Project Document

An assessment of the economic and social impacts of climate change on the health sector in the Caribbean

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Executive Summary

Climate change affects the fundamental bases of good human health, which are clean air, safe drinking water, sufficient food, and secure shelter[2]. Climate change is known to impact health through three climate dimensions: extreme heat, natural disasters, and infections and diseases. The temporal and spatial climatic changes that will affect the biology and ecology of vectors and intermediate hosts are likely to increase the risks of disease transmission. The greatest effect of climate change on disease transmission is likely to be observed at the extremes of the range of temperatures at which transmission typically occurs.

Caribbean countries are marked by unique geographical and geological features. When combined with their physical, infrastructural development, these features make them relatively more prone to negative impacts from changes in climatic conditions. The increased variability of climate associated with slow-moving tropical depressions has implications for water quality through flooding as well as hurricanes. Caribbean countries often have problems with water and sanitation. These problems are exacerbated whenever there is excess rainfall, or no rainfall.

The current report aims to prepare the Caribbean to respond better to the anticipated impact of climate change on the health sector, while fostering a subregional Caribbean approach to reducing carbon emissions by 2050. It provides a major advance on the analytical and contextual issues surrounding the impact of climate change on health in the Caribbean by focusing on the vector-borne and waterborne diseases that are anticipated to be impacted directly by climate change. The ultimate goal is to quantify both the direct and indirect costs associated with each disease, and to present adaptation strategies that can address these health concerns effectively to benefit the populations of the Caribbean.

In order to estimate the impact of climate change on the health sector of the Caribbean, the A2 and B2 scenarios of the Intergovernmental Panel on Climate Change (IPCC) were used. A predictive Poisson model was developed for malaria, dengue fever, leptospirosis, and gastroenteritis for the population sub-groups under age five, and over age five all of which have had major impacts, both in terms of the number of cases as well as the fiscal and indirect costs associated with them. It was recognized that several other diseases, such as skin cancers and Sahara-dust respiratory-related

2 World Health Organization (WHO), "Climate Change and Health: Fact Sheet N266" [online], http://www.who.int/mediacentre/factsheets/fs266/en/index.html [12 June 2012], 2010.

illnesses, as well as future extreme events, may become more relevant to the Caribbean over the period under consideration; however, as these health events do not yet have an established econometric relationship with climate, they have been considered in a separate section of the present report.

The empirical analysis was successful in identifying variations in the disease-specific impacts of climate change over the course of the forecast period and across the diseases considered. Specifically, the results indicated that the number of both malaria and leptospirosis cases would exceed the number of cases under the baseline climate scenario, whereas dengue fever would have high impact during the first and fourth decades, gastroenteritis in children over age five in the third decade, and gastroenteritis in children under age five in the first to third decades, respectively.

Treatment costs under the B2 scenario between 2011 and 2050 were projected to range from a low of US$ 17,851 for dengue fever to a high of US$ 1.94 million for gastroenteritis in the under-age-five population. The low treatment costs for dengue fever were driven by the comparatively lower per-unit treatment costs and the low level of cases during the first decade, whereas the associated per-unit treatment costs for gastroenteritis were higher. Treatment costs were slightly higher under the B2 scenario over the entire forecast period, 2011 to 2050. Additionally, the cost of gastroenteritis treatment declined over time in response to declines in the incidence of gastroenteritis cases under A2 and B2 over the forecast period. The treatment costs for malaria, dengue fever and leptospirosis increased over the forecast period, consistent with the general increase in the number of cases forecast. The unit costs associated with treating malaria were the lowest among the four diseases. These results indicated that malaria was the least of the disease threats facing the Caribbean. However, these cost estimates excluded the cost of human suffering, as well as the productivity losses associated with the number of cases.

The results indicated the importance of considering the indirect costs associated with the impact of climate change on the health sector showing that productivity losses were larger under B2 than under A2, for all four diseases, in all four decades. Losses reflected the pattern in the number of cases during the period and the length of the lost production time whilst the patient recovered. Losses for malaria were largest in the second decade, 2021–2030, due to the anticipated increase in the number of cases during the period and, therefore, the lost value of production time. Losses associated with gastroenteritis cases under-age-five were slightly larger than those for gastroenteritis in the over-age-five population, as the overall number of cases in the under-age-five population was relatively larger. Policy considerations in this context would thus be compounded by the need to determine the relative allocation of resources between gastroenteritis prevention and treatment options. The distribution between the two would have implications in terms of the size and cost of treatment and prevention.

The cost-benefit analysis of possible adaptation mechanisms indicated that the greatest expense in terms of direct adaptation costs were those associated with water supply and sanitation system programmes that would be designed primarily to reduce leptospirosis and gastroenteritis cases in the population both under age five and over age five. The adaptation costs for impregnated bed nets designed to prevent malaria, and the spraying programmes that target reductions in both malaria and dengue fever, respectively, follow in terms of expense. This ranking stands, in each instance, regardless of the climate scenario or size of the targeted population (see table 15). Dengue fever and malaria spraying programmes had the fastest payback period, within the first few years, followed by water and sanitation improvements designed to reduce gastroenteritis, and finally, water and sanitation for leptospirosis.

There are, however, some complementarities that are likely to materialize when a programme implemented for one disease helps reduce the number of cases of another disease, and thereby increases the benefits associated with the reduced number of cases of both diseases.

Policymakers should place emphasis on programmes that would assist in monitoring the likelihood of outbreaks, by monitoring the volume of rainfall and the maximum temperatures in each period, as part of an early warning mechanism that would pre-empt any potential increase in the number of malaria cases. Another important adaptation option for the Caribbean subregion relates to improvements in primary health-care services.

The primary goal of building adaptive capacity would be to reduce future vulnerability to climate variability and change. Given the profile of development in the Caribbean, and the relatively high dependence on coastal resources, community-level responses and the building of high levels of social capital will be critical to the composition of an effective response. Given the inter- and intra-State variations in geographical, geological and socioeconomic conditions, national and local authorities will have to develop localized priorities and strategies to address outbreaks or health issues that would not require a national approach. These local strategies should be filtered into the national response to climate change. A proportion of any expansion in resources to the health sector should be channelled into increasing the research effort, in order to identify potential mechanisms of disease transmission and, hence, to refining the potential adaptation strategies beyond those prescribed in the current report. It is essential that local capacity be improved, to ensure the enforcement of local planning restrictions that would facilitate resilience and/or minimize damage**.** Improvements in sanitation and access to higher-quality drinking water will continue to be important in the Caribbean in order to address waterborne illnesses and those associated with the improper disposal of solid waste. These improvements must form part of the local and national response to climate change, as they may require large amounts of investment, as indicated in the cost-benefit analysis.

I. Background information

Climate change is highly dependent on the concentration of greenhouse gases in the Earth's atmosphere. The Intergovernmental Panel on Climate Change (IPCC) defined climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer". (IPCC, 2011). IPCC further asserted that natural internal processes known as external forcings or persistent anthropogenic changes in the composition of the atmosphere or land use can contribute to climate change (IPCC, 2011). Examples of these forcings are: deviations in the Earth's orbit; variations in radiations from the sun; mountain-building; continental drift; and, changes in greenhouse gas concentrations. Short-term fluctuations in the changes of the movements of the ocean, for example the El Nino Southern Oscillation (ENSO), which affects the Caribbean, are often a result of climate change through ocean variability and movements.

Global warming and its implications for heavier, more intense and more persistent hydro events will result in:

a) more soil inundation by rainwater

b) increased numbers of vectors, such as mosquitoes that depend on water pooling, as well as bacterial and viral material transmitted by water sources typically through drinking and food consumption

c) saltwater intrusion into aquifers and sewerage disposal systems that may be located below sea level or close to the sea.

These impacts are likely to result in unwanted changes in the environment and will require the use of new methods and resources in order to replace and/or moderate those negative impacts. In addition to the impact of changing weather patterns on the health of the Caribbean population, there are concerns about the transmission of Saharan Dust, which has been linked to an increase in respiratory illnesses. It is possible that, under climate change, these dust storms will be facilitated increasingly by storm activity, resulting in increased numbers of cases of respiratory illness over time.

TABLE 1
ENVIRONMENTAL CHANGE DISEASES AND PATHWAYS IN THE CARIBBEAN

Environmental changes	Example diseases	Pathway and effect
Dams, canals and irrigation	Malaria	↑ breeding sites for mosquitoes
Agricultural intensification	Malaria	↑ crop insecticide; ↓ vector resistance
Urbanization, urban crowding	Cholera	↓ sanitation, hygiene; ↑ water contamination
	Dengue fever	Water collecting trash; ↑*Aedes Aegypti* mosquito breeding sites
Deforestation and new habitation	Malaria	↑breeding sites for vectors, immigration of susceptible people

Source: Information synthesised from literature on climate change and health by Author

The degree to which humankind will be able to mitigate its activities to reduce the scope of this change, in the case of large emitters, and the extent of the projected damage to those smaller countries that are impacted over and above their contribution to climate change has been an important part of the discussions at the international, regional and local levels. The intention has been to present policymakers with scenarios, implications and options to smooth the transition to the new, relatively uncertain, status quo.

Caribbean countries are characterized by differences in topography, topology, population, location and resource allocation. Generally however, these countries face similar health threats from climate change. Table 1 indicates some of the potential pathways of diseases due to environmental changes. It is estimated that each year, globally, climate change is responsible for the death of 150,000 persons, and leaves five million persons subject to illness (Climate Institute, 2010).

Some of the main impacts of climate change on health are:

a) Changes in temperature, in the form of increased heatwaves, that may induce diseases of the skin, eyes, or other sensitive, exposed parts of the body

b) Changes in rainfall patterns, compromising the quantity and quality of the water supply

c) Higher risk of the spread of vector-borne and waterborne diseases

d) A rise in coastal flooding due to rising sea levels, with potential implications for water quality and sewerage wash-outs.

Certainly, the Caribbean subregion is susceptible to these four challenges. Climate change is expected to accelerate the spread of disease, primarily because warmer global temperatures enlarge the geographical area in which the conditions exist for disease-carrying hosts to survive. In addition, geography has defined and limited the development and location of resources along sea fronts, which may be negatively impacted by sea-level rise and rain/flood events.

The present report considers the potential impact of climate change on the health profiles of 16 countries in the Caribbean subregion. These countries are classified as small island developing States (SIDS), characterized as having open economies, heavy dependence on trade, movement of labour to the productive areas of the country and to other countries, as well as limited geographical areas to facilitate relocation efforts. In this context, the climate change discussion has spurred governments in the Caribbean to understand the potential impacts, in order to structure their responses and restructure their countries' economies and societies, to build more resilience to the forecasted and unknown impacts. Social systems and institutions need to be able to improve their capacity to detect and counteract negative impacts on the health of the population.

The current report aims to prepare the Caribbean to respond better to the anticipated impact of climate change on the health sector, while fostering a joint approach to reducing carbon emissions by 2050. It presents and discusses issues in relation to health and health care in the Caribbean; it estimates an econometric model that encapsulates the historical relationship between four major diseases associated with climatic variations; it explores the likely morbidity associated with the diseases, and it presents estimates of the direct and indirect costs of the projected cases for each disease. This report concludes with a presentation of the costs and benefits associated with relevant health interventions as well as policy recommendations, in the form of adaptation strategies, for building comprehensive health-sector resilience in the Caribbean subregion and prescribe areas for future action.

II. Literature review

A. The impact of climate change on health

The warming of the Earth's atmosphere has been associated with adverse climate changes globally. It has sparked an increase in the number of observed cases and/or the introduction of many diseases to areas that had reported a relatively low incidence previously. In addition, threats to local ecosystems have the potential to threaten the health of the public to varying degrees. Global warming is projected to have consequences that vary temporally and spatially. All climate scenarios have indicated that populations will be impacted and that the harm associated with climate change will outweigh the benefits of greenhouse gas reduction efforts globally (Samet, 2000). Some (Spickett, Brown and Katscheria, 2008) have indicated that future global climatic and environmental circumstances might be significantly different from their current status if appropriate mitigation and abatement programmes are not implemented. The authors noted that, even with the most optimistic mitigation scenarios, the rate of warming might not be slowed sufficiently enough to minimize predicted climatic changes. Their results were expected to be robust over the next 50 to 100 years.

Climate change is not expected to introduce currently unknown causes of morbidity and mortality, but is expected to change the factors such as disease vectors and environmental exposure that may affect the rate and occurrence of morbidity and premature mortality. Scientists have documented extensively the phenomenon of excess mortality and morbidity during climate events. In recent decades, the dramatic epidemics, of hundreds of excess deaths associated with the 1995 heat wave in Chicago and the thousands of excess deaths in Europe in 2003, are examples of the globally publicized health impacts that have been associated with climatic events (Spickett, Brown and Katscheria, 2008). These experiences have caused Governments and public health agencies to take preventive action, particularly in relation to vulnerable populations, those with existing health conditions, poorer people without air conditioning, and those lacking social welfare support.

The United Nations Framework Convention on Climate Change (UNFCCC) has recommended that countries implement their best strategies to mitigate the effects of climate change on all sectors of the economy. Each country must develop and implement initiatives to improve health and sanitation to reduce the impact of diseases introduced and/or amplified by climate change, and procedures that would safeguard their citizens against the potential negative impacts of hurricanes and natural disasters, which may increase in strength and frequency when associated with climate change.

1. The health effects of climate change

Climate change affects the fundamental bases of good human health, which are clean air, safe drinking water, food security, and secure shelter (WHO, 2010). Climate change is known to impact health through three climatic dimensions: extreme heat, natural disasters, and infections and diseases. Increasing atmospheric temperature has often been associated with increased numbers of cardiovascular and respiratory diseases, particularly among elderly persons. Increased temperatures enliven the gases in the atmosphere, making life a burden to persons with respiratory illnesses such as asthma. In a study done by Githeko and others (2000), it was estimated that average global temperatures will have risen by 1.0° C to 3.5° C by the year 2100, and that this would increase the likelihood of many vector-borne diseases in new areas. Table 2 presents a summary of the vector-borne and waterborne diseases in the Caribbean.

The temporal and spatial climatic changes that will affect the biology and ecology of vectors and intermediate hosts are liable to increase the risk of disease transmission. The greatest effects of climate change on disease transmission are likely to be observed at the extremes of the range of temperatures at which transmission typically occurs. For many diseases, the greatest effect of climate change on transmission is said to have taken place when the temperatures are 14° C to 18° C at the lower end, and 35° C to 40° C at the upper end. Mosquito species, such as the *Anopheles gambiae complex, A. funestus, A. darling, Culex quinquefasciatus*, and *Aedes aegypti*, common in the Caribbean, are the main vectors transmitting most vector-borne diseases, and they are sensitive to temperature changes. Higher water temperatures spike the maturity periods of these mosquitoes as well as their capacity to reproduce during the transmission period. Undoubtedly, the changes will have unknown impacts on health status and health systems.

a) Malaria

Empirical evidence already links such epidemics as cholera and Rift Valley fever to changes in climate, while controversy surrounds the consequences of climate change on other diseases such as malaria (Samet, 2000), due to the fact that malaria can exist under normal climatic conditions. Malaria has been found in unexpected places and, in general, the number of cases has increased over time in the presence of warmer temperatures and variations in rainfall patterns. Barclay (2008) reported that changes in temperature can affect the development and survival of malaria parasites and the mosquitoes that carry them. Rainfall is an influence on the accessibility of mosquito habitats and the size of their populations. Wandiga (Barclay, 2008), had found that malaria epidemics first appeared in Kenya's highlands in the 1920s but, during the last 20 years, the frequency of outbreaks had been more pronounced, requiring only two months for the emergence of a malaria epidemic. He indicated that the ideal climatic conditions for malaria were a long rainy season that was warm and wet, followed by a dry season that was not too hot, followed by a hot, wet, short rainy season.

Malaria has risen to global prominence in the context of the Millennium Development Goals and the observed ravages of the disease in some countries, particularly in Africa. As a result, there have been many attempts at estimating the determinants or covariates of the disease. For example, Teklehaimanot and others (2004) used a Poisson regression with lagged climate, an autoregressive term, a time trend and indicator variables representing the week of the year. The biological evolution of the number of cases indicated that malaria cases should follow periods of increased temperature and rainfall, at lags of 4 to 12 weeks for rainfall, and lags of 4 to 10 weeks for both the minimum and maximum temperatures. The authors included the logarithms of the prior period's malaria cases in order to correct for potential autocorrelation. Graves and others (undated) used a Poisson regression to determine the statistical evidence for a reduction in the number of cases by dichlorodiphenyltrichloroethane (DDT), Malathion, impregnated bed nets and larval control. They found that malaria responded to differences in rainfall within approximately two and three months prior to the current period.

TABLE 2
VECTOR-BORNE AND WATERBORNE DISEASES IN THE CARIBBEAN

Malaria is a parasitic disease caused by the bite of an infected *Anopheles* mosquito. Malaria can reach endemic stages in the presence of climate change, through increased rainfall and the number of formal and informal water sources that are potential breeding sites. Prevention methods include: • Source reduction • Proper solid waste disposal • Prevention of mosquito bites by use of screens, protective clothing, insecticides and insect repellants.
Dengue fever comes in four strains and is spread by mosquitoes in urban areas. The most deadly strain of the dengue fever virus is dengue haemorrhagic fever which damages the circulatory system and internal organs severely. The major breeding sites for the *Aedes Aegypti* mosquitoes are mostly the artificial water containers commonly found in and around urban areas, particularly residences. Research has shown that the number of months with average temperatures higher than 18°C and the degree of urbanization were found to correlate with increasing risk of dengue fever. Prevention methods include: • Source reduction • Proper solid waste disposal • Prevention of mosquito bites by use of screens, protective clothing, insecticides and insect repellants.
The leptospirosis infection is associated with the *Leptospira* bacteria and is transmitted to humans and animals through water contaminated with animal urine that contacts broken skin and the mucous membranes of the eyes, nose and mouth. The disease occurs in both rural and urban areas, and in temperate and tropical climates. Leptospirosis may peak in rainy seasons in countries where it is endemic and reach epidemic levels in cases of flooding. Preventative measures include: • Source control • Interruption of the transmission route • Vaccination.
Gastroenteritis is an inflammation of the gastrointestinal tract that often results in diarrhoea, vomiting and abdominal pain. The transmission of gastroenteritis is normally due to the consumption of improperly-prepared foods or contaminated water, or close contact with infected individuals. The primary causes of gastroenteritis are the bacteria *Escheria coli* and *rotavirus*. Rotavirus is the most common cause in children while *norovirus* is the leading cause in adults. Preventative measures often include good sanitation practices and rotavirus vaccination for children.
Cholera is caused by the bacterium *Vibrio cholera*. People become infected by ingesting food or drinking water that has been contaminated by the faeces of other persons. To prevent the spread of cholera, the following four interventions are essential: • Provision of adequate, safe drinking-water • Proper personal hygiene • Proper food hygiene • Hygienic disposal of human excreta.
Typhoid and paratyphoid enteric fevers are infections caused by the bacteria *Salmonella typhi* and *Salmonella paprtyphi*, respectively, which are transmitted to humans via faeces in the ingestion process, causing bacterial infection of the intestinal tract and bloodstream. Paratyphoid fevers are generally milder than the full strain of typhoid. Typhoid and paratyphoid fever victims may continue to carry the bacteria even after the recovery period. The diseases are common in countries with problems of unsafe drinking water, inadequate sanitation facilities and flood-prone areas. Although a vaccine is available, it does not provide full protection from the infection. Therefore, the following prevention methods are advised: • Health education • Proper sanitation facilities • Exclusion of disease-carriers from food handling.

Source: Peggy Wu and others, "Higher temperature and urbanization affect the spatial patterns of dengue fever transmission in subtropical Taiwan", *Science of the Total Environment*, vol. 40, 2009

b) Dengue fever

Dengue fever is another vector-borne, infectious disease that flourishes in warm temperatures. The virus that causes dengue fever is transmitted by mosquitoes that have been infected by biting infected humans. The disease is then incubated for eight to ten days inside the mosquito, at which point the mosquito becomes infectious and can transfer the disease to anyone it bites (Heller, 2010). According to the United States Government Centers for Disease Control and Prevention, dengue fever is the most common cause of fever in travellers returning from the Caribbean, Central America, and South-Central Asia. Severe dengue fever can be fatal but, with good treatment, is fatal in less than 1 per cent of cases.

Improved mosquito control programmes and changes in socioeconomic conditions have decreased dengue fever outbreaks since the 1950s. Greenwire (2012) reported that, despite previous success in reducing the threat of malaria, health experts have not been surprised by the resurgence of dengue fever in the United States of America. The increase has been linked with increases in factors such as urbanization, increased travel, and the evolution of climate change. Texas Tech University (2012) reported that dengue fever outbreaks were usually seasonal, and forecast that southern States would experience a decrease in the magnitude of outbreaks in spring and fall, while northern areas would experience increases in the number of cases during the northern-hemisphere summer, when temperatures were higher. Their research revealed further that 40 per cent of the world's population was threatened by dengue fever, with approximately 100 million infections annually, making it the most important vector-borne disease globally.

The epidemiological correlates of dengue fever have been explored in the literature by Lu and others (2009) and Fairos and others (2010), both of whom used a Poisson model. Lu and others (2009) explored the relationship between monthly dengue fever incidence in the Guangzhou province in China, and weather variables. They found the minimum temperature and wind velocity to be significant predictors of the incidence of dengue fever. Using weekly data, Fairos and others (2010) found a two-to-three-week lag of the incidence of dengue fever in response to daily temperature and wind speed, whilst humidity impacted the number of cases only after two weeks. Neither of these studies included controls for the general socioeconomic environment in which these dengue fever cases were contracted.

c) Leptospirosis

The Centre for Disease Control (CDC) describes leptospirosis as a bacterial disease that affects humans and animals. It is caused by bacteria of the genus *Leptospira*. The urine of infected animals contains the bacteria that cause leptospirosis, which spreads to the human population though the domestic water supply or the soil, and can survive there for weeks or months. Without treatment, leptospirosis can lead to kidney damage, meningitis (inflammation of the membrane around the brain and spinal cord), liver failure, respiratory distress, and even death. The CDC noted that the incidence of leptospirosis infection among urban children appeared to be increasing.

Globally, leptospirosis cases have tended to be seasonal, particularly following periods of heavy rainfall in Central America, South America, the Caribbean, and South Asia (ECLAC, 2011). Despite this evidence, there has been relatively little data linking climate change to changes in the number of leptospirosis cases; this may be related to under-reporting of the number of leptospirosis cases. Globally, the number of observed cases of leptospirosis has tended to exhibit a seasonal trend. In the Caribbean, reports of gastroenteritis increase during the cooler, drier months of the year (ECLAC, 2011). The number of cases has been larger for children under the age of five years than for those over five years of age. More emphasis has been placed on diarrhoeal diseases in general (Onozuka, 2010). The results indicated a predictable, seasonal pattern of a 4 per cent increase in diarrhoea for every 10 mm decline in rainfall (Lloyd, 2007). The research emphasized the importance of preventative mechanisms, such as surveillance and reporting, vector-control measures, demographic changes, access to good-quality health services, and land-use changes (Kovats and others, 2001).

d) Gastroenteritis

Gastroenteritis outbreaks could be caused by viruses (such as rotavirus, adenovirus, Norwalk virus), bacteria (such as *campylobacterosis*, cholera or typhoid), or by parasites (such as the *Amoeba*, *cryptosporidium* and *cyclospora*)[3.] Jamaica, Guyana and Suriname are typically the countries in the Caribbean with the largest number of cases in both the population under age five and over five years of age. During the period of analysis, the gastroenteritis cases were associated mostly with the rotavirus and those outbreaks occurred chiefly in Jamaica. The relationship between climate (the importance of minimum temperature (cooler periods), rainfall or humidity) and the number of gastroenteritis cases has been estimated in the health economics literature with generally ambiguous

[3] Additional information on Gastroenteritis is available from http://new.paho.org/carec/dmdocuments/9.%20GE.pdf

results. Given the relative importance of the disease, and the observed relationship with cooler periods, the disease has been included in the empirical analysis.

2. The health profiles of countries in the Caribbean

Caribbean countries are marked by unique geographical and geological features that, given their level of physical, infrastructural development, make them relatively more vulnerable to the negative impacts of climate change. The increased variability of climatic conditions associated with slow-moving tropical depressions affect water quality, through flooding, as well as hurricanes, resulting in problems with water supply and sanitation. These problems are exacerbated when there is excess rainfall, or no rainfall. The present study focuses on the impact of extreme variations in climatic conditions namely temperature, precipitation, humidity and wind speed on the socioeconomic and infrastructural resources of selected Caribbean countries.

Following the chronic flooding that plagued Europe during the 1990s, the World Health Organization (WHO), at an international meeting in London in 2002, acknowledged the complexity of the damaging effects of floods. Floods frequently cause major infrastructural damage, including disruption to roads, rail lines, airports, electricity and water supply systems, and sewage disposal systems. The economic effects of floods have often been much greater than indicated by the physical effects of floodwater coming into contact with buildings and their contents. Indirect economic losses typically spread well beyond the flooded area and might last much longer than the flood itself. The local and regional economy might be affected badly by a major flood disaster and this might affect the national economy seriously. Previous studies of the health effects of floods assessed the direct effects caused by the floodwaters (such as drowning, injuries, and others) and the indirect effects caused by other systems damaged by the floods (such as waterborne infections, acute or chronic effects of exposure to chemical pollutants released into flood waters, vector-borne diseases, food shortages[4] and others).

Periodic reductions in average rainfall can have potentially serious impacts on water supply in island economies. Likewise, increases in sea level may result in increased salinity of the water supply, apart from inundation, erosion and other coastal hazards. Water availability issues due to flooding and high rainfall events have sanitation and sewerage infrastructural impacts, and imply the increased risk of diseases, such as cholera, diarrhoea, dengue fever, gastroenteritis, leptospirosis and malaria (table 3). Consideration might extend to food-borne diseases due to warmer sea surface temperatures during El Nino events, resulting in Ciguatera fish poisoning and, possibly, causing food insecurity.

In addition, there are environmental health impacts due to accelerated beach erosion, degradation of coral reefs and the degradation of the overall asset value of the coast due to sea-level rise and increased ocean temperatures. These negative impacts on vital environmental components will affect local populations, as well as have negative repercussions for the tourism-dependent economies that characterize the Caribbean subregion (Innis, 2007).

Vector-borne diseases are known to be weather sensitive (WHO, 2000) and can become endemic due to changes in weather patterns and the potentially low efficacy of preventative measures. Climatic changes that can affect the transmission of these diseases are: temperature rise, rise in sea level, altered precipitation patterns, humidity, and moisture of the soil (Haines and others, 2006). Changes in surface temperature can impact the number of cases of vector-borne diseases, due to increased survival rates of the vector, increased rate of growth of the vector population, induced changes in the feeding and biting behaviour of vectors, and changes in the susceptibility of pathogens, in vector activity and in the seasonality of pathogen transmission (Hunter, 2003). In addition, changes in rainfall patterns can impact the breeding sites of the vectors, the population of the vertebrate host, and the location of vertebrate hosts, by bringing them in closer contact with humans.

[4] The impact on food shortages has socioeconomic and health implications for the Caribbean, which already have a high food import bill in 'normal' times, associated with balance of payments and other fiscal constraints.

TABLE 3
DISEASES PREVALENT IN THE CARIBBEAN BY COUNTRY

Country	Malaria	Dengue fever	Leptospirosis	Gastroenteritis	Typhoid fever	Cholera	Food-borne diseases	Acute respiratory infections
Antigua and Barbuda	√	√		√	√		√	√
The Bahamas	√	√	√	√	√		√	
Barbados	√	√	√	√	√		√	
Belize	√	√	√	√	√	√	√	
Dominica		√	√	√	√		√	
Grenada	√	√	√	√	√		√	√
Guyana	√	√	√	√	√	√	√	
Haiti	√	√	√	√	√	√	√	
Jamaica	√	√	√	√	√		√	
Montserrat	√	√		√			√	
Saint Kitts and Nevis	√	√	√	√			√	
Saint Lucia	√	√	√	√	√		√	
Saint Vincent and the Grenadines	√	√	√	√	√		√	
Suriname	√	√	√	√	√	√	√	
Trinidad and Tobago	√	√	√	√	√		√	

Source: Caribbean Epidemiology Centre (CAREC) [online], http://www.carec.org, 2012

Caribbean countries are vulnerable to climate change, which is expected to result in the loss of human lives by the transmission of highly fatal diseases. Further, climate change would affect human health by “altering the geographical range and seasonality of certain infectious diseases, disturbing food-producing ecosystems, and increasing the frequency of extreme weather events, such as hurricanes”[5].

The present study focuses on the potential impact of climate change on human vector-borne and waterborne diseases, with the aim of quantifying both the direct and indirect costs associated with each disease, and presents adaptation strategies that address these impacts effectively to the benefit of the populations of the Caribbean.

5 World Health Organization (WHO), “Health topics: climate change” [online], Geneva, Switzerland, [19 June 2012] http://www.who.int/topics/climate/en/, 2012.

III. Economic analysis and forecasts

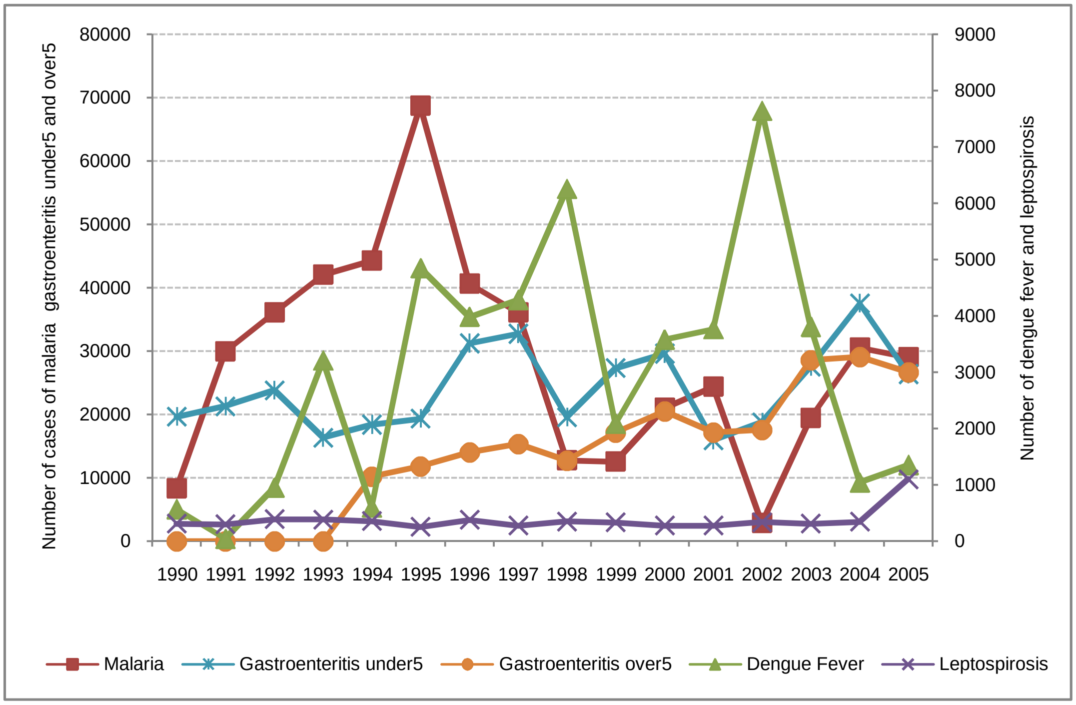
The current section presents the results of the econometric analysis. It adopts the methodology in the literature presented in section 2. Predictive relationships between each disease and the relevant climatic and socioeconomic controls have been estimated using a Poisson model. Once these relationships have been obtained, the projected climate variables, from 2011 to 2050, have been used to forecast the number of cases of each disease that can be expected between 2011 and 2050. These cases have been forecast at the country level and aggregated to provide Caribbean subregional forecasts. Subsection A presents information on the model approach. Subsection B presents an assessment of the historical climate data in the Caribbean between 1990 and 2005 along with the forecast climate data for the period 2011 to 2050. The model results are presented in subsection C, inclusive of the predicted number of disease cases for the forecast period. Individual Caribbean country forecasts can be viewed in annex 5.

