time in the domestic space, at home. The percentage of households headed by women ranges between about one third to just under a half in English-speaking Caribbean countries, and the households of these women tend to have more dependents than other households (C. F. Allen, 2018). Poorer women, and especially single heads of households, tend to spend more time at home and the quality of their housing provides little protection from mosquito breeding sites. They are also more likely to be involved in informal income-earning opportunities near their homes or in other places with relatively poor sanitation. Sporadic or non-existent water supply in these spaces can lead to water storage in uncovered containers, and to mosquito breeding in solid waste items (Diaz-Quijano & Waldman, 2012). People living in informal settlements are especially vulnerable (Heslop-Thomas & Bailey, 2006a).

Figure 10: Health promotion poster showing typical mosquito breeding sites



Source: CARPHA

A major study, *The Threat of Dengue Fever – Assessment of Impacts and Adaptation to Climate Change in Human Health in the Caribbean* was executed by the University of the West Indies and the Caribbean Epidemiology Centre, funded by the Assessments of Impacts and Adaptations to Climate Change (A.A. Chen, Chadee, & Rawlins, 2006). The study was conducted by the Climate Studies Group at UWI, which was also involved in the PRECIS Regional Climate Modelling project. The project aimed to determine the extent of association between climate and threat of dengue[7] in the region, and to identify effective options to ameliorate the impact of climate on the disease.

A retrospective study combined climate data from meteorological offices and data on dengue from CAREC. Seasonality was evident in the patterns of disease for individual Caribbean countries. A yearly pattern of warming first, then rainfall, followed by a dengue epidemic, was evident for several countries. Start or onset of the disease generally occurred during the summer period and followed the early temperature peak by a few weeks. Dengue epidemics were also found to be more likely during El Niño years or the year after. This seemingly arises because the latter part of the El Niño year is warmer and the early part of the following year is also wetter and warmer. The researchers

[7] Dengue has existed in the Caribbean since the 17th century. Infection with one subtype confers immunity from that subtype but can increase vulnerability to more severe symptoms, including Dengue Haemorrhagic Fever (DHF), if a person is infected with another subtype. It is therefore troubling that in recent years subtypes 1 to 4 have been circulating in the Caribbean. Of fifteen countries reporting dengue subtype data to CARPHA in 2014–'16, eight reported cases of more than one subtype. Since the 1980s, cases of dengue have risen in the region, with several major outbreaks and a transition from an endemic-epidemic state to a highly endemic state with annual outbreaks in multiple locations (Caribbean Public Health Agency et al., 2017).

also showed that dengue epidemics occurred approximately in line with El Niño events. A further important finding was that the association with temperature was much stronger than that of rainfall, possibly because human activities include water storage in times of low rainfall, thus extending opportunities for mosquito breeding beyond rainy periods (Amarakoon, Chen, Rawlins, Taylor, & Chadee, 2006). It should also be noted that very heavy rain can wash away standing water in which larvae grow.

This study assisted in the development of a temperature index to gauge the potential for the onset of dengue. The index was a moving average of monthly temperature, the Moving Average Temperature (MAT) Index. By monitoring the MAT Index in a given year and its approach to an average MAT value calculated for each country, it was possible to gauge the potential for onset of a dengue epidemic (M.A. Taylor et al., 2010).

A further measurement tool is the Breteau Index, which is the number of containers positive for larvae and pupae of the *Aedes aegypti* mosquito per 100 premises. The Breteau Index was mapped against the total dengue cases per year over a twenty-year period 1981-2001 in Trinidad and Tobago. It was found that the Index started to increase before the number of reported cases and some major outbreaks. Examination of monthly distribution of the Breteau Index shows that it starts to increase about a month before dengue cases start to increase (Chadee, Shivnauth, Rawlins, & Chen, 2006).

Chen et al (2006) went on to propose an early warning system for dengue consisting of:

