UNIVERSIDADE FEDERAL DO PARANÁ

SHEIKA TAMARA HENRY

# DENGUE FEVER IN JAMAICA: SCENARIOS WITH CLIMATE CHANGE

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Tese apresentada ao curso de Pós-Graduação em Geografia, Setor de Ciências da Terra, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor em Geografia.

Orientador: Prof. Dr. Francisco de Assis Mendonça

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em GEOGRAFIA da Universidade Federal do Paraná foram convocados para realizar a arguição da Tese de Doutorado de **SHEIKA TAMARA HENRY**, intitulada: **DENGUE FEVER IN JAMAICA: SCENARIOS WITH CLIMATE CHANGE.**, após terem inquirido a aluna e realizado a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

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Curitiba, 03 de Maio de 2019.

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**RESUMO**

A localização geográfica da Jamaica a torna vulnerável a riscos naturais, como enchentes e secas, que indiretamente levaram à disseminação da dengue na ilha. Embora as causas da dengue vinculem-se a fatores socioeconômicos e climáticos (que variam espacialmente), há ainda grande escassez no uso de procedimentos de pesquisa como o Sistema de Informação Geográfica (SIG) e técnicas de sensoriamento remoto que contribuam para analisar doenças e variáveis a elas associadas. Essa investigação científica visa preencher esta lacuna. Para tanto, aplicou-se uma abordagem baseada em cenários específicos na Jamaica para avaliar a vulnerabilidade à dengue em escala nacional sob condições climáticas atuais e futuras, isto, a partir do ponto de vista ecológico. Primeiramente, realizou-se uma avaliação de precisão de seis produtos de precipitação por satélite para analisar o nível de viés dentro do conjunto de dados antes do uso. Em seguida, examinou-se o padrão espaço-temporal da dengue para no país, seguido de uma avaliação da relação entre a dengue e algumas variáveis climáticas. A análise final incluiu uma avaliação da vulnerabilidade da dengue usando a estrutura do índice de doenças associadas à água (WADI) nos seguintes cenários: (1) Conjunto de dados de precipitação e temperatura do *World Clim* para 1970-2000; (2) Precipitação Infravermelha do Grupo de Perigos Climáticos com Dados da Estação (CHIRPS) e Temperatura da Superfície Terrestre (LST) como *proxy* para a temperatura do ar a partir do Espectrorradiômetro de Imagem de Resolução Moderada (MODIS) para o período de 2002 a 2016; (3) Temperatura máxima e precipitação sob o Cenário de Concentração Representativa (RCP) 8,5 cenário de mudança climática para 2030 *downscaled* em 25km baseado no Modelo Regional do Clima, RegCM4.3.5. Para esse fim, utilizaram-se os *softwares* R. *Commander*, ArcGIS, *Google Earth Engine*, ILWIS, Excel, DrinC e a ferramenta *Expert Mode* através da *Data Library Platform* do Instituto Internacional de Pesquisa para Clima e Sociedade (IRI) da Universidade de Columbia, em Nova York, Estados Unidos. Os resultados mostram que a dengue é onipresente na Jamaica, embora os surtos sejam frequentemente esporádicos. Kingston e St. Andrew representam a maioria dos casos, no entanto, do ponto de vista da taxa de incidência, outras localidades com populações menores, como Trelawny e Manchester, registaram altas taxas de incidência de dengue. Deste modo, constatou-se que alguns dos surtos de dengue ocorreram durante os episódios de *La Niña*, que também influenciaram os eventos climáticos extremos na Jamaica. No entanto, a chuva e o Índice Padronizado de Precipitação por 6 meses (Índice SPI) foram as únicas variáveis que apresentaram correlação positiva com a dengue. No que diz respeito a avaliação de vulnerabilidade à dengue, a mesma variou espacial e temporalmente em cada cenário, ainda que os maiores índices de vulnerabilidade à dengue foram observados nas áreas urbanas para todos os cenários. Além disso, os resultados sugerem que a extensão geográfica de dengue na Jamaica pode se expandir para maior elevação sob condições de mudanças climáticas. Isso indica a endemicidade da Jamaica à dengue e a possibilidade de ocorrência futura da doença no país, o que, de fato, confirma a que a ocorrência de dengue deve piorar com o impacto da mudança climática. Ao fim constatou-se que os resultados dessa investigação científica poderão ser úteis para medidas de controle de vetores de mudanças climáticas na Jamaica em condições atuais e futuras.



**Palavras–Chaves**: Dengue, Jamaica, Avaliação de Vulnerabilidade, Mudança Climática, Análise Multi-critério.

**ABSTRACT**

The location of Jamaica makes it vulnerable to natural hazards such as floods and drought, which have indirectly led to the spread of dengue fever on the island. Even though dengue is caused by socio-economic and climate factors that vary spatially, there is paucity in the use of Geographic Information System (GIS) and remote sensing techniques to analyse the disease and the associated variables. Consequently, this study aims to fill this gap, through the use of a scenario based approach to assess vulnerability to dengue in Jamaica under current and future climate change conditions, from an ecological perspective. First, an accuracy assessment of six satellite rainfall products was conducted in order to analyse the level of bias within the dataset prior to use. Afterwards, the spatio-temporal pattern of dengue fever for the island was examined, followed by an assessment of the relationship between dengue and some climate variables. The final analysis included a vulnerability assessment of dengue using the water-associated disease index (WADI) framework with the following scenarios: (1) World Clim rainfall and temperature dataset for 1970-2000; (2) Climate Hazard Group InfraRed Precipitation with Station data (CHIRPS) rainfall and Land Surface Temperature (LST) as proxy for air temperature from the Moderate Resolution Imaging Spectroradiometer (MODIS) for the period 2002 to 2016, and (3) maximum temperature and rainfall under the Representative Concentration Pathway (RCP) 8.5 climate change scenario for 2030 downscaled at 25km based on the Regional Climate Model, RegCM4.3.5. Analysis was conducted using the R Commander software, ArcGIS, Google Earth Engine, ILWIS, Excel, DrinC and the Expert Mode tool via the Data Library Platform at the International Research Institute for Climate and Society (IRI), University of Columbia in New York, USA. Results show that dengue fever is ubiquitous in Jamaica though outbreaks are often sporadic. Kingston and St. Andrew account for majority of the cases however, from an incidence rate standpoint, other parishes with lower population such as Trelawny and Manchester recorded higher incidence rates at times. The analysis also indicated that some of these dengue outbreaks occurred during La Niña episodes which have also influenced extreme weather events on the island. Notwithstanding, rainfall and the 6-months Standardized Precipitation Index (SPI Index) were the only variables that had a positive correlation with dengue. In the final assessment, vulnerability to dengue varies spatially and temporally in each scenario. However, a higher vulnerability to dengue was observed in the urban areas for all scenarios. The results suggest that the geographical range of dengue fever in Jamaica might expand to higher elevation under climate change conditions. This demonstrates the endemicity of Jamaica to dengue and the possibility for future occurrence of the disease on the island which might be more severe under climate change conditions. The findings from this study can therefore be useful for vector control measures under current and future climate change conditions in Jamaica.

**Key words:** Dengue, Jamaica, Vulnerability Assessment, Climate Change, Spatial Multi-Criteria Evaluation

**RESUMEN**

La ubicación geográfica de Jamaica la hace vulnerable a riesgos naturales, como inundaciones y sequías, que indirectamente llevaron a la diseminación del dengue en la isla. Aunque las causas de dengue se vinculan a factores socioeconómicos y climáticos (que varían espacialmente), hay gran escasez en el uso de procedimientos de investigación como el Sistema de Información Geográfica (SIG) y técnicas de aplicación de sensores remotos que contribuyen a analizar enfermedades y variables asociadas a ellas. Esta investigación científica pretende contribuir a llenar esta laguna.

Avanzamos a partir de un enfoque basado en escenarios específicos para evaluar la vulnerabilidad al dengue en escala nacional bajo condiciones climáticas actuales y futuras, desde el punto de vista ecológico. En primer lugar, se realizó una evaluación de la precisión de seis productos de precipitación por satélite para analizar el nivel de sesgo dentro del conjunto de datos antes del uso. Luego, se examinó el patrón espacio-temporal del dengue en el país, seguido de una evaluación de la relación entre el dengue y algunas variables climáticas. El análisis final incluyó una evaluación de la vulnerabilidad del dengue utilizando la estructura de índice de enfermedades asociadas con agua (WADI) en los siguientes escenarios: (1) un conjunto de datos de precipitación y de la temperatura de la Clim Mundial para 1970-2000; (2) Precipitación Infrarroja del Grupo de Peligros Climáticos con Datos de la Estación (CHIRPS) y Temperatura de la Superficie Terrestre (LST) como *proxy* para la temperatura del aire a partir del Espectrorradiómetro de Imagen de Resolución Moderada (MODIS) para el período 2002 a 2016; (3) Temperatura máxima y precipitación bajo el Escenario de Concentración Representativa (RCP) 8,5 escenario de cambio climático para 2030 *downscaled* en 25km basado en el Modelo Regional del Clima, RegCM4.3.5. Para tanto, se utilizaron los *softwares R Commander*, ArcGIS, *Google Earth Engine*, ILWIS, Excel, DrinC y la herramienta *Expert Mode* a través de la *Data Library Platform* del Instituto Internacional de Investigación para el Clima y la Sociedad (IRI) de la Universidad de Columbia en Nueva York, Estados Unidos. Los resultados sugieren que el dengue es omnipresente en Jamaica, aunque los brotes son a menudo esporádicos. Kingston y St. Andrew representan la mayoría de los casos, sin embargo, desde el punto de vista de la tasa de incidencia, otras localidades con bajas poblaciones, como Trelawny y Manchester, registraron altas tasas de dengue. Se constató también qque algunos de estos brotes de dengue ocurrieron durante los episodios de La Niña, que también influenciaron los eventos climáticos extremos en la Jamaica. La lluvia y el Índice Estandarizado de Precipitación por 6 meses (Índice SPI) fueron las únicas variables que presentaron una correlación positiva con el dengue. En la evaluación de vulnerabilidad, la misma varío, espacial y temporalmente, en cada escenario estudiado. Los mayores indices de vulnerabilidad al dengue se observarán en las zonas urbanas para todos los escenarios. Además, los resultados sugieren que el alcance geográfico del dengue en Jamaica puede expandirse hacia una mayor elevación en detrimento de los posibles cambios climáticos. Esto indica la endemicidad de Jamaica al dengue y la posibilidad de ocurrencia futura de la enfermedad en el país. Al fin se constató que los resultados de esta investigación científica serán útiles para medidas de control de vectores de cambio climático en Jamaica en condiciones actuales y futuras.

**Palabras claves**: Dengue, Jamaica, Evaluación de Vulnerabilidad, Cambio Climático, Evaluación Espacial Multicriterio.

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## LIST OF ABBREVIATIONS

CARICOM - Caribbean Community and Common Market

CCRIF - Caribbean Catastrophe Risk Insurance Facility

CMAP - CPC Merged Analysis of Precipitation

CMORPH - CPC morphing technique

CRU -Climatic Research Unit

CSGM - The Climate Studies Group Mona

DATASUS- Brazilian Health Information Systems

DESInventar- Disaster Information Management System Database

ECLAC - Economic Commission for Latin America and the Caribbean

EMDAT- The Emergency Events Database (TheInternational Disaster Database)

ENSO- The El Niño Southern Oscillation

ESSJ - Economic & Social Survey Jamaica

FDJ - Forestry Department of Jamaica

GAR - Global Assessment Report on Disaster Risk Reduction

GCMs - General Circulation Models

GEE - Google Earth Engine

GHCN - Global Historical Climatology Network

GIS – Geographic Information Systems

GPCC - Global Precipitation Climatology Centre

GPCP - Global Precipitation Climatology Centre

IBGE- Brazilian Institute of Geography and Statistics

IMF- International Monetary Fund

Inter-American Development Bank - IDB

IPCC - Intergovernmental Panel on Climate Change

IRI – International Research Institute for Climate and Society

JIS - Jamaica Information Service

KMA - Kingston Metropolitan Area

ME - Mean Error

MODIS - Moderate Resolution Imaging Spectroradiometer

MoH - Ministry of Health of Jamaica

MSJ – Meteorological Service of Jamaica

NDVI - Normalized Difference Vegetation Index

PAHO - Pan-American Health Organization

PIOJ - Planning Institute of Jamaica

PRECIS - Providing Regional Climates for Impact Studies

RCM - Regional Climate Models

RSME - root mean square error

Sea surface temperature - SST

SIDS- Small island developing states

STATIN - Statistical Institute of Jamaica

TRMM - Tropical Rainfall Measuring Mission

UN- The United Nations

UNFCCC- United Nations Framework Convention on Climate Change

UNDP- United Nation Development Fund

UNDRO- United Nations Disaster Relief Organization

UNISDR- United Nations International Strategy for Disaster Reduction

WHO - World Health Organization

WMO - World Meteorological Organization

WRR - World Risk Report

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**Chapter 1**

# 1 INTRODUCTION

This introduction brings together background information and a summary of the methodological approach that was used to conduct the research. It also includes the research problem, objectives, hypothesis and questions that were used to guide the research. Additionally, a brief outline of all the chapters is provided.

## 1.1 BACKGROUND INFORMATION

Climate change is regarded as the most significant threat to public health in the 21st century (COSTELLO et al., 2009). Even though the exact impact of climate change is still not known (Smith et al., 2014), it is expected that human health will be severely affected, as projections have been made for an increase in the spread of diseases. More specifically, climate change will result in an increase in the occurrence of extreme weather events such as floods and drought which will lead to the propagation of diseases spread by vectors (NATH & BEHERA, 2011). Currently, vector borne diseases affect about half of the world's population and have also caused approximately 700,000 deaths yearly (World Health Organization - WHO, 2017). Since vector borne diseases are sensitive to changes in weather conditions, climate change will modify the distribution range and incubation period of vectors (GITHEKO et al., 2000; BEZIRTZOGLOU; DEKAS & CHARVALOS, 2011).

Dengue fever is an example of a vector borne disease which has been described as a neglected tropical disease (NTD) by the WHO. According to the WHO (2012), dengue is currently considered a serious threat to public health worldwide and the most important vector borne disease. It is also classified as an arbovirus that is caused from the bite of an infected mosquito. The main vector responsible for this infection is the *Aedes aegypti* mosquito, and to a lesser extent, the *Aedes albopictus* mosquito which all carry four serotypes (DENV-1, DENV-2, DENV-3 and DENV-4) infection (ROHANI et al. 2009; LAMBRECHTS et al., 2010). Symptoms of dengue include a high fever and at least two of the following: severe headache, severe eye pain (behind the eyes), joint pain, muscle or bone pain, rash, mild bleeding from the nose or gums. A more severe form of the disease can lead to dengue haemorrhagic fever or dengue shock syndrome (RAJAPAKSE, 2011).

Global initiatives aimed at eliminating the *Aedes aegypti* mosquito from the continent dates back to the 1920s (Pan-American Health Organization - PAHO, 1997). In 1947, the eradication programme coordinated by PAHO to rid countries of the vector estimated at US$ 1,681,775,000, gained success in about twenty countries in 1962 (PAHO, 1997). However, by 1963, the futility of the eradication programme was highlighted due to the re-emergence of the mosquito in areas where eradication was accomplished. Countries with failed eradication plan included the United States, Venezuela and many Caribbean islands (BRATHWAITE - DICK et al. 2012).

Jamaica is an example of a country with unsuccessful elimination strategies, as the Aedes vector continues to thrive on the island. Dengue is believed to have emerged there from African slave ships (Powell; Tabachnick, 2013), although Halstead (2008) theorized its indirect emergence within the Americas from the spread of the Chikungunya virus, during the North Atlantic Slave Trade in 1827. As per the Ministry of Health of Jamaica - MoH (2016), dengue arrived in Jamaica for the first time in 1977 which resulted in approximately 60,000 cases and was caused by DENV-1 serotype. However, Ehrenkranz et al. (1971); Pinheiro & Nelson (1997) noted an earlier appearance of the virus in 1963 when DENV-3 was first isolated in Jamaica. Later, DENV-2 and DENV-3 were associated with the 1968 and 1969 episodes (Castle et al. 1999) though the prior was first detected serologically in 2007 (MoH, 2007). Between 1981 and 1982, DENV-4 was responsible for another epidemic (SAN MARTIN et al. 2010). Consequently, all four dengue serotypes circulate in Jamaica (BROWN et al. 2011; HESLOP-THOMAS, 2006).

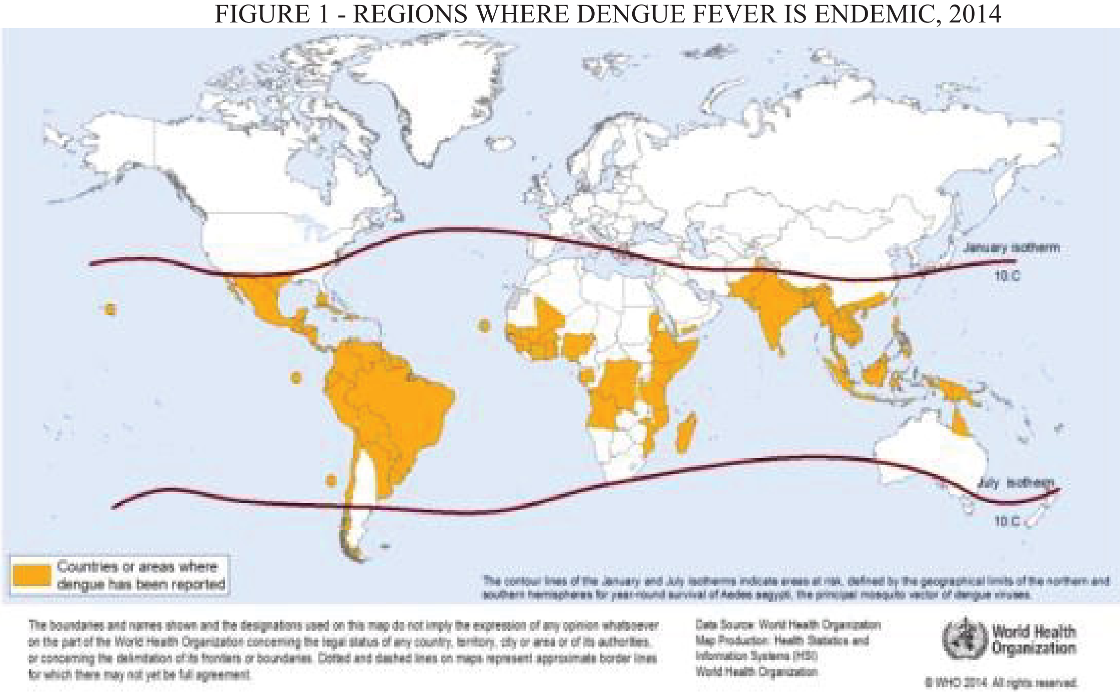
## 1.2 GLOBAL DISTRIBUTION OF DENGUE

The resilience of the *Aedes aegypti* mosquito has presented great risks to human health over the years, especially in the countries of the Global South[1] where dengue is endemic (Figure 1). The manifestation of this disease is found mainly in tropical areas between latitudes 35 ° N and 35 ° S, however, the vector has been detected in places located between 45 ° N and 40 ° S during the summer (TABACHNICK; POWELL, 1979). Brady et al. (2012) postulates that about 3.9 billion people in 128 countries are at risk of transmitting the dengue virus. Another estimate by the WHO (2014), suggests that approximately 40% of the population worldwide is at risk for dengue. Further, it was estimated that 2.35 million cases of dengue were reported in the Americas in 2015 of

[1] Global South refers to developing countries mainly in the Southern Hemisphere.

which 10,200 cases were attributed to severe dengue leading to 1,181 deaths (WHO, 2016). In 2015, Brazil alone recorded 1.5 million cases which is about three times higher than the number reported in 2014. Likewise, Delhi, in India, publicized its worst outbreak recorded since 2006 with over 15,000 cases in 2015 (WHO, 2015).

FIGURE 1 - REGIONS WHERE DENGUE FEVER IS ENDEMIC, 2014




SOURCE: WHO (2014)

According to Rogers et al. (2006), dengue transmission rates tend to be higher in the Caribbean, South America and Asia. Typically, areas with dengue are predisposed to physical and environment conditions that drive the disease along with an ineffective public health policy and poor sanitation practices that foster the proliferation of mosquitoes (Mendonça, 2007). In addition, the level of poverty among the population acts as an enabling factor for the spread of the virus. The Economic Commission for Latin America and the Caribbean - ECLAC (2015) assessment of poverty levels within Latin America where the disease is prominent noted that about 167 million people reside in poverty while 71 million live in extreme poverty.

The dominance of dengue in these destitute countries has led to the classification of the virus by the WHO as one of the 17 NTD related to poverty that mainly affects developing countries. This classification by the WHO is worrisome, and can have serious implications for disease mitigation, especially since sporadic outbreaks have been detected in new areas including developed countries. In 2010, France and Croatia recorded their first local transmission of the dengue virus (WHO, 2016). Another outbreak of the dengue virus resulted in more than 2,000 cases on the Madeira Islands of Portugal. In addition, imported cases of the virus were also reported in mainland Portugal and ten other European countries from travellers to dengue endemic regions (WHO, 2016). Similarly, cases of dengue have been recorded in Florida and Yunnan province of China in 2013 (WHO, 2016).

The emergence of dengue in new areas and elsewhere has demonstrated that the presence of the virus is not only attributed to poverty or negligence by so called third world countries. This, as, human health is strongly influenced by the climate through thermal conditions, dispersion (winds and pollution) and humidity of the air, exerting a significant influence on the manifestation of many diseases, epidemics and endemics, creating favorable conditions for the development of transmitters of contagious diseases (MENDONÇA, 2000). Additionally, increase in temperature by 2°C can expand the range of the dengue virus around the world (DONALÍSIO: GLASSER, 2002). So far, experts have theorized that roughly 3.8% of deaths from dengue were attributed to climate change (WHO, 2009).

Furthermore, mosquitoes have been adapting to their environment and becoming resistant to chemicals used for eradication purposes. The Aedes albopictus, for example, is another mosquito principally located in Asia that can cause dengue and has been found in North America and many European countries. This mosquito has the ability to survive in temperate regions of Europe with below freezing temperatures due to its adaptive nature and capacity to live in microhabitats (WHO, 2016).

Given the mosquito's adaptation capabilities and the predicted impact of climate change on health, there have been debates globally by academic researchers and health authorities regarding the ways in which diseases such as dengue can be mitigated. In response, a global strategy was formulated by the WHO (2012) for a reduction in dengue morbidity and mortality of 25% and 50% by 2020. This implies that WHO member countries which include Jamaica will have to implement policies and strategies to reduce dengue transmission rates in order to meet the targets outlined. However, such measures might be challenging in low to middle income countries with resource constraints and will call for researchers to conduct studies that take into account new approaches in endemic regions. Consequently, studies related to spatial and temporal vulnerability analysis of dengue becomes relevant within this regard.

## 1.3 PROBLEM STATEMENT

As mentioned earlier, all four dengue serotypes can be found throughout Jamaica. The occurrence of dengue fever in the Americas was concentrated mainly in cities with ports since the 19th century (GUZMAN & KOURI, 2003). However, it has become ubiquitous in urban areas since the start of the Twentieth Century especially in Jamaica. The fact that more than half (54%) of Jamaicans live in urban areas (World Bank, 2015) is a reason for concern as this might be one of the underlying reasons why the virus is still present on the island.

So far, studies on knowledge, attitudes and practices of dengue in Jamaica have been conducted (ALOBUIA et al. 2015, SHUAIB et al. 2010, STOLER et al. 2011). These investigations showed a lack of preventative measures being incorporated by respondents to minimize risk to disease transmission however, results differed in the knowledge of dengue and symptoms of the disease. While Stoler et al. (2011) and Alobuia et al. (2015) reported low awareness of dengue symptoms and breeding sites among participants in Saint Catherine and Western Jamaica respectively, Shuaib et. al, (2010) highlighted the opposite in their study in Westmoreland. The overall findings from these researchers also demonstrate the lack of precautionary guides being implemented by residents to reduce the spread of dengue even by participants who were aware of possible symptoms.

Likewise, dengue serotypes (Brown et al. 2011); antigenic structure of the virus (Roehrig et al. 1998); assessment of domestic containers for the A*edes aegypti* breeding sites (Chadee et al., 2009); vulnerability to dengue (Heslop-Thomas et al. (2006) and climate related impacts (TAYLOR et al. 2006) have been documented. Specifically, Taylor et al. (2006) conducted a regional dengue study based on statistical techniques of weekly, monthly and annual data (dengue, rainfall and temperature) between 1980 and 2001 in twenty seven Caribbean countries which included Jamaica. The results illustrated a seasonal trend as it relates to dengue occurrence which dominated during El Niño and El Niño years +1 years.

In the investigation by Heslop-Thomas et al. (2006), a perception based approach was used to assess vulnerability to dengue in Montego Bay, Jamaica. The analysis indicated that while dengue cases were mostly concentrated within the city, periodic cases were situated close to streams, gullies and informal settlements with limited access to piped water. Another observation was made regarding the improper storage of water in containers, as one of the habitats for the *Aedes aegypti* mosquito, responsible for the spread of dengue on the island. The study also revealed how the

Ministry of Health of Jamaica (MoH) thwarted responsibility for environmental sanitation and control of breeding sites onto the residents, as it was their purview that Government should not be held responsible for reducing mosquito breeding sites. However, 78 percent of the respondents believed that the Government should be responsible for dengue control. Results also demonstrated that many respondents were incognizant of dengue, the vector that causes the disease, symptoms and how it is transmitted. Furthermore, public sector agencies were more preoccupied with the implication of sea level rise and its impact on Jamaica in comparison to the potential health impacts of climate change (HESLOP et al., 2006).

Notwithstanding, ECLAC (2011) used a Poisson regression model to evaluate the economic impact of climate change on health in Jamaica between 2011 and 2050 regarding the following diseases: dengue fever, leptospirosis and gastroenteritis. The study included monthly dengue data, access to water and sanitation; rainfall and temperature; household health expenditure modelled with three climate change scenarios (Business as usual – diseases in the absence of climate change, A2 and B2) using the European Centre Hamburg Model, ECHAM, global climate model. While the model predicted a reduction in the number of gastroenteritis and leptospirosis with time, dengue was the only disease expected to rise over the next 40 years for both scenarios. Further, cost estimate for dengue treatment would amount to about US$25 million which represented 0.18% of the GDP in 2008. However, a reduction in the number of cases could be achieved if there is improvement in sanitation and access to potable water (ECLAC, 2011). When improvement by sanitation by 5% (2011-2050) is taken into account, cost averted for dengue was estimated at US$5,547,722 under A2 scenario and US$5,250,111 under B2 scenario indicating the importance of adaptation measures in reducing the spread of the disease. Some of the limitations in the study included the lack of use the following data: environmental vulnerability, socio-economic status and access to good health services (ECLAC, 2011).

Besides, the occurrence of extreme weather events such as floods and droughts has been implicated in the spread of dengue fever in Jamaica. Hence, the *Aedes aegypti* mosquito is normally targeted after these events in vector control programs which is costly. Based on analysis by the Planning Institute of Jamaica - PIOJ (2015), losses from major flood events have been valued at J $ 112.07 billion (1 US $ = 127J $) between 2001 and 2012. Of this value, the vector control measures during these episodes represented about J$ 359,988,528 of the cost which normally emphasize dengue reduction in the country (PIOJ, 2010, 2001, 2004, 2007, 2005, 2008, 2012 & The Economic Commission for Latin America and the Caribbean - ECLAC, 2001). Additional information can be obtained in table 1 regarding these events and cost.

TABLE 1 - MAJOR FLOOD EVENTS IN JAMAICA

| EVENT | **YEAR** | **CATEGORY** | **COST (USD MILLIONS)** | **% OF GDP** | **VECTOR BORNE CONTROL COST ($J)** | **TOTAL DAMAGE COST ($JB)** |
|---|---|---|---|---|---|---|
| Heavy Rain | 1986 | N/A | 76 | N/A | N/A | N/A |
| Hurricane Gilbert | 1988 | 3 | 1378 | 65 | N/A | N/A |
| Hurricane Michelle | 2001 | 4 | 53.64 | 0.8 | 6,000,000 | 2.52 |
| May /June Flood | 2002 | | 51 | 0.7 | 8,600,697 | 2.47 |
| Hurricane Charley | 2004 | 4 | | | | 0.44 |
| Hurricane Ivan | 2004 | 3 | 580 | 8 | 21,800,000 | 36.9 |
| Hurricane Dennis and Emily | 2005 | 4 | 96.8 | 1.2 | 16,540,000 | 5.98 |
| Hurricane Wilma | 2005 | 5 | 56 | 0.7 | 8,828,831 | 3.6 |
| Hurricane Dean | 2007 | 4 | 329 | 3.4 | 13,700,000 | 23.8 |
| Tropical Storm Gustav | 2008 | N/A | 214 | 2.1 | 151,510,000 | 15.5 |
| Tropical Storm Nicole | 2010 | N/A | 239.6 | 1.9 | 52,900,000 | 20.6 |
| Hurricane Sandy | 2012 | 1 | 107 | 0.8 | 80,109,000 | 9.7 |

SOURCE: PIOJ (2010, 2001, 2004, 2007, 2005, 2008, 2012); ECLAC (2001).

Over the years, reports from the Ministry of Health have alluded to increases in the *Aedes aegypti* index and dengue cases following tropical storm and hurricane events. For example, the MoH indicated that the Aedes household index had increased from 56% to over 80% due to the prolonged rainfall that caused the May/June flood in 2002 (PIOJ, 2002). While the report indicated no outbreaks in dengue for the period, further investigation is needed at the micro level to verify the number of dengue cases at hospital centres as there have been under-reporting of infectious diseases in Jamaica due to the lack of a fully integrated database to collect and disseminate data to the National Health Information System (PAHO, 2012).

Further, the passing of tropical storm Nicole in 2010 is an example of how extreme hydrological events can lead to an increase in the number of dengue cases according to officials from the Ministry of Health (JAMAICA INFORMATION SERVICE - JIS, 2011). This resulted in the Government of France donating J$1,184, 838.00 on February 2, 2011 to curb the number of dengue cases recorded in Jamaica after the storm (JIS, 2011). For vector mitigation, the western region, specifically the parishes of Hanover and Westmoreland, were targeted as a number of areas were inundated with standing water (JIS, 2010). Also, J$ 52,900,000 was spent by the Government of Jamaica with a significant amount of the cost aimed at eliminating breeding sites for the *Aedes aegypti* mosquito for dengue prevention (PIOJ, 2010).

Figure 2 provides an overview of an area in St. Elizabeth with standing water where elderly people were marooned following Tropical Storm Nicole for four days. This duration is the optimal time for the breeding of the *Aedes aegypti* mosquito.

FIGURE 2: STAGNANT WATER IN WILTON, ST. ELIZABETH AFTER TROPICAL STORM NICOLE IN 2010 WHERE ELDERLY PEOPLE WERE TRAPPED FOR

SOURCE: PIOJ (2010).

In another event reported by PIOJ (2013), concerns were raised regarding the potential increase in dengue fever from an augment in mosquito breeding sites after Hurricane Sandy in 2012. Prior to this event, about 2,198 suspected cases of dengue fever were reported in Jamaica. Later, the number of cases doubled to almost 5,000 cases after the hurricane despite the vector control measures which targeted the removal of mosquito breeding sites. These strategies involved spraying and fogging to destroy habitats by representatives from the MoH which conducted community visits in order to identify these areas after the catastrophe (JIS, 2012).

Increases in dengue cases following Hurricane Sandy could have been prevented as there was delay in eradicating potential mosquito breeding sites emanating from the demolition of bridges, impassable roads due to fallen trees, electric light poles and landslides (PIOJ, 2012). A synopsis of the impact of hurricanes that can prevent accessibility and delay vector control is presented below in Figure 3.

FIGURE 3 - IMPACT OF HURRICANE SANDY IN 2012


1. Destruction of a bridge in Kintyre, St. Andrew; 2**.** Road impassable from landslide in Oatley, Rose Hall, St. James.

SOURCE: PIOJ (2012)

The PIOJ (2012) report also documented the destruction of the National Water Commission´s infrastructures which included pipelines that provide running water to residents along with sewage treatment plants. The Seaview and Hope treatment plants in the Kingston Metropolitan Area were affected along with the Yallahs pipeline located in St. Thomas which also supplies water to the Kingston Metropolitan Area - KMA[2] (PIOJ, 2012). Leakage in this manner can create additional breeding sites from stagnant water and containers used to store water.

About J$111 million was assigned to dengue control by the Government of Jamaica after hurricane Sandy in 2012 (JIS, 2013). Approximately 38 million of this figure was used to purchase vehicles to assist with fogging in rural areas with accessibility problems and purchase 28 fogging machines. A total of 78,932 sites were examined while 179,390 containers were perused in order to identify mosquito and 34,739 were found to be breeding habitats. This resulted in 38,645 containers being treated (JIS, 2013). Further details regarding vector control strategies and expenditure after flood events can be obtained in box 1.

[2] In 1923, the Kingston and St. Andrew Corporation Act resulted in the fusion of Kingston and St. Andrew as one municipal unit (KSACA, 1923). As a result, Kingston and the suburban areas of St. Andrew are referred to as the Kingston Metropolitan Area (KMA).

BOX 1 - JAMAICA - DENGUE RELATED VECTOR CONTROL STRATEGIES AFTER FLOOD EVENTS

(Continues)

| Date | Treatment |
|---|---|
| October 21, 2004 | ▪ Vector control heightened in response to Hurricane Ivan on September 10, 2004. First, a supplies and needs assessment was conducted in order to identify the equipment required to mitigate against potential breeding sites. Larvicidal and fogging. Parishes mostly affected in hurricane: Thomas, Clarendon, and St. Mary. |
| October 12, 2007 | ▪ Increase in dengue between July and September 2007 (154 confirmed and 975 suspected cases), resulted in investment of $25 million in vector control to remove breeding sites. Out of this figure, only 10 million was used to target rats. |
| February 3, 2011 | ▪ The Director of Emergency Disaster Management and Special Services at the Ministry of Health reported the dengue outbreak following the passing of Tropical Storm Nicole in 2010. Government of France donated $1,184, 838.00 on February 2, 2011 to control the epidemic in Jamaica. Focused on western region (Hanover and Westmoreland with standing "pooling and ponding" water). |
| January 9, 2012 | ▪ Four of the main Regional Health Authorities received six vehicles from the Ministry of Health on January 18, 2012 to improve vector control. According to the Minister of Health, "Jamaica's vulnerability to natural disasters, droughts, storms and hurricanes, requires that the vector management and control programme is consistent, sustainable and effective". Directors of the North, South East and Western Regional Health Authorities given one vehicle each while south eastern received 2 vehicles due to accessibility relating to topography and size. |
| October 27, 2012 | ▪ Vector control resumed after Hurricane Sandy which occurred on October 24. |
| October 28, 2012 | ▪ Residents were encouraged to destroy mosquito breeding sites by Ministry of Health after Hurricane Sandy. The total number of suspected cases up to October 20, 2012, was estimated at 2,198 in comparison to 458 in 2011 for the same period and 2,709 in 2010. |
| January 11, 2013 | ▪ About 746 confirmed cases of dengue fever were recorded out of 5,613 suspected cases in 2012. Dengue cases continued to increase after Hurricane Sandy. About $111 million was assigned to dengue control by the Government after hurricane Sandy in 2012. Of this amount, $38 million was used to purchase vehicles to assist with fogging in rural areas with accessibility problems and purchase 28 fogging machines. Ten persons died from dengue in 2012. A total of 78,932 sites were examined while 179,390 containers were perused in order to identify mosquito and 34,739 were found to be breeding habitats. This resulted in 38,645 containers being treated. |

BOX 2 - JAMAICA - DENGUE RELATED VECTOR CONTROL STRATEGIES AFTER FLOOD EVENTS

(Concludes)

| Date | Treatment |
|---|---|
| February 8, 2013 | ▪ US$ 40,000 was donated to the Ministry of Health in response to the dengue outbreak after hurricane Sandy by the United Nations Development Programme on February 6, 2013. About Ja $5.2 million was used to purchase 28 fogging machines. The National Health Fund also provided Ja $9.2 million towards the purchase of 48 fogging machines. |

SOURCE: JIS (2004, 2006, 2007, 2011, 2012, 2013, 2014, 2015); Adapted by: Henry (2017)

The foregoing is reason for concern as extreme weather events are expected to intensify under future climate change conditions which might lead to an increase in the number of dengue cases for Jamaica. Despite the numerous dengue epidemics in Jamaica that vary spatially, there is paucity in studies using Geographic Information Systems (GIS) and remote sensing technology to analyse the disease. It is also evident that the traditional method used in the determination of mosquito breeding places which is often based on site inspection tends to be highly ineffective in dengue prone countries (Simmons et al., 2012) and therefore calls for a more multidisciplinary approach to understand the impact of dengue at the national level.