A. Modelling approach

In order to estimate the impact of climate change on the health sector of the Caribbean subregion, a predictive Poisson model was developed for four key diseases that have had major impacts, both in terms of the number of cases and the indirect, fiscal costs associated with them. The four diseases used in the model were malaria, dengue fever, leptospirosis, and gastroenteritis, using data for the population cohorts under age 5 and over age 5.

There are several other diseases such as skin cancers and Sahara Dust respiratory-related illnesses that may become more relevant to the Caribbean through the impact of future extreme climatic events over the period under consideration; however, as these do not yet have an established econometric relationship with climate, they have been considered in a separate section of the present report.

FIGURE 1
DISEASE CASES IN THE CARIBBEAN, 1990 – 2005
(Number of cases)



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

Figure 1 presents the number of annual cases of each disease being modelled over the period 1990 to 2005. The data on disease morbidity was sourced from the Caribbean Epidemiology Centre (CAREC) webpage[6]. The European Centre Hamburg (ECHAM) Global Circulation Model climate forecasts for each country in the Caribbean were provided by the Meteorological Institute of Cuba (INSMET). Data used in the models refer to the following 12 Caribbean countries: Antigua and Barbuda, the Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and Trinidad and Tobago.

B. Climate data and scenarios

1. Climatic conditions in the Caribbean 1990 - 2005

During the historical period 1990-2005, average annual precipitation in the Caribbean ranged from a minimum of 521 mm to a maximum of 741 mm (see table 4). The average temperature during the period was 27° C; relative humidity was between 78.9 per cent and 80.1 per cent, while wind speed at 10 metres was an average 4.9 m/s.

[6] CAREC website is available at http://www.carec.org

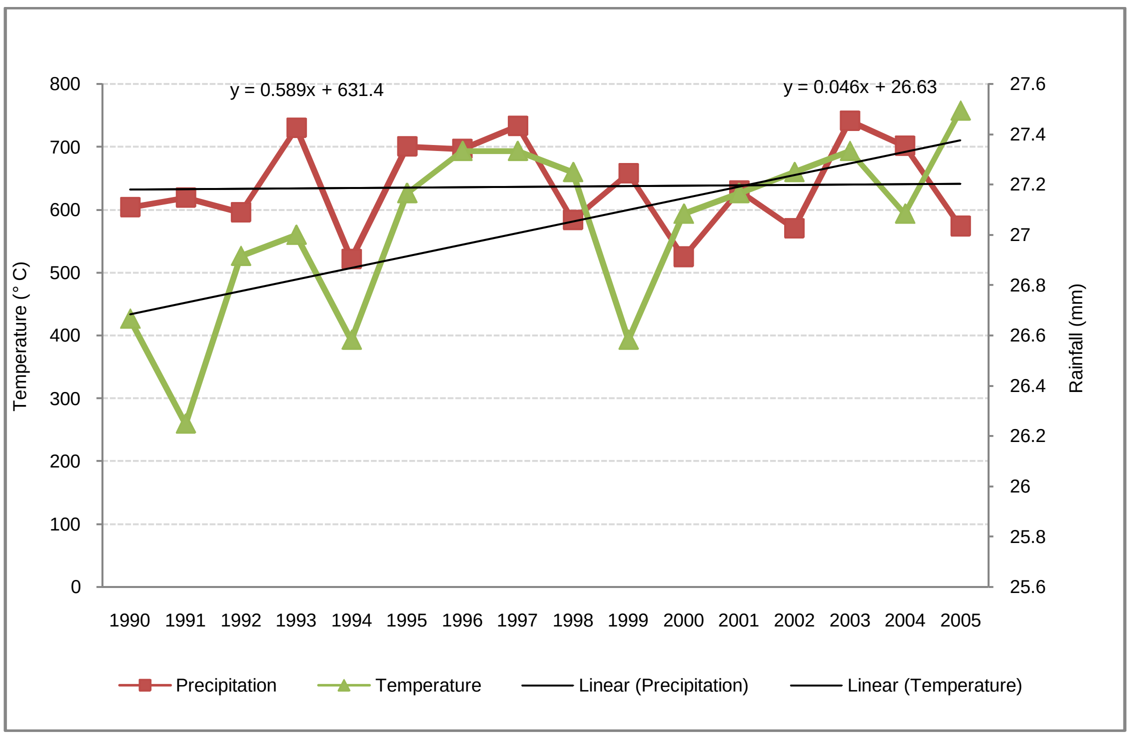
TABLE 4
DESCRIPTIVE STATISTICS OF CARIBBEAN CLIMATIC CONDITIONS 1990 – 2005

	Rain	Temperature	Humidity	Wind speed at 10 metres
Mean	636.4658	27.03086	79.47465	4.921701
Median	624.9917	27.125	79.5	4.916667
Maximum	741.0583	27.49375	80.08333	5.166667
Minimum	521.4833	26.25	78.91667	4.666667
Std. Dev.	73.64396	0.344878	0.324849	0.119817
Obs.	16	16	16	16

Source: Caribbean Epidemiology Centre (CAREC), [online], http://www.carec.org, 2012

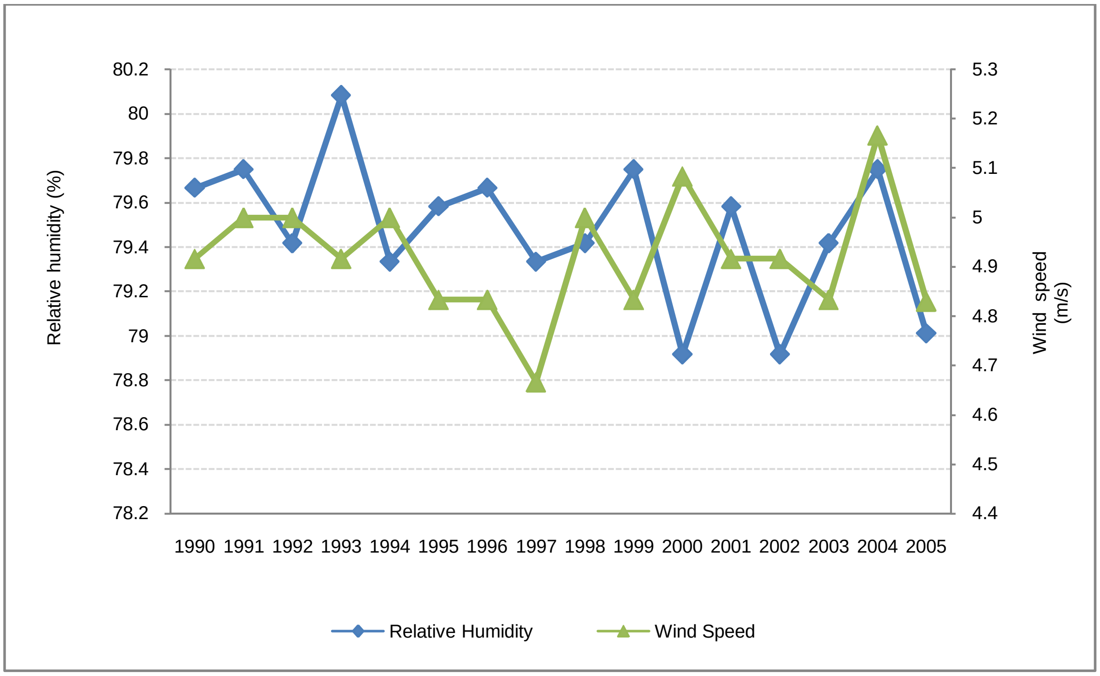
Average temperature and average precipitation in the Caribbean have been increasing, as illustrated in figure 2. Despite a slight decline between 2004 and 2005, average precipitation has increased from 603 mm (1990) to 701 mm (2004). Average temperature has increased from 26.7° C to 27.5° C. Average relative humidity has declined from 79.6 per cent to 79 per cent, whilst average wind speed at 10 metres has declined from 4.91 m/s to 4.83 m/s (figure 3).

FIGURE 2
AVERAGE CARIBBEAN TEMPERATURE AND RAINFALL, 1990 – 2005
(Degrees Celsius and millimetres)



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

FIGURE 3
CARIBBEAN COUNTRIES: HISTORICAL AGGREGATE AVERAGE RELATIVE HUMIDITY AND WIND SPEED AT 10 METRES, 1990 – 2005
(Percentage and metres/second)



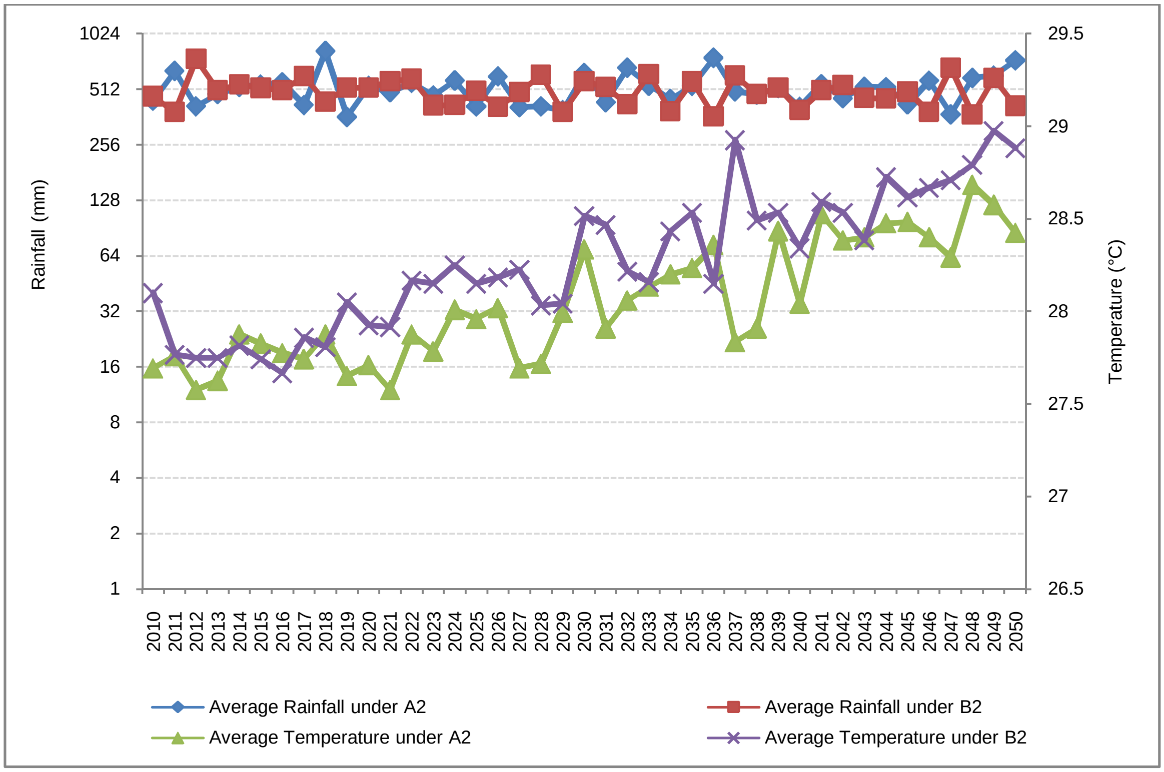
Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

2. Climate scenarios and forecast climate change in the Caribbean 2011-2050

The potential variations in climate will have impacts on the health status of the Caribbean populace. The impact of climate change on human health will be described using the A2 and B2 climate scenarios as prescribed by the IPCC *Special Report on Emissions Scenarios* (SRES). The climate data have included average temperature, precipitation, humidity and wind speed where relevant to each of the four diseases being considered. These climate data were downscaled using historical climatological data (average climate data constructed by averaging the historical data for each climate variable) and the anomalies from the ECHAM climate models for the period 2011 to 2050 for the A2 and B2 climate scenarios.

The A2 scenario has taken a comprehensive approach. Countries are viewed as part of a heterogeneous family of countries whose main aim is to preserve their national identity. Due to the assumed slow transition of fertility patterns, these countries contribute heavily to the increase in growth of the global population. Their low levels of economic development have put a burden on countries' ability to adapt to the impacts of climate change. The model has treated this as the Business-As-Usual (BAU) scenario. The B2 scenario has focused more on using each country's economic, social, and environmental resources to respond to climatic changes. The global population in the B2 scenario was assumed to grow at a slower rate than that under the A2 scenario. Economic development was assumed to be higher under the B2 scenario relative to the A2. Finally, in order to facilitate comparisons to the projected impact of climate change, a baseline scenario was constructed using a moving average of historical averages. Once the models were developed, the scenario data for 2006 to 2050 were used to predict the number of cases for each disease from 2011 to 2050.

FIGURE 4
AVERAGE FORECAST RAINFALL AND TEMPERATURE FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011 – 2050
(Millimetres and degrees Celsius)



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

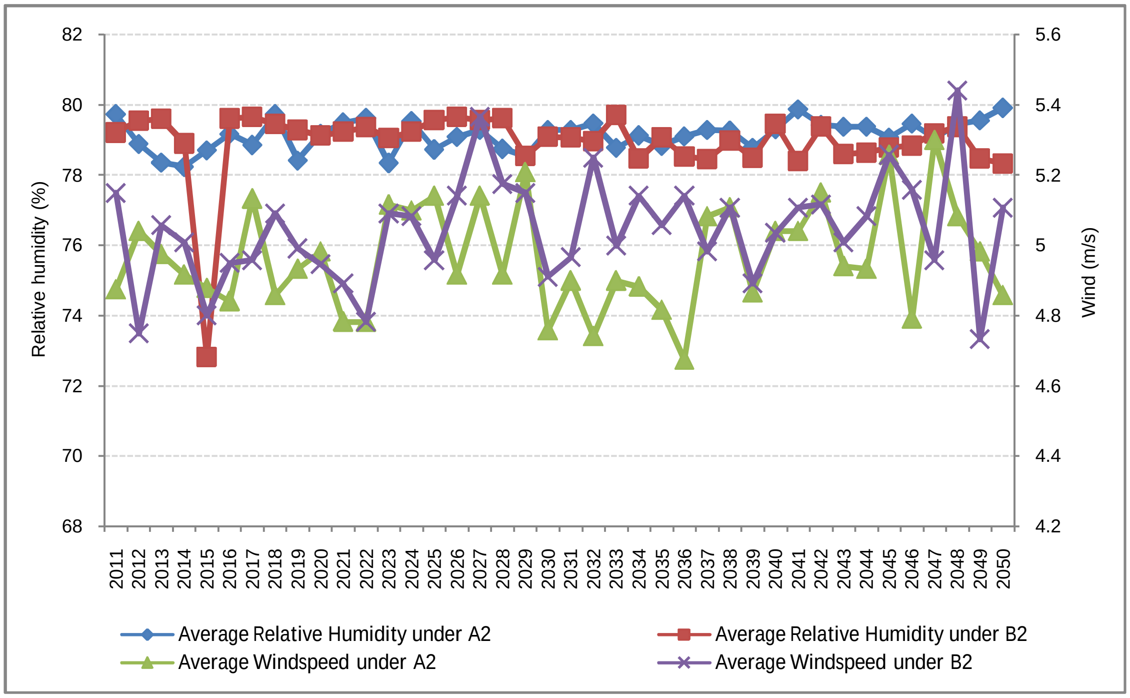
Rainfall under the A2 scenario is expected to exceed rainfall under B2, whereas B2 temperatures are forecast to exceed those under A2 for the majority of the years between 2011 and 2050 (see figure 4).

Relative humidity under A2 and B2 was similar, except during 2015 when there is a difference of about five percentage points. Wind speed at 10 metres was forecast to be higher under B2 than under A2.

C. Model results

The Poisson approach has been used in the health economics literature, since disease data are, by nature, head count data, for which the Poisson model is more appropriate than models such as Ordinary Least Squares. The coefficients from each model were used to forecast the number of disease cases that could be anticipated between 2011 and 2050 under the A2 and B2 scenarios based on the ECHAM model. The country-level forecasts obtained were then aggregated to obtain the aggregate Caribbean forecast, for each disease and for each of the decades 2011-2020, 2021-2030, 2031-2040 and 2041-2050, along with the baseline comparator. The model for malaria used annual data on the total number of registered cases of malaria for the period 1990 to 2005, and used the predictive Poisson model to capture the relationship between malaria and climate. The estimation has been guided by the findings in the health economics literature on the relationship between disease, climate and non-climate proxies, for the socioeconomic conditions, and for each country (figure 5).

FIGURE 5
AVERAGE FORECAST RELATIVE HUMIDITY AND WIND SPEED AT 10 METRES FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011 – 2050
(Percentage and metres/second)



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

1. Malaria

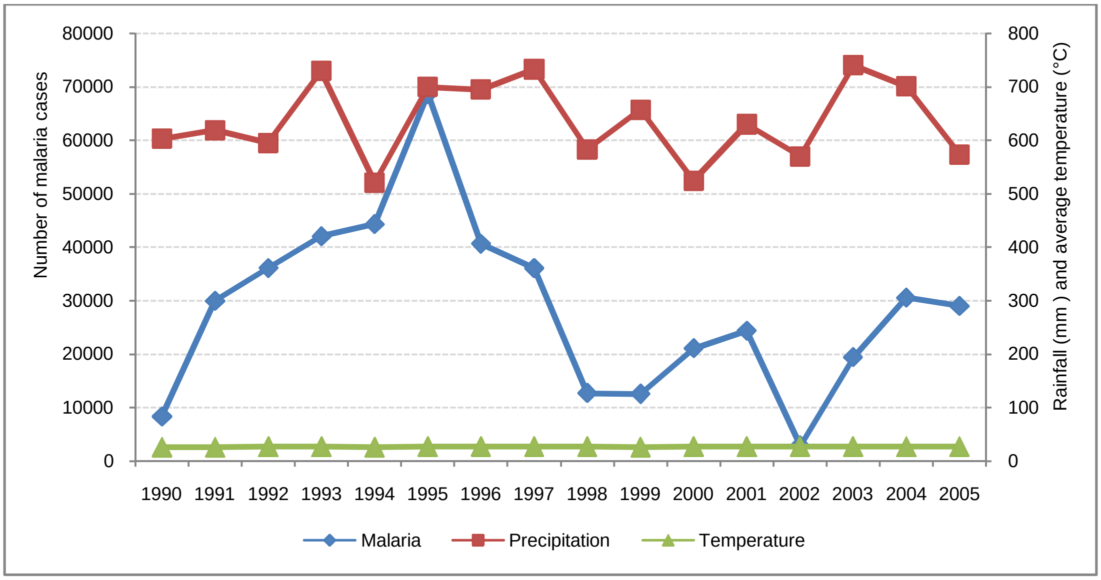
Between 1990 and 2005, there were approximately 28,725 malaria cases in the Caribbean (table 5). The standard deviation around the average number of cases in the Caribbean was approximately 16,418 cases, indicating a relatively high degree of fluctuation of malaria cases around the mean and across the Caribbean countries, as reflected in figure 6.

TABLE 5
AVERAGE NUMBER OF HISTORICAL MALARIA CASES IN THE CARIBBEAN 1990-2005

Mean	28 725.38
Median	29 529.5
Maximum	68 762
Minimum	2 921
Standard deviation	16 418.24
Observations	16

Source: Caribbean Epidemiology Centre (CAREC), [online], http://www.carec.org, 2012

FIGURE 6
TOTAL HISTORICAL NUMBER OF MALARIA CASES, AVERAGE TEMPERATURE AND RAINFALL IN THE CARIBBEAN, 1990 – 2005
(Degrees Celsius and millimetres/year)



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

$$Malaria_{i,t} = -0.383 + 0.001\, Rain_{i,t} + 0.445\, Temp_{i,t} - 8.008\, HDI_{i,t}$$

Equation (1)

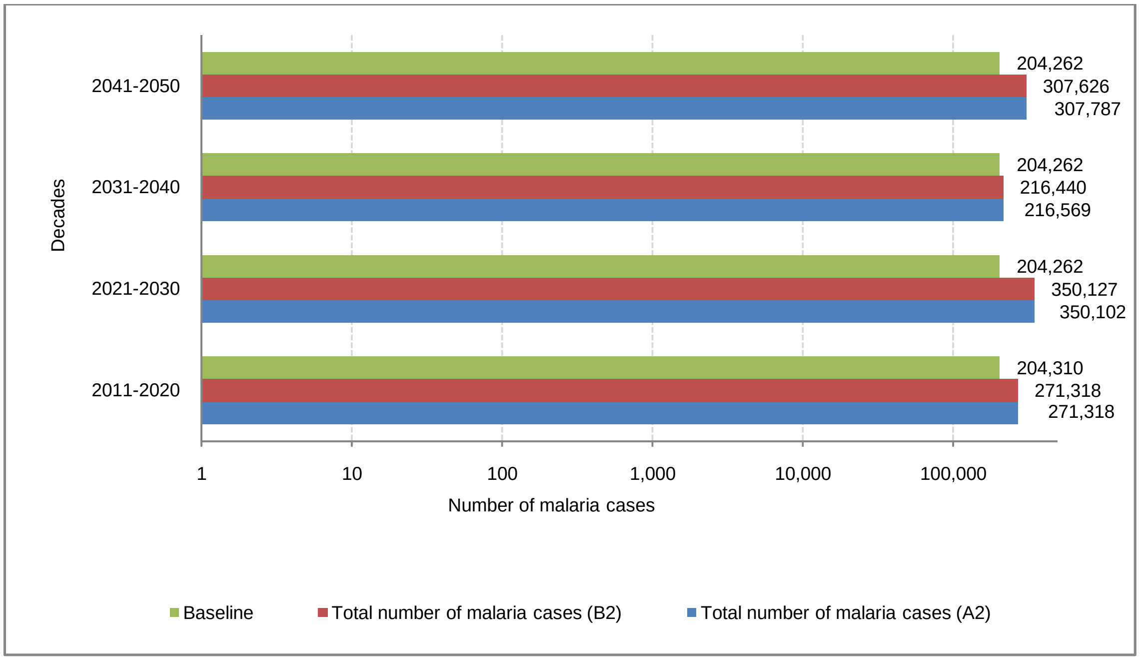
The model is presented above as Equation 1: details of the model output are presented in annex tables 4A to 4E. All the coefficients were statistically significant at the 5 per cent level (i.e. their p-values were less than 0.05). The findings, with respect to the impact of rainfall on the number of malaria cases, were consistent with the findings of the literature.[7] The results provided support for the inclusion of rainfall in the development of early warning systems for malaria, similar to the one that has been incorporated in the mapping Malaria Risk in Africa (MARA) model.

Interpretation of the coefficients indicates that every additional millimetre of rainfall would cause the number of malaria cases in the Caribbean to increase by three, whereas a 1° C increase in temperature would cause the number of malaria cases to increase by one.[8] The model also indicates that an increase in the human development index (HDI) across the Caribbean reduces the number of malaria cases by 100. This model has been used to predict the number of malaria cases between 2011 and 2050.

7 Blanco and Hernandez (2009), Odongo-Aginya and others (2005), Breit and others (2008), and Oluleye and Akinbobola (2010)

8 This is calculated as the exponent of (1 – estimated coefficient) shown in Equation 1.

FIGURE 7
FORECAST MALARIA CASES IN THE CARIBBEAN UNDER BASELINE, A2 AND B2 CLIMATE SCENARIOS 2011–2050



Source: Author's calculations based on results derived from Equation 1 and STATA -generated model output

a) Forecast malaria cases: 2011-2050

The temperature and rainfall projections under the A2 and B2 scenarios replaced the historical values and were used to predict the expected number of cases of malaria for the forecast period 2011-2050. Figure 7 indicates the predicted increases in the number of malaria cases in all countries.[9] Up to 2050, there was a marginal difference between the A2 and B2 scenarios, with a smaller number of cases forecast under A2 in the first two decades, but a larger number of cases in the latter two decades. The number of A2 and B2 malaria cases was larger than the historical baseline in all four decades, indicating the importance of considering and planning for the impact of climate change on malaria. The country-level results illustrated that changes were largely driven by what would happen in Guyana and to a lesser, but still significant, degree by occurrences in Belize (see annex 5).

b) Malaria summary

Climate variability is expected to result in more cases of malaria under A2 and B2 across the Caribbean than would have occurred under the baseline scenario. This difference is largest in the first, second and fourth decades, indicating the need for consistent vigilance against the propagating vectors and greater preventative measures to protect the potentially vulnerable populations. Direct and indirect costs should, therefore, be larger under climate change than under the baseline scenario. Adaptation strategies will need to be implemented in order to address the extent of the impact over the forecast period and beyond.

2. Dengue fever

The number of cases of dengue fever was substantially lower than the number of malaria cases during the historical period 1990 to 2005 (table 6). Aggregate Caribbean data recorded an average of

[9] The forecasts for countries, grouped by decade and disease, are presented in annex 5.

approximately 3,000 cases, with more years having a higher than average number of cases. During the historical period, there have been as few as 46 and as many as 7,641 cases. Given the expected changes in rainfall pattern, there is, however, potential for the increased occurrence in the number of cases of vector-borne diseases such as dengue fever, as well as in the associated dengue haemorrhagic fever.

TABLE 6
HISTORICAL DESCRIPTIVE STATISTICS FOR DENGUE FEVER IN THE CARIBBEAN, 1990 - 2005

Mean	3 002.5
Median	3 395
Maximum	7 641
Minimum	46
Standard deviation	2 187.147
Observations	16

Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

This is especially the case for Guyana that has particular constraints in relation to the speed and ease of runoff during periods of heavy rainfall, factors which would be likely to increase the prevalence of vectors if there were inadequate or inadequately targeted vector-control programmes.

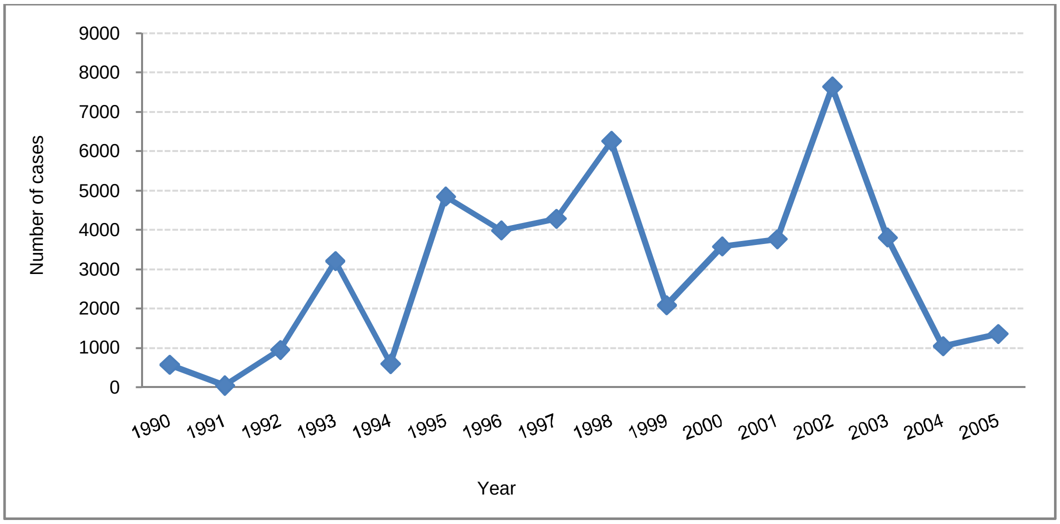
a) Model development and results

The dengue fever model estimated in the current study for the Caribbean was derived from the empirical strategy pursued by Lu and others (2009) and Fairos and others (2010). It included the human development index as a non-climatic, control variable that captured the socioeconomic status of the population, a factor that may influence the propensity of contracting dengue fever. Expectations were that, with higher levels of economic and social development, the number of dengue fever cases observed were likely to be reduced. Therefore, improvements in human development that reduced the proliferation of domestic breeding sites for the mosquito carrier would reduce the number of dengue fever cases, despite increased rainfall. Figures 8 and 9 present the historical dengue fever and climate data for the Caribbean for 1990-2005 that were used to estimate the model.

$$\text{Dengue}_{i,t} = 4.703 + 0.001\,\text{Rain}_{i,t-1} + 0.017\,\text{Time}_{i,t} - 0.17\,\text{Wind}_{i,t} + 0.249\,\text{Temperature}_{i,t} - 1.189\,\text{HDI}_{i,t} - 0.0864\,\text{Humidity}_{i,t}$$

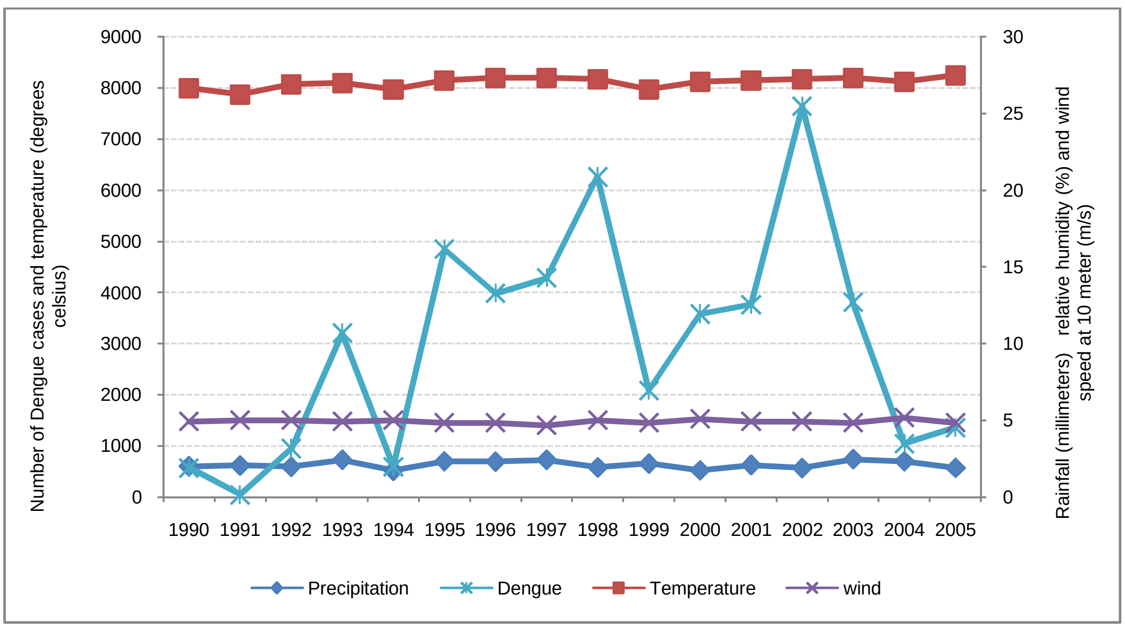
Equation (2)

FIGURE 8
AGGREGATE HISTORICAL NUMBER OF DENGUE FEVER CASES IN THE CARIBBEAN, 1990–2005



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

FIGURE 9
HISTORICAL DATA FOR THE CARIBBEAN: DENGUE FEVER, TEMPERATURE, RAINFALL, RELATIVE HUMIDITY AND WIND SPEED AT 10 METRES 1990 - 2005



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

The results of the empirical analysis, as presented in Equation (2) above (see regression output in annex 4), have confirmed the existence of a statistically-significant relationship between the annual number of dengue fever cases and several climate variables. In particular, the previous year's rainfall, the wind speed, temperature, and human development index during the current year have been shown to be significant explanatory variables of the number of dengue fever cases across the Caribbean. As with malaria, the HDI was used to proxy the socioeconomic status of the population and the likelihood of *Aedes aegypti* breeding and, therefore, the likelihood of increased numbers of dengue fever cases. Based on Equation (2), there are two additional cases of dengue fever in the following year for every additional millimetre of rainfall observed in the previous year.[10] The coefficient on the HDI variable was negative as expected reflecting the fact that higher levels of economic development may be correlated with reduced availability of mosquito-breeding locations, due to proper mechanisms of water storage, and increased vigilance ensuring the destruction of potential residential mosquito-breeding sites. Improvements in HDI reduced the number of dengue fever cases by eight. A 1° C increase in temperature increased the number of dengue fever cases by three. The time variable has been included as a control for the general trend towards increased numbers of dengue fever cases per month, as well as positive seasonality in the number of cases.

b) Forecast dengue fever cases: 2011-2050

Under the A2 and B2 scenarios, there was an increase in the number of dengue fever cases up to the third decade (2031-2040), followed by a decrease during the 2041- 2050 decade (see figure 10). There was a marginal difference between the A2 and B2 scenarios up to 2050 and, where differences existed; it was the A2 scenario that represented the smaller number of cases, except in the first decade where the number of cases under A2 was slightly larger. Baseline cases were larger than A2 and B2 cases in the middle two decades. In relation to the country-level graphs, annex 5 illustrates that changes were largely driven by what happened in Antigua and Barbuda and, to a lesser—but still significant—degree, by occurrences in the Bahamas. Cases in Saint Kitts and Nevis appeared to be relatively higher than the average number of cases for the Caribbean.

c) Dengue fever summary

Climate change, as represented by the A2 and B2 climate scenarios, is expected to result in increased occurrence of cases of dengue fever during parts of the forecast period 2011-2050, over and above the number of cases that would have occurred under the baseline in later decades. The number of cases forecast under A2 is marginally lower than the number of cases forecast under B2 over the forecast period. Adaptation strategies are required during the first decade to address the estimated surge in the number of cases under both climate change scenarios.

