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# AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE HEALTH SECTOR IN GUYANA

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## Notes and explanations of symbols:

The following symbols have been used in this study:
A full stop (.) is used to indicate decimals
n.a. is used to indicate that data are not available
The use of a hyphen (-) between years, for example, 2010-2019, signifies an annual average for the calendar years involved, including the beginning and ending years, unless otherwise specified.
The word ―dollar” refers to United States dollars, unless otherwise specified.
The term ―billion” refers to a thousand million.
The boundaries and names shown and the designations used on maps do not imply official endorsement or acceptance by the United Nations.

# Acknowledgements

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# List of acronyms

| | |
|---|---|
| ARI | acute respiratory infection(s) |
| BAU | business as usual |
| CAREC | Caribbean Epidemiology Centre |
| CARICOM | Caribbean Community |
| CCCCC | Caribbean Community Climate Change Centre |
| CCRIF | Caribbean Catastrophe Risk Insurance Facility |
| CDERA | Caribbean Disaster and Emergency Response Agency (now CDEMA) |
| CEHI | Caribbean Environmental Health Institute |
| CIESIN | Center for International Earth Science Information Network |
| CMC | CAREC member country |
| DALY | disability adjusted life year |
| DLMAL | projected differenced log malaria |
| ECHAM | European Center Hamburg Model |
| ENSO | El Niño Southern Oscillation |
| EPA | Environmental Protection Agency |
| FDS | first dry season |
| FWS | first wet season |
| GHGs | greenhouse gas emissions |
| GIS | geographic information system |
| IMF | International Monetary Fund |
| IPCC | Intergovernmental Panel on Climate Change |
| ITCZ | Intertropical Convergence Zone |
| LMAL | projected log malaria |
| MAPE | mean absolute percentage error |
| MOH | Ministry of Health |
| PAHO | Pan American Health Organization |
| QALY | quality adjusted life years |
| RDC | Regional Democratic Councils |
| RECCC | Review of the economics of climate change in the Caribbean |
| SDS | second dry season |
| SIDS | small island developing States |
| SWS | second wet season |
| UNDP | United Nations Development Programme |
| UNECLAC | United Nations Economic Commission for Latin America and the Caribbean |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WHO | World Health Organization |

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# I. BACKGROUND AND PURPOSE OF REPORT

Climate change is considered to be the most pervasive and truly global of all issues affecting humanity. It poses a serious threat to the environment, as well as to economies and societies. Whilst it is clear that the impacts of climate change are varied, scientists have agreed that its effects will not be evenly distributed and that developing countries and small island developing States (SIDS) will be the first and hardest hit. Small island developing States, many of whom have fewer resources to adapt socially, technologically and financially to climate change, are considered to be the most vulnerable to the potential impacts of climate change.

An economic analysis of climate change can provide essential input for identifying and preparing policies and strategies to help move the Caribbean closer to solving the problems associated with climate change, and to attaining individual and regional sustainable development goals.

Climate change is expected to affect the health of populations. In fact, the World Health Organization (WHO), in *Protecting Health from Climate Change* (2008), states that the continuation of current patterns of fossil fuel use, development and population growth will lead to ongoing climate change, with serious effects on the environment and, consequently, on human lives and health.

Assessing the economics of potential health impacts of climate variability and change requires an understanding of both the vulnerability of a population and its capacity to respond to new conditions. The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the degree to which individuals and systems are susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes (WHO and others, 2003).

The United Nations Economic Commission for Latin America and the Caribbean (ECLAC), in collaboration with the Caribbean Community Centre for Climate Change (CCCCC), is pursuing a regional project to ―Review the Economics of Climate Change in the Caribbean" (RECCC). The purpose of the project is to assess the likely economic impacts of climate change on key sectors of Caribbean economies, through applying robust simulation modelling analyses under various socio-economic scenarios and carbon emission trajectories for the next 40 years. The findings are expected to stimulate local and national governments, regional institutions, the private sector and civil society to craft and implement policies, cost-effective options and efficient choices to mitigate and adapt to climate change.

The RECCC Project has three phases:

- Phase 1 (Feasibility Study) of the RECCC in which the feasibility of conducting studies on the costs and benefits of taking action aimed at adapting to and mitigating climate change in the Caribbean, compared to a BAU scenario, has been analysed. The Feasibility Study proposed Phase 2
- Phase 2 involved sector assessments of climate change impacts at the regional level
- Phase 3, of which the present study is a part, entails national economic assessments of the impact of climate change on key economic sectors in twenty-three ECLAC/CDCC countries participating in the RECCC Project. Each country identified three priority sectors for which assessments would be undertaken.

As stated above, the present paper forms part of RECCC Phase 3. The present paper will:

- provide relevant data and analyse information pertaining to the health sector, to estimate the costs of identified and anticipated effects with and without the impacts associated with climate change

- undertake an economic analysis of the effects of climate change-related impacts on the health sector in Guyana over the next 40 years, based on various carbon emissions trajectories under a BAU scenario and two other scenarios (A2 and B2 as defined by IPCC) with certain adaptation and mitigation measures.

The report consists of three main sections as follows:

- **Section 1: Literature review and situational analysis of climate change and human health in Guyana -** presents a review of the linkages between climate change and health with a focus on the main diseases in the Caribbean subregion that are most sensitive to climate change. The section also establishes that, of the main diseases affecting the Caribbean , malaria has characterized the Guyanese health sector and is a major public health problem in Guyana.

- **Section 2: Estimating the impact of climate change on human health in Guyana -** In this section, a predictive empirical statistical modelling approach is used to estimate the relationship between climate and disease for four diseases in Guyana – malaria, dengue fever, leptospirosis and gastroenteritis. This involves the estimation of an econometric model using a Poisson regression in order to obtain the historical relationship between each disease and climate variables such as rainfall, humidity and temperature, as relevant, for the period 2008 – 2010. The relationship estimated is guided by the findings in the health economics literature between disease, climate and non-climate proxies for the socio-economic conditions within Guyana that may have an impact on the number of cases for each disease. The Poisson approach has been used in the health economics literature, since disease data are by nature count data, for which the Poisson model is more appropriate than models such as Ordinary Least Squares. The model which performed well was then used to forecast the number of disease cases that could be anticipated between 2011 and 2050 under the IPCC A2 and B2 scenarios. Using these forecasts, the cost effectiveness of treatment and prevention were calculated based on the approach of Markandya and Chiabai (2009) that developed a similar framework for various diseases in Africa. This provides an estimate of magnitude of the total direct costs that the Guyanese health sector could face in the four decades between 2011 and 2050. The productivity losses associated with the forecast cases were also estimated for the period 2011 and 2050 using the lost GDP, days lost, and the number of cases. All the direct costs and productivity losses were discounted using a rate of 2% to provide comparable present value estimates.

- **Section 3: Adaptation strategies –** discusses the fact that estimating the adaptation costs in the health sector is challenging not only because of the large existing uncertainties about how the climate will evolve over the coming century, but also because of the complex and often poorly understood chains through which health impacts are mediated. This section provides a comparative analysis of specific adaptation strategies or health interventions that can be implemented by the authorities to impact 10%, 40% and 50% of the Guyanese population. The total cost of extending these interventions to the respective segments of the population is calculated as the product of the number of persons in the population to be treated and the per person unit cost of the intervention. The two benefits that are calculated for each intervention are: (1) the value of the treatment costs that are averted as a result of the reduced number of cases in the treated population; and, (2) the value of the productivity losses that are averted as a result of the reduced number of cases in the treated population. These two benefits are summed to provide an estimate of the total benefits of the intervention being considered. The results of this section are intended to provide policymakers with a sense of the costs and benefits associated with addressing the additional disease cases of malaria, dengue fever, leptospirosis and gastroenteritis forecast in the previous section with particular health interventions between 2011 and 2050.

# II. LITERATURE REVIEW AND SITUATIONAL ANALYSIS OF CLIMATE CHANGE AND HUMAN HEALTH IN GUYANA

## A. SOCIO-ECONOMIC AND ENVIRONMENTAL CONTEXT

This country profile is necessary to the present report as it provides useful data and information for assessing the impacts of climate change on human health in Guyana. It is well known that the impacts of climate change on human health are affected by varying factors prevailing within a country. Some of these include the effectiveness of the public health service, population and demographic structure (where certain age groups are more vulnerable to certain health impacts) and location (e.g. persons in coastal regions are more vulnerable to hurricane impacts), socio-economic and environmental conditions, and national disaster preparedness and response. This is set against the baseline health status in the country from which climate change-induced impacts can be measured. Data from these diverse sectors are included here in order to ensure that overall assessment is comprehensive.

### 1. Geography and climate

Guyana, with an area of 83,000 square miles or 215,000 square kilometres, is located on the northern coast of South America, and is the only English-speaking country on that continent. The country is bordered by Suriname (formerly Dutch Guiana) on the east, Venezuela on the west and by Brazil on the south. The northern coastline faces the Atlantic Ocean.

Guyana is located at latitudes of 2°- 8° North of the equator and experiences a typically warm and moist tropical climate. Mean air temperature is 25°- 27.5° C throughout the year in most regions except the upland regions in the west of the country, where mean temperatures are a cooler 20°- 23° C. Guyana experiences two _wet‘ seasons; most of the country receives 250-450mm per month between May and July, and the second wet season affects mainly the northern, coastal regions which receive around 150-300mm per month in November to January (McSweeney and others, 2008). The Rupununi Savannahs experience one wet season (May-September) and one dry season (October- April). Relative humidity is high with 80% or more on the coastal zone, approximately 70% in the savannah zone and 100% in the forested zone (EC, 2006).

There are four main tropical and extra-tropical weather systems which influence weather in Guyana. These are: Intertropical Convergence Zone (ITCZ); Tropical Waves; Upper Level Troughs; Southern Hemisphere Upper Troughs; and El Niño Southern Oscillation (ENSO). Inter-annual variations in climate in this region are caused by the El Niño Southern Oscillation (ENSO). El Niño episodes bring dry conditions throughout the year and warmer temperatures between June and August, whilst La Niña episodes cause wetter conditions throughout the year and cooler temperatures between June and August (UNDP, 2009).

Guyana consists of four main natural regions. The coastal zone is a narrow, alluvial belt consisting mainly of clay and is about 2m below sea level. To the north-east of the country, sandy rolling plains stretch inland and gently undulate with altitudes that vary from 5m - 120m above sea level. The hilly sand and clay region is found just inland of the coastal zone, and is mostly covered with vegetation. The area takes up about 25% of the total area of the country. The interior savannahs account for almost 11% of the country's area and are vegetated mostly by grasses, scrub and low trees. The savannahs extend in the west from the southern part of the sandy rolling plains to the Rio Branco savannahs of Brazil. The main grasslands, known as the Rupununi savannahs, are characterized by intense dry periods. The forested highlands make up approximately 64% of the country's landmass. There are four major mountain ranges in this region; Kanuku, Pakaraima, Imataka and Acarai. The interior is very sparsely populated, principally by native Amerindian communities (EC, 2009).

The country is divided in 10 administrative regions and the local government structure consists of 10 Regional Democratic Councils (RDC), 65 Neighbourhood Democratic Councils (NDC), 6 municipalities and 76 Amerindian Village Councils. According to the existing government structure, the RDCs are administratively responsible for the delivery of services such as health and education to their respective populations (PAHO, 2009).

Regions 1, 2, 3, 4, and 5 are along the coast; Georgetown, the capital city is located near the border of Regions 3 and 4 and, consequently, the population as well as services and infrastructure are concentrated in these two regions. Region 6 includes portions along the coast and some inland areas and regions 7, 8, 9, and 10 are collectively referred to as ―the hinterland". There is great disparity among the regions, and socio-economic, infrastructural and environmental conditions vary greatly from one region to the next, requiring different policy interventions.

## 2. The Economy

In 2009, the country‘s GDP at current cost factor stood at G$ 202,258 million (US$ 1,006 million), with a growth rate of 6% (Bureau of Statistics, 2010). According to the United Nations database, GDP per capita (current US$) has increased, rising from US$ 970.4 in 2000 to US$ 1,542.7 in 2008. The Gross National Income (GNI) per capita was estimated at US $1,130 in 2006 (UNDP, 2009). Gross National Income per capita is 2008 was US$ 1,502.3 which is a 65% increase from US$ 910.5 in 2000 (United Nations, 2011). Guyana is listed among the world‘s heavily indebted poor countries (IMF, 2011).

Guyana relies heavily for its economic existence on the production and export of a few virtually unprocessed commodities, and the economy is traditionally based on three main export commodities: sugar, rice and minerals such as gold and bauxite. The most important sector in terms of contribution to GDP in Guyana is the agriculture, forestry and fishing sector, followed by government services, transport and communications, and mining and quarrying. The agricultural sector, which is based largely on sugar and rice production, is the major contributor to the Guyana economy and in 2008 accounted for about 36.3% of GDP (WTO 2009).

The forestry sector is another major economic contributor to the national economy, bringing in a significant portion of the national gross domestic product. Forests cover over 16 million hectares or 75% of the land surface of Guyana. Forest products comprise only a comparatively small percentage (about 4%) of annual export earnings. In addition to their economic importance, the Guyana forests provide habitat and food for native Guyanese (European Commission, 2006), and is the natural resource base for the country‘s tourism product, which has been growing in importance; the Government has highlighted ecotourism as an area for development.[1]

The 2002 Population and Housing Census reported that 19.7% of the labour force was employed in agriculture, hunting, and fishing. Farming households have a lower standard of living than non-farming households (EC, 2006). In fact, there is a higher incidence of poverty in rural areas where the poor are

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[1] Guyana National Development Strategy 2001 - 2010

largely self-employed in agricultural labour or manual labour. In contrast, poverty in urban areas is highest among the unemployed (Government of Guyana/ World Bank, 2001).

In 2010, Guyana was ranked 104 out of 169 countries on the Human Development Index. Investments in health, education, housing, water, sanitation and poverty programmes have increased from a baseline of 15.2% in 1997 to 20.8% of GDP in 2001 and 22% in 2005. These increased allocations have improved access to basic social services over that period, although challenges remain in the hinterland regions (Government of Guyana, 2007). In 2009, health expenditure as a percentage of national budget stood at 9.9%, compared to 7.5% in 2005 (Bureau of Statistics, 2010).

Although Guyana is very rich in natural resources, the country still faces considerable challenges in terms of overcoming poverty and providing for the equitable development of its people. Unemployment[2] is intrinsically related to poverty and remains a grave challenge as unemployment is increasing. Generally, unemployment is higher among women (19.6%) than men (9.04%). There is also a geographic dimension to unemployment in Guyana. At the regional level, it is highest in Regions 10, 9, 7, 4 and 6. Moreover, whereas men and women of Region 10 face this problem equally, more women face unemployment in both Regions 6 and 4 (European Commission, 2006).

According to the Guyana Millennium Development Goals Report for 2007, the proportion of those in extreme poverty comprised 19% of the population. The Household Income and Expenditure Survey undertaken in 2007 found that 31% of the Guyanese population is unable to afford the expenditure required for the basket of basic food and non-food items that define the national poverty line. The International Food Policy Research Institute places Guyana fifteenth of 84 countries in the 2009 Global Hunger Index.[3] Amerindians recorded the highest level of poverty among ethnic groups, while the prevalence of poverty is higher among women than men. Approximately 50% of Guyanese women are living in poverty, and nearly 30% of the households headed by women are characterized by absolute poverty; Amerindian women in rural areas were even more vulnerable than Afro- or Indo-Guyanese women (UNDP, 2009).

## 3. Population and demographics

In 2008, the population of Guyana was 763,000 (WHO, 2010). Compared to its land area (approx. 215,000 km$^2$), the population of Guyana is relatively small; the country has a population density which is less than four persons per km$^2$ of land area.

The country has experienced a consistently slow population growth rate over the last decade. In percentage terms, the population grew by 3.8 % between 1991 and 2002, reversing the decline of 4.7% experienced between 1980 and 1991. The life expectancy at birth in years for 2002 and 2007 was 64.1 and 66.8, respectively. The crude birth rate (CBR) was 17.1 in 2007 and the crude death rate (CDR) was 12.5 per 1,000 population for the same year. The total fertility rate in 2007 was 2.3 – showing a downward trend from 3.1 in 1990 (PAHO, 2009).

Four of the ten Administrative Regions have urban centres; in 2008, the combined population of these towns and the capital city of Georgetown accounted for 28% of the population. The remaining 72% of the population is clustered in villages, mostly along the coastal belt, as well as a few other settlements scattered deep in the country‘s hinterland (PAHO, 2007). The population of Guyana is concentrated along the coastline (Regions 4 and 6), with 43.1% located in Region 4 alone. Regional growth rates are

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[2] Unemployment is not measured systematically in Guyana, and private-sector information on employment is poor (WTO, 2009). The latest available unemployment figures were collected during the population census in 2002.

[3] A higher ranking on the Global Hunger Index is an indication of a greater level of malnutrition in the country.

highest for Region 8 (5.2% per annum), followed by Regions 1 and 9 with rates of 2.4% and 2.2 %, respectively. The other regions have lower growth rates (PAHO, 2009).

More than 90% of the population live in the coastal area where most of the economic activity takes place (EC, 2006). Marked disparities exist between coastal communities and the hinterland, especially as they relate to poverty levels, access to goods and services, employment opportunities and income levels (PAHO, 2009).

The country‛s population is aging and since 1970, there has been a decline in the numbers of those in the youngest age groups (0 – 9years), indicating a lowering of fertility rates. The median age of the population has also increased to 22.9 years from 18.6 in 1980 and 21.8 in 1991 (Bureau of Statistics, 2007). Additionally, the out-migration of Guyanese is also contributing to this phenomenon and remains a key future concern (EC, 2006). While the sex ratio is evenly balanced between males and females, there are variations within various age groups.

Guyana is a multiracial society comprising East Indian Guyanese (28.4%), African Guyanese (30.2%), Mixed (16.7%), Amerindians (9.1%) and Other (0.5%) (2001 Census). Although the official language is English, there are at least eight different languages spoken throughout the country (UNDP, 2009)

The indigenous peoples of Guyana (collectively known as Amerindians) are also major inhabitants of the hinterland, forest, savannah and highland. There are nine remaining tribes left, the Wapishiana, Akawaio, Arekuna, Macushi, Carib, Warrau, Patamona, Arawak and the Wai Wai. One issue of primary concern among Amerindian communities is land rights. Only half of the communities hold clear title to their land, despite a land titling programme in place since 1969 (European Commission, 2006). Amerindians, the predominant population group throughout most of the country‛s interior, are also the poorest social sector group and exhibit some of the lowest health indicators in Guyana.

## 4. Housing

The household population has grown only 3.3%, while the number of households has grown by 20.5%.The largest increase in housing has been in the coastal region that includes Georgetown (PAHO, 2005). The number of households has increased from 154,153 in 1991 to 182,609 in 2002 - an 18.5% increment. Approximately, 43% of all households are in Region 4, 17% in Region 6 and 14% in Region 3. These regions, in the same order of rank, were also the most populous regions in 1991, except that the proportions increased slightly in 2002. The majority of all households (71%) are headed by a male. This figure was slightly smaller than that of 1991 (Bureau of Statistics, 2007).

Household size is another poverty indicator which can be determined from the census data by using average household size as a proxy. Household size declined from 4.7 persons per household in 1991 to 4.1 persons in 2002, indicating a large increase in standing houses. At the regional level, Regions 2, 3, 4, 5, 6 and 10 are almost at the national average. In Regions 1, 8 and 9, however, average household size is above the national average, nearly 6 persons. This is an indicator of where some of the poorest households may be located (Bureau of Statistics, 2007). Overcrowding in buildings is therefore common in this region, particularly within mining communities. This encourages the transmission of obstructive pulmonary and other communicable diseases. Furthermore, the lack of housing has encouraged the expansion of squatting areas (Government of Guyana, 2001).

## 5. Water supply

A total of 80% of households have improved access to water (piped into house or yard, from bore hole, spring or rainwater), as defined by the Millennium Development Goals target for water (Bureau of Statistics, 2007).

Guyana has a high level of coverage for water supply in the capital city and coastal strip where the majority of the population resides. Although water resources are generally abundant, there are problems related to reliability of water services, water quality and consequently the spread of waterborne disease in Regions 1, 7, 8 and 9. With the exception of Georgetown, water is available for few hours a day, typically (EC, 2006).

Adequate water treatment levels remain below the WHO guidelines in many water systems. To compound matters, the poor condition of pipes allows for leakage and heightened risk of microbiological contamination. Inadequate inspections by the water authority have resulted in improper household connections, where it has been observed that pipes cross trenches with polluted water. (PAHO, 2009).

More than one third of households in Region 7, and a little over half in Regions 1 and 9, drink from unprotected dug wells and springs, and ponds/rivers or streams. The proportion of drinking from such water supply sources is quite substantial in Region 8, up to three-quarters of households, in addition to some 19% of households in Region 10 who have reported to obtain drinking water supply from like sources (Bureau of Statistics, 2007).

The high rate of diarrhoea is an indication of the many deficiencies of the water and sanitation sector. This was substantiated by an assessment conducted in 2002 by the Joint Monitoring Programme for Water Supply and Sanitation (JMP-WHO/UNICEF) which found that 7.7% of children under age 5 living in urban coastal areas had episodes of diarrhoea (PAHO, 2009).

As mentioned earlier, about 90% of the Guyana population live on a coastal belt that is 2 metres below sea level at Mean High Water (MHW). Most of the potable water being provided by artesian wells whose water tables are susceptible to saltwater intrusion makes increased salinity content of freshwater supplies, and the possible increase in water treatment costs, real possibilities in the face of climate change. Already, specific areas suffer from saltwater intrusion mainly due to the many drainage canals and water outlets overtopping and flooding as a result of heavy rainfall. Any rise in sea level that will exacerbate this situation can only lead to additional losses of millions of dollars, due to further destruction of livelihoods, degradation in the quality of life and decline in land quality. Since the coast is critical to the economic development of the entire economy, the ripple effects are expected to extend further than the coastal regions of Guyana (European Commission, 2006).

## 6. Sanitation

The modernization of the housing stock in Guyana has resulted in the increased use of water closets linked to a cesspit or septic tank. According to the 2008 Sanitation Strategic Plan for Guyana, 66% of households have pit latrines, and 24% have septic tanks. Two thirds of households still use pit latrines. However, 50% of pit latrines are below WHO Guidelines (JMP- WHO/UNICEF 2002) and many septic tanks are not properly operated or maintained. The only waterborne sewerage system, serving 7% of the national population in central Georgetown, is old and in urgent need of major rehabilitation (PAHO, 2009).

Disposal of solid waste is of grave concern in Georgetown. Solid waste disposal practices in Guyana have not kept pace with the demands posed by increases in population and waste generation. According to the 2004 Sectoral Analysis of Solid Waste, 102,900 metric tons of solid waste is generated per year in the greater Georgetown area, of which only 63,700 are disposed of at the main landfill. Collection coverage varies from 62% to 100% and the frequency rarely exceeds the once-a-week minimum standard. Also, Guyana currently does not have the capacity to dispose of hazardous waste (European Commission, 2006).

The high percentage of inadequate practices for the disposal of human excreta - poorly designed on-site sanitation, uncontrolled dumping of sludge from septic tanks, inadequate solid waste disposal, and poor maintenance of surface drains – combined with the issues related to drinking water quality and hygiene, represent major environmental health challenges for Guyana.

## 7. Environment and natural resources

Guyana has an abundance of natural resources: fertile agricultural lands on the coastal plain and in the riverine areas; vast areas of tropical hardwood forests of various ecosystems and with a multitude of plant and animal species; abundant fish and shrimping grounds, both in its numerous rivers and in the Atlantic Ocean to its north; and a wide variety of minerals, including gold, diamonds, a range of semi-precious stones, bauxite and manganese. Moreover, because of its many rivers (the word "Guyana" means "land of many waters"), its potential for hydropower is immense (Government of Guyana, 2001). Guyana does not currently have a formal system of data collection for environmental indicators.

It is noted in the Guyana National Biodiversity Strategy and Action Plan that tropical forests cover some 16.4 million ha of Guyana or about 76% of the total land area. Though total biodiversity in the Guiana Shield does not reach levels found in the forests of the Amazon basin, the forests of Guyana are valuable reservoirs of biodiversity. The value of the Guyana forests is enhanced by the fact that a high proportion are pristine,[4] containing many animal and plant endemics (it is estimated that 5% of all plant species in Guyana are endemic), providing numerous habitats for wildlife, and forming an integral part of the country‘s freshwater ecosystems.

Freshwater ecosystems are currently in relatively good condition, as the watersheds are still protected by large areas of pristine forests and their natural watercourses are mostly unaltered by dams and other water infrastructure (Ministry of Finance (MOF), 1997).

With respect to coastal resources, the coastal zone of Guyana is considered one of the most important natural regions in the country ,since over 90% of the population as well as economic and administrative activities, are concentrated in this area. The coastal zone of Guyana occupies approximately 7% of the total land area of the country, extending along the entire 430 km of the Atlantic coast and varying in width from 26 km to 77 km (MOF, 1997).

The rest of the coastal plain consists of mangrove forests and swamps. The former constitute the coastal forest type in the country most threatened with conversion (EPA, 2007). Over the years, net erosion along the Guyana coast and a general regression of the coastline has taken place at a relatively rapid rate. Evidence of this retreat can be seen along the coast - old sluice gates form isles far out to sea, and old shorelines and sand ridges run parallel to the present shoreline. Sea-level rise is one possible cause of coastal erosion. Given the importance of the coastal zone, this process has the potential to adversely affect the economic and socio-economic development of the entire county.

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[4] The forests of the Guiana Shield have been recognized as one of the last remaining ―frontier forests" of the world

Exploitation of marine resources contributes significantly to the national economy. The fishing industry‘s contribution to GDP was 1.59% in 2003. It employs an estimated 10,500 fishers and processors. However, exploitation of the fisheries resources represents the major threat to marine diversity (EPA, 2007).

## 8. Natural hazards

Unlike its island neighbours in the Caribbean Sea, Guyana is located outside the track of the Atlantic hurricanes. Nonetheless, the country is vulnerable to natural hazards and disasters that result from changing weather patterns, such as drought and floods. The topography of Guyana renders the country vulnerable to natural hazards, since most key investments are in low-lying areas protected by sea defences.

Frequent and uncontrolled breaches due to unanticipated high tides, whether due to natural or anthropogenic causes, will adversely affect sugar, rice and other agricultural production. Moreover, unfavourable weather, such as prolonged periods of heavy rainfall or prolonged periods of drought, also can jeopardize national agricultural production. These risks, if they occur, will negatively impact economic growth and poverty reduction (EC, 2006).

In January 2005, Guyana experienced its worst flood in recent history, occasioned by persistent heavy rains. High levels of damage occurred in the capital city and its surrounding areas, causing social and other disruption to approximately 62% of the population and a total GDP loss of about 59.49% (PAHO, 2009).

The recurrence of such disasters is highly likely, given a number of factors in Guyana such as the fact that the coastal zone is below sea level, and that a large segment of the population resides along the highly vulnerable coastal strip, where there exists inadequate infrastructure to prevent or mitigate the effects of such extreme weather events. The effects of climate change, such as extreme weather conditions (droughts and floods) and sea-level rise, in conjunction with poor sanitary conditions, are expected to heighten the country‘s vulnerability. This could result in an increase in communicable diseases such as malaria, dengue and diarrhoea, as well as other problems such as the contamination of drinking water sources, and significant declines in agricultural production due to land loss as a result of coastal inundation (PAHO, 2009).

Guyana does not have any specific policies or guidelines related to disaster risk reduction. Added to this is the fact that the legal framework that regulates land use is insufficient for regulating development, thereby making it more difficult to prevent building in areas that are vulnerable to flooding. Also, the Guyana Government continues to face tremendous technical and financial challenges in maintaining the drainage and irrigation system along the length of the coast between the Pomeroon and Corentyne Rivers. (UNDP, 2009).

## B. HEALTH STATUS AND DISEASE BURDEN IN GUYANA

Guyana currently ranks 128 of 191 countries in the World Health Organization 2000 ranking of world health systems.[5] This report introduced a new way of measuring the efficiency of health systems using a broad set of goals of the health system. The assessment was based on five indicators: overall level of population health; health inequalities (or disparities) within the population; overall level of health system responsiveness (a combination of patient satisfaction and how well the system acts); distribution of responsiveness within the population (how well people of varying economic status find that they are served by the health system); and the distribution of the health system's financial burden within the population (who pays the costs).The table below shows the country‘s performance comparative to its Latin American and Caribbean neighbours.

**Table 1: Health system attainment and performance in all WHO Member States, ranked by eight measures, estimates for 1997**

| **Member State** | **ATTAINMENT OF GOALS** | | | | | | **Health expenditure per capita in international dollars** | **PERFORMANCE** | |
|---|---|---|---|---|---|---|---|---|---|
| | **Health** | | **Responsiveness** | | **Fairness in financial contribution** | **Overall goal attainment** | | **On level of health** | **Overall health system performance** |
| | **Level (DALE)** | **Distribution** | **Level** | **Distribution** | | | | | |
| Guyana | 98 | 126 | 114 | 105-106 | 45-47 | 116 | 109 | 104 | **128** |
| Suriname | 77 | 94 | 87 | 79-81 | 172 | 105 | 72 | 77 | **110** |
| Belize | 94 | 95 | 105-107 | 90 | 146 | 104 | 88 | 34 | **96** |
| Trinidad | 57 | 75 | 141 | 108-109 | 69 | 56 | 65 | 79 | **67** |
| Venezuela | 52 | 76 | 69-72 | 92 | 98 | 65 | 68 | 29 | **54** |
| Jamaica | 36 | 87 | 105-107 | 73-74 | 115 | 69 | 89 | 8 | **53** |

Source: WHO, 2000
Legend: DALE – Disability-adjusted life expectancy

One could conclude that Guyana‘s comparatively lower performance in terms of the overall level of population health and the responsiveness of the health care system is relative to the country‘s health expenditure per capita, which is less than neighbouring countries. While it would not appear that there is a direct correlation between health expenditure per capita and health system performance, as Jamaica ranks just behind Belize in health expenditure per capita, yet is ranked 53rd in overall health system performance, compared to Belize‘s 96th place – this assessment brings into question the efficiency and effectiveness of the Guyana health care system, in particular the impact on the level of population health. The country ranks 104 of 191 countries with respect to the level of population health.

Compared to other neighbouring countries, Guyana ranks poorly with respect to basic health indicators, as is shown in the table below.

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[5] The report was last produced in 2000. WHO no longer produces such a ranking table, because of the complexity of the task.

## Table 2: Comparison of selected basic health indicators and socio-economic indicators

| Country | Total population ('000) | Basic health indicators | | | | | Socio-economic indicators | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Life expectancy | | Under-5 mortality rate (per 1 000) | | Maternal mortality ratio (per 100 000 live births) | GNI per capita (US$) | Total % of population using improved drinking-water sources | Total % of population using improved sanitation facilities | Estimated number of people (all ages) living with HIV | % of population below international poverty line of US$1.25 per day |
| | 2009 | 1990 | 2009 | 1990 | 2009 | 2005-2009 | 2009 | 2008 | 2008 | 2009 | 1994-2008 |
| Guyana | 762 | 62 | 67 | 61 | 35 | 110 | 1 450 | 94 | 81 | 5.9 | 8 |
| Suriname | 520 | 67 | 69 | 51 | 26 | 180 | 4 760 | 93 | 84 | 3.7 | 16 |
| Belize | 307 | 72 | 77 | 43 | 18 | 57 | 3 740 | 99 | 90 | 4.8 | 13 |
| Venezuela | 28 583 | 71 | 74 | 32 | 18 | 61 | 10 200 | - | - | - | 4 |
| Trinidad | 1 339 | 69 | 70 | 34 | 35 | 45 | 16 560 | 94 | 92 | 15 | 4 |
| Jamaica | 2 719 | 71 | 72 | 33 | 31 | 95 | 5 020 | 94 | 83 | 32 | >2 |
| Source: UNICEF, 2010 | | | | | | | | | | | |

Although the health profile of Guyana still suffers in comparison with most of the Caribbean, there has been remarkable progress over the last two decades. Life expectancy has increased from 62 years in 1990 to 67 years in 2009, and there has been a 43% reduction in the under-five mortality rate. The maternal mortality ratio now stands at 110 per 100,000 live births (UNICEF, 2010).

The epidemiological transition being experienced by most countries in the Caribbean subregion also characterizes the health trends in Guyana. That is to say, while some communicable diseases (CDs) still present formidable challenges to the health status of the population, there is now the movement towards the non- communicable diseases (NCDs) which accounts for the highest burden of mortality and morbidity. In addition, Guyana, like other countries in the Caribbean, is vulnerable to global epidemics and environmental threats (PAHO, 2009).

### 1. Morbidity

The Guyana Ministry of Health (MOH) Statistical Bulletin reported that the ten most prevalent diseases[6] recorded nationally among all ages in 2007 were (in order of prevalence):

1. Respiratory tract infections
2. Malaria
3. Hypertension
4. Accidents and injuries
5. Skin disorders
6. Worm infestation
7. Diabetes
8. Arthritis rheumatism
9. Eye infections
10. Anaemia

The top three conditions (respiratory tract infections, malaria and hypertension) make up just under half of all reported cases, with hypertensive diseases at 16.8%; other chronic diseases of the

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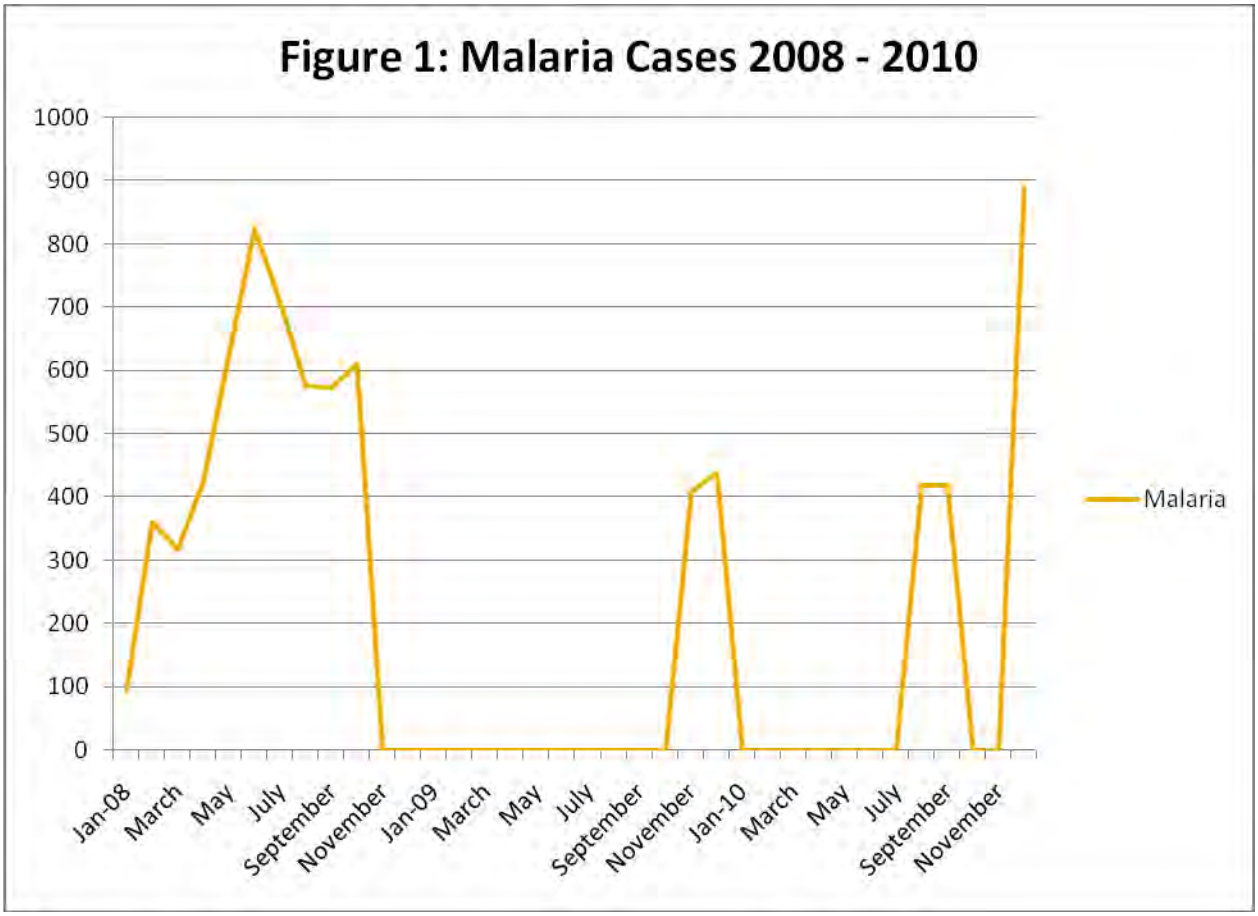
[6] More than 25% of cases are undiagnosed under the category of Symptoms, Signs & Abnormal Clinical Findings.

respiratory system at15.4%, and accidents and injuries at 12%. (MOH, 2009). However, the growing number of cases of neoplasms (cancers) is becoming a national concern.