According to WHO (2013), understanding the relationship between current climatic conditions and health outcomes can yield important information for future impacts related to climate change. Therefore, analysis of disease and weather anomalies can be used as a starting point in order to garner information about the impact of climate on the spread of diseases, prior to additional analysis (WHO, 2013).

## 1.4 OBJECTIVE

### 1.4.1 Main Objective:

The main objective of this study is to conduct a spatio-temporal vulnerability assessment of dengue occurrence in Jamaica, in order to understand the spread of the disease under current and future climatic conditions, from an ecological perspective.

**1.4.2** Specific Objectives**:**

1. To examine the spatial and temporal pattern of dengue fever in Jamaica.
2. To examine the association between dengue and climatic factors.
3. To assess vulnerability to dengue in Jamaica based on current and future climate change scenario based on the Representative Concentration Pathway (RCP) 8.5 emission scenario for 2030.

## 1.5 RESEARCH QUESTIONS

The following questions were used to guide this research:

1. What is the spatial and temporal distribution of dengue in Jamaica?
2. How can variation in climatic conditions account for the spread of dengue in Jamaica?
3. How does vulnerability to dengue vary under current and future climate change scenario based on the Representative Concentration Pathway emission scenario RCP 8.5 for 2030 in Jamaica?

## 1.6 HYPOTHESES

**1.** Precipitation has a greater effect on the occurrence of dengue in Jamaica in comparison to other climate variables.

**2.** Higher vulnerability to dengue will occur in urban areas compared to non urban areas.

**3.** Climate change will alter the geographical range of dengue on the island.

## 1.7 JUSTIFICATION FOR THE CLIMATE CHANGE SCENARIO

The representative concentration pathway (RCP) 8.5 was selected for the climate change scenario, as it is one of the two trajectories that represent the current trend in greenhouse gas emissions (Inter-American Development Bank - IDB, 2016). Moreover, the goal of this thesis is to show how data at different resolution can impact the results obtained from dengue vulnerability assessment conducted using spatial multicriteria evaluation (SMCE). According to Pulwarty, Nurse & Trotz (2010), scenario-based analysis in climate studies makes an important contribution to past assessments while providing new information.

## 1.8 SUMMARY

Table 2 provides a summary of the objectives and methods that will be used in this thesis which is discussed in detail in chapter 4.

TABLE 2 - SUMMARY OF THE OBJECTIVES AND METHODS

| Research Questions | Method |
|---|---|
| 1. What is the spatial and temporal distribution of dengue in Jamaica? | Statistical analysis: incidence calculation, GIS mapping and analysis |
| 2. What is the association with climatic conditions and dengue in Jamaica? | Statistical analysis: Correlation |
| 3. How does vulnerability to dengue vary under current and future climate change conditions in Jamaica? | Vulnerability analysis: Water-associated Disease Index (WADI) Framework<br>Three scenarios using: (1) World Clim rainfall and temperature dataset for 1970-2000; (2) CHIRPS rainfall and LST as proxy for air temperature from MODIS for the period 2002 to 2016; (3) maximum temperature and rainfall under the RCP 8.5 climate change scenario for 2030 downscaled at 25km based on the Regional Climate Model, RegCM4.3.5. |

## 1.9 THESIS STRUCTURE

This thesis is organized in 9 chapters. Chapter 1 is an introduction to the topic and includes the research problem, objectives, hypotheses, research questions and a summary of the methodological approach that will be conducted. Subsequently, Chapter 2 highlights the influence of climate on health before providing details regarding the occurrence of extreme events from an international and local perspective. The chapter also presents the climatology of Jamaica. In Chapter 3, climate change projections, its impact on health and dengue are discussed. The methodological approach utilized to carry out specific research objectives and the conceptual framework for the construction of the vulnerability assessment can be found in Chapter 4 while the theoretical concepts are addressed in Chapter 5. Additionally, information about the study area as it relates to the physical, social and geographical setting for the proliferation of dengue in Jamaica is incorporated in Chapter 6. The findings from the analysis are presented in Chapter 7. This is followed by a discussion in Chapter 8. The conclusion and recommendations are provided in Chapter 9 followed by the collation of literature sources as references.

# CHAPTER 2

## 2 EXTREME WEATHER EVENTS, HEALTH AND CLIMATE CHANGE

This chapter outlines the relationship between health and climate, and also trends in the occurrence in extreme events from a global and regional perspective, before examining the events that have occurred in Jamaica. Afterwards, the indices developed by ETCCDI for analyzing extreme events obtained from literature are presented. The climatology of Jamaica is also presented.

### 2.1 HEALTH AND CLIMATE

Extreme weather events (floods, drought, hurricanes etcetera) can have serious implications on human health and based on projections, these events are expected to intensify under climate change conditions, which might impact the spread of diseases such as dengue. Therefore, an overview of these events can provide information about present and past climatic conditions that can enhance decision making while preparing for future occurrence and their indirect impacts.

The WHO (1948) defined health as “a state of complete physical, mental and social-wellbeing and not merely the absence of disease or infirmity”. However, the foregoing has been criticized by numerous researchers (Bickenbach, 2015; Huber, Green, Van der Host & Jadad, 2011) as being outdated and unrealistic in today’s society because it is difficult to measure. For Bok (2004), health should be defined in relative terms as there is no individual who is completely healthy. Furthermore, the concept of health may vary geographically (Otgaar, Klijs & Van den Berg, 2016). Hence, being healthy is subjective.

According to Mendonça (2000), human health is strongly impacted by climate. This is experienced in different forms and range from extreme temperature to other catastrophic events such as storms. Sorre (1984) was an early pioneer who highlighted how human health is affected by climatic elements. Table 3 shows the physio-psychological manifestations of man by the specific climate elements theorized by Sorre (1984).

TABLE 3 - PHYSIO-PSYCHOLOGICAL MANIFESTATIONS OF MAN BY THE ACTION OF CLIMATE ELEMENTS

| Climatic Elements | Conditions and limits | Physiological manifestations |
|---|---|---|
| Altitude (Atmospheric pressure) | Maximum Limite: 8,000 metres | -Altitude sickness (Mal-das-montanhas): headache, fatigue, sensory changes, intellectual depression, indifference, sleepy, incoordination of movements, loss of memory).<br>- Reduction physical and mental faculties<br>- Sadness, lethargy |
| Radtiation (Associated with Luminosity) | 60º and 70º Latitude | -High radiation / luminosity: nervous exhaustion, mental disorders, irritation, sunstroke, euphoria.<br>-Low radiation / luminosity: organic deficiencies, rickets, depression, mental debility |
| Hygrothermia | Variable Limit. Optimim physiology for white race: 15° - 16° C / 60% RH | -Decreased respiratory capacity (for nostrilic Europeans)<br>-Thermal hyperpnea (between blacks) .<br>-Tiredness and exhaustion (white). |
| Wind and Atmospheric electricity | | -Morbidity, tiredness and dejection.<br>-decreased muscle tone, depression, hypersensitivity, irritability.<br>-Dehydration, desiccation of the integument.<br>-Nervous excitation, hallucinations, delirium.<br>-Palpitations, dyspnea, headache, neuralgia |

SOURCE: Sorre (1984)

From table 3, it can be ascertained that health is significantly affected by changes in altitude and other climatic changes. It also shows an optimum limit for different races and the side effects. Since then, other researchers have noted the impact of climate on the well-being of the human race.

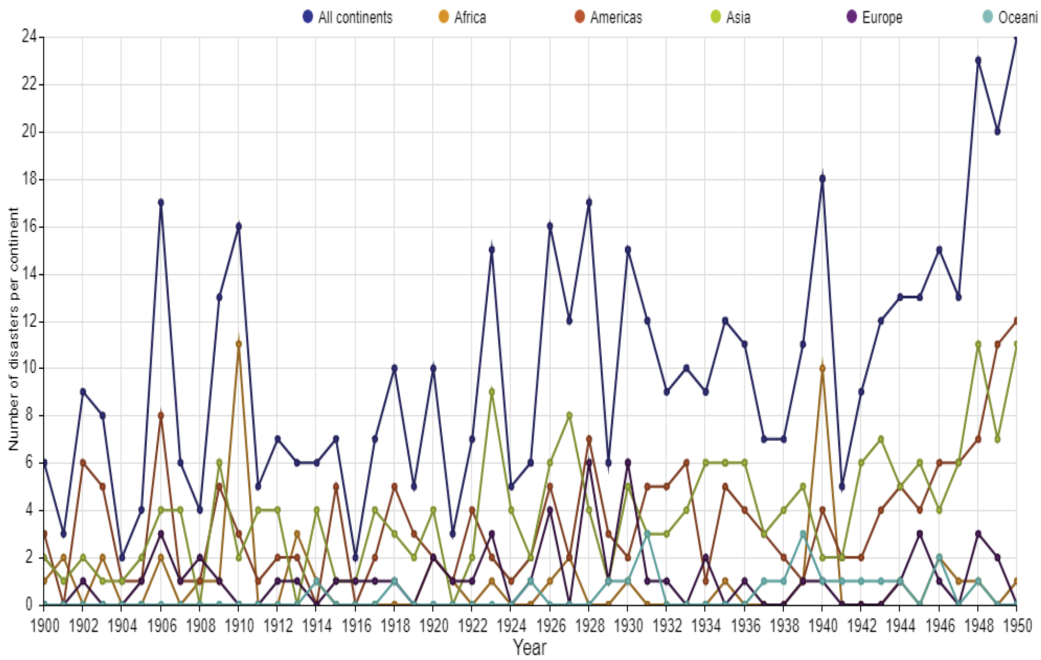
Ayoade (2004) theorized that temperature is perhaps the main variable that is responsible for many diseases, as in the case of infant mortality, which is normally caused from respiratory illnesses and diseases. Additional studies have shown that high and low temperatures can cause an increased in cardiovascular, respiratory and other illnesses (GASPARRINI, GUO & HASHIZUME, 2015).

Currently, there is concern regarding extreme events and the potential impact of climate change. According to Ebi & Bowen (2016), the occurrence of extreme events such as drought among others could increase vulnerability to health impacts. The authors have also made calls for a better understanding of these events (pattern, risk and consequence) as they could pose a threat to human health since very little is known about how they will impact vulnerability. Furthermore, as noted by Few (2007), the increase in extreme weather weather events will cause a rise in health related issues across the globe. Therefore, a thorough understanding of trend in extreme events is needed.

## 2.2 EXTREME EVENTS

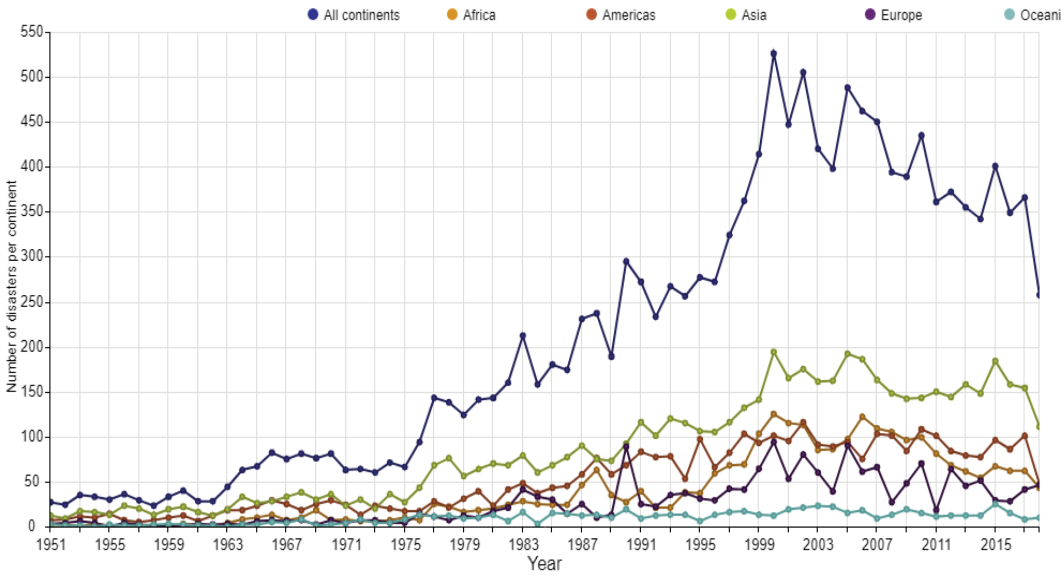
The number of extreme events has increased across the globe. In fact, fewer hazards were recorded with low recurrence period, making it easier for population at risk to recover quickly (Ebi and Bowen 2016). However, since the 1950s, the number of events has changed drastically (IPCC, 2014). Between 1900 and 1950 (Figure 4), approximately 484 natural hazards were documented worldwide in comparison to about 14,039 from 1951 to 2017 (EMDAT 2018). The major increase in extreme events seemed to have occurred during the 1990s which have been reduced in the 2000s (Figure 5). While there was fluctuation between the continents regarding the number of events for 1900 to 1950s, a higher number of disasters have taken place in the Americas from 1948 to 1950. However, by 1951, disasters on all continents remained constant until 1975 when Asia emerged as the continent with the highest number of disasters. The regions with the second highest number of disasters appear to be the Americas and Africa, though the Americas have dominated Africa since 2010 (Figure 5).

FIGURE 4 - GLOBAL DISASTERS BETWEEN 1900 AND 1950




SOURCE: Adapted from EMDAT (2018)

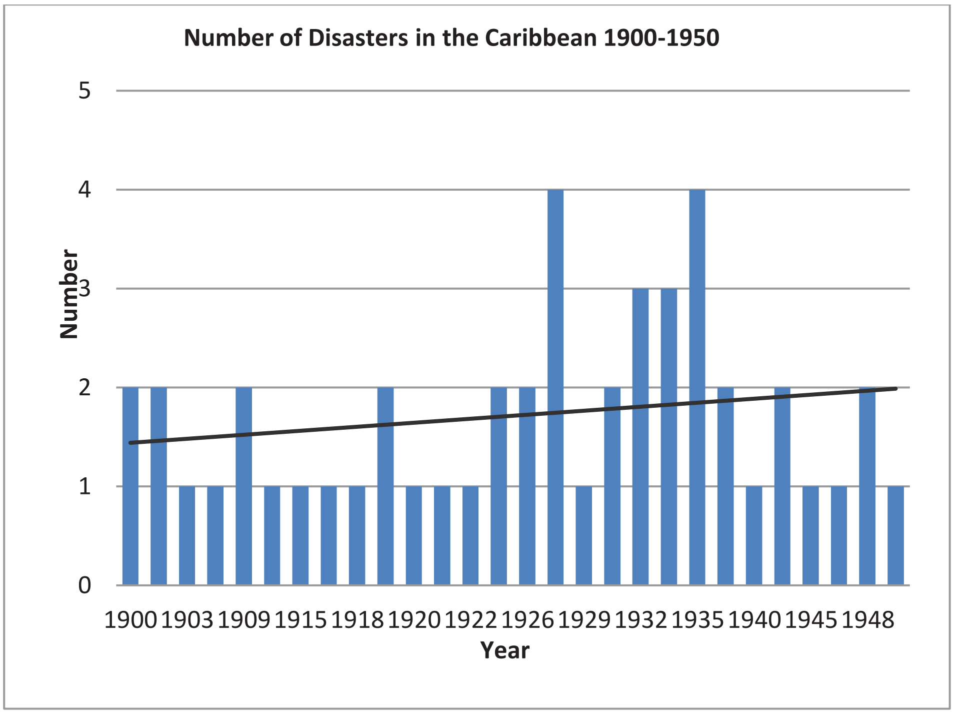
FIGURE 5 - GLOBAL DISASTERS BETWEEN 1951 AND 2015




SOURCE: Adapted from EMDAT (2018)

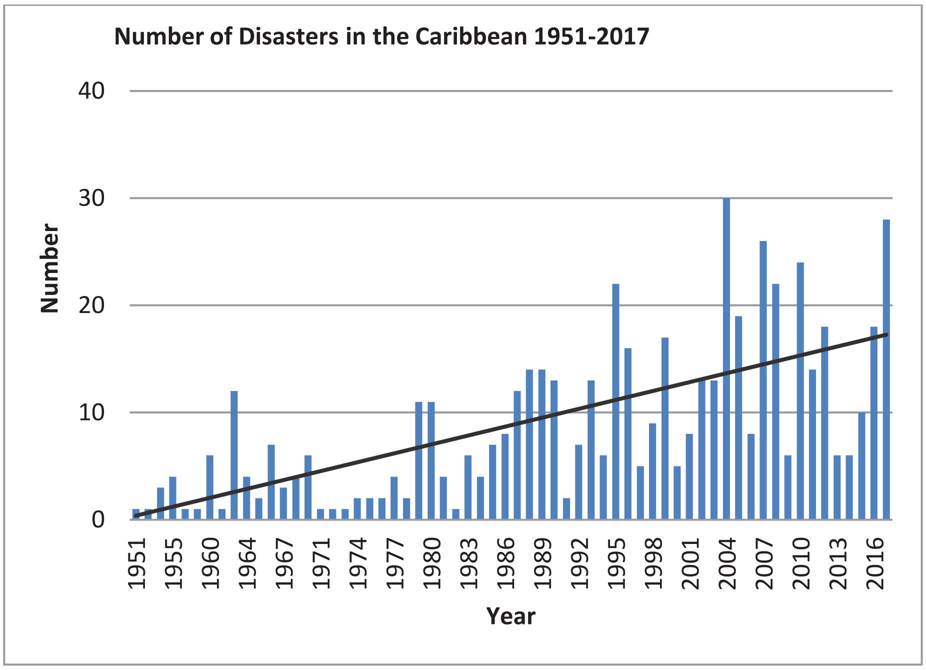
Akin to global trends, the frequency and intensity of extreme events within the Caribbean have increased. Approximately 44 events were recorded between 1900 and 1950 while about 547 events have been registered since 1951 for the region (EMDAT, 2018). This increase in frequency is illustrated in Figure 6 and 7 with the trend line.

FIGURE 6 - NUMBER OF DISASTERS IN THE CARIBBEAN 1900-1950




SOURCE: Adapted from EMDAT (2018)

FIGURE 7 - NUMBER OF DISASTERS IN THE CARIBBEAN 1951-2017

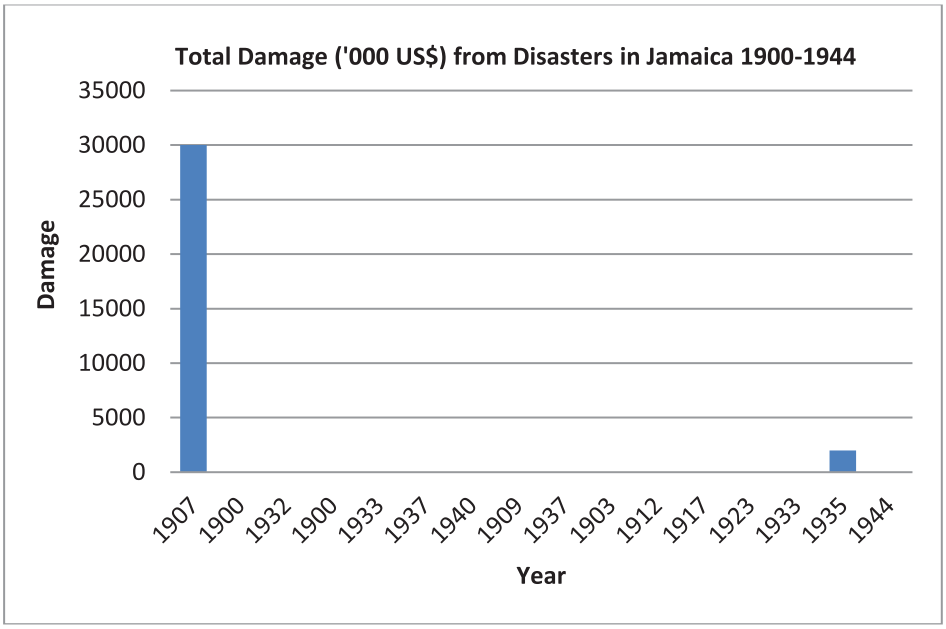



SOURCE: Adapted from EMDAT (2018)

Likewise, the intensity and magnitude of these events have increased as indicated by the number of people affected and damages respectively. Between 1900 and 1950, about 20, 2920 people were affected while total damages amounted to US$174,000,000 (EMDAT, 2018). On the other hand, around 55,934,039 people were affected from 1951 to 2017 and damages are estimated at approximately US$143,014,371,000. In terms of the number of deaths, 47,617 people died during the 1900 to 1950 events while 253,871 were killed from 1951 to 2017. The year 2010 caused the most damage (US$8,188,100,000) since the 1950s while 1928 was the most disastrous for the 1900-1950 period with damages amounting to about US$50,000,000 (EMDAT, 2018).

Similarly, the foregoing trend is also observed in Jamaica. Approximately 16 events occurred between 1900 and 1950 while about 40 events have been observed since the 1950s for the island (EMDAT 2018). For 1900 to 1950, damages were estimated at about US$32000, 000 in comparison to US$2,836,122.000 between 1951 and 2017. Figure 8 illustrates the total damages from disaster in Jamaica.

FIGURE 8 - TOTAL DAMAGE FROM DISASTERS IN JAMAICA 1900-1944

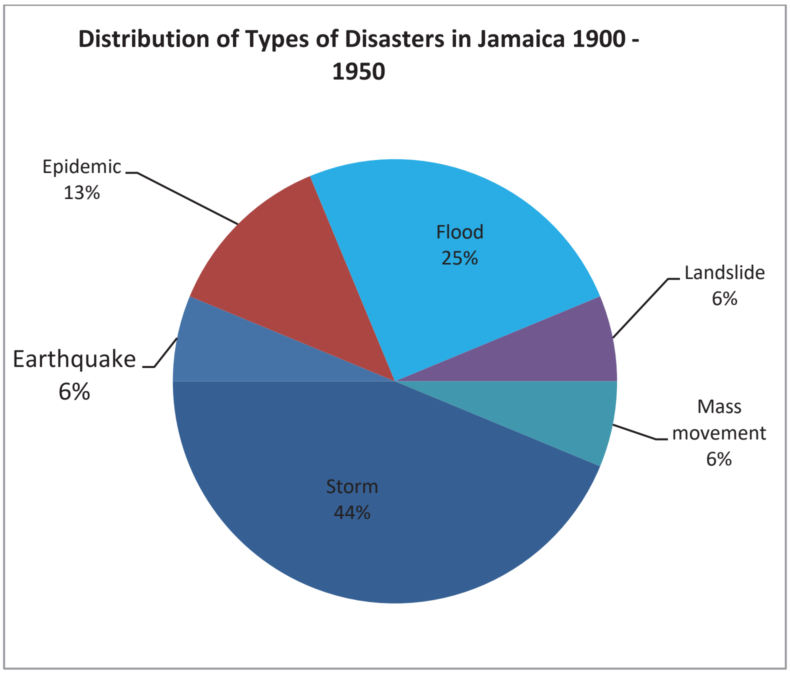



SOURCE: Adapted from EMDAT (2018)

While frequency and intensity of disasters have increased, the distribution of some types of hazards has fluctuated in the EMDAT database. For example, there has been a reduction in flood events by 2% and epidemics by 6%. However, the number of storms has increased by 20%. Also, mass movements, earthquakes and landslides might not have caused any major catastrophe since the 1950s while drought seems to only be recorded during that era (Figure 9 and 10).

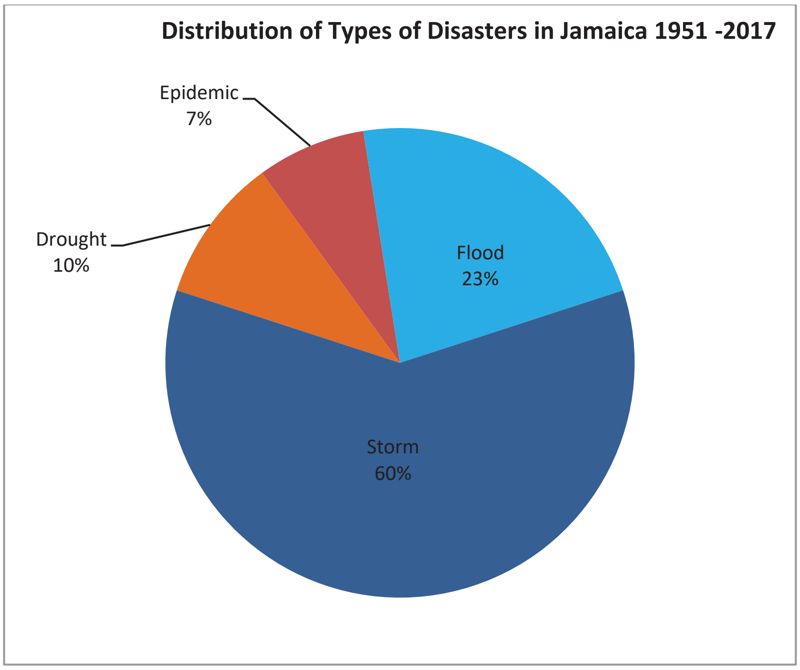
The increase in events such as droughts, precipitation and cyclones has been linked to human activity as demonstrated in the Fourth Assessment Report of the IPCC (IPCC 2007). Furthermore, the Fifth Assessment Report highlighted the likelihood of a reduced but greater occurrence of intense precipitation and higher temperatures in mid-latitudes and over tropical regions by the end of the century because of human induced global warming (IPCC 2013).

FIGURE 9 - DISTRIBUTION OF TYPES OF DISASTERS IN JAMAICA 1900-1950 IN PERCENTAGE




SOURCE: Adapted from EMDAT, 2018

FIGURE 10 - DISTRIBUTION OF TYPES OF DISASTERS IN JAMAICA 1951-2017 IN PERCENTAGE




SOURCE: Adapted from EMDAT, 2018

While EMDAT is a reliable platform for recording disasters, not all the events are included based on the following requirements needed for entry: at least 10 people killed, at least 100 people affected, state of emergency or call for international assistance for recovery (EMDAT, 2018). This can therefore lead to underreporting of disasters in the database. Likewise, underreporting can manifest when state agencies do not provide accurate reports about the impact of disasters. Hence, the decrease in epidemic indicated could be due to underreporting of diseases which is common problem worldwide (Gamado, Streftaris and Zachary, 2014) even though there is a recommended surveillance standard for communicable diseases provided by the World Health Organization.

In Puerto Rico, underreporting and inaccessibility to leptospirosis cases following Hurricane Maria led to a lawsuit by CNN to gain access to the data (Sutter and Pascual, 2018). Prior to the entity suing the Demographic Registry on the island, only 4 deaths were recorded by the Health Department but this number later changed to 26 (which more than doubled the number of cases for the previous year) following the intervention of the media outlet. In contrast, the Centre for Disease Control and Prevention (CDC) noted that about 17 confirmed and 25 suspected deaths were due to Leptospirosis after the hurricane (Sutter and Pascual, 2018).

Also, the CDC (2016), revealed that even though Brazil leads the world in the number of reported dengue cases, under-reporting was observed between 2009 and 2011 where only 57 of the 997 confirmed dengue cases were captured in surveillance system for disease (Sistema de Informação de Agravos de Notificação – SINAN). Despite the challenges, Brazil is known to provide access to data and was the first in the Americas to notify the public about the Zika Virus in 2015 even though the Summer Olympics of 2016 was to be held in the country (CDC, 2015).

## 2.3 EXTREME WEATHER INDICES

In order to comprehend the activities of previous extreme events, the trend analysis generated from the 21 ETCCDI (Expert Team on Climate Change Detection and Indices) indices obtained from Stephenson et al., (2014) for the Caribbean are examined for two periods: 1961-2100 and 1986-2010 (Table 4). The results indicate that a warming trend has been observed for the past 5 decades. More specifically, between 1961 and 2100, TX mean (annual maximum temperature) had a warming of 0.19$^{o}$C per decade while TNmean (annual mean daily minimum temperature) recorded a higher warming of 0.28$^{O}$C per decade. Moreover, a higher trend was observed for night time temperature compared to day time temperature indicating a reduction in the diurnal temperature range.

Additionally, while there was an increase in TX90P (warm days) and TN90P (warm nights), the frequency of TX10P (cool days) and TN10P (cool nights) was reduced (STEPHENSON et al., 2014).

While PRCPTOT (total precipitation) has increased, the trend was not statistically significantly (STEPHENSON et al., 2014). However, SDII (Simple daily intensity index) has increased significantly for 1961-2010 with reduction for 1986-2010. Even though there was a decrease in CDD (consecutive dry days) between 1986 and 2010, there was an upward trend for 1986-2010 which was statistically significant. Table 4 also demonstrates that the number of R95p (wet days) is increasing (STEPHENSON et al., 2014).

TABLE 4 - TREND ANALYSIS FOR THE CARIBBEAN FOR 1961-2010 AND 1986-2010

| **Element** | **Index** | **Description** | **1961-2010** | **1986-2010** | **Unit** |
|---|---|---|---|---|---|
| Temperature | TXmean | Annual maximum temperature | 0.19 | 0.12 | $^{O}C$ |
| | TNmean | Annual minimum temperature | 0.28 | 0.22 | $^{O}C$ |
| | DTR | Diurnal temperature range | -0.1 | -0.08 | $^{O}C$ |
| | TX90P | Warm days | 3.31 | 6.49 | % |
| | TX10P | Cool days | -1.8 | -0.08 | % |
| | TN90P | Warm nights | 4.07 | 5.97 | % |
| | TN10P | Cool nights | -2.55 | -0.76 | % |
| | TXx | Highest TX | 0.27 | 0.23 | $^{O}C$ |
| | TXn | Lowest TX | 0.18 | -0.02 | $^{O}C$ |
| | TNx | Highest TN | 0.23 | 0.31 | $^{O}C$ |
| | TNn | Lowest TN | 0.32 | 0.23 | $^{O}C$ |
| Precipitation | PRCPTOT | Annual precipitation | 0.16 | 3.46 | % |
| | SDII | Simple daily intensity index | 2.32 | 0.59 | mm day-1 |
| | CDD | Consecutive dry days | -0.81 | 1.25 | days |
| | CWD | Consecutive wet days | 0.25 | 0.22 | days |
| | R10mm | Days above 10 mm | 0.9 | 0.68 | days |
| | R20mm | Days above 20 mm | 0.46 | 0.82 | Days |
| | R50mm | Days above 50 mm | 0.21 | 0.44 | days |
| | RX1day | Max 1-day precipitation | 0.03 | 0.18 | % |
| | RX5day | Max 5-days precipitation | -0.03 | 0.18 | % |
| **Precipitation** | R95p | Very wet days | 0.95 | 2.05 | % |

SOURCE: Stephenson et al. (2014)

Similarly, CSGM (2017) analysed daily rainfall trend for Jamaica from 1940 to 2010 using ten extreme indices based on 13 stations. Results from nine of the 13 stations are presented in Table 5. The table shows that extreme rainfall events along with intensity have risen for the aforementioned period with the exception of CDD which has been decreasing.

TABLE 5 - MEAN TREND VALUES FOR RAINFALL BASED ON EXTREME INDICES 1940-2010 FOR JAMAICA

| Element | Description | 1940-2010 | Unit |
|---|---|---|---|
| CDD | Annual maximum number of consecutive dry days | -1.5 Days | |
| CWD | Annual maximum number of consecutive wet days | 0.2 Days | |
| PRCPTOT | Annual Total Precipitation | 71.3 Mm | |
| R10mm | Annual count of days when rainfall above 10mm | 1.2 Days | |
| R20mm | Annual count of days when rainfall above 20mm | 1.0 Days | |
| R95P | Very wet days | 18.9 Mm | |
| R99P | Extreme wet days | 6.2 Mm | |
| SDII | Simple daily intensity index | 0.4 mm/day | |
| RX1 | Maximum 1-day precipitation | 4.4 Mm | |
| RX5 | Maximum 5-day precipitation | 10.5 Mm | |

SOURCE: Adapted from CSGM (2017)

## 2.4 CLIMATE VARIABILITY IN JAMAICA

### 2.4.1 Climate of Jamaica

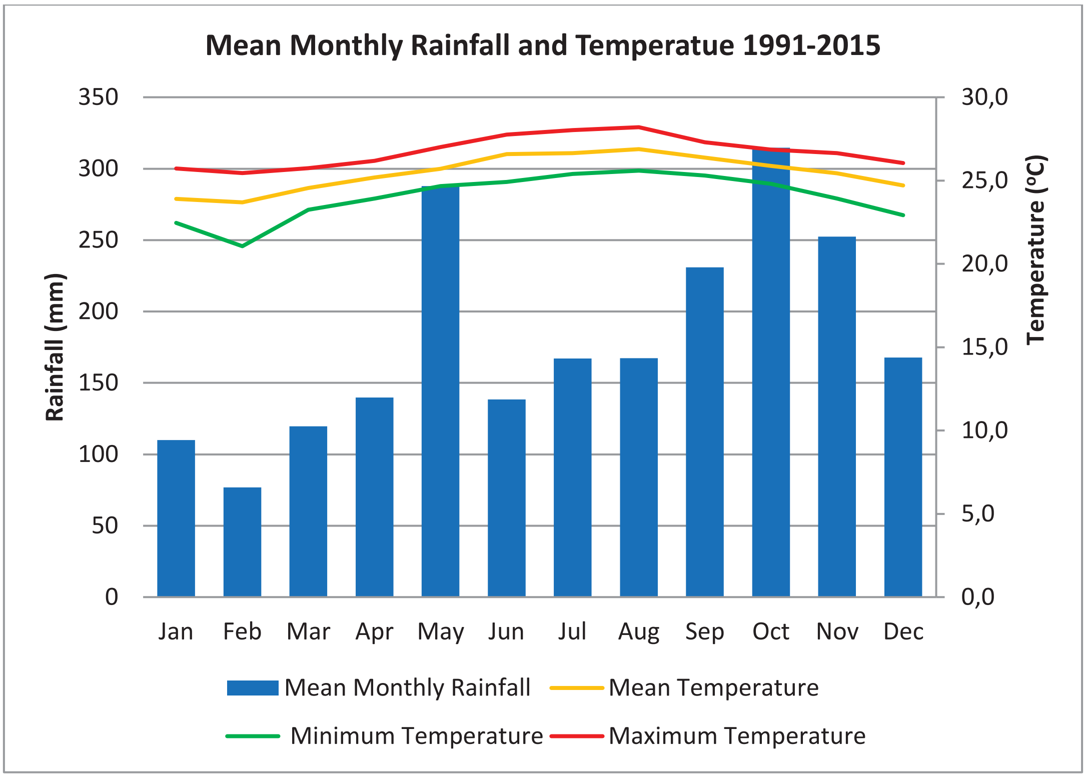
According to Stennet (1979), Jamaica is characterized by having a tropical and sub-tropical climate. Another classification by Koppen-Geiger in 2017, categorized Jamaica as having an equatorial climate (humid tropical) which can be further subdivided into three climate subtypes: Af (fully humid - tropical rainforest); Am (tropical monsoon) and Aw (desert -tropical savannah) (KOTTEK et al. 2006). The method used to derive the latter is based on statistical analysis of the average monthly temperature and precipitation from 1986 to 2010 provided by the Climatic Research Unit - CRU of the University of East Anglia and the Global Precipitation Climatology Centre - GPCC at the German Weather Service (RUBEL et al. 2017).

Rainfall regime in Jamaica can be characterized by two wet and one dry season. The early season occurs between May and July while the late rainfall season falls between August and November (Climate Studies Group Mona - CSGM, 2012). In the Caribbean, rainfall variability in the first rainfall season is influenced by sea surface temperature (SST) in the Tropical North Atlantic while the second season is impacted by SST in the

Equatorial Pacific. On the other hand, drought normally takes place from December to March, although a mid-summer drought (MSD) is present in late July which has been linked to the North Atlantic Subtropical High (NASH). According to CSGM (2010), NASH also called the Azores High, a large subtropical semi-permanent centre of high atmospheric pressure situated between 30 °N and 35°N south of the Azores in the Atlantic Ocean, influences dry conditions within the Caribbean during northern hemisphere winter. This occurs as the NASH is situated farthest south with strong easterly trade winds on its equatorial flank, a cold sea surface temperature (SST) and reduction in atmospheric humidity. However, precipitation is normally low and occurrence of same results from the passage of mid-latitude cold fronts (CSM, 2012). In spring, the Caribbean Sea tends to be warmer as the NASH moves northward with a reduction in the intensity of the trade winds and the southern flank of the NASH becomes convergent (TAYLOR; ALFARO, 2005).