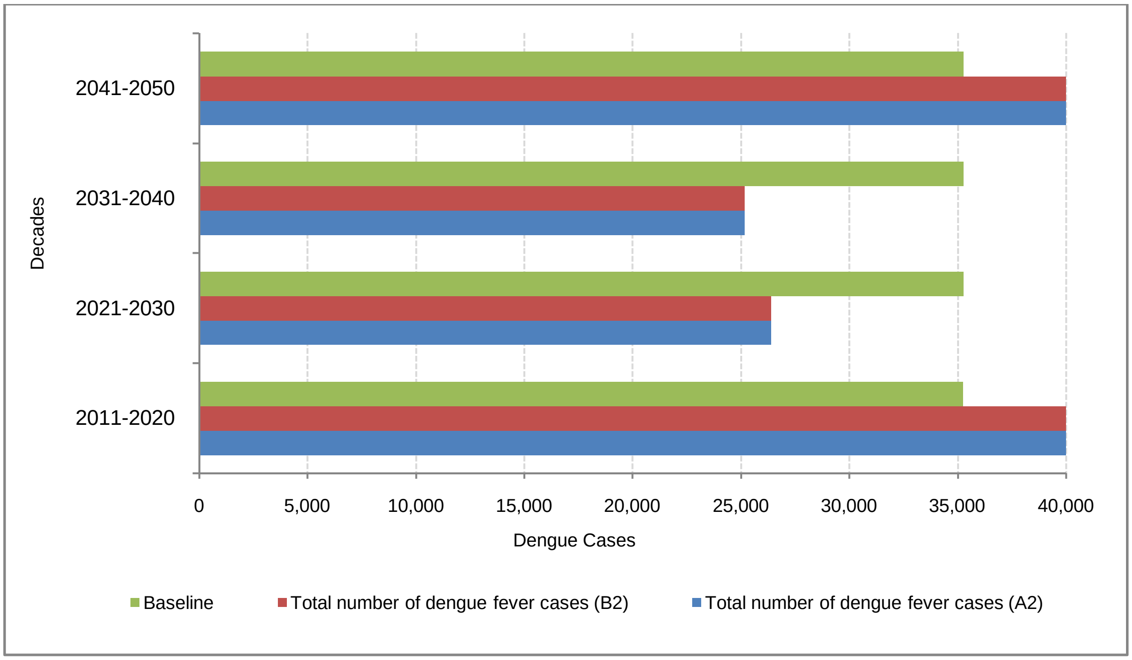
3. Leptospirosis

In endemic areas, the number of leptospirosis cases may peak during the rainy season and may even reach epidemic proportions in cases of flooding (WHO, 2007). The Pan-American Health Organization (PAHO) has stated that, due to the difficulty of diagnosing cases clinically, the number of cases of leptospirosis has been underreported, both in the Caribbean and worldwide.

Leptospirosis appears not to be as large a threat to the Caribbean as dengue fever and malaria, considering the number of cases reported between 1990 and 2005. Given the expected change in rainfall, there is, however, potential for the increased occurrence of diseases such as leptospirosis, as cooler temperatures, and the interaction with improper drinking water sources and agricultural practices may encourage, and widen, the spread of the bacteria (table 7; figure 11).

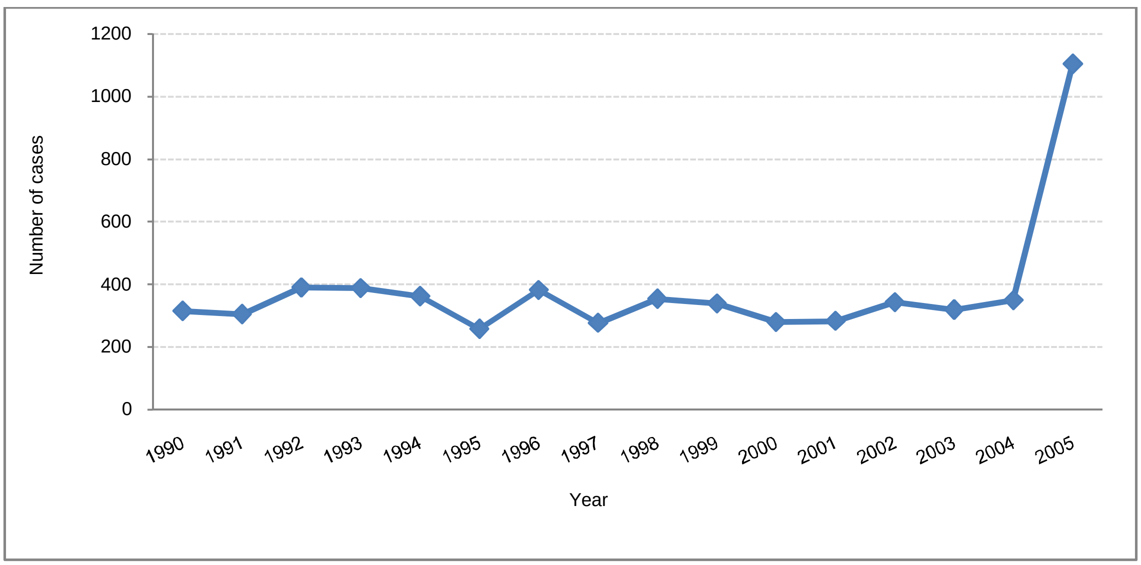
[10] This is calculated as the exponent of (1 – estimated coefficient) presented in Equation (2).

FIGURE 10
TOTAL NUMBER OF DENGUE FEVER CASES FORECAST FOR THE CARIBBEAN UNDER BASELINE, A2 AND B2 CLIMATE SCENARIOS, 2011-2050



Source: Author's calculations based on results derived from Equation 2 and STATA -generated model output

FIGURE 11
HISTORICALNUMBER OF LEPTOSPIROSIS CASES REPORTED IN THE CARIBBEAN, 1990-2005



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

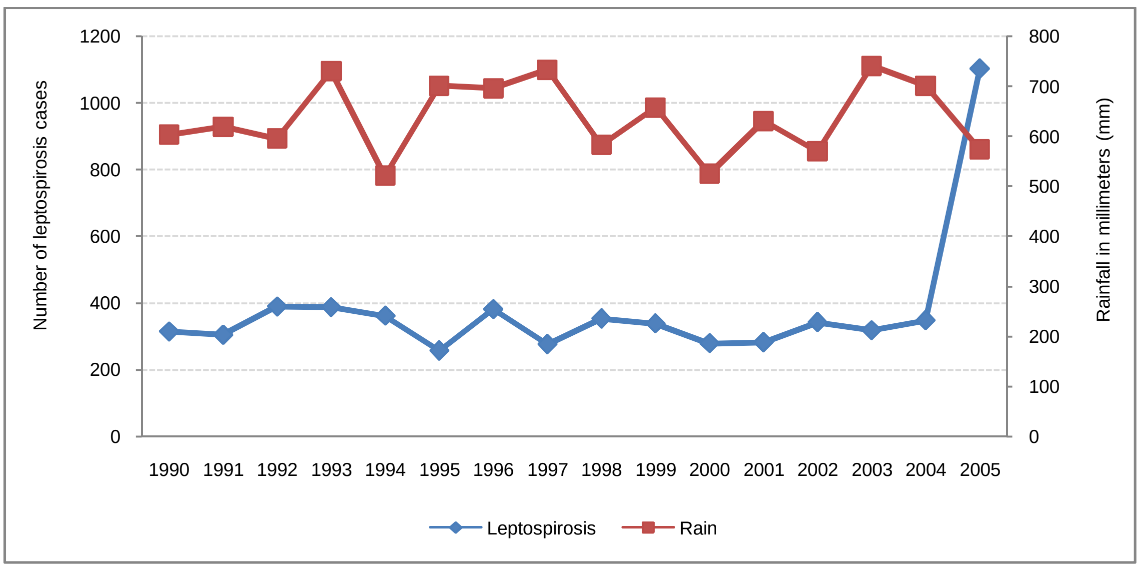
TABLE 7
DESCRIPTIVE STATISTICS OF LEPTOSPIROSIS CASES IN THE CARIBBEAN, 1990-2005

Mean	378
Median	341
Maximum	1 104
Minimum	258
Standard deviation	197.9502
Number of observations	16

Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

In developing an effective response to leptospirosis, efforts must be made to increase detection, both through early warning mechanisms generated by improved data collection, and through the introduction of health-care management protocols and practices. The Caribbean is reported to have experienced approximately 400 cases of leptospirosis between 1990 and 2005. The median number of cases is slightly lower at 350, indicating that the number of cases is typically larger than the mean number of cases. Despite the relatively lower number of leptospirosis cases relative to malaria and dengue fever, the potential severity of the cases including the potential for fatality, when cases were undetected could imply high levels of suffering and indirect costs in the Caribbean. In addition, vulnerable groups are more likely to be affected, since their communities are less likely to have proper drainage and sewage and, therefore, a higher risk of obtaining drinking water from contaminated sources (figure 12).

FIGURE 12
HISTORICAL CASES OF LEPTOSPIROSIS AND RAINFALL LEVELS IN THE CARIBBEAN, 1990-2005



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

a) Model formulation

Using weekly data, Carvalho and others (2007) found that temperature was not an important variable in explaining the number of incidences of leptospirosis. Humidity impacted the number of leptospirosis cases with a two-week lag, whereas total rainfall exhibited a nonlinear impact on the number of incidences, which the authors argued to be preliminary evidence of a threshold effect. They reported their best model as containing the number of days with more than 5 millimetres of rainfall per day and a structured time trend. This model was not consistent with the experiences of Caribbean countries. The model developed for the current project used the Carvalho approach as its point of departure. The final model is presented below as Equation (3) and excludes both temperature and humidity, as these variables did not improve the performance of the model in terms of the log likelihood, and were not individually significant at conventional levels.

$$\text{Leptospirosis} = -1.355 - 0.003\text{Rain}_{t-1} + 0.016\,\text{Time}_{t-1} + 3.193\,\text{Sanitation} + 0.004\text{Rain} * \text{Sanitation}$$

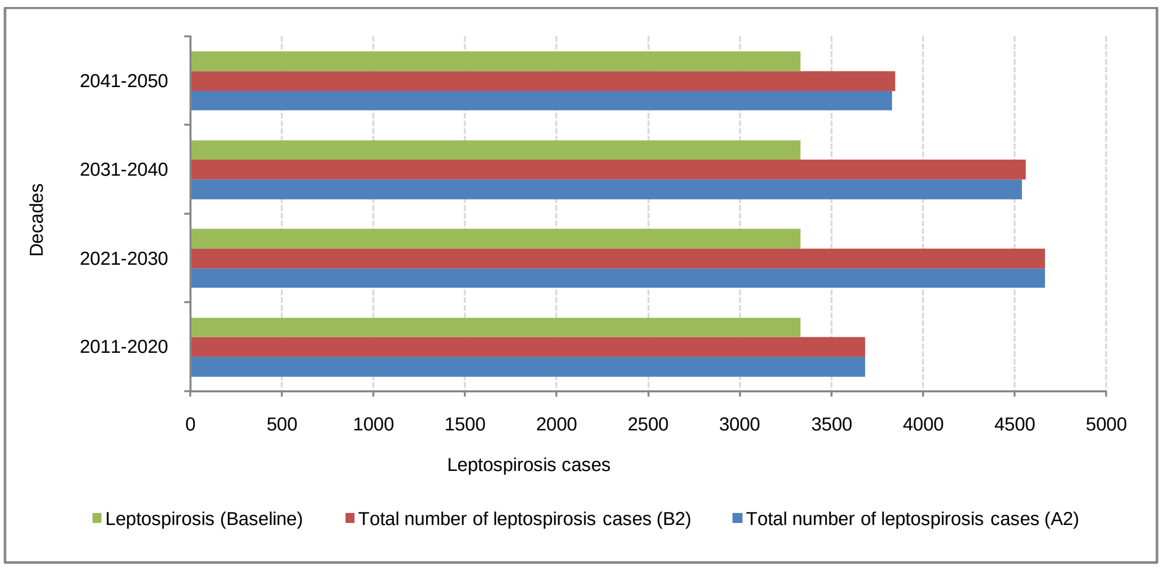
Equation (3)

The model included precipitation, sanitation and an interaction between the two variables' coefficients that indicated that increases in rainfall in the previous year reduced the number of leptospirosis cases by 2.7 cases, whereas improvements in sanitation increased the number of cases by 0.11 cases.

b) Forecasting leptospirosis cases: 2011-2050

The results have been presented in terms of forecasts of leptospirosis cases for the Caribbean by decade (see figure 13). The forecasts for countries grouped by decade, and the forecasts for each of the decades grouped by countries, are presented in annex 5.

FIGURE 13
NUMBER OF LEPTOSPIROSIS CASES IN THE CARIBBEAN BY DECADE UNDER BASELINE, A2 AND B2 CLIMATE SCENARIOS 2011-2050



Source: Author's calculations based on results derived from Equation 3 and STATA -generated model output

Figure 13 indicates an increase in the number of leptospirosis cases from the first to second decades under both A2 and B2 scenarios compared to the baseline, subsequent to which the number of cases declines slightly but not below the level of the first decade. In the second half of the forecast period, 2031-2050, the number of cases forecast under B2 exceeds the number of cases forecast under A2. In every instance, the number of cases under the baseline is lower than the number of cases under the climate scenarios for A2 and B2 from 2011-2050, confirming the importance of monitoring leptospirosis cases in the context of climate change. In relation to the country-level outcomes, changes in the number of leptospirosis cases were largely driven by the number of cases expected in Jamaica and Trinidad and Tobago, particularly during the second and third decades. The number of cases forecast for Guyana was somewhat greater than that of the other countries.

c) Leptospirosis summary

The number of leptospirosis cases is expected to be at its highest in the Caribbean during the middle decade of the forecast period 2011-2050, due to climate impacts in Jamaica and Trinidad and Tobago. The number of leptospirosis cases is expected to be higher than the forecasts based on historical trends, indicating the need to increase the capacity of national health authorities to prevent higher mortality rates, through the implementation of more intense, more efficient policies and programmes to detect and treat cases quickly.

4. Gastroenteritis

Gastroenteritis in the population under age five, a relatively important health consideration in the Caribbean, is broadly associated with polluted drinking water. The annual number of cases in the population under age five between 1990 and 2005 ranged from an annual minimum of 15,958 cases to a maximum of 37,545 cases, with a mean occurrence of 24,109 cases per annum. Gastroenteritis has also been a health concern in the population over age five, with a mean annual of 14,692 cases, and a maximum of 29,089 cases (table 8). Given the expected changes in rainfall patterns, there is, however, potential for the increased occurrence of cases during the relatively cooler times over the forecast period 2011 to 2050, given existing conditions in sanitation, drinking water and land use.

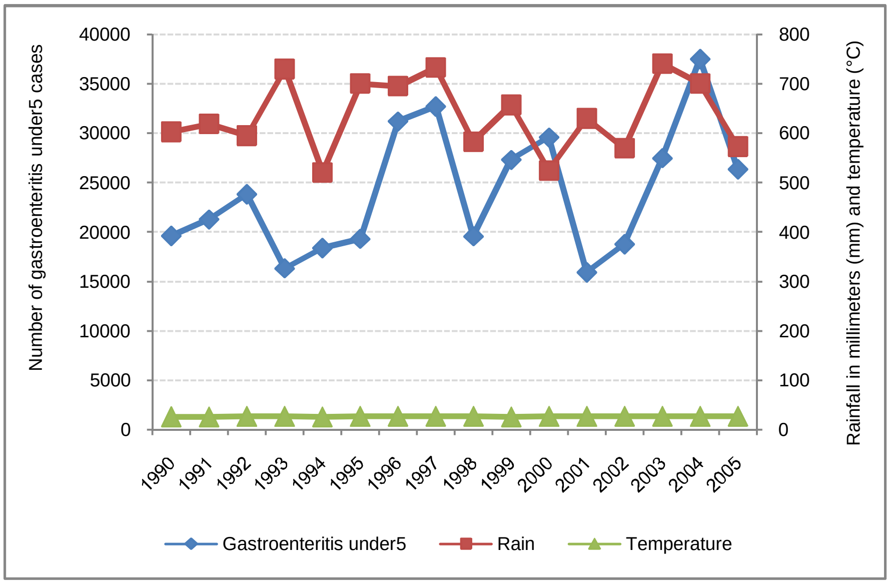
TABLE 8
HISTORICAL DESCRIPTIVE STATISTICS ON ANNUAL NUMBER OF CASES OF GASTROENTERITIS IN CHILDREN UNDER AGE FIVE AND IN THE POPULATION OVER AGE FIVE IN THE CARIBBEAN, 1990-2005

	Annual number of cases of gastroenteritis in children under age five	Annual number of cases of gastroenteritis in the population over age five
Mean	24 109.5	13 814.47
Median	22 584.5	14 692.5
Maximum	37 545	29 089
Minimum	15 958	0
Std. Dev.	6 437.657	9 942.581
Obs.	16	16

Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

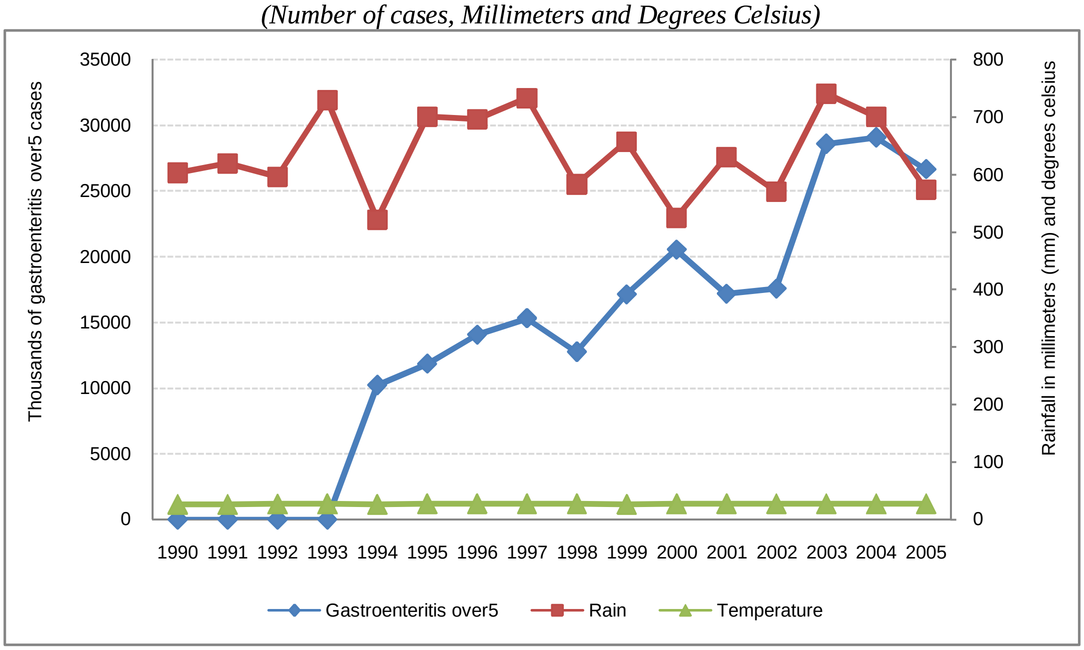
Figure 14 shows a relatively strong correlation between the number of gastroenteritis cases in the population under age five and precipitation; however, there is no visible sign of a relationship between the number of gastroenteritis cases in the population under age five and temperature, possibly due to the scale on the axes. The relationship between the number of gastroenteritis cases in the population over age five and precipitation only becomes apparent after 1998 (figure 15).

FIGURE 14
NUMBER OF CASES OF GASTROENTERITIS IN CHILDREN UNDER AGE FIVE, RAINFALL AND TEMPERATURE IN THE CARIBBEAN, 1990-2005
(Number of cases, Millimeters and Degrees Celsius)



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

FIGURE 15
HISTORICALNUMBER OF CASES OF GASTROENTERITIS IN THE CARIBBEAN IN THE POPULATION OVER AGE FIVE, RAINFALL AND TEMPERATURE 1990-2005
(Number of cases, Millimeters and Degrees Celsius)



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

a) Model development: number of gastroenteritis cases in children under age five

Equation (4) below presents the statistical model for gastroenteritis cases in the population of children under age five (see annex 4 for the complete model output).

$$\text{Gastroenteritis under 5 years} = 4.045 + 0.084\ \text{Temp}_{i,t} + 0.001\ \text{Rain}_{i,t} + 0.008\ \text{Time}_{i,t} - 0.621\ \text{Sanitation}_{i,t}$$

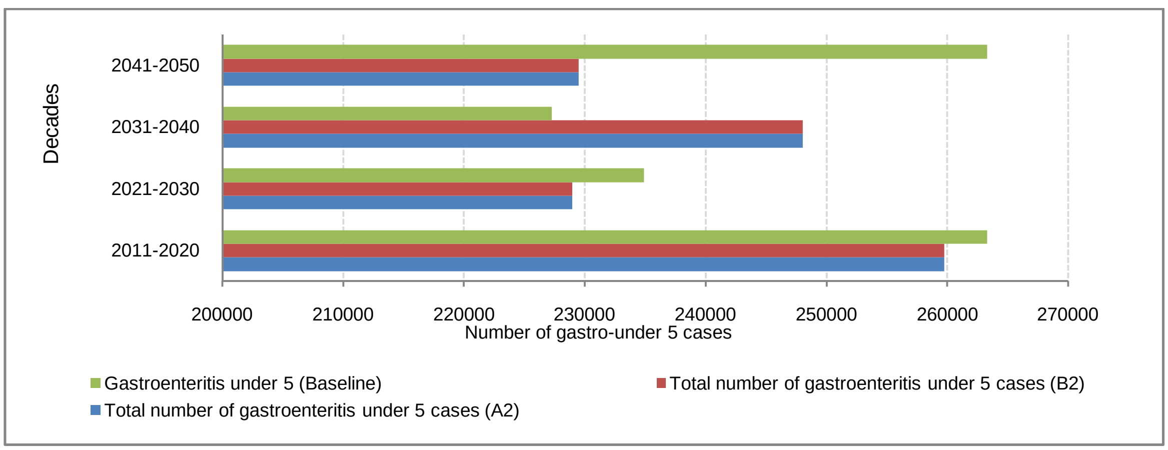
Equation (4)

For the population under age five, increases in temperature and increases in rainfall were each forecast to increase the number of cases by two cases per annum, respectively, confirming the relevance of both climate variables in the analysis. Improvements in sanitation were found to reduce the number of cases of gastroenteritis in this population group by five cases. These results were consistent with expectations, as children in this age group were likely to be more susceptible to gastroenteritis-related infections as they made up a larger proportion of the poorer population cohort in the Caribbean that was more likely to have less reliable access to pure drinking water.

b) Forecasting the number of cases of gastroenteritis in children under age five, 2011–2050

The results are presented in terms of forecasts for the Caribbean by decade (see figure 16). The figure indicates a large number of gastroenteritis cases in this sub-population up in the first decades of the forecast period. The projections under the baseline scenario are higher during the first, second and fourth decades, indicating a potential benefit from climate change in terms of the number of gastroenteritis cases in the population under age five that are observed. The number of cases forecast under A2 was relatively larger (by one case) than the number of cases forecast under B2 for three of the four decades, except in the decade 2031-2040, in which there was an equal number of cases forecast under A2 and B2. In addition, the number of cases in the third decade is considerably higher than under the baseline scenario.

FIGURE 16
FORECAST NUMBER OF CASES OF GASTROENTERITIS IN CHILDREN UNDER AGE FIVE FOR THE CARIBBEAN UNDER BASELINE, A2 AND B2 CLIMATE SCENARIOS 2011-2050



Source: Author’s calculations based on results derived from Equation 4 and STATA -generated model output

Warmer temperatures are forecast to result in a relatively lower number of gastroenteritis cases in this population sub-group during the first, second and fourth decades under both climate change scenarios (A2 and B2) in comparison to the predicted number of cases under the baseline scenario. This is consistent with the observations of gastroenteritis data, primarily in the cooler periods of the year. The changes in the number of cases of gastroenteritis in the population under age five were forecast to be largely driven by the number of cases expected in Jamaica, Guyana, and Antigua and Barbuda.

c) Model development: gastroenteritis in the population over age five

There was a small interaction between temperature and rainfall which helped to explain the susceptibility of the population over age five to contracting gastroenteritis. Increases in precipitation and temperature were forecast to reduce the number of gastroenteritis cases by six, while the interaction term between the two variables increased the number of cases by three (see equation 5). Despite the WHO findings that sanitation is a significant explanatory variable, it was excluded from the model, as it did not prove to be a statistically significant variable due to inadequate data points as well as the lack of disaggregated data.[11]

$$\text{Gastroenteritis over 5 years} = 16.48 - 0.460\ \text{Temp}_{i,t} - 0.022\ \text{Rain}_{i,t} + 0.001\ \text{Temp}_{i,t} * \text{Rain}_{i,t}$$

Equation (5)

d) Forecasting the number of gastroenteritis cases in the population over age five in the Caribbean: 2011-2050

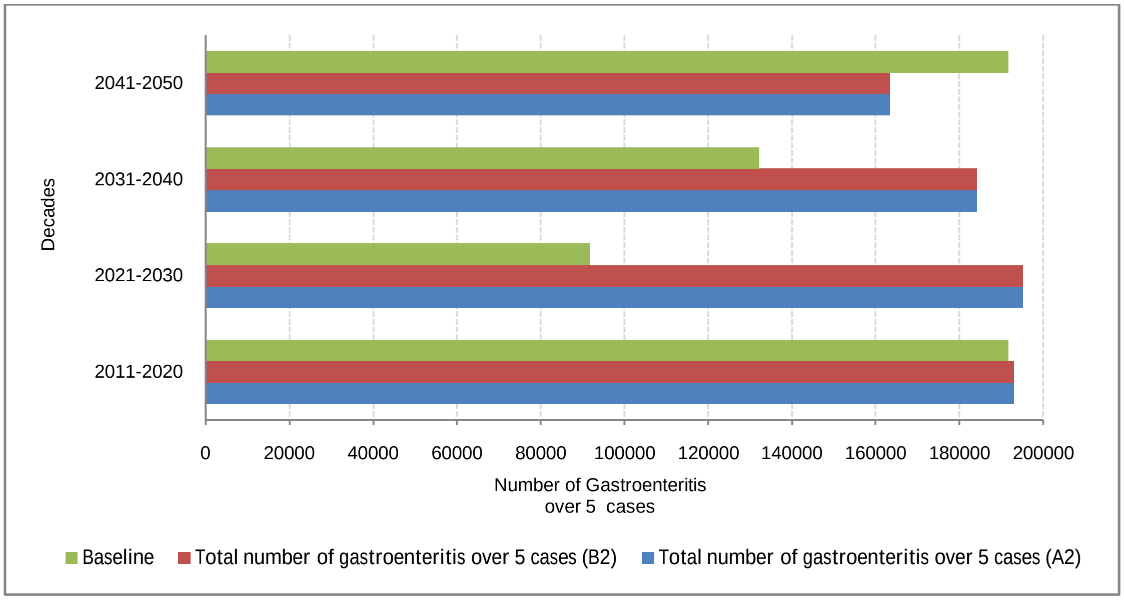
Figure 17 indicates that the number of gastroenteritis cases was forecast to be slightly higher in the sub-population over age five, after which the number of cases decreased by a total of 30,000 by the year 2050. The number of cases forecast under A2 was relatively larger than the number of cases forecast under B2 for all four decades from 2011 to 2050. In every decade except the last, the forecast number of A2 and B2 cases exceeded the forecast number of baseline scenario cases. This implies the need for policy and programmatic responses over the forecast period. Changes in the number of cases of gastroenteritis in the population over age five were largely driven by the number of cases forecast for Jamaica, followed by Guyana.

e) Gastroenteritis summary

The results have indicated that climate change has significantly different impacts on the number of gastroenteritis cases in the populations under age five and over age five. The number of cases of gastroenteritis was lower in the population under age five in the event of either the A2 or B2 scenarios in comparison to the baseline scenario in the middle of the forecast period. Public health officials and policymakers may, therefore, need to segment their policy and programmatic responses to adapt to these differential expectations. Whereas the number of forecast cases was greater under the A2 and B2 scenarios than under the baseline, the difference was larger in the population over age five during the middle two decades. The implications are significant in terms of the differential allocation of resources required to address the forecast number of cases. The costs, both direct and indirect, are presented in the next section.

[11] Inclusion of sanitation in the model reduced the log-likelihood of the model.

FIGURE 17
FORECAST NUMBER OF GASTROENTERITIS CASES IN THE POPULATION OVER AGE FIVE FOR THE CARIBBEAN UNDER BASELINE, A2 AND B2 CLIMATE SCENARIOS 2011-2050



Source: Author's calculations based on results derived from Equation 5 and STATA -generated model output

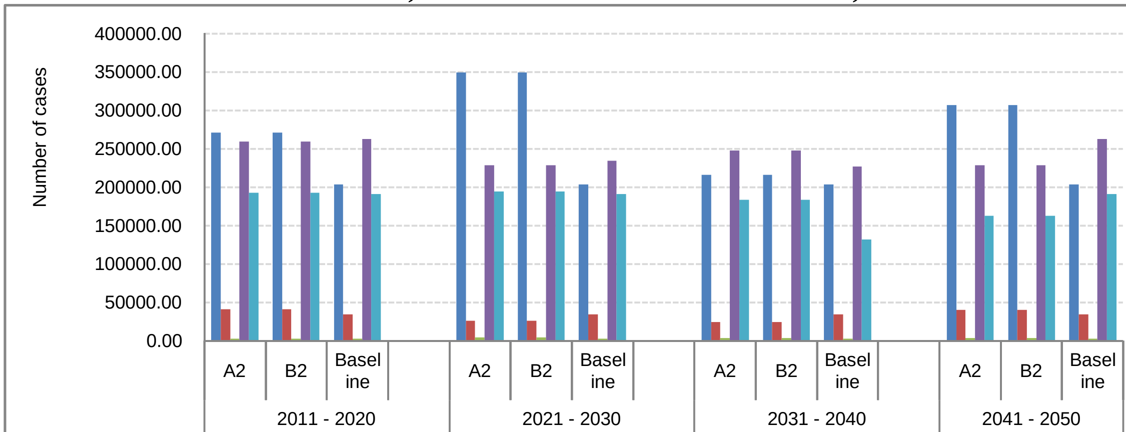
5. Health sector forecast summary

The empirical analysis presented in this section has been successful in identifying the disease-specific impacts of climate change on the Caribbean. More importantly, the results have indicated variations in this impact over the course of the forecast period and across the diseases considered. Specifically, the forecast number of both malaria and leptospirosis cases under climate change scenarios A2 and B2 will exceed the number of cases under the baseline scenario, whereas there was forecast to be a predominance of cases of dengue fever during the first and fourth decades, gastroenteritis in the population over age five in the third decade, and gastroenteritis in children under age five in the first to third decades, respectively.

IV. Estimating the direct and indirect costs of climate change to the health sector in the Caribbean

In the present section, decadal disease forecasts for the Caribbean (figure 18) have been used to estimate treatment and prevention costs, which are the direct costs associated with treating, or preventing, the number of forecast cases. These costs are not comprehensive, as the cost of the practical, technical and managerial resources that would be required to facilitate treatment, or prevention, have not been included.