Respiratory tract infections were number one in the Under age 5 and 5-14 age groups, while malaria was highest in the 65+ age range. Males and females alike are affected by respiratory tract infections, skin disorders, worm infestation, diabetes and arthritis rheumatism.

The main communicable diseases of concern to Guyana are HIV/AIDS, malaria and other vector-borne diseases such as dengue fever and filariasis. There has been a steady decline in reported cases of malaria over the last decade. Even though cases fluctuated at the regional level, malaria declined by 45% at the national level in the period between 2005 and 2007 (MOH, 2009). This could be accounted for by the effectiveness of the country‘s anti-malaria push. The Guyana Multiple Indicator Cluster Survey (MICS) (2006) measured malaria-related indicators only in the interior areas[7] and found that approximately 70% of children under age 5 slept under a mosquito net, a large increase from only 11% in 2000. Malaria is also thought to be a major contributory factor to anaemia in women and children. Data received from the Ministry of Health (2011) for the purposes of the present study indicate that the decline was temporary, as the number of cases increased between November 2009 and December 2010 (see figure 1).



Source: Data compiled by author

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[7] The coastal areas are considered to be malaria-free while the interior areas are considered to be high-risk malaria areas.

There are significant differences in the incidence and patterns of morbidity by region (see table 3). This is due, in part, to the geographical isolation of some communities and the attendant difficulties of delivering equipment and services to them, and in part to the fact that the deterioration of health infrastructure mainly affects the most remote communities. The Administrative Regions with the lowest overall morbidity rates are Regions 3, 4, 6 and 10. However, the reliability and completeness of the data are not uniform across regions, and are especially poor in areas where there are no health clinics, or where clinics are poorly staffed and statistics poorly reported. Hinterland areas are often the least accessible both by river and by air, and suffer from a lack of basic infrastructure and facilities, such as electricity and potable water, which makes the delivery of certain services a difficult task (Government of Guyana, 2001).

Malaria is endemic, and in 2007 represented the major cause of morbidity in Regions 1 and 9, which are also among the poorest areas of Guyana. The proliferation of mining camps in remote, often uninhabited, forested areas (Regions 1 and 9), added to the continuing proliferation in Regions 7 and 8, creates a challenging situation for health workers. The bulk of malaria cases have shifted from the hinterland regions to include Regions 2, 3, 4 and 5. See table 34 for an estimate of the regional distribution of the additional forecast cases.

Filariasis is endemic along the coastal strips, as is dengue fever. In general, diseases spread by vectors and those associated with environmental problems show the most rapid rates of increase (Government of Guyana, 2001).

**Table 3: Guyana: Morbidity by Administrative Region, 2007**

| **Region** | **Most prevalent diseases** | | | **Most prevalent causes of chronic communicable diseases** | | |
|---|---|---|---|---|---|---|
| | **All** | **Male** | **Female** | **All** | **Male** | **Female** |
| 1 | Malaria | Malaria | Respiratory Tract Infections | - | - | - |
| 2 | Respiratory tract infections | Respiratory tract infections | Respiratory tract infections | Other ill-defined chronic conditions | Other ill-defined chronic conditions | Other ill-defined chronic conditions |
| 3 | - | - | - | Hypertensive diseases | Other chronic disease of the respiratory system | Hypertensive Diseases |
| 4 | - | - | - | Hypertensive diseases | Accidents & injuries | Hypertensive diseases |
| 5 | Symptoms | Symptoms | Symptoms | Other ill-defined chronic conditions | Other ill-defined chronic conditions | Other ill-defined chronic conditions |
| 6 | Respiratory tract infections | Respiratory tract infections | Symptoms | Accidents & injuries | Accidents & injuries | Hypertensive diseases |
| 7 | Symptoms | Symptoms | Symptoms | Accidents & injuries | Accidents & injuries | Hypertensive diseases |
| 8 | Symptoms | Symptoms | Symptoms | Accidents & injuries | Accidents & injuries | Hypertensive diseases |
| 9 | Malaria | Malaria | Malaria | - | - | - |
| 10 | Symptoms | Worm | Symptoms | Accidents & | Accidents & | Other ill- |

| Region | Most prevalent diseases | | | Most prevalent causes of chronic communicable diseases | | |
|---|---|---|---|---|---|---|
| | All | Male | Female | All | Male | Female |
| | | Infestations | | injuries | injuries | defined chronic conditions |
| National | Symptoms | Symptoms | Symptoms | Hypertensive diseases | Accidents & injuries | Hypertensive diseases |
| Source: Ministry of Health – Statistics Unit<br>Legend: Symptoms – symptoms, signs & abnormal clinical findings | | | | | | |

The morbidity profile of Guyana can be improved substantially through enhanced preventive health care, better education on health issues, more widespread access to potable water and sanitation services, and increased access to basic health care of good quality. Poor environmental health is, in part, responsible for the seriousness of vector borne diseases, including malaria, filariasis and dengue fever.

Amerindians represent one of the groups most vulnerable to health issues. Their vulnerability is heightened with respect to malaria, acute respiratory diseases, waterborne diseases, nutritional deficiencies, and access to health care (GoG, 2001). This situation makes this population demographic especially vulnerable to the effects of climate change. The adaptation measures selected for Guyana must therefore prioritize capacity- and resilience-building within the Amerindian population.

## 2. Mortality

The picture differs with regard to mortality patterns. The leading cause of death nationally for all age groups is ischemic heart disease. The leading cause of death among females is cerebrovascular disease, and among males, ischemic heart disease. Table 4 shows the leading cause of death in each region. Non-communicable diseases account for more than 71% of all mortality cases. There were more male mortality cases of communicable diseases than female (by approximately 20%) (MOH, 2009a).

Ischemic heart diseases was the leading cause of death in four regions (2, 3, 6 and 10), while neoplasms was number one in two regions (1 and 4). The percentage of deaths in Region 8 was unusually high owing to the relatively low number of deaths that occurred here in 2007.

**Table 4: Number and cause of deaths by region, 2007**

| Region | Number of deaths | Major cause of death | | |
|---|---|---|---|---|
| | | All | Male | Female |
| 1 | 53 | Neoplasms | Hypertensive diseases | HIV disease |
| 2 | 333 | Ischemic heart diseases | Ischemic heart diseases | Ischemic heart diseases |
| 3 | 622 | Ischemic heart diseases | Ischemic heart diseases | Ischemic heart diseases |
| 4 | 2,545 | Neoplasms | Ischemic heart diseases | Neoplasms |
| 5 | 272 | Cerebrovascular diseases | Cerebrovascular diseases | Cerebrovascular diseases |
| 6 | 898 | Ischemic heart diseases | Ischemic heart diseases | Cerebrovascular Diseases |
| 7 | 81 | HIV disease(aids) | Ischemic heart diseases | HIV disease(aids) |
| 8 | 7 | Unspecified land transport accidents | Tuberculosis | Unspecified land transport accidents |
| 9 | 6 | Diabetes mellitus | Heart failure | Diabetes mellitus |
| 10 | 246 | Ischemic heart diseases | Ischemic heart diseases | Neoplasms |
| **NATIONAL** | **5,066** | **Ischemic heart diseases** | **Ischemic heart diseases** | **Cerebrovascular Diseases** |

Source: Ministry of Health – Statistics Unit & Maternal and Child Heath

## 3. National health care system in Guyana

Guyana currently has a National Health Plan geared towards improving the nation's health, supporting the Poverty Reduction Strategy, the goals of the National Development Strategy and Millennium Development Goals and achieving good value for money in the health sector. The National Health Plan focuses on the modernization and rationalization of health services, the decentralization of public health programmes to Health Management Committees as semiautonomous providers, the establishment of workforce development and human resource management systems, and the implementation of a national quality framework. Although this Plan is being implemented, there still exist many issues in the country's national health care system.

The Guyana health care system is based on the primary health care principles of equitable distribution of health services, intersectoral collaboration, and community participation. While there have been advances in the peripheral network of health services, the more remote regions of the country, such as Regions 1, 7, 8 and 9, enjoy only limited access to health care. This makes equity in health for many indigenous persons tremendously challenging, due to the fact that these communities are very difficult to reach and therefore, delivery and monitoring of health services is extremely problematic (PAHO, 2009).

Health care is provided free of charge to the public. Over the years, the health sector received significant increases in allocation from the general national budget and, in 2007, received approximately 10% of the total recurrent Government budget. Notwithstanding, primary health care is underfunded, with the major bias being towards hospital services (PAHO, 2009). Guyana does not have a national health insurance system; however, the National Insurance Scheme operates a social insurance programme for employees.

The health sector in Guyana is served by 230 nurses and midwives per 100,000 people, 50 physicians per 100,000 people, 4 dentists per 100,000 people, 0.5 psychiatrists per 100,000 people, and 250 hospital beds per 100,000 people (PAHO, 2007). External migration of health professionals—of all categories, including managers and health teachers/tutors—has created a serious workforce shortage in the health care field and placed constraints on health services provision to the population. In the public health sector, vacancy rates range between 25% and 50% in most professional categories. A geographical imbalance of professional staff also exists; 70% of the country‘s physicians are located in Georgetown, where only 25% of the population reside. For medical specialties, Guyana relies largely on non-nationals, who fill more than 90% of the medical speciality positions in the public sector (PAHO, 2007).

The health infrastructure in Guyana is very old and many buildings are in need of repair. The condition of equipment is also poor because of age and lack of maintenance. The utilization rate of the public facilities, especially at health centres and health posts, is very low. This is due mainly to the shortage of supplies, equipment, and health personnel, the high hidden costs for users (lengthy transportation, and waiting time), and the relative inaccessibility of the health centres and posts (GoG, 2001).

As previously discussed, the Ministry of Health, in the National Health Sector Strategy of 2008-2012 recognizes that health issues related to climate change are a reality and has cited the major flood of January – February 2005, the worst in Guyana‘s recorded history, as an example. Consequently, the Ministry has charged the resuscitated Environmental Health Unit to be the host coordinating unit to develop and assist in the execution of a health disaster related plan (Sookdeo, 2008).

The Ministry of Health is improving its Surveillance Unit with assistance from the Centre of Disease Control. This will enable the Ministry to engage in effective mitigation and adaptation measures to effectively monitor present disease conditions and to detect changes in disease patterns that may result from climate change and other influencing factors. Consequently, within the last few years, there has been more training of staff, more surveillance reporting sites, and more consistently reporting sites. The Surveillance Unit is also more proactive, calling sites weekly for reports, and developing an organized syndromic surveillance system to detect disease outbreaks rapidly (Sookdeo, 2008).

However, the institutional capacity of the health sector in Guyana must be enhanced to adapt to the potential impacts of climate change. The burden of current diseases will be further exacerbated by climate change and will require the health care system to be more responsive, equitable and effective within the context of scarce economic resources.

## C. CLIMATE CHANGE AND ITS IMPACTS

Climate change is considered to be the most pervasive and truly global of all issues affecting humanity, and poses a serious threat to the environment as well as to economies and societies. Climate change is associated with the warming of the planet Earth as a result of emissions of carbon dioxide and other greenhouse gases.

Changes in land use (e.g. deforestation) and the burning of coal, oil and natural gases are some activities that increase the amounts of greenhouse gases, especially carbon dioxide, emitted into the atmosphere. The accumulation of greenhouse gases in the atmosphere due to human activities is changing the climate by enhancing the natural greenhouse effect, leading to an increase in the Earth‛s average surface temperature. Through economic and social development, industrial and agricultural emissions of carbon dioxide, methane and other greenhouse gases are contributing to a warmer planet. Reducing the output of these gases will require a fundamental shift in industrial and manufacturing processes, agriculture and energy production.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) forecasts an increase in average world temperature by 2100 within the range 1.4° – 5.8° C. The increase will be greater at higher altitudes and over land. Globally, IPCC projects that average annual rainfall will increase, although many middle and lower latitude land regions will become drier, whereas elsewhere precipitation events (and flooding) could become more severe.

Climate change is expected to impact:

- Sea level – causing sea-level rise
- Ecosystems
- Human health
- Agriculture
- Tourism
- Water resources
- The poor

Whilst it is clear that the impacts of climate change are varied, scientists have agreed that its effects will not be evenly distributed and that developing countries and small island developing States (SIDS) will be the first and hardest hit. Small island developing States, many of whom have fewer resources to adapt socially, technologically and financially to climate change, are considered to be most vulnerable to the potential impacts of climate change. Additionally, it is expected that climate change will pose a significant threat to and drain public resources in many Caribbean States. Today, countries in the Caribbean continue to grapple with issues related to macroeconomic stability, reducing poverty levels and trade liberalization, to name a few.

Climate change is expected to affect ecosystem services in ways that increase vulnerabilities with regard to food security, water supply, natural disasters, and human health and will, in turn, affect socio-economic development. (IPCC, 2007b: 8; Stern, 2006; WHO, 2003; WHO, 2008). Furthermore, it was reported in the IPCC Third Assessment that, while developing countries are expected to experience larger percentage losses in GDP, global mean losses could be between 1% - 5% GDP for 4° C of warming.

Climate change also is expected to cause a further rise in sea level of about 20cm by the year 2030. Forecasts of rising sea levels are based on climate model results which indicate that the earth‛s average surface temperatures may increase by 1.5° – 4.5° C over the next 100 years. The warming can cause the sea to rise in two ways: through thermal expansion of ocean water, and through the melting and sinking of ice caps and mountain glaciers.

Furthermore, extreme climate events are expected to become more frequent with climate change. These events are expected to have their greatest impact in poor and/or developing countries and in small island developing States.

Climate change is also expected to affect the health of populations. In fact, the World Health Organization (WHO) in *Protecting Health from Climate Change* (2008) states that the continuation of current patterns of fossil fuel use, development and population growth will lead to ongoing climate change, with serious effects on the environment and, consequently, on human lives and health.

Climate change is considered by the Lancet Commission to be –the biggest global health threat of the twenty-first century”. Their 2009 Report, entitled *Managing the Health Effects of Climate Change* states that the effects of climate change on health will affect most populations in the upcoming decades, and will put the lives and well-being of billions of people at increased risk.

Therefore, the development paths that the world chooses will have a strong influence on this increase in greenhouse gas emissions. According to the Stern Review (2006), the scientific evidence points to increasing risks of serious, irreversible impacts from climate change associated with business-as-usual (BAU) paths for emissions. If, for example, high priority is placed on sustainable energy use, temperatures are expected to rise by 1.8° C (likely range: 1.1°–2.9° C). If societies place a lower emphasis on sustainability measures, temperatures are expected to rise by about 4.0° C (2.4°–6.4° C), with a greater probability of abrupt or irreversible impacts (WHO, 2008).

## 1. Climate variability in the Caribbean

There is strong evidence to suggest that changes and variations in climate are occurring in the Caribbean. Taylor (2002) analysed the inter-annual variability of the Caribbean rainfall season, which is divided into an early season (May - July) and a late season (August - November). He provides evidence that anomalies in sea surface temperature of the equatorial Pacific Ocean are associated with Caribbean rainfall patterns. A study of daily weather records of the Caribbean subregion since the late 1950s finds more very warm days, fewer very cold days and an increase in extreme precipitation. Climatic data also indicate that, since 1995, there has been an increase in the intensity and distribution of hurricanes in the Caribbean.

Climate change is being considered to be one of the most serious threats to sustainable development facing Caribbean Community (CARICOM) States, even though the contribution of CARICOM countries to global greenhouse gas emissions is negligible. In 2004, it was estimated that Central America and the Caribbean produced 558 metric tons of carbon dioxide ($CO_2$) or only 1.82% of total (global) greenhouse gas emissions. However, while the Caribbean produces only a small fraction of global greenhouse gas emissions, many of these countries are barely above sea level and are located in the hurricane belt, rendering them most vulnerable to the effects of climate change (CCCCC, 2009).

Some of the threats to Caribbean States include coastal erosion and salt water intrusion, an escalation in the frequency and intensity of tropical storms and hurricanes, and disruptions in rainfall and freshwater supply (Dellarue, 2009; CCCCC, 2009).

Climate change therefore has the potential to greatly exacerbate climate risks, and could increase expected loss by 1% - 3% of GDP by 2030 (CCCCC, 2010). For example, over the last three decades, the Caribbean subregion has suffered direct and indirect losses estimated at between US$ 700 million and US$ 3.3 billion owing to natural disasters associated with extreme weather events. In a –no-adaptation” scenario, such losses could be on the order of 5% – 30% of GDP on average (annualized values), with an even broader range for some specific countries. A 2008 study by Tufts University, entitled *The Caribbean and Climate Change: The Costs of Inaction*, reveals that for, just three categories—increased hurricane damages, loss of tourism revenue, and infrastructure damages—the annual cost to the Caribbean of inaction is projected to total US$ 22 billion annually by 2050 and US$ 46 billion by 2100. These costs represent 10% and 22%, respectively, of the current Caribbean economy.

Also, preliminary findings of the Caribbean Regional Economics of Climate Adaptation (ECA) study (CCRIF, 2010), reveal that there could be losses of up to 6% of GDP in some countries under current climatic and economic conditions. Among the hazards considered, hurricane-induced wind damage has the largest damage potential, accounting for up to 90% of the overall damage. The ECA study projects that overall expected loss as a proportion of GDP could rise to between 2% and 9% in the high climate change scenario by 2030. In absolute terms, expected loss may triple between 2010 and 2030, with wind remaining the single largest contributor.

Another significant threat posed by climate change relates to the deterioration in human health due to the increased presence of vector-borne tropical diseases, such as malaria and dengue fever, and the prevalence of respiratory illnesses. These diseases are expected to affect the well-being and productivity of the work force in the Caribbean, thus compromising growth and development potential.

The sectors and systems in Guyana identified as being most vulnerable to the effects of climate change are agriculture, coastal human settlements, and human health (ECLAC, 2010; GoG, 2002).

Additionally, a study by ECLAC (2010) reveals that, despite facing the same basic threats from climate change, the level of adaptation and response capacity differs widely between Member States. IPCC AR4 (2007a) indicates that projected climate change-related exposures will have the greatest impact on those populations with low adaptive capacity. Capacity-building is therefore critical for the Caribbean to address the challenges posed by climate change, and is a vital prerequisite for the development of detailed technical models and climate adaptation strategies to aid development planning.

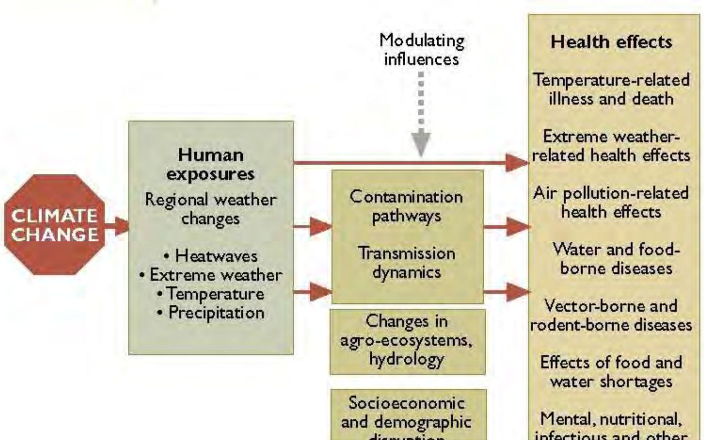
## D. IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH

Assessing the potential impact of climate change on human health requires an understanding of both the vulnerability of a population and its capacity to respond to new conditions. The vulnerability of a population to a health risk is dependent on various factors including:

- the local environment and social conditions
- the level of material resources
- the effectiveness of governance and civil institutions
- the quality of the public health infrastructure
- access to relevant local information on extreme weather threats
- adaptive policies

There is growing evidence that climate change will have profound effects on the health and well-being of citizens in countries throughout the world. The 2009 Lancet Commission report states that climate change will affect the key determinants of human health. Changing climate will inevitably affect the basic requirements for maintaining health: clean air and water, sufficient food and adequate shelter.

The main pathways by which climate change can affect population health are illustrated in the diagram below.



**Direct and indirect pathways by which climate change affects population health**

Source: WMO/ WHO/ UNEP, 200. Climate Change and Human Health – Risks and Responses

As shown in the figure above, these pathways involve a complexity of causal processes. There are also diverse health consequences, most of which are adverse, although some are beneficial. The climate change effects of higher temperatures, changes in rainfall and hurricane patterns and sea-level rise will potentially result in a number of changed health outcomes.

The World Health Organization (2008) has identified five major health consequences of climate change.

1. The agricultural sector is extremely sensitive to climate variability. Rising temperatures and more frequent droughts and floods can compromise food security. Increases in malnutrition are expected to be especially severe in countries where large numbers of the population depend on rain-fed subsistence farming. Malnutrition, much of which is caused by periodic droughts, is already responsible for an estimated 3.5 million deaths each year. This has particular implications for child growth and development (IPCC, 2007a) and could negatively affect the achievement of Millennium Development targets.

2. More frequent extreme weather events mean more potential deaths and injuries caused by storms and floods. In addition, flooding can be followed by outbreaks of disease, such as cholera, especially when water and sanitation services are already poor or where they have been damaged or destroyed. Storms and floods are already among the most frequent and deadly forms of natural disasters (WHO, 2008; IPCC 2007a; IPCC, 2007b; IPCC, 2001).

3. Both scarcity of water, which is essential for good hygiene, and excess water, due to more frequent and torrential rainfall, will increase the burden of diarrhoeal disease, which is spread through contaminated food and water (WHO and others. 2003b; IPCC 2007b). Diarrhoeal disease is already the second leading infectious cause of childhood mortality, and accounts for a total of around 1.8 million deaths each year.

4. Heatwaves, especially in urban ―heat islands", can directly increase morbidity and mortality, mainly in elderly people with cardiovascular or respiratory disease (IPCC 2007a). Apart from heatwaves, higher temperatures can increase ground-level ozone and hasten the onset of the pollen season, contributing to respiratory problems such as asthma attacks.

5. Changing temperatures and patterns of rainfall are expected to alter the geographical distribution of insect vectors that spread infectious diseases, thus bringing new challenges to the control of infectious diseases.

Many of the major diseases, including cholera and diarrhoeal diseases, as well as diseases carried by vectors, such as malaria and dengue fever, are highly climate-sensitive with respect to temperature and rainfall. Of these diseases, malaria and dengue are of the greatest public health concern (IPCC, 2001).

Climate change also is expected to have some beneficial effects. Studies in temperate areas have shown that climate change is projected to bring some benefits, such as fewer deaths from cold exposure (WHO, 2008). Overall, it is expected that these benefits will be outweighed by the negative health effects of rising temperatures worldwide, especially in developing countries.

The balance of positive and negative health impacts will vary from one location to another, and will alter over time as temperatures continue to rise. Critically important will be factors that directly shape the health of populations such as education, health care, public health initiatives and infrastructure, and economic development (WHO, 2008).

Table 5 summarizes some of the potential health outcomes due to climate change.

**Table 5: Potential health outcomes due to climate change**

| Health determinant due to climate change | Health outcome |
|---|---|
| Direct impact of heat and cold | Cardiovascular disease deaths; heat stress; hypothermia |
| Temperature effects on food-borne disease | Increased cases of diarrhoea; gastroenteritis; typhoid; Salmonella |
| Temperature effects on water-borne disease | Increased cases of diarrhoea; gastroenteritis; typhoid; cholera |
| Temperature, humidity, rainfall effects on vector-borne (and rodent-borne) diseases | Increased incidence of malaria; dengue fever; leptospirosis |
| Effects of extreme rainfall and sea-level rise on flooding [a] | Fatal injuries; non-fatal injuries; mental health effects |
| Changing patterns of agricultural yield | Malnutrition and undernutrition |
| Effect of flooding and drought on food and waterborne disease | Increased incidence of cholera; diarrhoea; gastroenteritis |
| Sea-level rise and reduced snowmelt impacts on freshwater availability | Water-related diseases in resident and displaced/ refugee populations |
| Drought and flooding, pests, diseases, biodiversity loss, economic disruption, dislocation and migration | Malnutrition and spread of disease in non-immune populations |
| Changes in air pollution and aeroallergen levels | Deaths and disease cases associated with air pollution e.g. chronic respiratory illnesses and asthma; and allergies e.g. hay fever |
| Destruction of health infrastructure in floods and storms | Increases in mortality and morbidity in affected areas |
| Temperature and precipitation effects on incidence and intensity of forest fires | Fatal and non-fatal injuries |
| Temperature and precipitation effects on incidence of dust storms | Fatal and non-fatal injuries; respiratory illnesses |
| Increased intensity of hurricanes due to higher sea surface temperature | Fatal and non-fatal injuries, displaced populations; mental health effects |
| Emergence or spread of pathogens via climate-change-driven biodiversity loss | New cases of infectious disease |

Note: a) Separately attributed to coastal floods, or inland floods and landslides

Source: Adapted from Campbell-Lendgrum and Woodruff (2007)

## 1. Impact of a changing climate on infectious diseases

Many recent studies have focused on the possible impacts that changing climate might have on the incidence of disease. Infections caused by pathogens that are transmitted by insect vectors are strongly affected by climatic conditions such as temperature, rainfall and humidity. These diseases include some of the most important current killers: malaria, dengue fever, yellow fever and other infections carried by insect vectors, and diarrhoea, transmitted mainly through contaminated water.

Dengue fever, for example, is the most important arboviral disease in humans, occurring in tropical and subtropical regions, particularly in urban settings. The incidence and geographic distribution of dengue fever have increased dramatically in the last 40 years. More than half the world‘s population now lives in areas at risk of infection. At present, no vaccine is available (Reiter, 2001). As with other mosquito-borne illnesses, the distribution of dengue fever is also highly dependent on climate. In the absence of changes in other determinants, studies suggest that climate change could expose an additional 2 billion people to dengue transmission by the 2080s.

Additionally, results obtained from the work of the Climate Studies Group at the University of the West Indies, Mona (Heslop-Thomas and others, 2006) have established an association between climate variability and the occurrence of dengue fever outbreaks in Jamaica. Peaks in occurrences are associated with warmer conditions, and the seasonality of the epidemics suggests that temperature and precipitation have some explanatory value. The preliminary results indicated a continuation of the warming trend, and have shown that a substantial number of people living in conditions that are conducive to the proliferation of the vector and virus are vulnerable, particularly those living in informal settlements with poor access to water and sanitation.

Like dengue fever, yellow fever is an arbovirus transmitted in humans by the *peridomestic Aedes sp.* mosquitoes, in particular *Ae. Aegypti*. It is widespread in villages and urban areas throughout the tropics and can also thrive in temperate climates. There are an estimated 2,000,000 cases of yellow fever causing 30,000 deaths worldwide each year. The virus in endemic in tropical areas of Africa and Latin America.

The number of yellow fever cases has increased over the past two decades due to declining population immunity to infection, deforestation, urbanization, population movements and climate change (WHO, 2011). While the populations of all countries in Latin America are at risk, Bolivia, Brazil, Columbia, Ecuador and Peru are at greatest risk.

As with malaria, the extrinsic incubation period of the yellow fever virus decreases with increasing temperature and, similarly, transmission is influenced by a range of non-climatic factors. Many of these are associated with rapid population growth, urbanization, and economic development.

The World Health Organization (2003 and 2008) also points to other diseases which show an association with climate variability and change, namely, rodent-borne and diarrhoeal diseases. Rodents, which proliferate in temperate regions following mild, wet winters, act as reservoirs for various diseases. Certain rodent-borne diseases are associated with flooding, including leptospirosis, tularaemia and viral haemorrhagic diseases. Other diseases associated with rodents and ticks, and which show associations with climatic variability, include Lyme disease, tick-borne encephalitis, and hantavirus pulmonary syndrome.

Leptospirosis is a bacterial disease that affects humans and animals, and has also been examined for climate sensitivity. For instance, the risk factors for leptospirosis in the parish of St. Andrew, Barbados were examined in a study done by Douglin and others (2003) (cited in CEHI, 2004). The study suggested that high rainfall in this parish might have contributed to the risk of contracting leptospirosis by enhancing the survival of leptospires in the soil and water. While the occurrence of leptospirosis in St. Andrew did show a strong association with the mean monthly rainfall, a less strong correlation was observed between the onset of the symptoms and rainfall either in the preceding month or in the preceding quarter. It is likely, therefore, that climate change could worsen the incidence of this disease, especially in countries which have a record of poor sanitation.

Viruses and bacteria transmitted through water and contaminated food can cause severe diarrhoea in children, often locking them into a vicious cycle of undernourishment, susceptibility to other infectious diseases, and eventually, death. Many diarrhoeal diseases vary seasonally, suggesting sensitivity to climate. In the tropics, diarrhoeal diseases typically peak during the rainy season. Both floods and droughts increase the risk of diarrhoeal diseases (IPCC, 2001; IPCC, 2007b; WHO, 2008). Major causes of diarrhoea linked to heavy rainfall and contaminated water supplies are: cholera, cryptosporidium, E. coli infection, giardia, shigella, typhoid, and viruses such as hepatitis A.

Higher temperatures and too much, or too little, water can all facilitate transmission of diarrhoeal disease. In countries with inadequate water and sanitation services, diarrhoea is much more common when temperatures are high. For example, WHO reports that rates of diarrhoeal disease in Lima, Peru, are 3–4 times higher in the summer than in the winter, increasing by 8% for every 1° C increase in temperature (WHO, 2008). Both flooding and unusually low levels of water can also lead to water contamination and bring higher rates of illness and death from diarrhoea. Warming and greater variability in precipitation threaten to increase the burden of diarrhoeal disease.

It is expected that, in the future, many other diseases will also be affected. Any disease caused, transmitted or harboured by insects, snails and other cold-blooded animals can be affected by a changing climate. For example, climate change is projected to widen significantly the area of China where schistosomiasis transmission occurs. Together, vector-borne diseases kill over 1.1 million people and cause the loss of 49 million years of healthy life, every year (WHO, 2008).

When infectious diseases appear in new locations where people do not have immunity, and health services may not have experience in controlling or treating infections, the effects can be dramatic, straining health services and economies.

## 2. The case of the Caribbean

Whilst there are not many studies undertaken on the impacts of climate change on human health in the Caribbean, those studies that do exist are finding significant associations between climate variability and increased prevalence of certain climate-sensitive diseases.

Bueno and others (2008), for example, contend that, in addition to greater precipitation during storms and other peak periods, more frequent and longer droughts are expected in parts of the Caribbean as a result of climate change. They continue by stating that negative health impacts will include greater heat stress for vulnerable populations (such as the elderly), worse sanitation conditions from limited water supplies or contaminated water from floods, and conditions that can favour the spread of water and vector-borne diseases, such as dengue fever, malaria, and diarrhoea. Public health systems may not always be adequate to cope with greater demands on their services.

Table 6 provides a snapshot of the main diseases in the Caribbean that are most sensitive to climate change.

### Table 6: The main diseases in the Caribbean that are most sensitive to climate change

| Diseases | Impacts |
|---|---|
| Dengue fever (DF) | DF is endemic in most Caribbean countries. Because of this, cases are reported every year. A total of 58,461 cases of Dengue fever (DF) and 1,386 cases of dengue haemorrhagic fever/dengue shock syndrome (DHF/DSS) have been reported among CAREC Member Countries (CMCs) during the period 1980-2005.<br>The general trend has been an increasing one, with outbreaks being reported with increasing frequency in recent years. It should be noted that laboratory confirmation of dengue fever and DHF/DSS has increased in recent years.<br>Additionally, results obtained from the work of the Climate Studies Group at the University of the West Indies, Mona (Heslop-Thomas and others, 2006) established an association between climate variability and the occurrence of dengue fever outbreaks in Jamaica. Peaks in occurrences are associated with warmer conditions, and the seasonality of the epidemics suggests that temperature and precipitation have some explanatory value. |
| Malaria | Caribbean nations with active malaria transmission are Haiti, Dominican Republic, Suriname, Belize and Guyana.<br>A total of 789,363 (suspected and confirmed) cases of indigenous malaria have been reported from CAREC member countries over a 25-year review period. Most of these were reported from three countries, namely, Guyana (65%), Suriname (24%) and Belize (11%).<br>Since the successful eradication of malaria from Trinidad and Tobago in 1965 (CAREC, CSR, March 1993), there have been at least three outbreaks involving importation and subsequent local transmission. Increased regional travel is likely to spur this trend, particularly in countries where surveillance and vector control systems are weak.<br>Despite the known causal links between climate and malaria transmission dynamics, there is still uncertainty about the potential impact of climate change on malaria at local scales. |
| Diarrhoeal disease/ Gastro-enteritis | A total of 739,856 GE cases among children less than 5 years of age were reported for the period 1980 to 2005. Reports for Jamaica, Guyana and Suriname accounted for 55%, 12% and 8% of all cases, respectively, over the review period.<br>Since 1994, when reporting of gastroenteritis for persons 5 years old and over began, there has been an increasing trend, from a low of 7,138 cases in 1994, to highs of 46,403 and 39,294 cases, in 2004 and 2005, respectively. |
| Leptospirosis | Humans become infected through contact (ingestion and dermal) with water, food, or soil containing urine from animals infected by *Leptospira* bacteria. The number of human cases worldwide is not well documented as leptospirosis is underreported in many areas of the world, including the Caribbean.<br>A total of 12,475 cases of leptospirosis were reported from CAREC member countries between 1980 and 2005. Most cases were reported from Jamaica (47%), Trinidad and Tobago (19%), Suriname (19%) and Barbados (6%). In 1995, countries began reporting cases as ‗suspected‘ and ‗confirmed‘. Between 1995 and 2004, 616 confirmed cases were reported from all member countries. These represented 10% of total cases reported. |
| Yellow fever | In the Americas, yellow fever is endemic in nine South American countries and in several Caribbean islands. During the period 1980-2005, no sylvatic or urban cases of yellow fever were reported to CAREC from any CAREC member countries (CAREC, 2008). The link between climate and yellow fever has not been studied as specifically as has the link with dengue fever. |

Source: Data compiled by author

Another study by Ortiz Bulto (2002) describes the use of a bioclimatological modelling methodology that finds seven diseases sensitive to climate change in Cuba: acute respiratory infections (ARIs), acute diarrhoeal disease (ADDs), viral hepatitis (VH), varicella (V), meningococcal disease (MD) and malaria due to *Plasmodium falciparum* and *P. vivax*. Ortiz Bulto concludes that the impacts of climate on human health are complex for any region and disease, including the costs of the impacts and the application of adaptation measures.

## E. THE IMPACT OF CLIMATE CHANGE ON THE PREVALENCE OF CLIMATE-SENSITIVE DISEASES IN GUYANA

### 1. Recent climate trends in Guyana

The consequences of global climatic change for local climate are still somewhat uncertain. McSweeney and others (2008) have found that mean annual temperature has increased by 0.3° C since 1960, an average rate of 0.07° C per decade. This rate of warming is less rapid than the global average. The rate of increase is similar (~0.1° C per decade) in all seasons, except February/ March/ April (FMA), when there is no apparent trend in temperature.

This research indicates that, although the rate of increase in mean temperature is moderate in Guyana relative to the global average increase, the increase in frequency of particularly hot days and nights has shown a significantly increasing trend since 1960 in every season (where data are available). The average number of ‗hot' days per year in Guyana has increased by 93 (an additional 25% of days) between 1960 and 2003. The rate of increase is seen most strongly in the summer months of June/July/August (JJA), when the average number of hot summer days has increased by 9 days per month (an additional 30% of summer days) over this period. The average number of ‗hot' nights per year increased by 87 (an additional 24% of nights) between 1960 and 2003. The rate of increase is seen most strongly in March/April/May (MAM) when the average number of hot MAM nights has increased by 10 days per month (an additional 34% of MAM nights) over this period (McSweeney and others, 2008).

The frequency of ‗cold' days and nights, annually, has decreased significantly since 1960, but not in all seasons. The average number of ‗cold ‗days per year has decreased by 37 (10% of days). This rate of decrease is most rapid in the summer months of June/July/August (JJA) when the average number of cold summer days has decreased by 4 days per month (14% of summer days) over this period. ‗Cold' nights have decreased in frequency at a similar rate to cold days (McSweeney and others, 2008).

Mean annual rainfall over Guyana has increased at an average rate of 4.8 mm per month (2.7%) per decade. Trends in seasonal rainfall are not statistically significant. Where data are available, there is no evidence of any significant trend in maximum 1- or 5- day rainfall (McSweeney and others, 2008).