The amount of rainfall is also influenced by the Northeast Trade Winds, tropical storms and hurricanes occurring between June and November. Further, hurricanes are more dominant during La Niña episodes due to a reduction in vertical wind shear and cooler SST in the tropical Pacific (Patricola, Saravanan & Chang, 2014). Moreover, a strong correlation has been obtained between the Atlantic meridional mode (AMM) and the occurrence of cyclones in the Atlantic at the inter-annual and decadal time scale (Vimont & Kossin, 2007). Conversely, drought conditions are associated with El Niño as SST becomes warmer at that time. Figure 12 illustrates the mean monthly rainfall and temperature for the island obtained from CRU via the World Bank website.

FIGURE 11 - JAMAICA - CRU MEAN MONTHLY RAINFALL AND TEMPERATURE 1991-2015



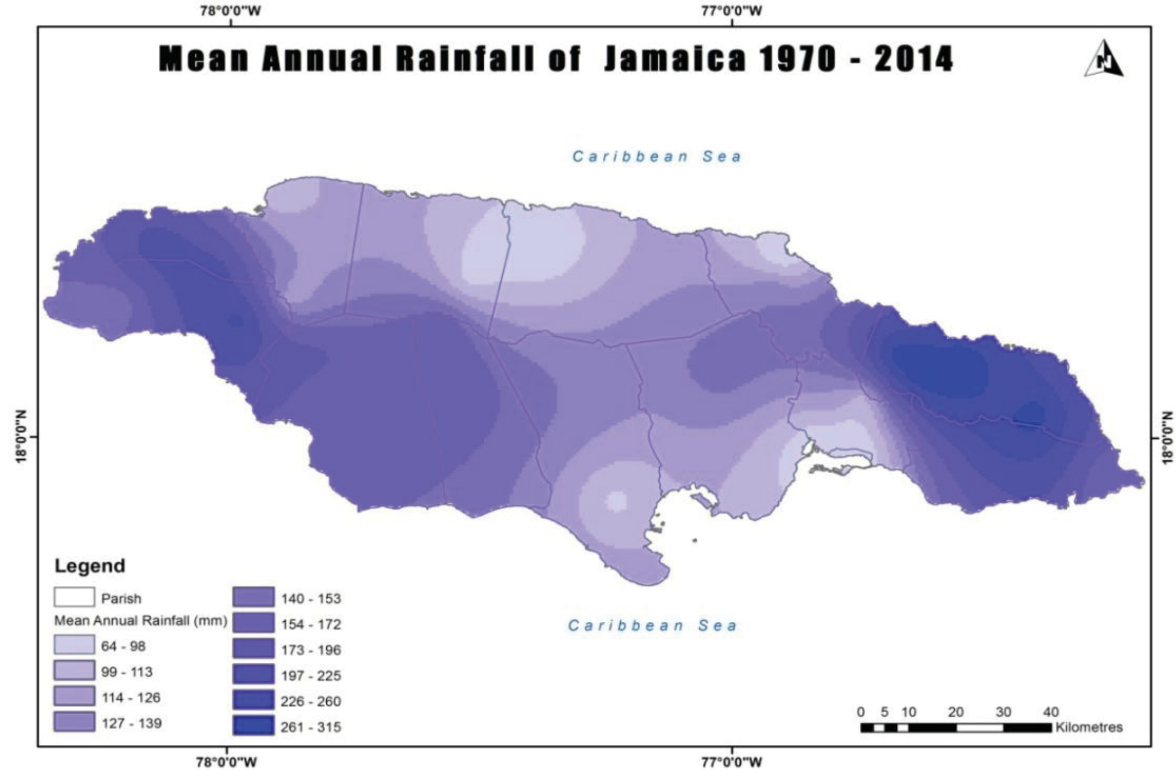

SOURCE: World Bank; Adapted By: Author (2017)

Average annual rainfall in 2015 was estimated at 1,307 mm while the average annual temperature was 28.4ºC for the same year.

### 2.4.2 Spatial Distribution of Rainfall in Jamaica

In terms of the spatial distribution of rainfall (Figure 12), the north-eastern section of the island receives more precipitation as a result of it being located on the windward side. This is where The Blue Mountain Peak, the highest point in Jamaica, is located. This is also where the North East Trade Winds enters Jamaica with moisture laden winds before it moves across the rest of the island. Consequently, as it reaches the leeward side of the highlands which is in the rain shadow, there is a reduction in moisture resulting in little to no rainfall in these areas. A typical example of the latter is Kingston and the Southern section of St. Catherine which is located on the south coast and receives minute amount of rainfall and displays semi-arid characteristics.

FIGURE 12 - JAMAICA - SPATIAL DISTRIBUTION OF RAINFALL ACROSS 1970-2014 USING KRIGING

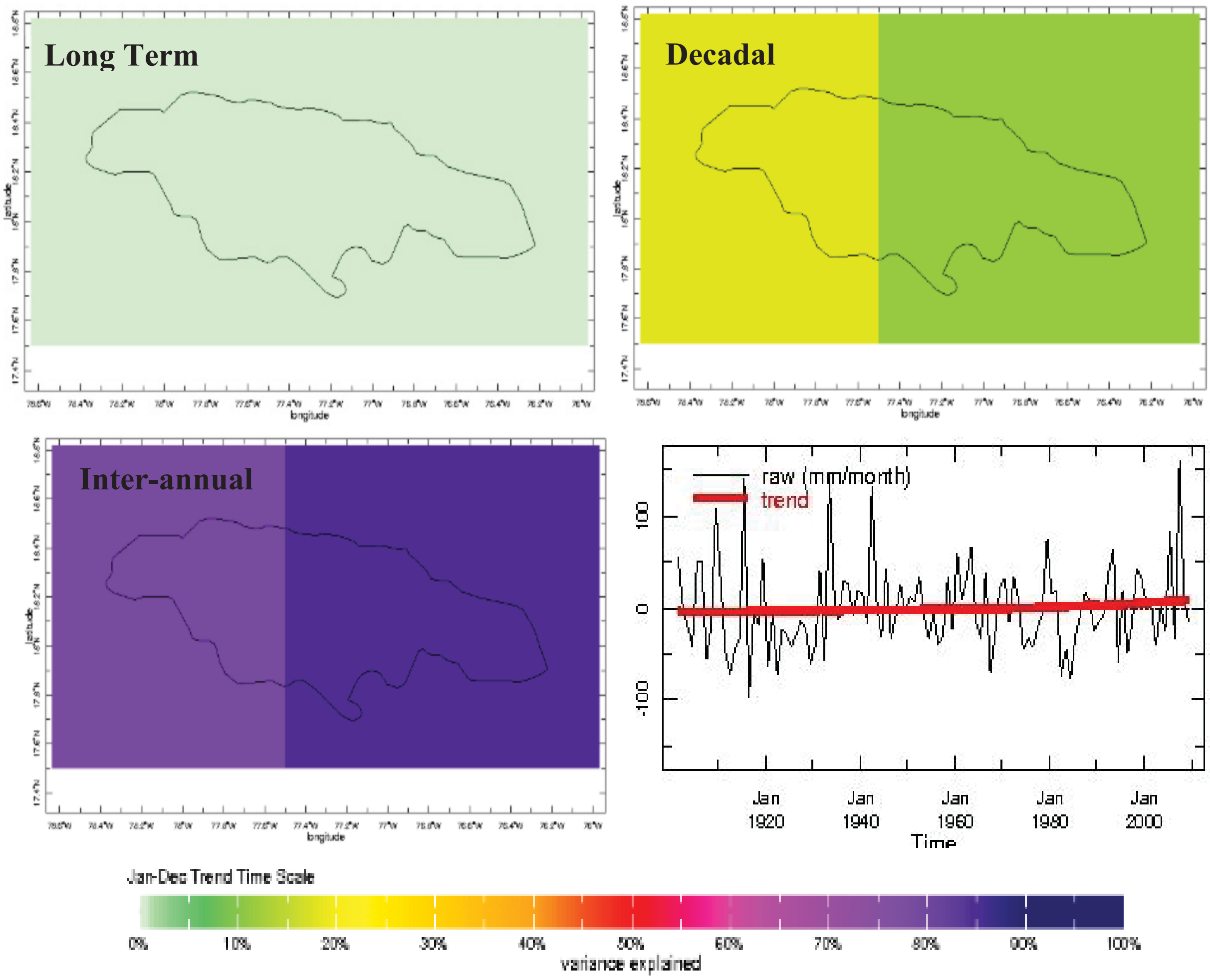



SOURCE: Adapted from Meteorological Service of Jamaica

### 2.4.3 Rainfall Trend

Figure 13 describes the timescale decomposition of rainfall for the twentieth century for Jamaica from CRU TS3.1 in terms of long-term trend, decadal and inter-annual components. From the figure, it can be observed that even though some amount of decadal variability impacts rainfall in Jamaica, inter-annual variability plays a greater role while the impact from long term trend is minimal. In all timescales, the trend is insignificant (0%). According to CSGM (2017), while inter-annual fluctuation in precipitation is modulated by the El Niño Southern Oscillation (ENSO) in Jamaica, the positive phase of the Atlantic Multi-decadal Oscillation (AMO) influences wet conditions at the decadal scale.

FIGURE 13 - JAMAICA - RAINFALL TREND BASED ON LONG TERM, DECADAL AND INTER-ANNUAL SCALE

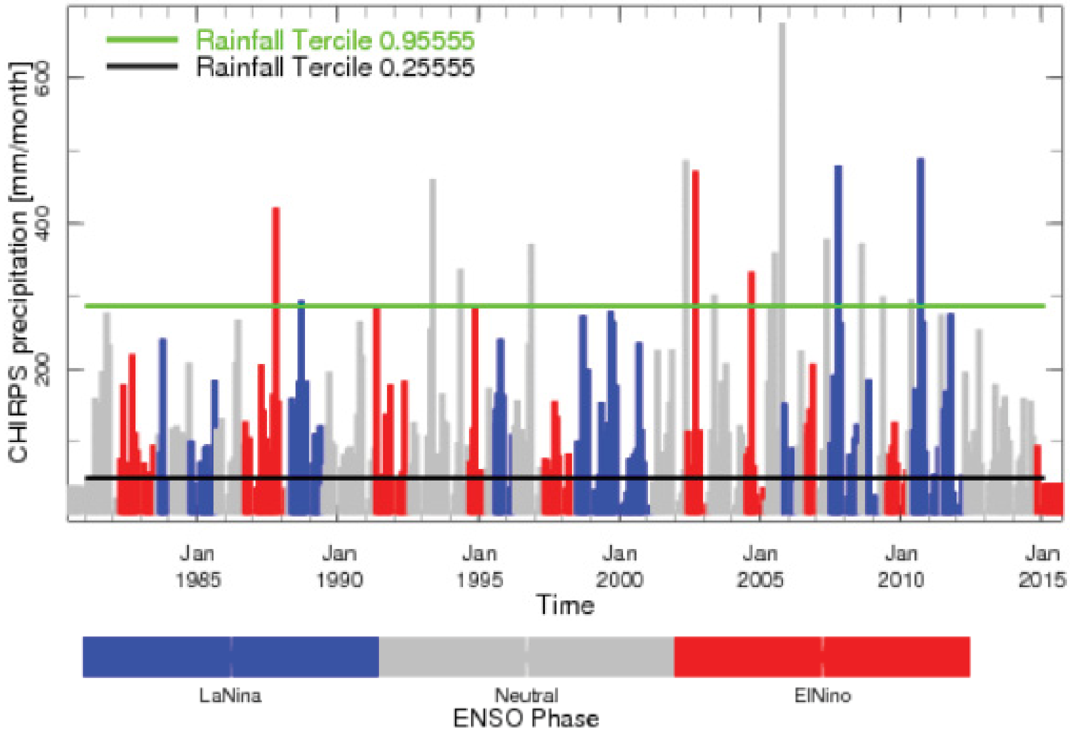



Source: IRI Data Library

### 2.4.4 Rainfall Exceedance Probability

Spatial average of rainfall percentile for Jamaica based on CHIRPS dataset for the period 1981 to 2015 shows that the 95th percentile was exceeded in 1988, 1989, 1993,1994, 1994, 1997, 2002, 2003, 2005, 2007, 2008 and 2010 (Figure 14).

FIGURE 14 - JAMAICA - RAINFALL EXCEEDANCE PROBABILITY



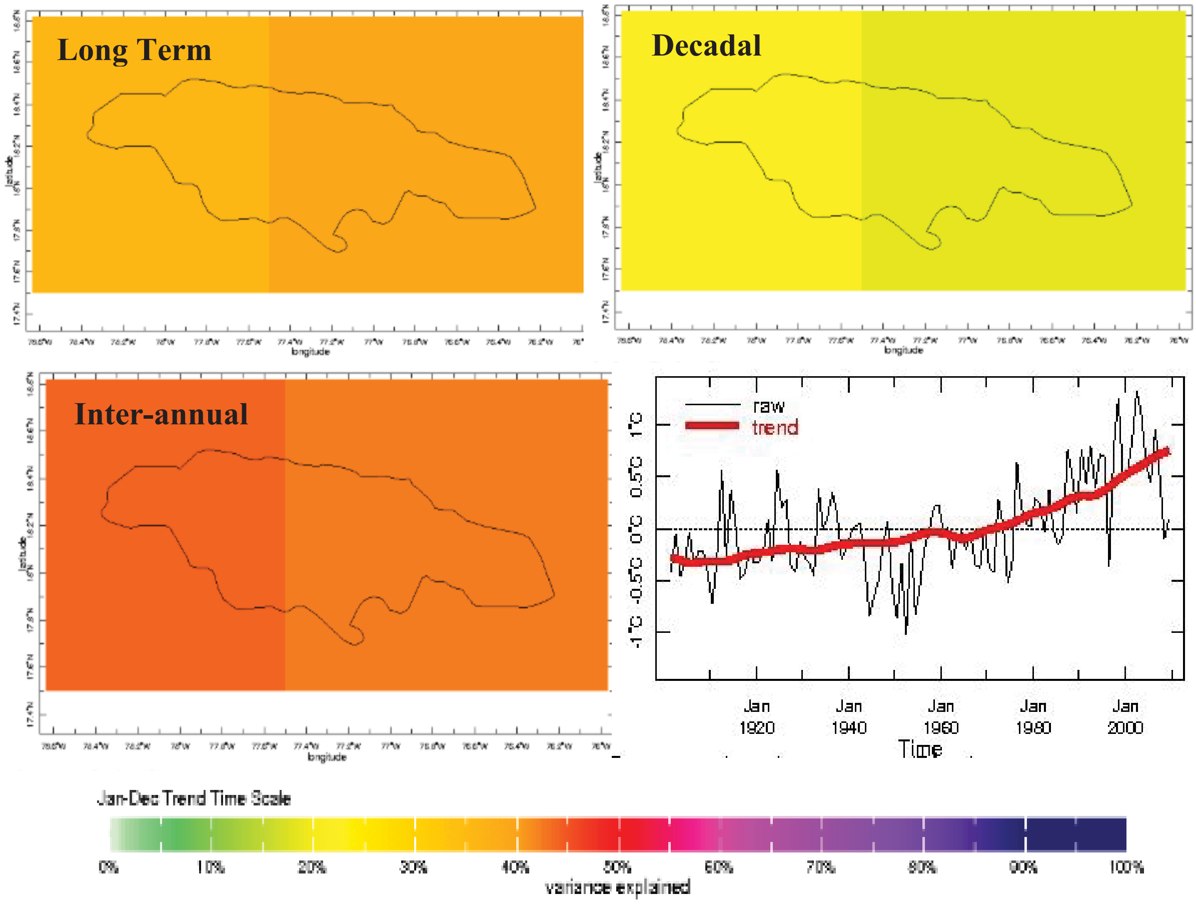

SOURCE: Adapted from IRI Data Library

### 2.4.5 Temperature Trend for Jamaica

According to CSGM (2017), the daily temperature range for Jamaica has decreased while there has been a dramatic increase in minimum temperature of -0.27$^{O}$C/decade in comparison to maximum temperatures between 1961 and 2010. Likewise, average temperature has also increased but at a rate of 0.16 $^{O}$C/decade for the same period (CSGM, 2017).

Further, Figure 15 shows Temperature Trend for Jamaica from data obtained from The University of East Anglia UEA3p1 via the IRI Data Library. It can be observed that long term trends, decadal and inter-annual timescale contribute to temperature variability on the island. Unlike precipitation which does not generate any significant trend, the trend observed for temperature is statistically significant (1%).

FIGURE 15 - JAMAICA - TEMPERATURE TREND BASED ON LONG TERM, DECADAL AND INTER-ANNUAL SCALE




Source: IRI Data Library

# CHAPTER 3

## 3 CLIMATE CHANGE PREDICTION AND IMPACTS

This chapter outlines the problem of climate change in small island developing states (SIDS) such as Jamaica. Likewise, the climate change projections are provided followed by its impacts on health and transmission of dengue.

### 3.1 CLIMATE CHANGE IN SMALL ISLAND DEVELOPING STATES

Climate change is a recurring problem within SIDS. Prior to the 1992 United Nations Conference on Environment and Development (Earth Summit) in Rio de Janeiro in Brazil, SIDS were formally identified as island developing countries (United Nations [UN], 2004). Following this meeting, the susceptibility of SIDS to extreme events was highlighted at the inaugural United Nations International Conference of SIDS which was held in 1994 in Barbados (UN, 2004). Since then, there has been on-going debate about the classification of SIDS, as even though they share certain similarities, each island state varies in population and land size. Furthermore, there is no acceptable definition and some SIDS like Guyana and Belize are actually mainland countries (Kelman & West, 2009). For this reason, some institutions like the World Bank, distinguishes between small states (20 countries) and SIDS, where the prior is assigned to countries with less than 1.5 million people (World Bank, 2016). Like the World Bank, The IMF makes reference to SIDS (43 countries) as small developing countries with population of less than 1.5 million but only incorporates members of the fund (IMF, 2016). On the other hand, the United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UNOHRLLS, 2013) recognizes 52 countries as SIDS (38 UN members and 14 non-UN Members or Associate Members) based on similar socio-economic and environmental challenges. SIDS are found in the Pacific; the Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS) and the Caribbean.

With regards to the Caribbean, SIDS are classified as UN members (Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, and Trinidad and Tobago) and non-UN or Associate Members such as Aruba, British Virgin Islands, Montserrat, Netherlands Antilles, Puerto Rico and the U.S. Virgin Islands (UNOHRLLS, 2013).

SIDS are among the most vulnerable places even though they generate less than 1% of greenhouse gases (Mainstreaming Adaptation to Climate Change [MACC], 2010). Their vulnerability to the effects of climate change is due to their low adaptive capacity and the following factors: the location of people, socio-economic activities and infrastructure along coast; limited natural resources; high sensitivity to external shock; dependence on freshwater resources; susceptibility to natural disasters; inadequate infrastructure and limited physical size which eliminates some adaptation options to climate change (United Nations Framework Convention on Climate Change - UNFCCC, 2005).

Over the Twentieth Century, mean sea level rise in the Caribbean has been estimated at approximately 10cm (PULWARTY, NURSE & TROTZ, 2010). At Port Royal in Jamaica, sea level rise was estimated at about 1.66 mm/year (CSGM, 2017). One of the demerits of sea level rise relates to the intrusion of sea water which could decrease freshwater supply (ECLAC, 2011) especially in countries marred by drought and the lack of constant tap water supply. Moreover, an increase in sea level could be devastating to the general population and infrastructure, as majority of Caribbean inhabitants and hotels are located near the coast (Mimura et al., 2007) with some infrastructure in areas below sea level (MYCOO, 2018). Sea level rise could also increase the presence of stagnant water which can be used as a breeding site thereby leading to the vector borne disease in coastal areas (RAMASAMY & SURENDRAN, 2013). While there no documentation in literature was identified of the Aedes vector using brackish/saline water as a breeding site, lack of evidence might be due to paucity in research (Ramasamy & Surendran, 2011). Furthermore, coastal zones in the Mediterranean region in Europe have been recognized as favorable sites for the Ades aegypti mosquito (European Centre for Disease Prevention and Control - ECDC, 2012).

The potential impact of climate change (Table 6) emanates from an increase in surface temperature brought about by the emission of greenhouse gases. In fact, since industrialization, global temperature has increased by about 0.85ºC, due to the emission of greenhouse gases caused by human activity (IPCC, 2012). In the region, tourism is a major economic earner and has also contributed to about 5% of emissions and air transportation alone accounted for up to 40% of emissions as well (SIMPSON et al., 2008). Additionally, $CO_2$ emissions from tourism are expected to increase up to 135% by

2035 under the business as usual scenario (World Tourism Organization [UNWTO] et al. 2008; Scott et al., 2008). These emissions have led to the occurrence of extreme weather events such as floods, droughts and hurricanes in many regions (IPCC, 2013).

TABLE 6 - POTENTIAL IMPACT OF CLIMATE CHANGE FOR CARIBBEAN SIDS

| **Variable** | **Projected Change** |
|---|---|
| Air and sea surface temperature | Rise of 1.4 ºC to 3.2ºC |
| Sea level rise | Rise of 0.18 to 0.59m |
| Ocean acidity | Reduction in pH of 0.014 - 0.35 units |
| Tropical storms and hurricanes | Likely to increase hurricane intensity with larger peak wind speeds and heavier precipitation |
| Precipitation | Most models predict a decrease in summer (June - August) precipitation in the Greater Antilles |
| Extreme weather events | Greater number of floods. |

SOURCE: Adapted from IPCC (2017)

According to the World Bank (2002), the economic impact of climate change on CARICOM (Caribbean Community) could range from approximately 5.6 percent of GDP for a low scenario to about 34% of GDP for a high scenario. SIDS are not only projected to be impacted by sea level rise, beach erosion, loss of coral reefs, but the adaptation cost might account for a large part of the gross domestic product (IPCC, 2014). So far, the Caribbean and Pacific SIDS have benefited from aid amounting to about US$ 55.6 billion to facilitate response to climate change (MYCOO & DONOVAN, 2017). Even with funding through aid and grants, adaptation cost might account for a large portion of GDP in SIDS (IPCC, 2014) which could hinder implementation. In fact, UNOHRLLS (2015) highlighted that a lack of adaptation for SIDS in the region could result in 10% loss in yearly GDP by 2050 which is around US$22 billion. According to Bueno et al., (2008), inaction could result in an economic impact of 21.7% of GDP by 2100. More specifically, losses in Grenada and Haiti might exceed 100% of GDP while losses in Jamaica, Cuba, Antigua and Barbuda, Turks and Caicos Island and Dominica equates to more than half of GDP (BUENO etal., 2008). Additional information regarding the economic impact of inaction to climate change can be found in the Appendix.

## 3.2 REPRESENTATIVE CONCENTRATION PATHWAYS AND CLIMATE CHANGE PREDICTION

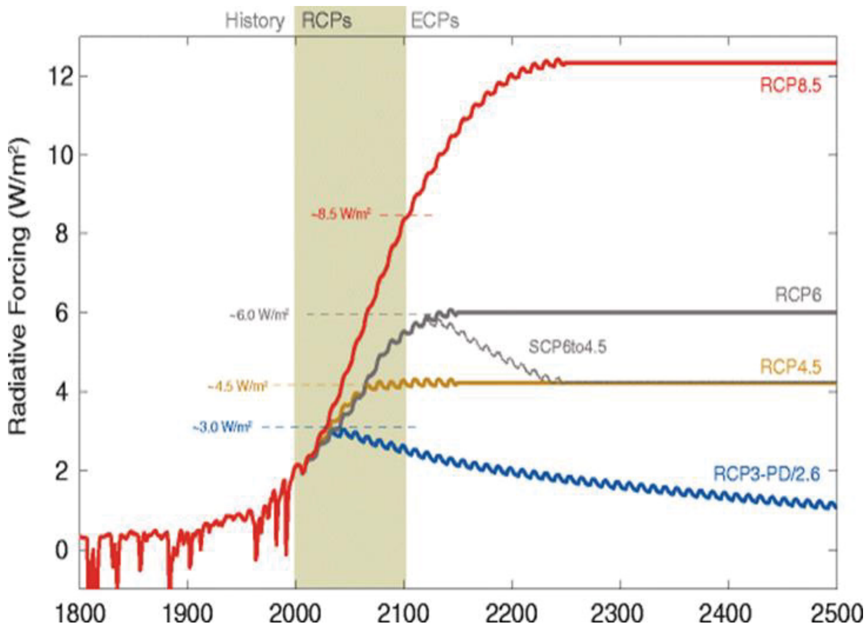
Four representative concentration pathways (RCPs) were developed by the IPCC in the Fifth Assessment Report (AR5) based on greenhouse gas concentrations and mitigation policies. These have replaced the emissions approach in previous reports by the IPCC. These RCPs (Table 7 and Figure 16) are represented as radiative forcing in Watts per square metre ($W/m^2$) and include one high greenhouse gas emission scenario (RCP8.5); two stabilizing concentration of $CO_2$ (RCP 4.5 and RCP6) and one low emission (RCP2.6) (MEINSHAUSSEN et al., 2011).

TABLE 7 - REPRESENTATIVE CONCENTRATION PATHWAYS

| RCPs | Radiative forcing | Rate of change in radiative forcing |
|---|---|---|
| RCP8.5 | 8.5 $W/m^2$ | Rising |
| RCP6 | 6 $W/m^2$ at stabilization after 2100 | Stabilising |
| RCP4.5 | 4.5 W/m2 at stabilization after 2100 | Stabilising |
| RCP2.6 | ~ 3 W/m2 before 2100 | Declining |

SOURCE: Adapted from IPCC (2018)

FIGURE 16 - RADIATIVE FORCING




SOURCE: Meinshaussen et al. (2011)

According to the IPCC (2013), global mean surface temperature is projected to increase between 2.6ºC and 4.8 ºC for RCP 8.5 for the period 2081-2100 relative to 1986-2005. For RCP 2.6, a change in temperature of 0.3 to 1.7ºC and 1.1 to 2.6ºC for RCP4.5 is expected IPCC (2013).

## 3.3 CLIMATE CHANGE PREDICTION FOR JAMAICA

For Jamaica, temperature is expected to increase through all RCPs up to 2100 (CSGM, 2017). Based on Global Climate Models (GCMs) with a baseline of 1986-2005, increase in average temperature might vary between 0.49ºC and 0.57 for 2020s to 0.65 - 0.85 in the 2030s. For the 2050s, mean temperature has been estimated at 0.85-1.80 and 0.82-3.09 between 2081 and 2100. Likewise, Regional Climate Models (RCM) predict an increase in temperature but at a higher magnitude.

In terms of rainfall, southern and eastern Jamaica will experience higher reduction in precipitation in comparison to the northern and western section of the island. This reduction seems to be greater for RCM in comparison to GCM (CSGM, 2017). Table 8 shows climate trends for Jamaica.

TABLE 8 - JAMAICA - CLIMATE TRENDS

(Commences)

| **Variable** | **GCM** | **RCM** |
|---|---|---|
| Temperature | Mean temperature increase will be 0.49°–0.57°C by the 2020s; 0.65-0.84ºC by the 2030s, 0.85°-1.80°C by the 2050s and 0.82-3.09ºC for 2081-2100 with respect to a 1986-2005 baseline over all four RCPs. | Temperature increases across all seasons of the year.<br><br>Higher magnitude increases for the downscaled grid boxes – up to 4ºC by end of century. |
| Rainfall | Reduction in the annual mean rainfall by 0 or 2%. The following are likely to occur:<br>2030s - up to 4% drier<br>2050s - up to 10% drier<br>2100 - up to 21% drier for RCP8.5 | Prediction of a drying trend from mid-2030s until 2100. |

TABLE 8 - JAMAICA - CLIMATE TRENDS

(Concludes)

| Variable | GCM | RCM |
|---|---|---|
| Sea Levels | Sea level rise for the Caribbean range from 0.26-0.82m by 2081-2100 relative to 1986-2005. For 2046-2065, SLR is 0.17-0.38 | All RCPs show mean sea level rise (SLR) between 0.58 and 0.87 for the north of Jamaica by 2081 - 2100. |
| Hurricanes | Frequency of storms to diminish but higher intensity is expected by 2081-2100.<br>Category 4 and 5 hurricanes are likely to increase for the next 80 years. | |

SOURCE: CSGM (2017)

The most severe dry phase is exhibited in RCP 8.5 with about 21% decrease in rainfall for the period 2081 to 2100 while 2030 and 2050 might experience a decline by about 4% and 9% respectively (Table 9).

TABLE 9 - JAMAICA - MEAN PERCENTAGE CHANGE IN RAINFALL USING 1986-2005 AS BASELINE

| RCP | 2020's (2020-2029) | 2030's (2030-2039) | 2050's (2050- 2059) | End of the Century (2081-2100) |
|---|---|---|---|---|
| RCP 2.6 | -0.02 | -0.15 | -0.36 | -0.45 |
| RCP 4.5 | -3.11 | -3.76 | -6.10 | -7.47 |
| RCP 6.0 | -1.8 | -2.67 | -2.66 | -8.85 |
| RCP 8.5 | -1.95 | -3.84 | -8.52 | -21.02 |

SOURCE: CSGM (2017)

Predictions from earlier models have also indicated a decrease in annual precipitation for the entire Caribbean. Downscaling of the HadCM3 for the A2 and B2 emission scenarios illustrates a near-linear decrease in summer precipitation up to the 2080s for a station in Jamaica (Intergovernmental Panel on Climate Change - IPCC, 2007). Further simulation based on the A1B scenario predicts an increase in temperature for the Caribbean by approximately 1.50 º C by 2050s by the end of the 21st century in comparison to the global average of 2.80 º C (PIOJ, 2012). On the other hand, the General Circulation Models (GCMs) projected rainfall for the Caribbean was -39% to +11% (CSGM, 2012).

Comparison of the GCMs with a downscaling model known as PRECIS (Providing Regional Climates for Impact Studies) RCM (Regional Climate Models) was conducted by CSGM (2012) for the B2 (low) and A2 (scenarios). This model has a finer resolution (50km) than the GCMs used in global projections and was used during the PRECIS Caribbean Initiative (TAYLOR et al., 2007).

According to the results presented (Table 10), there is likely to be an augment in air temperature for the island based on results obtained from both models. However, the projected increase in PRECIS (2.9 ºC -3.4 ºC by 2080) was higher than GCM (2.0 ºC to 3.0 ºC by 2080). On the other hand, GCM predicted increase and decrease in rainfall (-44% to+18% by the 2050s) even though PRECIS (-14%) projected a decrease in precipitation (-14% to -41% by the 2050s).

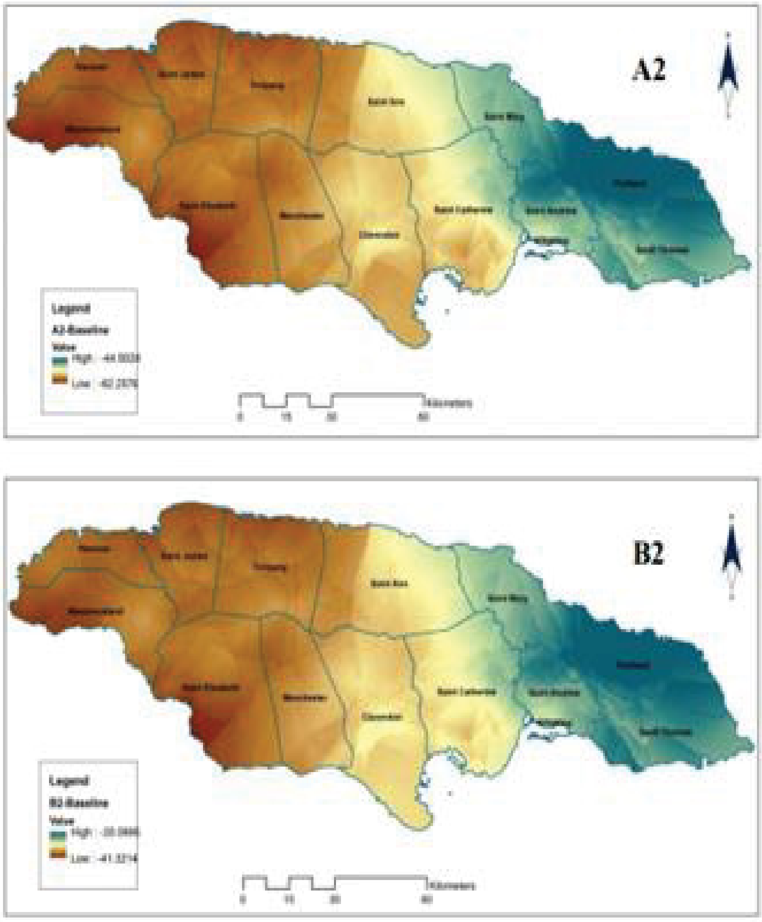
TABLE 10 - JAMAICA - GCMS AND RCMS PRECIS PROJECTIONS

| VARIABLE | GCM | RCMS PRECIS |
|---|---|---|
| Rainfall | -44% to +18% by the 2050s<br>-55% to +18% by the 2080s | -14% to -41% by 2080. |
| Air Temperature | 0.7 ºC to 1.8 ºC by 2050<br>2.0 ºC to 3.0 ºC by 2080<br>1.1ºC to 3.2 ºC by 2090 | 2.9 ºC to 3.4 by 2080 |
| Wind speed | -0.1 to +0.5ms$^{-1}$ by 2080 | -0.5ms$^{-1}$ by 2080 |
| Sea Surface Temperature | +0.9 ºC to + 2.7 ºC by 2080 | N/A |

SOURCE: CSGM (2012)

PRECIS was also used to compare climate variable baseline for Jamaica which indicated severe drying in the western section of the island with wetter conditions favouring eastern parishes (Figure 17). The reduction in rainfall is expected to be impacted greatly in the early and late rainfall season. CSGM (2012) opined that while the regional climate model (PRECIS) and the Statistical Downscaling Model showed a drying effect from a decrease in precipitation by 2050 across the island, precipitation intensity will increase by 2080. Some of the impacts resulting from this include an increase in storms, floods, tropical cyclones and hurricanes for the country.

FIGURE 17 - JAMAICA - PROJECTED PRECIPITATION CHANGES FOR A2 (TOP) AND B2 (BOTTOM) EMISSION SCENARIO COMPARING BASELINE TO 2071-2099 FROM DOWNSCALING MODEL.



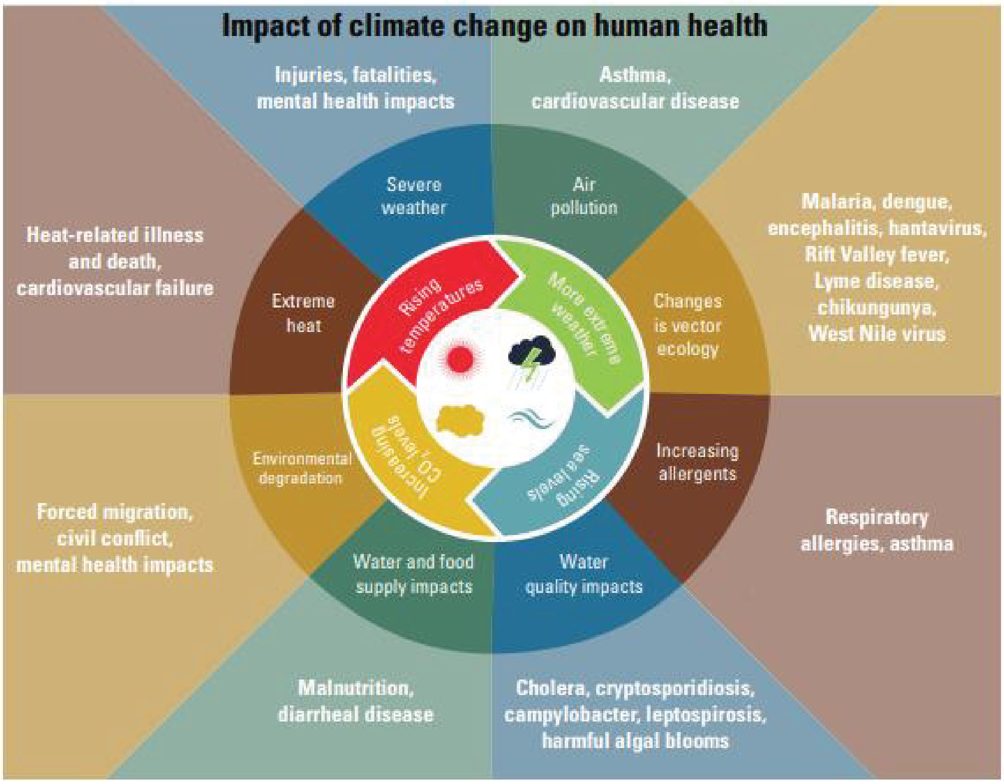

SOURCE: CSM (2012)

Notwithstanding that, the frequency of very hot nights annually will increase over the island based on A2 scenario (CSGM, 2012). An increase in temperature by 2ºC or 3 ºC within this regard can cause shorter incubation period for mosquito borne virus which can lead to a three-fold increase in the transmission of dengue and dengue haemorrhagic fever in Jamaica. Likewise, storms, floods, tropical cyclones and hurricanes can result in an increase in water, rodent and vector borne diseases such as dengue on the island (CSGM, 2012).