FIGURE 18
FORECAST NUMBER OF THE FOUR SELECTED DISEASE CASES FOR THE CARIBBEAN UNDER BASELINE, A2 AND B2 CLIMATE SCENARIOS, 2011-2050



	2011 - 2020			2021 - 2030			2031 - 2040			2041 - 2050		
	A2	B2	Baseline	A2	B2	Baseline	A2	B2	Baseline	A2	B2	Baseline
Malaria	2713	2713	2043	3501	3501	2042	2165	2164	2042	3077	3076	2042
Dengue	4150	4151	3524	2638	2638	3525	2516	2516	3525	4053	4054	3525
Leptospirosis	3685	3684	3330	4666	4666	3330	4537	4559	3330	3830	3847	3330
Gastro Under 5	2597	2597	2632	2289	2289	2348	2480	2480	2272	2294	2294	2632
Gastro Over 5	1929	1929	1915	1951	1951	1915	1841	1841	1322	1633	1633	1915

Source: Author’s compilation of figures 7, 10, 13, 16 and 17

The indirect costs, the estimated productivity losses, associated with the forecast cases were calculated based on the approach of Markandya and Chiabai (2009), by estimating the number of lost working days associated with one case of each disease, and multiplying that figure by the per capita gross domestic product of each country divided by 365 days, and then aggregated for all Caribbean countries. This yielded the forecast total direct cost to the Caribbean health sector in the four decades between 2011 and 2050. The productivity losses associated with the forecast cases were also estimated for the period 2011 to 2050 using lost gross domestic product (GDP), lost days, and number of cases. All the direct costs and productivity losses were discounted using rates of 1 per cent, 2 per cent and 4 per cent to provide comparable present value estimates (see annex 6 for the results of the 1 per cent and 2 per cent discounting).

A. Prevention versus treatment costs

The estimated treatment and/or prevention costs for each disease are presented in this sub-section using the average cost of treatment reported by Caribbean countries for each disease (see table 10). Where information was available, the estimated prevention costs were calculated based on the cost of preventive measures, such as impregnated bed nets (malaria and dengue fever) or vaccines (malaria and rotavirus (gastroenteritis)), in order to provide a comparative policy option for decision-makers (table 9). The malaria vaccine is still being developed and, therefore, the costs estimated and presented below are merely indicative.

TABLE 9
DATA ON DRUGS AND COST OF TREATING AND PREVENTING DISEASES IN THE CARIBBEAN
(United States dollars)

Disease	Treatment options	Treatment costs	Prevention options	Prevention costs
Malaria	Chloroquine	US$ 0.111	Impregnated bed nets	US$ 3
	Mefloquine		Vaccine	US$ 60
	Quinine			
	Doxycycline	US$ 0.18 per 100mg		
Dengue fever/dengue haemorrhagic fever	Rehydration fluids/salt (Dextrose)	US$ 1.84/50%	Impregnated bed nets	
	Acetaminophen for high fever			
	Paracetamol	US$ 0.37/240mg		
Gastroenteritis	Bactrim	US$ 3.16/240mg	Rotavirus vaccine	US$ 7.50
	Ciprofloxacin	US$ 0.26/250mg	Implementation of potable drinking water supply sources	
	Ampicillin	US$ 4.19/250mg		
Leptospirosis	Ampicillin	US$ 4.19/250mg	Implementation of proper sanitation systems	

Source: United Nations Economic Commission for Latin America and the Caribbean (ECLAC), based on official data

1. Methodology used to calculate the direct costs associated with malaria

Cost of using a vaccine to prevent malaria
= Cost of vaccine * Number of estimated malaria cases
= US$ 60 * Number of estimated malaria cases

Cost of using impregnated bed nets to prevent malaria
= Cost of impregnated bed nets * Number of estimated malaria cases
= US$ 3 * Number of estimated malaria cases

Cost of using Chloroquine to treat malaria
= Cost of Chloroquine * Number of estimated malaria cases
= US$ 0.111 * Number of estimated malaria cases

2. Methodology used to calculate the direct costs associated with dengue fever

Cost of treating dengue fever
= Unit treatment costs * Number of estimated dengue fever cases
= US$ 2.21 * Number of estimated dengue fever cases

3. Methodology used to calculate the direct costs associated with leptospirosis

Cost of treating leptospirosis
= Unit treatment costs * Number of estimated leptospirosis cases
= US$ 11.73 * Number of estimated leptospirosis cases

4. Methodology used to calculate the direct costs associated with gastroenteritis in children under age 5 and in population over age 5

Cost of using a rota-vaccine to prevent gastroenteritis
= Cost of vaccine * Number of estimated gastroenteritis cases
= US$ 7.50 * Number of estimated gastroenteritis cases

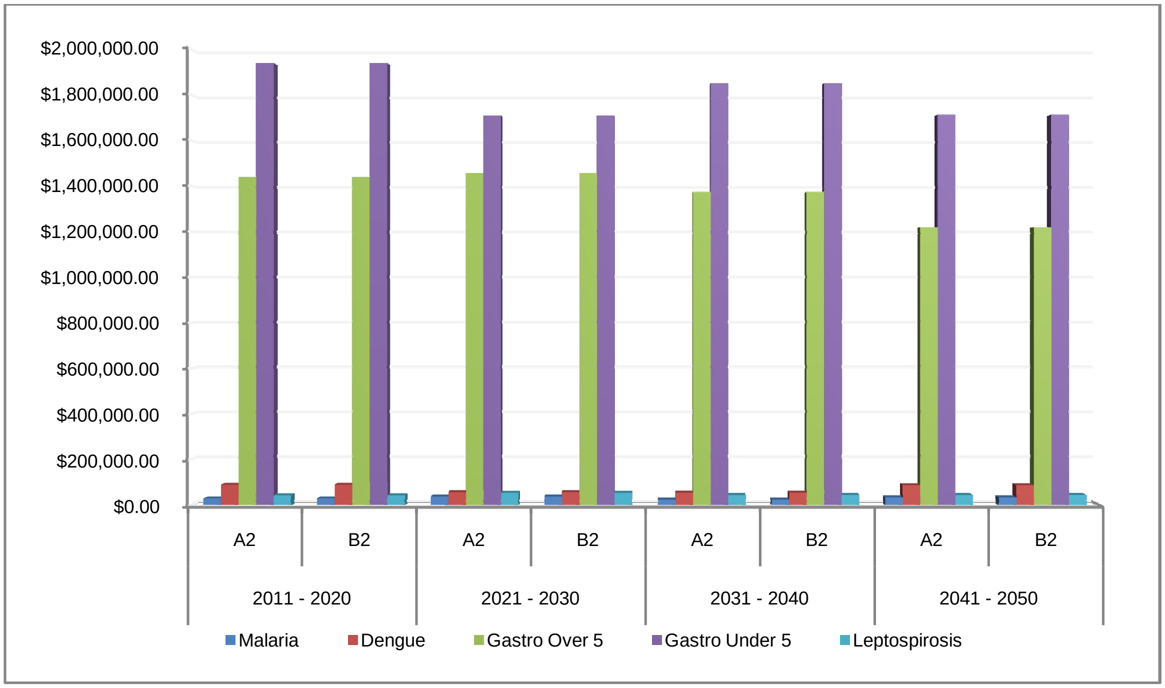
Cost of treating gastroenteritis
= Unit treatment costs * Number of estimated gastroenteritis cases
= US$ 7.61 * Number of estimated gastroenteritis cases

5. Direct cost of disease treatment and prevention 2011-2050

Treatment costs between 2011 and 2050 were projected to range from a low of US$ 17,851 for dengue fever under the B2 scenario (2011-2050) to a high of US$ 1.94 million for treating gastroenteritis in the population under age five under B2 during the same period. The low treatment costs of dengue fever were driven by the comparatively lower per-unit treatment costs and the low number of cases forecast during the first decade, whereas the associated per-unit treatment costs for gastroenteritis were higher.

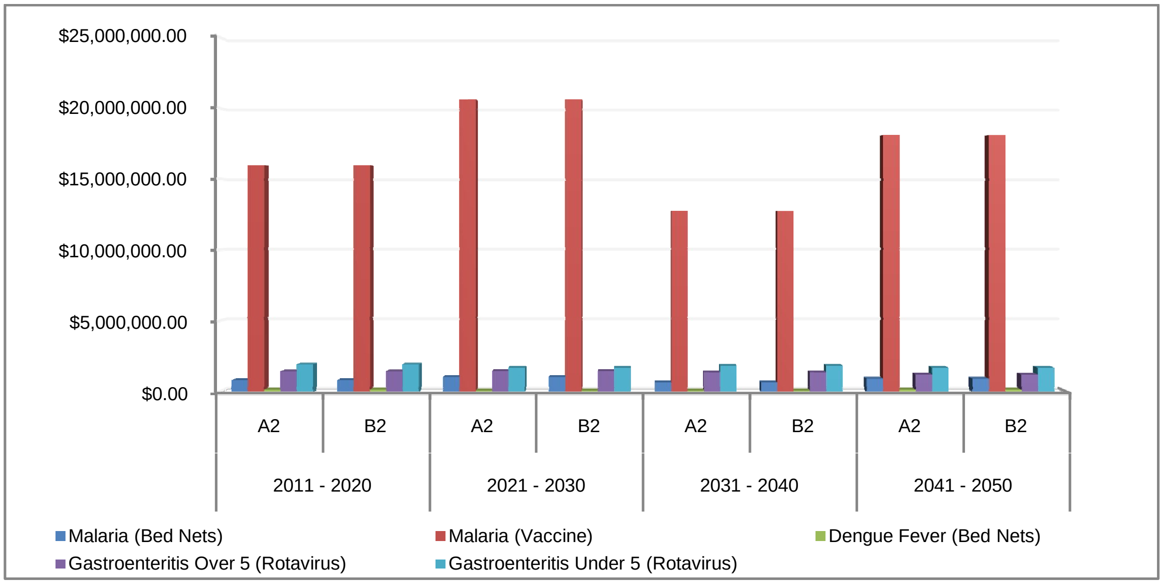
Figure 19 indicates that treatment costs were slightly higher under the B2 scenario over the entire forecast period 2011 to 2050. Additionally, the cost of gastroenteritis treatment declined over time as the number of gastroenteritis cases declined under A2 and B2 over the forecast period. The treatment costs for malaria, dengue fever and leptospirosis increased over the forecast period, consistent with the general increase in the forecast number of cases of each disease. The unit costs associated with treating malaria were lowest among the four diseases (figure 20). Based on these results, malaria would appear to be the least of the disease threats facing the Caribbean. However, the costs exclude the cost of human suffering, as well as the productivity losses associated with the number of cases.

FIGURE 19
NET PRESENT VALUE OF DISEASE TREATMENT COSTS FORECAST FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS (DISCOUNTED AT 2%), 2011–2050
(United States dollars)



Source: Author's calculation based on methodology and formulae above (sub-section A)

FIGURE 20
NET PRESENT VALUE OF DISEASE PREVENTION COSTS FORECAST FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS (DISCOUNTED AT 2%), 2011 – 2050
(United States dollars)



Source: Author's calculation based on methodology and formulae above (sub-section A)

The calculations with respect to preventing, as opposed to treating, the anticipated number of cases, have indicated that the situation presented in figure 19 would be reversed, and the costs associated with preventing malaria would stand out in comparison to the cost of preventing dengue fever or gastroenteritis, due to the anticipated cost of the malaria vaccine at US$ 60 per vaccine. Impregnated bed nets, therefore, would represent a more cost-effective preventive tool for malaria. In terms of the A2 and B2 scenarios, prevention costs appear to be similar regardless of climate scenario.

B. Productivity losses

Productivity losses, which were calculated by pro-rating Caribbean gross domestic product per capita per annum by the number of lost production days associated with each disease, are presented by decades in the figures below.

1. Methodology used to calculate the indirect costs associated with malaria

Productivity losses due to malaria
= Days lost * Number of estimated malaria cases * Discount rate * GDP per capita in 2007 United States dollars
= 10 * Number of estimated malaria cases * Discount rate * GDP per capita divided by 365 days.

2. Methodology used to calculate the indirect costs associated with dengue fever

Productivity losses due to dengue fever
= Days lost * Number of estimated dengue fever cases * Discount rate * GDP per capita in 2007 United States dollars
= 5 * Number of estimated dengue fever cases * Discount rate * GDP per capita in 2008 United States dollars divided by 365

3. Methodology used to calculate the indirect costs associated with leptospirosis

Productivity losses due to leptospirosis
= Days lost * Number of estimated leptospirosis cases * Discount rate * per person productivity cost
= 5.25 * Number of estimated leptospirosis cases * Discount rate

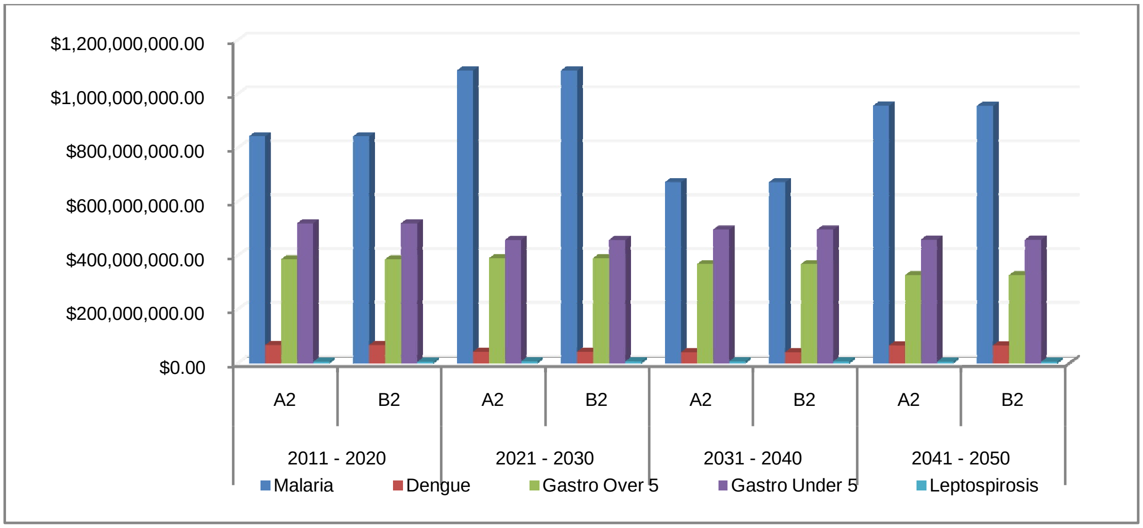
4. Methodology used to calculate the indirect costs associated with gastroenteritis

Productivity losses due to gastroenteritis
= Days lost * Number of estimated gastroenteritis cases * Discount rate * GDP per capita in 2008 United States dollars
= 6.44 * Number of estimated gastroenteritis cases * Discount rate * GDP per capita in 2008 United States dollars divided by 365

5. Results of productivity loss estimations 2011–2050

The results indicate the importance of considering the indirect costs associated with the impact of climate change on the health sector. In particular, the results have indicated that forecast productivity losses were larger under B2 than under A2 for all four diseases in all four decades (see figure 21). Losses reflected the pattern in the number of cases during the period and the length of the lost production time while the patient recovered. Losses for malaria were largest in the second decade 2021-2030 due to the forecast increase in the number of cases during that period and, therefore, the increases in lost production time and value to the Caribbean. Productivity losses forecast for cases of gastroenteritis in children under age five were slightly larger, than in the population over age five. The policy decision in relative allocation of resources between prevention and treatment options would determine the estimated indirect costs of treatment and prevention in terms of productivity losses.

FIGURE 21
FORECAST PRODUCTIVITY LOSSES IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS (DISCOUNTED AT 2%) FOR 2011–2050
(United States dollars)



Source: Author's calculation based on methodology and formulae above (sub-section B)

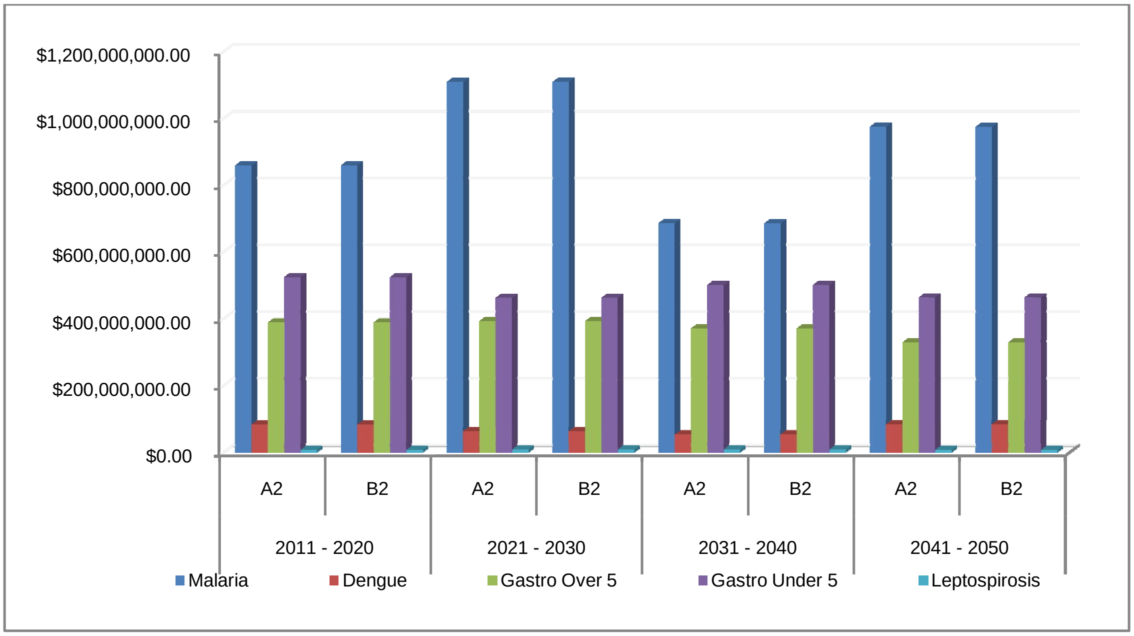
C. Estimation of total (direct + indirect) costs of climate change to the health sector in the Caribbean

The total costs associated with the forecast number of cases of each disease for 2011-2050 for the Caribbean have been presented in figure 22. The costs represent the sum of the direct and indirect health-sector costs presented in the previous two subsections. The malaria costs were driven up by the cost of prevention (prospective vaccine at US$ 60 per unit) and productivity losses. The total costs of gastroenteritis in the population under age five and populations over age five were the second and third highest costs.

These results highlight the importance of taking into account both the direct and indirect costs in estimating the impact of climate change. Malaria, in particular, has relatively low direct treatment costs. Treating the number of observed cases might not be considered a major fiscal burden. However, the cost of prevention, and the productivity losses, actually made malaria the disease with the highest impact under climate change of the four diseases considered and modelled in the present report.

The indirect costs associated with climate change impacts on health must be considered before determining the scope and scale of response efforts. Both collective and individual, country-based decisions would be needed to determine the ideal relative balance between prevention and treatment. The following section presents a cost-benefit analysis of possible adaptation mechanisms.

FIGURE 22
TOTAL DIRECT AND INDIRECT COSTS OF CLIMATE CHANGE TO THE HEALTH SECTOR IN THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS (DISCOUNTED AT 2%), 2011 – 2050



Source: Author’s summation of costs presented in figures 19, 20 and 21

V. Cost-benefit analysis of health sector climate change adaptation strategies

Given the total economic cost of climate change to health in the Caribbean, it is important to consider policies that might address these diseases in order to minimize their potential impact and increase population resilience, where possible, based on the costs and benefits associated with each policy option. Such measures include adaptation programmes that would ensure that the population was appropriately prepared for the potential impacts of climate change on their livelihoods and lifestyles. Adaptation has been defined as "the policies, practices, and projects with the effect of moderating damages and/or realizing opportunities associated with climate change and, in particular, in relation to the issues in human health that would include any measures implemented now and over the medium-term to reduce the potential negative health impacts of climate change" (IPCC, 2007).

Such changes would require improvements to institutional capacity to enable their implementation. In addition, regular, widespread messages must be transmitted to the population in order to increase awareness and build individual and community resilience.

Estimating the cost of adaptation presents a challenge, given the wide variety of methods and the intangible nature of some potential adaptation measures. In addition, the impacts of climate change on health in the Caribbean may evolve over time and, thereby, elucidate the channels and refine the adaptation methods and measures that have been most effective. Population dynamics, increased resilience, geographical movement of diseases, and the development of more cost-effective vaccines and other preventive mechanisms may alter the number of forecast cases, as well as the direct and indirect costs associated with adaptation.

The present section offers a comparative analysis of potential adaptation strategies that can be implemented by health authorities in 10 per cent and 50 per cent of the population in the Caribbean, in attempts to reduce the number of forecast cases for each disease. For malaria and dengue fever, once the number of forecasted cases has been adjusted downwards, the total cost of the adaptation is calculated based on the number of persons to be treated and the per person unit cost of the intervention. For gastroenteritis and leptospirosis the adaptation mechanism is applied at the household level. The number of households is calculated by taking the total Caribbean population and dividing it by the average number of persons per household. Similar to malaria and dengue, the adaptation costs are compared with the averted costs of each disease.

Two benefits have been calculated for each intervention, in the form of:

a) the value of the treatment costs that have been averted as a result of the reduced number of cases; and

b) the value of the productivity losses that have been averted as a result of the reduced number of cases.

These two benefits have been summed to provide an estimate of the total benefits of the intervention being considered, information on which policies can be based.

The results have provided an estimate of the costs and benefits associated with implementing these adaptation measures addressing the additional disease cases of malaria, dengue fever, leptospirosis and gastroenteritis forecast under climate change in the previous section between 2011 and 2050.

A. Malaria

The previous section presented the direct and indirect costs of prevention and treatment options, indicating that there were two adaptation options for malaria: the provision of impregnated bed nets and the implementation of a spraying regime aimed at reducing the prevalence of mosquitoes able to transmit disease to the population. Ultimately, these methods would reduce the number of forecast cases and the associated treatment, prevention and productivity costs that have been presented above.

The current section presents the impact of these two interventions on the number of cases, as well as the averted treatment costs. The impact estimates were sourced from the health economics literature, such as Graves and others (2008), who estimated that the use of insecticide-treated bed nets reduced the cases of malaria by 12 per cent in Eritrea. Assuming a similar level of treatment efficacy, table 10 presents the impact on treatment costs if the treated bed nets were offered to 10 per cent and 50 per cent of the 2010 population in the Caribbean under the A2 and B2 climate change scenarios, from 2011 to 2050.

The rate at which malaria affected the 2010 population was calculated for each intervention, to derive the number of cases that would exist without the treated bed-net or spraying intervention. That number was reduced by 12 per cent (under the treated bed-net intervention) or 35 per cent (under the spraying programme) to determine the number of cases that could be expected in the same 10 per cent of the population after the implementation of the treated bed-net and spraying programmes. The averted treatment costs were calculated as the difference between the number of cases after the intervention (treated bed nets or spraying) and the number of cases that would have been observed without the intervention. That difference was multiplied by the per-person cost of anti-malarial medicines, of US$ 0.111 per person.[12] If 10 per cent of the population were provided with impregnated bed nets, treatment costs of US$ 324 would be averted under the A2 scenario, whereas US$ 351 would be averted under the B2 scenario for the period 2011–2020 (see table 10).

The averted productivity losses were calculated as the difference between the number of cases with, and without, the intervention, multiplied by the number of days lost to malaria (10 days) and the GDP per capita divided by 365. The productivity losses are presented in the second panel in table 10. The table indicates that the averted productivity losses per decade would be highest under A2 at US$ 5,737,517 in the third decade (2031–2040), followed by under B2 at US$ 11,950,590 in the second decade (2021–2030).

[12] These are the same per person malaria treatment costs used in calculating direct treatment costs.

TABLE 10
COST BENEFIT ANALYSIS OF IMPLEMENTING MALARIA ADAPTATION STRATEGIES IN 10% AND 50% OF THE CARIBBEAN POPULATION, UNDER A2 AND B2 CLIMATE SCENARIOS, 2011–2050

		Averted treatment costs under A2	Averted treatment costs under B2	Averted production losses under A2	Averted production losses under B2	Total benefits under A2	Total benefits under B2
ADAPTATION STRATEGY: IMPREGNATED BED NETS							
10% of population	Total cost of providing treated bed nets = $ 10 768 192			Payback period: A2 = 2 years		B2 = 2 years	
	2011 - 2020	324	351	9 262 974	10 008 140	9 263 299	10 008 490
	2021 - 2030	367	419	10 470 440	11 950 590	10 470 807	11 951 008
	2031 - 2040	201	247	5 737 517	7 051 348	5 737 718	7 051 595
	2041 - 2050	253	335	7 223 313	9 565 959	7 223 566	9 566 294
50% of population	Total cost of providing treated bed nets = $ 53 840 961			Payback period: A2 = 2 years		B2 = 2 years	
	2011 - 2020	1 622	1 753	46 314 870	50 040 698	46 316 493	50 042 451
	2021 - 2030	1 834	2 093	52 352 201	59 752 948	52 354 035	59 755 041
	2031 - 2040	1 005	1 235	28 687 585	35 256 738	28 688 590	35 257 973
	2041 - 2050	1 265	1 675	36 116 566	47 829 793	36 117 831	47 831 469
ADAPTATION STRATEGY: SPRAYING PROGRAMME							
10% of population	Total cost of providing spraying programme = $ 1 292 183			Payback period: A2 = 2 years		B2 = 2 years	
	2011 - 2020	946	1 022	27 017 008	29 190 407	27 017 954	29 191 430
	2021 - 2030	1 070	1 221	30 538 784	34 855 886	30 539 854	34 857 107
	2031 - 2040	586	720	16 734 425	20 566 430	16 735 011	20 567 151
	2041 - 2050	738	977	21 067 997	27 900 713	21 068 735	27 901 690
50% of population	Total cost of providing spraying programme= $ 6 460 915			Payback period: A2 = 2 years		B2 = 2 years	
	2011 - 2020	4 732	5 112	135 085 038	145 952 035	135 089 770	145 957 148
	2021 - 2030	5 349	6 105	152 693 921	174 279 431	152 699 270	174 285 535
	2031 - 2040	2 931	3 602	83 672 123	102 832 152	83 675 054	102 835 754
	2041 - 2050	3 690	4 887	105 339 984	139 503 564	105 343 674	139 508 450

Source: Authors' calculations

The second form of intervention considered was a spraying programme. The impact of spraying was estimated by Graves and others (undated) to be approximately 35 per cent. The results of the cost benefit analysis of this intervention are presented in the lower half of table 10.

The averted treatment costs were calculated as the difference between the number of cases after the spraying intervention and the forecast number of cases that would have been observed without the intervention. That difference was multiplied by the cost of anti-malarial medicines at US$ 0.111 per person.[13] It was estimated that providing 10 per centof the population with a preventive spraying programme averted treatment costs for the period 2011-2020 by US$ 946 under the A2 scenario and by US$ 1,022 under the B2 scenario (see table 10).

The averted productivity losses were calculated as the difference between the number of cases with, and without, the intervention multiplied by the number of days lost to malaria (10 days) and the GDP per capita divided by 365. The productivity losses are presented in the second panel in table 10 and reflect, for example, that the productivity losses averted would be highest at US$ 34,855,886 in the second decade (2021–2030) under B2, followed by US$ 30,538,784 under A2, also in the second decade (2021–2030).

[13] World Health Organization, 2012

The results presented in table 10 are a reminder to policymakers of the need to assess, not only the direct, monetary benefits, but also the non-monetary benefits of implementing particular interventions, as these are often different and can result in different policy prescriptions. The productivity losses averted in the case of malaria far exceed the treatment costs. The cost of extending the treated-bed-net programme exceeds the cost of spraying the same proportion of the population by a factor of 10, when extended to 10 per cent of the population, and by a factor of 8, when extended to 50 per cent of the population.

B. Dengue fever

Given the absence in the literature of information on the impact of preventive methods on the number of dengue fever cases, the present section assumes that a spraying programme has been undertaken which has the same impact on dengue fever as it has had on malaria, resulting in a reduction in the number of dengue fever cases by 35 per cent. The results are presented in table 11 using a similar methodology to the one used in the previous sub-section on malaria. Specifically, the 2010 Caribbean population was calculated and multiplied by 10 per cent of the population to arrive at the number of cases that would be likely to exist without the spraying intervention. This number was reduced by 35 per cent to determine the number of dengue fever cases that could be expected in the same 10 per cent of the population after the implementation of the spraying programme. The averted treatment costs were calculated as the difference between the number of cases after the intervention and the number without the intervention, multiplied by the per person cost of dengue fever treatment. That difference was multiplied by the per-person cost of dengue fever treatment, of US$ 2.21 per person.[14]

During the first decade, averted treatment costs amounted to US$ 572 under A2, and US$ 618 under B2. Saved productivity losses during the same period were US$ 430,671 and US$ 465,365, under A2 and B2, respectively. If, instead, the spraying programme were extended to 50 per cent of the population, the averted treatment costs would increase to US$ 2,860 under A2 and US$ 3,091 under B2; and, productivity losses saved would amount to US$ 2,153,354 under A2 and US$ 2,326,825 under B2. Again, the results have reiterated the importance of considering the non-monetary benefits of interventions in the decision-making process. As expected, the averted costs and productivity losses performed in a manner similar to the trend in the number of forecast cases. The total cost of the spraying programme increased by a factor of four when extended to 50 per cent of the total population.

C. Leptospirosis

The potential effective intervention for leptospirosis would be improvements in water quality and sanitation systems, which have been estimated to reduce the number of leptospirosis cases by 30 per cent. The cost of providing improved sanitation is US$ 60 per person and improved water quality is US$ 50 per person, to yield a total cost of US$ 110 per person. A method similar to the one implemented with malaria has been used to calculate the averted costs—and therefore the benefits—associated with this combined programme for leptospirosis. The results indicated that averted costs increased from US$ 1,164 to US$ 6,792 under A2, and US$ 1,258 to US$ 7,337 under B2, when 10 per cent and 50 per cent of the population, respectively, were provided with improved water and sanitation systems. This represents a fourfold increase in benefits in the first decade. Productivity losses during the first decade increased from US$ 157,284 to US$ 917,491 under A2, and from US$ 169,898 to US$ 991,069 under B2. The costs expended to obtain those benefits were US$ 103.1 million and US$ 516 million, under A2 and B2, respectively, indicating very long payback periods for health sector benefits (table 12).

[14] World Health Organization, 2012

The forecast payback period for an improved water and sanitation supply infrastructure programme occurred over the very long term, outside the forecast period of 2011 to 2050.

Table 11
COST BENEFIT ANALYSIS OF DENGUE FEVER ADAPTATION STRATEGIES APPLIED TO 10% AND 50% OF THE CARIBBEAN POPULATION, FROM 2011–2050
(United States dollars)

		Averted treatment costs under A2	Averted treatment costs under B2	Averted production losses under A2	Averted production losses under B2	Total benefits under A2	Total benefits under B2
10% of population	Total cost of providing spraying programmes= $ 1 292 183 Payback period: A2 = 2 years B2 = 2 years						
	2011 - 2020	572	618	430 671	465 365	431 243	465 983
	2021 - 2030	1 147	1 310	863 750	986 181	864 898	987 491
	2031 - 2040	1 473	1 812	1 108 885	1 363 801	1 110 358	1 365 613
	2041 - 2050	849	1 125	639 070	847 233	639 919	848 358
50% of population	Total cost of providing spraying programmes= $ 6 460 915 Payback period: A2 = 2 years B2 = 2 years						
	2011 - 2020	2 860	3 091	2 153 354	2 326 825	2 156 214	2 329 916
	2021 - 2030	5 737	6 550	4 318 752	4 930 906	4 324 489	4 937 457
	2031 - 2040	7 365	9 058	5 544 427	6 819 006	5 551 792	6 828 064
	2041 - 2050	4 245	5 627	3 195 349	4 236 163	3 199 594	4 241 790

Source: Authors' calculations

Table 12
LEPTOSPIROSIS ADAPTATION STRATEGIES APPLIED TO 10% AND 50% OF THE CARIBBEAN POPULATION FOR 2011-2050

		Averted treatment costs under A2	Averted treatment costs under B2	Averted production losses under A2	Averted production losses under B2	Total benefits under A2	Total benefits under B2
10% of Population	Total cost of providing improved water and sanitation systems = US$ 98,708,429 Payback period: A2 = 2 years B2 = 2 years						
	2011 - 2020	1 164	1 258	157 284	169 898	158 449	171 155
	2021 - 2030	1 291	1 474	174 434	199 099	175 725	200 573
	2031 - 2040	1 112	1 375	150 264	185 670	151 376	187 044
	2041 - 2050	832	1 107	112 367	149 570	113 199	150 678
50% of population	Total cost of providing improved water and sanitation systems = US$ 493,542,143 Payback period: A2 = 2 years B2 = 2 years						
	2011 - 2020	6 792	7 337	917 491	991 069	924 284	998 406
	2021 - 2030	7 533	8 598	1 017 531	1 161 411	1 025 064	1 170 009
	2031 - 2040	6 489	8 018	876 538	1 083 074	883 027	1 091 092
	2041 - 2050	4 853	6 459	655 477	872 493	660 329	878 953

Source: Authors' calculations

D. Gastroenteritis

A major adaptation strategy in response to the potential increase in the number of gastroenteritis cases under the impact of climate change would be the improvement in water supply and sanitation systems to the relevant population groups. Similar costs and methodology have been used to construct the cost and benefits presented in table 13**.**

E. Summary

The cost-benefit analysis has indicated that the most expensive preliminary adaptation costs were incurred by the potable water supply and sanitation programmes, designed to reduce leptospirosis and gastroenteritis cases in the populations under- and over age five. The adaptation costs for impregnated bed nets, designed to prevent malaria, and for the spraying programmes that targeted reductions in malaria and dengue fever, were the next highest, respectively. That ranking remained, regardless of the climate scenario or size of the targeted population (table 14).