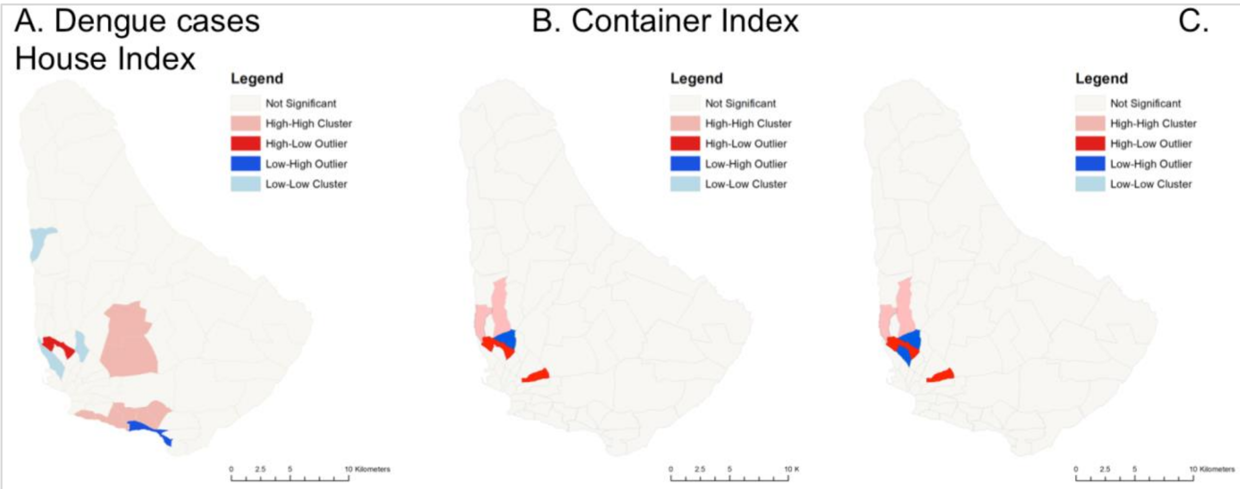
- Climate surveillance for the MAT Index;
- Epidemiology Surveillance for the Breteau Index, and
- First reported cases of dengue.

They suggest the relatively costly epidemiology surveillance be carried out after MAT Index readings indicate favourable conditions for dengue spread. The officers collecting Breteau data can simultaneously sensitise the population to the need for a clean environment. The level of alert can be increased once cases are reported (A. A. Chen, Chadee, & Amarakoon, 2006; M.A. Taylor et al., 2010). The research was conducted prior to the chikungunya and Zika epidemics, but the system could be used for predicting periods of maximum susceptibility to these diseases as well, as *Aedes aegypti* are also the vectors for these diseases, as well as for Yellow Fever.

More recently, a consortium of universities from Ecuador, South Africa, the US and UK collaborated with the governments of Barbados and Dominica and the Caribbean Institute for Meteorology and Hydrology (CIMH) to develop a spatio-temporal modelling framework for *Aedes aegypti* transmitted diseases in the Caribbean. This involved gathering local entomological, epidemiological, climate and census data from Barbados and Dominica and mapping them to identify "hot spots" of mosquito breeding and disease, and to make predictions as to when and where outbreaks would occur (see Figure 11) (Stewart Ibarra et al., 2017). Extensive consultations were carried out with local public health practitioners to identify strategies to strengthen the partnership between the climate and health sectors and identify climate and non-climate drivers of *Aedes aegypti* transmitted diseases. In partnership with stakeholders, they assessed the strengths and weaknesses of the health and climate sectors to identify key areas for capacity strengthening, including in the use of climate information in the health sector and ways that climate services can be developed and utilized in the public health decision-making process (Stewart-Ibarra et al., Submitted 2018).

Stakeholders identified mechanisms for mainstreaming climate services for health operations to control *Aedes aegypti* transmitted diseases, such as an online GIS platform that would allow for data sharing and the generation of seasonal epidemic forecasts (Stewart-Ibarra et al., Submitted 2018).

Figure 11: Mapping of dengue cases (A), container index (B) and House Index (C) to identify hotspots for dengue incidence in Barbados, 2013



NOTES: The maps show analysis of hotpots for A) dengue cases, B) the proportion of containers positive for Aedes aegypti larvae or pupae (Container index), and C) the proportion of homes positive for Aedes aegypti larvae or pupae. Significant hotspots (high-high) and outliers (high-low and low-high) are identified through LISA analysis (p<0.05)

Source: (Stewart Ibarra et al., 2017)

The project also examined how much predictive lead time can be gained by replacing observed climate information with seasonal (3 month) hindcasts (*i.e.,* retrospective forecasts) of both local climate conditions and the evolution of sea surface temperatures, using statistical models (Stewart Ibarra et al., 2017). The model parameters were estimated to produce probabilistic predictions of exceeding an island-specific outbreak threshold. The ability of the model to successfully detect outbreaks was assessed and compared to a baseline model, representative of current dengue surveillance practice (Lowe et al., 2018).

The study found that drought conditions positively influence dengue relative risk at long lead-times of up to five months, while excess rainfall increased the risk at shorter lead times between 1-2 months. Climate indicators, designed to monitor drought and heat, better explained variations in dengue risk than monthly summary statistics of measured precipitation and air temperature. These findings brought added precision to the work of Chen et al (2006) by looking at drought and heat stress in addition to the traditionally-used measures of rainfall and temperature. The study further found that including bidimensional exposure–lag–response functions of these indicators, rather than linear effects for individual lags, more appropriately described the climate-disease associations than traditional modelling approaches. The model was successfully able to distinguish outbreaks from non-outbreaks, with an overall proportion of correct predictions (hits and correct rejections) of 88%, compared to 66% for the baseline model (Lowe et al., 2018).