## 3.4 THE IMPACT OF CLIMATE CHANGE ON HEALTH

According to WHO (2010), climate change will impact the mechanisms that ensures good health (clean air, safe drinking water, food security and shelter). From Figure 18, the direct impacts on health include increase in extreme weather, rising temperatures, the increase in $CO_2$ and sea level rise. Indirectly, more extreme weather will lead to air pollution which can cause cardiovascular disease and also affect asthma patients. Another impact relates to changes in vector ecology and the spread of diseases such as malaria, dengue, and chikungunya among others. Severe weather will cause injuries, fatalities and mental health impacts while extreme heat will have an impact on heat-related illness and death along with cardiovascular failure. Forced migration, civil conflict, mental health impacts will result from environmental degradation and malnutrition and diarrheal disease will emanate from water and food supply due to increase in $CO_2$. Other impacts relate to increasing allergies and water quality impacts which will influence the spread of water borne diseases such as cholera.

FIGURE 18 - THE IMPACT OF CLIMATE CHANGE ON HUMAN HEALTH




SOURCE: Patz et al. (2000)

In 2003, about 70,000 people in Europe were killed because of heat wave (WHO, 2018). Furthermore, about 500,000 children die yearly from diarrhoeal diseases due to unsafe drinking water. According to WHO (2018), climate change will result in about 250,000 more deaths arising from malnutrition, malaria, diarrhea and heat stress between 2030 and 2050.

Confalonieri et al., (2007) have also reported how Europeans have been impacted directly and indirectly by climate change. According to the authors, the direct impacts from climate change have taken place through weather changes, and indirectly due to changes in water, air, food quality, ecosystems, agriculture, livelihoods and infrastructure.

In the United States of America, respiratory illnesses will become one of the most expensive diseases to treat in the future (CDC, 2015). Currently, cardiovascular disease is the major cause of death in the country, but the number of people affected by the disease, is expected to increase by 2030 (Roger et al., 2012).

According to the World Bank (2017), roughly 100 million of the population worldwide could be forced into extreme poverty, as a result of a changing climate by 2030. This would therefore increase their vulnerability to the harmful effects of climate change. While the impacts of climate change on health will be global, small island developing states (SIDS) will be the most severely affected (WHO, 2018). In terms of demographics, the elderly, children living in poverty and people with ill health, will be significantly affected. Also, developing countries with poor health systems will not be able to cope or respond adequately if assistance is not provided (WHO, 2018).

## 3.5 CLIMATE CHANGE AND DENGUE

It has been established that climate change will affect the distribution of vector borne diseases, especially those associated with the *Aedes aegypti* mosquito (Rogers, 2015; Campbell-Lendrum et al., 2015). Some of the factors that extend the limits of the disease include a change in mean temperature and rainfall (Liu-Helmersson et al., 2016; Monaghnan et al., 2016). Based on the likely impacts, models will need to be developed in order to simulate the potential risk related to disease transmission to inform adaptation strategies in light of climate change (Githeko, 2012). According to Patz (2000), models used for predicting future occurrence of disease range from statistical to process-based and can also be landscape-based. Statistical models assess the role of climate on disease transmission based on mathematical approaches to determine future outbreaks. The use of process-based models in the analysis of infectious disease provides the framework for a greater understanding of the factors that lead to transmission of the virus to host and the processes involve (Martens, 1998). However, one of the limitations of this model is the inability to take into consideration the interaction between the host and socio-environmental factors that are normally involved (MORIN, COMRIE & ERNST, 2013).

Studies concerning the impact of climate change on the spread of vector borne diseases caused by the *Aedes aegypti* mosquito have yielded mixed results. While most authors concur about the potential expansion of the vector in new areas as a result of climate change (Ebi & Nealon, 2016; Kyle & Harris, 2008; San Martín, Braithwaite, Zambrano, Solórzano, Bouckenooghe et al., 2010), others have noted a reduction in habitat suitability due to extreme conditions (ROGERS, 2015). Even though temperature beyond 32 $^{O}$C can prevent mosquitos from developing leading to death of adult population, Chadee & Martinez (2015) noted how the *Aedes aegypti* mosquito has been adapting to a changing climate as research shows that the vector in one instance changed their breeding site from drums to septic tanks to elude high temperature. Furthermore, the *Aedes aegypti* mosquito has been known to survive in higher temperature range in comparison to Aedes Albopictus.

Hales et al., (2002) used vapour pressure to estimate the global extent of dengue under climate change conditions and found that the geographical range of the disease could expand and affect a large number of people. Particularly, the study indicated that dengue propagation in 1.5 billion people (30% of the global population) was situated in areas with a 50% transmission rate. It also predicted that between 5 and 6 million (more than half of global population) people were likely to be impacted by dengue by 2085 in comparison to 3.5 billion (35% of people worldwide) when climate change is not taken into account.

Also, analysis of future global changes in the range of the *Aedes aegypti* mosquito based on rainfall and temperature variables indicate an augmentation of the mosquito breeding site under RCP8.5 by 13% in comparison to 8% with RCP4.5 between 2061 and 2080 (Monaghnan et al., 2016). In another global climate change predictive study by Monaghan et al., (2018), the current land mass of 56.9Mkm$^2$ with favourable climatic conditions for the *Aedes aegypti* mosquito is foreseen to increase from 8% under RCP 4.5 to 13% with RCP 8.5 for 2061-2080. Australia, Europe and North America were deemed to have greater exposure to the vector with climate change.

# CHAPTER 4

# 4 METHODOLOGY

In this chapter, the methodological approaches that were adopted for this research are discussed in detail. Particularly, it commences with the approaches used in research in order to provide the justification for the methodology that is suitable for studying climate related events and disease propagation in this case, dengue. It also incorporates a conceptual framework, the complexity of dengue studies and dengue as a function of urban environmental systems. Details about the steps and data collection process are also provided.

## 4.1 APPROACHES USED IN RESEARCH

The discourse regarding the appropriate methodology to be used when carrying out an investigation has been on-going without clear understanding as to the right approach to apply especially when studying complex phenomenon. Two of the most debated theories relate to the inductive and deductive approach. The prior method commences with observations and analysis gathered from data in order to arrive at theories and concept based on interpretation by the researcher (THOMAS, 2006).

However, Karl Popper was one of the critics of this method and later proposed the hypothetico-deductive approach, from the basis that scientific theories cannot be proven from induction. Within this regard, scientific investigations should commence with a hypothesis in order to ascertain falsification through predictive analysis or experimentation (POPPER, 1963). According to the author, this process includes the testing of a particular theory to prove the hypothesis false or to carry out repeated experiments for corroboration.

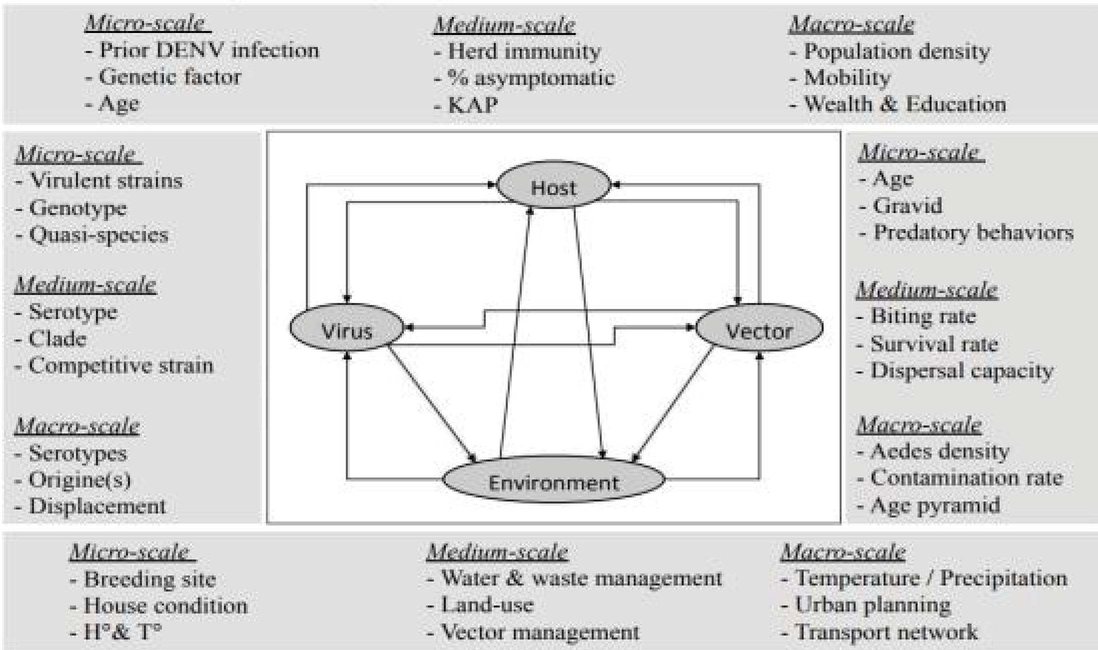
Conversely, there have been opponents of the latter, for its use in climate related studies due to the level of uncertainties involved in the data collection process and variability in environmental conditions that bring about changes in time and space. In most cases, these observations cannot be repeated and in other instances, generalizations are made based on measurements obtained from various instruments and different observers (GRAY, 2014). Moreover, researchers have been in search of new perspectives and methods to utilize in environmental and urban related study (MENDONÇA, 2004).

Furthermore, Onwuegbuzie & Leech (2005) noted that the methodological techniques used should be based on the purpose, questions and type of research being conducted. In this thesis, both the qualitative and quantitative techniques were used while a multidisciplinary approach formed the basis for the analysis. A multidisciplinary approach is characterized by the use of a wide variety of methods from other disciplines in order to achieve a common goal (FIORE & SALAS, 2007).

## 4.2 JUSTIFICATION FOR A MULTIDISCIPLINARY APPROACH

This thesis is multidisciplinary in nature as it seeks to tackle a very complex problem related to dengue occurrence within urban settings at different temporal scales in Jamaica. The notion of scales in dengue research has been a recurrent topic within the scientific community due to the complexity of the determinants responsible for its transmission. These vary from macro, medium to the micro level (DAUDE & MANEERAT, 2015) as presented in figure 19.

FIGURE 19 - DENGUE AS A COMPLEX SYSTEM AT DIFFERENT SCALES




SOURCE: Daudé & Maneerat (2015)

From the figure above, it can be observed that the variables responsible for dengue are diverse and tend to differ in space based on the vector- host interaction, replication of the virus and environmental conditions. This relationship explains the ecological characteristics of the host (human), the vector (infected mosquito) and the environmental characteristics that lead to transmission of the dengue virus which is related to the traditional epidemiological triad of disease.

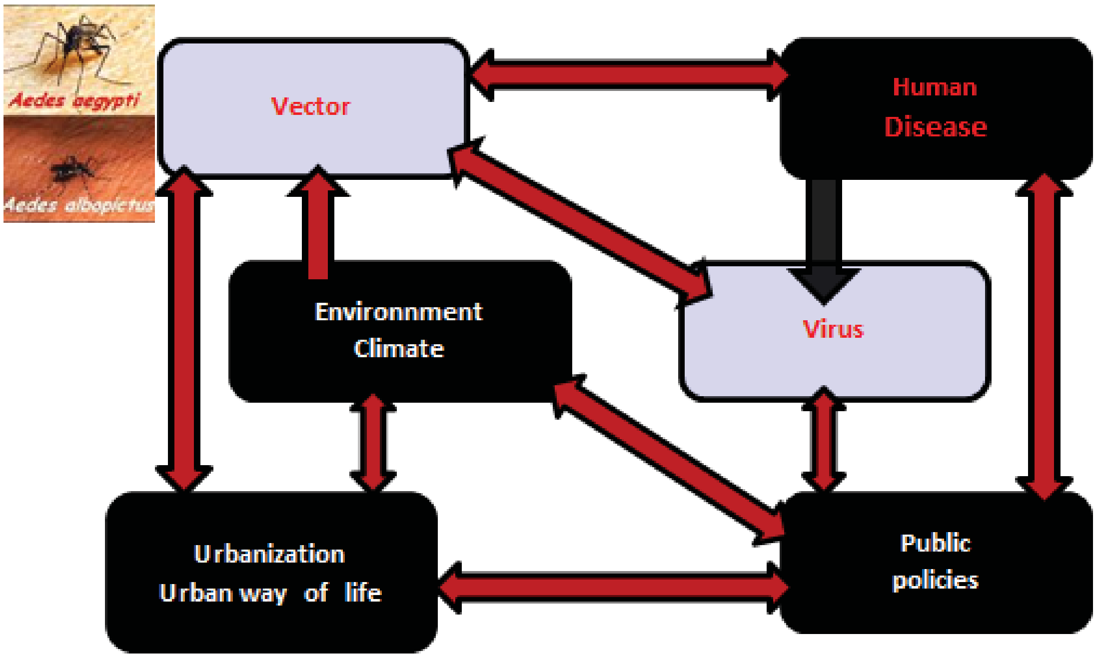
Further, with dengue occurring in urban areas, the characteristics of urbanization (population density, land use, transportation network and waste disposal) help to drive the disease along with the socio-economic conditions (age, wealth and education, house conditions) of the populace. The relationship between the foregoing and the biological aspect (serotype, Aedes density) when interface with climatic conditions (temperature, precipitation), create challenges for analysing the spread of dengue in a manner that is representative of the ideal scenarios that lead to an outbreak in a particular area.

More importantly, this concept shows that the causes of dengue varies and depending on the level of information used, the results obtained might point to different factors which makes understanding and studying dengue transmission very difficult. Even with these complications, Cardoso-Leite (2014); Peterson (2005); Peterson, (2007) reaffirmed the possibility of representing epidemiological cases with other variables at specific scales that is ideal for understanding the socio-economic and environmental factors that impact disease outbreak. However, for this to be successful, the data used in the analysis should be suitable for the study being undertaken at a particular resolution.

Moreover, one of the demerits in dengue analysis relates to the use of coarse resolution data which can have implications for disease mitigation. According to Murdock et al. (2017), the use of general circulation models even downscaled weather related data or in situ measurements from weather stations and remote sensing estimations are not sufficient to account for the presence of mosquito habitats at the micro level (community, neighbourhoods or household) as the vector does not respond at the same resolution (coarse).

In another approach by Aquino & Mendonça (2012), the multi-casual complexity of dengue is explained with 6 factors as shown in Figure 20. In this case, the relationship between man, the environment and urbanization has resulted in changes to the urban space and climate variation. These alterations among other factors lead to the presence of the dengue vector (*Aedes aegypti* and Aedes albopictus). Figure 20 shows the direct relationship between dengue and public policies, as the actions taken for vector control, can determine the occurrence of the disease. Also, the transformation (historical, social, urban networks, socio-economic and cultural conflicts) of urban areas indirectly reacts with the dengue vector.

FIGURE 20 - DENGUE FEVER MULTI-CASUAL COMPLEXITY

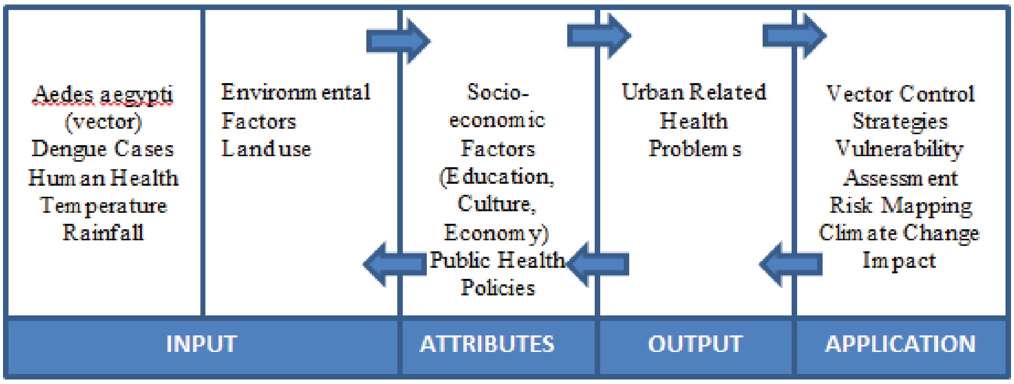



SOURCE: Adapted from Aquino & Mendonça (2012)

The analysis of dengue within urban settings therefore requires a multidisciplinary approach to confront the multifaceted issues surrounding the interaction between people, vector and the environment. Previously, Max Sorre (1933) formulated the Patogenic Complexes regarding disease which changed the analytical approach based soley on the physical environment. With his approach, the physical, biological and social elements are incorporated.

To illustrate the different elements involved in urban environmental systems and dengue in Jamaica, reference is made to figure 21. Figure 21 displays a schematic representation of an urban environmental system, in relation to dengue occurrence in Jamaica, which contains a series of inputs, attributes, outputs and applications. In this manner, climate, environmental factors and land use serve as input for the system with flows coming from social processes categorized as attributes. These attributes refer to the social and cultural characteristics of the population which generate different urban health related problems in urban areas and are classified as outputs. Resulting from these are possible solutions gained from studying the problems incorporated in the figure as applications.

FIGURE 21 - JAMAICA - URBAN ENVIRONMENTAL SYSTEMS AND DENGUE OCCURRENCE




SOURCE: Adapted from MENDONÇA (2004)

With this concept in mind, this research attempt to provide an explanation for the spread of dengue fever which prevails within urban setting in Jamaica through the use of several environmental and climate variables (rainfall, temperature, dengue cases and land use) that will act as input (drivers) for the disease. In addition, the different attributes (public health policies, socio-economic factors) are combined in order to comprehend the factors responsible for dengue propagation.

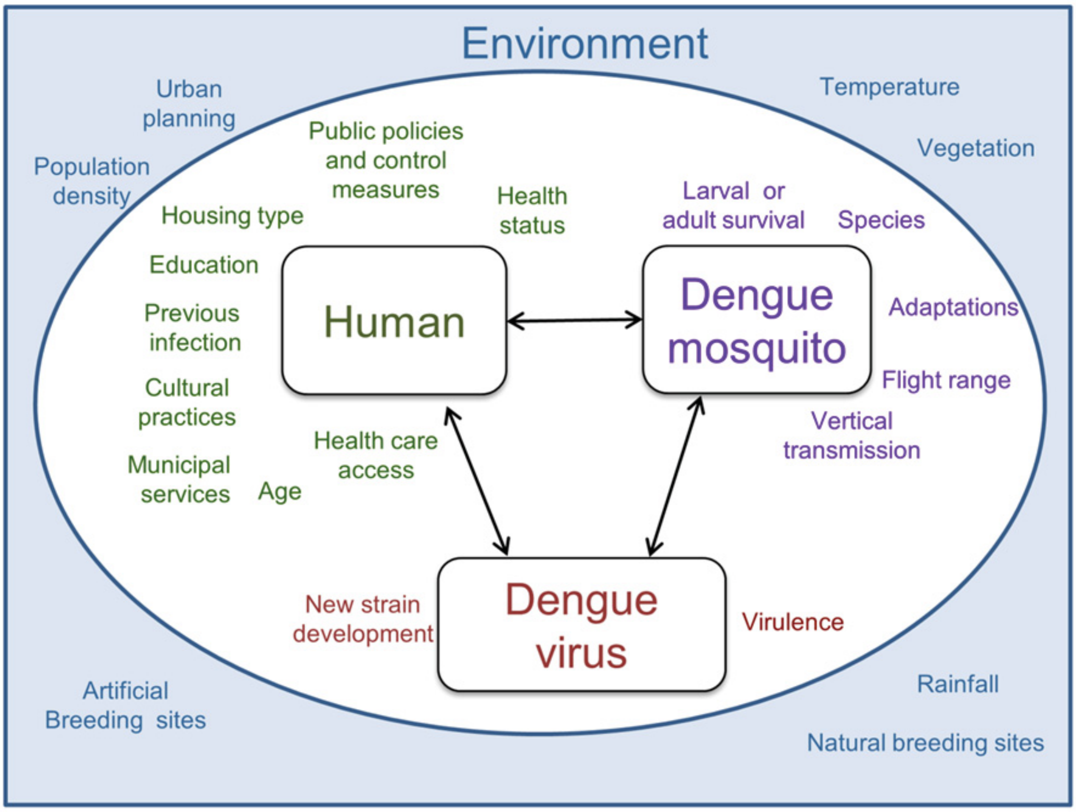
This approach provides the basis for the integration of numerous factors that can lead to a better understanding of the processes involved (HARRIS & LYON, 2014). Since the goal goes beyond solving a complex issue at one level and emphasis is on comprehending the rational for the phenomena impacting different scales, the multisdisciplinary approach becomes relevant (FIORE & SALAS, 2007).

## 4.3 CONCEPTUAL FRAMEWORK OF THE WADI FRAMEWORK

The conceptual framework of the vulnerability assessement used in this research is based on the WADI framework (Figure 22) provided by Dickin, Schuster-Wallace and Elliot (2013). This framework illustrates most of the variables that lead to the spread of dengue. Within this regard, dengue is a function of the socio-economic conditions of human beings, the environment, climate and the vector transmitting the virus. Housing type, education attainment, cultural practices, social amenities, public policies, health status and access to health care are examples of socio-economic conditions that play a role in the spread of the disease. All the aforementioned factors along with climatic factors (rainfall and temperature) and the environmental conditions (temperature, rainfall, vegetation, population density, improper planning and breeding sites) provide ideal conditions for the disease to spread among population at risk.

In countries where access to data is a major issue (Dickin, Schuster-Wallace and Elliot (2013) such as Jamaica, the use of the WADI methodology to analyze vulnerability to diseases transmitted by the *Aedes aegypti* mosquito becomes useful.

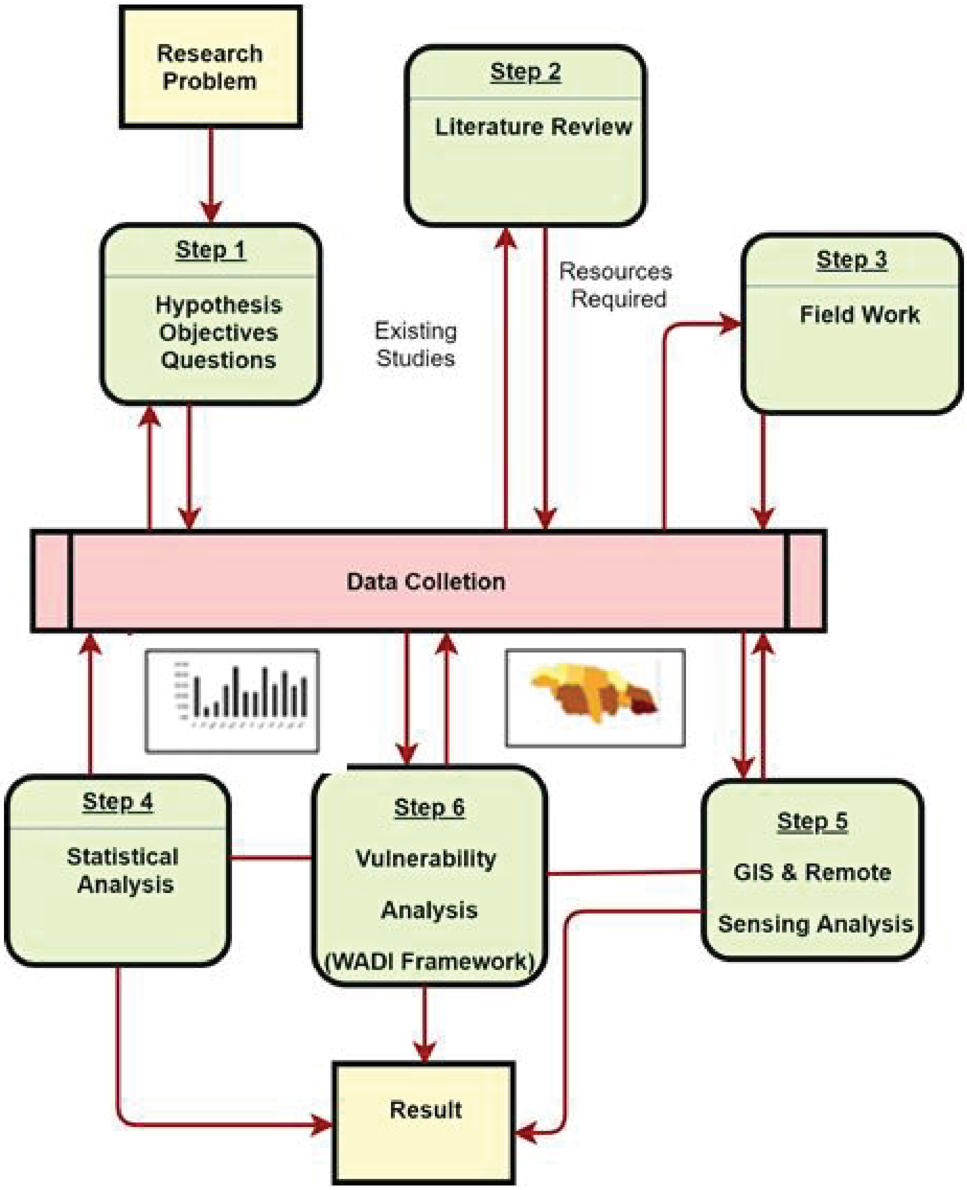
FIGURE 22 - THE WADI CONCEPTUAL FRAMEWORK




Source: Dickin, Schuster-Wallace and Elliot (2013)

The steps utilized in this research are summarized in the flow chart in Figure 23. Following the identification of the problem, the next step included the formulation of the objectives, questions and hypotheses from data gathered. Step 2 included a comprehensive review of pertinent and relevant literature sources as a part of the data collection process while step three takes into account the fieldwork. Ultimately, statistical analysis, GIS and remote sensing analysis and the vulnerability assessment are incorporated in steps 4, 5 and 6 respectively.

FIGURE 23 - METHODOLOGICAL FLOW CHART




SOURCE: Author (2017)

## 4.4 DATA COLLECTION TECHNIQUES

The secondary data used in this research included environmental, climate, socio-economic and dengue data. Some of these data are available within the public domain while others such as dengue had to be requested. The Normalized Difference Vegetation Index (NDVI) from the Moderate Resolution Imaging Spectroradiometer - MODIS was used to represent the vegetation greenness and was obtained from Google Earth Engine. MODIS is a sensor with various spatial resolutions (250m, 500m and 1km) on board the NASA Terra and Aqua satellites that were launched in 1999 and 2002 respectively. On the other hand, Google Earth Engine - GEE is a cloud- based platform that gives free access to pre-processed and georeferenced satellite data (GEE, 2017) that would have been tedious to acquire from other sources. With this tool, data can be imported and analysed as time series or change detection using programming languages written as codes from the code editor. In the same manner, visualization is possible through the console that also permits downloading of the data as CSV format or as graphs.

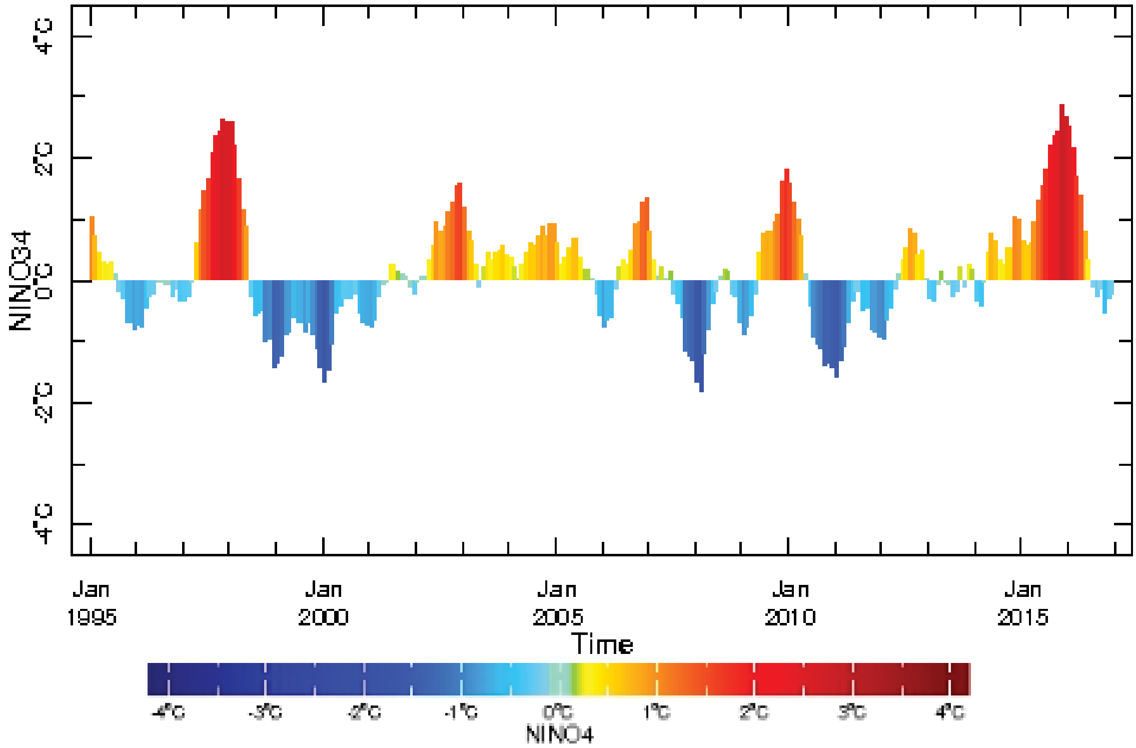
Satellite derived precipitation data from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) was obtained from the IRI Data Library available at Columbia University in New York while land surface temperature (LST) was procured from MODIS using Google Earth Engine. The space derived rainfall products was validated using precipitation data obtained from weather stations including the Meteorological Service of Jamaica.

Socio-economic data were collected from STATIN and PIOJ. Additionally, institutions and organizations engaged in dengue research such as the University of the West Indies were contacted during fieldwork in 2018.

Dengue data from 1995 to 2016 for Jamaica were collected from PAHO while yearly dengue data at the parish level between 2010 and 2015 were obtained from the MoH prior to fieldwork. During fieldwork, one year (2016) of dengue data at the community level was provided by MoH and also weekly data at the national level for 2010 to 2016.

Further analysis of the dengue data was conducted with the El Niño-Southern Oscillation (ENSO) from the NIÑO3.4 Index (Figure 24) between 1995 and 2016. The episodes with El Niño range from yellow to red while La Niña periods are represented in blue. The classification of El Niño and La Niña years are provided in Table 11.

FIGURE 24 - EL NIÑO AND LA NIÑA ACTIVITY BASED ON NINO3.4 INDEX BETWEEN 1995 AND 2016




SOURCE: IRI DATA LIBRARY

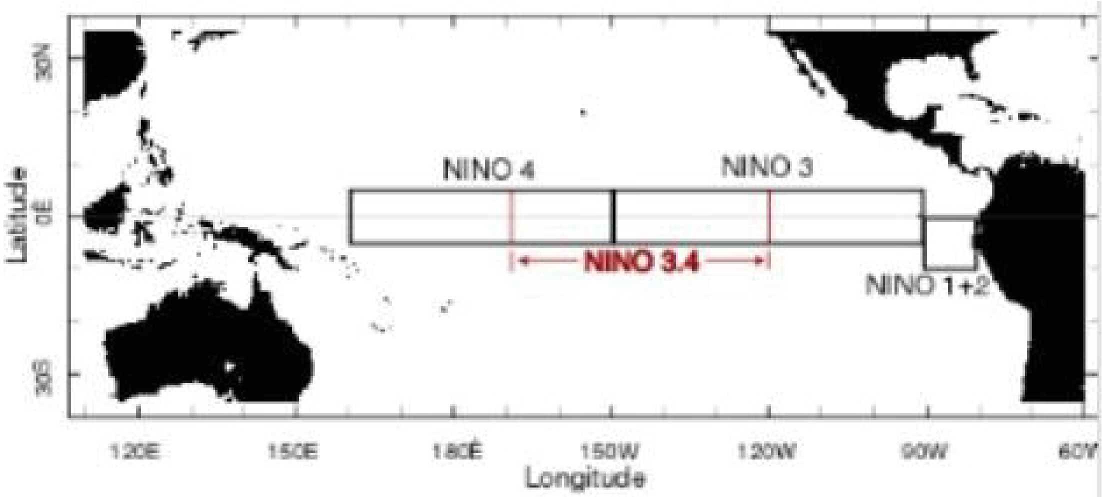
TABLE 11 - EL NIÑO AND LA NIÑA INTENSITY FOR 1995 TO 2016

| **El Niño** | | | **La Niña** | | |
|---|---|---|---|---|---|
| **Weak** | **Moderate** | **Very Strong** | **Weak** | **Moderate** | **Strong** |
| 2004-2005 | 1994-1995 | 1997-1998 | 2000-2001 | 1995-1996 | 1998-1999 |
| 2006-2007 | 2002-2003 | 2015-2016 | 2005-2006 | 2011-2010 | 1999-2000 |
| 2014-2015 | 2009-2010 | | 2008-2009 | 2011-2012 | 2007-2008 |
| | | | | | 2010-2011 |

SOURCE : https://ggweather.com/enso/oni.htm

A simplification of the NIÑO3.4 Index can be visualized in figure 25 which provides an overview of the different regions where El Niño and La Niño events are monitored.

FIGURE 25 - EL NIÑO REGIONS




SOURCE: IRI DATA LIBRARY (2017)

Notwithstanding that, relevant literatures were collected from search engines such as Google Scholar, PubMed, LILACS, SciELO among others. Also, public records with health data generated from institutions along with international health repositories such as WHO and PAHO were included. The methodological approach developed by Mayring (2000) for content analysis was incorporated in this regard. The first step involved placing the materials into categories followed by a reliability check. Afterwards, the analysis process was conducted in the form of a summary for the material to be condensed while preserving the content.

## 4.5 DATA ANALYSIS

In this section, the method used to analyse the level of accuracy in satellite-based rainfall data is presented followed by the steps used for analysing dengue and climate variables. The final analysis involves the vulnerability assessment.

An accuracy assessment of six satellite rainfall products of varying resolution from 2003 to 2013 was conducted using the methodology utilized by Dinku et al. (2007). This incorporated the calculation of the correlation coefficient, mean error (ME) and the root mean square error (RSME). The objective of using these statistical parameters methods is to identify and quantify the level of errors (bias) within the dataset. The data ranged from the Global Precipitation Climatology Project (GPCP); The National Oceanographic and Atmospheric Administration Climate Prediction Center (NOAA-CPC) merged analysis (CMAP); the CPC morphing technique (CMORPH); Tropical

Rainfall Measurement Mission (TRMM); The Global Historical Climatology Network (GHCN)and the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS). These were obtained via the IRI Data library platform. A summary of the products is presented in table 12 followed by a description of each.