TABLE 13
GASTROENTERITIS ADAPTATION STRATEGIES APPLIED TO 10% AND 50% OF THE CARIBBEAN POPULATION FOR 2011–2050

		Averted treatment costs under A2	Averted treatment costs under B2	Averted production losses under A2	Averted production losses under B2	Total benefits under A2	Total benefits under B2
POPULATION UNDER AGE FIVE							
10% of population	Total cost of providing improved sanitation and water supply systems = US $ 98,708,429						
	Payback period: A2 = Longer term B2 = Longer term						
	2011 – 2020	53 241	57 522	14 277 611	15 425 541	14 330 852	15 483 063
	2021 – 2030	41 110	46 919	11 024 562	12 582 259	11 065 673	12 629 178
	2031 – 2040	39 453	48 516	10 579 949	13 010 368	10 619 401	13 058 883
	2041 – 2050	32 336	42 845	8 671 466	11 489 683	8 703 801	11 532 528
50% of population	Total cost of providing improved sanitation and water supply systems = US$ 493,542,143						
	Payback period: A2 = Longer term B2 = Longer term						
	2011 – 2020	310 573	335 543	83 286 062	89 982 323	83 596 635	90 317 866
	2021 – 2030	239 811	273 695	64 309 947	73 396 513	64 549 758	73 670 208
	2031 – 2040	230 140	283 007	61 716 368	75 893 812	61 946 508	76 176 819
	2041 – 2050	188 626	249 929	50 583 549	67 023 149	50 772 174	67 273 078
POPULATION OVER AGE FIVE							
10% of population	Total cost of providing improved sanitation and water supply systems = US$ 98,708,429						
	Payback period: A2 = Longer term B2 = Longer term						
	2011 – 2020	39 554	39 553	10 607 069	10 606 966	10 646 622	10 646 519
	2021 – 2030	39 997	39 996	10 725 943	10 725 785	10 765 940	10 765 781
	2031 – 2040	37 745	37 743	10 122 103	10 121 563	10 159 848	10 159 306
	2041 - 2050	33 484	33 482	8 979 432	8 978 739	9 012 916	9 012 220
50% of population	Total cost of providing improved sanitation and water supply systems = US$ 269 204 805						
	Payback period: A2 = Longer term B2 = Longer term						
	2011 - 2020	230 730	230 727	61 874 566	61 873 968	62 105 296	62 104 696
	2021 - 2030	233 315	233 312	62 568 002	62 567 077	62 801 317	62 800 389
	2031 - 2040	220 180	220 169	59 045 598	59 042 450	59 265 779	59 262 619
	2041 - 2050	195 325	195 309	52 380 017	52 375 976	52 575 342	52 571 286

Source: Authors' calculations

The dengue fever and malaria spraying programmes had the fastest return on expenditure, with a payback period within the first few years, followed by water supply and sanitation system improvements designed to reduce gastroenteritis, and finally, improved water supply and sanitation systems for leptospirosis. Some benefits or complementarities are likely to materialize when a programme implemented for one disease helps to reduce the number of cases of another, and increases the benefits associated with a reduced number of cases of both diseases.

TABLE 14
TOTAL HEALTH SECTOR ADAPTATION COSTS AND BENEFITS FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE CHANGE SCENARIOS FOR 2011-2050
(United States dollars)

	Total cost of adaptation to climate change (US$)	Decade	Averted costs under A2	Averted costs under B2	Averted productivity losses under A2	Averted productivity losses under B2	Total benefits under A2	Total benefits under B2
Adaptation intervention extended to 10% of the Caribbean population								
Malaria	12 060 375	2011 - 2020	345	372	9 270 580	10 016 358	9 270 925	10 016 730
		2021 - 2030	390	445	10 479 038	11 960 403	10 479 428	11 960 848
		2031 - 2040	214	262	5 742 228	7 057 138	5 742 442	7 057 400
		2041 - 2050	269	356	7 229 245	9 573 814	7 229 514	9 574 170
Dengue fever	1 292 183	2011 - 2020	572	618	430 671	465 365	431 243	465 983
		2021 - 2030	1 147	1 310	863 750	986 181	864 898	987 491
		2031 - 2040	1 473	1 812	1 108 885	1 363 801	1 110 358	1 365 613
		2041 - 2050	849	1 125	639 070	847 233	639 919	848 358
Leptospirosis	98 708 429	2011 - 2020	1 164	1 258	157 284	169 898	158 449	171 155
		2021 - 2030	1 291	1 474	174 434	199 099	175 725	200 573
		2031 - 2040	1 112	1 375	150 264	185 670	151 376	187 044
		2041 - 2050	832	1 107	112 367	149 570	113 199	150 678
Gastroenteritis under age five	98 708 429	2011 - 2020	53 241	57 522	14 277 611	15 425 541	14 330 852	15 483 063
		2021 - 2030	41 110	46 919	11 024 562	12 582 259	11 065 673	12 629 178
		2031 - 2040	39 453	48 516	10 579 949	13 010 368	10 619 401	13 058 883
		2041 - 2050	32 336	42 845	8 671 466	11 489 683	8 703 801	11 532 528
Gastroenteritis over age five	98 708 429	2011 - 2020	39 554	39 553	10 607 069	10 606 966	10 646 622	10 646 519
		2021 - 2030	39 997	39 996	10 725 943	10 725 785	10 765 940	10 765 781
		2031 - 2040	37 745	37 743	10 122 103	10 121 563	10 159 848	10 159 306
		2041 - 2050	33 484	33 482	8 979 432	8 978 739	9 012 916	9 012 220
Adaptation intervention extended to 50 % of the Caribbean population								
Malaria	60 301 876	2011 - 2020	6 354	6 865	48 087 747	51 956 194	48 094 101	51 963 060
		2021 - 2030	7 182	8 198	54 356 180	62 040 217	54 363 362	62 048 415
		2031 - 2040	3 936	4 837	29 785 711	36 606 322	29 789 647	36 611 159
		2041 - 2050	4 955	6 562	37 499 064	49 660 659	37 504 019	49 667 221
Dengue fever	6 460 915	2011 - 2020	2 860	3 091	2 153 354	2 326 825	2 156 214	2 329 916
		2021 - 2030	5 737	6 550	4 318 752	4 930 906	4 324 489	4 937 457
		2031 - 2040	7 365	9 058	5 544 427	6 819 006	5 551 792	6 828 064
		2041 - 2050	4 245	5 627	3 195 349	4 236 163	3 199 594	4 241 790
Leptospirosis	493 542 143	2011 - 2020	6 792	7 337	917 491	991 069	924 284	998 406
		2021 - 2030	7 533	8 598	1 017 531	1 161 411	1 025 064	1 170 009

	Total cost of adaptation to climate change (US$)	Decade	Averted costs under A2	Averted costs under B2	Averted productivity losses under A2	Averted productivity losses under B2	Total benefits under A2	Total benefits under B2
		2031 - 2040	6 489	8 018	876 538	1 083 074	883 027	1 091 092
		2041 - 2050	4 853	6 459	655 477	872 493	660 329	878 953
Gastroenteritis under age five	493 542 143	2011 - 2020	310 573	335 543	83 286 062	89 982 323	83 596 635	90 317 866
		2021 - 2030	239 811	273 695	64 309 947	73 396 513	64 549 758	73 670 208
		2031 - 2040	230 140	283 007	61 716 368	75 893 812	61 946 508	76 176 819
		2041 - 2050	188 626	249 929	50 583 549	67 023 149	50 772 174	67 273 078
Gastroenteritis over age five	493 542 143	2011 - 2020	230 730	230 727	61 874 566	61 873 968	62 105 296	62 104 696
		2021 - 2030	233 315	233 312	62 568 002	62 567 077	62 801 317	62 800 389
		2031 - 2040	220 180	220 169	59 045 598	59 042 450	59 265 779	59 262 619
		2041 - 2050	195 325	195 309	52 380 017	52 375 976	52 575 342	52 571 286

Source: Author's calculations

The economics of treatment and prevention measures differs greatly between malaria and gastroenteritis. It is more cost-effective to treat than to prevent malaria, whereas it is more cost-effective to prevent gastroenteritis. This can be attributed to the global response to curtailing the impact that malaria can have on human health once it has been contracted, of increasing the availability of anti-malarial medication on a wide scale. Prevention efforts with respect to the availability of vaccines and the availability and the durability of impregnated bed nets will need to be expanded at the local level in order to match the affordability of the treatment costs. In contrast, the cost associated with medical care (treatment) of gastroenteritis illnesses during convalescence was comparatively higher than the cost of the rotavirus vaccine in a prevention programme. However, when combined with the productivity losses associated with gastroenteritis, it may be socially beneficial to prevent additional cases of gastroenteritis. The relatively low level of both the direct and indirect costs associated with leptospirosis suggests that the health authorities need to assign proportionately fewer resources to prevention and treatment of that disease.

TABLE 15
TOTAL COST OF CARIBBEAN HEALTH SECTOR ADAPTATION MEASURES APPLIED TO 10% AND 50% OF THE POPULATION UNDER A2 AND B2 CLIMATE CHANGE SCENARIOS, 2011-2050
(United States dollars)

	Total cost US$	Decade	Total averted costs (benefits) under A2	Total averted costs (benefits) under B2
10% of population	224 229 656	2011 – 2020	34 838 090	36 783 451
		2021 – 2030	33 351 664	36 543 871
		2031 – 2040	27 783 426	31 828 247
		2041 – 2050	25 699 349	31 117 954
50% of population	1 121 148 278	2011 – 2020	196 876 529	207 713 943
		2021 – 2030	187 063 990	204 626 477
		2031 – 2040	157 436 753	179 969 753
		2041 – 2050	144 711 459	174 632 328

Source: Author's calculations

Policy interventions should, therefore, prioritize programmes that would evaluate the likelihood of outbreaks, by monitoring the volume of rainfall and the maximum temperatures in each period, as part of an early warning mechanism that would pre-empt potential increases in the number of malaria cases observed. An early warning monitoring system would be likely to have a complementary, secondary impact, in terms of reducing the observed number of additional cases of dengue fever and leptospirosis. The cost of sourcing vaccines for the prevention of gastroenteritis would be the next important cost, one that increased over the period of the forecast. Gastroenteritis prevention costs were approximately equal for both population sub-groups, under- and over- five years of age. In addition, the interventions should take into consideration the complementarities in terms of reduced cases and costs (increased benefits) between two or more diseases.

Another important adaptation option for the Caribbean would be the improvement of primary health-care services. Many of the countries in the Caribbean have already indicated a high level of commitment to the improvement of primary health care. Such efforts need to be continued and expanded, as part of preventive efforts against the spread of the four diseases considered in the present report. Traditionally, such efforts have been supported through central government budgets: however, there may be a role for private involvement, in relation to supporting public-awareness campaigns and improved sanitation and water supply provision. Nevertheless, Governments in the Caribbean will have to accept and fulfill their ultimate responsibility for public health, even in the presence of private involvement. The costs associated with primary health care will vary locally, and will be impacted by local approaches to public-sector modernization and rationalization and, hence, cannot be specified or estimated for the purposes of the present report.

VI. Other diseases and climate change-related events with potential implications for Caribbean countries

Climate change could impact other diseases, such as skin cancer, cataracts and respiratory illnesses. In addition, the health status of the Caribbean population could be threatened by extreme events whose frequency and severity of occurrence may increase simultaneously with the impact of climate change. These issues are considered in the current section, there being—to date—no available model of the relationship between such events and climate change.

A. Extreme events

An extreme weather event is an infrequent, meteorological event that has a significant impact on the society or ecosystem at a particular location. Between 1970 and 2008, IPCC reported that more than 95 per cent of natural-disaster-related deaths occurred in developing countries. The Caribbean has had a long history of extreme events, resulting in destruction of land and infrastructure, and in health issues and loss of life. Should the frequency of extreme weather events increase, there would be an increase in the number of deaths, injuries, stress-related disorders, and other adverse health effects associated with the social disruption, enforced migration and resettlement that these events would entail.

The Caribbean Catastrophe Risk Insurance Facility (CCRIF) was designed to help Caribbean member Governments limit the financial impact of the extreme of the extreme events such as high-category hurricanes and extreme cases of droughts, by providing financial support once the parametric policy has been implemented. The 16 Caribbean member countries have committed to the renewal of their earthquake and hurricane policies for 2012-2013. The United States National Oceanic and Atmospheric Administration (NOAA) predicted that the 2012 hurricane season would have less activity than preceding years since 1981. There should be fifteen named storms, inclusive of four to eight hurricanes, some of which were forecast to become major hurricanes (CCRIF, 2012). The CCRIF insurance covers extreme events, but the Facility has now instituted an insurance policy against excess rainfall. Since its inception in 2007, CCRIF has made eight payouts for three earthquake and five hurricane events. The total cost of those payouts was US$ 32,179,470 (CCRIF, 2012).

TABLE 16
NATURAL DISASTERS IN THE CARIBBEAN BY TYPE AND COUNTRY

Country	Drought	Earthquake	Epidemic	Extreme temperatures	Flood	Mass movement wet	Storm	Total
The Bahamas							12	12
Belize				1	3		8	12
Dominica		1					5	6
Guyana	1				4	1		6
Grenada							4	4
Haiti	3		1		22		23	49
Jamaica	1		2		4		14	21
Saint Lucia		1				1	4	6
Suriname					2			2

Source: Emergency Events Database (EM-DAT): The ofda/CRED International Disaster Database www.emdat.be – Université Catholique de Louvain - Brussels - Belgium

TABLE 17
DISASTER OCCURRENCES BY CARIBBEAN COUNTRY BY YEAR

Country	Disaster/Event	Year
Bahamas (the)	Hurricane Frances	2004
Belize	Hurricane Jeanne	2004
	Hurricane Keith	2000
	Hurricane Dean	2007
Dominica	Hurricane Dean	2007
Grenada	Hurricane Ivan	2004
Guyana	Floods	2005
Haiti	Hurricane Jeanne	2004
	Tropical storms Fay, Gustav, Hanna, Ike	2008
Jamaica	Hurricane Michelle	2001
	Hurricane Ivan	2004
Saint Lucia	Hurricane Dean	2007
Saint Vincent and the Grenadines	Hurricane Lenny	1999
	Tropical Storm Lili	2002
	Hurricane Ivan	2004
	Hurricane Emily	2005
	Hurricane Dean	2007
	Hurricane Tomas	2010
Suriname	Floods	2006

Source: Caribbean Catastrophe Risk Insurance Facility (CCRIF), 2012

In 2011, the Facility offered assistance to Caribbean countries in two ways. The first way was by offering its Real-Time Forecasting System (RTFS) to all members, and the second was training in the use of the system (CCRIF, 2011). RTFS is a storm-impact forecasting tool which provides users with real-time hurricane hazard and impact information. It can support users in effective disaster - preparedness and response, evacuation decision making, planning for pre-positioning of equipment and supplies, as well as contingency planning to secure critical infrastructure and operations prior to a hurricane.[15]

TABLE 18
EARTHQUAKE AND CYCLONE EVENTS IN THE CARIBBEAN

Event and Year of Occurrence	Country	Payout (US$)
Earthquake, 29 November 2007	Dominica	528 021
Earthquake, 29 November 2007	Saint Lucia	418 976
Tropical Cyclone Ike, September 2008	Turks and Caicos Islands	6 303 913
Earthquake, 12 January 2010	Haiti	7 753 579
Tropical Cyclone Earl, August 2010	Anguilla	4 282 733
Tropical Cyclone Tomas, October 2010	Barbados	8 560 247
Tropical Cyclone Tomas, October 2010	Saint Lucia	3 241 613
Tropical Cyclone Tomas, October 2010	Saint Vincent and the Grenadines	1 090 388
Total for the period 2007 - 2010		32 179 470

Source: Caribbean Catastrophe Risk Insurance Facility (CCRIF), 2012

IPCC has noted that changes in climate extremes will vary across regions, as each has its unique vulnerability and is exposed to different hazards. The Panel, therefore, recommended the tailoring of risk management and adaptation to local and regional needs and circumstances, in order to reduce/eliminate the factors contributing to exposure and vulnerability. Ultimately, this would reduce the impact of extreme events on the population of the Caribbean.

B. Sahara dust and the prevalence of respiratory diseases

Dust emissions from natural sources may change in future as a result of anthropogenically-forced climate change. The Sahara Desert is a major source of atmospheric dust. It has been estimated that over 50 per cent of the total annual dust loading in the atmosphere, estimated at 2 billion – 4 billion tons globally, comes from the Sahara Desert (Goudie and Middleton, 2001).

The United States National Aeronautics and Space Administration (NASA) Earth Observatory reported that a well-defined plume of dust swept across the entire Atlantic Ocean on June 24, 2009 (Earth Observatory, 2009). An image taken by the Moderate Resolution Imaging Spectroradiometer on the NASA Aqua satellite in three consecutive overpasses showed the dust extending from its origin in the Sahara Desert, in Africa, to the Lesser Antilles Islands, on the eastern edge of the Caribbean Sea. Such spectacular dust storms are not uncommon. The migration of Saharan dust begins when storms in North Africa lift Saharan sand and dust into the upper atmosphere, where they are carried thousands of miles across the Atlantic Ocean into the Caribbean and southern parts of the Atlantic United States.

Various studies have suggested a potential link between dust levels and human health. Research has shown that there may be a correlation between high concentrations of particles of less than 2.5 µm (0.0025 mm) in diameter (PM2.5) and increases in emergency-room admissions for respiratory and cardiovascular disease that have been reported in North America, Asia and Europe. The primary health concern associated with Saharan dust is the particulate matter—microscopic dust (less than the thickness of hair, < 2.5 µm) which can sidestep the lungs' natural defences. These tiny particles can contribute to cardiovascular problems, as well as respiratory diseases such as asthma, especially in children.

[15] This is the definition given by Caribbean Catastrophe Risk Insurance Facility (CCRIF), 2012

According to the Trinidad Guardian, recent research in Trinidad has shown that the symptoms of rhinitis in the student population exceeded 30 per cent.[16] Although the reasons for such a high prevalence of allergic disease in Caribbean youth remain obscure, preliminary data from Trinidad have hinted at a higher prevalence of these disorders among students attending schools in urban areas. The dust particles act as carriers of known asthma triggers, such as biological materials, including bacteria, viruses, fungal spores and pollen. They have also been shown to transport various pollutants, such as metals and pesticides. To date, more than 200 species of viable bacteria and fungi have been identified from air samples collected during Saharan dust events in Trinidad and Tobago. However, there is still uncertainty about whether dust clouds could transport other asthma triggers, such as pollen.[17]

There is very little information available on the projected volume/movement of Saharan Dust into the Caribbean. In one study, using a projection from the National Center for Atmospheric Research coupled Climate System Model, Mahowald and Chao (2003) suggested that global dust emissions may decrease by 20–60 per cent by 2090, mainly as a consequence of a climate-induced decrease in desert extent. These expectations, should they be realized, would have positive spin-offs for the number of respiratory diseases experienced, particularly in the Eastern Caribbean. This issue is an important consideration in the context of increased storm and dust activity.

C. Increased ultraviolet rays, skin cancer and cataract cases

Another health concern, relevant to the Caribbean in the context of global warming, is the potential relationship between climate change and the number of cases of skin cancer and cataracts. According to the Skin Cancer Foundation (2012), skin cancer is the uncontrolled growth of abnormal skin cells. It occurs when unrepaired DNA damage to skin cells (most often caused by ultraviolet radiation from sunshine or tanning beds) triggers mutations, or genetic defects, that lead the skin cells to multiply rapidly and form malignant tumours. Globally, temperature has increased steadily over the past quarter of a century, and has been predicted – by the latest report from IPCC – to increase with time (McMichael, 2003). This increase in temperature is due mainly to human activity that triggers the emission of greenhouse gases, which destroy the protective ozone layer, thus causing more heat to be trapped within the atmosphere.

Simultaneously, research by the WHO has indicated that skin cancer has also been increasing over time. WHO estimated that between two million and three million non-melanoma skin cancers, and 132,000 melanoma skin cancers, occurred globally each year, and that one out of every three cancers detected was skin cancer This has led some researchers to consider the possibility that climate conditions – in particular, the depletion of the ozone layer – were related to the number of cases of skin cancer (Reuell, 2012). Using data on the exposure of six lab mice to ultraviolet rays, Findlay (1979) found that four of the six specimens developed a malignant tumor that resulted in skin cancer. McMichael (2003) later definitively asserted that the highest risk of skin cancer was linked to that of ultraviolet radiation of relatively short wavelengths (UVB) exposure instead of ultraviolet radiation of

[16] The Guardian reported studies indicating a 17-fold increase in the prevalence of asthma in Barbados from 1973 to 1996, with acute asthma attacks accounting for 22.3 per cent of the Queen Elizabeth Hospital emergency-room visits in 1999. This increase could have corresponded to the observed increase in African dust flux affecting Barbados. ("Saharan dust blows in respiratory problems" [online], *Trinidad and Tobago Guardian*, [2 November 2012], http://www.guardian.co.tt/news/2011/07/01/saharan-dust-blows-respiratory-problems, July 2011.)

[17] Dr. Marissa Gowrie of the University of the West Indies has reported that local pollen, in the presence of other factors such as dust concentrations, relative humidity, wind speed, and temperature variations, contributed to increases in paediatric asthma. A predictive model based on the interactions of these factors was created, which forecast paediatric asthma admissions for 84.7 per cent of the asthma cases studied over a two-year period. A key component of the model was the inclusion of lag time which took into account the incubation time before the onset of asthma symptoms. The model forecast paediatric asthma a week in advance, using data on asthma admissions from the three previous days. It showed that asthma increased when there was a certain combination of factors, specifically, days of high pollen, high dust, high wind speed, and high temperature variations, coupled with two consecutive days of high relative humidity.

relatively long wavelengths (UVA) exposure, and that UVB exposure (from both sunlight and artificial sources) had been linked conclusively to cutaneous malignant melanoma (CMM)[18] and non-melanoma skin cancer.

The World Skin Cancer Foundation has agreed with this finding, and has stated that there is a correlation between ultraviolet light and specifically basal cell carcinoma[19] in darker-skinned persons. This may explain the relatively higher incidence of this malignancy among darker-skinned populations living in sunnier climates (Gohara and Perez, 2012). This finding is troubling for countries of the Caribbean; for instance, countries such as Guyana that have reported an increase in the incidence of skin cancer within a segment of the population, as a result of higher incidences of UVB radiation and higher surface temperatures.

While these findings are potentially alarming, additional research is needed to determine at what temperatures and which forms of skin cancer are more prevalent in the Caribbean because of climate change. Fabbrocini and others (2010), concluded that rising temperatures accompanying climate change may lead to increasing incidence of skin cancer in human populations, and agreed that more research was needed. They have, however, stated that it was hard to isolate how temperature differed from ultraviolet radiation in its influence on the incidence of skin cancer on different Caribbean skin types. McMichael (2003) found that there was a strong correlation between all types of skin cancer and the amount of ultraviolet rays that reached the earth among homogeneous populations, with ultraviolet radiation being the predominant factor, and temperature the second most important, causing skin cancer. In response to the upward trend in the number of skin cancer patients, during 2012 the United Kingdom charity Cancer Research UK released research which revealed that people with lighter eyes, skin or hair, or with a skin phototype (persons who sunburned easily or did not tan), had an increased risk of skin cancer from the sun, depending on their exposure to ultraviolet radiation at a particular time of day (solar noon), latitude (ultraviolet radiation is highest at the equator), altitude (ultraviolet radiation increases with altitude), weather conditions (thick clouds reduce the impact of ultraviolet radiation) and reflection (ultraviolet radiation reflects and, therefore, can reach body parts not exposed to sunlight).

Dr. Frank Apperly examined the statistics on cancer deaths across North America and Canada, and showed there was a relationship between sunlight, ambient temperature and skin cancer. He concluded that:

> "sunlight produces immunity to cancer in general and, in places where the mean temperature is less than about 5.5° C, or 42° F, even to skin cancer. However, at mean temperatures higher than this, solar radiation causes more skin cancer despite the increased general immunity to the disease"[20] (cited in Hobday, 2000)

While there are some favourable claims of the benefit of sunlight in treating one form of skin cancer, the *mycosis fungoides*,[21] enough research is not available to verify this assertion**.**

The United States National Library of Medicine (2012) defines cataracts as the clouding of the lens of the eye. Cataracts are associated with many different factors, such as age, climate, birth or trauma. This disease may be treated adequately by surgical intervention and, when left untreated, can cause blindness. However, according to Andreas Mueller, in his statement made on World Health Day 2008[22], ultraviolet radiation exposure (climate condition) was one of the top three causes of cataracts,

[18] This is the most serious form of skin cancer and accounts for about three quarters of all skin cancer deaths.
[19] This is a slow-growing form of skin cancer.
[20] Richard Hobday, "How sunlight can prevent serious health problems." [online], Lifestyle Laboratory, [18 October 2012], http://lifestylelaboratory.com/articles/hobday/sunlight-prevent-problems.html,.2000.
[21] These are diseases in which lymphocytes (a type of white blood cell) become malignant (cancerous) and affect the skin.
[22] More information on cataracts is available from http://www.oteurope.com/ophthalmologytimeseurope /Cataract+News/Climate-change-increasing-incidence-of-cataracts

similar to the case with skin cancer. The numbers of cataract cases worldwide has been on an upward trend along with increases in ultraviolet radiation and temperature.

Research has shown the existence of a positive relationship between cataracts and climatic conditions produced by the sun, such as increases in temperature. The extent to which climatic conditions cause cataracts directly, and the extent to which it is a significant variable is, however, still undetermined. Epidemiology has suggested that there is a correlation between sun exposure and nuclear cataracts. The risk was highest among those who had significant sun exposure at a young age (Neale, Purdie, Hirst and Green, 2003). This caused increases in eye temperature, which in turn increased the risk factor for lens disorders such as cataracts. Thus, with the prospect of increased global temperatures, the prevalence of cataracts may increase. In addition, the authors found that the closer people lived to the Equator, the greater their chances of developing cataracts. They found that wearing a hat appeared to be protective for nuclear cataracts, whereas hat-wearing appeared to be associated with a slightly increased risk of developing nuclear opacity after adjusting for sun exposure. De Gruijl and others (2003) stated that cortical cataracts were relatively more prevalent than other types of cataract in populations living in temperate climates, and that the incidence increased closer to lower latitudes. They reiterated that nuclear cataracts were more common in populations nearer the Equator (i.e. in tropical climates) because of the warmer climate. Another study in southern France has suggested that sunlight exposure increased the risk of severe cortical or mixed cataracts. In that study, wearing sunglasses did not reduce the risk of these cataracts, although it did for posterior sub-scapular cataracts.[23]

In the Caribbean, untreated cataracts are one of the most prevalent causes of blindness. It is estimated that, of the population of approximately 13.3 million in the selected countries of the Caribbean, around 1 per cent is blind, of which 60 per cent are due to cataracts (Sightsavers, 2012). Cataract treatment has become a cause for concern in the Caribbean, due to the lack of public health-care or private monetary resources to diagnose and treat cataracts. In January 2010, the international charity, Sightsavers, and its partners started a five-year project to bring eye-care to the Caribbean.

D. Summary

The present study has estimated the health costs associated with malaria, dengue fever, leptospirosis and gastroenteritis. It is not yet feasible to estimate the potential costs associated with skin cancers, cataracts and extreme events as the expected changes in climate occur. The potential impacts of these diseases should not be overlooked, however, and for this reason, have been outlined for the benefit of policymakers and other stakeholders.

[23] This is a type of cataract that typically starts near the centre of the back part of the capsule surrounding the lens. More information is available from the Skin Cancer Foundation at http://www.skincancer.org/skin-cancer-information.

VII. Conclusions and recommendations for the Caribbean response to climate change

Estimating the cost of climate change adaptation strategies that impact human health is a challenge. Adaptation that affects health outcomes is often either implemented to address multiple goals, or taken outside the health sector. Policies and measures to prevent potential health impacts are often implemented to reduce the burden of all preventable diseases, and not merely those most impacted by climate change. Improvements in potable water supply and sanitation services are undertaken, not only to reduce the incidence of all waterborne disease, including diarrhoea, but also to meet a broader set of goals, such as the Millennium Development Goals.

The primary goal, therefore, of building adaptive capacity is to reduce future vulnerability to climate variability and change. Increasing the adaptive capacity of a population requires increasing the ability of countries, communities and individuals to cope, effectively and efficiently, with the challenges of climate change (WHO, 2003).

In order to build the capacity of the Caribbean to respond to the potential impacts of climate change presented in the current report, there needs to be a coordinated, integrated, multi-sectoral approach to developing a coordinated and synergistic response that will have sustained, long-term impact across many sectors. This includes health practitioners, technical support in the agricultural sector, operators in the water sector along with tourism personnel and entrepreneurs. This will ensure that the institutions will be able to sensitize their stakeholders appropriately using a consistent, coordinated set of tools, in order to ensure private and public response to the issues that are likely to be associated with climate change.

Given the profile of development in the Caribbean, and the relatively high dependence on coastal resources, community-level responses – and the building of high levels of social capital – will be critical to the composition of an effective response. Specifically, it will be important to develop the basic elements of the public health infrastructure to ensure the availability of resources, to improve surveillance which will facilitate early warning systems for each disease, to increase levels of vector control mechanisms to discourage mosquito breeding, coupled with active programmes to destroy potential and existing, residential mosquito-breeding sites, and to enhance emergency-preparedness and -response to increase dependability and reduce disaster-related illnesses.

Where possible, the depletion of the freshwater supply must be addressed as, despite the abundance of freshwater, there are shortages even during regular periods which may encourage the use of substandard supplies due to their convenience (World Bank, 2002). Policymakers may want to consider the widespread implementation of mechanisms such as:

a) rainwater harvesting

b) the use of more efficient water closet and laundry appliances that reduce water demand incrementally

c) the implementation of desalinization plants and

d) improved management of water resources, inclusive of forest and other surface ecosystems that encourage watershed activity and, therefore, increase water supply.

Another key area is the development of local institutional capacity to perform economic analyses that will enable refinement of the parameters and changes in the relative responses to each disease. The cost estimates that have been presented in the current report have been underestimated—at the very least. There has been no attempt to measure the lasting physical and mental impacts of these diseases on the patients, nor the ethical decisions involved in balancing treatment versus prevention in the context of Caribbean fiscal challenges. In addition, the benefits accruing from increased adaptation in other sectors, which would reduce the sector-specific burden on health, have not been captured here, and neither have the costs, should any sector not adapt adequately to prevent potentially negative impacts on the health status of the population.

Increased and expanded institutional capacity will be required in order to implement treatment and prevention strategies. Governments will have to take the lead, given their substantial control of the majority of health facilities, particularly in relation to primary health care. The primary health-care system will need to provide a quick-response, high-impact approach to the potential impacts of climate change. The Caribbean may benefit from a technical committee considering health-care and climate change adaptation strategies at the technical and operational level. This will facilitate and streamline local response and support systems.

Despite the many omissions and, perhaps, oversimplification in the models, the results have provided an estimate of the magnitude of the impacts of climate change on health. It is, therefore, possible, and appropriate, for policymakers to derive relevant, and appropriate, decisions that will support the general improvement of the health status of the Caribbean population from the perspective of large potential monetary and non-monetary costs. In response to the costs presented and the potential adaptation strategies, the present report can provide a quantitative and qualitative framework, and policy prescriptions that are indicative and that can be mainstreamed into existing national policies and development activities.