The authors concluded that use of climate indicators and forecasts, which are routinely monitored and forecasted by the Regional Climate Centre at the CIMH, the framework could be used operationally to provide quarterly dengue outlooks in the Caribbean Health-Climatic Bulletin, a source of climate-smart decision-making guidance for Caribbean health practitioners.[8] This framework could be extended to model the risk of dengue and other arboviruses in the Caribbean region (Lowe et al., 2018)

3.5 Mental health consequences and stress

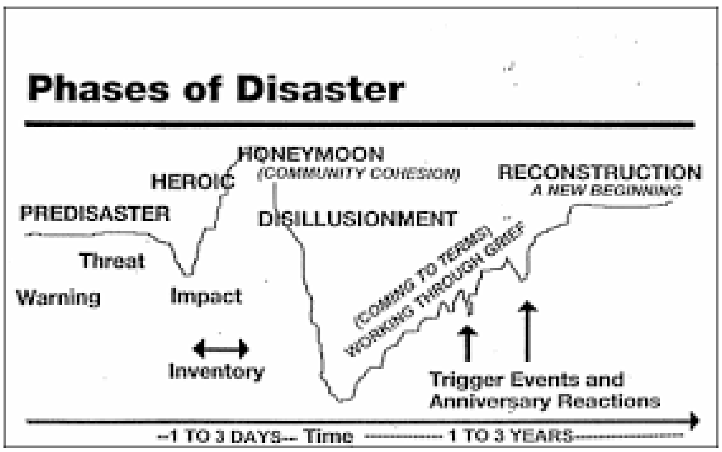
Psychological impacts of climate variability and change, ranging from mild stress responses to chronic stress or other mental health disorders, are generally indirect (Portier CJ et al., 2010) and have received little consideration in the literature on climate and health in the Caribbean, or in policy initiatives to address climate change in the region (see chapter 5). Weather can affect mood and disposition to other stresses encountered by people. Extreme heat can decrease psychological resilience. Vulnerability to negative mental health consequences of climate variability and change is related to various forms of social inequality and power imbalances. The effects of climate change impact the social, economic, and environmental determinants of mental health, with the most severe consequences being felt by communities who were already disadvantaged prior to the event (Portier CJ et al., 2010) Perceived inequality and injustice can have more important negative impacts on mental health and prevalence of violence than absolute, measurable levels of inequality (UNDP, 2012). Along these lines, it can be expected that resentment and negative feelings may result unless the health consequences of climate change on vulnerable populations, and on SIDS as a whole, are addressed to the satisfaction of the Caribbean people, and especially the poor and marginalised (Reckien et al., 2016). Thus, in looking at mental health consequences of climate variability and health, it is especially important to consider the social and behavioural context as presented in the diagram at the beginning of this chapter, and the vulnerability factors discussed in chapter 2. Additionally, psychotropic drugs interfere with the body's ability to regulate temperature; individuals being treated with these drugs or taking them for recreational purposes could be at increased risk of heat-related illness during extreme heat events (Martin-Latry et al., 2007).

The mental health consequences of disasters, such as those caused by hurricanes, range from acute traumatic stress to more chronic stress-related conditions such as post-traumatic stress disorder, complicated grief, depression, anxiety disorders, somatic complaints, poor concentration, sleep difficulties, sexual dysfunction, social avoidance, irritability, and drug or alcohol abuse. Chronic stress also increases negative health consequences among people with NCDs, and can increase susceptibility to NCDs (Portier CJ et al., 2010).

[8] The Caribbean Health-Climatic Bulletin and the Regional Climate Centre at the CIMH are described in chapter 5.

Psychological effects have been found to proceed through phases. The initial period among many survivors is, surprisingly, not usually characterised by extremely negative feelings. It may be termed a psychological "honeymoon" as people bond with others in joint efforts to recover and share stories that are full of hope. Some others have negative responses characterized by despair; this can result in looting, theft and violence, as has happened repeatedly following hurricanes in the Caribbean, as elsewhere (Helsloot & Ruitenberg, 2004; Tierney, Bevc, & Kuligowski, 2006). After this period, people start to do an inventory of their real-life situation; "reality" sets in. They may be faced with grieving for loved ones, loss of employment and property, and the enormity of repair and reconstruction. This is a period of disillusionment, marked by sentiments of abandonment, resentment, disorientation, disharmony and discontent. Stressors can continue to erode people's sense of confidence and mastery. Eventually, most people emerge from this into a phase of reconstruction and eventual recovery. This process can take over a year and be gradual, with some relapses (Dominica Community Mental Health Team, 2017).