What is widely accepted by climate officials is that climate change in Guyana will lead to longer periods of drought, and precipitation of higher intensity, as it has been observed within the last two decades that monthly rainfall is accounted for by fewer days with higher rainfall. This will have obvious and complex implications for the health of the Guyanese populace (Sookdeo, 2008).

### 2. Global Circulation Model (GCM) projections of future climate

The mean annual temperature is projected to increase by 0.9° to 3.3° C by the 2060s, and 1.4° to 5.0° C by the 2090s. The range of projections by the 2090s under any one emissions scenario is 1.5°-2.5° Celsius. The projected rate of warming is similar in all seasons, but more rapid in the southern, interior regions of the country (inclusive of the Rupununi savannahs) than in the northern, coastal regions (McSweeney and others, 2008; GoG, 2002).

All projections indicate substantial increases in the frequency of days and nights that are considered ‗hot' in current climate. Annually, projections indicate that ‗hot' days are projected to occur on 18%-56% of days by the 2060s, and 19%-79% of days by the 2090s. All projections indicate decreases in the frequency of days and nights that are considered ‗cold' in current climate. These events are expected to become exceedingly rare, occurring on maximum of 4% of days in the year, and potentially not at all, by the 2090s (McSweeney and others, 2008).

There is still some uncertainty regarding future precipitation patterns in Guyana. Projections of mean annual rainfall from different models in the ensemble project a wide range of changes in precipitation for Guyana (McSweeney and others, 2008). In general, the largest decreases in total rainfall are projected for the wettest season, May/June/July (MJJ) (-68 to +21mm per month).

The proportion of total rainfall that falls in heavy events does not show a consistent direction of change, but tends towards positive changes, particularly in the southern parts of the country in the seasons NDJ and FMA. Maximum 1- and 5-day rainfall trends show little consistent change, but tend towards positive changes in the November/December/January (NDJ) and February/March/April (FMA) seasons in the southern parts of the country (McSweeney and others, 2008).

In the Initial National Communication (2002), it is projected that again, southern Guyana is targeted for the largest decreases in both the doubling $CO_2$ and tripling $CO_2$ scenarios of $CO_2$ concentration. However, with the tripling of $CO_2$ concentration, northern Guyana (including the coast) is also expected to be affected by significant rainfall decreases.

### 3. Impact of climate trends and projects on the incidence of disease in Guyana

Clear links have not yet been established between climate change and human health outcomes in Guyana. However, in the Initial National Communication of Guyana to UNFCCC (2002), it is theorized that perhaps modest effects on human health could occur through:

1. the direct impact of temperature (heat stress and cardio- and cerebro-vascular conditions related to temperature extremes)

2. climate-related chronic, contagious, allergic, and vector-borne diseases (e.g. malaria and dengue fever); asthma and hay fever, linked to plants or fungi whose ranges and life cycles are strongly affected by climate and weather; and mosquito and tick-borne diseases, such as encephalitis and Lyme disease, especially where conditions are already warm and humid, with poor drainage, as in the coastal region of Guyana

3. premature birth, which has an adverse effect on human reproduction

4. pulmonary conditions such as bronchitis and asthma, related to urban and rural smog that may increase with climate change; and effects of increased ultraviolet radiation on suppression of the immune system.

The report further articulates that malaria and climate stress mortality are ―very probable”, whereas dengue fever and cholera are ―probable”. Encephalitis, onchoceriasis and yellow fever are ―possible” (Pelling, 1997; Government of Guyana, 2002).

Other impacts of climate change on human health in Guyana are anticipated, including loss of life due to extreme events such as floods, and indirect impacts associated with malnutrition and health quality. Based on the coastal location of the majority of the country‘s infrastructure, the major concerns that face the country in the context of an increased number and intensity of extreme weather events are: flood hazards associated with high precipitation, sea and riverine inundation of the coastal plain due to sea-wall breaches and overtopping, and the inadequacy of drainage to facilitate quick run-off. In addition, the accumulation of vast amounts of water during extreme flooding events can provide ample breeding grounds for various vectors that are detrimental to human health.

Climate-induced effects on other sectors such as agriculture, fisheries, water and coastal resources, and social and economic conditions might also affect human health. Decreases in food production might result in poorer diets, and sea-level rise and changed precipitation patterns may result in the deterioration of water supplies. Greater numbers of humans could migrate from one area to another, changing the geographic range and susceptibility of human populations to many diseases. In general, any event that reduces standards of living will have an adverse impact on human health.

### a) Malaria

Malaria is one of the most common vector-borne diseases in Guyana. As indicated in the previous section, over the last seven years, the epidemiological profile of the disease in Guyana has changed considerably to reflect a significant reduction in the total number of cases since 2000. In addition, there has been a marked decrease in the number of malaria-related mortality cases: from 34 deaths in 1998 to 10 in 2007, a reduction of 71% (PAHO, 2009). The level of malaria incidence fell in 2008 and 2009 to just over 11,000 cases (MOH, 2010),[8] and by 2010 the number of cases were approximately 1,728.

The disease is endemic in the interior regions of Guyana, particularly the Administrative Regions of 1, 7, 8 and 9. The mean prevalence rate for malaria during the years 1995 to 2007 for these regions is substantially higher than the national prevalence rate. Rambajan (1994) contends that, besides the conducive tropical environment, the high prevalence of malaria in these regions is the result of transient populations such as miners, resistant parasites and impoverished living conditions. Hale and others (2003) further pointed out that, besides these factors, malaria is also influenced by climate factors. However, research examining the relationship between climatic conditions and malaria is sparse (Sookdeo, 2008).

### b) Dengue fever

Dengue fever is an acute fever caused by a flavivirus. The disease can occur in two forms: dengue fever (DF) and dengue haemorrhagic fever/ dengue shock syndrome (DHF/ DSS). The disease is most serious in children and spreads rapidly and may affect large numbers of people during an epidemic resulting in reduced work productivity, but most importantly causing the loss of lives.

As dengue fever is endemic in most Caribbean countries, cases are reported every year. A total of 58,461 cases of dengue fever and 1,386 cases of DHF/DSS have been reported among Caribbean Epidemiology Centre (CAREC) member countries during the period 1980-2005. The general trend has been an increasing one, with outbreaks being reported with increasing frequency in recent years (CAREC 2008).

Dengue fever is another vector-borne disease that is endemic in Guyana. While the reported cases may fall somewhat short of the reality, a total of 248 cases were reported by MOH in 2006 and 352 in 2007 with most of the cases being from the coastal areas of Regions 1, 3, 4 and 9. During 2010, 627 cases of dengue fever were confirmed in Guyana by the health authorities. So far, there have been no reported deaths from dengue hemorrhagic fever. However, serotypes 1 and 2 have been identified through laboratory diagnosis by CAREC in 2000 (PAHO, 2009).

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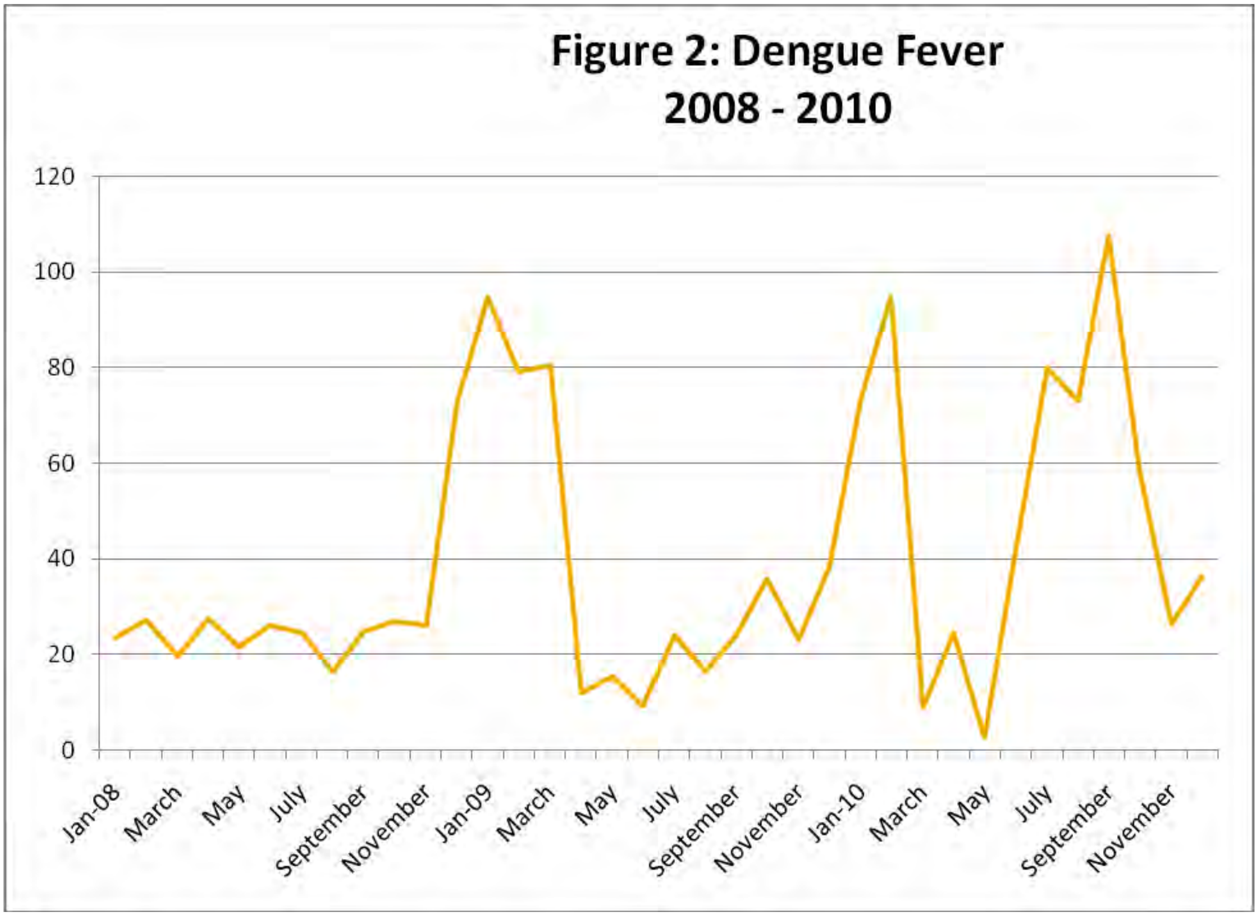
[8] In 2010, the first quarter statistics showed that the goal of reducing the level of cases to under 10,000 will not be reached, as the number of cases for the first quarter was close to 3,000.



Source: Data compiled by author

Since 2000, surveillance of dengue fever has improved, although weaknesses remain in overall case reporting and in reporting of circulating serotypes. In 2002, the largest number of cases (202) was recorded. For the first ten months of 2010, the Ministry of Health reported that there were 1,000 cases of dengue fever compared to 760 for the same period in 2009. The increase in the prevalence rate is thought by the Ministry of Health to be a consequence of climate change. Over the years, statistics have shown that the figures for dengue fever have risen (MOH, 2010).

Most of the reported cases of dengue fever in Guyana are from the coastal zone. The presence of dengue in this zone can be attributed to the fact that the *Aedes aegypti* vector breeds in urban environments where there is an increased use of containers to hold water. Hales and others (2003) pointed out that climate change can also influence the prevalence of dengue, as it is associated with warmer and humid weather and that increased rainfall can affect the vector density and transmission potential.

### c) Yellow fever

Although yellow fever continues to be an important public health problem in the Americas,[9] there have been no reported case of the disease in Guyana since 1968. The country has integrated universal child immunization against yellow fever and has implemented ―catch-up” campaigns in all age-groups in the entire country.

The link between climate and yellow fever has not been studied as well as the link with dengue fever and, for obvious reasons, there is no evidence of research on Guyana. However, it is possible to see a re-emergence of the disease in that country as a result of climate change. It is possible that, if forested areas are cleared to establish human settlements as coastal populations retreat inland to escape rising sea levels, then there is a risk that new (possibly non-immune) immigrants could become exposed to the forest transmission cycle of the virus. The favourable conditions provided by human habitation further increases the risk of transmission within the population. Critical adaptation measures must therefore include full immunization of communities, surveillance and testing capabilities, as well as adequate sanitation and water supply.

### d) Gastroenteritis and other waterborne diseases

Gastroenteritis (GE) outbreaks could be caused by viruses (e.g. rotavirus, adenovirus, norwalk virus, etc.), by bacteria (e.g. diseases such as campylobacteriosis, cholera, typhoid fever, etc.), or by parasites (amoeba, cryptosporidium, cyclospora).

Between 1980 and 2005, a total of 739,856 GE cases were reported among children under age 5 among CAREC member countries. Reports for Jamaica, Guyana and Suriname accounted for 55%, 12% and 8% of all cases, respectively, over the review period (CAREC, 2008). Since 1994, when reporting of gastroenteritis for persons aged 5 and over began, there has been an increasing trend, from a low of 7,138 cases in 1994 to highs of 46,403 and 39,294 cases in 2004 and 2005, respectively. During 2010, there were 30,861 cases of gastroenteritis in the Guyanese population, with approximately 38% of the cases being among the population under age 5.

The Ministry of Health in Guyana considers gastroenteritis a major public health problem and reports that, for every 10,000 population in Guyana, approximately 800 instances of the illness occur each year. The rate in children under age 5 is about 1,200 episodes for every 10,000. This means that almost 30% of deaths of children under age 5 are caused by diarrhoeal illnesses. Gastroenteritis occurs in every geographic region of the country. However, the disease‘s occurrence is seasonal with the highest incidence occurring in the months of December, January, February and March (MOH, 2010).

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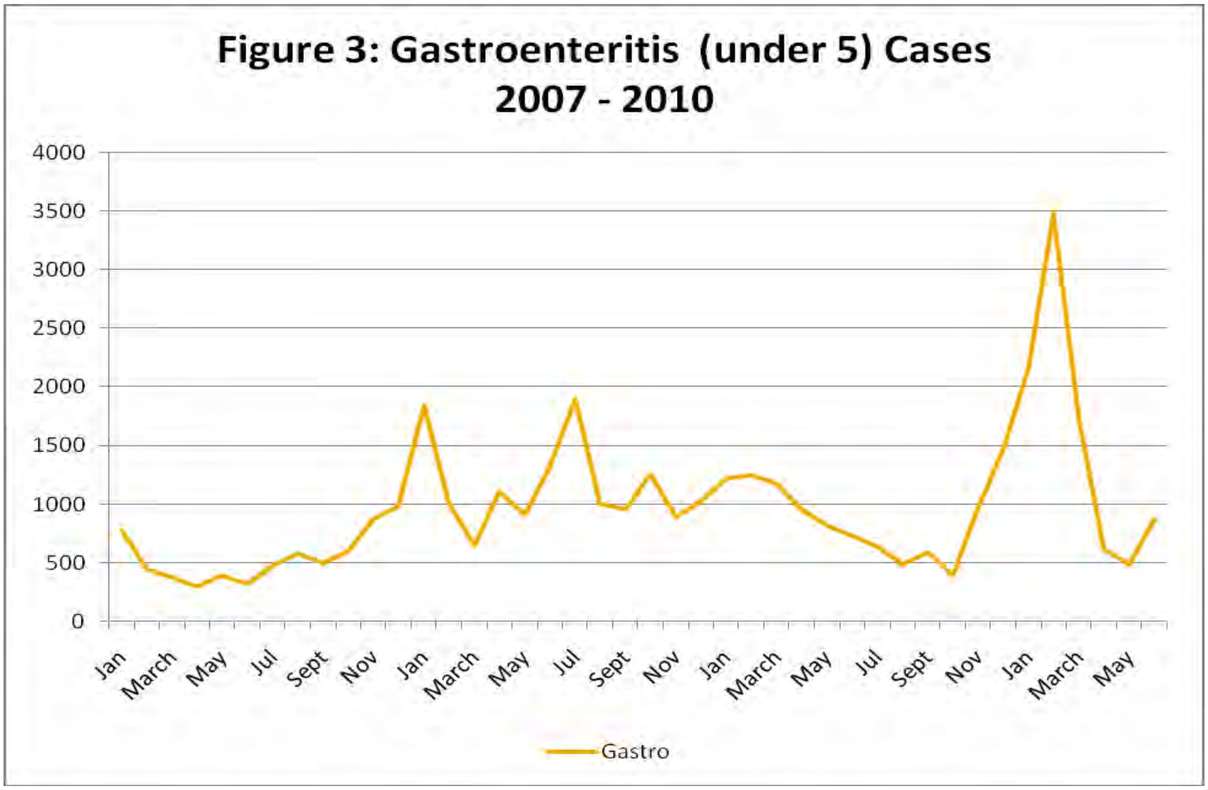
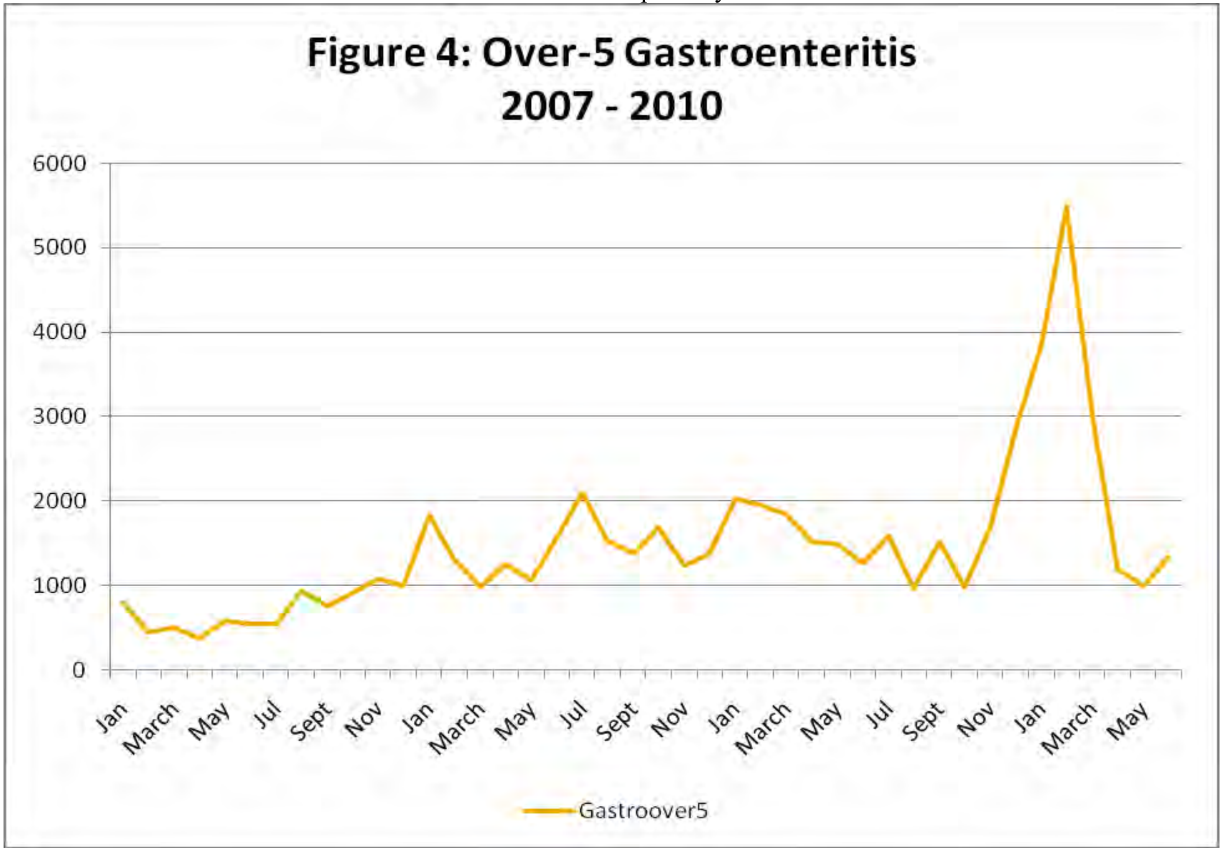
[9] Between 1985 and 1999, Bolivia, Brazil, Colombia, Ecuador, Peru, Venezuela and French Guiana reported 2,935 cases and 1,764 deaths. During this period, more than 80% of all yellow fever reports in the American Region came from Bolivia and Peru. However, from January to May 2000, a total of 66 confirmed cases were reported in Brazil, which represent more than 90% of all the cases notified in the Region during this period.



Source: Data compiled by author



Source: Data compiled by author

Rotavirus is ranked as one of the most common causes of diarrhoea in children under age 5 everywhere in the world. In Guyana, it is estimated from studies among children in the last five years that rotavirus causes up to one third of all diarrhoea illnesses in children. In 2010, the Ministry of Health began introducing the rotavirus vaccine among vulnerable children, and during 2011 the vaccine will become a part of the routine vaccination programme. It is expected that this will significantly reduce morbidity and mortality in Guyanese children. In addition, since gastroenteritis is primarily caused by viruses and bacteria spread through contaminated food or water, the Ministry urges persons to adopt hygienic practices such as hand-washing, boiling water, and cooking food thoroughly. These are important steps being taken as Guyana enters the last phase of its programme to achieve the health-related Millennium Development Goals (MDGs) (Ministry of Health, 2010).

Climate and other environmental factors contribute significantly to the prevalence of waterborne diseases. Human exposure to waterborne pathogens is often the result of consuming contaminated drinking water, recreational water and food. Acute diarrhoea is one of the major outcomes. In Guyana, the prevalence of acute diarrhoeal diseases more than tripled between 1995(9.35) to 2007 (33.05). Whilst it may be argued that this is the result of improved surveillance, the steady annual increase within the last twelve years is a justifiable cause for concern. Moreover, the prevalence rate of acute diarrhoea in the interior locations of Administrative Regions 1, 7, 8 and 9 is alarmingly higher. In most instances, the prevalence in these regions ranges from 50 to 234. These high figures are likely the result of relying on the creeks and rivers for drinking water, and poor sanitary conditions attributed to the lack of ready access to clean water, and inadequate waste disposal facilities (Sookdeo, 2008). Households (in Regions 1, 8 and 9) where the household size is above the national average are at increased risk of transmission of diarrhoea and other communicable diseases.

Although, the data collected does not allow for assessment of the seasonal prevalence of diarrhoea, it is claimed by health officials that there is an increase in diarrhoea during periods of heavy rainfall and prolonged dry spells. This is attributed to the fact that intense rainfall washes contaminants into water supplies, and drought conditions diminish the availability of fresh water, leading to poor sanitation and health.

Ministry of Health data tabulated since the beginning of the twenty first century indicate that the prevalence of typhoid, which also results in diarrhoea, is relatively low, with the total number of cases ranging from 157 in 2003 to 360 in 2006 (Sookdeo, 2008).

### e) Typhoid fever

Typhoid fever is a systemic bacterial disease contracted by consuming food or water that has been contaminated with the bacterium *Salmonella typhi*. The number of typhoid cases in Guyana has shown an overall increase since the 1980s. This already worsening situation is expected to be exacerbated by climate change, particularly in areas where water supply and sanitation is substandard, as may occur in Guyana due to the proximity of sewerage systems to the coastline, inadequate sanitation provision, and the potential for these provisions to contaminate the sources of potable water.

### f) Chronic respiratory illnesses and asthma

According to (Sookdeo, 2008), asthma in Guyana is comparatively lower than other Caribbean countries. Within the last twelve years, the prevalence of asthma in Guyana has increased steadily, but marginally from 2.88 cases in 1995 to 4.28 in 2007. However, these figures are not homogenous throughout the country as, when examined according to Administrative Regions, the results indicate that, for most of the years within the past decade, the prevalence of asthma ranged between 10 and 18 cases for Regions 2 and 10.

The higher rate in Region 10 may be attributed to allergens emitted by the bauxite company, for example, dust particles, carbon dioxide, sulphur and nitric oxides. These, along with allergens from forest flowering and local temperature and barometric changes, can play significant roles in triggering acute asthmatic attacks (Monteil , 2001, in Persaud and others, 2006). However, it is likely that there are infectious agents in the dust that causes asthma attacks (Gyan and others ; Blades and others, 2002).

The reasons for the higher presence of asthma in Region 2 are uncertain, but it is most likely the result of higher environmental allergens. Persaud and others (2006) reported that there appears to be a seasonal variation of asthma in Guyana, as there is a higher incidence from March to September (drier periods) and a smaller peak incidence during the wet period in the latter part of the year. It was also reported that males, East Indians and children below age 5 are more vulnerable to asthmatic attacks (Sookdeo, 2008).

Because of the great sensitivity of dust emissions to climate, future changes in climate could result in large changes in emissions from Africa and elsewhere, which could, in turn, lead to impacts on climate over large areas. Aerosols, including mineral dust, can affect climate directly by scattering and absorbing solar radiation, and indirectly by modifying physical and radiative cloud properties and precipitation processes. These aerosols also have direct impacts on human health, especially by inducing breathing difficulties (Prospero and Lamb, 2003 cited in CEHI 2004). This is likely to affect adults, although children and elderly people may be more susceptible, in particular those predisposed to chronic respiratory illnesses and asthma (Prospero and others, 2003). Persons living in and around mining communities and inhabitants of the hinterland region are also at risk.

### g) Chronic non-communicable diseases (CNCDs)

Guyana, like many other Caribbean territories, is burdened by high numbers of chronic non-communicable diseases (CNCDs), which constitute the leading causes of death. While there is an absence of scientific research linking the increased incidence of cardiovascular and cerebrovascular disease in Guyana to climatic factors, it is reasonable to conclude that the projected increases in the number of ‗hot days‘ and ‗hot nights‘ could potentially induce, or worsen, cardiovascular and cerebrovascular diseases, particularly in the elderly, as a result of heat stress. Persons with chronic respiratory illnesses may also be at risk.

# III. ESTIMATING THE IMPACT OF CLIMATE CHANGE ON HUMAN HEALTH IN GUYANA

The theoretical relationships between environmental health and hazard are well known (WHO, 2003; WHO, 2008; IPCC, 2007). However, in Guyana, little empirical research (Pelling, 1997) of the linkages has been undertaken. In assessing the impact of climate change on human health globally, the focus has been on identifying the key health outcomes and producing estimates based on the local conditions. In Guyana, focus has been on communicable diseases of significance – malaria, dengue, gastroenteritis and leptospirosis – all of which are expected to be associated with the flood events that are anticipated to impact Guyana with increasing likelihood and intensity as a result of climate change. The focus in the present study is therefore to estimate the impact of climate change on these four diseases, thereby assessing the cost of the key threats of climate change to Guyana in terms of human health.

There are various methods used to forecast the future health impacts of climate change. These are summarized in table 7.

**Table 7: Methods used to forecast the future health impacts of climate change**

| Methodology | Measurement | Function |
|---|---|---|
| Analogue Studies | Qualitative or quantitative | Describe basic climate/health relationship, e.g. correlation of increased occurrences of dengue fever in the warmer, drier periods of the first and second years of El Niño events<br>Analogue of a warming trend, e.g. association of changes in malaria incidence with a trend in temperature<br>Impacts of extreme event, e.g. assessment of mortality associated with a heat wave<br>Geographical analogue, e.g. comparison of vector activity in two locations, the second location having a climate today that is similar to that forecast for the first location |
| Early effects | Empirical | Analysis of relationships between trends in climate and indicators of altered health risk (e.g. mosquito range) or health status (e.g. heat-attributable mortality) |
| Predictive Models | Empirical-statistical models | Extrapolation of climate/disease relationships in time (e.g. monthly temperature and food-poisoning in a population) to estimate change in temperature-related cases under future climate change scenarios<br>Extrapolation of mapped climate/disease (or vector) relationships in time and space to estimate changes in distribution of disease (or vector) with future changes in climate (e.g. increase in diarrhoeal diseases in the rainy season in the tropics) |
| | Process-based / biological models | Models derived from accepted theory. Can be applied universally, e.g. vector-borne disease risk forecasting with models based on established vector life cycle and behaviour |
| | Integrated assessment models | Comprehensive linkage of models: ‗vertical‘ linkage in the causal chain and ‗horizontal‘ linkage for feedbacks and adaptation/adjustments, and the influences of other factors (population growth, urbanization, and trade). e.g. modelling the impact of climate change on agricultural yield, and hence on food supplies and the risk of malnutrition. |

Source: Data compiled by author

The present study utilizes the predictive/statistical model and seeks to extrapolate the climate/disease relationship in time, to estimate changes in temperature and/or rainfall related cases under future climate change. Rogers and Randolph (2000) and Hales and others (2002) have used this approach to estimate relationships for malaria and dengue, respectively. This method allows for obtaining estimates that can be tested for their statistical significance.

## A. DEFINING THE MODEL USED TO ASSESS THE IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH IN GUYANA

A predictive, empirical statistical modelling approach is used in the present study to estimate the relationship between climate and disease. This involves the estimation of an econometric model using a Poisson regression in order to obtain the historical relationship between each disease and climate variables such as rainfall, humidity and temperature, as relevant, for the period 2008 – 2010. The relationship that is estimated is guided by the findings in the health economics literature between disease, climate and non-climate proxies for the socio-economic conditions within Guyana that may have an impact on the number of cases for each disease, using EViews 6. The statistical relationship that is generated by the regression analysis is assessed using: an in-sample forecast analysis (including the MAPE), a residuals analysis, improvements in the log-likelihood of the specification associated with the inclusion of particular variables, as well as the statistical significance ($p \leq 0.05$) and sign of each coefficient in the specification compared with expectations. The Poisson approach has been used in the health economics literature, since disease data are, by nature, count data, for which the Poisson model is more appropriate than models such as Ordinary Least Squares.

If the model performs well based on these criteria, then it is used to forecast the number of disease cases that could be anticipated between 2011 and 2050 under the A2 and B2 scenarios using anomalies provided by the ECHAM model. A BAU comparator was also calculated for each disease by applying a two-period moving average process[10] to the historical disease series and extrapolating the number of disease cases from 2011 to 2050. If the regression did not produce sensible, statistical relationships, no projections were calculated, as the absence of this relationship would indicate that there was no statistical basis on which to project the future effects of climate on that particular disease.[11] Using these forecasts, the cost effectiveness of treatment and prevention were calculated, based on the approach of Markandya and Chiabai (2009) in developing a similar framework for various diseases in Africa. This provides an estimate of the magnitude of total direct costs that the Guyanese health sector could face in the four decades between 2011 and 2050. The productivity losses associated with the forecast cases were also estimated for the period 2011 and 2050 using the lost GDP, days lost, and the number of cases. All the direct costs and productivity losses were discounted using a rate of 2% to provide comparable present value estimates.

## B. DATA

### 1. Data description and sources

As noted above, the data used in this analysis pertain to four diseases – malaria, dengue, gastroenteritis and leptospirosis – that were provided by the Ministry of Health in Guyana in the form of epidemiological weeks that were aggregated over four-week intervals for the period 2008 to 2010. These data had to be transformed into monthly data to be consistent with the format of the climate and non-climate data, to facilitate the analysis.[12] The monthly climate data relating to maximum and minimum temperature,

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[10] The two-period moving average process is displayed on the line graph of the number of cases for each disease in the sections that follow.

[11] This was not an issue in this analysis.

[12] The recording of the dataset in terms of four-weekly epicalendar units presented a challenge to the analysis since it was not congruent with the other data series pertaining to the climate and non-climate variables. The average of

precipitation and humidity for the period 2008 to 2010 were sourced from the Statistical Bulletin for Guyana.[13]

Non-climate controls were also included in the analysis, as proxies for the socio-economic status of the general population which is generally thought to have an impact on the number of disease cases. These data include the Human Development Index, access to sanitation, and access to drinking water.[14] These variables are included as proxies for changes in the socio-economic and other related environmental factors that are likely to influence the extent of disease incidence in Guyana.

The aim of the modelling approach is to estimate the impact of climate change on human health in Guyana to 2050 under the A2 and B2 scenarios prescribed by the Intergovernmental Panel on Climate Change (IPCC). The two scenarios make different assumptions about the rate of development, population growth, emissions, and mitigation measures that occur during the period of analysis. A BAU scenario for 2011 to 2050 is also constructed by applying a two-period moving average to the historical disease data.

| | |
|---|---|
| **A2** | Countries are assumed to operate on the basis of self-reliance and increased heterogeneity with a focus on regional sources of wealth and a slower profile of per capita economic growth and technological change. Additionally, fertility patterns converge slowly across the regions of the world and results in a continuously increasing population. |
| **B2** | Emphasis is placed in this context on local solutions to ensure economic, social and environmental sustainability. Similar to A2, the population increases continuously but at a comparatively lower rate. Economic development is intermediate and the rate of technological change is less rapid and more diverse than in the alternative A1 and B1 scenarios, neither of which are considered here. The environmental protection and social equity focus is at the local and regional levels. |
| **BAU** | The business as usual scenario was developed for the period 2011 to 2050 by applying a two period moving average to the historical disease data. |

Forecasted precipitation, temperature and humidity data were downscaled using the historical climatology (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 scenarios. These anomalies were provided by ECLAC based on the précis grids for the coordinates 58W-5N.

The focus in this analysis is to estimate regressions that sufficiently model the historical relationship between the historical climate and disease data. Attention is given to the diseases that are known to be sensitive to climate and therefore more likely to be impacted by climate change. This ensures that the policy recommendations that emerge from this analysis, which are intended to guide both the

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the four-weekly data was calculated in order to obtain disease data for the usual calendar months. The methodology was obtained from the PAHO webpage at http://www.paho.org/english/sha/be993calend.htm in conjunction with the actual 2008, 2009 and 2010 calendar. This disease data represents the series that were used in this analysis.

[13] Available from: http://www.statisticsguyana.gov.gy.

[14] The Human Development Index was obtained from the United Nations Development Programme webpage at http://hdr.undp.org/en/statistics/ whilst data on access to sanitation and drinking water were both sourced from the Environmental Performance Index tabulated by Yale University for the years 2008 and 2010 on their program webpage at http://epi.yale.edu/.

local and global response, focus the attention of policymakers on the priority health issues at the local level. The analysis attempts the estimation of separate models for malaria, dengue, gastroenteritis and leptospirosis in relation to climate variables, as these are the three diseases that are known to be, and/or are likely to become, of concern in terms of their impact on the Guyanese population.

A Poisson regression model is estimated for each disease and is then rerun using the relevant A2 and B2 climate forecasts, in order to obtain forecasts for the number of disease cases between 2011 and 2050. The model and forecast number of cases for malaria, gastroenteritis, leptospirosis and dengue are then presented. The direct costs of prevention and treatment, as well as the indirect productivity losses as a result of the number of disease cases, are presented for each disease. This section also presents a comparative analysis of the direct and indirect costs of malaria, leptospirosis, gastroenteritis and dengue, along with a sensitivity analysis and an extrapolation of the likely regional distribution of each disease, by scenario and decade, using the 2007 disease distribution as reported by the Ministry of Health of Guyana.

### a) Data limitations

Given the relatively long time horizon over which climate change affects human welfare, attempts were made to develop a long time series (ten years minimum) of monthly data, including disease, and climate and non-climate variables, to form the basis of model development and analysis. There were several challenges in this process, linked largely to a reported fire at the Ministry of Health Guyana in 2009 which destroyed a considerable amount of health data and limited the availability of the disease data to four-week data for the period 2008 to 2010. Climate variables were available for a much longer period on a monthly basis however only the entries that correspond to this period were included in the analysis. The non-climate variables that are included in the regression to control for the socio-economic conditions that are likely to impact disease incidence and or prevalence were available on an annual basis.[15]

## 2. Climate data[16]

**Table 8: descriptive statistics of climate variables 2008 to 2010**

| | RAIN | TEMPMAX | TEMPMIN | HUMIDITY |
|---|---|---|---|---|
| Mean | 201.04 | 30.45 | 24.14 | 71.83 |
| Median | 182.95 | 30.55 | 24.20 | 72.00 |
| Maximum | 474.70 | 32.00 | 25.90 | 86.00 |
| Minimum | 20.00 | 28.70 | 22.50 | 60.00 |
| Std. Dev. | 145.21 | 1.03 | 0.75 | 4.84 |
| Observations | 30 | 30 | 30 | 30 |

Source: Data compiled by author

There are, traditionally, two rainy seasons with mean annual rainfall of 2,500 mm in Georgetown.

Guyana lies within the equatorial trough zone and the seasons and climate are determined mainly by the variation in rainfall patterns. The two wet and two dry seasons in a calendar year are:

- First dry season (FDS) - late January to early April
- First wet season (FWS) - late April to early July
- Second dry season (SDS) - late July to early November
- Second wet season (SWS) - late November to early January

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[15] For the purposes of estimating the regression, these data were assumed to be the same for each month of the year for which the data were available.

[16] Explanations of the data exploration process are detailed in appendix 1.