TABLE 12 - SUMMARY OF THE SATELLITE PRODUCTS

| PRODUCT | TEMPORAL RESOLUTION | SPATIAL RESOLUTION (°) | STARTING DATE |
|---|---|---|---|
| GPCP | Monthly | 2.5 | 1979 |
| CMAP | Monthly | 2.5 | 1979 |
| CMORPH | Three-hourly | 0.25 | 2002 |
| CHIRPS | Monthly | 0.05 | 1981 |
| TRMM 3B42 | Three-hourly | 0.25 | 1998 |
| GHCN | Monthly | 0.5 | 1950 |

SOURCE: Dinku (2007); Funk et al. (2015)

The Tropical Rainfall Measuring Mission (TRMM 3B42) uses radar, PMW and in situ measurements to estimate rainfall based on a 3-hourly time scale at 0.25° spatial resolution between 50° N and -50°S (HUFFMAN et al. 2007). This product commenced operation in 1998 through 2015. One of the strength of this dataset is the provision of calibration with station data and other post-processing analysis from the Global Precipitation Climatology Centre (GPCC) (HUFFMAN et al. 2007; BYTHEWAY, et al. 2013).

The Global Precipitation Climatology Centre (GPCP) combines satellite (infrared and microwave) and gauge data following uncertainty analysis where errors are identified and removed (HUFFMAN et al. 1997; ADLET et al. 2003). This result in the provision of global estimation of monthly rainfall values since 1979 based on a 2.5 ° resolution in a gridded format HUFFMAN et al. (1997).

CPC Merged Analysis of Precipitation (CMAP) offers rainfall data generated from the merging of satellite (IR and microwave) and gauge measurements at 2.5 ° resolution elaborated by XIE; ARKIN (1997). According to Dinku et al. (2007), bias is eliminated using a series of statistical analysis (blending technique and maximum likelihood approach). The data can be obtained in pentad or monthly time scale and has been made available since 1979.

The Global Historical climatology Network (GHCN) is a database with historical climate data collected from numerous stations dating back to 1950 and has a resolution of 0.5. This product is made available once accuracy assessment is conducted to remove bias generated during the collection process or emanating from changes at the sites. Consequently homogenization process is carried out before the data can be accessed (NOAA, 2017).

The CHIRPS data, developed by the US Geological Survey (USGS) and the University of California Santa Barbara (USB), is comprised of measured observations and satellite data from NASA (Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis version 7 (TMPA 3B42 v7) and NOAA since 1981 at 0.05° spatial resolution for 50°S-50°N. Daily, pentad and monthly data are available from this product (FUNK et al. 2015).

The CPC morphing technique (CMORPH) was first launched in 2002. It contains three-hourly data at 0.25 resolution from different microwave derived sources and has been discussed by Joyce et al. (2004). This product uses PMW and morphing techniques from IR images to estimate rainfall values.

The first step involved plotting the monthly time series of the dataset for the period 2003 to 2013 using the same the point location for the Manley International Airport Weather Station located between 17.9 Nº and 76.8º W in Kingston, Jamaica provided in the GHCN metadata from the IRI Data Library. Secondly, each data source was checked thoroughly to ensure they had the same start and end date. Thirdly, the correlation, ME and RMSE were derived in order to estimate the level of accuracy for each product. The first assessment was conducted using data obtained from satellite based in situ measurements as a reference (GHCN) followed by fine scale resolution (CHIRPS) and the station data obtained from the MSJ also as references. Analysis of the former was completed in Excel.

The ME is based on the average of the sets of values from two datasets. With this method, the assumption of bias can be determined based on the values which are used to predict over estimation or underestimation of the rainfall data obtained from the satellites. The method used is illustrated in equation 1:

$$\text{ME} = \frac{I}{N}\sum_{j=I}^{N}(\text{x} - \text{y}) \qquad \textit{Equation 1:}$$

where N is the number of datasets used (gauge and satellite) indicated by x and y respectively in mm. On the other hand, the RMSE is the square root of the difference of the observed and estimated values (equation 2):

$$\text{RMSE} = \sqrt{\frac{I}{N}\sum_{j=I}^{N}(\text{x} - \text{y})2} \qquad \textit{Equation 2}$$

where N is the number of dataset used (gauge and satellite) indicated by x and y respectively in mm.

To establish the relationship between two datasets x and y, the Pearson Correlation Coefficient was used. The Correlation Coefficient varies from -1 which represents a perfect negative linear correlation to +1 showing a perfect positive linear correlation.

## 4.6 DENGUE DATA

The incidence rate for dengue at the parish level was calculated based on the 2011 population census data obtained from the STATIN using the formula below:

$$\frac{Number\text{ of dengue cases}}{Population} \times 100{,}000 \qquad \textit{Equation 3}$$

The association between dengue and climate data was analysed using correlation analysis in Excel.

## 4.7 6-MONTH SPI INDEX

The Standardized Precipitation Index (SPI) was computed based on 3, 6, 9 and 12 monthly time scales with the Drought Calculator (DrinC) software (Tigkas, Vangelis & Tsakiris, 2013). The SPI uses a threshold from +2 to -2 or less to characterize wet and dry periods respectively (Table 13). With this method, surplus rainfall and discharge data are indicated by positive values whereas a negative SPI and SDI signify dry periods. However, only values of -1.0 and less are classified as drought.

TABLE 13 - SPI CLASSIFICATION

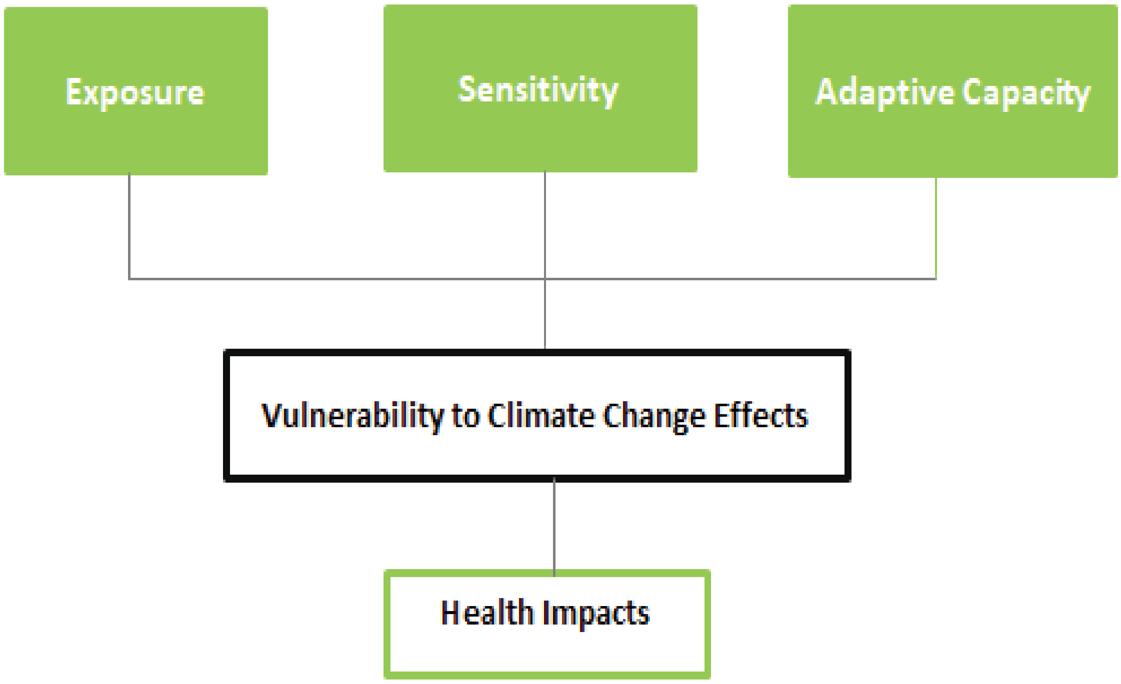
| SPI VALUES | CLASSIFICATION |
|---|---|
| 2.0+ | Extremely Wet |
| 1.5 to 1.99 | Very Wet |
| 1.0 to 1.49 | Moderately Wet |
| -99 to .99 | Near Normal |
| -1.0 to -1.49 | Moderately Dry |
| -1.5 to -1.99 | Severely Dry |
| -2 and less | Extremely Dry |

SOURCE: Tsakiris & Vangelis (2004)

## 4.8 VULNERABILITY ASSESSMENT

In this study, vulnerability is defined as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes” (IPCC, 2001, pg 6). Within this regard, vulnerability to climate change hazards can be seen as a function of exposure, sensitivity and the adaptive capacity put in place for mitigation (IPCC, 2001). Figure 26 shows the three components of vulnerability to climate change.

FIGURE 26 - THE THREE COMPONENTS OF VULNERABILITY TO CLIMATE CHANGE




Adapted from IPCC (2001)

Exposure refers to "the nature and degree to which a system is exposed to significant climatic variations" (IPCC, 2001, p.987). Sensitivity on the other hand pertains to the susceptibility of people at risk (Birkman & Cardona, 2013). This includes socio-economic factors that influence an individual's susceptibility to be exposed to a hazard. Adaptive Capacity refers to "the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC, 2001, p.6).

Both exposure and sensitivity determine the damage sustained to a system but adaptive capacity determines the ability of the system to cope and manage the effects. According to Kovats et al., (2003), vulnerability to climate change from a health perspective can be achieved through the integration of exposure, sensitivity and adaptive capacity by following these steps: formulation of the problem, analysis and integration.

## 4.9 WADI MAPPING PROCESS

The following process was followed in order to create the WADI dengue index: (1) evidence Assessment for WADI framework (2) data assessment and collection of data available within the public domain (3) combination of the susceptibility, exposure and adaptive capacity in order to create an index and (4) final output of the vulnerability index in the form of a map. Table 14, 15 and 16 shows the exposure, sensitivity and adaptive capacity components that were used in the analysis based on Dickin, Schuster-Wallace and Elliot, 2013.

TABLE 14 - THRESHOLDS FOR CREATING EXPOSURE COMPONENT FOR DENGUE

| **Exposure** | **Dimension** | **Value** | **Source** |
|---|---|---|---|
| Population Density (per 1000km$^2$) | <0.1 | 0 | 2011 Census, STATIN |
| | >0.1 to <0.15 | 0.25 | |
| | >0.15 to <0.25 | 0.50 | |
| | >0.25 to <0.30 | 0.75 | |
| | >0.30 | 1.0 | |
| Land cover component | Urban | 1 | Forestry Department of Jamaica |
| | Agricultural/plantation | 0.50 | |
| | Mixed vegetated / agricultural | 0.25 | |
| | Forest | 0 | |
| Temperature | Maximum monthly temperature | >20ºC and ≤34 ºC : linear increase in exposure up to 1; ≤20 ºC or >34 ºC : 0 exposure | WorldClim MODIS CCCCC |
| Precipitation | Monthly cumulative precipitation | <300mm precipitation: linear increase in exposure up to 1; >300mm monthly precipitation: 0 exposure | WorldClim CHIRPS CCCCC |

SOURCE: DICKIN et al. (2013)

TABLE 15 - SUSCEPTIBILITY INDICATORS FOR DENGUE

| | Components | Dimension | Source |
|---|---|---|---|
| Individual | Age under 15 | % of population under 15 years | 2011 Census, STATIN |
| | Age over 65 years | % of population under 15 years | 2011 Census, STATIN |
| Community | Housing quality | Number of housing living in squatter settlement per parish | 2011 Census, STATIN |
| | Piped water | % of households using water closet per parish | 2011 Census, STATIN |
| | Sanitation | % of household using water closet per parish | 2011 Census, STATIN |
| | Garbage Collection | % of household using public and private garbage collection system per parish | 2011 Census, STATIN |
| | Lack of Education | % of the population with no form of schooling | 2011 Census, STATIN |

SOURCE: DICKIN et al. (2013)

Normally, the adaptive capacity should include the accessibility to health services (hospitals, health centres), vector control measures, community participation and educational level (HARYANTO, 2018). However, due to lack of data, only access to health clinics and female secondary educational level were incorporated (Table 16).

TABLE 16 - ADAPTIVE CAPACITY FOR DENGUE

| | Components | Dimension |
|---|---|---|
| Community | Health care access | % of household >5km from health clinic per parish |
| | Female education Level | % of females completing secondary education per parish |

SOURCE: Dinkin et al. (2013)

The susceptibility indicator is comprised of variables that influence sensitivity to the proliferation of dengue. All the components were standardized using the following equation:

$$Susceptibility\ component\ x = (x - xmin) \,/\, (xmax - xmin) \quad \textit{Equation 4}$$

where x refers to the observed value and xmax and min are the highest and lowest values from the dataset. From this, values were assigned between 0 and 1. However, in some instances, the indicator values were reversed by subtracting the indicator value from 1 to reflect higher or lower vulnerability based on the input data using the suggestions from Morath, Mielbrecht, Bell and Livengood (2016). The following equation shows the method used to reverse the indicator value:

$$Reversed\ indicator\ =\ 1 -\ compressed\ value \qquad Equation\ 5$$

The SMCE with the WADI approach involved the use of data with different types of spatial and temporal resolution. Specifically, the vulnerability assessment included the following scenarios: (1) World Clim rainfall and temperature dataset for 1970-2000 (A); (2) CHIRPS rainfall and LST as proxy for air temperature from MODIS for the period 2002 to 2016; (3) Maximum temperature and rainfall scenario using RCP 8.5 for 2030 downscaled at 25km based on RegCM4.3.5 Model.

The latter was obtained from The Caribbean Community Climate Change Centre (CCCCC) which is the principal institution within the region with responsibility for climate change and adpatations. The maximum temperature for 2030 was converted from Kelvin to Degrees Celsius in Excel. Also, the total precipitation rate for 2030 was converted to mm per month.

For climate change analysis, the population and land cover data are normally projected to reflect the period under investigation. However, as indicated by Brunckhorst, et al., (2011), one of the limitations of assessing vulnerability to climate change relates to the inability to predict some of the key variables between 2030 and 2070. This is further compounded by inaccessibility to data. In this study, politics related to accessing spatial data in Jamaica prevented the incorporation of the expected future land use and population density in the climate change scenario hence, the 2011 data were used. Furthermore, it is envisaged that increase in the urban population of Jamaica will be minimal (4%) by 2030 (Jamaica Country Report, 2016). Moreover, a study on the Caribbean island of Dominica by Richards (2018), showed the insignificance of population density as an indicator for the spread of dengue fever on the island.

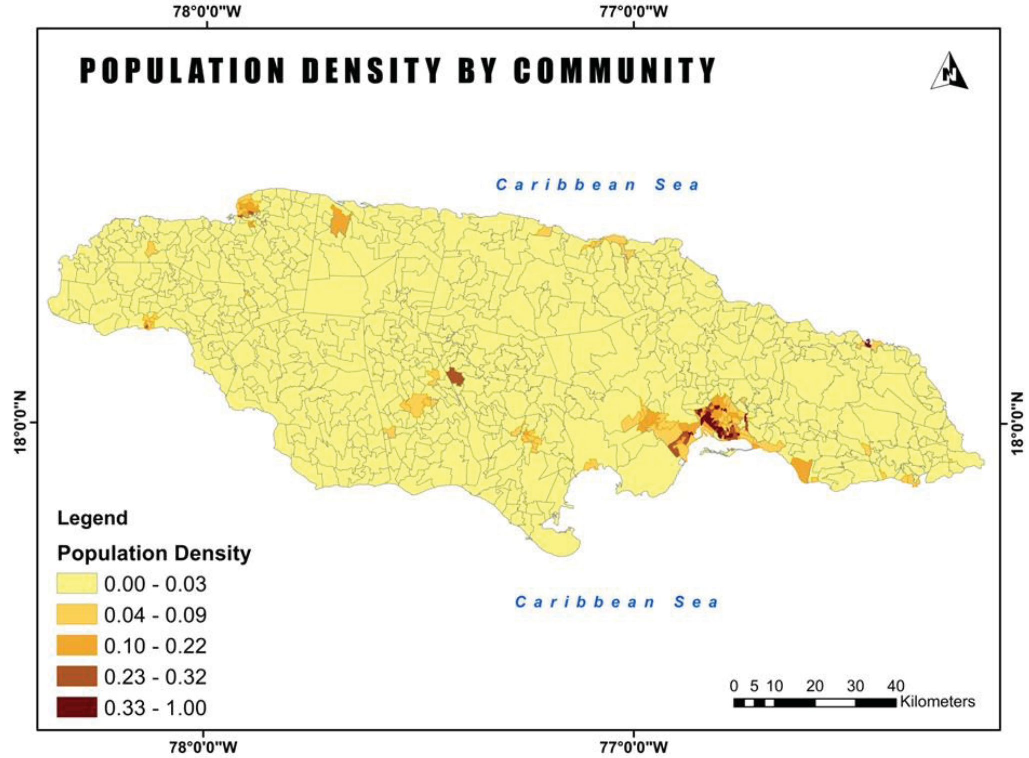
The spatial data were prepared in ArcGIS and analysis was conducted in ILWIS (The Integrated Land and Water Information System). ILWIS was developed by the International Institute for Aerospace Survey and Earth Sciences in The Netherlands. This software permits the manipulation and analysis of both raster and vector data. SMCE in ILWIS allows for the standardization of components and can be applied to various scenarios. The first step included a selection of the problem. After this, the factor maps were generated and then standardization of the input data was conducted using the goal and benefit options. The next step involved the application of weights to the factor maps. A weighting of 75% was applied to the exposure component and 12.5% to for susceptibility and adaptive capacity respectively similar to Dickins (2014). However, in the WADI framework by Dickin (2014), only the exposure (75%) and sensitivity (25%) were included, though the latter was comprised of adaptive capacity. The final output is a map with values ranging from 0 to 1, where 0 highlighted in red represents unsuitable areas and values near 1 ranging from yellow to green are more suitable areas.

## 4.10 VULNERABILITY INDICATORS

### 4.10.1 Population Density

While high population density is normally associated with the proliferation of dengue, it has had a negative relationship with the disease in some countries. In Sri Lanka, high dengue incidence was reported in some districts with high population density although low incidence was found in some populated areas (Sirisena et al., 2017). One explanation for the foregoing, relates to difference in elevation, as dengue seems to be restricted to altitude below 1000m in that country (Sirisena et al., 2017). Interestingly, high dengue incidence was discovered in areas with low population density in Sao Paulo, Brazil and when high incidence was found in populated areas, they were confined to low level rooms in apartment buildings (Araujo et al., 2015). Likewise, Schmidt, Suzuki & Thiem (2011) revealed that population density did not cause an increase in dengue cases in Vietnam. Figure 27 shows the normalized population density used in the analysis. From the figure, the highest population density can be found in Kingston and St. Andrew and in Southeast Portmore.

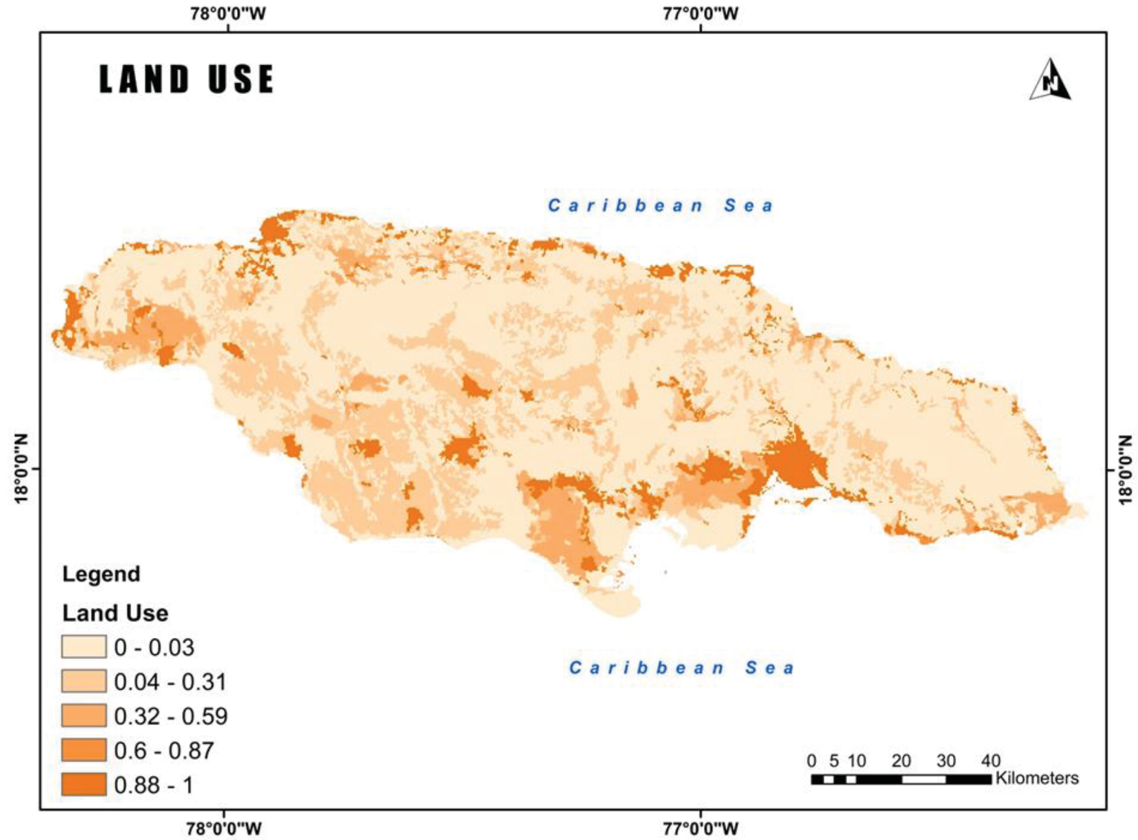
FIGURE 27 - JAMAICA - POPULATION DENSITY BY COMMUNITY




4.10.2 Land Use

Dengue became an urban disease in the Americas due to the rapid urbanization and the failure of the *Aedes aegypti* eradication programme in the 1950s (Mulligan, Dixon, Sinn & Elliott, 2015). In Jamaica, the term urban relates to regions with at least 2,000 people with adequate facilities and amenities for modern living (STATIN, 2011). Even though majority of the informal settlements are concentrated around built up areas on the island, some squatter settlements are located in forest reserves and protected areas, (Rapid Assessment of Squatting Report, 2007). Despite the tendency for the disease to occur mostly in urban areas, greater risk to dengue has been reported in rural areas of Vietnam by Tai et al., (2005) and Schimdt, Suzuki & Thiem (2011) due to the ecological conditions that promote the spread of the disease (Tai et al., 2005). Figure 28 shows the normalized Land use used in the analysis.

FIGURE 28 - JAMAICA - LAND USE

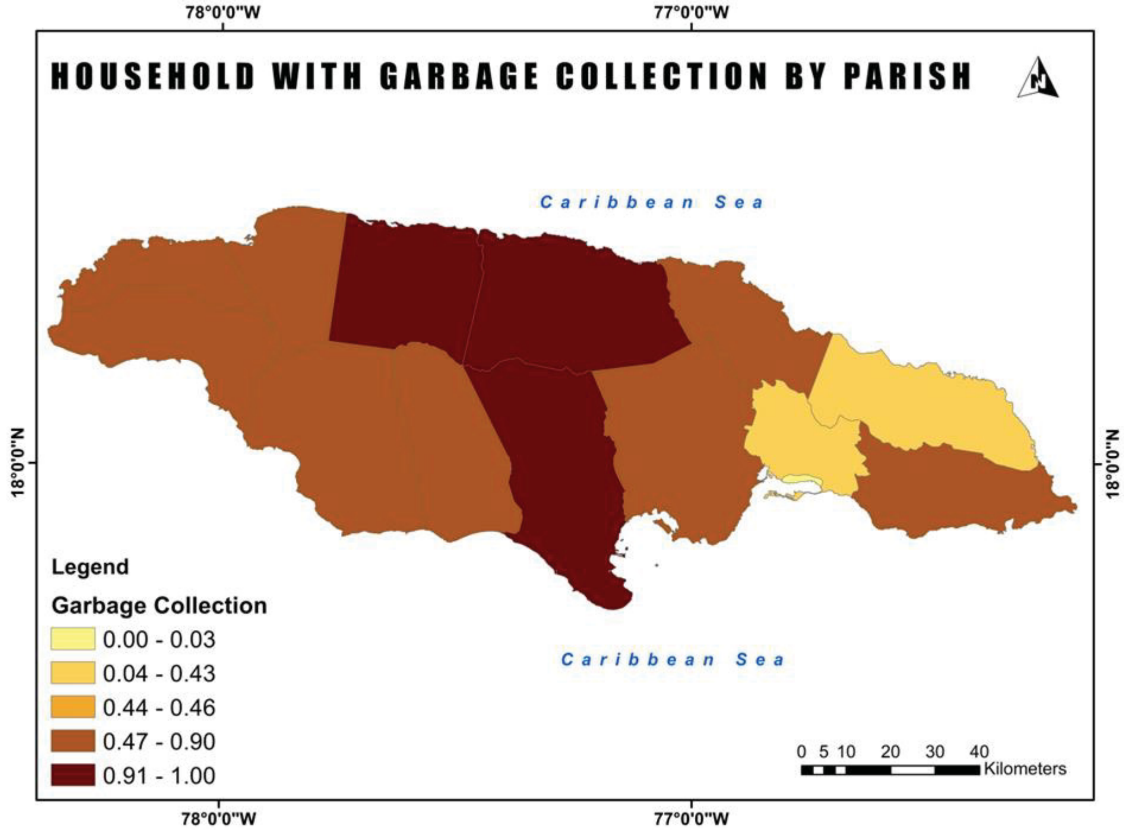



From the figure, it is evident that majority of the population (score of 1) reside in urban areas that are mainly close to coastal areas while forested areas are located inland (See appendix).

4.10.3 Garbage Collection

Irregular garbage collection has been linked to the spread of dengue (MacCormack-Gelles et al., 2018). In many informal settlements in Jamaica, 63% used open dumps and burning of garbage as their disposal methods while only 37% of the inhabitants benefited from garbage collection (Rapid Assessment of Squatting Report, 2008). Recommendation was made by MacCormack-Gelles et al., (2018) for special attention to be placed on Scrapyards and places with tyres for vector control intervention even during periods without outbreaks. Figure 29 shows the percentage of household that uses puplic and private garbage collection to discard waste.

FIGURE 29 - JAMAICA - PERCENT HOUSEHOLD USING PUPLIC AND DPRIVATE GARBAGE COLLECTION SYSTEM PER PARISH

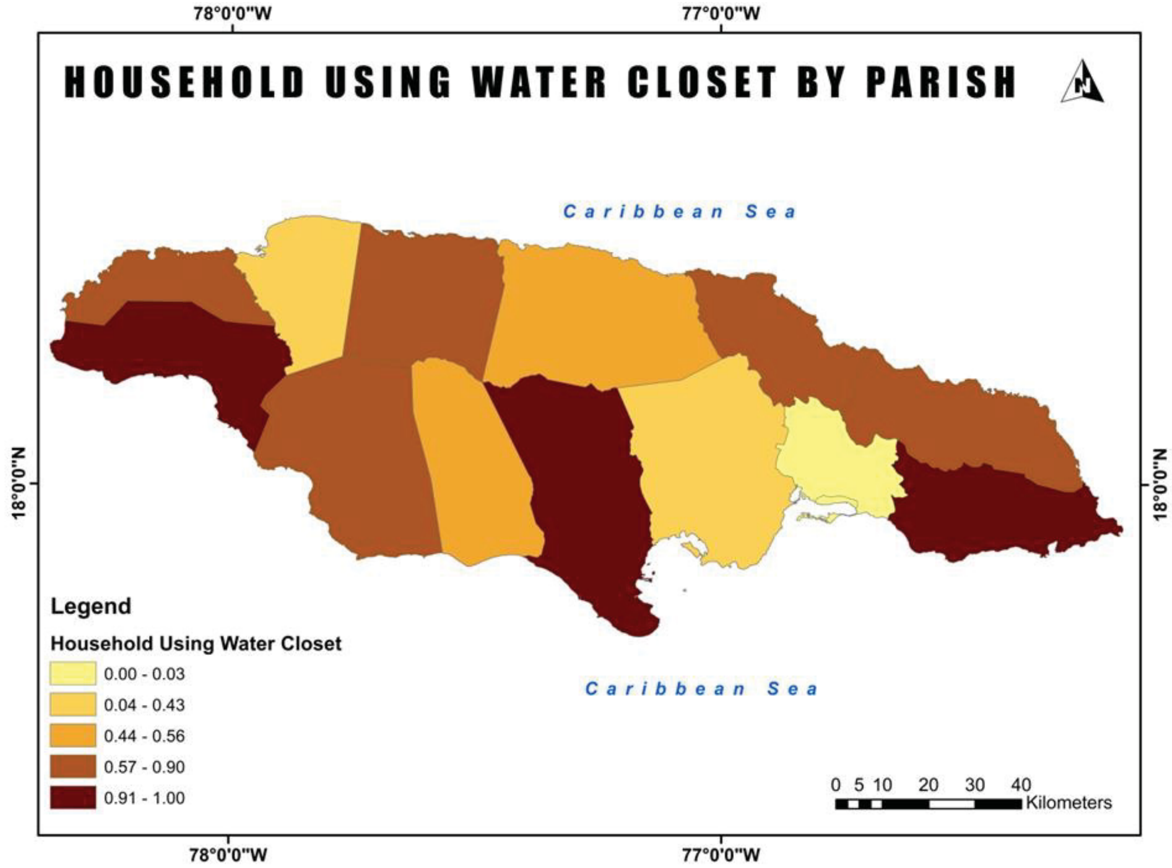



Based on the figure, Clarendon, Trelawny and St. Ann have the lowest access to garbage collection services while Kingston and St. Andrew and Portland had greater access.

4.10.4 Water Closet

In regards to toilet facility, about 201,455 households still use pit latrines while 18,104 do not have toilet facilities. In fact, the use of pit latrines is also present in educational institutions which led the Ministry of Education of Jamaica to implement Sanitation Projects geared towards their replacement with flush toilets (Jamaica Observer, 2012; 2016). Figure 30 demonstrates the percentage of households using piped water per parish.

FIGURE 30 - JAMAICA - HOUSEHOLD USING WATER CLOSET PER PARISH

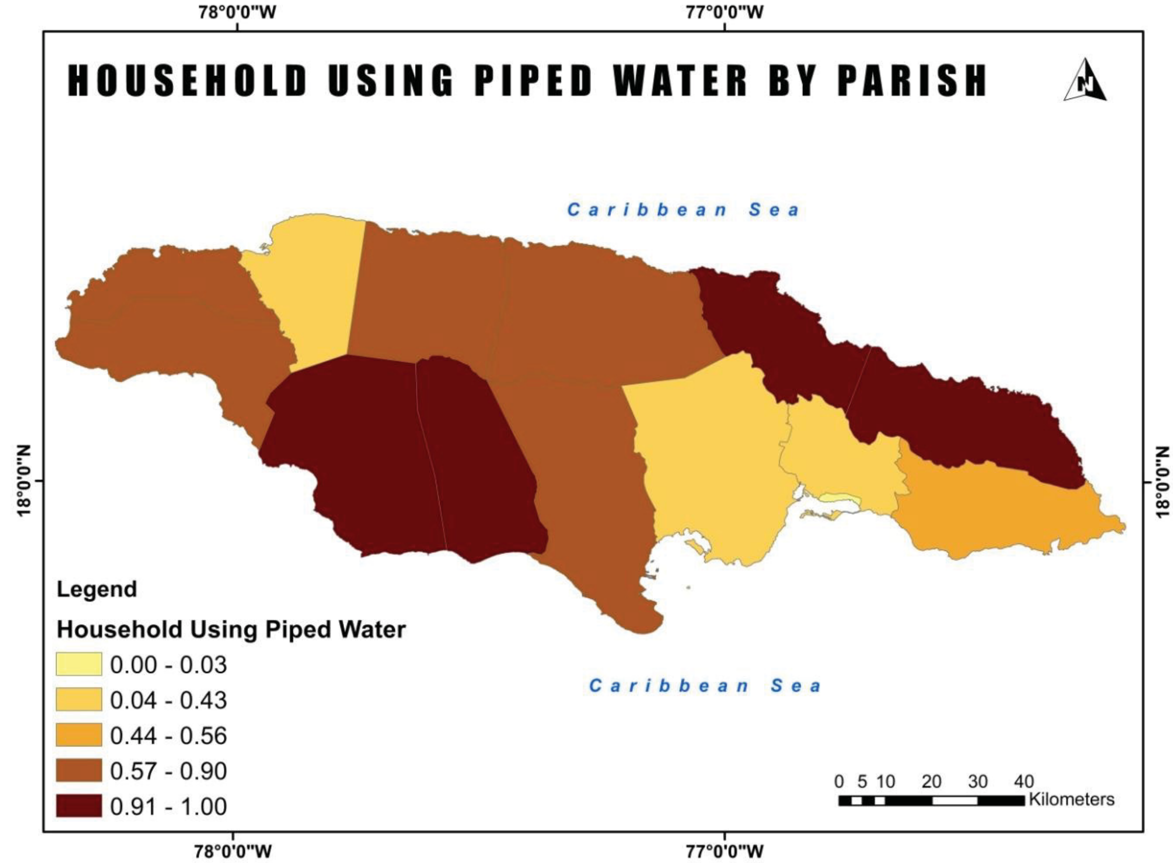



Kingston and St. Andrew are the only parishes with a high percentage of households using water closet. On the other hand, St. Thomas, Clarendon and Westmoreland have the least access.

### 4.10.5 Piped Water

Irregular and lack of water supply have also been identified as factors that promote the spread of dengue. As indicated by MacCormack et al., (2018), the intermittent supply of water even when adequate supply is available, leads to the storage of water and the creation of breeding sites for the mosquito vector that causes dengue. In Jamaica, Heslop-Thomas (2006) noted that greater risk to dengue was found in households in Montego Bay Jamaica that stored water due to lack of piped water supply. This finding coincides with other studies in other countries in the Americas (Ryan et al., 2019). Figure 31 shows the percent household using piped water in Jamaica.

FIGURE 31 - JAMAICA – HOUSEHOLD USING PIPED WATER

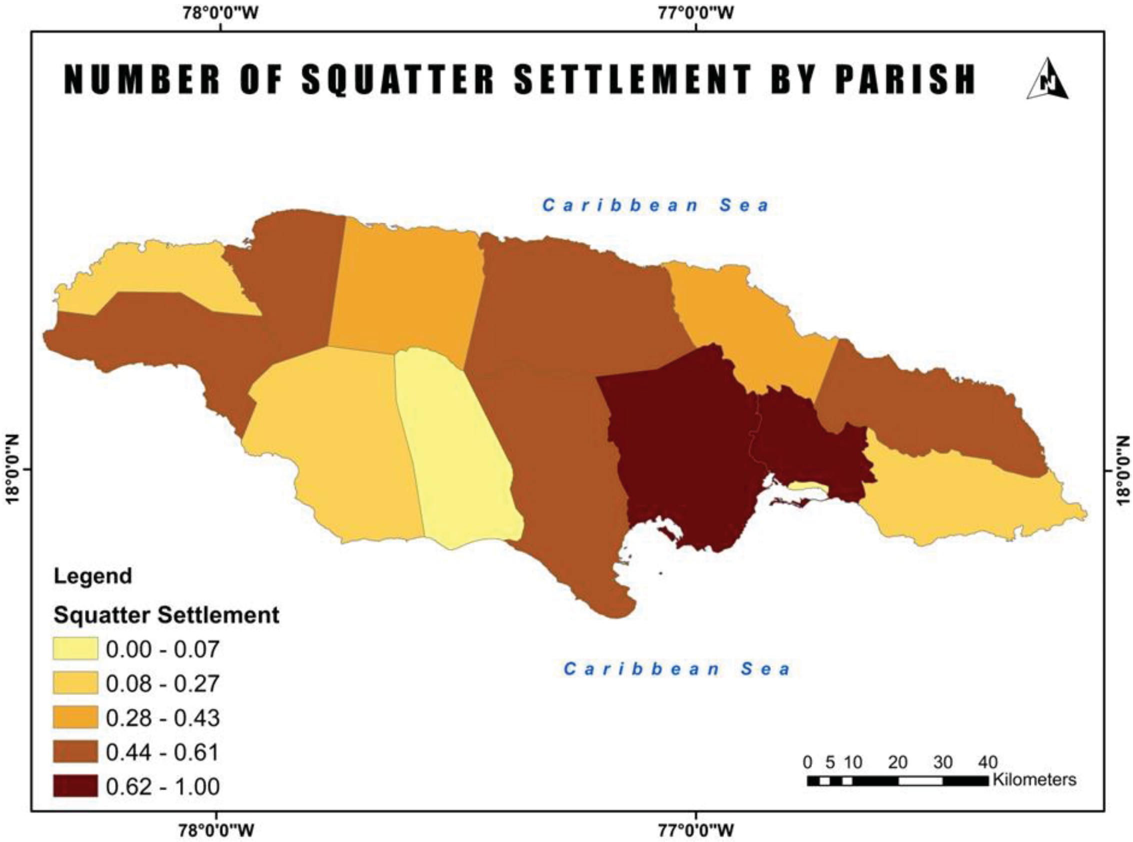



The percentage of household using piped water varies across the island. Households using piped water seem to be lowest in Manchester, St. Elizabeth, St. Ann and Portland compared to St. James, St. Catherine, Kingston and St. Andrew where piped water use is higher.