In the context of a variety of national development plans (both operational and in process of development), it is important that these tools be implemented from a perspective highly cognizant of the need to climate-proof institutions and programmes, by considering and planning for alternatives that consider the linkages between physical development, health concerns and diseases. This will require significant investment in human capacity, to facilitate data gathering, storing and processing, and reporting on directly- and indirectly- health-related events. Interventions, ideally implemented on an inter-sectoral basis, would facilitate early warning of potential threats, and reduce their impact.

Given the inter- and intra- country variation in geographical, geological and socioeconomic conditions, national and local authorities will have to develop localized priorities and strategies, to address nuances that may give rise to a heightening of health issues that would not require a national approach. This should be channelled into the national response and strategic actions in relation to climate change. With the expansion in resources to the health sector, there must be an increase in the research effort, in order to identify possible mechanisms for disease and illness transmission, and to refine the potential adaptation strategies beyond those prescribed in the current report. It is essential that local capacity be improved to ensure the enforcement of local planning restrictions that would facilitate resilience and/or minimize damage. Improvements in sanitation and access to higher-quality drinking water will continue to be important in the Caribbean in order to address waterborne illnesses and those associated with the improper disposal of solid waste. This must form part of both the local and national response to climate change, as it may require large amounts of investment, as indicated in the cost-benefit analysis.

Once countries in the Caribbean subregion have developed their understanding of the potential impact of climate change on their populations, and are comfortable with the particular strategies on which they will focus in the medium term, it is important that the required culture change be initiated through a widespread, coordinated and consistent, educational campaign, through social and other far-reaching types of media.

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Annexes

Annex 1
Model approach

A Poisson regression model was used to model the climate-disease relationships for each disease in the present study. The Poisson regression model assumes that the disease observations are independent Poisson variables. The Poisson model allows for the analysis of rare events such as diseases that may, or may not, occur in a particular period, and belongs to the Generalized Linear class of models.

The assumptions of the Poisson regression model include the following:

- Logarithm of the disease rate changes linearly with equal increment increases in the exposure variable
- Changes in the rate from combined effects of different exposures or risk factors are multiplicative
- At each level of the covariates, the number of cases has variance equal to the mean
- Observations are independent.

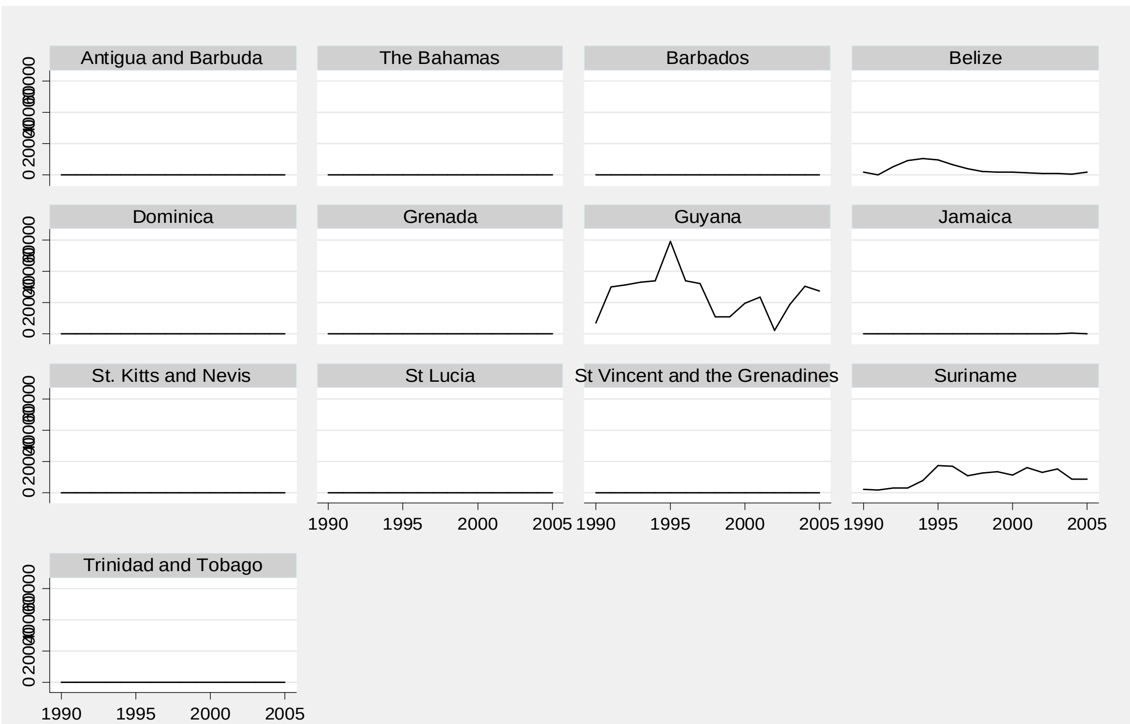
Poisson models have been used in the health and hazard literature to investigate a variety of issues. Examples include the number of cargo ships damaged by waves (a classic example given by McCullagh and Nelder, 1989); the number of deaths due to AIDS in Australia per quarter (three-month periods) from January 1983–June 1986 (Dobson, 1990); number of violent incidents exhibited over a six-month period by patients who had been treated in the emergency room of a psychiatric hospital (Gardner, Mulvey, and Shaw, 1995); daily homicide counts in California (Grogger, 1990); founding (establishment) of day-care centres in Toronto (Baum and Oliver, 1992); and, the political party -switching among members of the United States House of Representatives (King, 1988).[24]

[24] More information on Poisson models is available from http://www.ed.uiuc.edu/courses/EdPsy490AT/lectures/4glm3-ha-online.pdf

Annex 2
Characteristics of Caribbean countries and the pathways between climate and health[25]

Malaria has remained endemic in the mainland countries of the Caribbean, namely, Belize and Guyana, and on the island of Hispaniola (Haiti and the Dominican Republic). The disease has been eradicated from local populations in all other Caribbean countries, yet these countries have maintained surveillance for reported cases, because of the continued presence of the mosquito vector. Small outbreaks of malaria have occurred in recent years among the local populations in Grenada and Trinidad and Tobago, but these have been brought quickly under control. Recently, Belize, Haiti and Guyana received grants from The Global Fund to Fight AIDS, Tuberculosis and Malaria to help tackle this mosquito-borne disease.

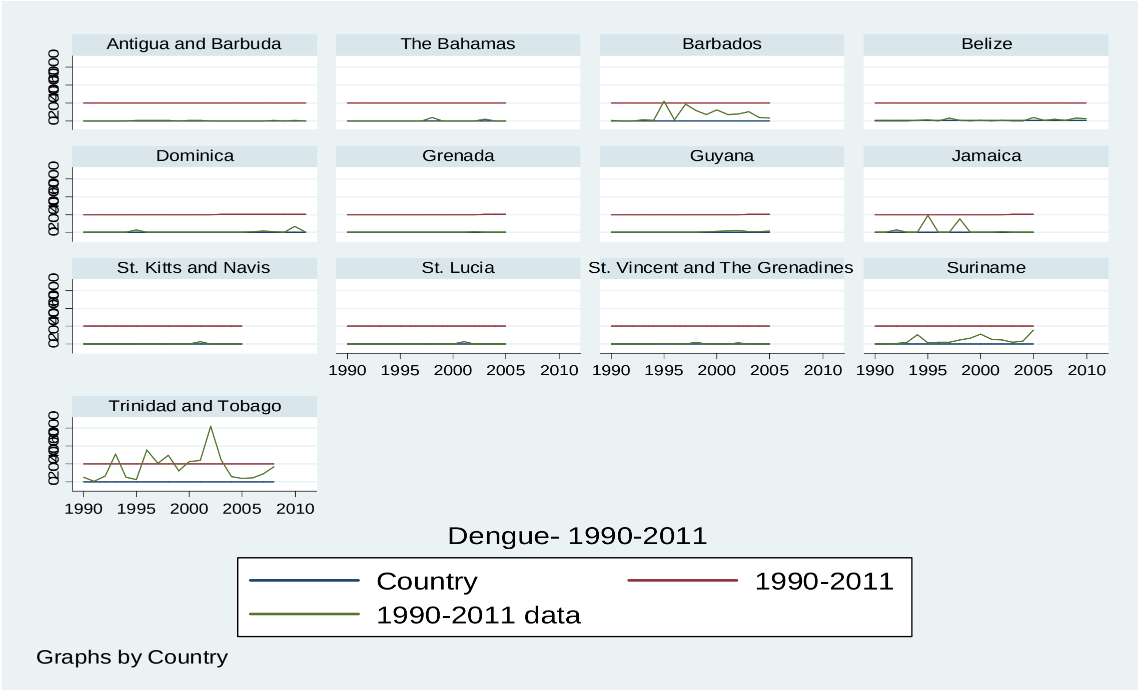
FIGURE A1
INCIDENCE OF MALARIA IN CARIBBEAN COUNTRIES 1990-2005



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

[25] No formal reports on their progress towards the Millennium Development Goals have been made by the Bahamas, Grenada, Guyana, Saint Vincent and the Grenadines, Trinidad and Tobago, or Montserrat.

FIGURE A2
INCIDENCE OF DENGUE FEVER IN CARIBBEAN COUNTRIES 1990-2005



Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

The following profiles present an overview of the progress made by the countries of the Caribbean towards the Millennium Development Goals corresponding to vector-borne and waterborne illnesses, water, and sanitation in each country.

Antigua and Barbuda[26]

The small islands of Antigua and Barbuda are easily impacted by extreme climatic events such as hurricanes, storms, floods, droughts and sea floods. The most dangerous impact of all is that of hurricanes which, more often than not, result in loss of lives, destruction of property, and the transmission of infectious diseases. These events cause disruption in the water supply and its availability. Little or no rainfall reduces the water supply, while too much rainfall contaminates its contents through floods and landslides.

Changes in the hydrological cycle in Antigua and Barbuda mainly affect health in the form of malaria and dengue fever, both diseases endemic to the Caribbean. The two islands boast a strong vector-control unit, and it has been some years since the occurrence of human cases of leptospirosis. Dengue fever has been maintained at normal endemic levels, with 4 cases in 2002, and no cases between 2003 and 2005 (Antigua and Barbuda, 2007).

[26] More information is available from http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20Country%20Reports/Antigua%20and%20Barbuda/Antigua%20and%20Barubuda_MDGReport_2004.pdf, [23 July 2012].

TABLE A1
HEALTH CONCERNS IN ANTIGUA AND BARBUDA 1990-2001

GOALS / INDICATORS		UNIT	1990 /1991	1995	1996	1997	1998	1999	2000	2001
Goal 6: Combat HIV/AIDS, malaria and other diseases										
Prevalence and death rate associated with gastroenteritis < 5 years	Prevalence	◙	1180.4	1076.7	1001.3	3035.2	1483.8	2013.9	963.9	974.4
	Death rate		0	0	0	0	0	0	0	0
Prevalence and death rate associated with dengue fever	Prevalence	◙	0	82.8	8.7	14.5	4.3	2.8	11.1	10.6
	Death rate		0	0	0	0	0	0	0	0
Prevalence and death rate associated with malaria	Prevalence	◙	0	3.0	2.9	0	0	1.4	0	2.6
	Death rate		0	0	0	0	0	0	0	0

Source: Antigua and Barbuda, 2007

◙ = per 100,000 population

The Government of Antigua and Barbuda has proposed that the health sector adapt to climate change by creating public awareness and embarking on programmes directed at improving health data management and monitoring (Challenger, 2001).

The Bahamas

The Bahamas archipelago is prone to hurricanes during the Atlantic hurricane season[27] with tropical storms and hurricanes occurring most frequently in the months of September to November (BEST Commission, 2001). The intensity of these storms results in flooding of the islands. The country is highly vulnerable to the effects of global climate change and, because the islands are low-lying, is vulnerable to any rise in sea level. The ENSO episodes of 1995 and 1998 were responsible for the bleaching of the coral reefs of the country.

While examining the effects of climate change on the economy, the Government of the Bahamas has realized that human health is most often affected by the impacts. Changes in climatic conditions have, over the years, caused the following changes in the health sector:

- An increased incidence of mosquito-borne and other vector-borne diseases (such as dengue fever). Higher temperatures favour the proliferation of mosquitoes and other disease carriers, and increased rainfall and flooding in the Northern Islands provides increased breeding area
- Other diseases attributed to climate change include Lyme disease, hantavirus, and cholera, resulting from higher temperatures, and greater humidity and rainfall
- A higher occurrence of heat-stress-related illnesses and conditions, particularly among the old and the poor
- An increase in waterborne diseases, particularly following extreme rainfall events, and flooding. *Cryptosporidiosis* is one of many waterborne diseases whose prevalence could increase with increased precipitation and flooding triggered by climate change
- Indirect impacts of climate change on agriculture and fisheries and on the food and freshwater supplies, and indirect impacts on various economic sectors and employment, are also likely to

[27] From June 1st - November 30th

impact human health (Bahamas National Climate Change Committee and BEST Comission, 2001).

The Government of the Bahamas has designed the following strategies to safeguard human health against the negative impacts of climate change:

- To promote the necessary health-related research and information-gathering in order to strengthen the basis for sound decision making
- To ensure that appropriate short-, medium- and long-term measures to address health-related climate change issues are incorporated into national health plans
- To inform, sensitize and educate health personnel and the public-at-large about climate change -related health matters, and
- To ensure that, to the extent possible, preventative measures and resources for treatment, such as vaccines and medications, are made available (Bahamas National Climate Change Committee and BEST Comission, 2001).

Barbados[28]

Barbados normally has two types of season: wet and dry. The country is located on the perimeter of the Atlantic storm zone, hence its vulnerability to changes in atmospheric temperature. Climate change is predicted to impact mostly the water supply and, given the nature of the country and the scarcity of water, the result of this impact is increased incidences of vector-borne and gastrointestinal disease. According to the World Health Organization, Barbados has the highest incidence of dengue fever in all the Americas, which is a direct link between changes in climatic patterns and the increase of the presence of the infected *Aedes aegypti* mosquito (Bahamas National Climate Change Committee and BEST Comission, 2001).

The Ministry of Health of Barbados, in collaboration with the WHO and UNDP, has designed a project to ensure public safety and prevent the occurrence of dengue fever by treating wastewater. The project is designed as follows:

- Develop procedures and guidelines for the effective recharge of aquifers using wastewater
- Develop strategies, policies and procedures for the use of wastewater for irrigation, ensuring that the quality and safety of agriculture crops is assured;
- Develop guidelines and standards for the safe use of wastewater
- Develop monitoring systems for using wastewater in agriculture and aquifer recharge
- Social acceptance of the use of treated wastewater
- Enhance current rainwater storage facilities for the prevention of the breeding of the *Aedes aegypti* mosquito (Innis, 2007).

The expectation is for water to be safe for drinking and for the high incidence of dengue fever to be reduced and eradicated from the country.

Vector control

Barbados is not as affected by malaria as other countries in the Caribbean, and the reported cases in the country are found mostly among visitors and returning migrants. In an effort to limit the number of cases, the Ministry of Health has issued warnings to travellers. They have increased their efforts to diagnose and control

[28] More information is available from http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20 Country%20Reports/Barbados/2007%20Barbados_national_rpt.pdf

the disease to prevent similar outbreaks in the country. The number of occurrences of dengue fever and leptospirosis is higher. The Ministry of Health has tried to combat the rate of infection by making regular visits to inspect drainage and refuse facilities on properties.

Water and sanitation

Barbados can be considered a water scarce country. There are periods of water shortage during the dry season, causing the health, tourism, agricultural and industrial sectors to have limited access to water. However, it can be claimed that 100% of Barbadians have access to an improved water source or potable water, inclusive of standpipes and from neighbours. Also, the entire population uses improved sanitation facilities.

Belize[29]

UNFCCC described Belize as a country that was vulnerable to the impacts of hurricanes and climate change. An increase in temperature-induced changes in climate would result in an increase in the frequency of storms in the area and – given the level of vulnerability of Belize – the possibility of damage would be higher. Access to safe drinking water has improved over the years in Belize, although there have been issues with sanitation and inadequate water supply.

Malaria is one of the major vector-borne diseases in Belize. During the years 2001-2005, there were 1163 malaria cases reported in 2001, 1113 cases in 2002, 1319 cases in 2003, 1065 cases in 2004, and 1549 cases in 2005. Cooperation with Guatemala and Mexico has aided directly in the control—and possible prevention—of malaria and dengue fever, among other vector-borne diseases. Dengue fever in Belize is as endemic as malaria. However, over the years, the incidence has been lower, with minor outbreaks but no fatalities.

The following initiatives are being undertaken to decrease the occurrence of malaria and dengue fever in Belize:

- Implementation of residual indoor house spraying in all six districts in priority localities
- Implementation of spraying in all six districts, towns and priority villages
- Treatment of all domestic containers that have tested positive for the *Aedes aegypti* larvae
- Management of extensive breeding sites
- Provision of presumptive treatment for all suspected malaria cases
- Full, radical treatment of all positive cases
- Collection of weekly surveillance data
- Implementation of the serological testing of dengue fever at the Central Medical Laboratory
- Improvement in the collection and documentation of blood samples for dengue fever serology
- Contact tracing on a timely basis for malaria and dengue fever
- Implementation of the informational, educational and communicational plan (Belize, 2006).

Vector control

In 2010, Belize reported being on track to achieve its Millennium Development Goal to halt the occurrence of malaria by 2015. The incidence of malaria cases per 1,000 persons in the population fell significantly, from 49.3 per 1,000 persons in 1994 to 1.7 per 1,000 persons in 2008. In line with the trend and reported incidence, Belize has been one of the nine countries in the Caribbean reporting a greater-than-50 per cent decrease in new malaria cases between 2000 and 2008. This has been associated with the implementation of an intense malaria prevention and control programme in the country.

[29] More information is available from http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20Country%20Reports/Belize/2010.pdf

Water and sanitation

According to the Statistical Institute of Belize, the share of the population with access to an improved potable water source increased from 43.6 per cent in 1995 to 76.4 per cent in 2006. While the percentage of the population with access to improved sanitation facilities increased from 41 per cent in 1995 to 64 per cent in 2007, and to approximately 70 per cent in 2008, achieving this Goal by 2015 may prove unfeasible (see table A2).

TABLE A2
MILLENNIUM DEVELOPMENT GOALS PROFILE FOR BELIZE

Goals	Targets	Indicators	Baseline	2009 Target	2009 Achievement	Target 2015	Progress to 2015
Combat HIV/AIDS, malaria and other diseases	By 2015, halt tuberculosis and malaria	Incidence of malaria (cases per 1,000 population)	49.3 (1994)	-	1.7 (2008)		On track
Ensure environmental sustainability	Halve population without access to safe drinking water	Population with sustainable access to potable water source	43.8 (1995)	80.8	76.4 (2006)	100	On track
	By 2020, to have achieved livelihood improvement. Owners of their own dwelling.	Population with proper sanitation facilities	41 (1995)	94.6	64.4 (2007)	100	Slow

Source**:** Belize, 2006

Dominica[30]

Extreme weather events such as hurricanes and droughts, and long-term alterations in weather patterns, have contributed to the vulnerability of the health sector in Dominica. Dominica has been defined by some diseases that can spiral when under the influence of climatic changes, for example, typhoid, dengue fever, gastroenteritis and leptospirosis. The breeding of the *Aedes Aegypti* mosquito has continued to be a problem in Dominica, as there are numerous breeding grounds for these mosquitoes, namely, drums, discarded tyres and other containers. While malaria is endemic to the Caribbean, Dominica has not been prone to outbreaks. Climate change in Dominica, through extreme precipitation and changes in the weather pattern, has had impacts on the health of the population. However, the severity of the impact has not been measured. The location of the country in the Caribbean archipelago makes its susceptible to El Niño Southern Oscillation episodes, which has not only been detrimental to the health of the population but also to the country's economy. The country is highly dependent on its rivers and streams for the supply of water. Any changes in the normal levels of precipitation result either in drought or in extreme flooding, both of which alter the level of sanitation of the population. Climate change is often accompanied by increases in temperature, which can increase the frequency and intensity of hurricanes and tropical storms in the area. This increases the chances of transmission of vector-borne and waterborne diseases.

Vector control

Since the 1960s, Dominica has not had any reported cases of malaria. However, because of the endemic levels in the Caribbean and the high levels of migration, there is concern about the reoccurrence of the disease.

TABLE A3

[30] For more information see http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20Country%20Reports/Dominica/Dominica_MDGReport_2006.pdf

MILLENNIUM DEVELOPMENT GOALS HEALTH GOALS FOR DOMINICA

Goal	United Nations Millennium Development Goals Guidelines	Level of achievement aligned to development agenda
Goal 6	Combat HIV/AIDS, malaria and other diseases	Lagging achievement
Target 8	Have halted by 2015, and begun to reverse, the incidence of malaria and other major diseases	Achieved
Indicator	Prevalence and death rates associated with malaria	2005: 0 deaths due to malaria
	Proportion of population in malaria risk areas using effective malaria prevention and treatment measures	-
Goal 7	Ensure environmental sustainability	Partial achievement
Target 10	Halve, by 2015, the proportion of people without sustainable access to safe drinking water.	Achieved/ close to universal access to safe drinking water
Indicator	Proportion of population with access to improved sanitation.	-

Source: Cisne Pascal, "Dominica: A Plan of Action for Localizing and Achieving the Millennium Development Goals" [online], Organization of Eastern Caribbean States, [23 July 2012], http://www.undp.org/content/dam /undp/library/MDG/english/MDG%20Country%20Reports/Dominica/Dominica_MDGReport_2006.pdf, 2006

Water and sanitation

By 2001, the majority of households in Dominica have had access to safe water through public water supply pipelines into their dwellings or via public stand pipes. Sanitation has improved in that a smaller percentage of households were without toilets in 2001 than in 1991.

Grenada

The main effect of climate change on Grenada's health system has been through the increased presence of vector-borne, communicable diseases, in the form of malaria, dengue fever, dengue haemorrhagic fever, leptospirosis and elephantiasis. There also have been recorded a wide variety of acute respiratory infections during the hurricane seasons from 1 June to 30 November. Gastroenteritis has become a problem during July precipitations.

The *Anopheles* mosquitoes thrive best in low-lying flood areas. The high incidence of gastroenteritis in Grenada has been associated with the use of pit latrines, as well as low-lying areas that store water during floods. Cases of all these diseases tend to be reported in excess during the annual hurricane season.

Jamaica[31]

Jamaica is highly vulnerable to hurricanes, flooding, and earthquakes. In a 2005 World Bank ranking of natural disaster hotspots, Jamaica ranked third among 75 countries with two or more hazards, with 95 per cent of its total area at risk.[10] Between 2004 and 2008, five major events caused damage and losses estimated at US$ 1.2 billion. These events have had a significant impact on human welfare, economic activities, infrastructure, property and natural resources. Outbreaks of dengue fever and leptospirosis experienced in 2007 were largely influenced by weather conditions.

Vector control

By 2008, Jamaica had made progress in the Millennium Development Goals targets for 2015, in halting, and reversing, the incidence of malaria and the provision of safe drinking water and basic sanitation. The sustainability of these two Goals has been impacted by extreme climatic conditions and this has, therefore, been detrimental to the health of the population.

[31] More information is available from http://www.jm.undp.org/files/GOJ%20National%20Report%20to%20 UNAMR-Final.pdf

The malaria outbreak of 2006 was managed by the public health system and—while it resulted in 191 cases—there were no associated deaths, due to the policies in place geared towards the treatment of malarial cases. However, vector control – to prevent the re-emergence of previously-controlled, communicable diseases – has proven to be challenging. The country has had two malarial outbreaks since 2006, with the number of cases in both outbreaks being approximately 386 by September 2008. The Ministry of Health responded by increasing surveillance, public awareness and access to education, strengthening laboratory capacity, and improving all forms of vector control and methods of early detection.

TABLE A4
MILLENNIUM DEVELOPMENT GOALS PROFILE FOR JAMAICA
GOAL 6: COMBAT HIV AND AIDS, MALARIA AND OTHER DISEASES

Targets	Indicators *(source)*	1990	2000	2008	Comment
6c	6.6 Incidence of malaria (imported prior to 2006)	0	7	191	Malaria had been eliminated for many years but there were 186 imported cases in 2006, followed by local transmission in 2007. Poor sanitation in urban inner-city areas now cited for more recent local outbreaks in Kingston.
	Deaths associated with malaria	0	0	0	

Source: Planning Institute of Jamaica, "Jamaica Millennium Development Report" [online], United Nations Economic and Social Council Annual Ministerial Review, Geneva, Switzerland, July, http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20Country%20Reports/Jamaica/Jamaica_MDGReport_2009.pdf, 2009

Water and sanitation

Water and sanitation indicators appear to have remained unchanged because of the difficulty in halving the gap since 1990, when the proportion of the population with access to safe drinking water was over 91 per cent, and with access to basic sanitation, over 99 per cent. The focus has been on improvements in the quality and sustainability of water access, with a target of 85 per cent of the population receiving piped water to their dwellings by 2015. Over the period 1990-2008, the proportion of the population with piped water to their dwelling has increased to 70 per cent (see table A4).

Improvements in the quality and sustainability of basic sanitation have focused on enabling universal access to water closets. Over the period 1990-2008, the proportion of the population with water closets has increased by 13 percentage points to 64 per cent. Increased attention is now being paid to upgrading sewage plants, cleaning drains and improving garbage collection in order to combat pests, improve vector control and mitigate damage from natural disasters.

TABLE A5
MILLENNIUM DEVELOPMENT GOALS FOR JAMAICA GOAL 7: ENSURE ENVIRONMENTAL SUSTAINABILITY

Targets	Indicators *(source)*	1990	2000	2007	Comment
7c.	7.8 Proportion of population using an improved drinking water source	91.7% (61.2%*)	91.5% (66.6%*)	91.7% (70.2%*)	92% have access to safe drinking water, while 98.9% have access to basic sanitation.
	7.9 Proportion of population using an improved sanitation facility (Planning Institute of Jamaica)	99.1% (51.4%**)	99.8% (62.2%**)	98.9% (64.3%**)	Access to water has improved but challenge is sanitation issues e.g., management of solid waste and poor hygiene.

Source: Planning Institute of Jamaica, "Jamaica Millennium Development Report" [online], United Nations Economic and Social Council Annual Ministerial Review, Geneva, Switzerland, July, http://www.undp.org/content/dam/undp/library/MDG

/english/MDG%20Country%20Reports/Jamaica/Jamaica_MDGReport_2009.pdf, 2009

N.B. The Millennium Development Goals definition of an improved drinking water source includes rainwater.
* Piped water at home (indoor or private outside).
** Use of water closet (exclusive or shared)

Saint Kitts and Nevis[32]

Vector control

There have been no incidences of malaria in Saint Kitts and Nevis prior to 2006. However, the authorities have continued to keep the environment clean, to eliminate possible breeding sites for such diseases.

Water and sanitation

The 2001 Survey of Living Conditions in Saint Kitts and Nevis reported that 65 per cent of the population had indoor piped water from a public source. Also, 90 per cent of the population has access to improved sanitation in the form of water closet, indoor bathing facilities and public garbage disposal system.

Saint Lucia

The low-lying coastal area of Saint Lucia and the occurrence of tectonic and cyclonic activities have made the country susceptible to any form of change in climatic conditions. The social and economic constraints of the country, while manageable, considered with the physical constraints of the coastline, put the country in a vulnerable position which will have a significant effect on the health of the population.

Malaria and dengue fever are said to be the two diseases that are likely to be most impacted by anthropogenic climate change (Bishnu and others, 2001). Dengue fever is considered endemic to the Caribbean, with regular outbreaks throughout the Caribbean, Saint Lucia being no exception. In the period 1998-2002, there were three indigenous cases of the eight that were reported for malaria. There were 49 cases of dengue fever confirmed in the period 1995-1999, and 86 cases in 2000-2005. The increase in the number of cases of dengue fever reported was due to the introduction of *syndromic surveillance* (PAHO, 2010) in which rapid tests for dengue fever were used to strengthen the surveillance system.

Climate change, through increased precipitation, is the factor responsible for the increases in the incidence of waterborne, food- and vector-borne diseases and their transmission. Temperature change can also spiral the incidence and prevalence of these diseases. If the rate of recurrence or strength of natural disasters should increase, the possible implications for Saint Lucia are centred on health, through the need for sanitation after the event and the cost of recovery of the systems that have been affected.

Suriname[33]

Access to clean water and sanitation services in Suriname is less than equitable. Water service in the country has a 2:1 urban-to rural ratio.

Vector control

Suriname has used the following indicators to track the progress of malaria in the country:

- Incidence and death rates associated with malaria
- Proportion of children under five sleeping under insecticide-treated bed nets
- Proportion of children under five with fever who are treated with appropriate anti-malarial drugs.

[32] More information is available from http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20Country%20Reports/Saint%20Kitts%20and%20Nevis/St%20Kitts%20and%20Nevis_MDGReport_2006.pdf,

[33] More information is available from http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20Country%20Reports/Suriname/Suriname_MDGReport_2009.pdf

Malaria cases reported in Suriname have been decreasing since 1995, because of the effectiveness of the health policies in the area and the implementation of the Roll Back Malaria programme. Malaria is prevalent, mainly in the interior districts of Brokopondo and Sipaliwini and, therefore, those have been the areas most targeted for the use of insecticide-treated bed nets. The preventive interventions of the Global Fund to Fight AIDS, Tuberculosis and Malaria and the Government of Suriname have reduced the total number of malaria positives from 12,197 in 2001 to 1,487 in 2008. These interventions accounted for the approximately 90 per cent reduction in reported cases of malarial incidence. It was also found that treatment with Coartem® [34] reduced the malaria mortality rate in the country. Suriname is on target to achieve the Goal to rid the country of malaria by 2015.

Water and sanitation

Approximately 91.7 per cent of the population in Suriname obtain their drinking water from an improved source, and 89.8 per cent of the total population is reported to use improved sanitation facilities (see table A6).

TABLE A6
SURINAME WATER-RELATED MILLENNIUM DEVELOPMENT GOALS

Goal	Will goal be reached?	Status of supporting environment
Halt and begun to reverse the incidence of malaria and other major diseases	Probably	Strong
Halve proportion of people living without access to safe drinking water and basic sanitation	Potentially	Weak but improving

Source: Suriname, "Suriname Millennium Development Goals progress report 2009" [online], Ministry of Planning and Development Cooperation, Paramaribo, [23 July 2012], http://www.undp.org/content/dam/undp/library/MDG/english/MDG%20Country%20Reports/Suri name/Suriname_MDGReport_2009.pdf, 2009

Trinidad and Tobago

While 69 per cent of households had water piped into the dwelling, only 26 per cent had a continuous supply of water in 2006 (PAHO, 2007). The majority of households in the country have access to storage tanks, and the safety of drinking water is tested by environmental degradation activities.

The leading cause of death in Trinidad and Tobago is ischemic heart disease.[35] However, the diseases promoted by climate change factors still pose a threat to the islands. Food-borne illnesses and leptospirosis have been on the decrease, whereas dengue fever, inclusive of dengue haemorrhagic fever and gastroenteritis has been increasing. There have been years in which there have been no cases of diseases like cholera and typhoid fever reported in the country. Malaria in Trinidad and Tobago was said to have been eradicated in 1965. However, in 2001-2005, 13 indigenous and 29 imported cases of the disease were reported, none of which resulted in fatality.[36] Gastroenteritis was the most frequently reported disease for the period 2000-2005.[37] Acute respiratory infections were also on the rise for the period 2000-2005.