There are four main tropical and extra-tropical weather systems which influence weather in Guyana. These are: Intertropical Convergence Zone (ITCZ); Tropical Waves; Upper Level Troughs; Southern Hemisphere Upper Troughs; and El Niño Southern Oscillation (ENSO). The ITCZ is brought about by the confluence of the Northeast and Southeast Trade Winds. When the convergence is strong, copious rainfall is experienced but, when it is weak, rainfall may even be absent.

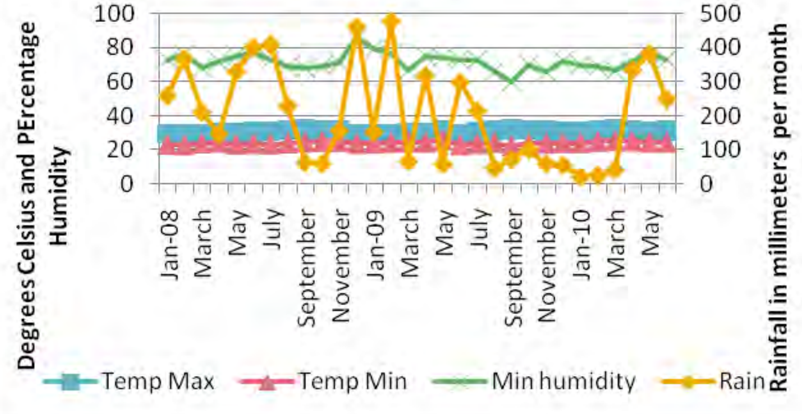
Guyana is not affected by cyclones or hurricanes, but there are innumerable instances of floods occurring as a result of high precipitation, sea and riverine inundation of the coastal plain (FAD, 1990a as cited by CDERA, 2003). The climate is humid tropical, with temperatures of 26° C to 28° C. Diurnal variation in temperature is smallest on the coast where the maritime effect is most pronounced. In that area, daily maximum temperatures average 29.6° C while daily minimum temperatures average 24.0° C.

### 3. Historical climate data

The historical data on temperature and rainfall were sourced from the Guyana Bureau of Statistics online portal. A summary of the available data[17] is provided in table 8 and is illustrated in figure 5. These data are used to estimate the relationship between climate and disease outcomes.

Figure 5 confirms the statistical analysis presented in table 8. They both indicate that Guyana experienced an average of 201 millimetres of rainfall per month for the period, with a standard deviation of 145 millimetres; maximum and minimum temperatures of 30.45° and 24.14° Celsius, respectively, with a standard deviation of 1.03° and 0.74° Celsius, respectively; and an average humidity of 71.8%. Figure 5 also indicates that, between January 2008 and July 2010, both maximum and minimum temperatures had increased, whilst rainfall declined over the period. There is also some amount of variation in the humidity data.

Figure 5: Climate Data 2008-2010



Source: Data compiled by author

### 4. Forecast A2 and B2 climate-based scenario data 2011 – 2050

In order to obtain the forecast number of disease cases under each scenario, the rainfall and temperature data associated with the scenarios were obtained. The anomaly data were obtained from the simulations of

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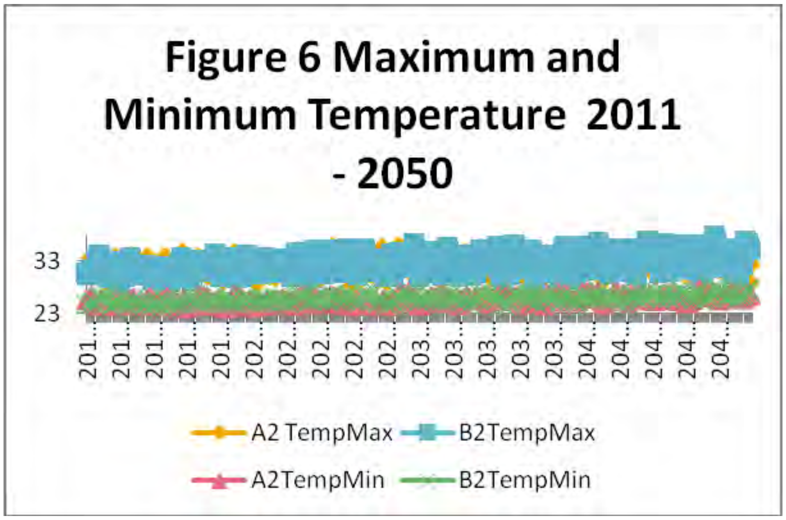
[17] See footnote 1.

the European Center Hamburg Model (ECHAM) Global Climate Model (GCM) developed by the Max Planck Institute for Meteorology.[18] Temperature and precipitation forecasts for the A2 and B2 scenarios were based on a ten-point average for Guyana calculated from the ECHAM Model output. They were calculated by downscaling the climatology for rainfall and temperature by the A2 and B2 anomalies from the ECHAM model. This provided both rainfall and temperature data for the period 2011 to 2050. The forecast data for temperature (maximum and minimum), rainfall and humidity are shown in figures 6, 7a and 7b, respectively.



Source: Data compiled by author

Figure 6 indicates that both maximum and minimum temperatures are expected to be higher under both A2 and B2 between 2011 and 2050, with B2 exhibiting less variation in comparison with A2. In addition, the forecast temperatures for 2011 to 2050 are higher than the historical values for 2008 to 2010, as expected. Similarly, precipitation is expected to be higher under both the A2 and B2 scenarios, with more variability in rainfall being exhibited under the A2 scenario. Humidity is forecast to trend downwards over the forecast period 2011 – 2050, again with A2 reflecting more variation than B2. These are the forecasts that are included in the regression model to determine the size and direction of the relationship between climate and health outcomes.

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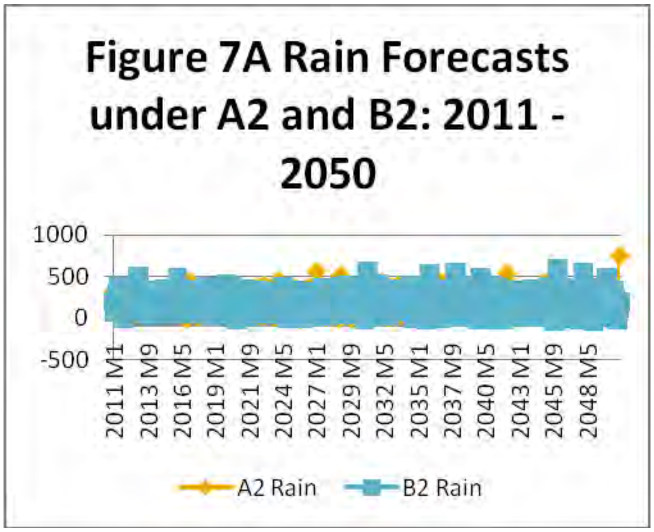
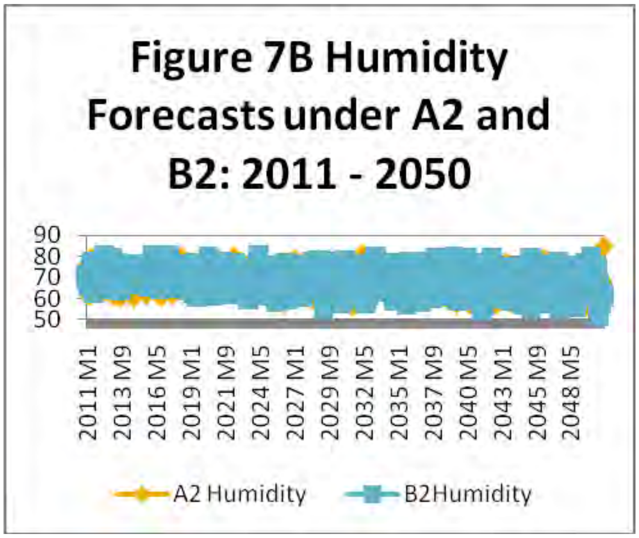
[18] This model, which has its origins in the global forecast models developed at ECMWF, has been continuously revised for use in climate research. The population forecasts were obtained from the United Nations Economic Affairs Council and were used to provide a consistency check for the forecast number of disease cases given the estimated relationship and the climate-related forecasts.

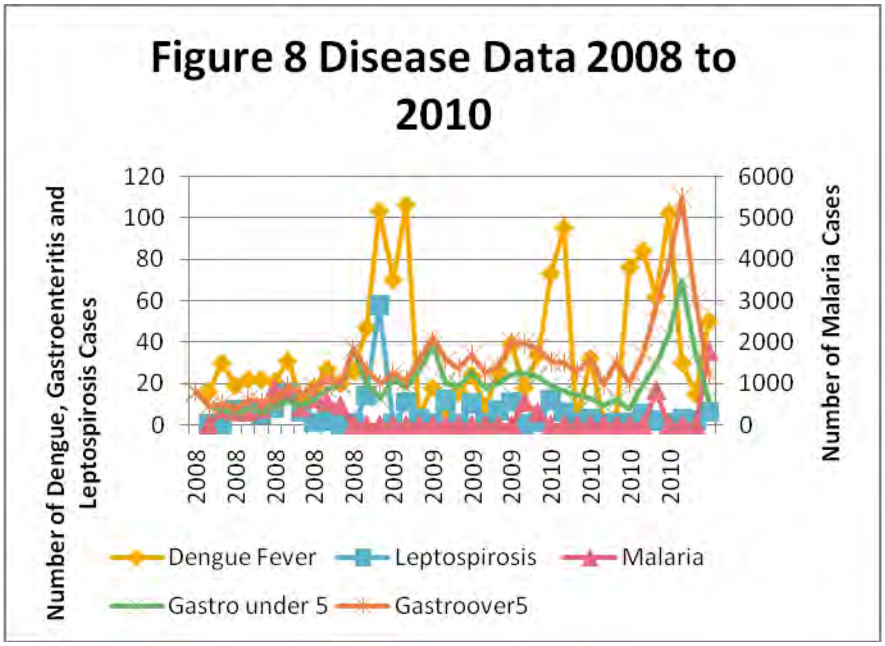




Source: Data compiled by author

**a) Disease data**

The diseases being analysed in this study are malaria, dengue, gastroenteritis and leptospirosis. The data are presented in figure 8 below.



Source: Data compiled by author

The data indicate that malaria is the most serious of the three diseases in terms of the number of cases, which outstrips the sum of the gastroenteritis, leptospirosis and dengue cases over the entire period. The number of cases of malaria has increased over time. Dengue fever also displays an increase over the period 2008 to 2010 and is the disease with the second largest number of cases during this period, with an increased number of spikes during the latter part of the year.

### b) Properties of the climate and disease data

The disease data represent the number of disease cases that were confirmed. Precipitation data report the total amount of rainfall recorded for the Georgetown area. Both the maximum and minimum temperatures were included in the dataset. Data on humidity were available for 0800 and 1400 hours for the period under study, from which the lower of the two were included in the final dataset.

(i) Correlation analysis

The Spearman Rank Correlation methodology was used as a measure of the existence of a relationship between each disease and the climatic and non-climatic variables. The results indicate that there is a negative relationship between the number of cases of dengue and the one period lag of the maximum temperature at the 24% significance level. The level of rainfall and the non-climatic controls do not seem to have a significant relationship with the number of reported dengue cases.

The number of malaria cases in a given period is correlated with the second lag of rain at the 11% significance level. In terms of the non-climatic data, the number of malaria cases has a very strong negative relationship with the level of human development (HDI), access to improved sanitation (SANITATION) and access to improved water (WATER).

The strongest statistically significant correlation for leptospirosis is with the second lag of the maximum temperature. The first and second lag of rain and the first lag of maximum temperature are significant correlates of leptospirosis at the 14%, 15% and 27% levels, respectively.

(ii) Stationarity

Since the data are time series, they were also tested for nonstationarity using the Augmented Dickey-Fuller and KPSS tests. In every case, an intercept and a trend were added for completeness. The results are presented in table 9. With the exception of malaria, the diseases were unambiguously stationary series. For malaria, the ADF test was unable to reject the null; however, given the fact that the KPSS is a stronger test, and the fact that its results indicate that malaria was a stationary series, the analysis was pursued assuming stationarity. The climate data are also unambiguously stationary series, with the exception of the data on the maximum temperature which were treated as stationary based on the KPSS test.

**Table 9: Results of Unit Root Testing**

| **Variable** | **ADF** | **ADF + Intercept** | **ADF+ None** | **KPSS** | **KPSS + Trend** | **CONCLUSION** |
|---|---|---|---|---|---|---|
| Dengue | Reject null | Reject null | Reject null | Unable to reject null | Unable to reject null | Stationary |
| Malaria | Unable to reject null | Unable to reject null | Reject null | Unable to reject null | Unable to reject null | Stationary based on KPSS |
| Leptospirosis | Reject null | Reject null | Reject null | Unable to reject null | Unable to reject null | Stationary |
| Under-5 Gastroenteritis | Reject null | Reject null | Reject null | Unable to reject null | Unable to reject null | Stationary |
| Over-5 Gastroenteritis | Reject null | Reject null | Reject null | Unable to reject null | Unable to reject null | Stationary |
| Rain | Reject null | Reject null | Unable to reject null | Unable to reject null | Unable to reject null | Stationary |
| Max Temp | Unable to reject null | Unable to reject null | Unable to reject null | Unable to reject null | Unable to reject null | Stationary based on KPSS |

**Table 9: Results of Unit Root Testing**

| Variable | ADF | ADF + Intercept | ADF+ None | KPSS | KPSS + Trend | CONCLUSION |
|---|---|---|---|---|---|---|
| Min Temp | Reject null | Reject null | Unable to reject null | Unable to reject null | Unable to reject null | Stationary |
| Humidity | Reject null | Reject null | Unable to reject null | Unable to reject null | Unable to reject null | Stationary |

ADF Null Hypothesis: Series being tested has a Unit Root
KPSS Null Hypothesis: Series being tested is Stationary
Source: Data compiled by author

## C. MODEL METHODOLOGY – THE POISSON REGRESSION ANALYSIS

As discussed above, a Poisson regression model is used to model the climate-disease relationships for each disease in the current 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:

1. Logarithm of the disease rate changes linearly with equal increment increases in the exposure variable

2. Changes in the rate from combined effects of different exposures or risk factors are multiplicative

3. At each level of the covariates, the number of cases has variance equal to the mean

4. 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 (the classic example given by McCullagh & Nelder, 1989); the number of deaths due to AIDS in Australia per quarter (three-month periods) from January 1983 – June 1986; the 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, & Shaw, 1995); the daily homicide count in California (Grogger, 1990); the founding of day care centres in Toronto (Baum & Oliver,1992); and the political party switching among members of the United States House of Representatives (King, 1988).[19]

The climate-disease models that are pursued in the present analysis were estimated using EViews 6 which calculates the Poisson model using the raw data and thus, no transformations such as taking the natural logarithms were performed on the data. The model was developed based on the findings of the health literature for each disease. The results of the correlation analysis, as well as the statistical changes in the model output, were used to inform the variables that are included in the final models that are presented below.

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[19] http://www.ed.uiuc.edu/courses/EdPsy490AT/lectures/4glm3-ha-online.pdf.

## D. MALARIA

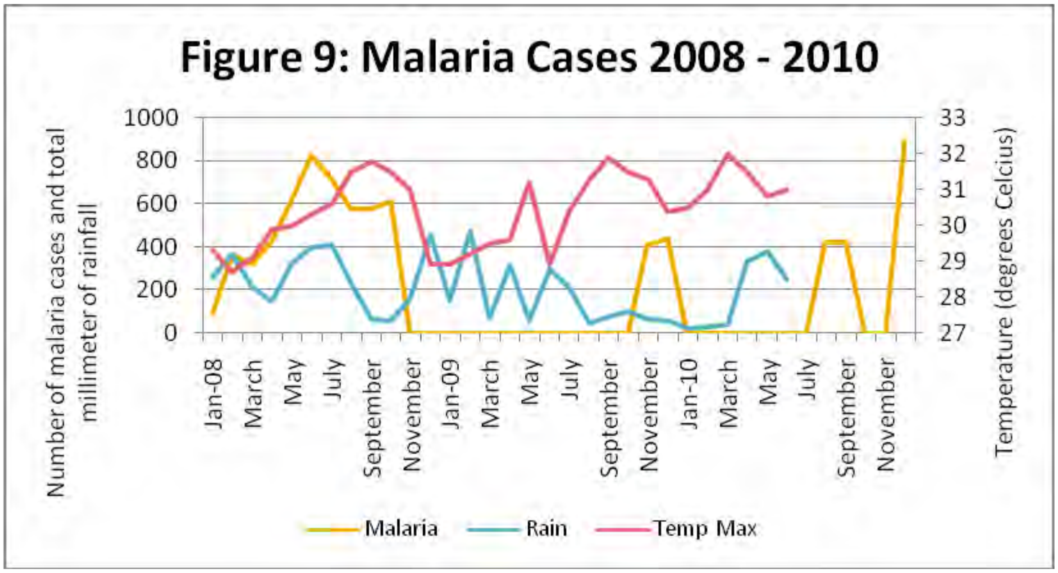
### 1. Historical Data

Over the thirty-six months being considered in this analysis, there were an average of approximately 214 malaria cases each year (See table 10). The standard deviation around the average number of cases is approximately 287.11 cases and indicates a relatively high degree of fluctuation of malaria cases around the mean, as is reflected in figure 9.

**Table 10: Descriptive statistics for malaria in Guyana 2008 - 2010**

| | MALARIA |
|---|---|
| Mean | 213.72 |
| Median | 0.00 |
| Maximum | 889.00 |
| Minimum | 0.00 |
| Std. Dev. | 287.11 |
| Observations | 30 |

Source: MOH Guyana



Source: Data compiled by author

Given malaria's rise to global prominence, there have been many attempts at estimating the determinants or covariates of the disease. In investigating the determinants of malaria, Teklehaimanot and others (2004) use 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 indicates that malaria cases should follow periods of increased temperature and rainfall at lags of 4 to 12 weeks for rainfall, and 4 to 10 weeks for both the minimum and maximum temperature. The authors also include the logarithms of last period‘s malaria cases in order to correct for potential autocorrelation. Graves and others (undated) also use a Poisson regression to determine the statistical evidence for a reduction in the number of cases by DDT, malathion, impregnated bed nets and larval control used over the period, whilst addressing the effects of satellite-derived climate variables. They find that malaria responds to differences in rainfall two and three months prior to the current period.

## 2. Model results

In Step 1, a Poisson regression model was estimated in order to obtain the predictive relationship between malaria cases, climate, and a socio-economic control variable, the Human Development Index (HDI) between 2008 and 2010. The variables included in the regression are: rainfall; the first, second and third lags of rainfall; the maximum temperature and the first, second and third lags of the maximum temperature; a time trend; a control for seasonal variability in the disease; and HDI.

A stepwise approach was used to eliminate variables in order to identify the model with the best fit. Variables that had a p-value that was greater than or equal to 0.05 were eliminated from the model. The final model includes the variables that result in the highest log-likelihood and provide the best-fit between climate and malaria. The results are presented and discussed below.

$$Malaria_t = constant + \alpha_1\, Rain_{t-1} + \alpha_2 Rain_{t-2} + \alpha_3\, Max\ Temp_t + \alpha_4\, Max\ Temp_{t-1} + \alpha_5\, Time + + \alpha_6 Seasonal\ Control + + \alpha_7\, HDI$$

***Equation (1)***

## 3. Results

All the coefficients were statistically significant at the 5% level (i.e. their p-values are less than 0.05). The findings with respect to rainfall are consistent with the findings of Blanco and Hernandez (2009); Odongo-Aginya and others (2005); Breit and others (2008); and Oluleye and Akinbobola (2010). The results advocate for the inclusion of rainfall in the development of early warning systems for malaria. This has been incorporated in the Mapping Malaria Risk in Africa (MARA) model for Africa.

```
Dependent Variable: MALARIA
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/04/11   Time: 01:22
Sample (adjusted): 2008M03 2010M06
Included observations: 28 after adjustments
Convergence achieved after 11 iterations
Covariance matrix computed using second derivatives
==========================================================================
                              Coefficient    Std. Error   z-Statistic   Prob.
==========================================================================
              C                 807.6884     27.53459     29.33359    0.0000
            RAIN               -0.002186     0.000206    -10.60989    0.0000
          LAGRAIN               0.003115     0.000235     13.23783    0.0000
          LAGRAIN2              0.001225     0.000161     7.598660    0.0000
          TEMPMAX               0.549737     0.037950     14.48580    0.0000
        LAGTEMPMAX              0.497077     0.062119     8.001990    0.0000
          @TREND                0.512244     0.022328     22.94190    0.0000
  SIN((2*3.14*@TREND)/12)       2.623176     0.101572     25.82568    0.0000
            HDI                -1397.629     46.99127    -29.74231    0.0000
==========================================================================
R-squared                       0.642788   Mean dependent var        196.7500
Adjusted R-squared              0.492383   S.D. dependent var        283.0487
S.E. of regression              201.6645   Akaike info criterion     151.6340
Sum squared resid               772702.8   Schwarz criterion         152.0622
Log likelihood                 -2113.876   Hannan-Quinn criter.      151.7649
Restr. log likelihood          -5906.921   LR statistic              7586.091
Avg. log likelihood            -75.49557   Prob(LR statistic)        0.000000
==========================================================================
```

The output indicates that there is a statistically significant relationship between the number of malaria cases and the climate data for the period 2008 to 2010. In terms of the interpretation of the coefficients presented in the model output, there are an additional 11 cases[20] of malaria associated with a 1-millimetre increase in rainfall (this period and up to two periods prior) coupled with a 1-degree increase in the monthly maximum temperature (this period and one lag). The model also indicates that a one unit increase in HDI for Guyana reduces the number of malaria cases by 1,398 cases.

## 4. Validating the model

Figure 10 provides a statistical assessment of the ability of the model to forecast. These assessments were performed by EViews. The plots and embedded table that were generated indicate that the Poisson regression provides forecasts for the number of malaria cases that are consistent with the actual number of cases for the period 2008 to 2010 and, therefore, will provide comparatively accurate forecasts of the number of malaria cases through to 2050.

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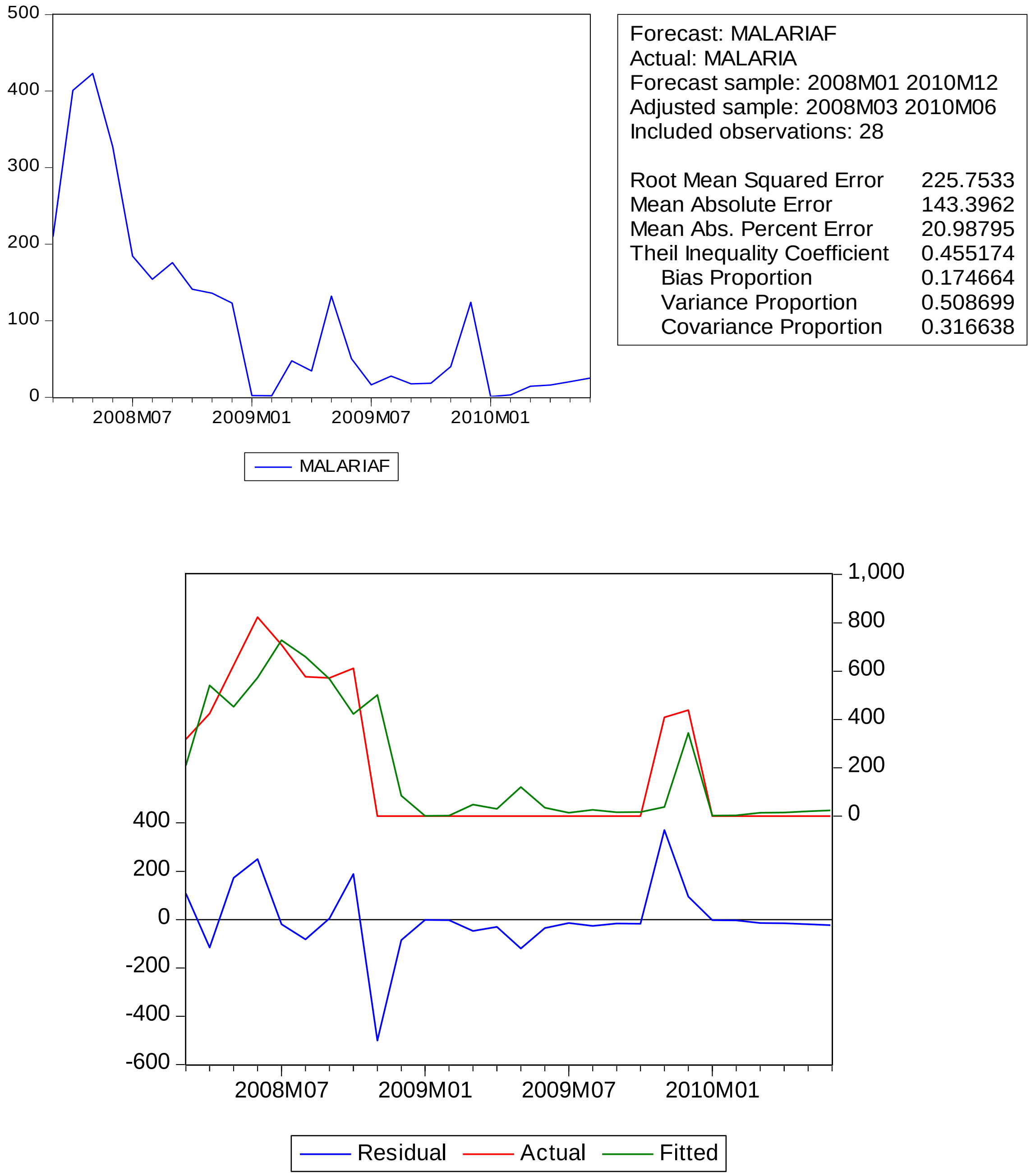
[20] This is calculated by taking the exponents of $(1-\alpha)$ of each estimate/coefficient.

Figure 10: Malaria model performance



```
Forecast: MALARIAF
Actual: MALARIA
Forecast sample: 2008M01 2010M12
Adjusted sample: 2008M03 2010M06
Included observations: 28

Root Mean Squared Error        225.7533
Mean Absolute Error            143.3962
Mean Abs. Percent Error        20.98795
Theil Inequality Coefficient   0.455174
     Bias Proportion           0.174664
     Variance Proportion       0.508699
     Covariance Proportion     0.316638
```

Source: Data compiled by author

The Theil inequality coefficient, in particular, indicates that the model provides forecasts that are 55% better than a ―naïve guess” at the number of malaria cases in the next period. The bias proportion indicates that the mean of the forecast sample is only 17.4% different from the mean of the actual historical data. Based on the covariance proportion, 30% of the forecast errors are unsystematic – that is, they cannot be explained by a statistical relationship. The mean absolute percentage error (MAPE) indicates a differential of 21% between the actual disease data and the forecast value calculated by the model which is an acceptable level. When taken together, the validation measures imply that the model should provide relatively stable and dependable forecasts for the 2011 to 2050 period and can be used for policymaking purposes. These forecasts are calculated in Step 2 and the results are presented below.

## 5. Generating climate-based disease forecasts for 2011 to 2050

In Step 2, the forecast number of malaria cases is obtained by rerunning equation (1) and including the A2 or B2 climate forecast data in order to obtain the forecast number of malaria cases in logarithms for each scenario. These forecasts are presented in table 11 and figure 11 in ten-year bands.

**Table 11: Forecast number of cases of malaria in Guyana under BAU, A2 and B2: 2011 – 2050**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2011 to 2020** | | **2021 to 2030** | **2031 to 2040** | **2041 to 2050** | **2011 to 2020** | **2021 to 2030** | **2031 to 2040** | **2041 to 2050** |
| | **Total number of cases for each decade** | | | | | **Deviation of A2 and B2 cases viz BAU cases** | | | |
| **MALARIA** | **A2** | 32 827 | 34 397 | 36 315 | 39 914 | 8 056 | 6 517 | 9 220 | 14 695 |
| | **B2** | 31 473 | 36 359 | 38 870 | 43 032 | 6 702 | 8 480 | 11 774 | 17 813 |
| | **BAU** | 24 771 | 27 880 | 27 096 | 25 219 | 0 | 0 | 0 | 0 |

Source: Author‘s calculations

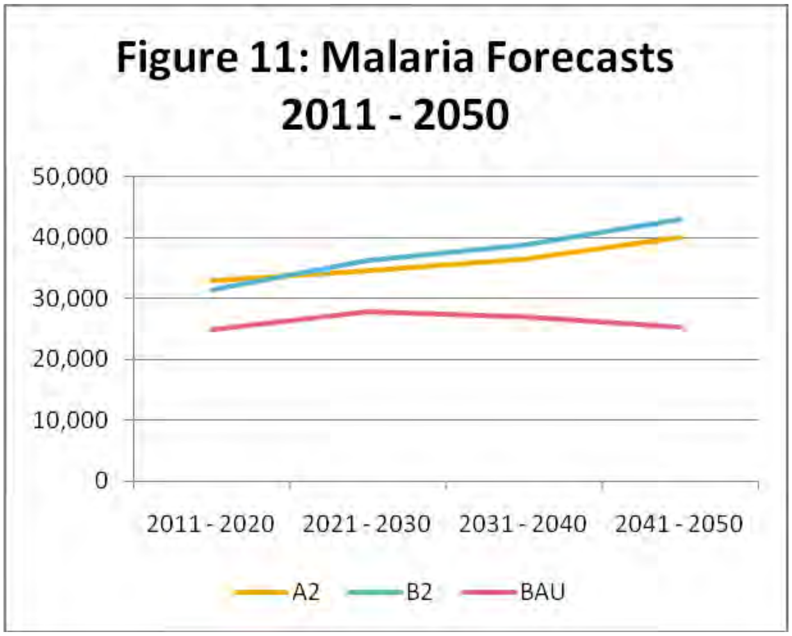


Figure 11: Malaria Forecasts 2011 - 2050

Source: Data compiled by author

Figure 11 and table 11 present the number of malaria cases from 2011 to 2050. The table indicates that the number of malaria cases is forecast to increase from 32,827 to 39,914 under the A2 scenario between 2011-2020 and 2041-2050, respectively. The number of malaria cases is lowest under BAU in relation to the two climate-based scenarios A2 and B2, by 32% and 27%, respectively, for the first decade of the forecast period 2011 to 2020. A comparison of the two climate-based scenarios indicates that the A2 scenario has a higher number of cases than B2 during the first decade to 2020.

However, during the second to the fourth decades, the model forecasts a larger number of malaria cases under the B2 scenario. These changes are associated with the variances in temperature and rainfall associated with a changing climate, that are higher under B2 during the latter half of the forecast period, as well as the likely improvements in HDI in the future under a B2 scenario – which ought to result in fewer cases in this scenario. By the last decade, the total number of malaria cases under B2 is 71% and 8% more than the total number of cases under BAU and A2, respectively.

Compared with the BAU scenario, the number of cases under the A2 scenario is larger by 8,100 to 14,800 from the first to the fourth decades of the forecast period. The differences in the number of cases between the first and fourth decades of the forecast period, under the B2 scenario in comparison with the A2 scenario, is 6,700 and 17,800.

## 6. Direct costs

Unit costs - This analysis assumes that malaria can be prevented in two ways – using impregnated bed nets at a cost of US$ 3 per net and or using a vaccine at a cost of US$ 60 per dose.[21] If data were available on the cost of vector control for Guyana, this would also have been used as a potential form of prevention. The alternative is to treat the disease using an antimalarial drugs such as chloroquine at an estimated cost of US$ 0.111 per dose.[22] The prevention and treatment costs implied by the number of malaria cases forecast by the model are presented in table 12.

### *a) Calculation of prevention costs*

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

### *b) Calculation of treatment costs*

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

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[21] The latest information obtainable on the state of readiness of a malaria vaccine – that is expected to have a 30% protective efficacy – was that it would be available in 2015. Hence, the calculations with respect to this analysis only use this option beginning in 2016.

[22] Given the global imperatives in relation to malaria, it may be possible that a conglomerate of foundations will facilitate a mass distribution of prevention and treatment products that would facilitate the distribution of these products to the Guyanese population at relatively little cost to the Government.

**Table 12: Direct costs associated with preventing or treating malaria using 1%, 2% and 4% discount rates for 2011 – 2050 (US$)**

| | | 2011 – 2020 | | | 2021-2030 | | | 2031-2040 | | | 2041-2050 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MALARIA | Direct costs | Nets[23] | Vaccine[24] | Antimalarial medicine [25] | Nets | Vaccine | Antimalarial medicine | Nets | Vaccine | Antimalarial medicine | Nets | Vaccine | Antimalarial medicine |
| | 1% discount rate | | | | | | | | | | | | |
| | **A2** | 97 506 | 1 950 115 | 3 608 | 102 170 | 2 043 400 | 3 780 | 107 867 | 2 157 346 | 3 991 | 118 557 | 2 371 141 | 4 387 |
| | **B2** | 93 486 | 1 869 712 | 3 459 | 107 998 | 2 159 968 | 3 996 | 115 454 | 2 309 084 | 4 272 | 127 817 | 2 556 348 | 4 729 |
| | **BAU** | 73 578 | 1 471 563 | 2 722 | 82 811 | 1 656 229 | 3 064 | 80 483 | 1 609 652 | 2 978 | 74 909 | 1 498 171 | 2 772 |
| | 2% discount rate | | | | | | | | | | | | |
| | **A2** | 96 550 | 1 930 997 | 3 572 | 101 168 | 2 023 366 | 3 743 | 106 810 | 2 136 196 | 3 952 | 117 395 | 2 347 895 | 4 344 |
| | **B2** | 92 569 | 1 851 382 | 3 425 | 106 940 | 2 138 792 | 3 957 | 114 322 | 2 286 446 | 4 230 | 126 564 | 2 531 285 | 4 683 |
| | **BAU** | 72 857 | 1 457 136 | 2 696 | 82 000 | 1 639 992 | 3 034 | 79 694 | 1 593 872 | 2 949 | 74 174 | 1 483 483 | 2 744 |
| | 4% discount rate | | | | | | | | | | | | |
| | **A2** | 94 693 | 1 893 862 | 3 504 | 99 223 | 1 984 455 | 3 671 | 104 756 | 2 095 115 | 3 876 | 115 137 | 2 302 743 | 4 260 |
| | **B2** | 90 789 | 1 815 778 | 3 359 | 104 883 | 2 097 661 | 3 881 | 112 124 | 2 242 475 | 4 149 | 124 130 | 2 482 607 | 4 593 |
| | **BAU** | 71 456 | 1 429 114 | 2 644 | 80 423 | 1 608 453 | 2 976 | 78 161 | 1 563 220 | 2 892 | 72 748 | 1 454 954 | 2 692 |

Source: Author‘s calculations

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[23] The cost of these nets were obtained from the 2004 joint WHO – RBM – UNICEF – PSI – MSH PROJECT *Sources and prices of selected products for the prevention, diagnosis and treatment of malaria* available at http://www.who.int/medicines/areas/access/AntiMalariaSourcesPricesEnglish.pdf

[24] This was calculated using an estimated cost of US$ 60 per treatment, which is the expected cost of the vaccination when released. http://www.scidev.net/en/opinions/new-vaccines-are-not-the-only-answer-to-malaria.html

[25] The cost of these antimalarial drugs were obtained from the 2004 joint WHO – RBM – UNICEF – PSI – MSH PROJECT *Sources and prices of selected products for the prevention, diagnosis and treatment of malaria* available at http://www.who.int/medicines/areas/access/AntiMalariaSourcesPricesEnglish.pdf

The direct costs of treating and preventing malaria – bed nets, vaccines and antimalarial medicines – reflect the same pattern regardless of the discount rate (1%, 2% and 4%) applied. Since the cost of treatment and prevention are fixed per unit costs, it is expected that, regardless of the discount rate, the total direct costs associated with treating or preventing the disease will reflect the size of these per unit costs. The trends observed in the total costs of preventing and treating malaria using the three discount rates in table 12 indicate that the costs associated with impregnated nets, vaccines and antimalarial medicine are 32% larger under the A2 and B2 scenarios than under the BAU during the first decade. By the last decade, 2041 to 2050, the number of cases under the A2 scenario is 58% larger than those associated with the BAU.

## 7. Indirect costs

The indirect costs associated with malaria are the productivity losses related to the number of cases. Productivity loss assumes that the average number of days lost due to malaria is 10 days,[26] GDP per capita of US$ 1,518[27] and a discount rate of 2%. Table 13 presents productivity losses based on a 1% and 2% discount rate.