4.10.6 Informal Settlement

Undeniably, the spread of dengue is also related to housing conditions especially where informal settlements are located. As a result, dengue is often seen as a disease that affects the poor but as noted by Mulligan, Dixon, Sinn and Elliott (2015), dengue also transcends social barriers and is also found in wealthy neighborhoods. For example, high incidence of dengue was found in both slums and wealthy regions with high LST in Sao Paulo, Brazil (Araujo et al., 2015). While squatting in Jamaica used to be confined to marginal lands in the past (Tindigarukayo, 2017), today some of these settlements are located near upscale residential areas (The Jamaica Gleaner, 2016). Actually, about 20% of Jamaicans reside in squatter settlements with about 82% located in urban areas (Rapid Assessment of Squatting Report, 2007) and roughly 25% situated within 100m of waterways (National Squatter Survey, 2004). At the parish level, Saint Andrew accounts for majority of these informal settlements followed by Saint Catherine while Kingston records the lowest. Figure 32 shows the number of squatter settlements mapped as at 2007.

FIGURE 32 - JAMAICA - NUMBER OF SQUATTER SETTLEMENT MAPPED AS AT MARCH 2007 BY PARISH

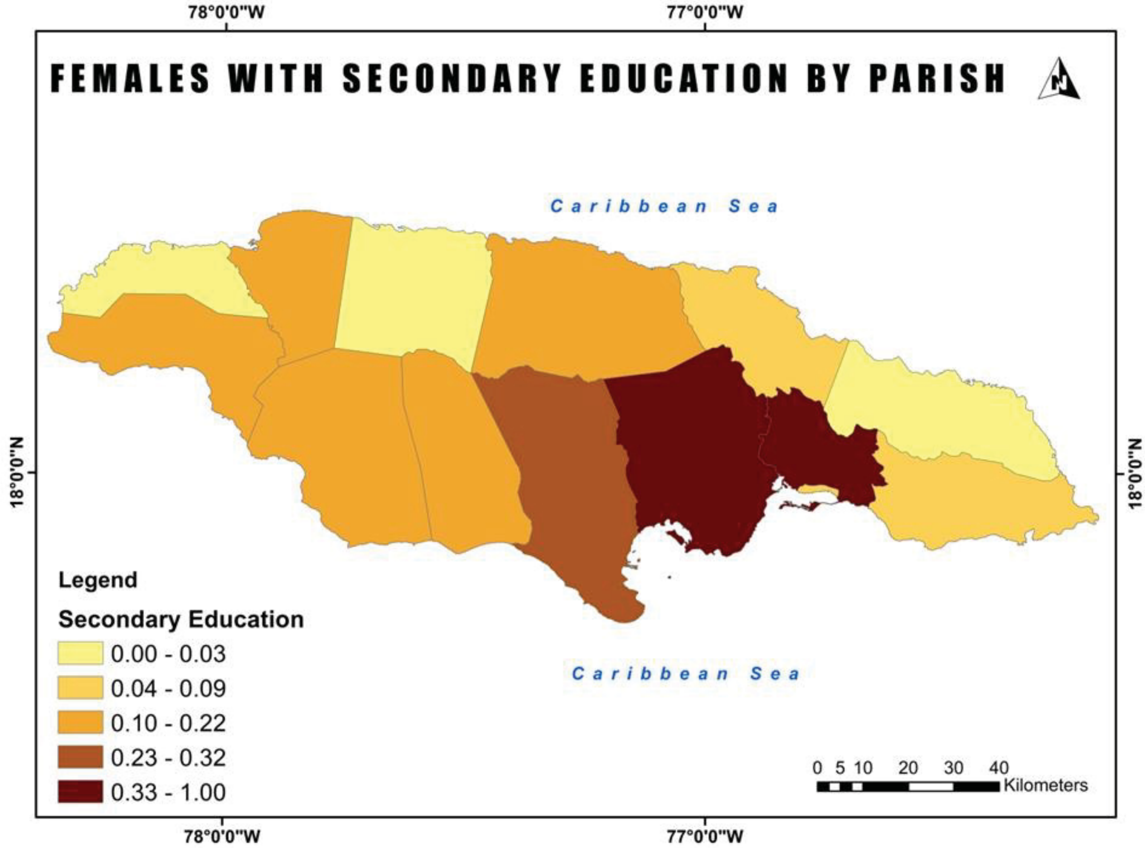



From the figure, the number of squatter settlements mapped appears to be greater in St. Catherine and St. Andrew while Manchester has the lowest.

4.10.7 Females With Secondary School Education

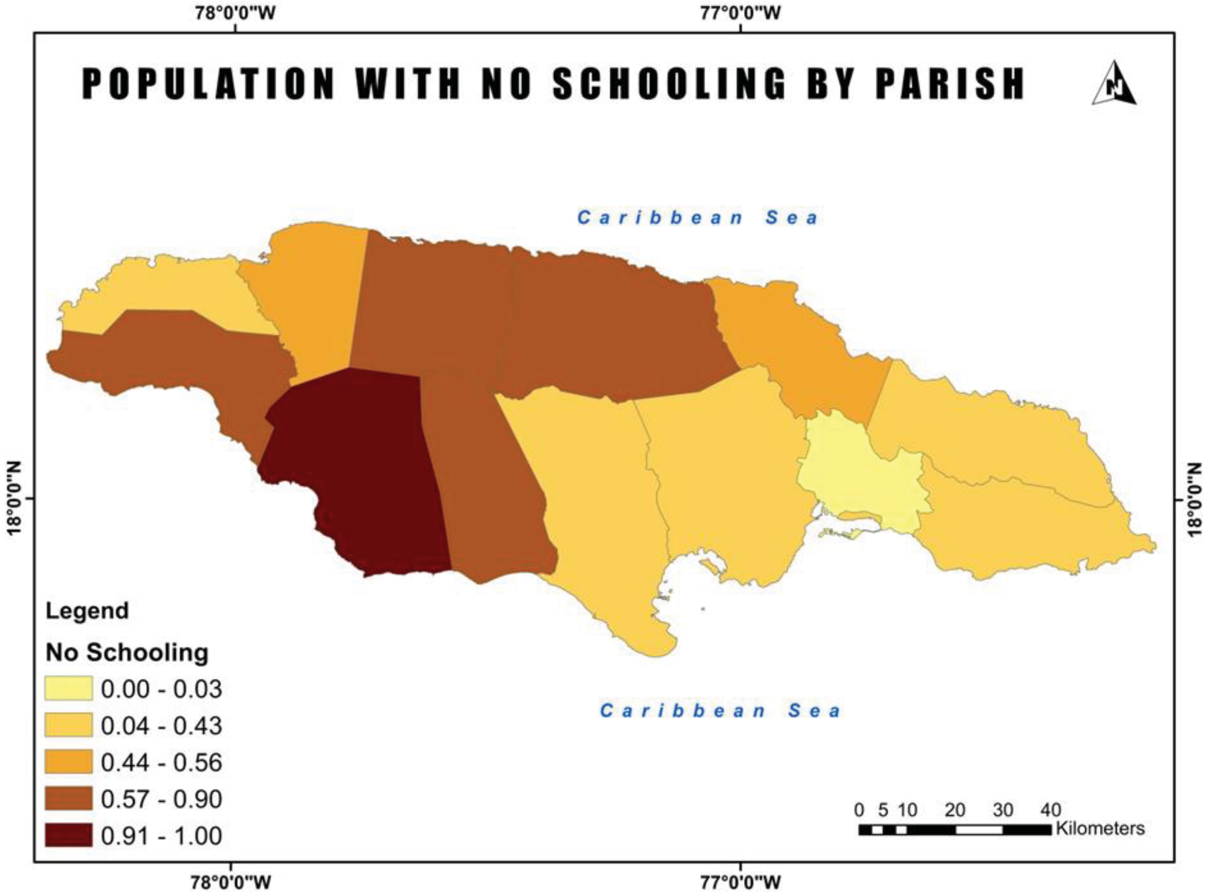
Even though the government of a country has responsibility for dengue control, the wider population also has an obligation to aid in the prevention of mosquito breeding sites (Alves et al., 2015). However, in many instances, the people at risk are incognizant of dengue and ways in which they can reduce the spread of the disease. For example, Heslop-Thomas, 2006) indicated how one community in St. James, Jamaica with majority of females as heads of the household, had limited education and were unable to identify the cause and symptoms related to dengue (Heslop-Thomas, 2006). In contrast, respondents with some level of education in Southeast Brazil were able to identify the dengue vector compared to their counterparts. The percentage of females with secondary school education is shown in Figure 33 while the percentage of population with no form of schooling is illustrated in Figure 34.

FIGURE 33 - JAMAICA - FEMALES WITH SECONDARY SCHOOL EDUCATION PER PARISH




Based on Figure 33, majority of females with at least secondary education are mostly concentrated in St. Catherine and St. Andrew. The parishes with the highest number of females with secondary education include Portland, Trelawny and Hanover. In terms of lack of education, St. Elizabeth has the highest number of people with no schooling while St. Andrew has the lowest (Figure 34).

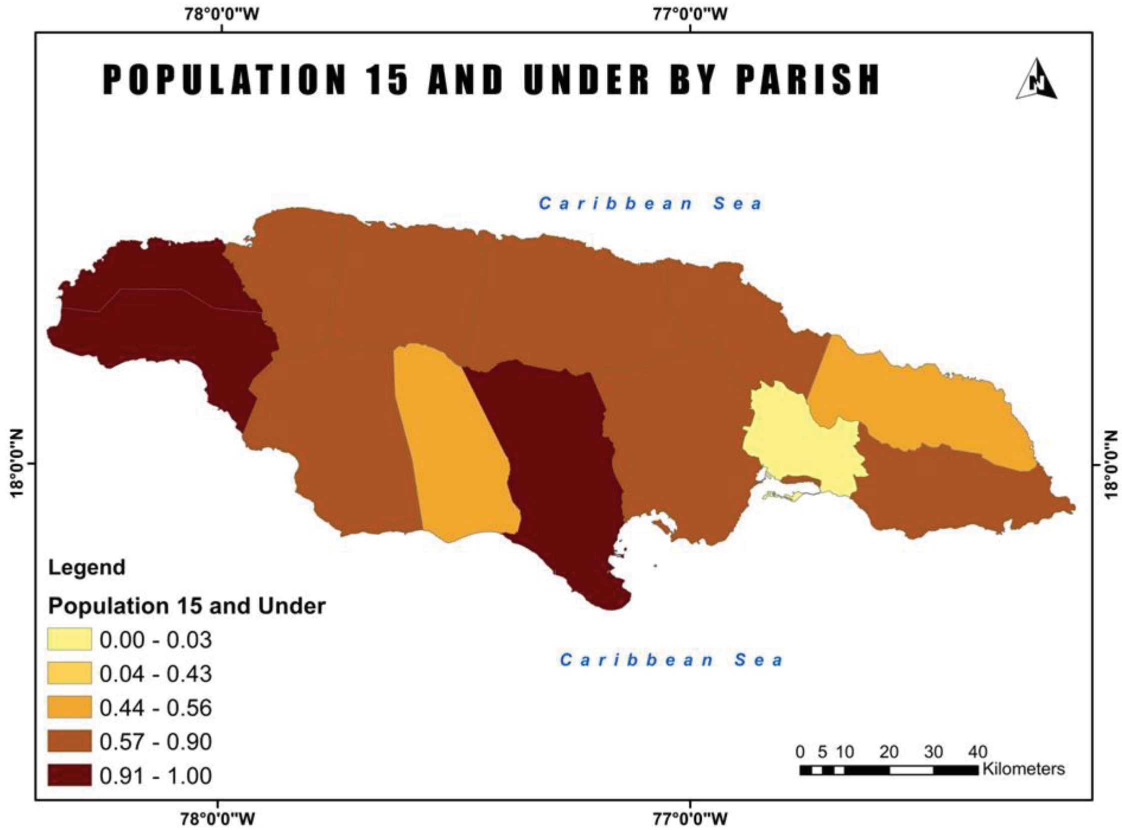
FIGURE 34 - JAMAICA - POPULATION WITH NO SCHOOLING




4.10.8 AGE

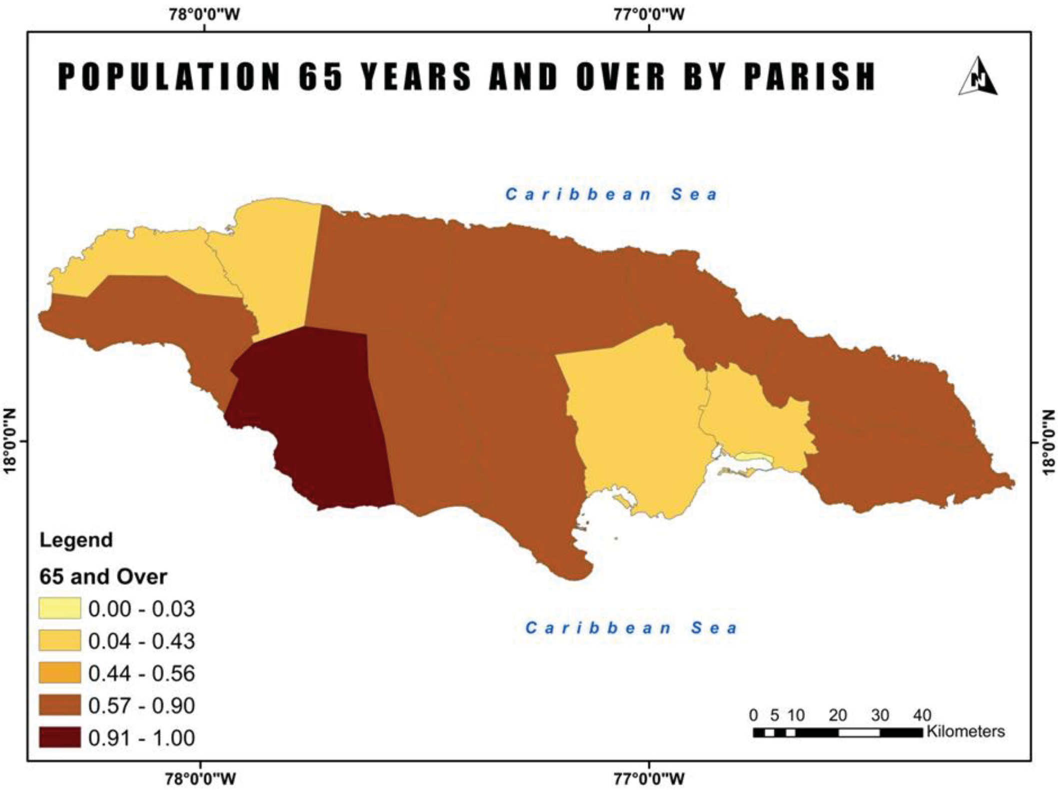
In regards to the severity of dengue among populations at risk, age is one of the determining factors (Guzman, 2002). Generally, dengue is more prevalent in children and the elderly as they are normally at their abode for long periods of time (Mattos-Almeida et al., (2007). While Thai, Nishiura and Hoang (2011) describe dengue as a pediatric disease, Lee et al., (2013) show how patients over 65 years tend to have more health related complications from dengue than children. In Barbados, dengue was mostly observed in patients 0-15 years (Kumar, Gittens-St. Hilaire & Nielsen, 2018). In Puerto Rico, hospitalization and death rate from dengue were higher in patients 65 and over than their younger counterparts (Garcia-Rivera & Rigau-Perez, 2003). Jamaica's population pyramid shows a demographic transition with the second largest increase being among the 60 and over age range (WHO, 2018). This implies that the elderly might face higher rates of illnesses as they are more vulnerable to infections. Figure 35 and 36 show the percentage of population under 15 and over 65 years old respectively.

FIGURE 35 - JAMAICA - PERCENTAGE OF POPULATION 15 AND UNDER PER PARISH




The population with highest number of people 15 years and under include Clarendon, Westmoreland and Hanover while St. Andrew has the lowest. For population over 65 years old and over, St. Elizabeth has the highest while St. Catherine, Kingston, St. James, Hanover and St. Andrew account for the lowest.

FIGURE 36 - JAMAICA - PERCENT OF POPULATION OVER 65 YEARS OLD



# CHAPTER 5

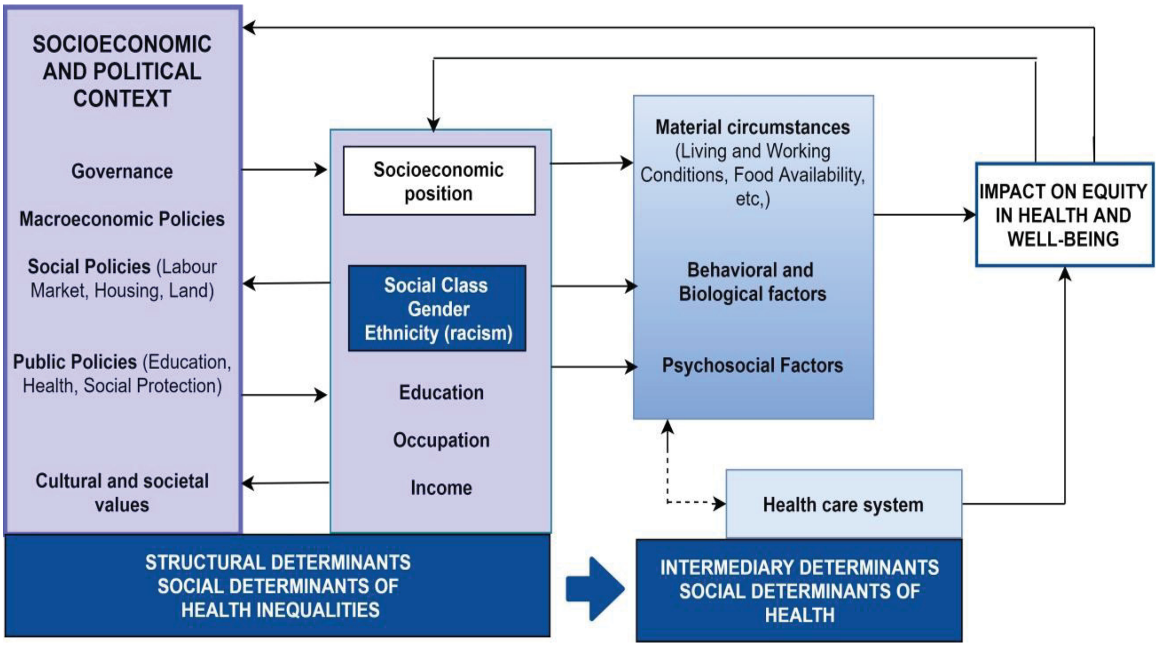
# 5 THEORETICAL CONCEPTS

An analysis of the relationship between the climatic and environmental factors that lead to the spread of dengue is presented in this chapter. It commences with the social and environmental determinants of health and vice versa for dengue. Additionally, this chapter will provide a summary of the history of the *Aedes aegypti* mosquito in the Americas and the relevance of Health Geography in studying this phenomenon followed by limitations that exist when studying the disease pertaining to data access.

## 5.1 SOCIAL AND ENVIRONMENTAL DETERMINANTS OF HEALTH

Various factors affect health which can be distinguished into social and environmental determinants. However, the traditional approach to theses determinants are normally illustrated in isolation. For example, the conceptual framework for social determinants of health produced by the WHO Commission on Social Determinants of Health (Figure 37), shows that health can be influenced by structural and intermediary determinants (Solar and Irwin, 2007). With this concept, structural determinants incorporate the socio-economic and political context to illustrate how one's socio-economic status is influenced by politics and societal structure which is a predilection for the intermediary determinants. In this manner, the policies at the national level create gaps between the rich and the poor and reinforce the hierarchical configuration that determines access to resources and power through education, work and income which leads to inequality in health. For example, individuals with poor education, low income, unemployed or low salary and marginalized because of class, race or gender, have the propensity to be exposed to certain preconditions that affect health outcomes due to government policies and cultural norms.

FIGURE 37 - SOCIAL DETERMINANTS OF HEALTH

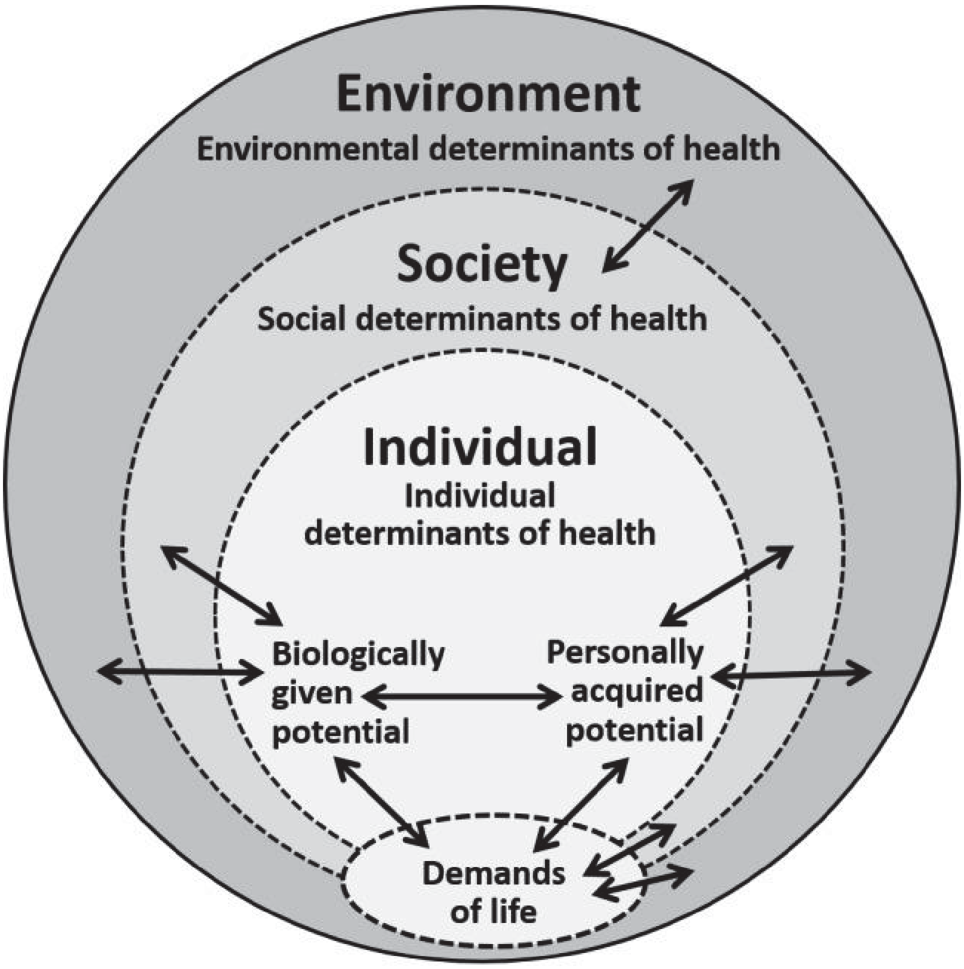



SOURCE: Adapted from Solar and Irwin (2007)

Furthermore, from a gender standpoint, males and females are normally affected by different types of diseases. The foregoing therefore forms the precursors for the intermediary determinants which are based on material circumstances (living and working conditions, food availability etc.), behavioural, biological and psychosocial factors, along with the health care system that impacts health. Essentially, individuals can be predisposed to illnesses based on living and working conditions or when there is inaccessibility to the health care system. In a study by United Nations (UN) HABITAT (2003; 2007), about 43% of people living in urban areas worldwide live in slums are poor, unemployed, have poor living conditions and poor health.

One of the demerits of the abovementioned concept is that it fails to incorporate the environmental determinants that are normally interrelated. Conversely, a more relatively new approach to the determinants of health is exhibited by the Meikirch Model (Bircher and Hahn (2017) involving four components: (1) environmental determinants (2) social determinants (3) individual determinants and (4) Demands of life. The overarching framework of the model focuses on the individual and shows how different factors affect one's health especially those marginalized by society. Therefore, the demands of life constitute the basic necessities (access to water, waste disposal, food etc.) required for survival which are predetermined from birth or are personally acquired in order to respond to and adapt to the modern world. Thus, individuals will have different type of exposure depending on society and their environment. The social determinants are intertwined with the demands of life where poverty, poor standard of living and inequality are concerned and are some of the factors that lead to poor health. For the environmental determinants, these can be explained in terms of the living and working conditions such as air quality, food, soil, disasters, natural resources and also climate which can lead to exposure to certain kinds of disease. Unlike other approaches, this model focuses on the individual and shows how different factors affect one's health especially those marginalized by society. Figure 38 illustrates how socio-environmental factors affect the spread of diseases.

FIGURE 38 - SOCIAL AND ENVIRONMENTAL DETERMINANTS OF HEALTH




SOURCE: Bircher and Hahn (2017)

Authors such as Bircher and Hahn (2017) have shown how geographical location can determine the health of an individual. This was supported in a recent study conducted by Prüss-Ustin et al., (2017), where over 76% of the 133 diseases examined were environmentally connected. Moreover, cases of goiters prior to the increase use of salt in

Switzerland were associated with a shortfall of iodine which is generally in short supply in that country (Bircher and Hahn, 2017). Further, reduction in environmental risks could lead to decrease in up to one fourth of the infections recorded worldwide leading to a better quality of life (Prüss-Ustün et al., 2017).

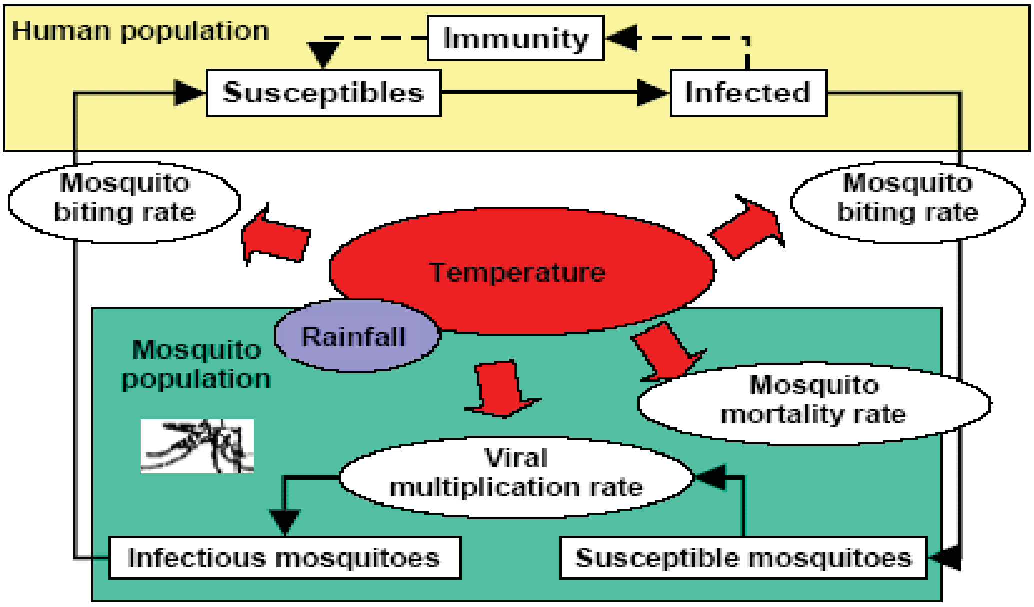
## 5.2 ENVIRONMENTAL AND SOCIO-ECONOMIC FACTORS THAT IMPACT DENGUE

### 5.2.1 Climate Variables

Climate can be described according to the mean and variability of weather pattern over a 30year period (IPCC, 2007). Some of the climatic factors include humidity, precipitation and temperature. These components can have a direct or indirect impact on the ecology of the dengue vector as they determine growth, reproduction and interaction between host and mosquito (Morin et al. 2013). According to Tun - Lin et al., (2000), temperature suitability for the presence of the *Aedes aegypti* mosquito range from 20 °C to 30 °C in Australia. Elsewhere, 11.9 °C has been observed as the minimum temperature for the dengue virus to survive (Mccarthy et al. 2001). Within this regard, temperature affects the development, longevity and incubation period of mosquito in that, a higher or lower value determines its survival (Hopp & Foley, 2001).

However, it is important to note that temperature alone cannot account for the abundance of dengue as rainfall act as one of the determinants for the survival rate of mosquitoes (Prompou, 2005; Jansen & Beebee, 2010; Rueda et al. 1990). For Promprou (2005), an increase in precipitation provides the ideal condition for the creation of mosquito habitats which can lead to an increase in the mosquito population. On the other hand, extremely heavy rainfall reduces the presence of mosquitoes through the destruction of mosquito breeding sites but there exist a possibility whereby mosquito borne diseases can be increased after runoff once the virus is present (Nasci & Moore, 1998). Additional details about the impact of rainfall and ponding creating breeding sites can be obtained in from Gubler et al. (2001). Nevertheless, a lack of rainfall can lead to drought conditions resulting in the inadequate storage of water which is a source point for mosquitoes (WHO, 2012). Figure 39 illustrates the impact of rainfall and temperature on the biting rate, mortality rate and multiplication of infected mosquitoes that infect human population with no immunity.

FIGURE 39 - THE IMPACT OF RAINFALL AND TEMPERATURE ON THE SURVIVAL OF MOSQUITOES




SOURCE: Martens et al. (1995)

### 5.2.2 Flood and Dengue

Some studies have demonstrated the relationship between floods and dengue. In 2007, Brathwaite-Dick et al. (2012) reported about 7,332 cases of dengue fever in Bolivia that were linked to major flooding influenced by El Niño. Equivalently, high vulnerability to dengue fever was observed for Honiara in the Solomon Islands in April 2014 after a trough caused flooding in many provinces (Shortus et al. 2014). According to the authors, the water from the deluge and displacement of people in emergency shelters were among the principal factors that lead to the increase in vulnerability and risk to dengue.

Besides, research has also shown that stagnant water is one of the breeding sites for the *Aedes aegypti* mosquito that cause dengue (WHO, 2017; EPA, 2016; CHEN et al. 2010). Standing water from heavy rain or overland flow from rivers can serve as breeding sites even though these habitats can be destroyed from high precipitation intensity (WHO, 2017; CARVAJAL & WATANABE 2014). In this manner, an abundance of mosquito following flood events can occur from the hatching of mosquito eggs within 1 week (Dieng et al. 2012) and subsequently lead to the spread of dengue within a month (DIBO et al. 2008; HII et al. 2012). Consequently, the time frame for dengue transmission varies between weeks or months after flood events.

Furthermore, a study by Watanabe et al. (2015) at the Ehime University in Japan using machine learning techniques has proclaimed an increase in dengue cases after heavy rainfall events in the city of Metro Manila in the Philippines. The method included analysing the relationship between precipitation and dengue cases through the creation of a GIS-based predictive model along with regression modelling of dengue cases, flood intensity and land use at the administrative level in order to ascertain risk at the local level.

Even with supported literature, some researchers (Watson, 2007) have refuted the association of floods with dengue. However, others have begun to incorporate flooding among the variables for dengue transmission in their investigation. For Carvajal & Watanabe (2014), the presence of dengue vectors are determined by type of household, vegetation, climate conditions, artificial water-holding containers, population density and affected flood prone areas.

In another study, Hashizume et al. (2012) incorporated river levels and rainfall data to analyze the spread of dengue based on hospital admissions data from 11 locations in Dhaka Bangladesh. The investigation was undertaken for the years between 2005 and 2009 thereby taking into account the impact of flooding from overland flow. The authors utilized a general linear Poisson regression model in which adjustments were made for other determinants (seasonal variation, public holidays and temperature). The results indicated that hospitalisations for dengue fever were synonymous with an increase or decrease in river levels.

Apart from that, high humidity is also one of the elements though related to rainfall and temperature that also influence the spread of dengue. In Thailand, a combination of temperature and humidity resulted in an increase in the number of mosquitoes that transmit dengue (Feng & Velasco-Hernández, 1997). Likewise, in a study conducted by Alkhaldy (2017) in Jeddah, Saudi Arabia, there was a stronger correlation between low relative humidity and high temperature for dengue cases.

### 5.2.3 Social Determinants of Dengue

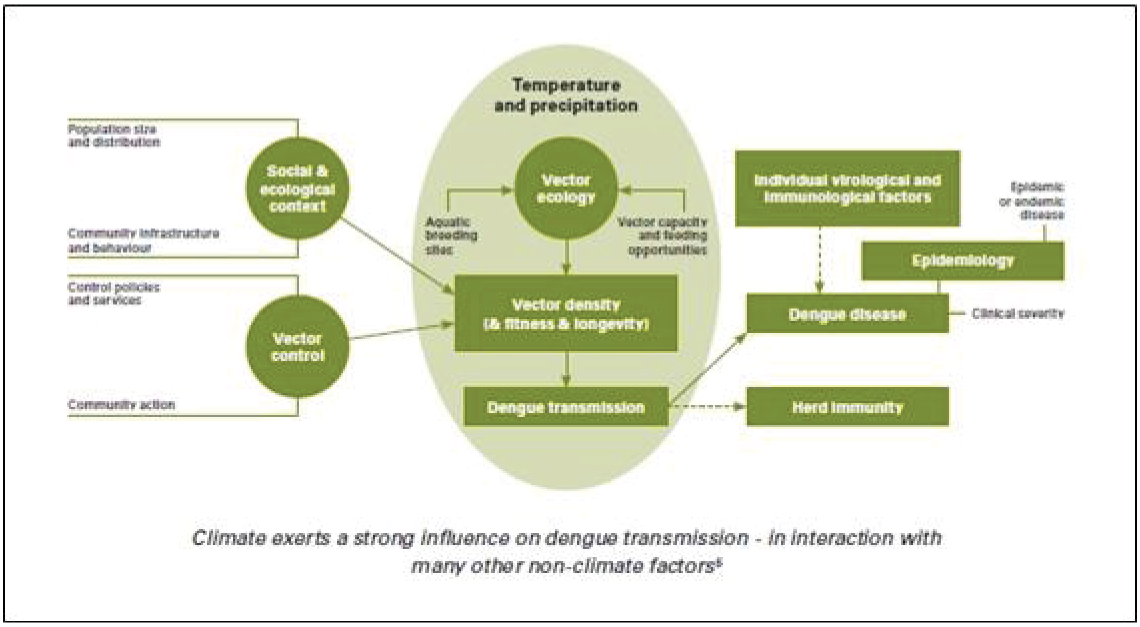
While climate plays an integral role for the survival of the *Aedes aegypti* mosquito, non-climatic factors are important as they determine the extent to which the dengue virus is transmitted (Van Kleef et al. 2010). Rapid urbanization, population growth, an ineffective vector control programme, the movement of people, land use and access to health care are some of the other factors that favour dengue transmission (Gubler, 1998; CDC, 2014). Furthermore, Bhatt et al. (2013) noted that a higher risk to dengue fever is normally encountered based on proximity to low-income urban and peri-urban centers along with a good transportation network.

Other studies at the micro level have shown how the combination of temperature and urbanization create urban heat island which promotes the spread of dengue (Misslin et al. 2016). Likewise, findings for a community based study in Venezuela between 2010 and 2011 using a sample size of 2012 respondents in 840 households by Vincenti-Gonzalez et al. (2017) identified dengue hotspots among individuals working as domestic workers, living in deplorable housing, using containers to store water, proximity to improper waste disposal and irrespective of steps taken to prevent dengue transmission like using repellents.

In Trinidad, the analysis of transportation network and dengue hemorrhagic fever cases were closer to class 3 (32%) and class 4 (57%) road networks but further away from class 1 (0%), class 2 (7%) and class 5 (4%) which inherently is away from forested areas. Also, there have been numerous researches pointing to the impact of dengue serotypes as the leading cause of epidemic among population at risk (Yung et al. 2015; Matheus et al. 2012).

In summary, the proliferation of dengue can be demarcated as a function of vector ecology; vector density; social and ecological context; vector control policies; individual virological and immunological factors; epidemiology and the herd community as elaborated by the WHO (2012) in figure 40.