[34] *Artemether Lumefantrine* tablets, a fixed-dose artemisinin-based combination therapy
[35] Central Statistical Office. Population and vital statistics report. Ministry of Planning and Development, Government of Trinidad and Tobago, 2010
[36] Pan American Health Organization, Trinidad and Tobago, 2007
[37] National Surveillance Unit, Trinidad and Tobago, http://www.health.gov.tt/sitepages/default.aspx?id=171

Annex 3
Total number of reported diseases across the Caribbean

TABLE A7
CARIBBEAN HISTORICAL DATA SET 1990 – 2005

Year	Malaria	Dengue fever	Leptospirosis	Gastroenteritis under age 5	Gastroenteritis over age 5
1990	8 359	573	315	19 657	0
1991	30 013	46	305	21 313	0
1992	36 175	951	390	23 856	0
1993	42 117	3 209	388	16 363	0
1994	44 361	600	362	18 425	10 227
1995	68 762	4 850	258	19 341	11 852
1996	40 712	3 985	382	31 241	14 061
1997	36 139	4 286	277	32 755	15 324
1998	12 772	6 258	354	19 605	12 759
1999	12 597	2 086	339	27 351	17 137
2000	21 131	3 581	280	29 627	20 542
2001	24 418	3 765	283	15 958	17 185.5
2002	2 921	7 641	343	18 798	17 574
2003	19 470	3 808	319	27 521	28 606
2004	30 613	1 045	349	37 545	29 089
2005	29 046	1 356	1 104	26 396	26 675

Source: Caribbean Epidemiology Center (CAREC), [online], http://www.carec.org, 2012

Annex 4
STATA[38] -generated model output

FIGURE A3
MALARIA

```
Random-effects Poisson regression               Number of obs      =       192
Group variable: country                         Number of groups   =        13

Random effects u_i ~ Gamma                      Obs per group: min =         1
                                                               avg =      14.8
                                                               max =        16

                                                Wald chi2(3)       =  21432.17
Log likelihood  = -78834.609                    Prob > chi2        =    0.0000
```

malaria	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
temperature	.4453178	.0038595	115.38	0.000	.4377532	.4528823
hdi	-8.007798	.0603483	-132.69	0.000	-8.126078	-7.889517
newrain	.0009258	7.84e-06	118.09	0.000	.0009104	.0009411
_cons	-.3830258	.8825505	-0.43	0.664	-2.112793	1.346741
/lnalpha	2.306829	.303374			1.712227	2.901431
alpha	10.04252	3.046641			5.541285	18.20016

Likelihood-ratio test of alpha=0: chibar2(01) = 4.0e+05 Prob>=chibar2 = 0.000

.

FIGURE A4
DENGUE FEVER

```
Random-effects Poisson regression               Number of obs      =       195
Group variable: country                         Number of groups   =        12

Random effects u_i ~ Gamma                      Obs per group: min =        12
                                                               avg =      16.3
                                                               max =        20

                                                Wald chi2(6)       =   2095.80
Log likelihood  = -28430.979                    Prob > chi2        =    0.0000
```

dengue	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
rain_1	.0004671	.0000251	18.64	0.000	.000418	.0005162
t	.0169674	.0010631	15.96	0.000	.0148837	.0190511
hdi	-1.188876	.0576798	-20.61	0.000	-1.301926	-1.075826
wind	-.1696081	.0105132	-16.13	0.000	-.1902137	-.1490026
temperature	.2489792	.0145967	17.06	0.000	.2203701	.2775883
humidity	-.0864238	.0048839	-17.70	0.000	-.095996	-.0768515
_cons	4.702703	.7056557	6.66	0.000	3.319643	6.085762
/lnalpha	.9010131	.3321588			.2499939	1.552032
alpha	2.462096	.8178068			1.284018	4.721055

Likelihood-ratio test of alpha=0: chibar2(01) = 4.3e+04 Prob>=chibar2 = 0.000

[38] STATA Data Analysis and Statistical Software for Professional Researchers

FIGURE A5
LEPTOSPIROSIS

```
Random-effects Poisson regression               Number of obs      =       177
Group variable: country                         Number of groups   =        11

Random effects u_i ~ Gamma                      Obs per group: min =        11
                                                               avg =      16.1
                                                               max =        20

                                                Wald chi2(4)       =     84.40
Log likelihood  =   -1981.61                    Prob > chi2        =    0.0000
```

lepto	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
rain_1	-.0034802	.0007362	-4.73	0.000	-.0049231	-.0020373
t	.0159955	.0025095	6.37	0.000	.011077	.020914
sanitation	3.193243	.8268395	3.86	0.000	1.572668	4.813819
rain_1san	.0039296	.0008096	4.85	0.000	.0023429	.0055163
_cons	-1.35515	.8140697	-1.66	0.096	-2.950697	.2403974
/lnalpha	.6099893	.3712959			-.1177373	1.337716
alpha	1.840412	.6833373			.8889296	3.81033

Likelihood-ratio test of alpha=0: chibar2(01) = 6698.79 Prob>=chibar2 = 0.000

FIGURE A6
GASTROENTERITIS IN CHILDREN UNDER AGE FIVE

```
Random-effects Poisson regression               Number of obs      =       178
Group variable: country                         Number of groups   =        12

Random effects u_i ~ Gamma                      Obs per group: min =         2
                                                               avg =      14.8
                                                               max =        16

                                                Wald chi2(4)       =    467.92
Log likelihood  = -3191.7693                    Prob > chi2        =    0.0000
```

gastround~_5	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
total_rain	.0007463	.0000415	18.01	0.000	.0006651	.0008276
temperature	.0843469	.0168958	4.99	0.000	.0512318	.117462
sanitation	-.6206173	.0758594	-8.18	0.000	-.7692991	-.4719356
t	.0080873	.0019244	4.20	0.000	.0043155	.0118591
_cons	4.045112	.6548795	6.18	0.000	2.761572	5.328653
/lnalpha	.8544506	.3322755			.2032027	1.505699
alpha	2.350083	.7808748			1.225321	4.507301

Likelihood-ratio test of alpha=0: chibar2(01) = 6.2e+04 Prob>=chibar2 = 0.000

FIGURE A7
GASTROENTERITIS IN THE POPULATION OVER AGE FIVE

```
Random-effects Poisson regression               Number of obs      =       120
Group variable: country                         Number of groups   =        10

Random effects u_i ~ Gamma                      Obs per group: min =        12
                                                               avg =      12.0
                                                               max =        12

                                                Wald chi2(3)       =   1125.03
Log likelihood  = -7301.9826                    Prob > chi2        =    0.0000
```

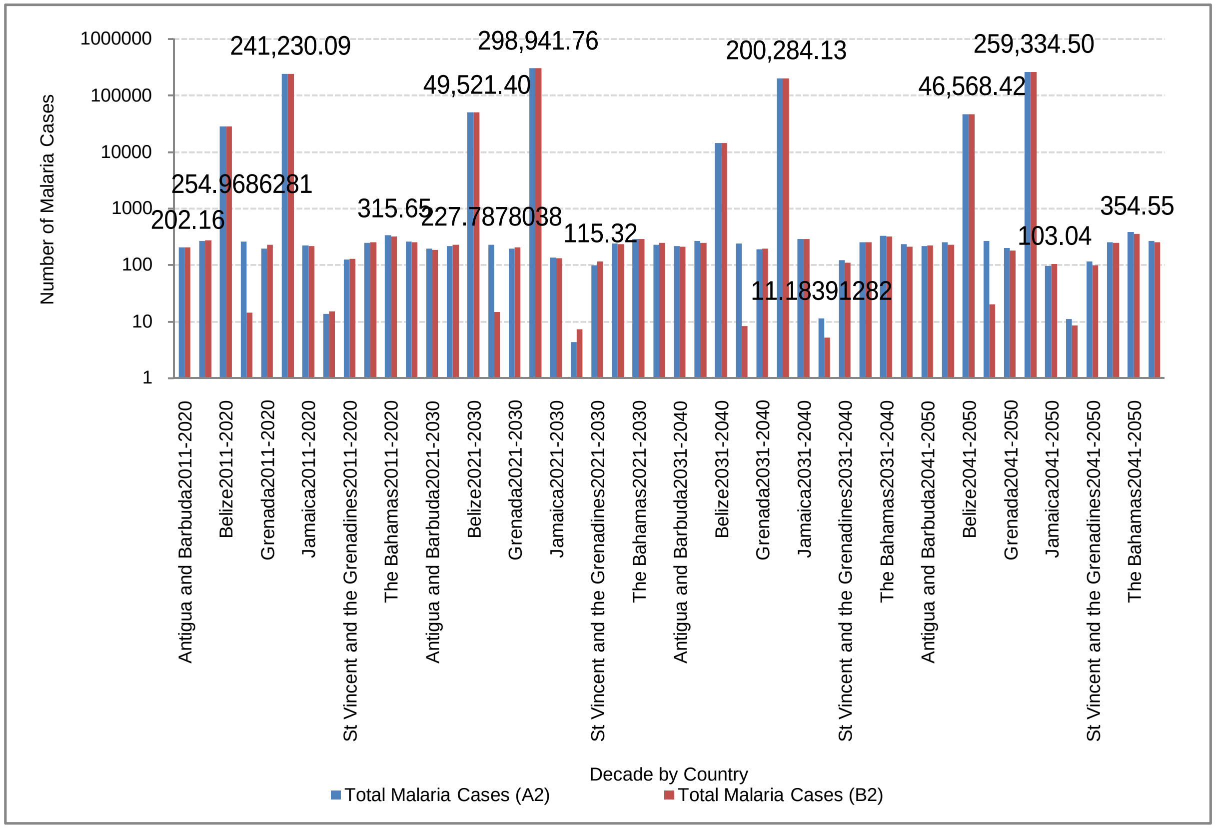
gastroover_5	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
newrain	-.0221944	.0007764	-28.59	0.000	-.0237162	-.0206727
temperature	-.4597066	.0334095	-13.76	0.000	-.5251879	-.3942252
tem_rain	.0008767	.0000299	29.35	0.000	.0008182	.0009352
_cons	16.48488	.923215	17.86	0.000	14.67541	18.29435
/lnalpha	-1.014123	.4250609			-1.847227	-.1810188
alpha	.3627204	.1541783			.1576738	.8344197

Likelihood-ratio test of alpha=0: chibar2(01) = 3064.19 Prob>=chibar2 = 0.000

.

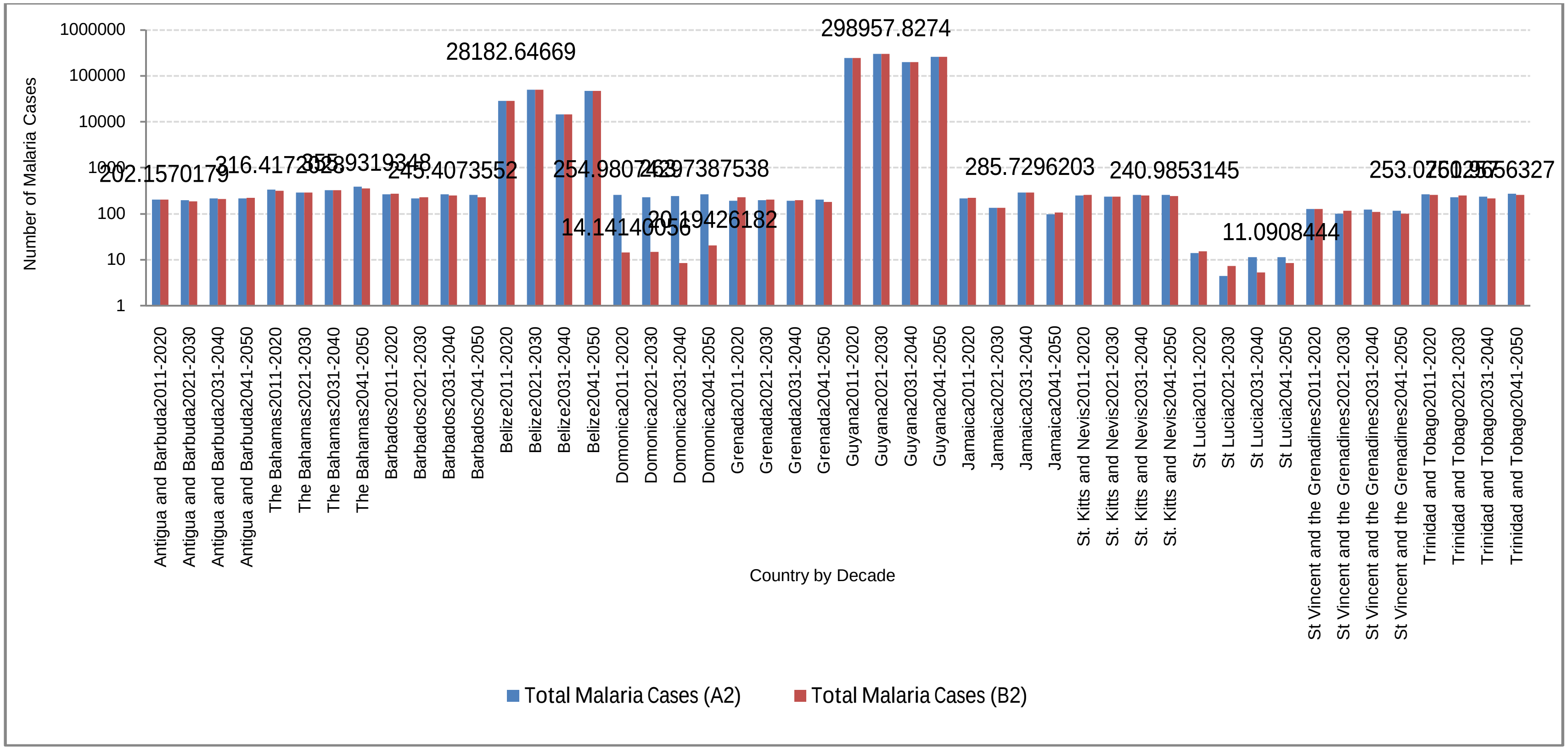
ANNEX 5
COUNTRY FORECASTS

FIGURE A8
FORECAST CARIBBEAN MALARIA CASES BY DECADE AND COUNTRY UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



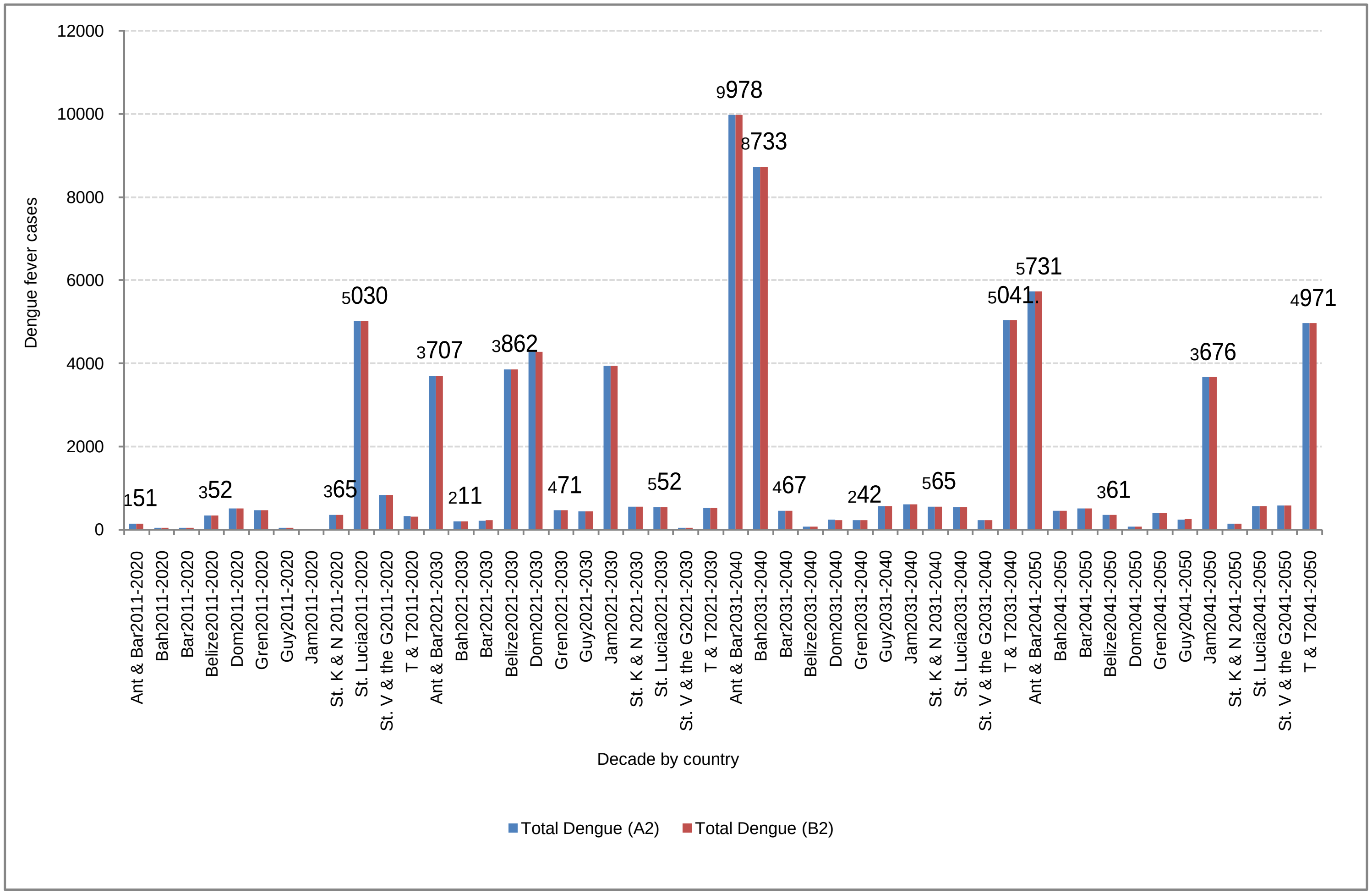
Source: Author's calculations based on results derived from Equation 1 and STATA -generated model output

FIGURE A9
FORECAST CARIBBEAN MALARIA CASES BY COUNTRY AND DECADE UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



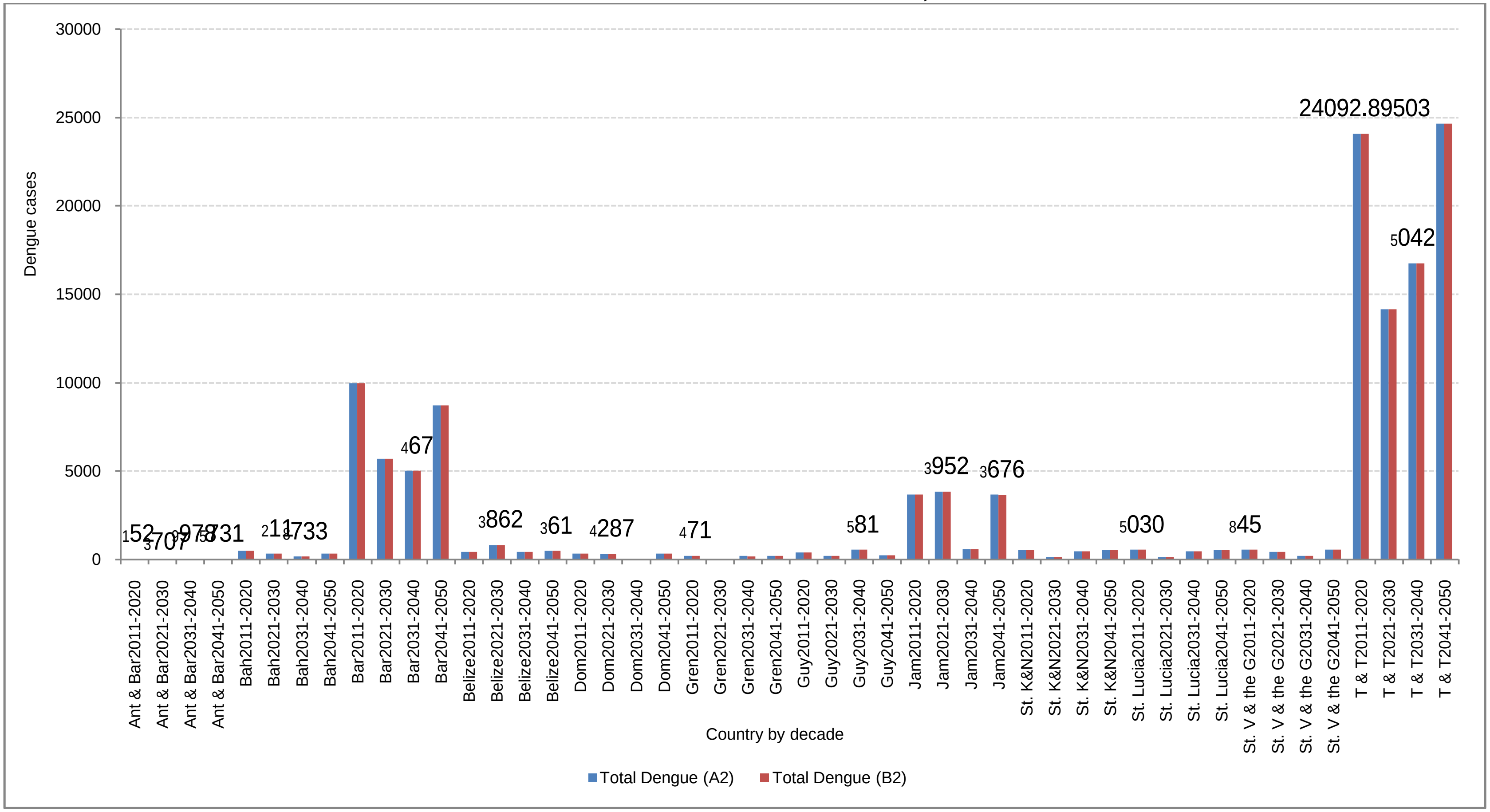
Source: Author's calculations based on results derived from Equation 1 and STATA -generated model output

FIGURE A10
FORECAST CARIBBEAN DENGUE FEVER CASES BY DECADE AND COUNTRY UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



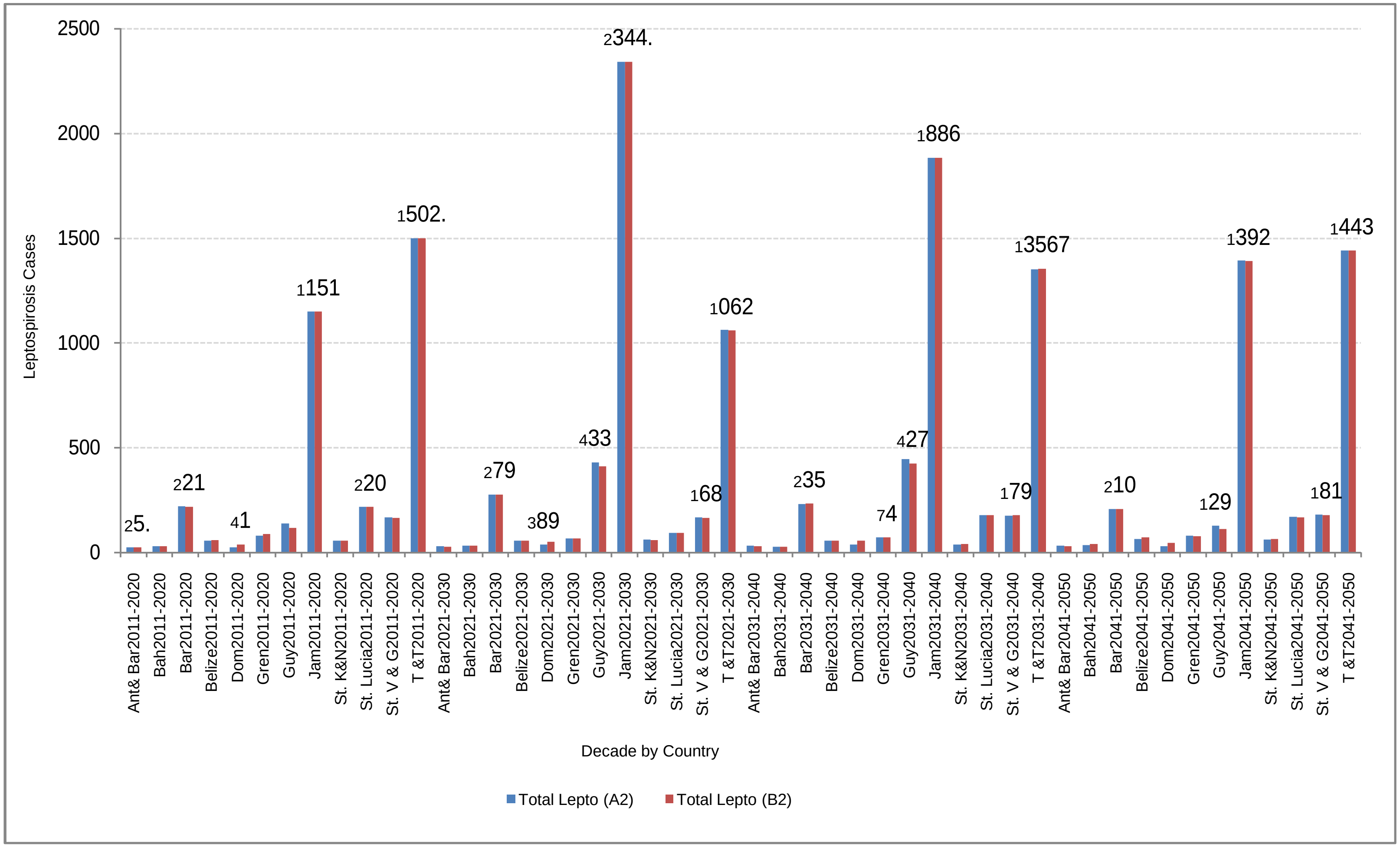
Source: Author's calculations based on results derived from Equation 2 and STATA -generated model output

FIGURE A11
FORECAST CARIBBEAN DENGUE FEVER CASES BY COUNTRY AND DECADE UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



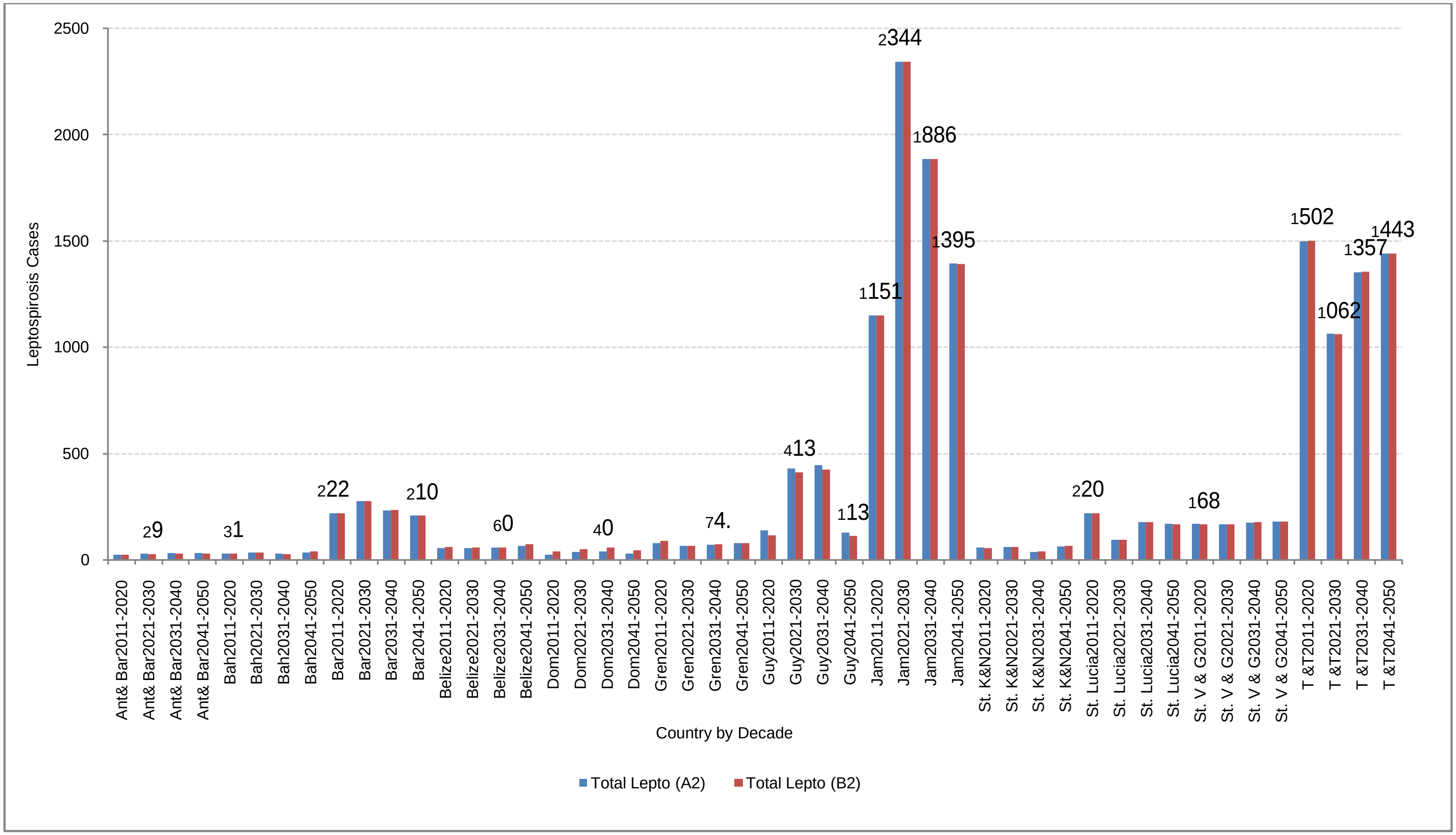
Source: Author's calculations based on results derived from Equation 2 and STATA -generated model output

FIGURE A12
FORECAST CARIBBEAN LEPTOSPIROSIS CASES BY DECADE AND COUNTRY UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



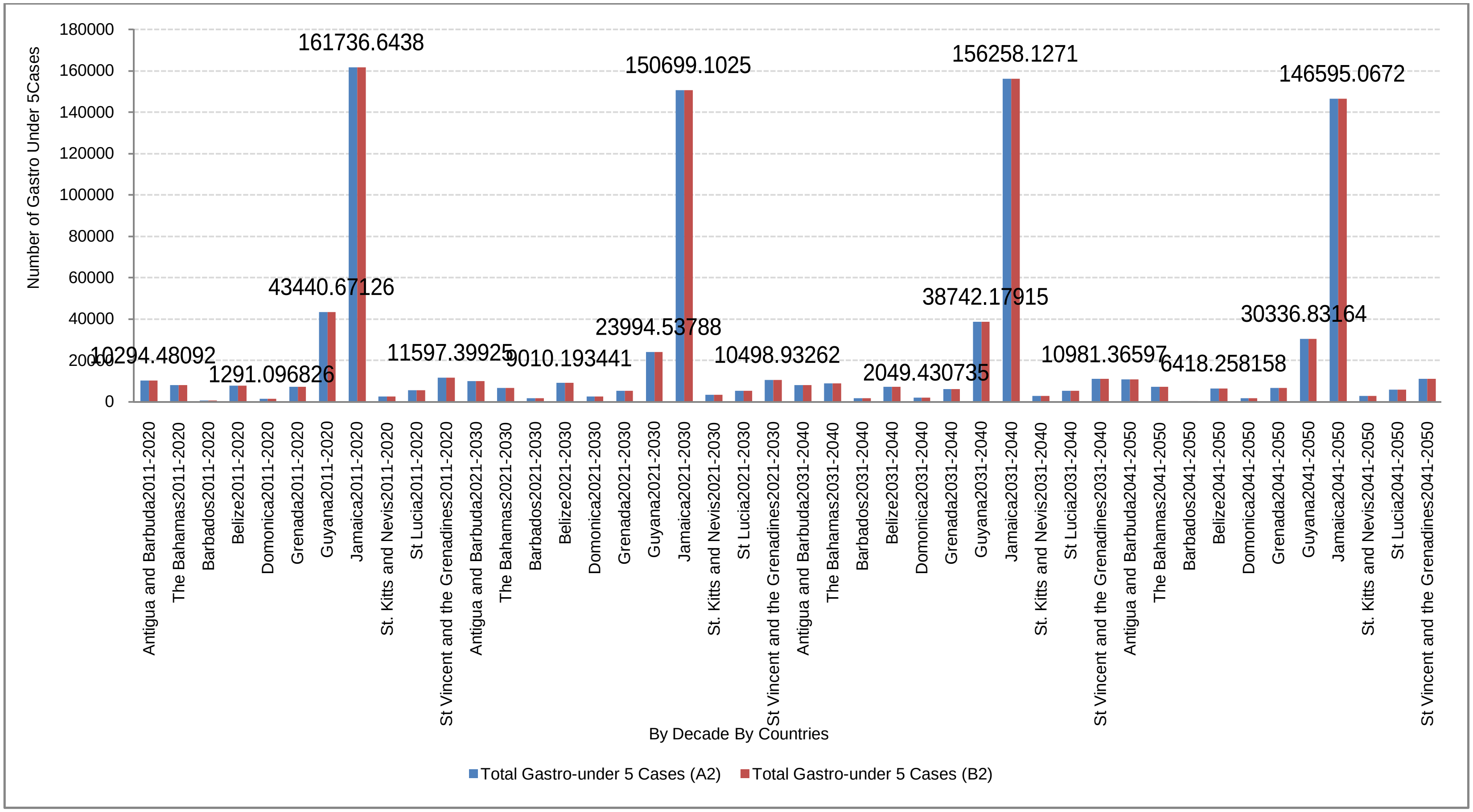
Source: Author's calculations based on results derived from Equation 3 and STATA -generated model output