### a) Calculation of productivity losses

Productivity losses due to malaria = Days lost * Number of estimated malaria cases * Discount Rate * GDP per capita in 2008 US$ = 10 * Number of estimated malaria cases * 2% * 1518 divided by 365 days

**Table 13: Productivity losses as a result of malaria cases for Guyana 2011 – 2050 under A2, B2 and BAU climate scenarios using a 1%, 2% and 4% discount rate (US$)**

| | | 2011 – 2020 | 2021 – 2030 | 2031 – 2040 | 2041 – 2050 |
|---|---|---|---|---|---|
| **MALARIA** | **1% discount rate** | | | | |
| | A2 | 1 351 724 | 1 416 384 | 1 495 366 | 1 643 558 |
| | B2 | 1 295 992 | 1 497 183 | 1 600 543 | 1 771 934 |
| | BAU | 1 020 015 | 1 148 016 | 1 115 732 | 1 038 458 |
| | **2% discount rate** | | | | |
| | A2 | 1 338 472 | 1 402 498 | 1 480 706 | 1 627 445 |
| | B2 | 1 283 286 | 1 482 505 | 1 584 851 | 1 754 562 |
| | BAU | 1 010 015 | 1 136 761 | 1 104 793 | 1 028 277 |
| | **4% discount rate** | | | | |
| | A2 | 1 312 732 | 1 375 527 | 1 452 231 | 1 596 148 |
| | B2 | 1 258 608 | 1 453 995 | 1 554 373 | 1 720 821 |
| | BAU | 990 591 | 1 114 900 | 1 083 547 | 1 008 503 |

Source: Author‘s calculations

The productivity losses are lowest under the BAU scenario throughout the entire forecast period 2011 to 2050 as indicated in Table 13. A2 is associated with the highest levels of productivity loss, in

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[26] The literature indicates a wide range of estimates in relation to the number of days lost, from 4 days (Onwujekwe and others, 2000 ); 6.2 days (Mustafa and Babiker, 2007) to 16 days Asenso-Okyere and others (2009). For the present study, the average of the extreme number of days was used to perform the cost estimates in order to provide an average anticipated cost.

[27] IMF database available at www.imf.org.

comparison with both the B2 climate-based and BAU scenarios during the first decade, by 32% and 4%, respectively. Beginning in 2021 and continuing through to 2050, the productivity losses associated with the B2 scenario exceed the losses associated with A2 and BAU by 8% and 70.7%, respectively.

### 8. Summary of the impact of climate change on malaria and assessment of possible health interventions

An empirical Poisson regression model is estimated and the A2 and B2 climate data are applied in order to forecast the number of malaria cases anticipated under the A2 and B2 scenarios. The number of malaria-related illnesses is anticipated to increase under the two climate-based IPCC scenarios being assessed in the present study, namely, the A2 and B2 scenarios, as well as the BAU, which is calculated as a moving-average process on the historical number of malaria cases. As a result, the direct (treatment and prevention costs) and indirect costs (productivity losses) are estimated to increase over time in relation to malaria between 2011 and 2050 under each scenario. During the first decade, the number of cases and their associated direct and indirect costs are highest under the A2 scenario, in comparison to the cost and number of cases under the B2 scenario and BAU. Between 2021 and 2050, this is reversed, with the largest number of cases and the highest costs being associated with the B2 scenario, followed by A2, then BAU. Based on the monetary per unit costs of impregnated bed nets, vaccines, and antimalarial medicines such as chloroquine, providing anti-malarial medicines to the infected population is cheaper regardless of the scenario or the time period within the forecast. There are, however, ethical and other considerations that must be added to these monetary costs when deciding from a policy perspective between treatment and prevention.

## E. DENGUE

Lu and others (2009) and Fairos and others (2010) both use a Poisson regression to model the relationship between dengue and climate variables. For the Guangzhou province in China, Lu and others (2009) attempted to estimate the best relationship between monthly dengue incidence and weather variables, and found minimum temperature and wind velocity to be significant predictors of the incidence of dengue. Using a one-month lag on humidity and minimum temperature are positive, significant explanatory variables of this period‘s incidence of dengue and were found to improve the fit of the model. Using weekly data, Fairos and others (2010) found a two- to three- week lag of the incidence of dengue in response to daily temperature and wind speed, whilst humidity impacted incidence significantly only after two weeks. Neither of these studies included controls for the broad socio-economic environment in which these dengue cases were contracted.

Following the approach taken in the literature, the dengue model estimated in the present study for Guyana proceeds from the empirical strategy pursued by Lu and others (2009) and Fairos and others (2010). The HDI is included as a non-climate variable that is intended to act as a control for the socio-economic status of the population. It is expected that higher levels of economic and social development should reduce the number of dengue cases that are observed. The in-sample forecasts and residuals analysis are used as additional measures of the model performance, in conjunction with the changes in the log-likelihood as well as the sign and statistical significance of each individual coefficient as indicators of the model‘s ability to be used for forecasting purposes.

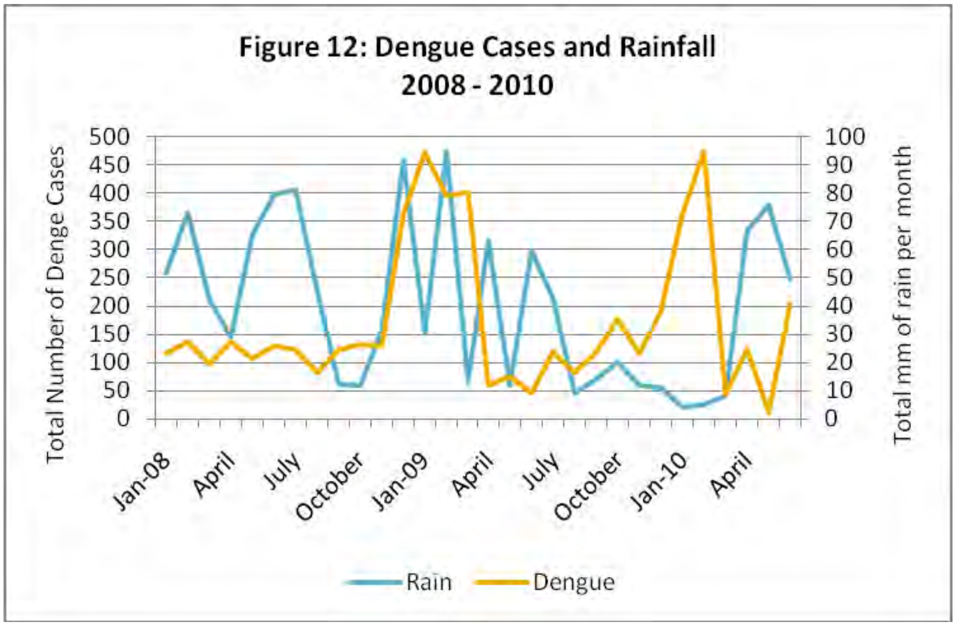
## 1. Historical data

There were fewer cases of dengue than malaria observed between 2008 and 2010. The expected changes in the rainfall pattern increase the potential for the occurrence of vector-borne diseases such as dengue and dengue haemorrhagic fever (DHF). This is especially the case in Guyana, where particular constraints in relation to the speed and ease of runoff during periods of heavy rainfall are likely to increase the prevalence of vectors if there are inadequate or inadequately-targeted vector control programmes.

**Table 14: Descriptive statistics for dengue in Guyana 2008 – 2010**

| | DENGUE |
|---|---|
| Mean | 34.67 |
| Median | 25.00 |
| Maximum | 95.00 |
| Minimum | 3.00 |
| Std. Dev. | 26.05 |
| Observations | 30 |

Source: MOH Guyana



Source: Data compiled by author

Figure 12 reflects the increased volatility in the number of dengue cases observed during 2009 and 2010 in comparison with those observed during 2008.

## 2. Model

This is the first step in the estimation process and it involves the estimation of the relationship between rainfall and the number of dengue cases. The results are presented in Equation (2). The variables that were included in the regression are: rainfall; the first, second and third lags of rainfall; the maximum temperature and the first, second and third lags of the maximum temperature; a time trend; a control for seasonal variability in the disease; and, the HDI.

A stepwise approach was used to eliminate variables and identify the model that most closely fits the historical data. Variables that had a p-value that was greater than or equal to 0.05 were eliminated from the model. Ultimately, the model with the highest log-likelihood was selected as the best-fit and is presented below.

$$Dengue_t = constant + \alpha_1 \, Rain_{t-1} + \alpha_2 \, Time + \alpha_3 \, Seasonal\ Control + \alpha_4 HDI$$

*Equation (2)*

## 3. Results

The results of the empirical analysis presented in Equation (2) above, and the regression output below, indicate that there is a statistically significant relationship between the monthly number of dengue cases and last months‘ rainfall and HDI which is used to proxy the socio-economic status of the population. Based on Equation (2), there is a small, statistically significant increase of two cases[28] for every additional millimetre of rainfall that is observed per month in Guyana. The coefficient on the HDI variable is positive, reflecting the fact that higher levels of economic development may be correlated with the availability of increased vector-breeding locations as a result of higher levels of water storage. The time and seasonal controls indicate a general trend to increased number of dengue cases per month as well as positive seasonality in the number of cases.

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[28] This is calculated as the exponent of (1 – estimated coefficient).

Dependent Variable: DENGUE
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/04/11 Time: 00:34
Sample (adjusted): 2008M02 2010M06
Included observations: 29 after adjustments
Convergence achieved after 8 iterations
Covariance matrix computed using second derivatives

**4.**

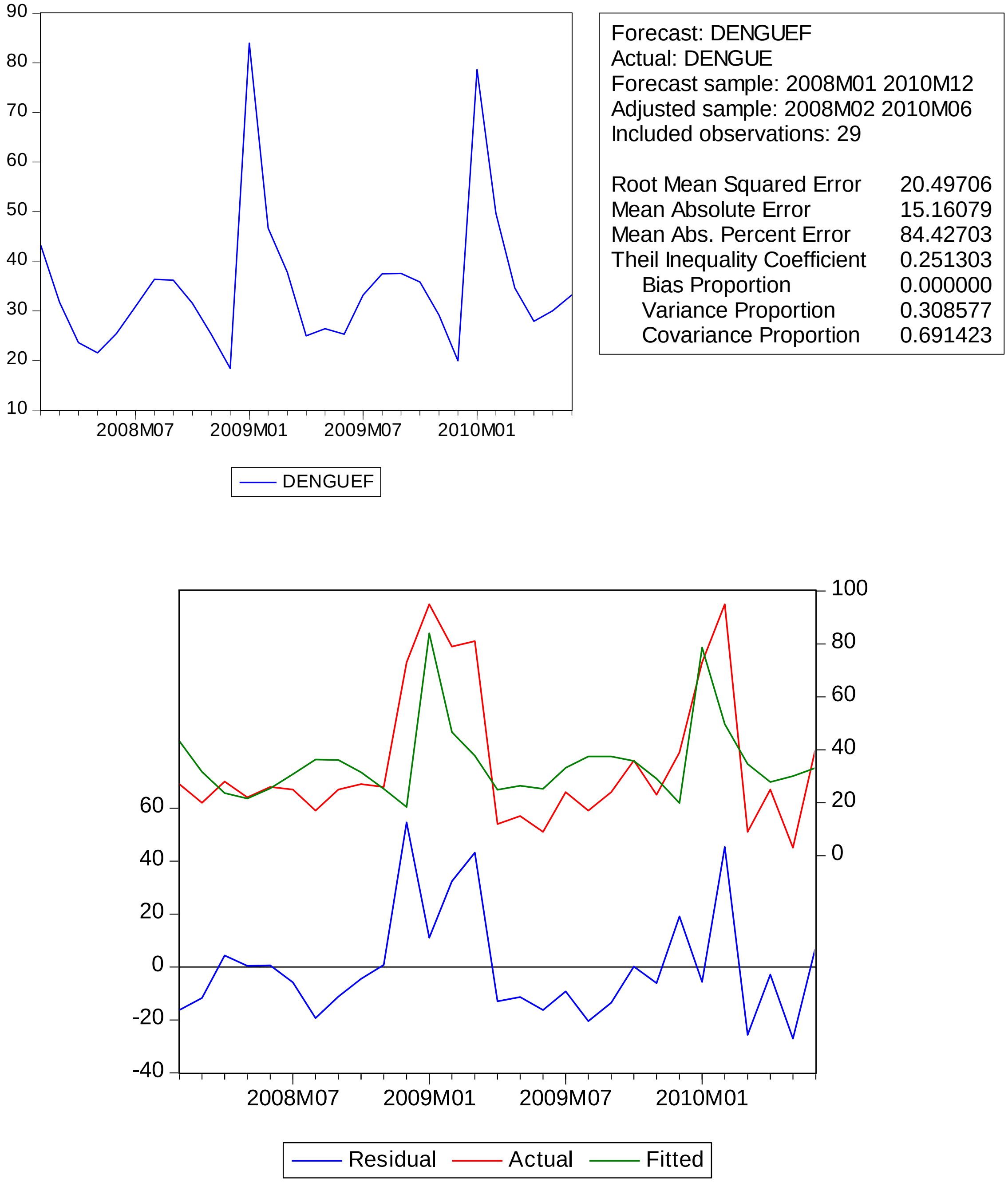
| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C | -177.3576 | 14.97001 | -11.84753 | 0.0000 |
| LAGRAIN | 0.000470 | 0.000230 | 2.041998 | 0.0412 |
| @TREND | -0.141209 | 0.013538 | -10.43086 | 0.0000 |
| SIN((2*3.14*@TREND)/12) | -0.603017 | 0.064597 | -9.335093 | 0.0000 |
| HDI | 302.9161 | 25.10673 | 12.06514 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.377267 | Mean dependent var | 35.03448 |
| Adjusted R-squared | 0.273478 | S.D. dependent var | 26.43386 |
| S.E. of regression | 22.53123 | Akaike info criterion | 17.51320 |
| Sum squared resid | 12183.75 | Schwarz criterion | 17.74894 |
| Log likelihood | -248.9415 | Hannan-Quinn criter. | 17.58704 |
| Restr. log likelihood | -322.4920 | LR statistic | 147.1012 |
| Avg. log likelihood | -8.584188 | Prob(LR statistic) | 0.000000 |

## 5. Validating the model

Figure 13 presents the statistical assessments that were performed in order to determine the ability of the chosen Poisson specification to forecast the number of dengue cases for 2011 to 2050. These assessments were estimated by EViews and the plots and embedded table that were generated indicate that the Poisson regression provides forecasts that fit the data and therefore will provide comparatively accurate forecasts through to 2050. The specific statistics assessed include the Theil inequality and the bias and covariance proportions. The Theil inequality coefficient indicates that the model provides forecasts that are 75% better than a —naïve guess” at the number of dengue cases that may arise in the next period. The bias proportion indicates that the mean of the forecast sample is not statistically different from the mean of the actual historical data. The covariance proportion, which accounts for approximately 70% of the mean squared forecast errors, also confirms this. Since the model provides adequate forecasts, the anticipated cases of dengue between 2011 and 2050 are forecast in Step 2 and the results are presented below.

Figure 13 Model performance statistics



```
Forecast: DENGUEF
Actual: DENGUE
Forecast sample: 2008M01 2010M12
Adjusted sample: 2008M02 2010M06
Included observations: 29

Root Mean Squared Error      20.49706
Mean Absolute Error          15.16079
Mean Abs. Percent Error      84.42703
Theil Inequality Coefficient 0.251303
     Bias Proportion         0.000000
     Variance Proportion     0.308577
     Covariance Proportion   0.691423
```

Source: Data compiled by author

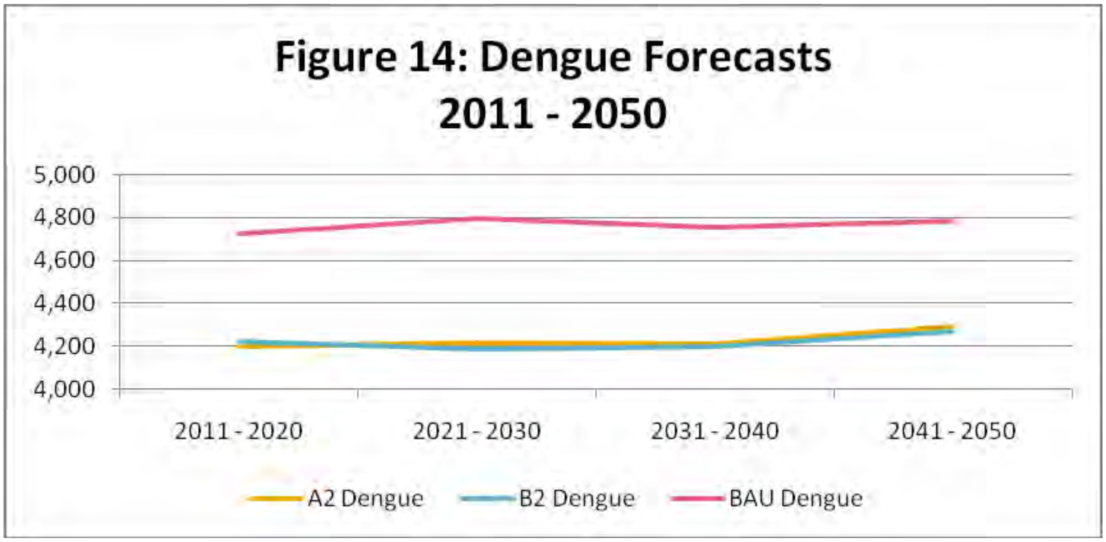
## 6. Forecasts

Similar to the malaria model, Step 2 involves the re-estimation of the regression model using the rainfall data associated with A2 and B2 climate-based scenarios, in order to forecast the associated number of cases that can be anticipated between 2011 and 2050 under A2 and B2. The number of cases under the BAU scenario for the period 2011 to 2050 is estimated as a two-period moving average of the historical data series from 2008 to 2010. The number of cases is presented in table 15. The results are presented on the basis of decades in the tables that follow.

**Table 15: Forecast cases of dengue in Guyana under BAU, A2 and B2: 2011 – 2050**

| | | 2011 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 | 2011 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 |
|---|---|---|---|---|---|---|---|---|---|
| | | Additional number of cases for each decade | | | | Deviation of A2 and B2 cases viz BAU cases | | | |
| **DENGUE** | A2 | 4 200 | 4 215 | 4 210 | 4 295 | -524 | -578 | -542 | -488 |
| | B2 | 4 220 | 4 189 | 4 201 | 4 272 | -504 | -605 | -551 | -511 |
| | BAU | 4 724 | 4 794 | 4 751 | 4 782 | 0 | 0 | 0 | 0 |

Source: Author‘s calculations



Source: Data compiled by author

The results presented in table 15 and figure 14 indicate that the number of dengue cases increases over time, with the number of cases being largest under BAU in all four decades. The number of cases under BAU exceeds the number of A2 and B2 cases by 11% and 12%, respectively. In numerical terms, the difference in the number of dengue cases between the A2 and B2 scenarios is very small – 20 cases in the 2011 to 2020 decade, and 23 cases in the 2041 to 2050 decade.

### 7. Direct costs associated with dengue

In Step 3, only the direct treatment costs are calculated, as no prevention data were available for dengue. A per patient treatment cost of US$ 828 is used for the present study, based on WHO data[29] from a study of the cost of dengue treatment in either tropical/sub-tropical countries; this figure was adjusted to represent non-fatal ambulatory and non-fatal hospitalized care, as well as risk of death. The cost is limited to the number of officially-reported dengue cases. The formulae are presented below and the results are shown in table 16.

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[29] WHO, *Dengue Guidelines for Diagnosis, Treatment, Prevention and Control* (2009)

### a) *Calculation of treatment costs*

Cost of treating dengue = Unit treatment costs * Number of estimated dengue cases
= US$ 828 * Number of estimated dengue cases

**Table 16: Direct costs of treating dengue in Guyana between 2011 and 2050 under A2, B2 and BAU, using a discount factor of 1%, 2% and 4% (US$)**

| | | 2011 – 2020 | 2021 – 2030 | 2031 – 2040 | 2041 - 2050 |
|---|---|---|---|---|---|
| | | **Treatment** | **Treatment** | **Treatment** | **Treatment** |
| **DENGUE** | | **1% discount rate** | | | |
| | **A2** | 3 443 112 | 3 455 838 | 3 451 023 | 3 520 834 |
| | **B2** | 3 459 336 | 3 434 122 | 3 443 778 | 3 501 796 |
| | **BAU** | 3 872 437 | 3 929 938 | 3 895 197 | 3 920 669 |
| | | **2% discount rate** | | | |
| | **A2** | 3 409 356 | 3 421 957 | 3 417 189 | 3 486 316 |
| | **B2** | 3 425 421 | 3 400 454 | 3 410 016 | 3 467 465 |
| | **BAU** | 3 834 472 | 3 891 409 | 3 857 009 | 3 882 231 |
| | | **4% discount rate** | | | |
| | **A2** | 3 343 792 | 3 356 150 | 3 351 474 | 3 419 271 |
| | **B2** | 3 359 548 | 3 335 061 | 3 344 438 | 3 400 783 |
| | **BAU** | 3 760 732 | 3 816 574 | 3 782 836 | 3 807 573 |

Source: Author‘s calculations

Consistent with the trend in the number of cases forecast for the period 2011 to 2050 (see table 16), treatment costs are highest under BAU throughout the entire period, as a result of the fact that the BAU scenario accounts for the largest number of cases throughout the period. During the first decade 2011 to 2050, treatment costs are slightly higher under B2 than A2 by approximately 0.5%. Treatment costs under BAU are 12% and 11% higher than the treatment costs associated with A2 and B2 scenarios, respectively.

## 8. Indirect costs

Step 4 involves the calculation of two types of indirect costs associated with the forecast number of dengue cases obtained from Step 2. The productivity loss of dengue is calculated under the assumptions that the average number of days lost due to dengue is 5 days, GDP per capita is US$1,518, and discount rate of 2%. The results are presented in table 17.

### a) Calculation of productivity loss

Productivity losses due to dengue
= Days lost * Number of estimated dengue cases * Discount Rate * GDP per capita in 2008 US$ = 5 * Number of estimated dengue cases * 2% * 1,518 divided by 365

**Table 17: Present value of productivity losses as a result of dengue in Guyana for 2011 – 2050 under A2, B2 and BAU scenarios at 1%, 2% and 4% discount rates (US$)**

| | | 2011 – 2020 | 2021 – 2030 | 2031 – 2040 | 2041 – 2050 |
|---|---|---|---|---|---|
| **DENGUE** | **1% discount rate** | | | | |
| | **A2** | 86 471 | 86 790 | 86 670 | 88 423 |
| | **B2** | 86 878 | 86 245 | 86 488 | 87 945 |
| | **BAU** | 97 253 | 98 697 | 97 825 | 98 464 |
| | **2% discount rate** | | | | |
| | **A2** | 85 623 | 85 940 | 85 820 | 87 556 |
| | **B2** | 86 027 | 85 400 | 85 640 | 87 082 |
| | **BAU** | 96 300 | 97 729 | 96 866 | 97 499 |
| | **4% discount rate** | | | | |
| | **A2** | 83 977 | 84 287 | 84 169 | 85 872 |
| | **B2** | 84 372 | 83 757 | 83 993 | 85 408 |
| | **BAU** | 94 448 | 95 850 | 95 003 | 95 624 |

Source: Author‘s calculations

Consistent with the fact that the number of dengue cases is higher under BAU than under the A2 and B2 scenarios between 2011 and 2050, there is a 1.2% increase in the productivity losses associated with BAU during the forecast period. During the first decade between 2011 and 2020, dengue-related productivity losses are 13% and 12% larger under the BAU than under the B2 and A2 scenarios. This difference in productivity losses between the A2 and B2 scenarios and the BAU remains the same through to the last decade. In terms of the two climate-based scenarios, A2 and B2, productivity losses are higher under A2 than under B2 between 2021 and 2050. These patterns between the A2, B2 and BAU productivity losses decline as expected as the discount rates increase from 1% to 4%.

## 9. Summary

The number of dengue cases and the value of the direct (treatment) and indirect (productivity losses associated with the forecast dengue-related cases) costs are highest under the BAU scenario between 2011 and 2050. In terms of the A2 and B2 scenarios, the treatment and indirect costs are higher under the A2 scenario for the majority of the forecast series between 2021 and 2050, a reversal of what is observed during the 2011 to 2020 period. Given the absence of the prevention data, a direct inference cannot be made about the cost effectiveness of prevention versus treatment costs. However, given the fact that the BAU scenario is associated with the highest level of cases and costs, it is clear that there are definite benefits associated with adaptation to climate change, as reflected in the results associated with the B2 scenario.

## F. LEPTOSPIROSIS

### 1. Model

Carvalho and others (2007) explore the covariates of the number of incidences of leptospirosis. They find that temperature was not an important variable. 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 argue to be preliminary evidence of a threshold effect. They report their best model as containing the number of days with more than 5mm of rainfall per day and a structured time trend.

**Table 18: Descriptive statistics for leptospirosis in Guyana 1980 - 2005**

| | **LEPTOSPIROSIS** |
|---|---|
| Mean | 6.97 |
| Median | 4.50 |
| Maximum | 44.00 |
| Minimum | 0.00 |
| Std. Dev. | 9.05 |
| Observations | 30 |

Source: MOH Guyana

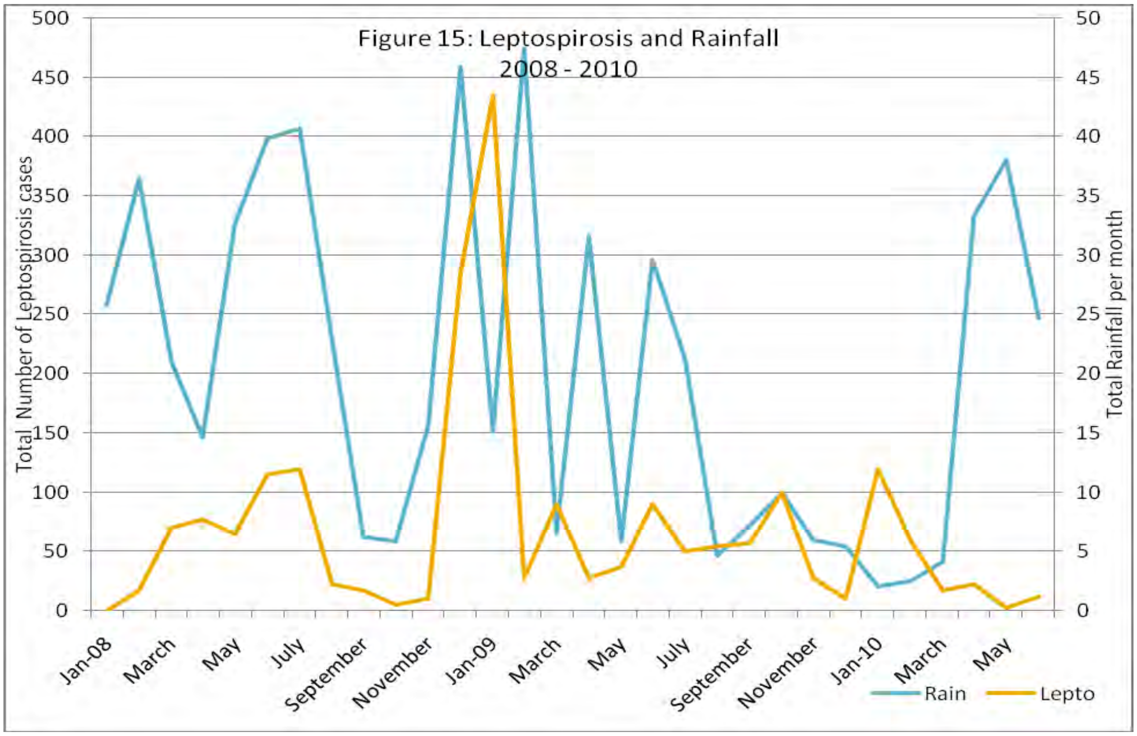


Figure 15: Leptospirosis and Rainfall
2008 - 2010

Source: Data compiled by author

The model developed for this project used Carvalho's approach as its point of departure. The variables that were included in the development of the regression model are: rainfall; the first, second and third lags of rainfall; the maximum temperature and the first, second and third lags of the maximum temperature; a time trend; a control for seasonal variability in the disease; and, sanitation.

A stepwise approach was used to eliminate variables in order to identify the model with the best fit. Variables that had a p-value that was greater than or equal to 0.10 were eliminated from the model. Ultimately, the model with the highest log-likelihood was selected as the best-fit and is presented below. As a result, the final model presented below as Equation (3) excludes both temperature and rainfall as they do not improve the performance of the model in terms of the log likelihood and are not generally found in the literature to be determinants of the number of cases of leptospirosis (See Carvalho and others (2007)).

$$\textit{Leptospirosis} = \textit{constant} + \alpha_1\, \textit{Rain}_{t-1} + \alpha_2\, \textit{Rain}^2_{t-1} + \alpha_3\, \textit{Time} + \alpha_4\, \textit{Seasonal Control} + \alpha_5\, \textit{Sanitation}$$

***Equation (3)***

## 2. Results

The results of the estimation are represented in Equation (3) and in the model output below. The number of leptospirosis cases in a given month is determined to have a statistically significant relationship with the amount of rainfall and its square during the previous month, as well as the level of sanitation that is available to the population. These results are broadly consistent with the a priori expectations which prescribe that, as the volume and intensity of rainfall increase, the number of cases of leptospirosis increases. The positive sign on the sanitation variable is likely to be the result of inadequate data, or an indication that there needs to be more widespread and higher quality sanitation infrastructure in order for this variable to have the expected impact on the number of cases of leptospirosis. The signs on the time trend and seasonal adjustment are negative, which indicate a general decline in the number of leptospirosis cases between 2008 and 2010, and a countercyclical seasonality, respectively.

Dependent Variable: LEPTO
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/04/11 Time: 00:38
Sample (adjusted): 2008M02 2010M06
Included observations: 29 after adjustments
Convergence achieved after 9 iterations
Covariance matrix computed using second derivatives

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C | -8.790902 | 3.481420 | -2.525091 | 0.0116 |
| LAGRAIN | -0.004109 | 0.002486 | -1.652800 | 0.0984 |
| LAGRAIN^2 | 1.20E-05 | 4.81E-06 | 2.500224 | 0.0124 |
| @TREND | -0.131322 | 0.033095 | -3.968049 | 0.0001 |
| SIN((2*3.14*@TREND)/12) | -0.597736 | 0.153057 | -3.905326 | 0.0001 |
| SANITATION | 0.180842 | 0.055119 | 3.280917 | 0.0010 |

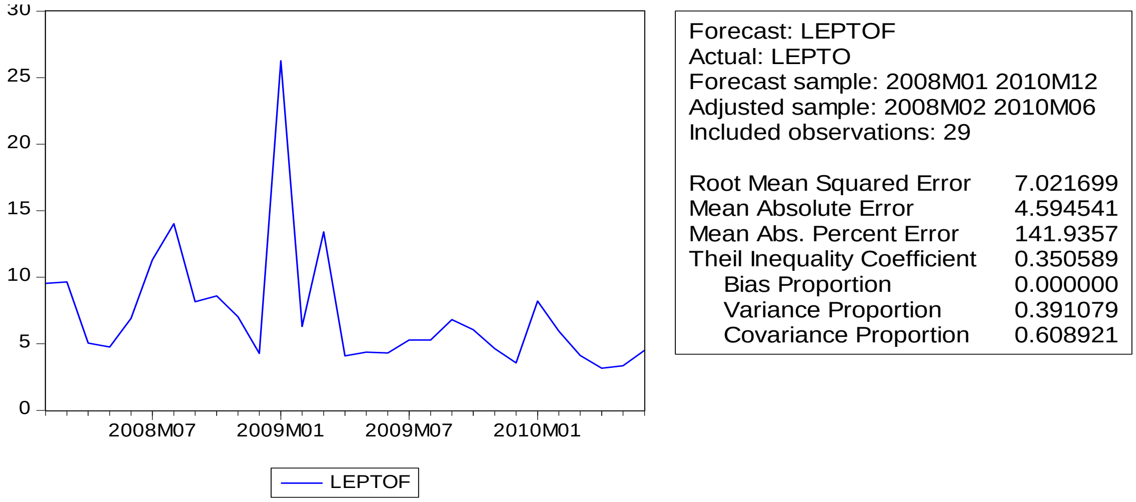
| | | | |
|---|---|---|---|
| R-squared | 0.385487 | Mean dependent var | 7.206897 |
| Adjusted R-squared | 0.251897 | S.D. dependent var | 9.115839 |
| S.E. of regression | 7.884557 | Akaike info criterion | 9.095676 |
| Sum squared resid | 1429.824 | Schwarz criterion | 9.378565 |
| Log likelihood | -125.8873 | Hannan-Quinn criter. | 9.184274 |
| Restr. log likelihood | -157.6602 | LR statistic | 63.54585 |
| Avg. log likelihood | -4.340942 | Prob(LR statistic) | 0.000000 |

## 3. Validating the model

The in-sample forecasts produced by the model suffer from the sharp variations in the number of cases of leptospirosis particularly between November 2008 and February 2009, based on the size of the mean absolute percentage error (MAPE). However, visual comparison of the actual and fitted values indicates a relatively close fit of the number of cases that are calculated based on Equation (3) and the actual data on the number of cases of leptospirosis. Nevertheless, the sharp spike between November 2008 and February 2009 is somewhat under-predicted by the model given the absence of similar spikes in previous periods.

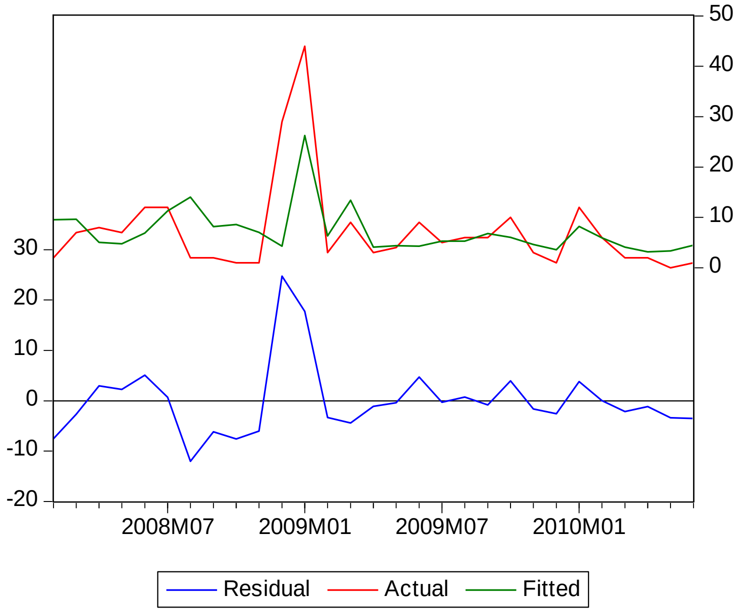
However, the Theil inequality coefficient indicates that the model provides forecasts that are 65% better than a naive guess at the number of leptospirosis cases that may arise in the next period. The bias proportion indicates that the mean of the forecast sample is not statistically different from the mean of the actual historical data. The covariance proportion, which accounts for approximately 61% of the mean squared forecast errors, also confirms this. Based on the Theil, bias and covariance statistics, the model can be regarded as providing adequate forecasts: therefore, the model is used in the next section to provide forecasts of the number of leptospirosis cases that may be anticipated between 2011 and 2050. Step 2 presents the forecasts related to the number of leptospirosis cases in the following section.

Figure 16 Model performance for leptospirosis



```
Forecast: LEPTOF
Actual: LEPTO
Forecast sample: 2008M01 2010M12
Adjusted sample: 2008M02 2010M06
Included observations: 29

Root Mean Squared Error       7.021699
Mean Absolute Error           4.594541
Mean Abs. Percent Error       141.9357
Theil Inequality Coefficient  0.350589
     Bias Proportion          0.000000
     Variance Proportion      0.391079
     Covariance Proportion    0.608921
```



Source: Data compiled by author

## 4. Forecasts

In Step 2, the regression model is re-estimated using the rainfall data associated with the A2 and B2 scenarios, in order to forecast the climate-associated number of leptospirosis cases under A2 and B2 in comparison with those associated with BAU .