FIGURE 40 - INTERACTION BETWEEN CLIMATIC AND NON-CLIMATIC VARIABLES IN DENGUE TRANSMISSION




SOURCE: WHO (2012)

In a simplier manner, the presence of dengue is influenced by environment, climate, urbanization and public policies which provide the ideal conditions for the germination of the vector that spreads the virus to humans at risk (TAUIL, 2002; MENDONÇA, 2009).

The abovementioned factors provide an insight as it pertains to the spread of dengue which can lead to greater understanding of the presence of the virus within the Americas.

## 5.3 HISTORY OF DENGUE FEVER IN THE AMERICAS BEFORE THE 1950S

The term dengue originated from the Swahili language ‘Ka dinga pepo’ which signifies febrile illness (Rigau-Pérez, 1998). While Gubler (1997) noted the first dengue like epidemic to occur within the Americas happened in 1635 in Martinique and Guadeloupe, Halstead (2008) theorized that dengue emerged indirectly within the region from the spread of the chikungunya virus during the North Atlantic slave trade in 1827. According to Halstead, the dengue like epidemic in 1827 and 1828 was later discovered to be that of chikungunya based on epidemiological features. Similarly, Carey (1971) illustrated the misclassification of chikungunya virus for dengue in India due to the similarities in the symptoms for both diseases. Consequently, the earlier reports regarding the fevers classified as dengue might not be attributed to dengue. Table 17 provides an overview of the dengue like epidemics within the Americas since 1635.

TABLE 17 - EARLY DENGUE LIKE EPIDEMIC WITHIN THE AMERICAS

(Continues)

| Year | Country | Source |
|---|---|---|
| 1635 | Martinique and Guadeloupe | Gubler, 1997 |
| 1699 | Panama | Halstead, 2008 |
| 1780 | Philadelphia in the United States | Rush, 1789 |
| 1818 | Peru (50,000 cases) | Gubler, 1997 |
| 1827-1828 | Virgin Islands, Cuba, Colombia, Venezuela, United States (New Orleans, Pensacola, Savannah and Charleston), Mexico | Ehrenkranz et al., 1971 |
| 1828 | Cuba called dunga | Muñoz, 1828 |
| 1845-1849<br><br>1846 | New Orleans<br>Cuba<br>Brazil | Ehrenkranz et al., 1971<br>Guitera & Cartaya, 1906<br>Gubler, 1997; Mariano, 1916 |
| 1850 | United States (New Orleans, Charleston, Augusta, Savannah) and Havana in Cuba | Fenner, 1851<br>Arnold, 1858<br>Ehrenkranz et al., 1971 |
| 1851 | Lima, Peru | Gubler, 1997<br>Schneider, 2001 |
| 1873 | New Orleans with 40,000 cases | Bemiss, 1880 |
| 1879-1880 | Southern United States port cities | Falligant, 1881 |
| 1880-1912 | 1896 in Curitiba, Brazil<br>1889 in Iquique, Antofagasta, Tarapacá, Tacna and Arica, Chile<br>1885-86 in Texas<br>1898-1899 in Florida<br>1897 in Havana Cuba<br>1882 in Bahamas<br>1904-1912 in Panama | Reis, 1896<br>Benavente, 1899<br>Menger, 1897<br>Rerick,1902<br>Delfin, 1897<br>Ehrenkranz et al., 1971<br><br>Beverley & Lynn 1912 |
| 1916 | Rio Grande do Sul, Brazil<br>Corrientes and Entre Rios, Argentina | Mariano,1916Gaudino,1916 |
| 1917 | Puerto Rico | King, 1917 |

TABLE 17 – EARLY DENGUE LIKE EPIDEMIC WITHIN THE AMERICAS

(Concluded)

| **Year** | **Country** | **Source** |
|---|---|---|
| 1918 and 1922 | Galveston, Texas in the United States<br>30,000 cases in 1922<br>Expanded to Louisiana, Florida and Georgia | Levy, 1920<br>Rice, 1922<br>Ehrenkranz et al.1971 |
| 1922 | Niteroi and Rio de Janeiro Brazil | Pedro, 1923 |
| 1934 | Miami, United States impacted 10% of the population which expanded to Georgia | Griffitts, 1935 |
| 1941-1946 | 1941 in Texas (Prevalence of disease: United States: reports from states for week ended November 29, 1941. Public Health Rep. 1941;56:2350–2361.)<br>1941-1942 in Panama Canal<br>1944 in Havana, Cuba<br>1945 in Puerto Rico<br>1945-1946 in Caracas Venezuela<br>1945-1946 in Bermuda, Bahamas and Sonora in Mexico Georgia | Fairchild, 1945<br>Pittaluga, 1945<br>Diaz-Rivera, 1946<br>Dominici,1946<br>Scheneider, 2001<br>Ehrenkranz et al. 1971 |

### 5.3.1 Dengue in the Americas since the 1950s

Anderson et al. (1956) reported the premier isolation of DEN-2 from a patient in the 1953 outbreak in Trinidad. Between 1963 and 1943, outbreak of the DENV-3 (Halstead, 2006) commenced in Jamaica with 1,500 cases which eventually reached Puerto Rico and resulted in 27,000 cases then to the Lesser Antilles and Venezuela with 10,000 cases (GRIFFITHS, 1968; NEFF et al.1967; BRICENOROSSI, 1964). Likewise, another outbreak started in Jamaica in 1968 and 1969 (Ventura &, Hewitt, 1970) which later caused proliferation in Puerto Rico (CDC, 1971), the Lesser Antilles (Jonkers et al., 1969). DENV-1 first discovered in the Americas and was responsible for outbreaks when it was detected in Jamaica and later in Cuba, Puerto Rico and other islands (PAHO, 1979).

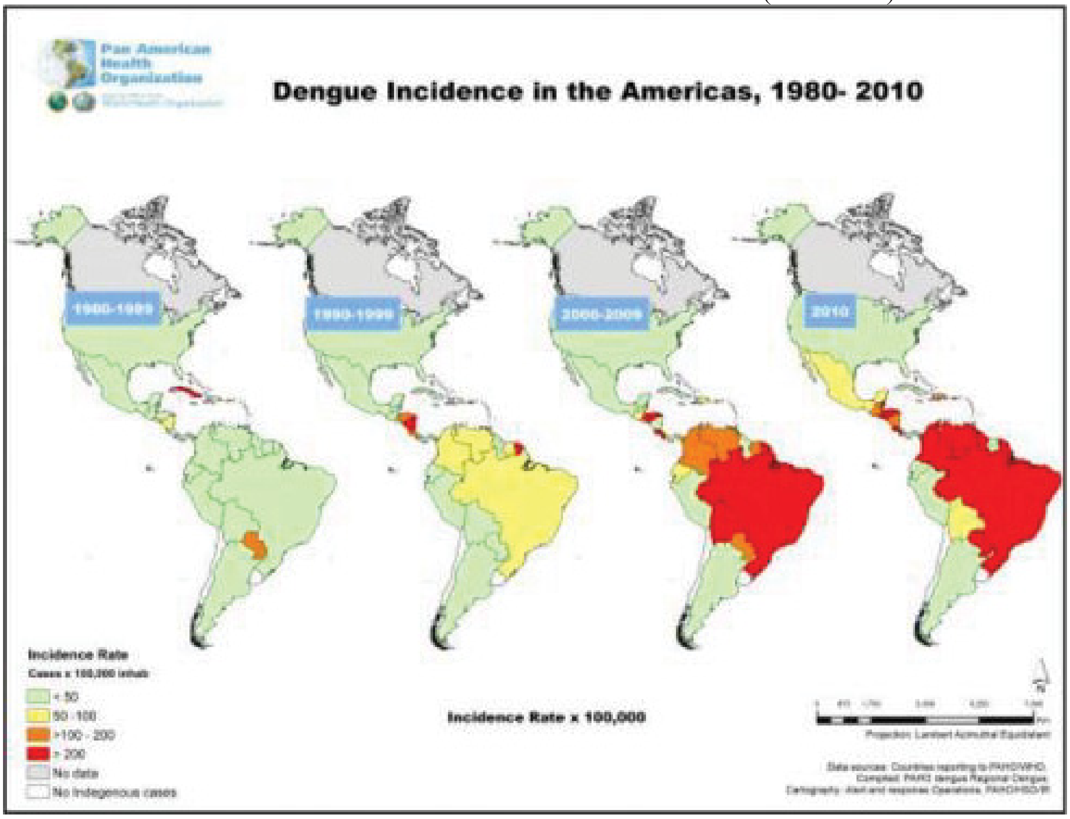
This later resulted in further epidemic in 1978 in Central America, South America, Mexico before it was found in 1980 in Texas (Gubler & Meltzer, 1999). Table 18 provides a summary of the cases since the 1950s.

TABLE 18 – AMERICAS – DENGUE CASES SINCE THE 1950s

| Year | Serotype | Country | Source |
|---|---|---|---|
| 1963-1964 | DENV-3 | Jamaica with 1,500 cases<br>Puerto Rico<br>Venezuela | Halstead,2006<br>Griffiths, 1968<br>Neff et al.1967<br>Bricenorossi algac,1964 |
| 1968-<br>1969 | DENV-3, DEN-2<br>DENV-2 | Jamaica<br>Puerto Rico<br>Haiti<br>Lesser Antilles<br>Venezuela | CDC, 1971<br>Ventura & Hewitt, 1970<br>Schneider, 2001<br>Jonkers et al., 1969<br>Llopis et al., 1979 |
| 1971-1972-<br>1973 | DENV-2 | 1971 in Columbia<br>1972,1973 and 1975 in Puerto Rico | Groot, 1975<br>Schneider, 2001 |
| 1975-1977 | DENV-3 | Magdalena Valley in Columbia | Groot et al., 1979 |
| 1977 | DENV-1 | Jamaica<br>Cuba<br>Puerto Rico | |
| 1978 | DENV-1 | Texas | |
| 1981 | DENV-2<br>DENV-4 | Cuba with 344,203 cases and 10,312 DHF while 158 people died Eastern Caribbean<br>Eastern Caribbean | Halstead, 2006<br>Guzman et al., 1984<br>Pinheiro & Corber 1997 |

Dengue incidence in the Americas between 1980 and 2010 has been mapped by PAHO and is shown below (Figure 41).

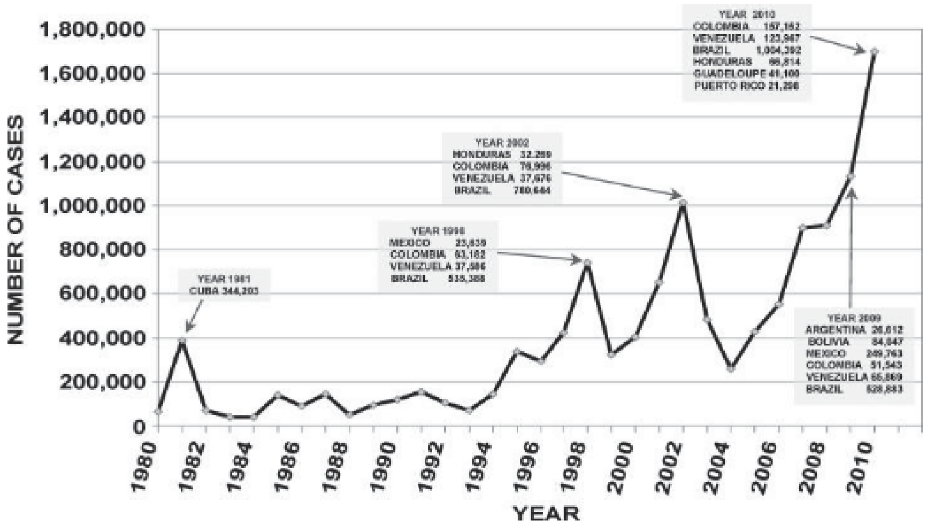
FIGURE 41 – AMERICAS – DENGUE INCIDENCE (1980-2010)




SOURCE : BRATHWAITE DICK et al. (2012)

As it relates to the number of cases, Braithwaite-Dick et al. (2012), provides an overview in figure 42.

FIGURE 42 – AMERICAS – NUMBER OF DENGUE CASES 1980 – 2010




SOURCE : BRATHWAITE DICK et al. (2012)

The resurgence and persistence of the *Aedes aegypti* mosquito within the Americas has led to numerous researches in many disciplines geared towards understanding transmission of the dengue virus to aid eradication efforts. One such field is Health / Medical Geography.

### 5.3.2 Approach to Health Geography

Medical / Health Geography are terms used interchangeably depending on geographical region and comprise of two branches. The first relates to mapping and modelling of diseases in relation to geographical factors while the other pertains to the geographical distribution of health services and accessibility. Hunter (1974) defined Medical Geography as the application of geographical concepts and techniques to health related problems. For Valencius (2000), Medical Geography was incorporated to preserve the history of medicine as an important component for the appreciation of modern theory and practices. Within this regard, the discipline traces historical studies of illnesses with links to the local space along with techniques utilized in contemporary societies.

Regardless of the different perspectives, Medical Geography became popular in the nineteenth century based on the influence of historical studies analysing the impact of health in space. One of the earliest investigations supporting this theory can be traced back to the ancient Greek era when Hippocrates conducted his study on airs, waters and places. In the seventeenth century, scholars in Britain, France and Italy continued with the Hippocratic approach to disease with studies concerning environmental impact on health (VALENCIUS, 2000). Between 1661 and1678, Thomas Sydenham conducted research on epidemics in London and provided the framework for the construction of an empirical approach (quantitative assessment) to evaluate the effect of environmental factors on diseases (ANSTEY, 2011; VALENCIUS, 2000). Another milestone was with the application of cartography by John Snow in 1854 that involved the spatial mapping of dwellings of cholera victims in relation to the water pumps in London (SHIODE, 2015). His results indicated that the cholera was caused from the contaminated pump and led to a reduction in new cholera cases (SHIODE, 2015).

Likewise, in the United States, the term Medical Geography in the early to mid-nineteenth century was influenced mainly by the Hippocratic view of environment and the occurrence of diseases although the French, British, German and also played a role (VALENCIUS, 2000). Daniel Drake was regarded as one of the pioneers of Medical

Geography in the United States who contributed to the meteorological and social determinants of disease of the American West (VALENCIUS, 2000).

In Brazil, the evolution of Medical Geography is well documented. Afrânio Peixoto, Oswaldo Cruz, Adolf Lutz and Carlos Chagas are examples of early pioneers who conducted studies from a Medical Geography point of view (LACAZ, 1972). However, by the mid-1970s the concept of Medical Geography became known as Health Geography (Geografia da Saude) that shifted the focus of disease to health from a cultural and social dimension (GUIMARÃES, 2000). Additional information regarding Health Geography in Brazil can be obtained from Mendonça, Mattozo & Fogaca (2014).

Notwithstanding that, many geographers in the Caribbean region have conducted research on the role social and environmental factors have on the geographic distribution of disease and risk ecology since the 1980s (WEIL, 1991). While Haddock (1981) studied schistosomiasis, Hunter and Arbona (1984) conducted research on tuberculosis in Puerto Rico. In Grenada, Taylor et al. (1986, 1990) investigated the risk factors associated with childhood diarrhoea in order to improve the programs that were implemented to promote oral rehydration therapy. Taylor also worked with other geographers to identify household characteristics associated with patterns of health care utilization in five communities in Grenada (POLAND et al., 1990).

In Jamaica, Bailey (1988) 102nalysed spatial and socioeconomic variations in mortality, morbidity and malnutrition in children based on hospital records and health surveys. Other studies were also done by Bailey and Phillips (1990) on spatial patterns of health care utilization in Kingston. In another research, Bailey and Powell (1982) examined the use of contraceptives in the Kingston-St. Andrew. Bailey (1989) also described the disease outbreak in the Office of Disaster Preparedness and Emergency Management – ODPEM shelters in Jamaica after Hurricane Gilbert.

## 5.4 HEALTH DATA CHALLENGES AND IMPACT ON DENGUE STUDY

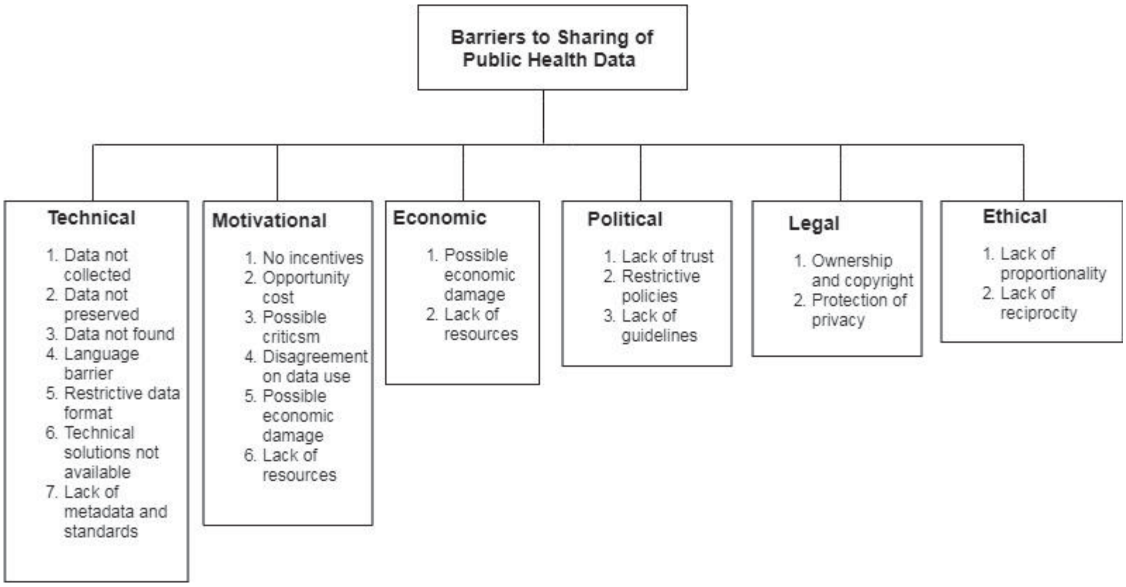
The problem with data access in the health sector especially in the Global South is not new (Serwadda et al., 2018). In fact, multinational agencies and donor organizations have led numerous calls for improvement with health data so that it to be made available to the public (Boerma, 2015). Even though health data have been produced within the health sector made possible by global initiatives (WHO, PAHO) geared towards the eradication of diseases, meeting health targets among other goals, accessibility to this information presents major challenges for researchers (Nyella, 2011; MCGRAIL & BLACK, 2005) especially in Jamaica. According to Abouzahr; Boerma (2006), hindrance to health data in most instances is due to the lack of a proper integrated database to consolidate the data rapidly in addition to the lack of a universal methodology being used in each country to collect and disseminate the information (EVANS; STANLEY, 2003).

Jamaica is an example of a country that still uses a paper based system at the health facilities but plans are in place to create a National Health Information System Strengthening and E-Health system (MoH, 2013). Currently, data collected at hospitals and clinics have to be entered in databases at various levels that are not connected to a main system to allow for easy access and dissemination of data. Even PAHO (2010) has described the databases used in Jamaica as being fragmented as the inadequate collaboration between agencies and ministries act as a hindrance to the generation of important and reliable statistics (HENRY, 2017). Jamaica has started to provide information via an open data platform (*data.gov.jm*). However, time series with dengue data is not yet available.

Consequently, the method to gain access to dengue data requires formal request to the permanent secretary or to medical officers from the hospitals or health ministry. This process can be time consuming and in most cases the data received is not at the required resolution or contain detailed information that can be used to explain disease pattern.

Six barriers to accessing public health data have been identified by Van Panhuis et al., (2014) shown in Figure 43. These barriers can be classified as technical (data not collected), motivational (possible criticism), economic (possible economic damage), political (lack of trust), legal (ownership and copyright issues) or ethical (lack of proportionality).

FIGURE 43 – BARRIERS TO SHARING OF PUBLIC HEALTH DATA




So, if data is not available at various scales to researchers, the factors driving the disease at all levels of society cannot be addressed and so diseases such as dengue will continue to thrive which stymies eradication efforts.

The problem with heath data is not only synonymous to Jamaica as other jurisdictions have similar issues as it relates to the type of information that is needed for dengue analysis. In a preliminary investigation on access to health data in Brazil and Jamaica conducted by Henry (2017), it was revealed that health data (including dengue) was more accessible in Brazil (made possible by a number of health information systems that collect health related data that is made available free of charge via the interactive web platform called DATASUS which is the Information Department of Sistema Único de Saúde – SUS). However, the same level of bureaucracy can be encountered in both countries when obtaining health data at a scale that is suitable for modelling diseases such as Dengue, Zika Virus and Chikungunya. For Coelho et al. (2016), daily and weekly data are the ideal scales for dengue modelling and this is not possible with data generated from DATASUS in Brazil as it is provided on a monthly basis per municipality. As a result, fine scale data has to be requested from the ethics committee (Comitê de Ética em Pesquisa, CEPs) which is where the delay in obtaining data arises.

### 5.4.1 Evaluation of Satellite Rainfall Sources

The analysis of rainfall data temporally and spatially in countries with risk to natural and biological hazards can yield important information needed in order to respond to health emergencies. Within this regard, rapid access to climate datasets becomes relevant. However, in data poor countries such as Jamaica where access to data is often times bureaucratic and costly, the traditional method of obtaining station data based on request is rather time consuming and can increase the response time in the disaster management process. Additionally, the amount of rain gauges tends to be minute and is not proportionally distributed especially in mountainous regions.

To fill this gap, data obtained from satellite sources are increasingly being utilized (CECCATO; DINKU 2010; DINKU et al. 2007; JIANG et al. 2012; LI et al. 2009). Additional information regarding the challenges and solutions can be obtained from CECCATO et al. (2014). These alternatives range from infrared (satellite), radar to microwave sensors (AGHAKOUCHAK et al. 2012; HONG, 2006). However, most of the products approximate rainfall values from the thermal infrared (IR) or passive microwave (PMW) sensors (Manz et al. 2016) while others use a multi-sensor combined approach (LEVIZZANIE et al. 2002). The prior provides an estimation of rainfall based on the temperature of the top of the clouds and the PMW is based on ice scattering within the clouds (MANZ et al. 2016).

With such diverse options being made available, the issue of data quality becomes questionable as these products use various methods in order to arrive at an estimation of precipitation values in time and space. As such, satellite sources are prone to errors from detection and the retrieval algorithm used to random errors from sampling frequency (PRAT & BARROS, 2010). According to Serrat-Capdevila et al. (2016), some of the errors in the satellite sources include not detecting true events, misrepresentation of actual rainfall values and discrepancies in rainfall magnitude estimation.

Moreover, tropical countries have local influences based on relief that might not be detected by satellites. In some areas, error occurs due to location, landscape characteristics, storm and cloud formation (EBERT et al. 2007). Dinku et al. (2010) have shown that IR sensors underestimate rainfall from orographic effects in high altitude within tropical areas. In another study, Dinku et al. (2007) compared 10 satellite rainfall products over the tropical Ethiopian mountain range using station data as reference from 1990 to 2004. The performance of the products varied according to spatial resolution used in the analysis. However, products based on PWM and a combination of IR sensors along with statistical methods recorded good results.

Kimani et al. (2017) assessed the performance of seven satellite products spatially and temporally based on monthly and yearly timescales using gridded rain gauge dataset over East Africa from 1998 to 2012. Apart of the objective was to evaluate the capacity of the products to account for convective and orographic rainfall by 106nalysed106 wind patterns over complex topography. While representation of rainfall values under normal conditions was consistent for each products, their inability to record large rainfall events from orographic effects was noted as one of the causes of underestimated precipitation value. Also, relief and wind effect influenced rainfall pattern over the study area and overestimation was observed with an increase in high altitude.

Likewise, Thiemig et al. (2012) studied six satellite products based on daily, monthly and annual time span in Zambezi, Volta, Baro-akobo and Juba Shabelle Basins against topography and in situ measurements. Good performance was achieved in tropical areas but poor results were encountered in semi-arid and mountainous zones. Furthermore, rainfall days and rates were overestimated in tropical regions and some of the sources had difficulties accounting for seasonal variation.

On the other hand, Zhao et al. (2016) 106nalysed the accuracy of one satellite derived precipitation product in the Northwest region of China based on annual, seasonal and monthly periods using gauged data as reference from 1998 to 2013. The results showed a strong correlation in the rainy season in mountainous and low lying region but underperformance occurred during the dry season over flat areas. Gebremichael et al. (2014) in their assessment of three satellite rainfall products over the Blue Nile River Basin reported overestimation of mean precipitation in low elevation areas while underestimation was evident in mountainous regions.

Based on the foregoing, the sole use of satellite data can result in error in analysis hence validation from ground based observations is necessary (Dinku et al. 2017; Sungmin et al. 2016) prior to conducting any study. Currently, in situ rainfall data have been integrated with satellites in an attempt to complement existing precipitation sources to overcome this issue (Neirini et al. 2015; Yang, et al. 2016; Boushaki et al. 2009).

### 5.4.2 Rainfall Data Quality Collected from Weather Station

Similar to satellite derived rainfall, data collected from weather stations are prone to errors and require quality control to detect outliers or inhomogeneity in the dataset collected from source points. According to Ben-Gal (2005), the identification of outliers should be among the primary task in any form of data analysis. Such evaluation can indicate observations that appear to be anomalous or distant from the other observations which are the reasons they are called outliers and have been discussed in detail by BARNETT and LEWIS (1994) & JOHNSON (1992). While outliers can be incorrect recordings, they might be evidence of extreme events and so should be evaluated using appropriate statistical methods before discarded.

As it relates to shift in climate variables over time, a non-homogenous dataset can result from a number of issues. These can range from human error in reading, archiving of the data or systematic error when the information is not recorded in the correct format (SHEPHARD et al., 2014). Also, replacement of instrument, changes in the station location or in the natural environment due to urbanization can cause a non-uniform sample. Apart from that, Duchon and Biddle (2010) have demonstrated how evaporation losses and the effect of winds can alter rainfall in gauges by deflection.

Based on the aforementioned, homogeneity analysis is important in order to reduce the level of uncertainty that might be present in the analysis (ARELLANO-LARA & ESCALANTE-SANDOVAL, 2015). Some examples of techniques used for this include: principal component analysis, hierarchical ascending clustering (ARELLANO-LARA & ESCALANTE-SANDOVAL, 2015). However, the RhtestV4 software developed by Wang & Feng (2013) and operated in the R Commander software was utilized in this research to account for homogeneity in the rainfall data received from the Meteorological Service of Jamaica – MSJ.

The Rhtest V4 tool has undergone modification from the previous RhtestV3 package which evolved from RhtestV2 and is used to identify and alter change points present in climate data in which first order autoregressive errors are likely to be present (WANG et al, 2010). It uses the penalized maximal t test outlined by Wang et al. (2007) along with the penalized maximal F test explained in Wang (2008b), both of which are enclosed in a recursive testing algorithm (Wang, 2008a) with the lag-1 autocorrelation of the samples being tested (WANG & FENG, 2013) .

One of the strengths of this software is the ability for alteration to be conducted using a reference series made possible by the inclusion of the Quantile Matching – QM algorithm so data can be adjusted based on metadata to become similar to their counterparts as elaborated by VINCENT (2012) and WANG et al. (2010). Moreover, there is an option available for adjustment without incorporating a reference series and metadata if none is available but will require further analysis due to the level of unreliability that might permeate from that process. It also accounts for autocorrelation and addresses uneven distribution of false alarm rate and detection power (WANG et al., 2007, WANG, 2008b).

Additional analysis was conducted using the Geostatistical Analyst in ArcGIS 10.4 to explore the precipitation dataset obtained from the MSJ in order to detect outlier within the dataset based on the methodology proposed by Krivorucho (2011); Gribov and Krivoruchko, (2012).

Discrepancies in climate data are reasons for concern as they can affect the final results in any analysis being conducted. One of the obstacles faced in this research is the lack of metadata for the weather station data collected and so there is no information regarding the instruments used and change of sites to alter some of the change points if any is discovered. Information is however available regarding the location of each station in lat/long coordinates and the elevation.

The World Meteorological Organization- WMO (2011) emphasizes the importance of quality control in samples prior to analysis. Even though the WMO (2012) have established guidelines quality control based on approved guidelines, there is no agreed standard and so the technique chosen is based on the individual's subjectivity. Furthermore, most of the methods being utilized have been developed in environments that are not similar to those being 108nalysed and so there might be some form of bias still present in the results even after analysis has been completed.

## 5.5 VULNERABILITY ASSESSMENT

The study of vulnerability involving climate related impacts on human health provides the framework for the incorporation of a multisdisciplinary approach. According to UNISDR (2004), vulnerability is one of the components of risk. Risk has traditionally been expressed by UNISDR (2004) as:

$$Risk = Hazard\ (frequency\ and\ severity) * Vulnerability\ (exposure/capacity) \qquad Equation\ 6$$

Even though a plethora of definition exists for vulnerability (Adger, 1999; Allen, 2003, Nicholls et al., 1999; Eakin & Luers, 2008), there is no agreement on a specific term that should be utilized. Vulnerability therefore becomes complex and confusing, as technocrats with varying backgrounds are compelled to select a suitable definition based on the nature of their study, or create a new term. Table 19 shows examples of some of the definitions that have been utilized over the years.

TABLE 19 – DEFINITIONS OF VULNERABILITY

| Author | Definition |
|---|---|
| UNDRO, 1991 | The degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage). |
| Tobin & Montz, 1997 | The probability of a community, a structure, services or a geographical area to be damaged or disrupted by the impact of a certain hazard. |
| Blaikie et al., 1994 | The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from a natural hazard. |
| Kelly & Adger, 2000 | The ability or inability of individuals and social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being. |
| IPCC, 2001 | The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. |
| Jones and Boer, 2003 | The amount of (potential) damage caused to a system by a particular climate-related event or hazard. |
| Allen, 2003 | The state that exists within a system before it encounters a hazard event. |
| Pelling, 2003 | Exposure to risk and inability to avoid or absorb potential harm. |
| Wisner, Blaikie, Cannon & Davis, 2003 | The characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process). |
| Provention Consortium, 2007 | The potential to suffer harm or loss, related to the capacity to anticipate a hazard, cope with it, resist it and recover from its impact. |
| UNISDR, 2011 | The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. […] arising from various physical, social, economic, and environmental factors. |

The above terminologies show that vulnerability is a function of exposure, sensitivity and the ability to cope or adapt to the impacts (also see Figure 27). While some definitions focus only on the hazard and sensitivity (example Jones and Boer, 2003; Office of the United Nations Disaster Relief Co-ordinator – UNDRO, 1991; Jones and Boer, 2003), others incorporate capacity (example IPCC, 2001; Pelling, 2003; Provention Consortium, 2007). Additionally, authors like Blaikie et al., (1994) made the distinction between biophysical and social vulnerability while others (Kelly & Adger, 1999; Allen, 2003) only focus on social vulnerability (Brooks, 2003). In most studies regarding climate change, emphasis is normally placed on exposure without incorporating capacity (Nicholls et al., 1999). However, in hazard impact assessment, vulnerability is influenced by exposure based on the nature of the hazard, probability of the hazard occurring, magnitude of exposure and sensitivity to the hazard (Brooks, 2003).

### 5.5.1 Vulnerability Scale

Based on the above definitions, it is also evident that vulnerability can be characterized at different degrees of complexity and scale (Birkman, 2013). Within this context, vulnerability is viewed as multi-dimensional (physical, social, economic, environmental and institutional), multiple structure, dynamic, scale dependent (local, subnational, national or global) and site specific. Table 20 demonstrates some pros and cons of vulnerability assessment at different scales.

TABLE 20- PROS AND CONS FOR VULNERABILITY ASSESSMENTS AT DIFFERENT SCALES

| Level | Pros | Cons |
|---|---|---|
| Local | More detailed information can be included<br>Complexity can be better captured<br>Certain methods to collect data (e.g. participatory approach) can only be applied on local level<br>Data availability for one place is mostly high | Transferability of the approach to another level or region implies loss of information<br>Mapping of a whole river system is severely constrained by data availability<br>Some data are very local specific and therefore complicated to compare with other cities or a region |
| Sub-national | Large-scale patterns and processes can be identified<br>Intermediate level of analysis facilitates the incorporation of data from other spatial levels<br>Data at regional level often available for whole country | Important vulnerability components can hardly be captured as e.g. perception or thresholds – tendency of simplification<br>Dependency on available data as own collection is constrained<br>Validation is difficult to carry out<br>Variations in nature are difficult to |

| | | |
|---|---|---|
| | Less complex approaches are more Applicable | capture |
| National/global | Meets the demand of allocating funds for parts of the world most affected by natural hazards or by social insecurity | Detection of root causes or holistic insights over patterns of vulnerability is limited |

SOURCE: Fekete, Damm & Birkman (2009)

# CHAPTER 6

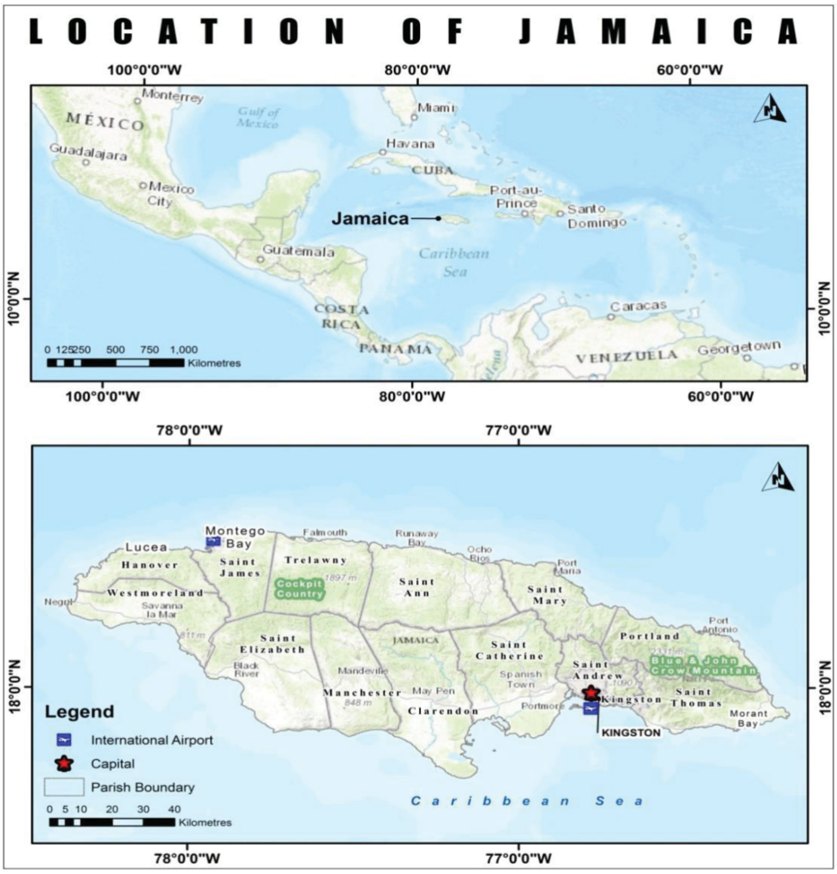
## 6 DENGUE FEVER IN JAMAICA: GEOGRAPHICAL CONTEXT

This chapter provides information about the study area as it relates to the physical, social and geographical setting along with the proliferation of dengue in Jamaica and previous studies regarding the disease.

### 6.1 LOCATION, SIZE AND GEOGRAPHY

The island of Jamaica is located in the Caribbean Sea (Figure 44). This region can be found south of Florida (North America) and north of South America and consists of a group of islands in the form of an archipelago which is also referred to as the West Indies. Jamaica is the third largest country within this zone but is the largest of the English speaking islands.

FIGURE 44 – JAMAICA – LOCATION




SOURCE: ESRI, DIVA GIS; Adapted By: HENRY, 2017

Jamaica has approximately 10,991km$^2$ of land area and is situated between 18°15’N longitude and 77°20’ W latitude which is about 145 km south of Cuba and 190 km west of Haiti (NANDI et al. 2016). These islands are also part of another group known as the Greater Antilles.

Politically, it is comprised of fourteen parishes (which signify states or provinces in other countries) with Kingston as its Capital. Within each parish, there is a capital with towns and commercial activities. However, the two parishes with city status are Kingston and Saint James.

## 6.2 PHYSICAL CHARACTERISTICS

The physical relief is comprised of a mountainous terrain with steep slopes running from east to west while flat lands are mostly concentrated on the coasts. The most recent land use assessment conducted in 2015 by the Forestry Department of Jamaica – FDJ (2017), indicated that about 40% (439,937.8 hectares) of the island is dominated by forests.