FIGURE A13
FORECAST CARIBBEAN LEPTOSPIROSIS CASES BY COUNTRY AND DECADE UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



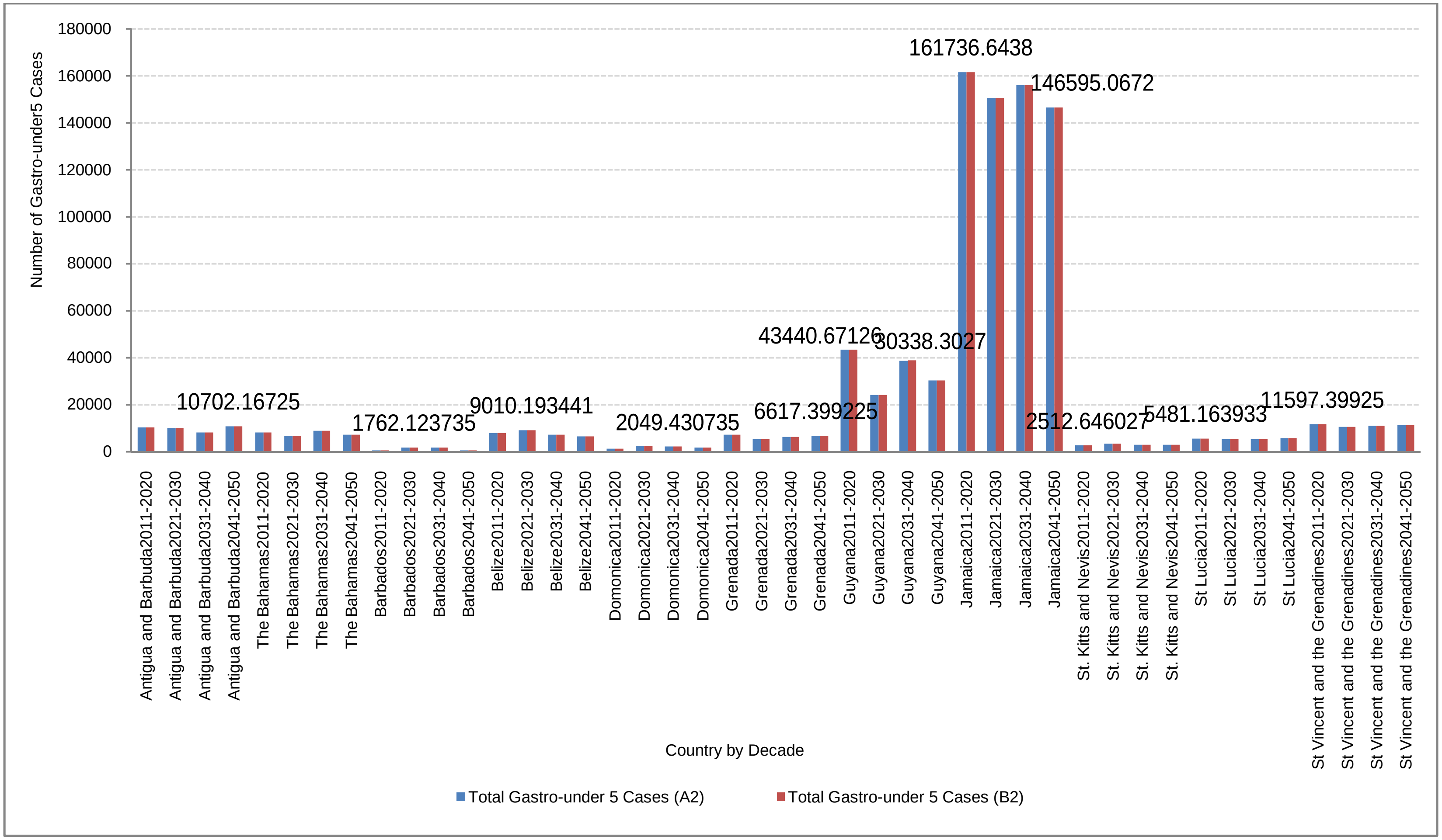
Source: Author's calculations based on results derived from Equation 3 and STATA -generated model output

FIGURE A14
FORECAST CARIBBEAN GASTROENTERITIS CASES IN CHILDREN UNDER AGE 5 BY DECADE AND COUNTRY UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



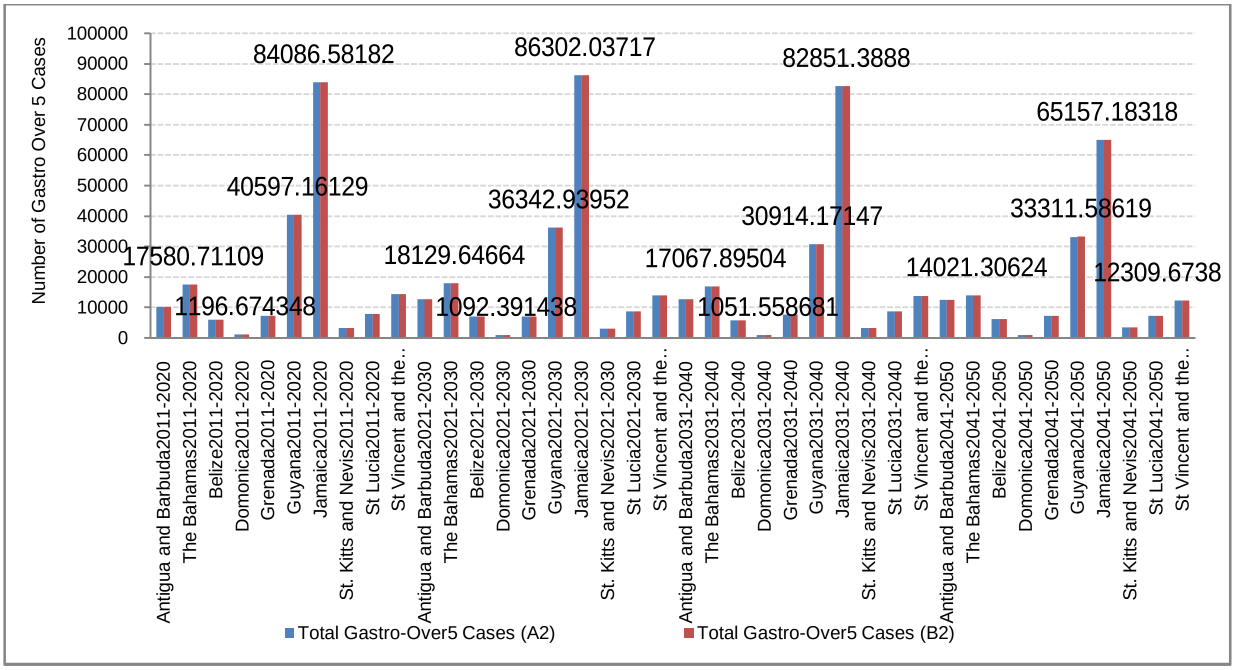
Source: Author’s calculations based on results derived from Equation 4 and STATA -generated model output

FIGURE A15
FORECAST CARIBBEAN GASTROENTERITIS CASES IN CHILDREN UNDER AGE 5 BY COUNTRY AND DECADE UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



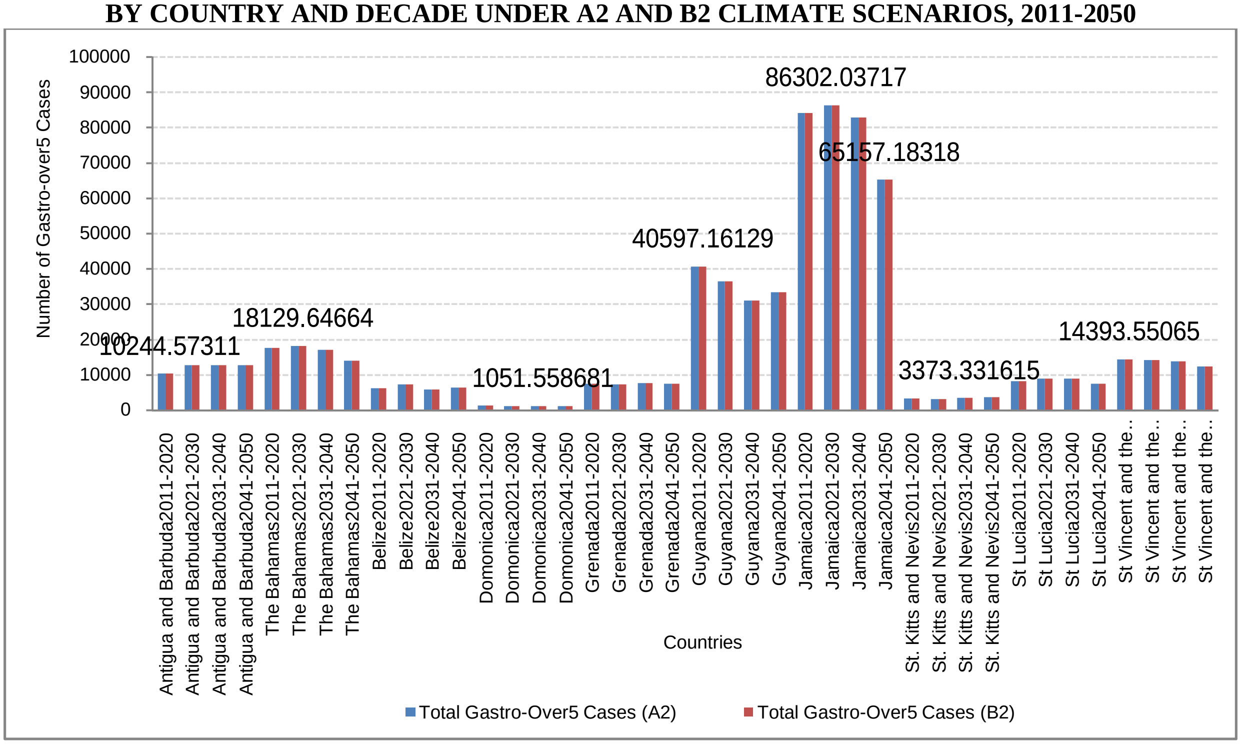
Source: Author's calculations based on results derived from Equation 4 and STATA -generated model output

FIGURE A16
FORECAST CARIBBEAN GASTROENTERITIS CASES IN POPULATION OVER AGE 5 BY DECADE AND COUNTRY UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



Source: Author's calculations based on results derived from Equation 5 and STATA -generated model output

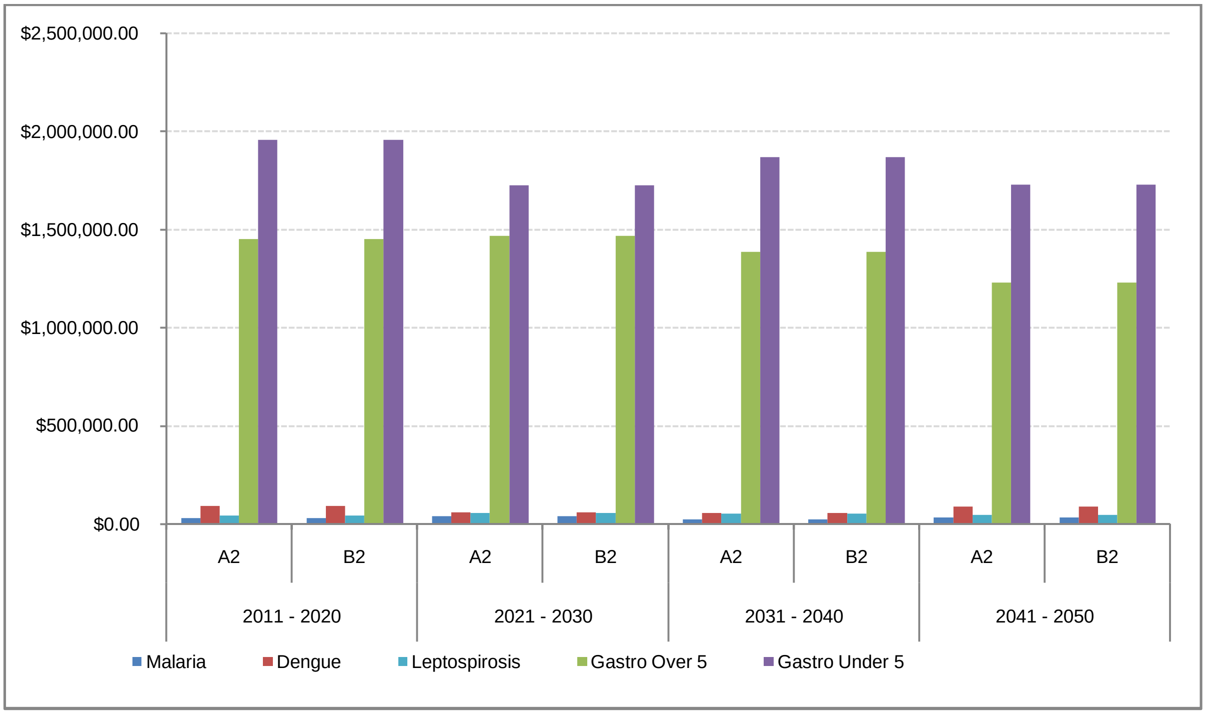
FIGURE A17
FORECAST CARIBBEAN GASTROENTERITIS CASES IN POPULATION OVER AGE 5 BY COUNTRY AND DECADE UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050



Source: Author's calculations based on results derived from Equation 5 and STATA -generated model output

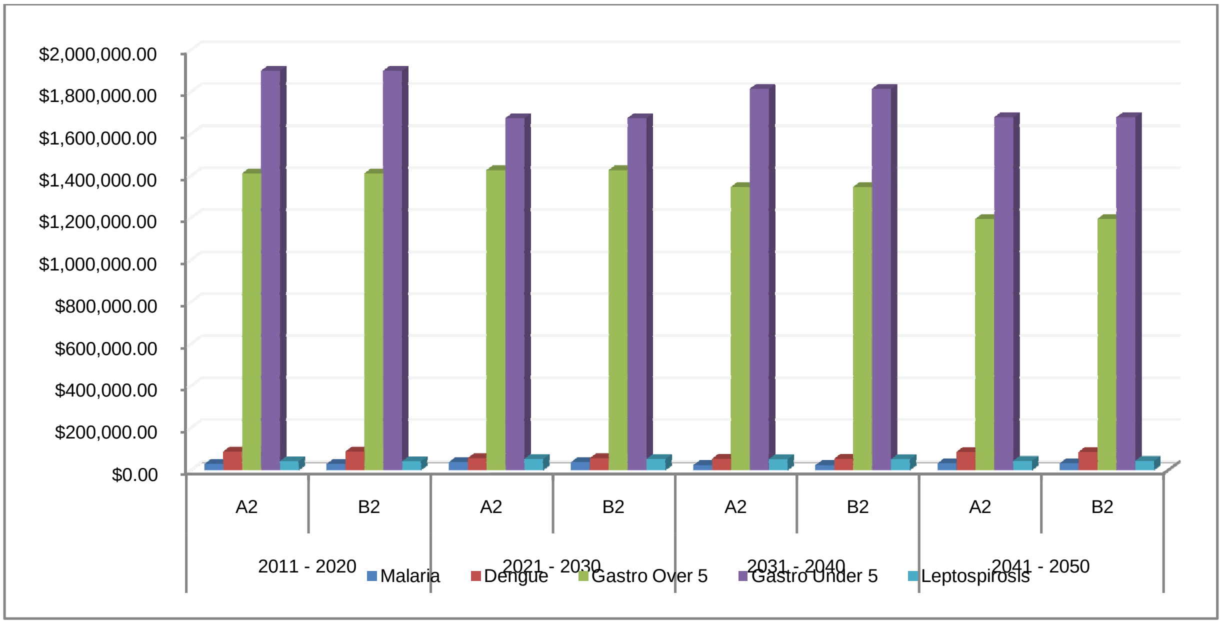
Annex 6
Net present value of direct, indirect and total costs associated with the impact of climate change on health in the Caribbean Discounted at 1% and 4% discount rates

FIGURE A18
DISEASE TREATMENT COSTS FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 1%



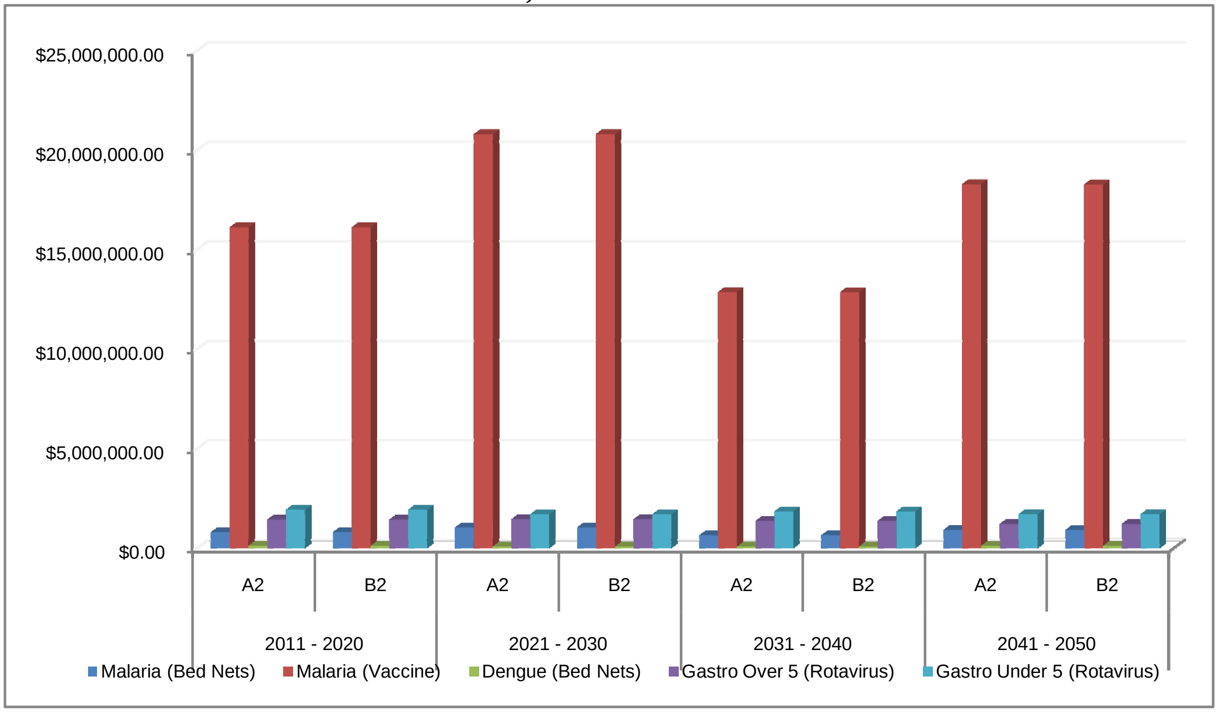
Source: Author’s Calculation based on methodology in Section IV sub-section A

FIGURE A19
DISEASE TREATMENT COSTS FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 4%



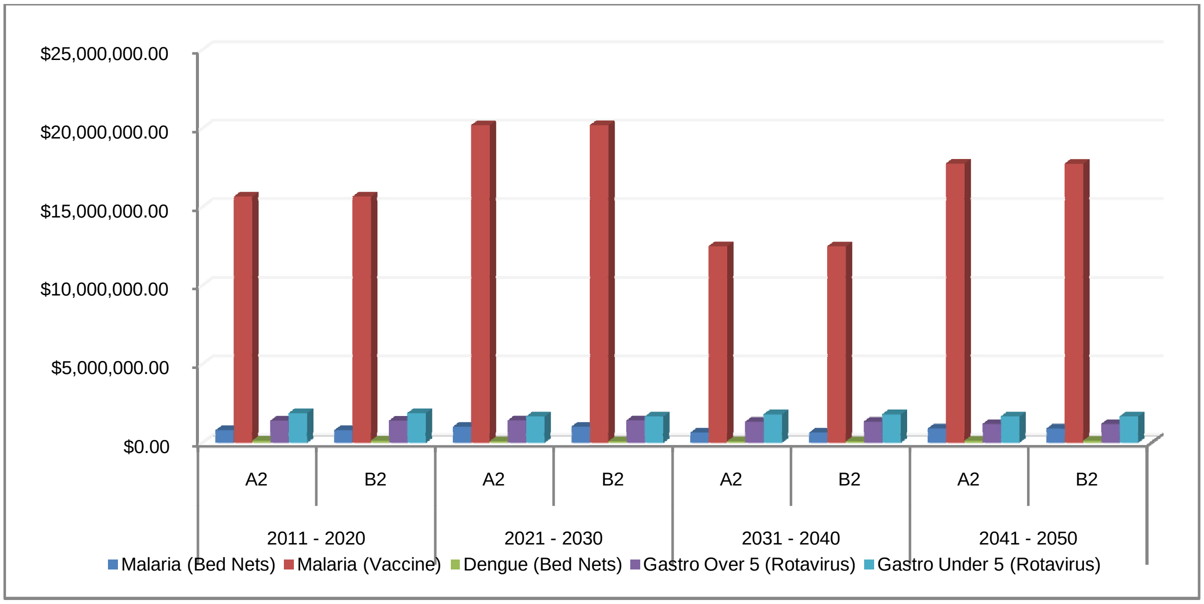
Source: Author's Calculation based on methodology in Section IV sub-section A

FIGURE A20
DISEASE PREVENTION COSTS FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 1%



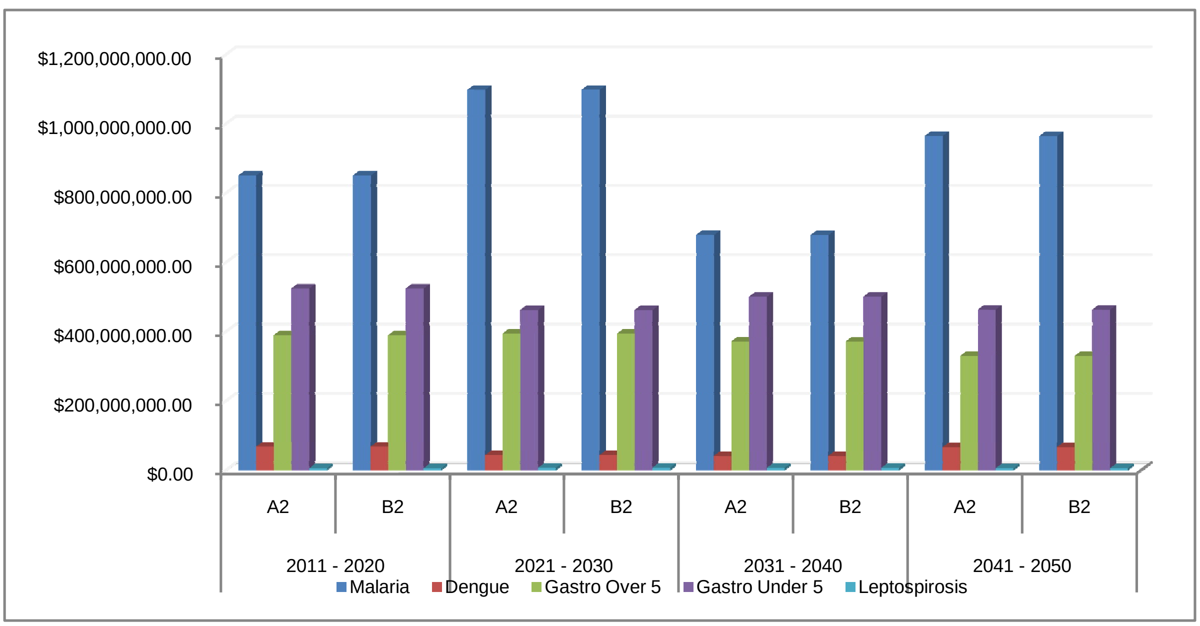
Source: Author's Calculation based on methodology in Section IV sub-section A

FIGURE A21
DISEASE PREVENTION COSTS FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 4%



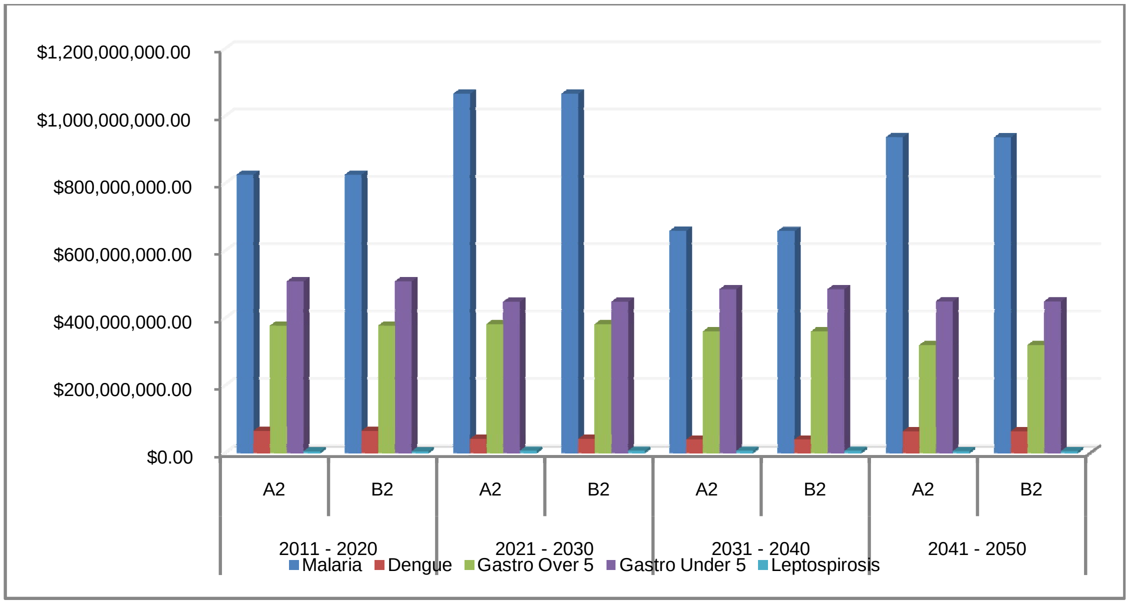
Source: Author's Calculation based on methodology in Section IV sub-section A

FIGURE A22
DISEASE PRODUCTIVITY LOSSES FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 1%



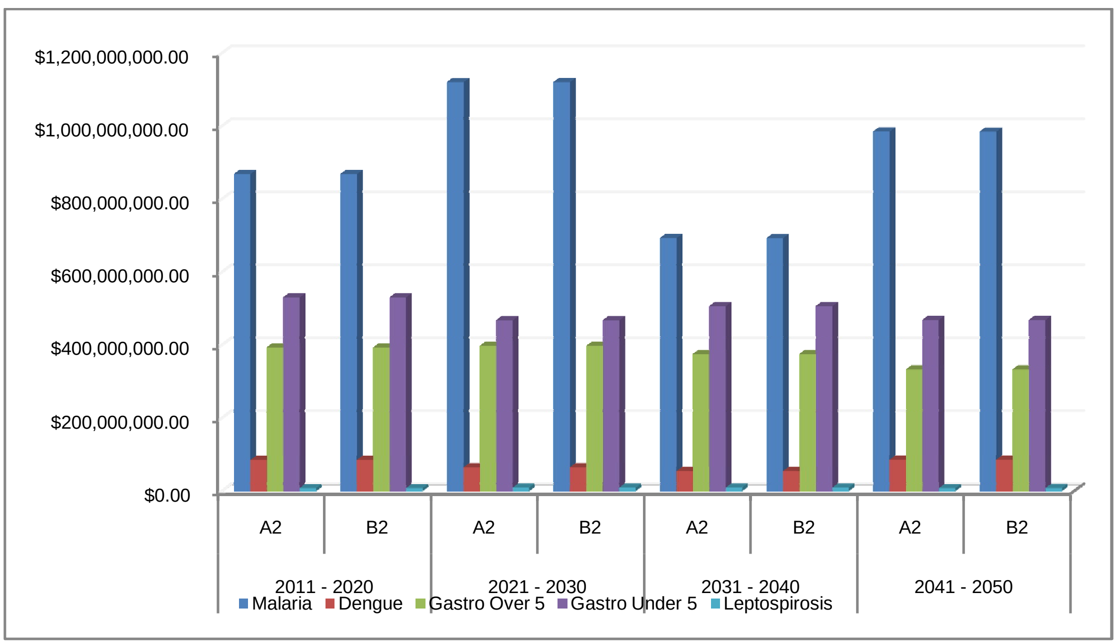
Source: Author's Calculation based on methodology in Section IV sub-section B

FIGURE A23
DISEASE PRODUCTIVITY LOSSES FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 4%



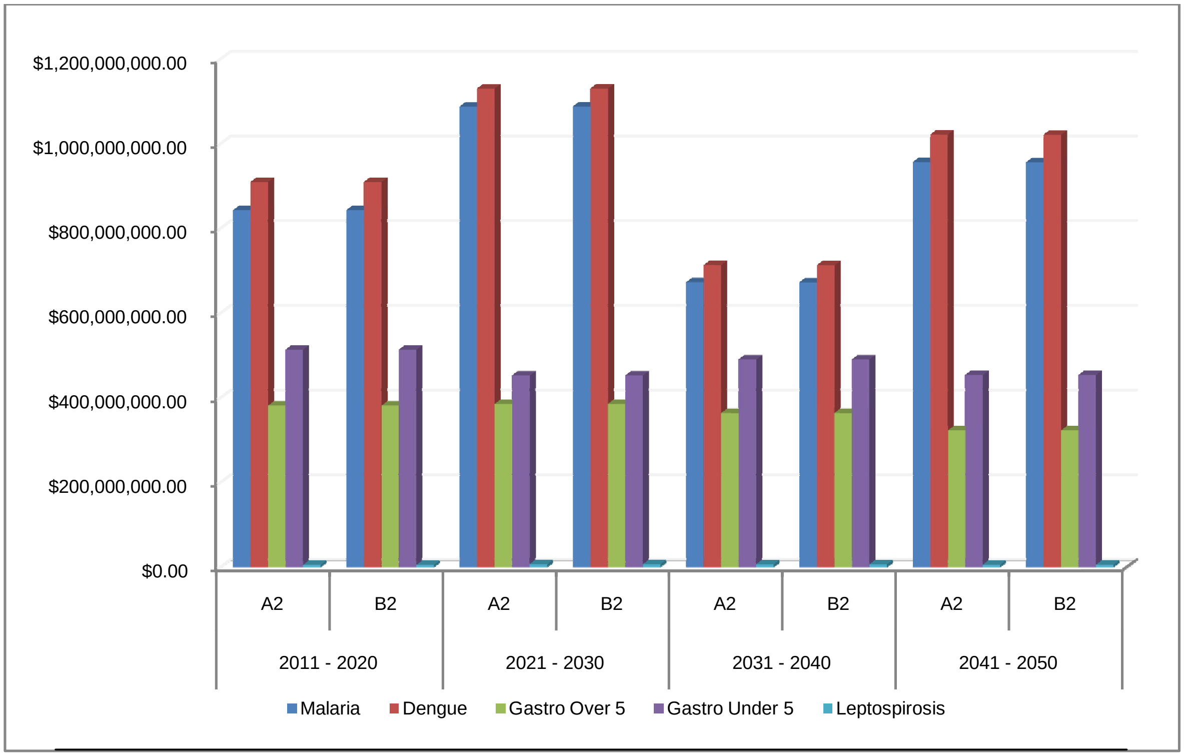
Source: Author's Calculation based on methodology in Section IV sub-section B

FIGURE A24
TOTAL HEALTH COSTS (DIRECT+INDIRECT) FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 1%



Source: Author's Calculation based on methodology in Section IV sub-sections A and B

FIGURE A25
TOTAL HEALTH COSTS (DIRECT+INDIRECT) FOR THE CARIBBEAN UNDER A2 AND B2 CLIMATE SCENARIOS, 2011-2050, DISCOUNTED AT 4%



Source: Author’s Calculation based on methodology in Section IV sub-section A and B