**Table 19: Forecast cases of leptospirosis in Guyana under BAU, A2 and B2: 2011 – 2050**

| | | 2011 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 | 2011 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 |
|---|---|---|---|---|---|---|---|---|---|
| **LEPTOSPIROSIS** | | Total number of cases for each decade | | | | Deviation of A2 and B2 cases vis-à-vis BAU cases | | | |
| | A2 | 690 | 763 | 732 | 734 | -41 | 32 | 1 | 3 |
| | B2 | 716 | 679 | 779 | 767 | -15 | -52 | 48 | 36 |
| | BAU | 731 | 731 | 731 | 731 | 0 | 0 | 0 | 0 |

Source: Author‘s calculations

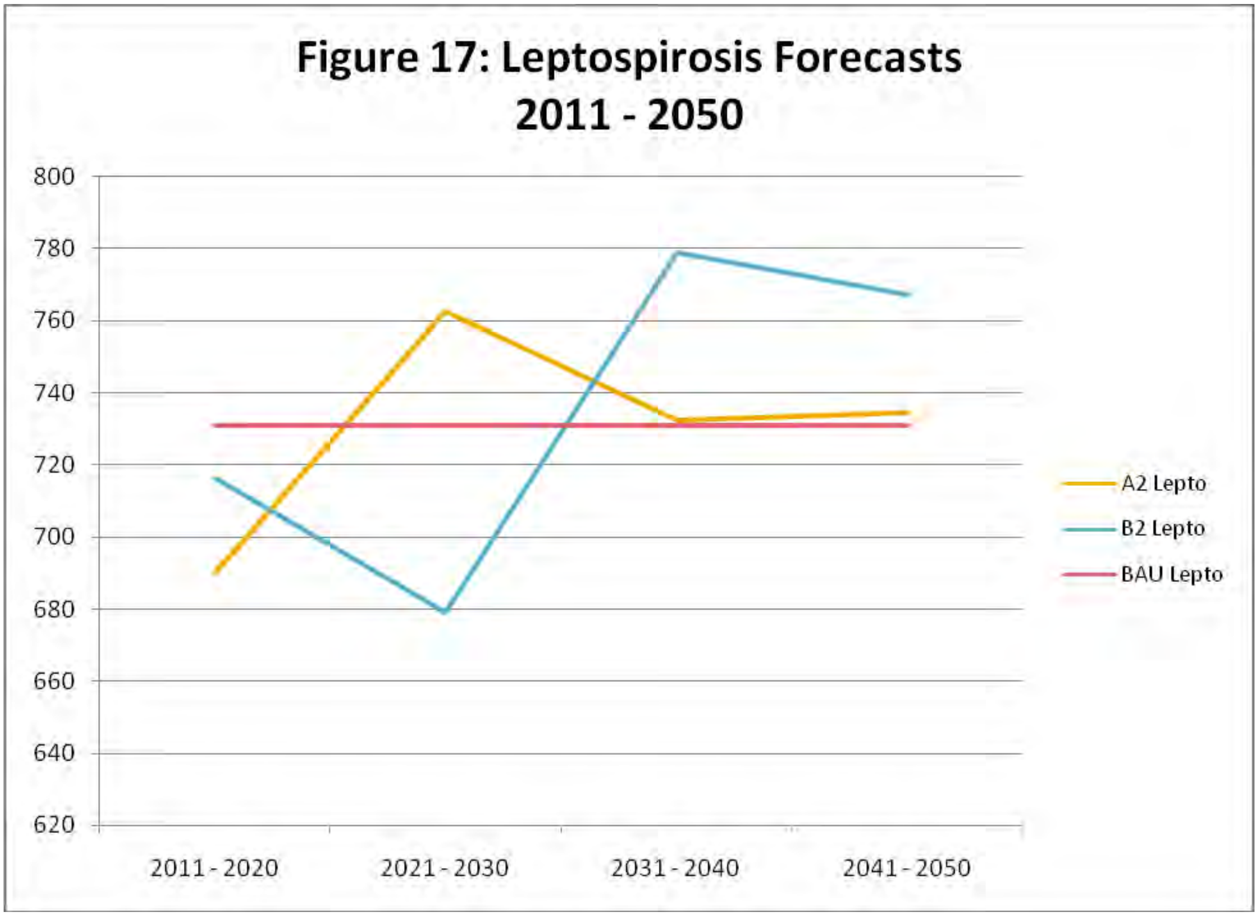


Figure 17: Leptospirosis Forecasts 2011 - 2050

Source: Data compiled by author

The results presented in table 19 and figure 16 indicate that the number of leptospirosis cases increases over the forecast period, with the number of cases being largest under BAU in the first and third decades followed by B2-related cases. During the first decade, the number of leptospirosis cases is 15% and 11% larger under BAU than under the A2 and B2 scenarios, respectively. During the second decade, the A2-related cases are the largest of the three scenarios, 7% and 12% over BAU and B2, respectively. In the last decade, the number of cases under A2 and BAU is forecast to be equal at 734 cases, whilst there are likely to be 767 cases under the B2 scenario.

## 5. Direct costs associated with leptospirosis

In Step 3, only the direct treatment costs are calculated, as no prevention data were available for leptospirosis. A per patient treatment cost of US$ 2 is used for this study, based on WHO data from a study of the cost of leptospirosis treatment. The cost is limited to the number of officially reported leptospirosis cases. The formulae are presented below and the results are shown in table 20.

### a) Calculation of treatment costs

Cost of treating leptospirosis = Unit treatment costs * Number of estimated leptospirosis cases = US$2 * Number of estimated leptospirosis cases

**Table 20: Direct costs of treating leptospirosis in Guyana between 2011 and 2050 using a discount factor of 1%, 2% and 4% (US$)**

| | | **2011 – 2020** | **2021 – 2030** | **2031 – 2040** | **2041 – 2050** |
|---|---|---|---|---|---|
| | | Treatment | Treatment | Treatment | Treatment |
| **LEPTOSPIROSIS** | **1% discount rate** | | | | |
| | A2 | 1 366 | 1 510 | 1 450 | 1 454 |
| | B2 | 1 419 | 1 345 | 1 542 | 1 519 |
| | BAU | 1 448 | 1 448 | 1 448 | 1 448 |
| | **2% discount rate** | | | | |
| | A2 | 1 353 | 1 495 | 1 436 | 1 440 |
| | B2 | 1 405 | 1 332 | 1 527 | 1 504 |
| | BAU | 1 433 | 1 433 | 1 433 | 1 433 |
| | **4% discount rate** | | | | |
| | A2 | 1 510 | 1 450 | 1 454 | 1 510 |
| | B2 | 1 345 | 1 542 | 1 519 | 1 345 |
| | BAU | 1 448 | 1 448 | 1 448 | 1 448 |

Source: Author‘s calculations

Treatment costs are highest under BAU during the first decade of the forecast period, followed by the B2 and A2 scenarios. The BAU costs are 9% and 7% larger than the A2 and B2 costs, respectively, during the first decade. During the second decade, treatment costs are highest under A2 followed by BAU (4%) and B2 (5%). By the third and fourth decades, BAU returns to having the largest number of cases in comparison with A2 and B2.

## 6. Indirect costs associated with leptospirosis

Step 4 involves the calculation of two types of indirect costs associated with the forecast number of leptospirosis cases obtained from Step 2 a. The productivity loss for leptospirosis is calculated on a per person productivity loss basis of US$ 5.25 per person per case at discount rates of 1%, 2% and 4%. The results are presented in table 21.

### a) Calculation of productivity losses

Productivity losses due to leptospirosis = Number of estimated leptospirosis cases * Discount Rate * per person productivity cost = 5.25 * Number of estimated leptospirosis cases * 2%

**Table 21: Productivity losses associated with leptospirosis in Guyana for 2011 – 2050 using 1%, 2% and 4% discount rates (US$)**

| | | 2011 – 2020 | 2021 – 2030 | 2031 – 2040 | 2041 – 2050 |
|---|---|---|---|---|---|
| **LEPTOSPIROSIS** | **1% Discount Rate** | | | | |
| | A2 | 3 587 | 3 964 | 3 807 | 3 817 |
| | B2 | 3 724 | 3 530 | 4 048 | 3 987 |
| | BAU | 3 800 | 3 800 | 3 800 | 3 800 |
| | **2% Discount Rate** | | | | |
| | A2 | 3 552 | 3 925 | 3 769 | 3 780 |
| | B2 | 3 688 | 3 496 | 4 009 | 3 948 |
| | BAU | 4 092 | 3 664 | 4 125 | 3 780 |
| | **4% Discount Rate** | | | | |
| | A2 | 3 484 | 3 849 | 3 697 | 3 707 |
| | B2 | 3 617 | 3 428 | 3 932 | 3 872 |
| | BAU | 3 690 | 3 690 | 3 690 | 3 690 |

Source: Author‘s calculations

The productivity costs associated with leptospirosis follow the trends observed in the number of cases and the estimate of the associated direct costs, and decline by the same percentage as the discount rate increases from 1% to 4%. Productivity losses are largest under BAU during the first and third decades. During the first decade, the losses associated with BAU are 15% and 11% larger than under the A2 and B2 scenarios, respectively. In the third decade, the difference in productivity losses between BAU and A2 and B2 cases are 10% and 3%, respectively. In the last period, both A2 and BAU have the same level of productivity losses at US$ 3,780, while the B2 losses are higher, at US$ 3,948.

### 7. Summary

The number leptospirosis cases and the associated direct costs and productivity losses, which are calculated using a two-period ahead moving average of the historical cases, are highest under the BAU scenario. These results indicate the comparative benefit of implementing measures in the immediate, medium and longer term, that act to reduce the number of cases with which the system has to contend. This will also reduce the direct and indirect costs that are associated with the disease.

## G. GASTROENTERITIS

### 1. Model

The health economics literature is generally ambiguous about the relationship between climate and gastroenteritis. Some studies find a relationship between minimum temperature and gastroenteritis but no relationship with rainfall or humidity, whilst others are unable to detect a relationship with temperature or humidity but find one with rainfall. As a result, the approach in the present analysis was to explore the relevance of each of the three climate variables along with the HDI in explaining gastroenteritis. The gastroenteritis cases were separated into patients that were under 5 years old and those that were over 5 years old.

**Table 22: Descriptive statistics for gastroenteritis in Guyana: 2007 to 2010 (monthly data)**

| | Gastro (<5) | Gastro (>5) |
|---|---|---|
| Mean | 963.26 | 1469.07 |
| Median | 880.50 | 1295.50 |
| Maximum | 3475.00 | 5491.00 |
| Minimum | 297.00 | 384.00 |
| Std. Dev. | 595.90 | 940.98 |
| Observations | 42 | 42 |

Source: CAREC

A stepwise approach was used to eliminate variables in order to identify the models for the population under age 5 and over age 5 cases that have the best fit. Variables that had a p-value that was greater than or equal to 0.10 were eliminated from the models. Ultimately the models with the highest log-likelihood were selected as the best-fit. The functional forms are presented below, as Equation (4) for the population under age 5, and Equation (5) for the population over age 5. As a result, the final model is presented below in two separate subsections.

$$\text{Gastroenteritis under 5 years} = \text{constant} + \alpha_1\,\text{Minimum Temperature}_t + \alpha_2\,\text{Rain} + \alpha_3\,\text{Time} + \alpha_4\,\text{Seasonal Control} + \alpha_5\,\text{Dummy}$$

***Equation (4)***

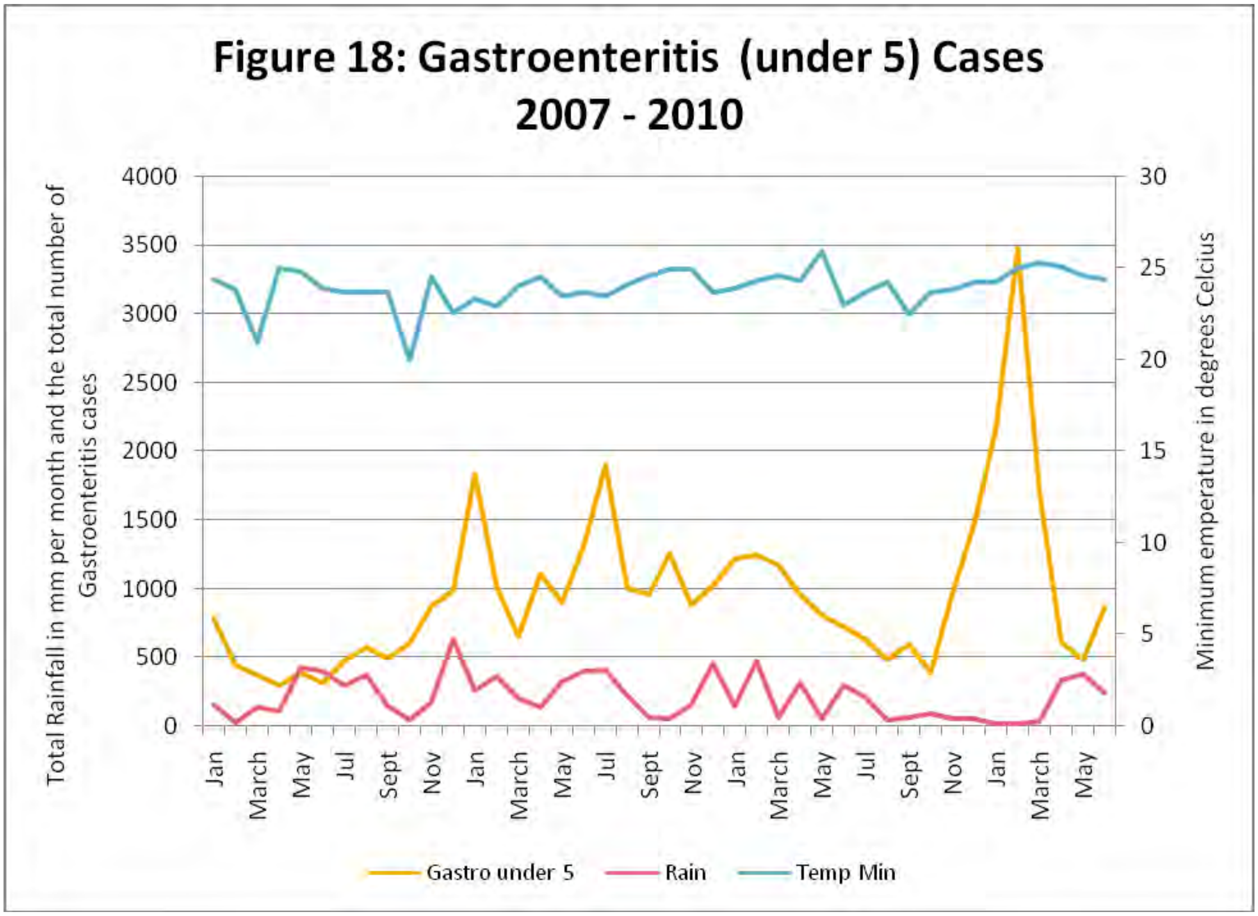
$$\text{Gastroenteritis over 5 years} = \text{constant} + \alpha_1\,\text{Minimum Temperature}_t + \alpha_2\,\text{Rain} + \alpha_3\,\text{Time} + \alpha_4\,\text{Seasonal Control}$$

***Equation (5)***

## 2. Results

## 3. Gastroenteritis in the population under age 5

Figure 17 presents the time series plot of the number of gastroenteritis cases in the Guyanese population under age 5. The graph indicates periods in which the number of cases spikes during the period 2007 and 2010. The two-period moving average is used to forecast the number of cases under BAU.



Source: Data compiled by author

The specification for gastroenteritis for the population under age 5 is represented in Equation (4) above and results of the estimation are presented in the model output below. The number of gastroenteritis cases in a given month is determined to have a statistically significant relationship with the amount of rainfall, the minimum temperature during the current period, and HDI.[30] The coefficients are consistent with our a priori expectations which prescribe that, during wet, cool periods, the number of gastroenteritis cases increases in the population under age 5. The positive signs on HDI and sanitation variables (see appendix 1) are likely to be reflective of the impact that improved levels of development can have on water quality, if the institutional structures do not regulate and monitor the impact that this development can have on the quality of potable water, and the role that the improper disposal of waste can have on vector-breeding. Since this is counterintuitive, these variables are excluded from the analysis. The signs on the time trend and seasonal adjustment are negative, which indicate a general decline in the number of gastroenteritis cases between 2008 and 2010 and a countercyclical seasonality, respectively. The set of dummy variables were included to improve the fit of the model. Dummy05, Dummy052008 and dummy0520082 take on a value of 1 during January 2010, January 2009 and July 2009, respectively, and zero otherwise.

---

[30] The HDI is used in the gastroenteritis analysis because the data on sanitation and water are not available for 2007.

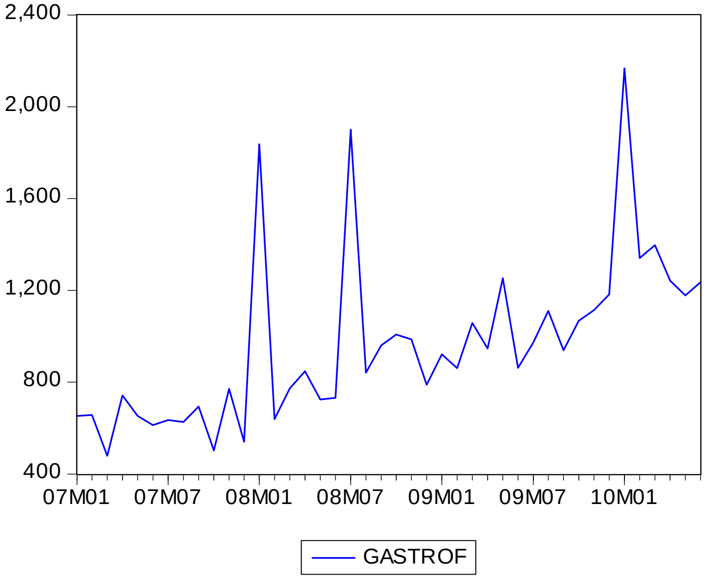
```
Dependent Variable: GASTRO
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/17/11   Time: 23:36
Sample (adjusted): 2007M01 2010M06
Included observations: 42 after adjustments
Convergence achieved after 6 iterations
Covariance matrix computed using second derivatives
==========================================================================
                           Coefficient    Std. Error   z-Statistic    Prob.
==========================================================================
           C                4.043157      0.142344      28.40413     0.0000
        TEMPMIN             0.102435      0.005964      17.17461     0.0000
          RAIN             -0.000387      3.74E-05     -10.34439     0.0000
         @TREND             0.016401      0.000477      34.36792     0.0000
        DUMMYO5             0.576553      0.023590      24.44070     0.0000
      DUMMYO52008           0.989075      0.024705      40.03475     0.0000
     DUMMYO520082           0.961476      0.024884      38.63775     0.0000
==========================================================================
R-squared                   0.397716   Mean dependent var          963.2619
Adjusted R-squared          0.294467   S.D. dependent var          595.8976
S.E. of regression          500.5302   Akaike info criterion       183.7359
Sum squared resid           8768568.   Schwarz criterion           184.0255
Log likelihood             -3851.454   Hannan-Quinn criter.        183.8420
Restr. log likelihood      -6457.018   LR statistic                5211.128
Avg. log likelihood        -91.70128   Prob(LR statistic)          0.000000
==========================================================================
```

## 4. Validating the model

The mean absolute percentage error indicates that, 41% of the time, the model forecasts are different from the actual historical data. This is likely to be associated with the three spikes in the data that are observed in January 2008, 2009 and 2010.  However, visual comparison of the actual and fitted values indicates a relatively close fit of the number of cases that are calculated based on Equation (4) and the actual data on the number of cases of gastroenteritis in the population under age 5.

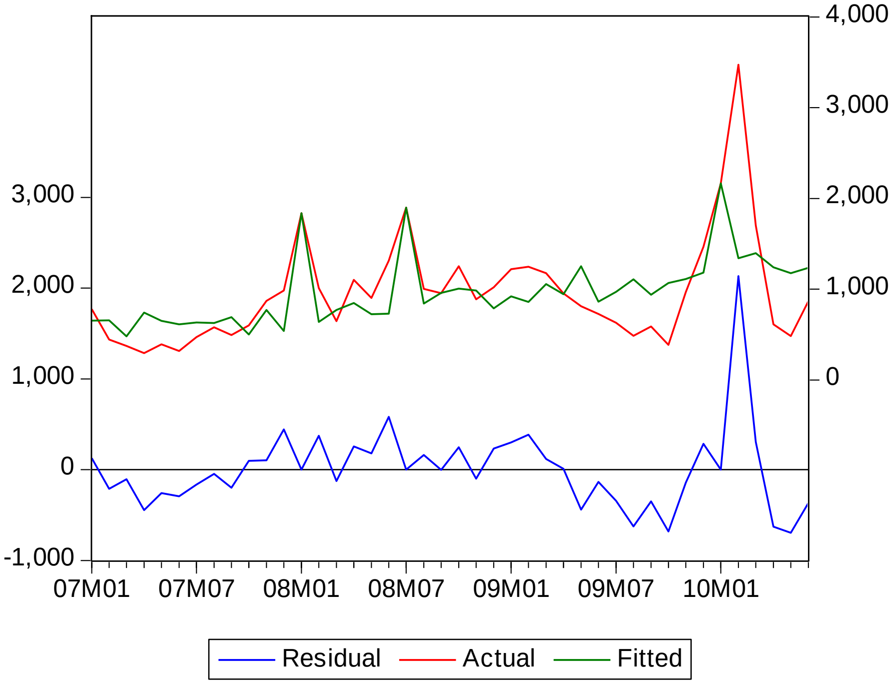
The Theil inequality coefficient indicates that the model provides forecasts that are 79% better than a naive guess at the number of gastroenteritis cases in the population under age 5 that may arise in the next period. The bias proportion indicates that the mean of the forecast sample is not statistically different from the mean of the actual historical data. The covariance proportion which accounts for approximately 76% of the mean squared forecast errors also confirms this. Based on the Theil, bias and covariance statistics, the model is likely to provide good forecasts and is therefore used in Step 2 in the next section to forecast gastroenteritis cases in the population under age 5 for the period 2011 and 2050 .

**Figure 19. Model performance for gastroenteritis cases in the population under age 5**



```
Forecast: GASTROF
Actual: GASTRO
Forecast sample: 2007M01 2070M12
Adjusted sample: 2007M01 2010M06
Included observations: 42

Root Mean Squared Error       456.9195
Mean Absolute Error           302.2263
Mean Abs. Percent Error       41.08555
Theil Inequality Coefficient  0.211667
     Bias Proportion          0.000000
     Variance Proportion      0.242043
     Covariance Proportion    0.757957
```



Source: Data compiled by author

## 5. Forecasts

In Step 2, the regression model is re-estimated using the climate data associated with the A2 and B2 scenarios. The forecast function in EViews is used to estimate the climate-associated number of cases under A2 and B2 in comparison with those associated with BAU gastroenteritis cases in the population under age 5.

**Table 23: Forecast cases of gastroenteritis in Guyana under BAU, A2 and B2: 2011 – 2050**

| | | 2011 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 | 2011 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 |
|---|---|---|---|---|---|---|---|---|---|
| **Under age 5 gastroenteritis** | | **Total number of cases for each decade** | | | | **Deviation of A2 and B2 cases vis-à-vis BAU cases** | | | |
| | **A2** | 129 541 | 134 538 | 140 494 | 153 507 | 9 918 | 17 810 | 28 393 | 36 507 |
| | **B2** | 126 821 | 141 605 | 143 071 | 156 232 | 7 198 | 24 878 | 30 970 | 39 232 |
| | **BAU** | 119 623 | 116 727 | 112 102 | 117 000 | 0 | 0 | 0 | 0 |

Source: Author‘s calculations

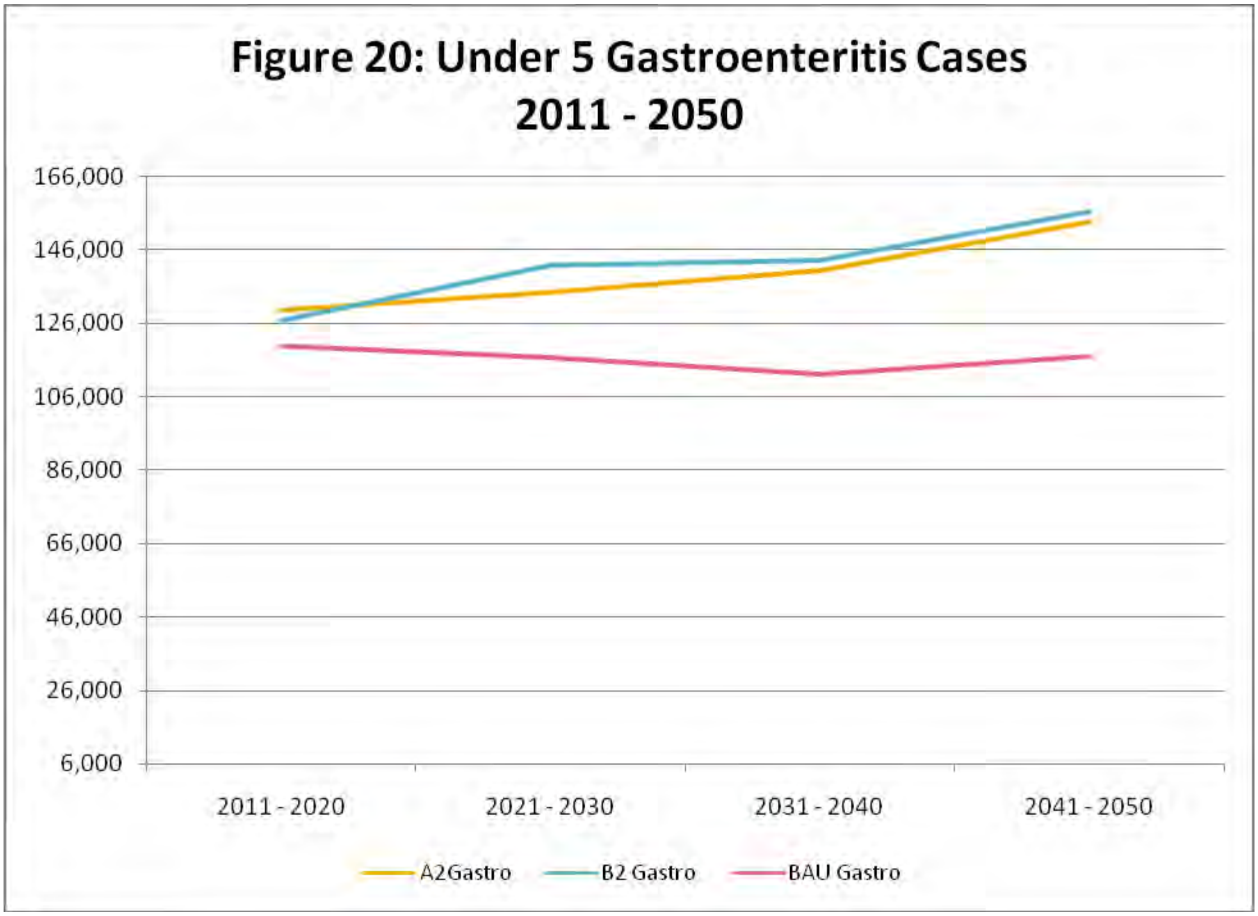


Figure 20: Under 5 Gastroenteritis Cases 2011 - 2050

Source: Data compiled by author

The results presented in table 23 and figure 20 indicate that the number of under age 5 gastroenteritis cases remains relatively flat over the forecast period under BAU, whereas the number of cases in the population under age 5 increases under the A2 and B2 scenarios. These trends are likely to be associated with the fact that, under the A2 and B2 scenarios, minimum temperatures are expected to rise and, therefore, so would the number of cases of gastroenteritis, unless targeted adaptation mechanisms are implemented.

The number of cases in the population under age 5 under A2 exceeds the number under BAU by between 10,000 and 37,000 throughout the four decades considered in the current analysis. B2 cases exceed BAU cases by 7,000 to 40,000. Under a B2 scenario, without specific attempts to improve sanitation, the number of gastroenteritis cases in the under age 5 population is likely to increase from the 2020s onwards, and to exceed the number of cases forecast under the A2 scenario and BAU comparator.

## 6. Direct costs associated with gastroenteritis cases in the population under age 5

Using the forecast number of gastroenteritis cases from Step 2, Step 3 calculates the direct costs of preventing and/or treating gastrointestinal illnesses. The disease is assumed to be preventable using a rotavirus vaccine at a total cost of US$ 7.50 per dose.[31] Once gastroenteritis has been contracted, treatment costs are reported to be approximately US$ 200 per case,[32] which includes both the in- and out-patient costs[33] associated with the convalescence period. These costs are presented in table 24.

### a) Calculation of prevention costs

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

### b) Calculation of treatment costs

Cost of treating gastroenteritis = Unit treatment costs * Number of estimated gastroenteritis cases = US$ 200 * Number of estimated gastroenteritis cases

**Table 24: Direct costs of estimated morbidity and mortality for under age 5 gastroenteritis illnesses in Guyana under BAU, A2 and B2 scenarios using 1%, 2% and 4% discount rates: 2011 – 2050 (US$)**

| | | 2011 – 2020 | | 2021-2030 | | 2031-2040 | | 2041-2050 | |
|---|---|---|---|---|---|---|---|---|---|
| **Under age 5 gastroenteritis** | **DIRECT COSTS** | **Treatment costs** | **Prevention costs** | **Treatment costs** | **Prevention costs** | **Treatment costs** | **Prevention costs** | **Treatment costs** | **Prevention costs** |
| | **1% discount rate** | | | | | | | | |
| | **A2** | 25 651 709 | 961 939 | 26 641 122 | 999 042 | 27 820 686 | 1 043 276 | 30 397 418 | 1 139 903 |
| | **B2** | 25 113 073 | 941 740 | 28 040 573 | 1 051 521 | 28 330 982 | 1 062 412 | 30 937 020 | 1 160 138 |
| | **BAU** | 23 687 748 | 888 291 | 23 114 307 | 866 787 | 22 198 373 | 832 439 | 23 168 363 | 868 814 |
| | **2% discount rate** | | | | | | | | |
| | **A2** | 25 400 221 | 952 508 | 26 379 934 | 989 248 | 27 547 934 | 1 033 048 | 30 099 404 | 1 128 728 |
| | **B2** | 24 866 866 | 932 507 | 27 765 665 | 1 041 212 | 28 053 227 | 1 051 996 | 30 633 716 | 1 148 764 |
| | **BAU** | 23 455 515 | 879 582 | 22 887 696 | 858 289 | 21 980 741 | 824 278 | 22 941 223 | 860 296 |
| | **4% discount rate** | | | | | | | | |
| | **A2** | 24 911 756 | 934 191 | 25 872 628 | 970 224 | 27 018 166 | 1 013 181 | 29 520 569 | 1 107 021 |
| | **B2** | 24 388 657 | 914 575 | 27 231 710 | 1 021 189 | 27 513 742 | 1 031 765 | 30 044 606 | 1 126 673 |
| | **BAU** | 23 004 447 | 862 667 | 22 447 548 | 841 783 | 21 558 035 | 808 426 | 22 500 045 | 843 752 |

Source: Author‘s calculations

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[31] See Clark and others and Constenla (2008).

[32] This is at a substantially less than the cost in the United States at US$ 2,999 to US$ 3,400. See Chow and others (2010).

[33] See Rheingans and others (2007).

In monetary terms, the cost of preventing gastroenteritis is lower than the costs of treating the disease regardless of the decade considered. The direct costs associated with treating and preventing gastroenteritis in the population under age 5 remain relatively flat throughout the entire period under the BAU scenario using three discount rates – 1%, 2% and 4%. Under A2 and B2, the costs increase over the forecast period from US$ 35 million to US$ 30 million under A2 using a 2% discount rate, reflecting the increase in the number of cases in the population under age 5. The A2 scenario is associated with the highest costs in the first decade, similar to the pattern in the number of forecast cases; however, this changes during the second decade when the number of gastroenteritis cases in the population under age 5 under the B2 scenario exceeds the number of cases under the A2 scenario.

### 7. Indirect costs associated with gastroenteritis cases in the population under age 5

In Step 3, the forecast number of gastroenteritis cases in the population under age 5 obtained from Step 2 are used to estimate the associated productivity losses. Productivity losses are calculated under the assumptions of the average number of days lost due to gastroenteritis is 6.44 days, GDP per capita of US$ 1,518 and a discount rate of 2%. The results are presented in table 25.

#### a) Calculation of productivity losses

Productivity losses due to gastroenteritis = Days lost * Number of estimated gastroenteritis cases * Discount rate * GDP per capita in 2008 US$ = 6.44 * Number of estimated gastroenteritis cases * 2% * 1518 divided by 365

The productivity losses (see table 25) reflect the same decline observed in the number of gastroenteritis cases in the population under age 5 forecast by the model. In particular, the productivity losses due to gastroenteritis cases in the population under age 5 is highest under the A2 scenario in the first decade, at approximately US$ 3.4 million for 2011 - 2020, and US$ 4.0 million for the decade 2041-2050. Under the B2 scenario, the productivity losses exceed those under the A2 scenario in the three decades between 2021 and 2050 by 5.3%, 1.8% and 1.8%, respectively.

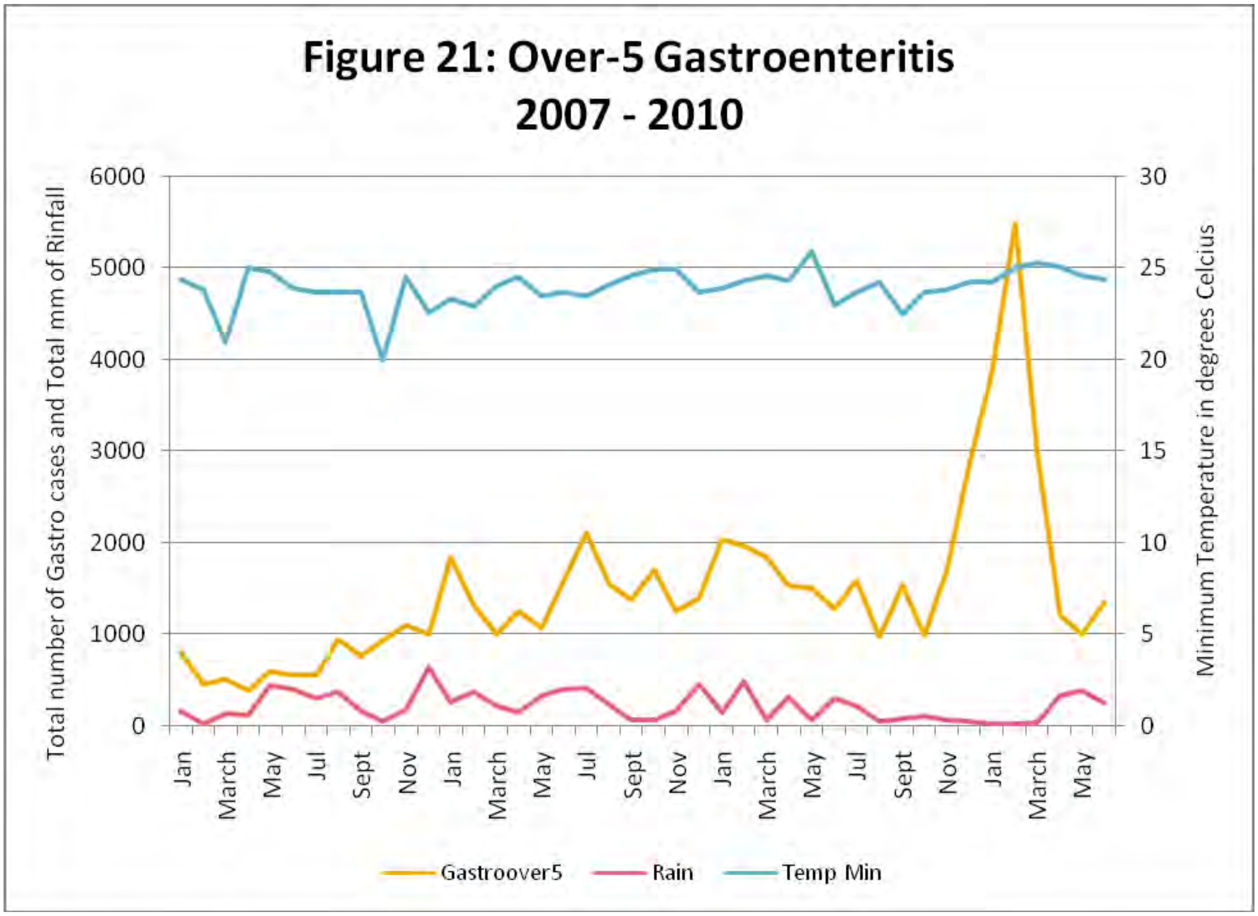
**Table 25: Indirect costs of estimated morbidity and mortality for gastroenteritis illnesses in the population under age 5 in Guyana under BAU, A2 and B2 scenarios using 1%, 2% and 4% discount rates: 2011 – 2050 (US$)**

| | | 2011 – 2020 | 2021-2030 | 2031-2040 | 2041-2050 |
|---|---|---|---|---|---|
| Gastroenteritis in population under age 5 | Indirect costs | Productivity losses | Productivity losses | Productivity losses | Productivity losses |
| | 1% discount rate | | | | |
| | A2 | 3 435 192 | 3 567 691 | 3 725 655 | 4 070 722 |
| | B2 | 3 363 060 | 3 755 101 | 3 793 992 | 4 142 984 |
| | BAU | 3 172 185 | 3 095 392 | 2 972 733 | 3 102 631 |
| | 2% discount rate | | | | |
| | A2 | 3 401 514 | 3 532 714 | 3 689 129 | 4 030 813 |
| | B2 | 3 330 089 | 3 718 287 | 3 756 796 | 4 102 366 |
| | BAU | 3 141 085 | 3 065 045 | 2 943 589 | 3 072 213 |
| | 4% discount rate | | | | |
| | A2 | 3 336 100 | 3 464 777 | 3 618 184 | 3 953 298 |
| | B2 | 3 266 049 | 3 646 781 | 3 684 550 | 4 023 475 |
| | BAU | 3 080 680 | 3 006 102 | 2 886 981 | 3 013 132 |

Source: Author‘s calculations

## 8. Gastroenteritis in the population over age 5

Figure 20 presents the time series plot of the number of gastroenteritis cases in Guyana in the population over age 5. The graph indicates periods in which the number of cases spikes, with a particularly large one around January 2010. The two-period moving average is used to forecast the number of gastroenteritis cases in the population over age 5 under BAU.