Figure 12: Psychological phases of response to disaster



Source: (Benjamin, 2015)

The development of human resources to assist in the psychological recovery of people affected by disaster is important. There are efforts in various Caribbean countries to train citizens in the provision of psychological first aid and more long-term counselling and support skills. See chapter 4 for examples following the 2017 hurricanes.

Neurological health can also be affected by climate factors, including malnutrition; exposure to hazardous chemicals, biotoxins, and metals in air, food, and water; and changes in pest management. Some harmful algal blooms contain neuro-toxins that affect foetal, post-natal and adult development (Portier CJ et al., 2010).

4. Discussion: Implications for research and surveillance

Climate science in the Caribbean took a major step forward with the PRECIS modelling project in the early 2000s, enabling the production of data that can be used in adaptation and mitigation planning. The project faced challenges that are common to research in the region: limited hardware and data storage capacity; gaps in time-series data; inadequate funding for the time spent by researchers on the project other than for their attendance at meetings. To address the enormous challenges posed by climate change in the Caribbean, more attention should be paid to building and funding research capacity. At the same time, the researchers on the PRECIS project demonstrated resourcefulness and resilience in their determination to generate results useful for the Caribbean people, building further capacity among staff and students and adding a university in Suriname to the list of institutions with climate modelling capacity. Such determination is laudable but should not be taken for granted; accurate knowledge on climate variability and change is too important to leave research under-resourced.

Integration of climate and health data is a developing field of research in the Caribbean. An important project was the one on the associations between dengue fever and climate change. This project, like the PRECIS RCM work, was conducted primarily by the Climate Studies Group based at UWI, Jamaica, showing the historical importance of this group of scientists. The dengue project (A.A. Chen et al., 2006) enabled seasonal patterns in dengue incidence to be associated with particular climate patterns, and provided the basis of early warning systems based on climate data, epidemiological surveys and health surveillance data. These types of data, while not usually complete in each Caribbean country, can in principle be collected by environmental health departments with minimal technological capacity. This work has recently been supplemented by spatio-temporal modelling by a consortium of universities in collaboration with ministries responsible for health and the CIMH (Stewart Ibarra et al., 2017). This project brought statistical modelling and the use of Geographic Information Systems to assist in identifying probably hotspots of dengue vulnerability, and thus enabling geographic as well as temporal prediction of vulnerability. The project also brought together stakeholders in Barbados and Dominica and regional and international experts to enable climate and health alliance and capacity-building. The modelling work, however, relied to some extent on external expertise and the use of technologies which may be beyond the current reach of some Caribbean countries and territories. This illustrates the need for further training and the provision of technologies to enable further climate and health research and use of data in decision-making. Sadly, climate change is itself a threat to human resource capacity-building, as we saw in the section on population displacement above.

Attention has been paid in Caribbean research to hypothesised links between Sahara dust and asthma, with mixed results. The experience of this body of research highlights the complexity of climate and health linkages, with the need to control for multiple environmental and social influences coinciding with the extreme difficulty of doing so. Sahara dust is but one of several potential environmental influences on asthma, for example; others may include humidity and allergens such as pollen. These may be associated in their turn with social determinants of health, such as location and quality of housing. Multi-variate research is needed, but there is a challenge in that statistical capacities to do such research is limited, especially in the smaller Caribbean territories. To avoid dependence on outside expertise, again, local capacity-building and human resource retention strategies are needed.

There is also a need to strengthen and make further use of existing surveillance information, combining data from weather stations with health surveillance data. By monitoring both simultaneously, it is possible, without the use of high-level statistical expertise, to identify climate-related patterns of disease. CARPHA data on cases of food-borne, vector-borne and respiratory diseases can be used. Syndromic surveillance data is also an important source, enabling weekly tracking of gastroenteritis and fever symptoms. These may be mapped against information for example on temperature and precipitation. Outbreaks associated with severe weather events such as hurricanes may be investigated. Chapter 4 provides some examples of the sorts of analyses that may be helpful. Chapter 5 presents initiatives by Caribbean agencies such as CIMH and CARPHA to collaborate in the provision of integrated climate and health information.

Climate and health research in the Caribbean have concentrated on a limited range of health issues; mostly mosquito-borne diseases and asthma. This chapter has relied largely on global reviews to identify climate and health links. Given the projections of the PRECIS-RCM and other climate research projects, attention should be paid to strengthening the local evidence base on a wider range of health topics. The research should be informed by the specific vulnerabilities of SIDS identified in chapter 2 and the climate drivers and exposure pathways identified earlier in the current chapter.

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