Source: Data compiled by author

The results of the estimation for gastroenteritis in the population over age 5 are represented in Equation (5) and in the model output below. The number of gastroenteritis cases in a given month is determined to have a statistically significant relationship with the minimum temperature during the current period, and with HDI.[34] In contrast to the preferred relationship for the Guyanese population under age 5, the number of cases in the over age 5 population is not responsive to the amount of rainfall that is observed in any period. The coefficient on the temperature is consistent with a priori expectations which prescribe that, during periods of cooler temperatures, the number of gastroenteritis cases increases in the population. As with the case of the under age 5 infants, the positive sign on HDI is likely to be reflective of the impact that improved levels of development can have on water quality - if the institutional structures do not regulate and monitor both the impact that this development can have on the quality of potable water, and the role that the improper disposal of waste can have on vector breeding. The signs on the time trend and seasonal adjustment are negative, which indicate a general decline in the number of gastroenteritis cases in the population over age 5 between 2008 and 2010, and a countercyclical seasonality, respectively.

---

[34] HDI was used in the gastroenteritis analysis as data on sanitation and water for Guyana were not available for 2007.

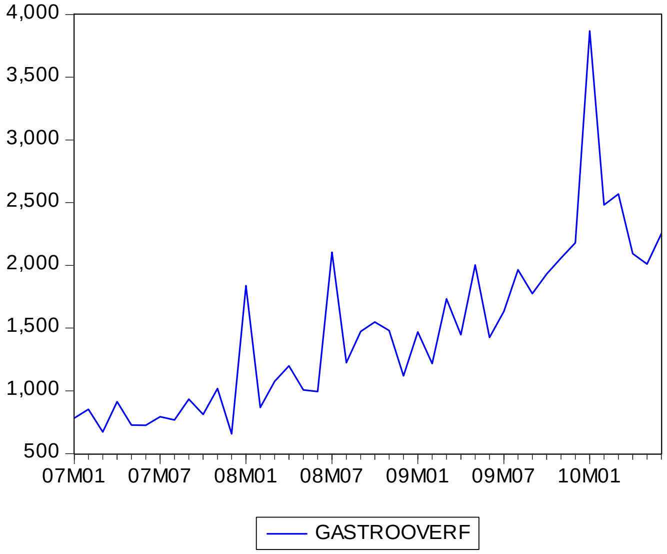
```
Dependent Variable: GASTROOVER5
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/17/11   Time: 23:44
Sample (adjusted): 2007M01 2010M06
Included observations: 42 after adjustments
Convergence achieved after 6 iterations
Covariance matrix computed using second derivatives
========================================================================
                         Coefficient    Std. Error   z-Statistic   Prob.
========================================================================
           C              5.188775      0.113005      45.91652     0.0000
        TEMPMIN           0.065205      0.004753      13.71759     0.0000
          RAIN           -0.000751      3.06E-05     -24.53848     0.0000
         @TREND           0.027467      0.000395      69.59574     0.0000
        DUMMYO5           0.520413      0.017734      29.34528     0.0000
      DUMMYO52008         0.671892      0.024334      27.61126     0.0000
     DUMMYO520082         0.741849      0.023269      31.88151     0.0000
========================================================================
R-squared                 0.528766   Mean dependent var          1469.071
Adjusted R-squared        0.447984   S.D. dependent var          940.9763
S.E. of regression        699.1248   Akaike info criterion       204.9112
Sum squared resid         17107141   Schwarz criterion           205.2008
Log likelihood           -4296.135   Hannan-Quinn criter.        205.0173
Restr. log likelihood    -10092.00   LR statistic                11591.73
Avg. log likelihood      -102.2889   Prob(LR statistic)          0.000000
========================================================================
```

## 9. Validating the model

The MAPE statistic indicates that the model forecasts are different from the actual historical data 31% of the time. This is likely to be associated with sharp increase in the number of cases that are observed around January 2010. Visually, actual and fitted values indicate a relatively close fit of the number of cases that are calculated based on Equation (5) and the actual data on the number of cases of gastroenteritis in the population over age 5.

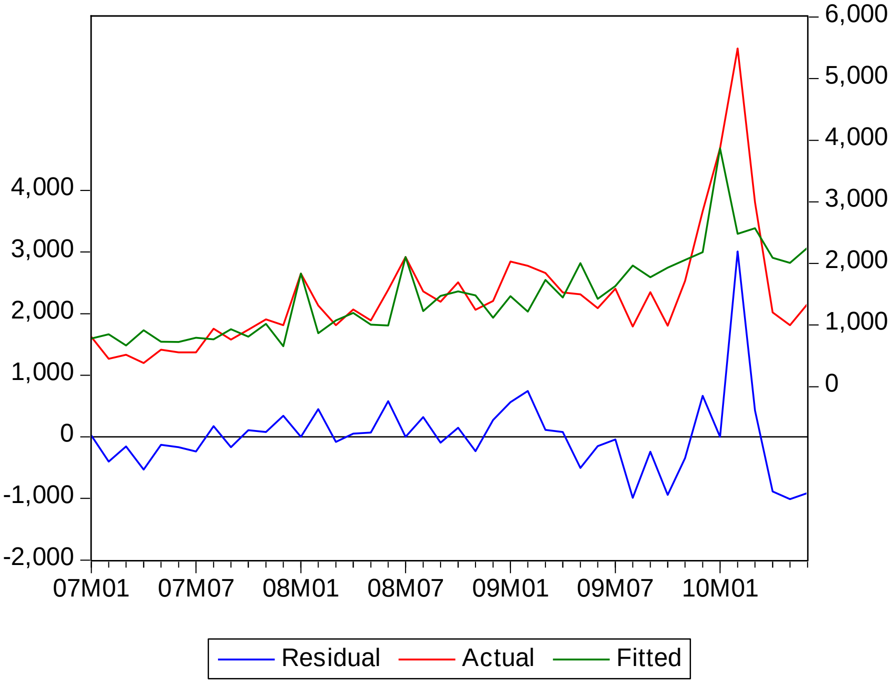
The Theil inequality coefficient indicates that the model provides forecasts that are 81% better than a naive guess at the number of gastroenteritis cases in the population over age 5 that may arise in the next period. The bias proportion indicates that the mean of the forecast sample is not statistically different from the mean of the actual historical data. The covariance proportion, which accounts for approximately 83% of the mean squared forecast errors, also confirms this. Based on the Theil, bias, and covariance statistics, the model is likely to provide good forecasts, and is therefore used in Step 2 in the next section to forecast gastroenteritis cases in the population over age 5 for the period 2011 to 2050.

Figure 22: Model performance for gastroenteritis cases in the population over age 5



```
Forecast: GASTROOVERF
Actual: GASTROOVER5
Forecast sample: 2007M01 2070M12
Adjusted sample: 2007M01 2010M06
Included observations: 42

Root Mean Squared Error        638.2107
Mean Absolute Error            391.2690
Mean Abs. Percent Error        31.05572
Theil Inequality Coefficient   0.190550
     Bias Proportion           0.000000
     Variance Proportion       0.177788
     Covariance Proportion     0.822212
```



Source: Data compiled by author

## 10. Forecasts

In Step 2, the regression model is re-estimated using the climate data associated with the A2 and B2 scenarios. The forecast function in EViews is used to estimate the climate-associated number of gastroenteritis cases in the population over age 5 under A2 and B2, in comparison with those associated with BAU.

**Table 26: Forecast cases of gastroenteritis in the population over age 5 in Guyana under BAU, A2 and B2: 2011 – 2050**

| | | **2011 – 2020** | **2021 – 2030** | **2031 – 2040** | **2041 – 2050** | **2011 – 2020** | **2021 – 2030** | **2031 – 2040** | **2041 – 2050** |
|---|---|---|---|---|---|---|---|---|---|
| **Over age 5 gastroenteritis** | | **Total number of cases for each decade** | | | | **Deviation of A2 and B2 cases vis-à-vis BAU cases** | | | |
| | A2 | 203 324 | 210 756 | 220 391 | 241 202 | 19 110 | 32 403 | 50 638 | 64 023 |
| | B2 | 197 624 | 223 130 | 225 279 | 247 866 | 13 410 | 44 777 | 55 526 | 70 687 |
| | BAU | 184 214 | 178 353 | 169 753 | 177 179 | 0 | 0 | 0 | 0 |

Source: Author's calculations

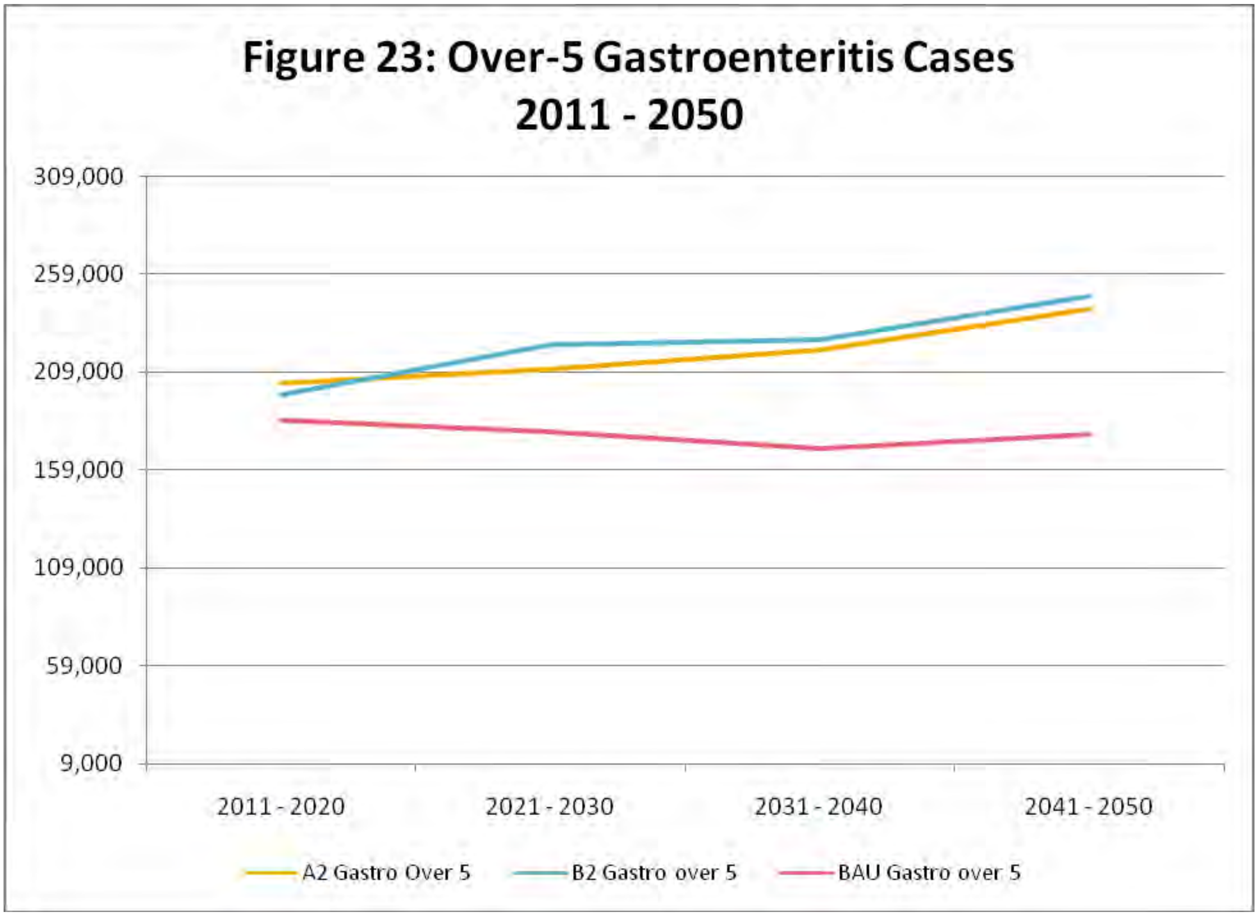


Figure 23: Over-5 Gastroenteritis Cases 2011 - 2050

Source: Data compiled by author

The results presented in table 26 and figure 23 indicate that the number of over age 5 gastroenteritis cases remains relatively flat over the forecast period under BAU whereas the number of cases in the population over age 5 increases under the A2 and B2 scenarios as a result of the climatic impacts. A2 has the largest number of gastroenteritis cases in the population over age 5 during the first decade, in comparison to both the B2 scenario and the BAU comparison case. However, this is quickly reversed during the second to fourth decades where the B2 scenario is associated with a larger number of gastroenteritis cases in the population over age 5 than both A2 and BAU.

## 11. Direct costs associated with gastroenteritis cases in the population over age 5

Using the forecast number of gastroenteritis cases from Step 2, Step 3 calculates the direct costs of preventing and/or treating gastrointestinal illnesses. The disease is assumed to be preventable using a rotavirus vaccine at a total cost of US$ 7.50 per dose.[35] Once gastroenteritis has been contracted, treatment costs are reported to be approximately US$ 200 per case,[36] which includes both the in- and out-patient costs[37] associated with the convalescence period. These costs are presented in table 27.

### a) Calculation of prevention costs

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

### b) Calculation of treatment costs

Cost of treating gastroenteritis = Unit treatment costs * Number of estimated gastroenteritis cases = US$ 200 * Number of estimated gastroenteritis cases

**Table 27: Direct costs of estimated morbidity for gastroenteritis illnesses in the population over age 5 in Guyana under BAU, A2 and B2 scenarios using a 1%, 2% and 4% discount rate: 2011 – 2050 (US$)**

| | | **2011 – 2020** | | **2021-2030** | | **2031-2040** | | **2041-2050** | |
|---|---|---|---|---|---|---|---|---|---|
| **Over age 5 Gastroenteritis** | **DIRECT COSTS** | **Treatment costs** | **Prevention costs** | **Treatment costs** | **Prevention costs** | **Treatment costs** | **Prevention costs** | **Treatment costs** | **Prevention costs** |
| | **1% discount rate** | | | | | | | | |
| | **A2** | 40 262 193 | 1 509 832 | 41 733 835 | 1 565 019 | 43 641 752 | 1 636 566 | 47 762 853 | 1 791 107 |
| | **B2** | 39 133 490 | 1 467 506 | 44 184 134 | 1 656 905 | 44 609 684 | 1 672 863 | 49 082 397 | 1 840 590 |
| | **BAU** | 36 478 106 | 1 367 929 | 35 317 333 | 1 324 400 | 33 614 472 | 1 260 543 | 35 084 991 | 1 315 687 |
| | **2% discount rate** | | | | | | | | |
| | **A2** | 39 867 465 | 1 495 030 | 41 324 679 | 1 549 675 | 43 213 891 | 1 620 521 | 47 294 590 | 1 773 547 |
| | **B2** | 38 749 828 | 1 453 119 | 43 750 957 | 1 640 661 | 44 172 334 | 1 656 463 | 48 601 197 | 1 822 545 |
| | **BAU** | 36 120 478 | 1 354 518 | 34 971 085 | 1 311 416 | 33 284 918 | 1 248 184 | 34 741 020 | 1 302 788 |
| | **4% discount rate** | | | | | | | | |
| | **A2** | 39 100 783 | 1 466 279 | 40 529 974 | 1 519 874 | 42 382 855 | 1 589 357 | 46 385 078 | 1 739 440 |
| | **B2** | 38 004 639 | 1 425 174 | 42 909 592 | 1 609 110 | 43 322 866 | 1 624 607 | 47 666 559 | 1 787 496 |
| | **BAU** | 35 425 853 | 1 328 470 | 34 298 564 | 1 286 196 | 32 644 824 | 1 224 181 | 34 072 924 | 1 277 735 |

Source: Author‘s calculations

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[35] See Clark and others and Constenla (2008).

[36] This is at a substantially less than the cost in the United States at US$ 2,999 to US$ 3,400. See Chow and others (2010).

[37] See Rheingans and others (2007).

Direct costs associated with treating and preventing gastroenteritis cases in the population over age 5 also decrease throughout the entire period under A2 and B2, whereas they remain relatively flat under BAU reflecting the pattern observed in the number of cases. During the first decade, using a 2% discount rate, the A2 treatment costs are the highest at US$ 40 million and increase to US$ 47 million during the last decade. By the second decade, however, the B2 costs exceed the A2 scenario costs of treatment and prevention for the number of cases forecast by the model. Under BAU, treatment and prevention costs decline from US$ 36 million and US$ 1.4 million, respectively, to US$ 34.7 million and US$ 1.3 million, respectively.

## 12. Indirect costs associated with gastroenteritis cases in the population over age 5

In Step 3, the forecast number of gastroenteritis cases in the population over age 5 obtained from Step 2 are used to estimate the associated productivity losses. Productivity losses are calculated under the assumptions that the average number of days lost due to gastroenteritis are 6.44 days, GDP per capita is US$ 1,518 and the discount rate is 2%. The results are presented in table 28.

### a) Calculation of productivity losses

Productivity losses due to gastroenteritis = Days lost * Number of estimated gastroenteritis cases * Discount rate * GDP per capita in 2008 US$ = 6.44 * Number of estimated gastroenteritis cases * 2% * 1518 divided by 365

The productivity losses associated with treatment and prevention shown in table 28 reflect the same patterns observed in the number of gastroenteritis cases in the population over age 5 forecast by the model. In particular, the productivity lost due to gastroenteritis cases in the population over age 5 is highest under the A2 scenario in the first year at roughly US$ 167million, versus US$ 163 million and US$ 152 million under the B2 and BAU -associated losses. However, from the second to the last decade, the productivity losses are largest under the B2 scenario, at US$ 184 million to US$ 204 million.

**Table 28.**
**Indirect costs of estimated morbidity and mortality for gastroenteritis illnesses in the population over age 5 in Guyana under BAU, A2 and B2 scenarios, using 1%, 2% and 4% discount rates: 2011 – 2050 (US$)**

| | | **2011 – 2020** | **2021-2030** | **2031-2040** | 2041-2050 |
|---|---|---|---|---|---|
| **Gastroenteritis** | **Indirect costs** | **Productivity losses** | **Productivity losses** | **Productivity losses** | **Productivity losses** |
| | **1% discount rate** | | | | |
| | **A2** | 167 446 599 | 173 567 017 | 181 501 861 | 198 641 126 |
| | **B2** | 162 752 433 | 183 757 578 | 185 527 399 | 204 128 984 |
| | **BAU** | 151 708 947 | 146 881 401 | 139 799 366 | 145 915 112 |
| | **2% discount rate** | | | | |
| | **A2** | 165 804 966 | 171 865 379 | 179 722 431 | 196 693 664 |
| | **B2** | 161 156 821 | 181 956 033 | 183 708 502 | 202 127 719 |
| | **BAU** | 150 221 604 | 145 441 387 | 138 428 784 | 144 484 572 |
| | **4% discount rate** | | | | |
| | **A2** | 162 616 409 | 168 560 276 | 176 266 230 | 192 911 093 |
| | **B2** | 158 057 651 | 178 456 878 | 180 175 647 | 198 240 648 |
| | **BAU** | 147 332 727 | 142 644 438 | 135 766 692 | 141 706,023 |

Source: Data compiled by author

## 13. Summary of gastroenteritis cases in the population under and over age 5

The analysis of gastroenteritis indicates that the number of additional cases is larger among the population over age 5. As a result, the associated treatment and prevention costs, as well as the productivity losses, are larger in this demographic grouping. The A2 scenario shows the highest number of cases, the highest direct costs and the largest productivity losses between 2011 and 2050. The BAU scenario presents fewer cases, costs and losses in comparison to both the A2 and B2 cases. This is possibly associated with the fact that additional cases of gastroenteritis are dependent on minimum temperatures, which is not characteristic of the A2 and B2 scenarios.

# IV. COST BENEFIT ANALYSIS, ADAPTATION STRATEGIES AND POLICY RECOMMENDATIONS

In order to cope with the adverse health effects of climate change, adaptation measures, plans and programmes must be put in place. Adaptation is defined in terms of –policies, practices, and projects with the effect of moderating damages and/or realizing opportunities associated with climate change.” Adaptation related to human health includes the strategies, policies and measures undertaken, now and in the future, to reduce potential adverse health effects. Adaptive capacity describes the general ability of institutions, systems and individuals to adjust to potential damages, to take advantage of opportunities and to cope with the consequences.

Estimating the adaptation costs in the health sector is challenging, not only because of the large existing uncertainties about how the climate will evolve over the coming century but also because of the complex and often poorly understood chains through which health impacts are mediated. Climate change is difficult to predict with accuracy in any projection model that has to contend with uncertainty about potential collective actions to mitigate greenhouse gases as well as unknown factors in climate science itself. The health outcomes that are linked to climate change depend on a host of other factors as well, some of which are not likely to be currently anticipated, such as the emergence of new diseases, and others that are difficult to predict, such as the development of vaccines to address existing and new ailments. the baseline health status of a country is the single largest determinant, among the sources of uncertainty that are amenable to quantitative analysis, of the likely impact of climate change and the cost of adapting to it.

## A. ADAPTATION STRATEGIES

This section provides a comparative analysis of specific adaptation strategies or health interventions that are implemented by the authorities to impact 10%, 40% and 50% of the Guyanese population. The total cost of extending these interventions to the respective segment of the population is calculated as the product of the number of persons in the population to be treated and the per person unit cost of the intervention. The two benefits that are calculated for each intervention are: (1) the value of the treatment costs that are averted as a result of the reduced number of cases in the treated population; and, (2) the value of the productivity losses that are averted as a result of the reduced number of cases in the treated population. These two benefits are summed to provide an estimate of the total benefits of the intervention being considered. The results of this section are intended to provide policymakers with a sense of the costs and benefits associated with addressing the additional disease cases of malaria, dengue, leptospirosis and gastroenteritis forecast in the previous section, with particular health interventions between 2011 and 2050.

### 1. Malaria

#### a) Bed nets & spraying programmes

For the purposes of the present study, two types of adaptation measures – the provision of impregnated bed nets, and the implementation of a spraying regime – are considered as the interventions that can prevent additional cases of malaria. The methodology and results of the impact of both of these interventions on the number of cases and on the averted treatment costs are presented below. The health economics literature has investigated the potential impact of using treated bed nets and spraying programmes on the number of observed cases of malaria. The impact of these two programmes on the number of cases, the treatment costs and productivity losses are calculated, presented and discussed below.

Graves and others (undated) estimate that the use of insecticide-treated bed nets reduces the cases of malaria by 12% in Eritrea. Table 29 presents the impact on treatment costs if the bed nets are offered to

10%, 40% and 50 % of the 2010 Guyanese population under the three scenarios. The second form of intervention considered, in relation to reducing the number of cases and investigating the impact on the direct and indirect costs associated with malaria at the national level, was a spraying programme. The impact of this type of programme was also estimated by Graves and others (undated) and found to be approximately 35%. The results of this type of intervention are presented in table 30.

In the case of the two interventions, the first step is to calculate the rate at which malaria affects the 2010-year population. Multiply that rate by 10% of the population to arrive at the number of cases that would be likely to exist without the bed net or spraying intervention. This number is then reduced by 12% (bed net) or 35 % (spraying programme) to determine the number of cases that can be expected in the same 10% of the population after the implementation of the bed net or spraying programme, respectively. The averted treatment costs are 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 antimalarial medicines. The averted productivity losses are 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 (US$ 1,518 in 2008 dollars), divided by 365.

**Table 29: Provision costs, treatment costs averted and production losses averted after the implementation of a bed net programme delivered to 10%, 40% and 50% of the Guyanese population: 2011 – 2050 (US$)**

| | | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10% of population | **Total cost of providing bed nets $231 000**<br>**Payback period: A2 – 17 years B2 – 15 years BAU – 18 years** | | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted per year of each scenario** | | | | **Benefit 2: Productivity losses averted per year of each scenario** | | | | **Total benefits per year of each scenario** | | | |
| | A2 | 39 | 36 | 34 | 33 | 14 709 | 13 501 | 12 627 | 12 294 | 14 749 | 13 537 | 12 660 | 12 327 |
| | B2 | 41 | 43 | 44 | 47 | 15 237 | 16 287 | 16 619 | 17 562 | 15 277 | 16 331 | 16 664 | 17 609 |
| | BAU | 34 | 37 | 34 | 31 | 12 733 | 13 775 | 12 889 | 11 565 | 12 767 | 13 812 | 12 923 | 11 596 |
| | | | | | | | | | | | | | |
| 40% of population | **Total cost of providing bed nets $924 000**<br>**Payback period: A2 – 17 years B2 – 15 years BAU – 18 years** | | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total Benefits** | | | |
| | A2 | 157 | 144 | 135 | 131 | 58 837 | 54 004 | 50 507 | 49 175 | 58 994 | 54 148 | 50 642 | 49 306 |
| | B2 | 163 | 174 | 177 | 187 | 60 947 | 65 150 | 66 478 | 70 247 | 61 109 | 65 324 | 66 655 | 70 434 |
| | BAU | 136 | 147 | 138 | 123 | 50 931 | 55 102 | 51 555 | 46 260 | 51 067 | 55 249 | 51 693 | 46 383 |
| | | | | | | | | | | | | | |
| 50% of population | **Total cost of providing bed nets $ 1 155 000**<br>**Payback period: A2 – 17 years B2 – 15 years BAU – 18 years** | | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 196 | 180 | 169 | 164 | 73 547 | 67 505 | 63 133 | 61 469 | 73 743 | 67 685 | 63 302 | 61 633 |
| | B2 | 203 | 217 | 222 | 234 | 76 183 | 81 437 | 83 097 | 87 808 | 76 387 | 81 655 | 83 319 | 88 043 |
| | BAU | 170 | 184 | 172 | 154 | 63 664 | 68 877 | 64 444 | 57 825 | 63 833 | 69 061 | 64 616 | 57 979 |

Source: Author‘s calculations

**Table 30: Provision costs, treatment costs averted and productivity losses averted after the implementation of a spraying programme delivered to 10%, 40% and 50% of the Guyanese population: 2011 – 2050 (US$)**

| | | 2010 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 | 2010 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 | 2010 to 2020 | 2021 to 2030 | 2031 to 2040 | 2041 to 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10% of population | **Total cost of spraying $27,720**<br>**Payback period: A2 – 1 year B2 – 1 year BAU – 1 year** | | | | | | | | | | | | |
| | | **Benefit 1: treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 115 | 105 | 98 | 96 | 42 902 | 39 378 | 36 828 | 35 857 | 43 017 | 39 483 | 36 926 | 35 952 |
| | B2 | 119 | 127 | 129 | 137 | 44 440 | 47 505 | 48 473 | 51 222 | 44 559 | 47 632 | 48 603 | 51 358 |
| | BAU | 99 | 107 | 100 | 90 | 37 137 | 40 178 | 37 592 | 33 731 | 37 236 | 40 286 | 37 693 | 33 821 |
| | | | | | | | | | | | | | |
| 40% of population | **Total cost of spraying $110, 880**<br>**Payback period: A2 – 1 year B2 – 1 year BAU – 1 year** | | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 458 | 420 | 393 | 383 | 171 609 | 157 511 | 147 311 | 143 427 | 172 067 | 157 932 | 147 705 | 143 810 |
| | B2 | 474 | 507 | 517 | 547 | 177 761 | 190 020 | 193 893 | 204 886 | 178 236 | 190 527 | 194 411 | 205 433 |
| | BAU | 396 | 429 | 401 | 360 | 148 548 | 160 714 | 150 370 | 134 924 | 148 945 | 161 143 | 150 771 | 135 284 |
| | | | | | | | | | | | | | |
| 50% of population | **Total cost of spraying $136, 800**<br>**Payback period: A2 – 1 year B2 – 1 year BAU – 1 year** | | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: productivity losses averted** | | | | **Total Benefits** | | | |
| | A2 | 573 | 525 | 491 | 479 | 214 511 | 196 889 | 184 139 | 179 284 | 215 083 | 197 415 | 184 631 | 179 762 |
| | B2 | 593 | 634 | 647 | 684 | 222 202 | 237 525 | 242 366 | 256 108 | 222 795 | 238 159 | 243 013 | 256 791 |
| | BAU | 496 | 536 | 502 | 450 | 185 685 | 200 892 | 187 962 | 168 655 | 186 181 | 201 428 | 188 464 | 169 105 |

Source: Author‘s calculations

Policymakers considering table 29 and table 30 are reminded of the importance of allowing for both the monetary and non-monetary benefits of particular interventions, as these are often different and can result in distinct policy prescriptions than would otherwise be implemented. In the case of malaria, the productivity losses averted far exceed the averted treatment costs, indicating that the intangible losses that are also averted, and the reduction in the transmission of malaria as a result of averting 12 % of the cases, should be considered. The results show that the cost of providing bed nets increases by 300% and 25 % for the three coverage rates, and exceeds the treatment costs averted several times over, regardless of both the scenario being considered and the proportion of the population that is included in the adaptation strategy. This would imply that it is more cost effective to forego the bed net programme, or to implement it on a small scale. The bed net programme also has a seemingly lengthy payback period of approximately 16 years. The averted costs of treatment decline between 2011 and 2050 under A2 by 15% to 16% for 10%, 40% and 50 % coverage, respectively. For B2, the costs averted increase by 15%, whilst under BAU, the costs averted decline by 9% for all three coverage rates.

The averted productivity costs follow a similar pattern in terms of each scenario. However, they are of a larger magnitude than the averted treatment costs. These results indicate the importance of including both the direct (treatment) and indirect (productivity) losses in assessing the costs and benefits of the intervention. Altogether, the total benefits are highest under the high-emission A2 scenario at the outset of the forecast period. However, by the end of the period, the total benefits are largest under the B2 scenario. These results indicate that the introduction of this bed net programme generates both tangible and intangible benefits, in the form of lower treatment and prevention costs and lower productivity losses associated with the incidence of malaria in Guyana. Despite these benefits, the programme has a relatively lengthy payback period and is therefore likely to be associated with high opportunity costs (i.e. of other programmes that may yield larger benefits in relation to the costs).

The introduction of a spraying programme results in a reduction in the number of cases by 35%, within the population to which the programme is administered under the A2 and B2 scenarios, in relation to the BAU series, the number of cases without this intervention (see table 11). As a result, the direct and indirect costs associated with malaria are also reduced (see table 30), interpreted as the benefits of implementing the spraying programme.

In comparison to the bed net programme, the spraying programme has a 1-year payback period, indicating that the programme yields benefits that exceed the associated costs within the first year of implementation. The recommendation would therefore be that, if policymakers have equal access to both types of interventions, then they should invest in spraying programmes, *ceteris paribus,* since spraying programmes reduce the number of malaria cases by a larger proportion, thereby resulting in earlier benefits through lower treatment costs and lower productivity losses. The spraying programmes yield larger dividends in terms of these costs, given their relatively larger impact on the number of malaria cases.

### 2. Dengue

Given the absence in the literature of information on the impact of prevention methods on the number of dengue cases, this section assumes that a spraying programme is undertaken which has the same impact on dengue as it has on malaria, resulting in a reduction in the number of dengue cases by 35% (see table 31). In the first step, the rate at which dengue affects the 2010-year population is calculated; this figure is then multiplied by 10 % of the population to arrive at the number of cases that would be likely to exist without the spraying intervention. This number is then reduced by 35 % to determine the number of cases that can be expected in the same 10 % of the population after the implementation of the spraying programme. The averted treatment costs are 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 treatment. The averted productivity losses are calculated as the difference between the number of cases with and without the intervention, multiplied by the number of days lost to dengue (5 days) and the GDP per capita (US$ 1,518 in 2008 dollars), divided by 365.

**Table 31: Provision costs, treatment costs averted and productivity losses averted after the implementation of a spraying programme delivered to 10%, 40% and 50% of the Guyanese population: 2011 – 2050 (US$)**

| | | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10% population | | **Total cost of spraying $27, 270**<br>**Payback period: A2 – 1 year B2 – 1 year BAU – 1 year** | | | | | | | | | | | |
| | | **Benefit 1: treatment costs averted** | | | | **Benefit 2: productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 109 280 | 96 078 | 84 992 | 76 813 | 2 744 | 2 413 | 2 134 | 1 929 | 112 025 | 98 491 | 87 126 | 78 742 |
| | B2 | 118 623 | 108 963 | 104 297 | 101 227 | 2 979 | 2 737 | 2 619 | 2 542 | 121 602 | 111 700 | 106 916 | 103 769 |
| | BAU | 140 989 | 137 540 | 131 241 | 127 350 | 3 541 | 3 454 | 3 296 | 3 198 | 144 530 | 140 995 | 134 537 | 130 549 |
| | | | | | | | | | | | | | |
| 40% population | | **Total cost of spraying $110,880**<br>**Payback period: A2 – 1 year B2 – 1 year BAU – 1 year** | | | | | | | | | | | |
| | | **Benefit 1: treatment costs averted** | | | | **Benefit 2: productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 437 122 | 384 313 | 339 967 | 307 250 | 10 978 | 9 652 | 8 538 | 7 716 | 448 100 | 393 964 | 348 505 | 314 966 |
| | B2 | 474 490 | 435 853 | 417 186 | 404 908 | 11 916 | 10 946 | 10 477 | 10 169 | 486 407 | 446 799 | 427 664 | 415 077 |
| | BAU | 563 956 | 550 162 | 524 964 | 509 402 | 14 163 | 13 817 | 13 184 | 12 793 | 578 120 | 563 979 | 538 148 | 522 195 |
| | | | | | | | | | | | | | |
| 50% population | | **Total cost of spraying $136, 800**<br>**Payback period: A2 – 1 year B2 – 1 year BAU – 1 year** | | | | | | | | | | | |
| | | **Benefit 1: treatment costs averted** | | | | **Benefit 2: productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 546 402 | 480 391 | 424 959 | 384 063 | 13 722 | 12 065 | 10 672 | 9 645 | 560 125 | 492 455 | 435 631 | 393 708 |
| | B2 | 593 113 | 544 817 | 521 483 | 506 135 | 14 896 | 13 683 | 13 097 | 12 711 | 608 009 | 558 499 | 534 580 | 518 846 |
| | BAU | 704 945 | 687 702 | 656 205 | 636 752 | 17 704 | 17 271 | 16 480 | 15 991 | 722 650 | 704 973 | 672 686 | 652 744 |

Source: Author‘s calculations

The spraying programme reduces the number of dengue cases in the population by 35%, which results in a reduction in the treatment costs and the productivity losses associated with dengue. This reduction in treatment costs and productivity losses are interpreted as the benefits of implementing the spraying programme. The results in table 31 indicate that, regardless of scenario and the proportion of the population that is exposed to the programme, the benefits are reduced over time as a result of the decline in the number of cases throughout the four decades. Under A2, B2 and BAU, the declines are 30%, 15% and 10 %, respectively. Table 31 also shows that the investment pays for itself within one year regardless of the scenario or the size of the population, and that the benefits of implementing the programme are largely associated with reduced treatment costs. This is in contrast to malaria, which has a comparatively lower treatment cost and higher productivity loss.

### 3. Leptospirosis

The intervention being considered in the case of leptospirosis is one in which there is improved water quality and sanitation, which is estimated to reduce the number of leptospirosis cases by 30%. The cost of providing improved sanitation is US$ 60 per person and improved water quality is US$ 50 per person, yielding a total cost of US$ 150 per person.[38]

The following steps are used to calculate the benefits: calculate the rate at which additional leptospirosis cases affect the 2010-year population; multiplying that rate by 10% of the population would arrive at the number of cases that would be likely to exist without the sanitation and water intervention. This number is then reduced by 30% to determine the number of cases that can be expected in the same 10% of the population after the implementation of the water and sanitation programme.

The averted treatment costs are 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 leptospirosis treatment.

The averted productivity losses are calculated as the difference between the number of cases with and without the intervention, multiplied by the number of days lost to leptospirosis (5.25 days) and the GDP per capita (US$ 1,518 in 2008 dollars), divided by 365.

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[38] World Bank Working Paper Series 5618.

**Table 32: Provision costs, treatment costs averted and productivity losses averted after the implementation of a sanitation improvement programme aimed at preventing additional cases of leptospirosis delivered to 10%, 40% and 50% of the Guyanese population: 2011 – 2050 (US$)**

| | | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10% population | | **Total cost of water and sanitation improvement programme $2,213,750**<br>**Payback Period: A2 - not within period B2 - not within forecast period BAU – not within forecast period** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total Benefits** | | | |
| | A2 | 226 | 199 | 176 | 159 | 594 | 522 | 462 | 417 | 820 | 721 | 638 | 576 |
| | B2 | 246 | 226 | 216 | 210 | 645 | 592 | 567 | 550 | 890 | 818 | 783 | 760 |
| | BAU | 292 | 285 | 272 | 264 | 766 | 748 | 713 | 692 | 1 058 | 1 032 | 985 | 956 |
| | | | | | | | | | | | | | |
| 40% population | | **Total cost of water and sanitation improvement programme $8,855,000**<br>**Payback Period: A2 - not within period B2 - not within forecast period BAU – not within forecast period** | | | | | | | | | | | |
| | | **BENEFIT 1: Treatment Costs Averted** | | | | **BENEFIT 2: Productivity Losses Averted** | | | | **TOTAL BENEFITS** | | | |
| | A2 | 1 056 | 928 | 821 | 742 | 2 772 | 2 437 | 2 156 | 1 948 | 3 827 | 3 365 | 2 977 | 2 690 |
| | B2 | 1 146 | 1 053 | 1 008 | 978 | 3 009 | 2 764 | 2 645 | 2 567 | 4 155 | 3 816 | 3 653 | 3 545 |
| | BAU | 1 362 | 1 329 | 1 268 | 1 230 | 3 576 | 3 488 | 3 329 | 3 230 | 4 938 | 4 817 | 4 597 | 4 460 |
| | | | | | | | | | | | | | |
| 50% population | | **Total cost of water and sanitation improvement programme $11,068,750**<br>**Payback Period: A2 - not within period B2 - not within forecast period BAU – not within forecast period** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total Benefits** | | | |
| | A2 | 1 320 | 1 160 | 1 026 | 928 | 3 465 | 3 046 | 2 694 | 2 435 | 4 784 | 4 206 | 3 721 | 3 363 |
| | B2 | 1 433 | 1 316 | 1 260 | 1 223 | 3 761 | 3 454 | 3 307 | 3 209 | 5 193 | 4 770 | 4 566 | 4 432 |
| | BAU | 1 703 | 1 661 | 1 585 | 1 538 | 4 470 | 4 360 | 4 161 | 4 037 | 6 173 | 6 022 | 5 746 | 5 575 |

Source: Author‘s calculations

More than one-half of the benefits of implementing the water and sanitation programme accrue to the reduction in productivity losses that are associated with the additional cases of leptospirosis that would have been observed in the absence of the programme. In terms of weighing alternative uses of the cost of the programme, the payback period of this kind of infrastructure programme is shown to occur over the very long term, and not during the forecast period 2011- 2050 considered in the present analysis.

## 4. Gastroenteritis

Improved water and sanitation are the adaptation measures that are explored for gastroenteritis cases, in relation to the costs and benefits and the payback period for the project. The cost of the water and sanitation improvement project is the same as for leptospirosis, at US$ 115 per person. The following steps are used to calculate the benefits: calculate the rate at which additional gastroenteritis cases affect the 2010-year population; multiply that rate by 10% of the population to arrive at the number of cases that would be likely to exist without the sanitation and water intervention. This number is then reduced by 30% to determine the number of cases that can be expected in the same 10% of the population after the implementation of the water and sanitation programme. The averted treatment costs are 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 gastroenteritis treatment. The averted productivity losses are calculated as the difference between the number of cases with and without the intervention, multiplied by the number of days lost to gastroenteritis (6.44 days) and the GDP per capita (US$1,518 in 2008 dollars), divided by 365.

**Table 33: Provision costs, treatment costs averted and productivity losses averted after the implementation of a sanitation programme to prevent additional cases of gastroenteritis in the population under age 5 that is delivered to 10%, 40% and 50% of the Guyanese population: 2011 – 2050 (US$)**

| | | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10% population | | **Total cost of sanitation improvement programme $2,213,750**<br>**Payback period: A2 - 2 years B2 - 2 years BAU – 2 years** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 697 848 | 634 858 | 587 286 | 568 429 | 93 454 | 85 018 | 78 647 | 76 122 | 791 302 | 719 877 | 665 934 | 644 551 |
| | B2 | 738 121 | 762 614 | 735 444 | 766 544 | 98 847 | 102 127 | 98 488 | 102 653 | 836 968 | 864 741 | 833 933 | 869 197 |
| | BAU | 739 227 | 693 392 | 641 084 | 645 043 | 98 995 | 92 857 | 85 852 | 86 382 | 838 222 | 786 249 | 726 936 | 731 426 |
| | | | | | | | | | | | | | |
| 40% population | | **Total cost of sanitation improvement programme $8,855,000**<br>**Payback period: A2 - 3 years B2 - 3 years BAU – 3 years** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total Benefits** | | | |
| | A2 | 3 256 624 | 2 962 673 | 2 740 669 | 2 652 669 | 436 116 | 396 751 | 367 021 | 355 237 | 3 692 740 | 3 359 424 | 3 107 690 | 3 007 906 |
| | B2 | 3 444 566 | 3 558 865 | 3 432 074 | 3 577 204 | 461 285 | 476 592 | 459 612 | 479 047 | 3 905 851 | 4 035 457 | 3 891 686 | 4 056 252 |
| | BAU | 3 449 728 | 3 235 829 | 2 991 724 | 3 010 203 | 461 976 | 433 332 | 400 642 | 403 116 | 3 911 704 | 3 669 161 | 3 392 366 | 3 413 319 |
| | | | | | | | | | | | | | |
| 50% population | | **Total cost of sanitation improvement programme $11,068,750**<br>**Payback period: A2 - 3 years B2 - 3 years BAU – 3 years** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 4 070 780 | 3 703 341 | 3 425 836 | 3 315 836 | 545 145 | 495 939 | 458 777 | 444 046 | 4 615 925 | 4 199 280 | 3 884 613 | 3 759 882 |
| | B2 | 4 305 708 | 4 448 582 | 4 290 092 | 4 471 505 | 576 606 | 595 739 | 574 515 | 598 809 | 4 882 314 | 5 044 321 | 4 864 607 | 5 070 315 |
| | BAU | 4 312 160 | 4 044 787 | 3 739 655 | 3 762 753 | 577 470 | 541 665 | 500 802 | 503 896 | 4 889 631 | 4 586 451 | 4 240 457 | 4 266 649 |

Source: Author's calculations

**Table 34: Provision costs, treatment costs averted and productivity losses averted after the implementation of a sanitation programme to prevent additional cases of gastroenteritis in the population over age 5 that is delivered to 10%, 40% and 50% of the Guyanese population: 2011 – 2050 (US$)**

| | | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | 2010 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10% population | | **Total cost of sanitation improvement programme $2,213,750**<br>**Payback period: A2 - 2 years B2 - 2 years BAU – 2 years** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 1 095 322 | 1 135 358 | 1 187 262 | 1 299 376 | 146 682 | 152 043 | 158 994 | 174 008 | 1 242 004 | 1 287 401 | 1 346 257 | 1 473 384 |
| | B2 | 1 064 616 | 1 202 018 | 1 213 595 | 1 335 274 | 142 570 | 160 970 | 162 521 | 178 815 | 1 207 186 | 1 362 988 | 1 376 115 | 1 514 089 |
| | BAU | 992 377 | 960 799 | 914 473 | 954 478 | 132 896 | 128 667 | 122 463 | 127 821 | 1 125 273 | 1 089 466 | 1 036 936 | 1 082 299 |
| | | | | | | | | | | | | | |
| 40% population | | **Total cost of sanitation improvement programme $8,855,000**<br>**Payback period: A2 - 2 years B2 - 2 years BAU – 2 years** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 5 111 504 | 5 298 337 | 5 540 558 | 6 063 754 | 684 516 | 709 536 | 741 973 | 812 038 | 5 796 020 | 6 007 873 | 6 282 531 | 6 875 792 |
| | B2 | 4 968 210 | 5 609 416 | 5 663 442 | 6 231 277 | 665 326 | 751 195 | 758 430 | 834 472 | 5 633 536 | 6 360 611 | 6 421 872 | 7 065 750 |
| | BAU | 4 631 094 | 4 483 728 | 4 267 540 | 4 454 231 | 620 181 | 600 446 | 571 495 | 596 496 | 5 251 275 | 5 084 174 | 4 839 035 | 5 050 726 |
| | | | | | | | | | | | | | |
| 50% population | | **Total cost of sanitation improvement programme $11,068,750**<br>**Payback period: A2 - 2 years B2 - 2 years BAU – 2 years** | | | | | | | | | | | |
| | | **Benefit 1: Treatment costs averted** | | | | **Benefit 2: Productivity losses averted** | | | | **Total benefits** | | | |
| | A2 | 6 389 381 | 6 622 922 | 6 925 697 | 7 579 693 | 855 645 | 886 920 | 927 467 | 1 015 048 | 7 245 025 | 7 509 842 | 7 853 164 | 8 594 740 |
| | B2 | 6 210 262 | 7 011 770 | 7 079 303 | 7 789 097 | 831 658 | 938 993 | 948 037 | 1 043 090 | 7 041 920 | 7 950 764 | 8 027 340 | 8 832 187 |
| | BAU | 5 788 868 | 5 604 660 | 5 334 425 | 5 567 788 | 775 226 | 750 558 | 714 369 | 745 620 | 6 564 094 | 6 355 217 | 6 048 794 | 6 313 408 |

Source: Author‘s calculations

Tables 33 and 34 indicate that the treatment costs that are averted by the water and sanitation programme are more than 90% of the total benefits associated with the implementation of the programme to both the under age 5 and over age 5 populations in Guyana. The water and sanitation programme reduces the number of gastroenteritis cases in the population by 30%, which results in a reduction in the treatment costs and the productivity losses associated with gastroenteritis in both population groups. These reductions in treatment costs and productivity losses are interpreted as the benefits of implementing the water and sanitation programme. The results in table 33 and table 34 indicate that, under the A2 and B2 scenarios in both population groups and for the proportions of the population exposed to the programme, the benefits increased over time as a result of the increase in the number of cases throughout the four decades. Under BAU, the benefits (costs averted) decline in the two populations, regardless of the proportion of the population of that is targeted for the programme. Table 33 also shows that the investment pays for itself within 2 years if 10% of the population receives improved water and sanitation, but within 3 years if the programme were extended to 40% and 50% of the population. In terms of the population over age 5, the payback period of the investment is 2 years, regardless of the proportion of the population to which the programme is extended.

## 5. Summary

The provisional costs for each disease indicate that the most expensive disease, in terms of direct adaptation costs, are water and sanitation programmes designed to reduce leptospirosis and gastroenteritis in both the populations under and over age 5.

The adaptation costs for impregnated bed nets designed to prevent malaria and the spraying programmes that target reductions in both malaria and dengue, follow, respectively. This ranking stands regardless of the scenario and size of the targeted population, in each instance.

In terms of payback period, dengue and malaria spraying programmes are the fastest, within 1 year, followed by water and sanitation for gastroenteritis, bed nets for malaria and finally, water and sanitation for leptospirosis. There are, however, some benefits or complementarities that are likely to materialize when a programme is implemented for one disease that also helps to reduce the number of cases, and therefore to increase the benefits associated with the reduced number of cases of both diseases.

The economics of treatment and prevention measures differ 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 the disease and the effort to curtail the impact that malaria can have on human health once it is contracted. Prevention efforts, with respect to the availability of vaccines and the availability and durability of impregnated bed nets, will need to be expanded in order to match the affordability of the treatment costs.

In contrast, the costs associated with medical care (treatment) of gastroenteritis illnesses during convalescence are comparatively higher than the costs 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 levels of both direct and indirect costs associated with leptospirosis suggest that health authorities need to assign proportionately fewer resources to either the prevention or treatment of the disease.

Policy should therefore place emphasis on programmes that will 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 potential increases in the number of malaria cases that are observed. This early warning monitoring system is also likely to have a complementary, secondary impact in terms of reducing the number of additional cases of dengue and leptospirosis that are observed.

The costs of sourcing vaccines for the prevention of gastroenteritis are next in importance, and these costs increase over the period of the forecast. Gastroenteritis prevention costs are approximately equal for those population segments under and those over 5 years old. In addition, the interventions should take into consideration the complementarities in terms of reduced cases and costs (increased benefits) between two or more diseases.

For Guyana, building adaptive capacity for health also will require a cross-disciplinary dialogue between health practitioners, decision makers, the public, and the climate change science community. As a component of the overall need for adaptation to climate change, adaptive strategies in health have to be based on actions that the Government, institutions, and the public can take, to adjust to impacts, moderate their damage, or cope with their consequences. Most relevant actions for adaptive capacity will be those enabling commonly accepted good public health and development practices, beyond climate change considerations. The creation and maintenance of basic public health infrastructure, in terms of training, surveillance, immunization, vector control, and emergency preparedness and response, will both provide development benefits and increase resilience to the health impacts of climate change. As the situation changes, novel actions and strategies may need to be developed, new technologies invented, and the relationships between natural and man-made systems and human health better analysed.

It is clear that the cost estimates for the health sector reported in the present paper are an underestimate of the total health sector cost, as this assessment only includes the cost of the impact of malaria, gastroenteritis, leptospirosis and dengue fever to climate change. The health sector adaptation cost reported here would be higher, for example, if any of the agricultural sector adaptation measures fail, raising levels of malnutrition. Even if these additional costs were included, the reported costs would still have underestimated the true cost of adapting to climate change, because of the omission of adaptation costs for other health impacts.

The present report also includes policy recommendations that will support not only achievement of health outcomes but other climate related impacts. In fact, total adaptation costs for Guyana are projected to exceed US$ 1 billion at the national level. While all of these adaptation needs must eventually be met, the Office of the President (2010) has identified a portfolio of urgent, near-term investments in the highest priority areas where the population and economic activity are concentrated. These include:

1. Upgrading infrastructure and assets to protect against flooding through urgent, near-term measures (US$ 225 million)
2. Hinterland Adaptation Measures (US$ 10 million)
3. Addressing systematic and behavioural concerns(US$ 33 million)
4. Developing innovative financial risk management and insurance measures to resiliency (US$ 10 million).
5. Switching to flood resistant crops (US$ 10 million).

In addition to these urgent near-term measures, an additional US$ 500 million to $600 million of long-term adaptation measures have been identified, including:

- Upgrading the Conservancy to recognized engineered standards (US$ 410 million)
- Expanding beyond the priority regions in upgrading the sea wall (US$ 15 million to $60 million)
- Expanding the drainage and irrigation programme (US$ 30 million to $119 million).

It is clear that such programmes to address behavioural concerns and the upgrading of the sea wall will contribute to a reduction in the incidence of communicable diseases such as gastroenteritis.

The present report can provide a general framework and some policy prescriptions to ensure that climate change issues and the potential implications of climate change on human health are mainstreamed into national policies and development activities. The objective is to avoid, or minimize, the impact of disasters related to climate change by increasing coping capacity at various levels (including economic sectors and communities) within the country. Some key actions that could be adopted include:

- Creating mechanisms to fully consider the impacts of climate change on human health and ‗climate proof ' all national policies and plans, especially those that may be related to, or interact with, human heath – as for example, the linkages between environmental sustainability and human health.
- Strengthening data gathering, processing and reporting procedures to increase the availability of data for analysis and planning
- Identifying strategic priorities for adaptation to climate change, especially as it relates to human health
- Strengthening the capacity of the health sector to adapt to the future risks expected as a result of a changing climate
- Undertaking research to identify health sector-specific strategies for adaptation, particularly as it relates to diseases such as malaria and gastroenteritis
- Promoting education and discussion about climate change through local and community media
- Infusing climate change issues into the physical planning system
- Applying disaster risk reduction frameworks to build on climate change mitigation measures
- Improving sanitation systems and access to potable water
- Developing and implementing public education and awareness programmes on the impacts of climate change

Estimating the cost of adapting human health to climate change is challenging, since adaptation actions that affect health outcomes are 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 just those related to climate change. Improvements in water and sanitation services are often undertaken not only to reduce the incidence of all waterborne diseases, 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 shares similar goals with sustainable development – increasing the ability of countries, communities and individuals to cope, effectively and efficiently, with the changes and challenges of climate change (WHO, 2003).[39]

## B. FORECASTS OF REGIONAL DISTRIBUTION OF DISEASE

In this section, the disease forecasts that were presented in the previous sections are broken down by scenario and by region, using the 2007 regional disease profile. The map of the 10 Administrative Regions within Guyana is shown below in order to illustrate the spatial distribution that the forecast number of cases of each disease is likely to follow based on the 2007 distribution. The intention of this

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[39] WHO (2003), *Health and Global Environmental Change* SERIES No. 1: Methods of assessing human health vulnerability and public health adaptation to climate change.

section is to provide information to policymakers in order to facilitate improved targeting of the additional resources that are likely to be required by the health facilities in the Regions. These resources are necessary in order to cauterize the impact that increased numbers of cases can have on their facilities, in addition to the impact on human health and population dynamics.

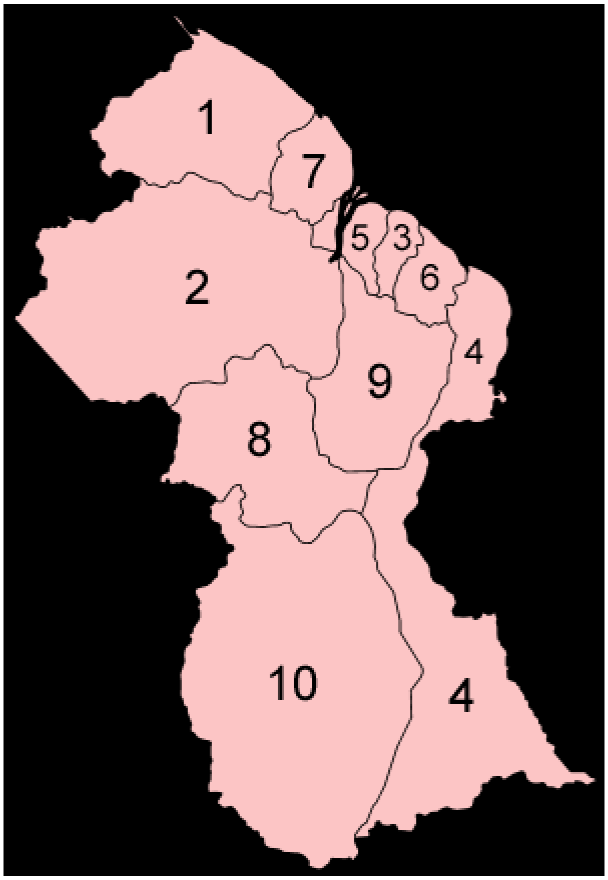

Table 35 presents the results of the distributional analysis on the number of additional cases of each disease, during the four decades and across the four Regions. The results indicate that, under all three scenarios:

- Malaria will heavily impact the populations of Region 4 (inland), Region 7 (coastal) and Region 1(coastal), in all four decades.
- Regions 4 and 9 (inland), Region 1 and Region 10 (inland) are likely to encounter the brunt of the dengue cases in all three scenarios.
- Only 5 of the 10 Regions – Region 4, Region 3 (coastal), Region 10, Region 1 and Region 6 (coastal) – register new leptospirosis cases between 2011 and 2050, in order of likely location of the new cases.
- Both populations under age 5 and over age 5, in Regions 4, 3 and 10, will experience the larger share of gastroenteritis under A2, B2 and BAU.

  Based on the results of the above analysis, it is reasonable to expect that the health facilities and populations that are located in Regions 4, 1 and 10 will be in need of comparatively more resources, since they are expected to be burdened with all four diseases – malaria, dengue, leptospirosis and gastroenteritis – for the entire forecast period.

Population and poverty dynamics should also be used to inform the response of the health authorities, in addition to the forecasts of the regional breakdown. Added to the extra expenditure on interventions and staffing resources that will be required, the authorities may find it necessary to construct additional health facilities, in order to contend with other diseases that are likely to become endemic between 2011 and 2050.

**Table 35: Regional distribution of diseases under the A2, B2 and BAU scenario: 2011 – 2050**

**A2**

| | Region | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MALARIA | 2011 - 2020 | 4 878 | 3 481 | 121 | 9 888 | 0 | 0 | 6 703 | 3 182 | 3 087 | 1 487 | 0 |
| | 2021 - 2030 | 5 111 | 3 647 | 127 | 10 361 | 0 | 0 | 7 023 | 3 335 | 3 234 | 1 558 | 0 |
| | 2031 - 2040 | 5 396 | 3 851 | 134 | 10 939 | 0 | 0 | 7 415 | 3 521 | 3 415 | 1 645 | 0 |
| | 2041 - 2050 | 5 931 | 4 232 | 147 | 12 023 | 0 | 0 | 8 150 | 3 870 | 3 753 | 1 808 | 0 |
| DENGUE | 2011 - 2020 | 140 | 65 | 367 | 3 023 | 65 | 76 | 97 | 22 | 162 | 140 | 43 |
| | 2021 - 2030 | 141 | 65 | 368 | 3 034 | 65 | 76 | 98 | 22 | 163 | 141 | 43 |
| | 2031 - 2040 | 141 | 65 | 368 | 3 030 | 65 | 76 | 97 | 22 | 162 | 141 | 43 |
| | 2041 - 2050 | 144 | 66 | 375 | 3 091 | 66 | 77 | 99 | 22 | 166 | 144 | 44 |
| LEPTO | 2011 - 2020 | 25 | 0 | 49 | 518 | 0 | 0 | 25 | 0 | 0 | 49 | 25 |
| | 2021 - 2030 | 0 | 54 | 572 | 572 | 0 | 0 | 27 | 0 | 0 | 54 | 27 |
| | 2031 - 2040 | 52 | 549 | 0 | 549 | 0 | 0 | 26 | 0 | 0 | 52 | 26 |
| | 2041 - 2050 | 551 | 0 | 0 | 551 | 0 | 0 | 26 | 0 | 0 | 52 | 26 |
| GASTRO under-5 | 2011 - 2020 | 183 | 970 | 3 885 | 5 411 | 352 | 103 | 101 | 144 | 798 | 2 113 | 0 |
| | 2021 - 2030 | 168 | 893 | 3 576 | 4 980 | 324 | 95 | 93 | 133 | 734 | 0 | 0 |
| | 2031 - 2040 | 177 | 939 | 3 763 | 5 240 | 341 | 99 | 98 | 139 | 773 | 2 046 | 0 |
| | 2041 - 2050 | 175 | 930 | 3 723 | 5 186 | 337 | 98 | 97 | 138 | 765 | 2 024 | 0 |
| GASTRO over-5 | 2011 - 2020 | 302 | 1 602 | 6 415 | 8 934 | 581 | 170 | 168 | 238 | 1 317 | 3 488 | 0 |
| | 2021 - 2030 | 267 | 1 417 | 5 673 | 7 901 | 514 | 150 | 148 | 210 | 1 165 | 3 085 | 0 |
| | 2031 - 2040 | 284 | 1 508 | 6 039 | 8 410 | 547 | 160 | 158 | 224 | 1 240 | 3 283 | 0 |
| | 2041 - 2050 | 285 | 1 510 | 6 046 | 8 420 | 547 | 160 | 158 | 224 | 1 241 | 3 287 | 0 |

**B2**

| | Region | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MALARIA | 2011 - 2020 | 3 681 | 2 627 | 91 | 7 462 | 0 | 0 | 5 058 | 2 401 | 2 329 | 1 122 | 0 |
| | 2021 - | 4 143 | 2 956 | 103 | 8 398 | 0 | 0 | 5 693 | 2 703 | 2 622 | 1 263 | 0 |

**Table 35: Regional distribution of diseases under the A2, B2 and BAU scenario: 2011 – 2050**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2030 | | | | | | | | | | |
| | 2031 - 2040 | 4 026 | 2 873 | 100 | 8 162 | 0 | 0 | 5 533 | 2 627 | 2 548 | 1 227 | 0 |
| | 2041 - 2050 | 3 747 | 2 674 | 93 | 7 596 | 0 | 0 | 5 149 | 2 445 | 2 371 | 1 142 | 0 |
| DENGUE | 2011 - 2020 | 158 | 73 | 413 | 3 400 | 73 | 85 | 109 | 24 | 182 | 158 | 49 |
| | 2021 - 2030 | 160 | 74 | 419 | 3 451 | 74 | 86 | 111 | 25 | 185 | 160 | 49 |
| | 2031 - 2040 | 159 | 73 | 415 | 3 420 | 73 | 86 | 110 | 24 | 183 | 159 | 49 |
| | 2041 - 2050 | 160 | 74 | 418 | 3 442 | 74 | 86 | 111 | 25 | 184 | 160 | 49 |
| LEPTO | 2011 - 2020 | 28 | 0 | 57 | 596 | 0 | 0 | 28 | 0 | 0 | 57 | 28 |
| | 2021 - 2030 | 25 | 0 | 51 | 534 | 0 | 0 | 25 | 0 | 0 | 51 | 25 |
| | 2031 - 2040 | 29 | 0 | 57 | 601 | 0 | 0 | 29 | 0 | 0 | 57 | 29 |
| | 2041 - 2050 | 26 | 0 | 52 | 551 | 0 | 0 | 26 | 0 | 0 | 52 | 26 |
| GASTRO under-5 | Region | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Unknown |
| | 2011 - 2020 | 150 | 797 | 3 190 | 4 443 | 289 | 84 | 83 | 118 | 655 | 1 735 | 0 |
| | 2021 - 2030 | 163 | 865 | 3 464 | 4 824 | 314 | 92 | 90 | 128 | 711 | 1 883 | 0 |
| | 2031 - 2040 | 180 | 955 | 3 824 | 5 326 | 346 | 101 | 100 | 142 | 785 | 2 079 | 0 |
| | 2041 - 2050 | 98 | 521 | 2 088 | 2 908 | 189 | 55 | 55 | 77 | 429 | 1 135 | 0 |
| GASTRO over-5 | 2011 - 2020 | 184 | 973 | 3 897 | 5 428 | 353 | 103 | 102 | 144 | 800 | 2 119 | 0 |
| | 2021 - 2030 | 250 | 1 328 | 5 319 | 7 409 | 482 | 141 | 139 | 197 | 1 092 | 2 892 | 0 |
| | 2031 - 2040 | 326 | 1 730 | 6 928 | 9 650 | 627 | 183 | 181 | 257 | 1 423 | 3 767 | 0 |
| | 2041 - 2050 | 125 | 661 | 2 648 | 3 688 | 240 | 70 | 69 | 98 | 544 | 1 440 | 0 |
| **BAU** | | | | | | | | | | | |
| | Region | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Unknown |
| MALARIA | 2011 - 2020 | 4 677 | 3 337 | 116 | 9 480 | 0 | 0 | 6 426 | 3 051 | 2 959 | 1 426 | 0 |
| | 2021 - 2030 | 5 403 | 3 856 | 134 | 10 952 | 0 | 0 | 7 424 | 3 525 | 3 419 | 1 647 | 0 |
| | 2031 - 2040 | 5 776 | 4 122 | 143 | 11 708 | 0 | 0 | 7 937 | 3 768 | 3 655 | 1 761 | 0 |
| | 2041 - 2050 | 6 394 | 4 563 | 159 | 12 962 | 0 | 0 | 8 787 | 4 172 | 4 046 | 1 949 | 0 |
| DENG | 2011 - 2020 | 141 | 65 | 369 | 3 037 | 65 | 76 | 98 | 22 | 163 | 141 | 43 |

**Table 35: Regional distribution of diseases under the A2, B2 and BAU scenario: 2011 – 2050**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 - 2030 | 140 | 65 | 366 | 3 015 | 65 | 75 | 97 | 22 | 162 | 140 | 43 |
| | 2031 - 2040 | 140 | 65 | 367 | 3 024 | 65 | 76 | 97 | 22 | 162 | 140 | 43 |
| | 2041 - 2050 | 143 | 66 | 373 | 3 075 | 66 | 77 | 99 | 22 | 165 | 143 | 44 |
| LEPTO | 2011 - 2020 | 0 | 0 | 0 | 537 | 0 | 0 | 26 | 0 | 0 | 51 | 26 |
| | 2021 - 2030 | 0 | 0 | 0 | 509 | 0 | 0 | 24 | 0 | 0 | 49 | 24 |
| | 2031 - 2040 | 0 | 0 | 0 | 584 | 0 | 0 | 28 | 0 | 0 | 56 | 28 |
| | 2041 - 2050 | 0 | 0 | 0 | 575 | 0 | 0 | 27 | 0 | 0 | 55 | 27 |
| GASTRO under-5 | 2011 - 2020 | 176 | 936 | 3 748 | 5 221 | 339 | 99 | 98 | 139 | 770 | 2 038 | 0 |
| | 2021 - 2030 | 174 | 922 | 3 694 | 5 144 | 334 | 98 | 96 | 137 | 758 | 2 008 | 0 |
| | 2031 - 2040 | 171 | 905 | 3 625 | 5 049 | 328 | 96 | 95 | 134 | 744 | 1 971 | 0 |
| | 2041 - 2050 | 167 | 887 | 3 553 | 4 948 | 322 | 94 | 93 | 132 | 730 | 1 932 | 0 |
| GASTRO over-5 | 2011 - 2020 | 282 | 0 | 5 987 | 8 339 | 542 | 158 | 156 | 222 | 1 229 | 3 255 | 0 |
| | 2021 - 2030 | 290 | 0 | 6 152 | 8 569 | 557 | 163 | 161 | 228 | 1 263 | 3 345 | 0 |
| | 2031 - 2040 | 275 | 0 | 5 848 | 8 145 | 529 | 155 | 153 | 217 | 1 201 | 3 180 | 0 |
| | 2041 - 2050 | 267 | 0 | 5 665 | 7 890 | 513 | 150 | 148 | 210 | 1 163 | 3 080 | 0 |

Source: Data compiled by author

# ANNEX I: DEFINING THE MODEL FOR GASTROENTERITIS

Based on the literature, gastroenteritis is expected to be impacted by the level of sanitation, rainfall and minimum temperatures. Although sanitation data were not readily available, two approaches were attempted. The first approach attempted to use HDI as an indicator of broad development or the welfare status, which would implicitly reflect the availability of sanitation infrastructure. The second approach was to source data on access to sanitation from the Environmental Performance Index (EPI) prepared at Yale University for the years 2008 and 2010.[40] The years 2008 and 2010 were averaged to estimate the value of the score for the year 2009. The data point for the year 2007 was calculated by holding the relationship between the HDI and EPI sanitation constant and calculating backwards for the year 2007. Neither the sanitation nor the HDI variable has the expected sign in either the under age 5 or over age 5 population. As a result, the final model does not include a control for these aspects of the socio-economic status of the country. The output from the four regression analyses, with each of these variables for the two segments of the population, are presented below.

```
Dependent Variable: GASTRO
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/17/11   Time: 22:08
Sample (adjusted): 2007M01 2010M06
Included observations: 42 after adjustments
Convergence achieved after 6 iterations
Covariance matrix computed using second derivatives
=================================================================================
                            Coefficient     Std. Error    z-Statistic      Prob.
=================================================================================
           C                  -1.323150      0.201306      -6.572820      0.0000
          RAIN                 3.51E-05      3.82E-05       0.919148      0.3580
        TEMPMIN                0.076283      0.006462       11.80542      0.0000
         @TREND               -0.065428      0.001626      -40.25048      0.0000
 SIN((2*3.14*@TREND)/12)      -0.274159      0.009639      -28.44328      0.0000
       SANITATION              0.117407      0.002258       51.98932      0.0000
=================================================================================
R-squared                      0.361459    Mean dependent var           963.2619
Adjusted R-squared             0.272773    S.D. dependent var           595.8976
S.E. of regression             508.1672    Akaike info criterion        188.7253
Sum squared resid              9296420.    Schwarz criterion            188.9735
Log likelihood                -3957.230    Hannan-Quinn criter.         188.8162
Restr. log likelihood         -6457.018    LR statistic                 4999.574
Avg. log likelihood           -94.21977    Prob(LR statistic)           0.000000
=================================================================================
```

---

[40] The EPI is published every other year.

```
Dependent Variable: GASTRO
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/10/11   Time: 18:07
Sample (adjusted): 2007M01 2010M06
Included observations: 42 after adjustments
Convergence achieved after 9 iterations
Covariance matrix computed using second derivatives
======================================================================
                              Coefficient   Std. Error  z-Statistic   Prob.
======================================================================
            C                  -113.5075    2.511796    -45.18979    0.0000
           RAIN                 0.000355    3.91E-05     9.088869    0.0000
         TEMPMIN                0.090120    0.006346     14.20193    0.0000
          @TREND               -0.080010    0.002084    -38.39682    0.0000
 SIN((2*3.14*@TREND)/12)       -0.400945    0.011908    -33.67049    0.0000
           HDI                  199.3732    4.210522     47.35118    0.0000
======================================================================
R-squared                      0.347344   Mean dependent var      963.2619
Adjusted R-squared             0.256697   S.D. dependent var      595.8976
S.E. of regression             513.7533   Akaike info criterion   202.0688
Sum squared resid              9501929.   Schwarz criterion       202.3170
Log likelihood                -4237.444   Hannan-Quinn criter.    202.1598
Restr. log likelihood         -6457.018   LR statistic            4439.147
Avg. log likelihood           -100.8915   Prob(LR statistic)      0.000000
======================================================================
```

```
Dependent Variable: GASTROOVER5
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/17/11   Time: 22:50
Sample (adjusted): 2007M01 2010M06
Included observations: 42 after adjustments
Convergence achieved after 6 iterations
Covariance matrix computed using second derivatives
==========================================================================
                             Coefficient    Std. Error   z-Statistic    Prob.
==========================================================================

           C                  -0.123564      0.158150     -0.781311    0.4346
        TEMPMIN                0.063314      0.005194      12.19044    0.0000
         @TREND               -0.040727      0.001349     -30.18182    0.0000
  SIN((2*3.14*@TREND)/12)     -0.264738      0.007354     -35.99914    0.0000
       SANITATION              0.101971      0.001895      53.80808    0.0000
==========================================================================

R-squared                      0.506445   Mean dependent var         1469.071
Adjusted R-squared             0.453088   S.D. dependent var         940.9763
S.E. of regression             695.8850   Akaike info criterion      203.6137
Sum squared resid              17917469   Schwarz criterion          203.8205
Log likelihood                -4270.887   Hannan-Quinn criter.       203.6895
Restr. log likelihood         -10092.00   LR statistic               11642.23
Avg. log likelihood           -101.6878   Prob(LR statistic)         0.000000
==========================================================================
```

```
Dependent Variable: GASTROOVER5
Method: ML/QML - Poisson Count (Quadratic hill climbing)
Date: 06/10/11   Time: 18:08
Sample (adjusted): 2007M01 2010M06
Included observations: 42 after adjustments
Convergence achieved after 9 iterations
Covariance matrix computed using second derivatives
==========================================================================
                            Coefficient    Std. Error   z-Statistic   Prob.
==========================================================================
           C                 -102.2008      1.905871     -53.62417    0.0000
        TEMPMIN               0.070502      0.005092      13.84452    0.0000
        @TREND               -0.059506      0.001626     -36.58595    0.0000
  SIN((2*3.14*@TREND)/12)    -0.377546      0.008565     -44.07765    0.0000
          HDI                 181.3888      3.214021      56.43673    0.0000
==========================================================================
R-squared                     0.554979   Mean dependent var          1469.071
Adjusted R-squared            0.506869   S.D. dependent var          940.9763
S.E. of regression            660.7844   Akaike info criterion       200.9913
Sum squared resid             16155533   Schwarz criterion           201.1982
Log likelihood               -4215.817   Hannan-Quinn criter.        201.0671
Restr. log likelihood        -10092.00   LR statistic                11752.37
Avg. log likelihood          -100.3766   Prob(LR statistic)          0.000000
==========================================================================
```

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