According to Stennet (1979), Jamaica can be grouped into the following geomorphic zones:

- Interior mountain ranges: This is situated in the east, centre and western end of the island. Moving eastwards, the highest point is the Blue Mountain Peak (a national park) in the parish of Portland which is 2,256m while other mountain ranges such as the Mocho Mountains and John Crow Mountains can be found in the center and western section respectively. These landforms consist of shales, conglomerates and tuffs and volcanic rocks. However, variation exist as the Blue Mountain is composed of steeper slopes with very thin slopes in comparison to the central and western region which has a more gentler slope with deeper soils affected by erosion.

- Limestone plateau and hills: These encompass about two-thirds of Jamaica and possess thin soil with good drainage. They also have gentle slopes excluding the Cockpit Country.

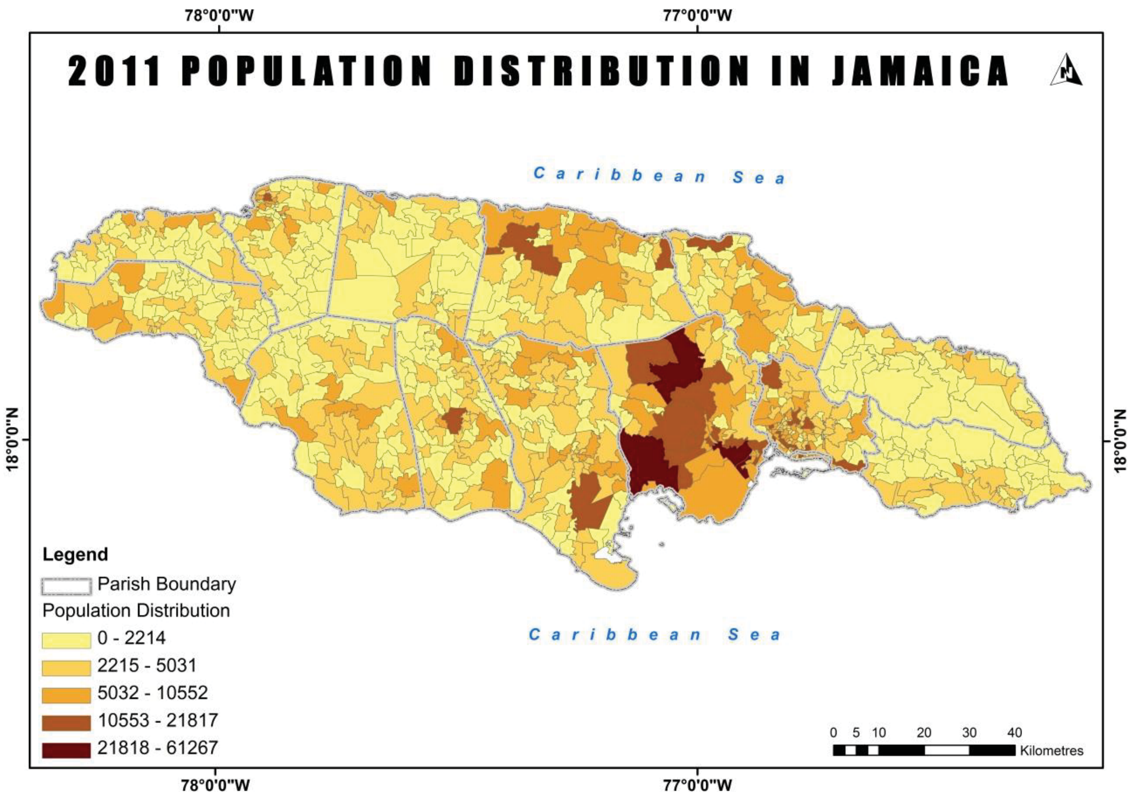
- Coastal plains: These tend to be flat though variation in slope is present and is demarcated by alluvial soils. The southern section of the island is comprised of broader plains than in the north.

As it relates to lithology, white limestone (60%) dominates with volcanics and volcanolastics estimated at 25% followed by alluvium (10%) and yellow limestone (5%), (Nandi et al., 2016).

## 6.3 SOCIO-DEMOGRAPHIC CHARACTERISTICS

According to the most recent census in 2011, approximately 2,697,983 persons reside in Jamaica in comparison to 2,607,632 recorded in 2001 which represents a population increase of about 3.5% (Statistical Institute of Jamaica – STATIN, 2011). Almost half (1,041,084) of Jamaicans live within the KMA as per census report. While St. Andrew possess the largest population (573,369), Saint Catherine (516,218) is the second most populated parish and Hanover is the least (69,533) inhabited. Figure 45 illustrates the spatial distribution of the population per parish.

FIGURE 45 – JAMAICA – POPULATION DISTRIBUTION 2011




SOURCE: STATIN (2011); Adapted by: Henry (2017)

Even though thirteen parishes experienced annual growth, Kingston was the only one with a decline in the growth rate of -0.80%. The census also revealed that the fastest growing regions between 2001 and 2011 were St. Catherine and St. James. St.

Andrew accounted for the highest percentage in population distribution (21.3%) followed by St. Catherine with 19.1% then Clarendon which recorded 9.1% (STATIN, 2011). Table 21 illustrates the population characteristics for each parish.

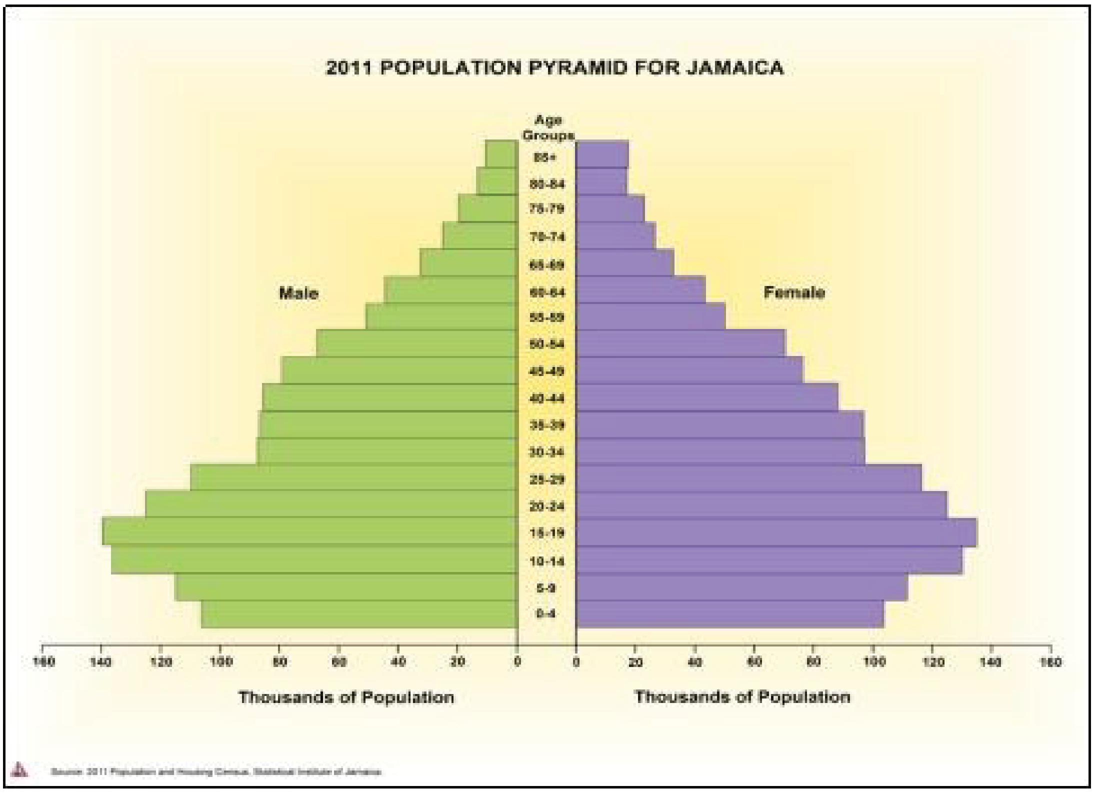
TABLE 21 – JAMAICA – POPULATION CHARACTERISTICS OF EACH PARISH

| **Parish** | **CapitaL** | **Population 2011** | **Population distribution 2011 (%)** | **Population 2001** | **Population distribution 2001 (%)** | **% change 2001-2011** | **Annual % rate of growth (2001-2011)** |
|---|---|---|---|---|---|---|---|
| Kingston | Kingston | 89,057 | 3.3 | 96,052 | 3.7 | -7.28 | -0.80 |
| St. Andrew | Half Way Tree | 573,369 | 21.3 | 555,828 | 21.3 | 3.16 | 0.33 |
| St. Thomas | Morant Bay | 93,902 | 3.5 | 91,604 | 3.5 | 2.51 | 0.26 |
| Portland | Port Antonio | 81,744 | 3.0 | 80,205 | 3.1 | 1.92 | 0.20 |
| St. Mary | Port Maria | 113,615 | 4.2 | 111,466 | 4.3 | 1.93 | 0.20 |
| St. Ann | St. Ann's Bay | 172,362 | 6.4 | 166,762 | 6.4 | 3.36 | 0.35 |
| Trelawny | Falmouth | 75,164 | 2.8 | 73,066 | 2.8 | 2.87 | 0.30 |
| St. James | Montego Bay | 183,811 | 6.8 | 175,127 | 6.7 | 4.96 | 0.51 |
| Hanover | Lucea | 69,533 | 2.6 | 67,037 | 2.6 | 3.72 | 0.38 |
| Westmoreland | Savanna-la-Mar | 144,103 | 5.3 | 138,948 | 5.3 | 3.71 | 0.38 |
| St. Elizabeth | Black River | 150,205 | 5.6 | 146,404 | 5.6 | 2.60 | 0.27 |
| Manchester | Mandeville | 189,797 | 7.0 | 185,801 | 7.1 | 2.15 | 0.22 |
| Clarendon | May Pen | 245,103 | 9.1 | 237,024 | 9.1 | 3.41 | 0.35 |
| St. Catherine | Spanish Town | 516,218 | 19.1 | 482,308 | 18.5 | 7.03 | 0.72 |
| Total | | 2,697,983 | 100.0 | 2,607,632 | 100.0 | 3.46 | 0.36 |

SOURCE: STATIN (2011); Adapted by: Author (2017)

The census also depicted an aging population as is exhibited by the population pyramid in figure 46. In 2011, about 1,363,450 of the inhabitants of Jamaica were females while 1,334,533 represented males (STATIN, 2011). The dependable population was estimated at 920,441 which comprise of the children less than fifteen years of age (702,835) and those over 65 years of age (217,606). In addition, the total number of people between 15 and 29 was 751,489 whereas 1,026,053 belonged to the 30-64 category (STATIN, 2011).

FIGURE 46 – JAMAICA – POPULATION PYRAMID 2011




SOURCE: STATIN (2011)

## 6.4 GOVERNANCE SYSTEM

Jamaica was first colonized by the Spanish in 1494 until 1655 when the British took control of the colony and gained independence from the latter on August 6, 1962 (JIS, 1990). It has a constitutional monarchy with Queen Elizabeth II as the head of state and a parliamentary democracy system of governance based on the Westminster model (JIS, 1990). Three branches of Government exist: executive, legislative and judicial. The executive branch is formed by Ministers of Cabinet headed by the Prime Minister which is a model of the British Parliament. Jamaica is a member of the Caribbean Community and Common Market (CARICOM) which fosters free movement of people, economic integration and trade among member countries.

While the Prime Minister leads the country, all parishes are governed by a Mayor who is elected and performs duties at Parish Councils at the local government level. These parishes are also divided into sixty three constituencies with Members of

Parliament in charge. In addition, the island is subdivided into three counties: Cornwall, Middlesex and Surrey.

## 6.5 ECONOMY

Jamaica is classified as an upper middle income[3] country (World Bank, 2015). The service industry was the main economic activity in 2015 which accounted for 79.3% of Gross Domestic Product – GDP, while the producing industries such as agriculture, mining, quarrying and construction amounted to 24.7% of GDP (Economic & Social Survey Jamaica - ESSJ, 2015). According to the World Travel and Tourism Council - WTTC (2015), direct foreign exchange earnings from tourism resulted in around US$1.2 billion in 2014. In 2015, GDP per capita was estimated at US$5,114.231 in comparison to US$5,101.12 in 2014 meanwhile debt to GDP ratio at the end of March 2015 was expressed at 135.6 percent, making Jamaica one of the world's most indebted countries (ESSJ, 2015).

Despite its economic woes, Jamaica was placed 99th out of 188 countries on The Human Development Index (HDI) with a score of 0.719 in 2015 which is classified in the high human development category that include other regions such as Brazil, China, Ecuador, Malaysia and Mexico (UNDP, 2015).

## 6.6 HEALTH SYSTEM AND STATUS

Life expectancy was estimated at 75.7 in 2014 (UNDP, 2015). In 2012, deaths from HIV/AIDS were approximated at about 46.80 per 100,000 populations while deaths from tuberculosis among HIV-negative people were 0.52 per 1000,000 population. In Jamaica, maternal mortality ratio was 80 per 100,000 live births whereas under- five year mortality was totalled at 17 per 1,000 live births in 2012. However, malaria related deaths had a zero per 100,000 population (WHO, 2015) due to its eradication from the island.

As can be seen in table 22, Jamaica has challenges as it relates to chronic diseases. In 2012, stroke was the leading cause of death with 16.5% of all fatalities (WHO, 2015). Ischaemic heart disease, stroke, diabetes mellitus, hypertension heart disease,

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[3] Upper middle-incomeeconomies are those countries with a GNI per capita between $ 4,036 and $ 12,475. Other countries in this category include: Argentina, Brazil, China, Malaysia and the Russian Federation.

lower respiratory infections, trachea, bronchus and lung cancers in total accounted for 48.6% of deaths in Jamaica in 2012.

TABLE 22 - JAMAICA - TOP TEN CAUSE OF DISEASE / 2012

| **Disease** | **%** |
|---|---|
| Stroke | 16.5 |
| Ischaemic Heart Disease | 11.0 |
| Diabetes Mellitus | 10.8 |
| HIV/AIDS | 6.6 |
| Hypertensive heart disease | 5.5 |
| Interpersonal violence | 3.8 |
| Prostate Cancer | 3.3 |
| Kidney disease | 2.8 |
| Lower Respiratory Infections | 2.5 |
| Trachea bronchus lung cancers | 2.3 |

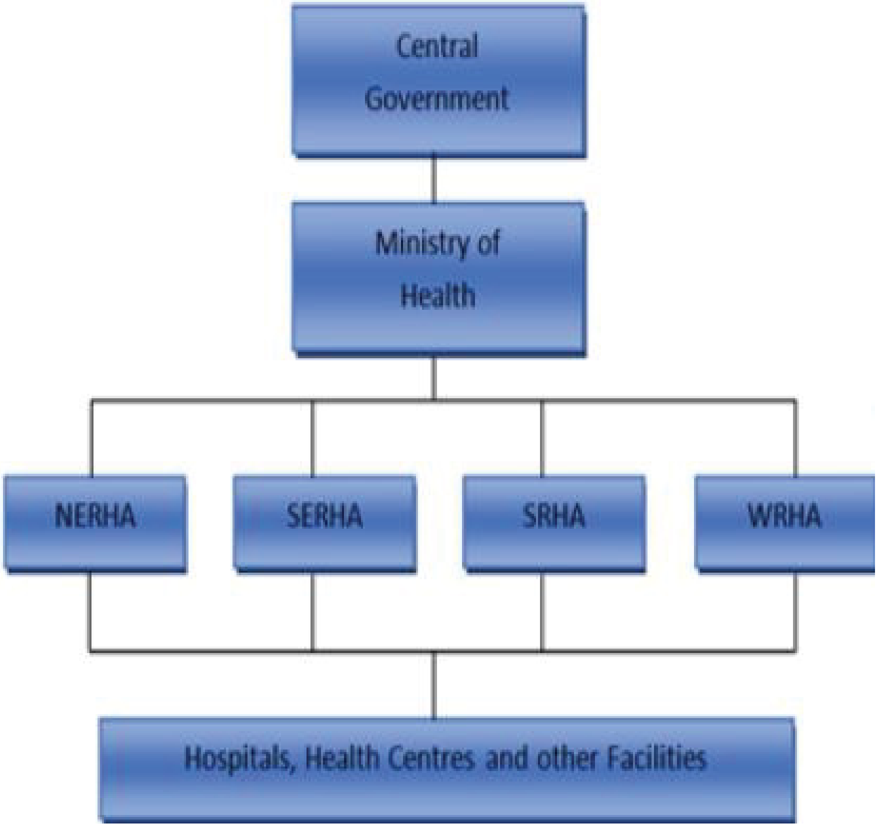
SOURCE: WHO (2015)

The other leading causes of deaths included HIV/AIDS, prostate cancer and kidney disease.

## 6.7 PUBLIC HEALTH SYSTEM

In Jamaica, the Government provides free access to health care at the primary, secondary and tertiary level in public health facilities. The Ministry of Health is a ministry of the Government of Jamaica. In 1997, the administrative operation of the hospitals was decentralized through the passing of the National Health Services Act which resulted in four RHAs being formed: North East Regional Health Authority (NERHA), Western Regional Health Authority (WRHA), Southern Regional Health Authority (SRHA) and the South East Regional Health Authority (SERHA). Figure 47 shows the function of the public health system in Jamaica.

FIGURE 47 - JAMAICA - FUNCTION OF THE PUBLIC HEALTH SYSTEM

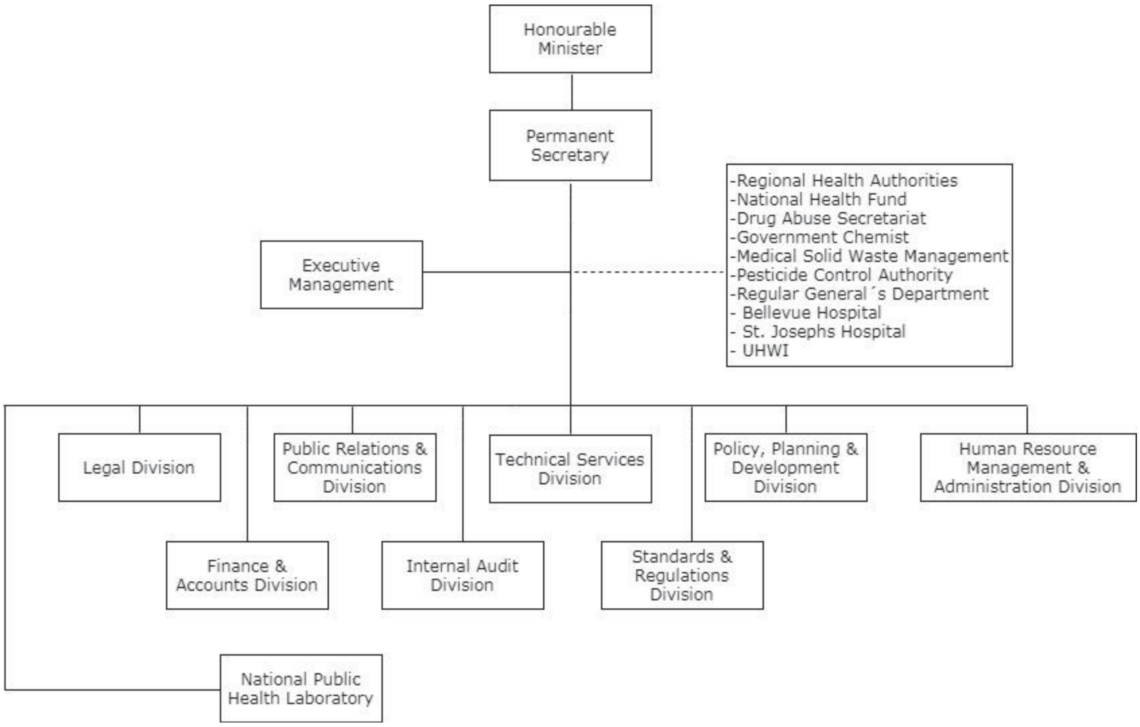



SOURCE: JAMAICA (2009), (MoH/ RHAS); Adapted by: Author (2017)

The NERHA includes the parishes of Portland, St. Mary and St. Ann while WRHA comprises of Trelawny, St. James, Hanover and Westmoreland (Ministry of Health Jamaica - MoH, 2015). The SRHA covers St. Elizabeth, Manchester and Clarendon however, SERHA consists of the following: St. Catherine, Kingston, St. Andrew and St. Thomas (JAMAICA, 2011). Consequently, the role of the Ministry of Health involves planning, coordination and policy implementation while the RHAs manage the public health hospitals and clinics.

Figure 48 includes the organizational chart with the dunction of the Ministry of Health of Jamaica. The figure shows that the Ministry is headed by the Minister of Health through political appointment followed by a Permanent Secretary. The next level is Executive Management then 8 divisions and the Public Health Laboratory.

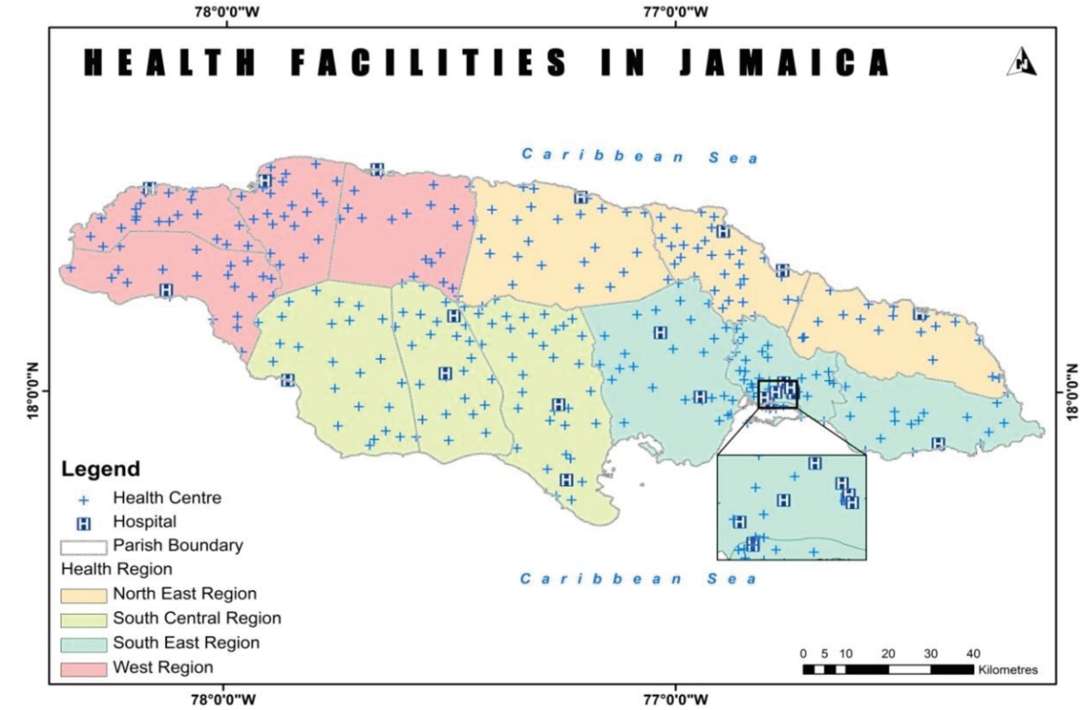
FIGURE 48 - JAMAICA - MINISTRY OF HEALTH ORGANIZATIONAL CHART




SOURCE: MoH

Jamaica's health system is comprised of 316 health centres and 24 hospitals of which 6 are specialist institutions (MoH, 2013). Figure 49 shows the public health facilities in Jamaica. The figure indicates that majority of the hospitals are situated in Kingston and St. Andrew while other parishes have at least one facility.

FIGURE 49 - JAMAICA - PUBLIC HEALTH FACILITY

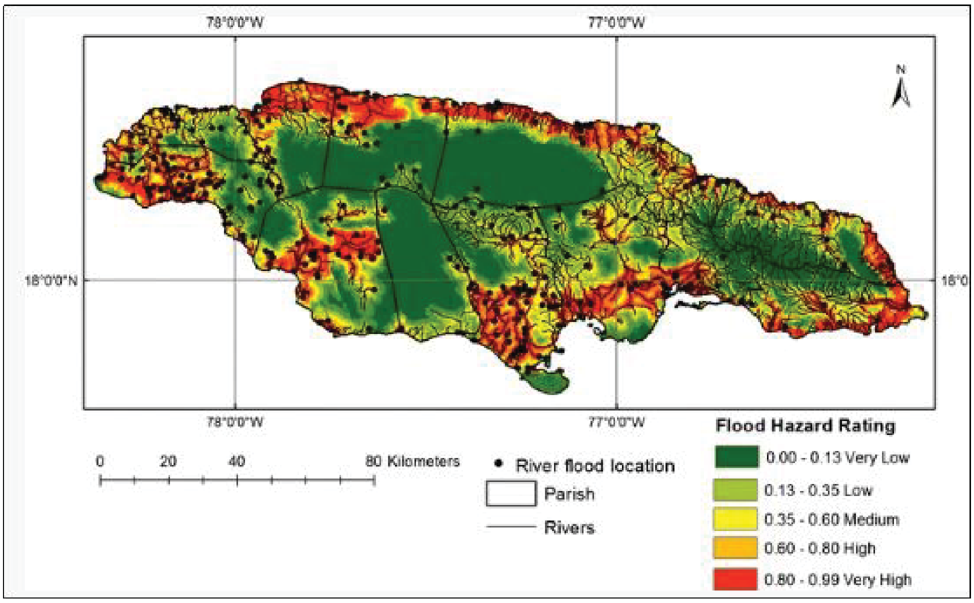



SOURCE: MoH, Adapted by: Author (2017)

## 6.8 AREAS PRONE TO FLOODING IN JAMAICA

In Jamaica, about 82% of the population resides within 5km of the coast where the urban centres and capitals are located on a flat terrain (PIOJ, 2009) which provide the ideal condition for residual water to emanate from heavy precipitation or overland flows from rivers. So far, mapping of areas prone to river flooding using principal component analysis by Nandi et al, (2016) have exhibited higher flood hazard rating for river networks close to coastal areas (Figure 50).

FIGURE 50 - JAMAICA - AREAS PRONE TO RIVER FLOODING




SOURCE: Nandi et al. (2016)

In a more detailed representation, Mona GIS (2017) has mapped the locations of daily reported flood events (blue) from newspaper archives in Jamaica (Figure 51). The figure shows a clustering of events occurring in each parish with majority experienced along the coast.

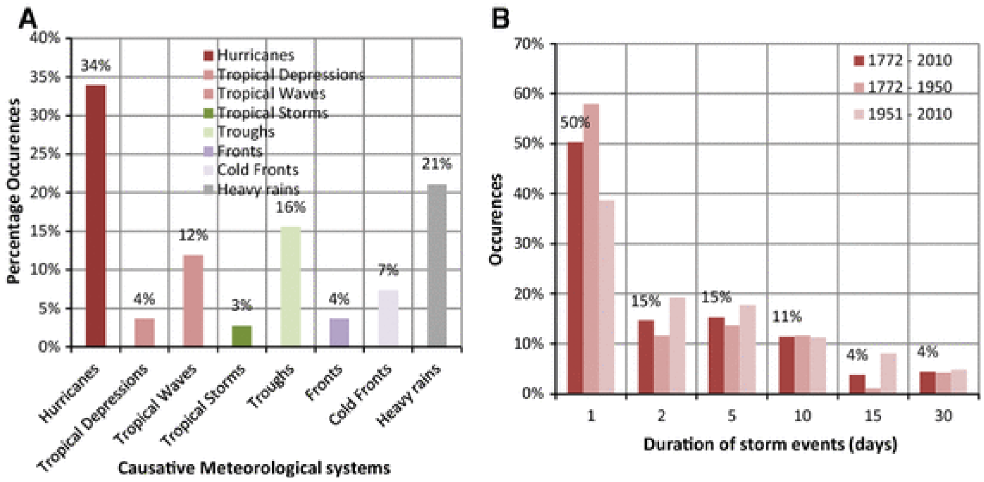
FIGURE 51 - JAMAICA - POINT LOCATION OF HISTORICAL FLOOD EVENTS


SOURCE: MONA GIS (2017)

## 6.9 ATMOSPHERIC SYSTEMS THAT INFLUENCE FLOODING IN JAMAICA

Analysis of atmospheric systems (Figure 52) that influence flooding in Jamaica highlights that majority of the incidents result from heavy rainfall but systems such as hurricanes, tropical waves and troughs represented 62% as the causative factor (Burgess et al. 2015).

FIGURE 52 - JAMAICA - ATMOSPHERIC SYSTEMS THAT CAUSE FLOODS OVER THE YEARS




SOURCE: Burgess, et al. (2015)

The other causes include fronts, cold fronts, tropical storms and tropical depressions (18%). In terms of storm duration, one day events were more frequent with about 50% occurrence.

The aforesaid are reasons for concern as future climate change scenarios have predicted increases in dengue cases for Jamaica to aggravate the situation as regional climate model (PRECIS) and the Statistical Downscaling Model predict an increase in rainfall intensity which might increase storms, floods, tropical cyclones and hurricanes by 2080 (CSGM, 2012). Some of the impacts from these relate to an increase in vector borne disease in particular dengue in the country since projections were made for an increase in temperature between 2.9°C and 3.4°C by the 2080s which can cause a shorter incubation period for the *Aedes aegypti* mosquito to reproduce (CSGM, 2012). Furthermore, population density and the lack of immunization of population at risk act as a determining factor for the pattern of dengue fever during these catastrophes (CSGM, 2012).

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# CHAPTER 7

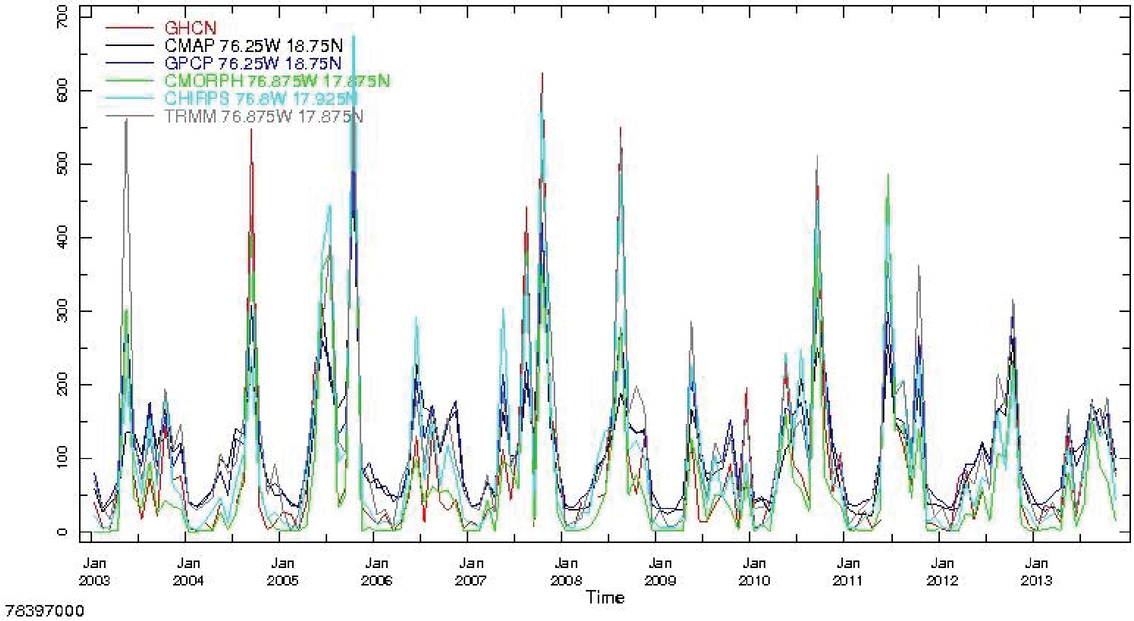
## 7 DENGUE FEVER IN JAMAICA: CHALLENGES IN THE CONTEXT OF GLOBAL CLIMATE CHANGE (RESULTS)

This chapter illustrates the findings from the analysis conducted as it relates to dengue and the socio-environmental factors. Firstly, the results from the rainfall accuracy assessment are presented followed by analysis of the dengue cases based on the climatic and socio-environmental variables at the national level. Subsequently, further analysis is conducted at the parish level. The final analysis involves the vulnerability scenario assessment.

### 7.1 RESULTS FROM THE INCONSISTENCY IN RAINFALL DATA ANALYSIS

This section, the results from the accuracy assessment between the rainfall data obtained from satellite products and the weather station at the Norman Manley International Airport in Kingston, Jamaica are examined first. Figure 53 displays the monthly time series of the rainfall data collected from CMAP, GPCP, TRMM, GHCN, CMORPH and CHIRPS. The figure illustrates similar tendencies for the various sources as it relates to the periods with high and low precipitation values. While there have been high precipitation between 2003 and 2009, there is a gradual decrease in rainfall since 2010 with few extreme events. Notwithstanding that, CMAP underestimates the large precipitation events over the entire period even though it follows a similar pattern with the other products in some instances. Likewise, GPCP displayed a similar tendency with CMAP but the representation of the extreme events deviated from time to time.

FIGURE 53 - MONTHLY TIME SERIES OF RAINFALL DATA OBTAINED FROM VARIOUS SATELLITE PRODUCTS BETWEEN 2003 AND 2013 IN MM




SOURCE: IRI DATA LIBRARY; Adapted by: Author (2017)

### 7.1.1 GHCN AS A REFERENCE WITH SATELLITE SOURCES

All the data sources seem to have a relatively good correlation ranging from 0.79 to 0.88 with greater variation in the level of bias (Table 23). The relationship between TRMM and GHCN seems to be very strong as indicated by the high correlation coefficient (0.88) in comparison to the other products. This implies that the estimation for low and high precipitation values is close for both sources. On the other hand, CMAP appears to have the weakest relationship indicated by the low correlation (0.79). Within this regard, the high rainfall values are under estimated while low values are augmented by CMAP. Even though CMORPH pairs well with GHCN (correlation of 0.84), the level of bias tend to be the highest of all the products (mean error of 24.3) and therefore indicates over estimation of the true rainfall value. The CHIRPS dataset with a correlation of 0.87 shows a strong relationship with GHCN and has the lowest negative bias which can be associated to some level of underestimation of the actual precipitation value. The difference between the products seems to be huge as depicted by the RMSE although the direction of the error cannot be inferred from this as it is the difference of the values hence the large numbers.

TABLE 23 - STATISTICAL ANALYSIS OF SATELLITE PRODUCTS WITH GHCN

| Dataset | Correlation | Mean Error | Root Mean Square Error |
|---|---|---|---|
| CMAP | 0.7885007 | -19.40183 | 81.85078 |
| GPCP | 0.8680109 | - 28.25095 | 70.37971 |
| CMORPH | 0.8492032 | 24.26299 | 54.34245 |
| TRMM | 0.8821458 | -32.41344 | 52.92472 |
| CHIRPS | 0.8664678 | -11.40397 | 55.30405 |

SOURCE: IRI DATA LIBRARY; Adapted by: Author (2017)

### 7.1.2 Comparison With CHIRPS

In another analysis using Chirps as reference, the strongest relationship was with GPCP (0.93) although it had the third highest negative bias (-15.47) suggesting that it underestimates the precipitation values. GHCN exhibited the weakest relationship (correlation = 0.87) followed by CMAP (correlation = 0.89). The positive bias between GHCN and Chirps shows that there is over estimation of the rainfall by GHCN in this case (Table 24).

TABLE 24 - STATISTICAL ANALYSIS OF SATELLITE PRODUCTS WITH CHIRPS

| Dataset | Correlation | Mean error | Root Mean Square Error |
|---|---|---|---|
| CMAP | 0.8922763 | -5.727741 | 64.08018 |
| GPCP | 0.9264499 | -15.46912 | 57.36854 |
| CMORPH | 0.9136873 | 33.11445 | 59.43593 |
| TRMM | 0.9075893 | -22.44144 | 56.69995 |
| GHCN | 0.8664678 | 11.40397 | 55.30405 |

SOURCE: IRI DATA LIBRARY; Adapted by: Author (2017)

### 7.1.3 Comparing Satellite Products With MSJ Station Data

Two pairs of rainfall data for the Norman Manley International Airport in Jamaica were received from the Meteorological Service of Jamaica however, only one was used in this analysis. Table 25 includes a summary of the findings.

Table 25 - COMPARISON OF SATELLITE PRODUCTS WITH MSJ AS REFERENCE

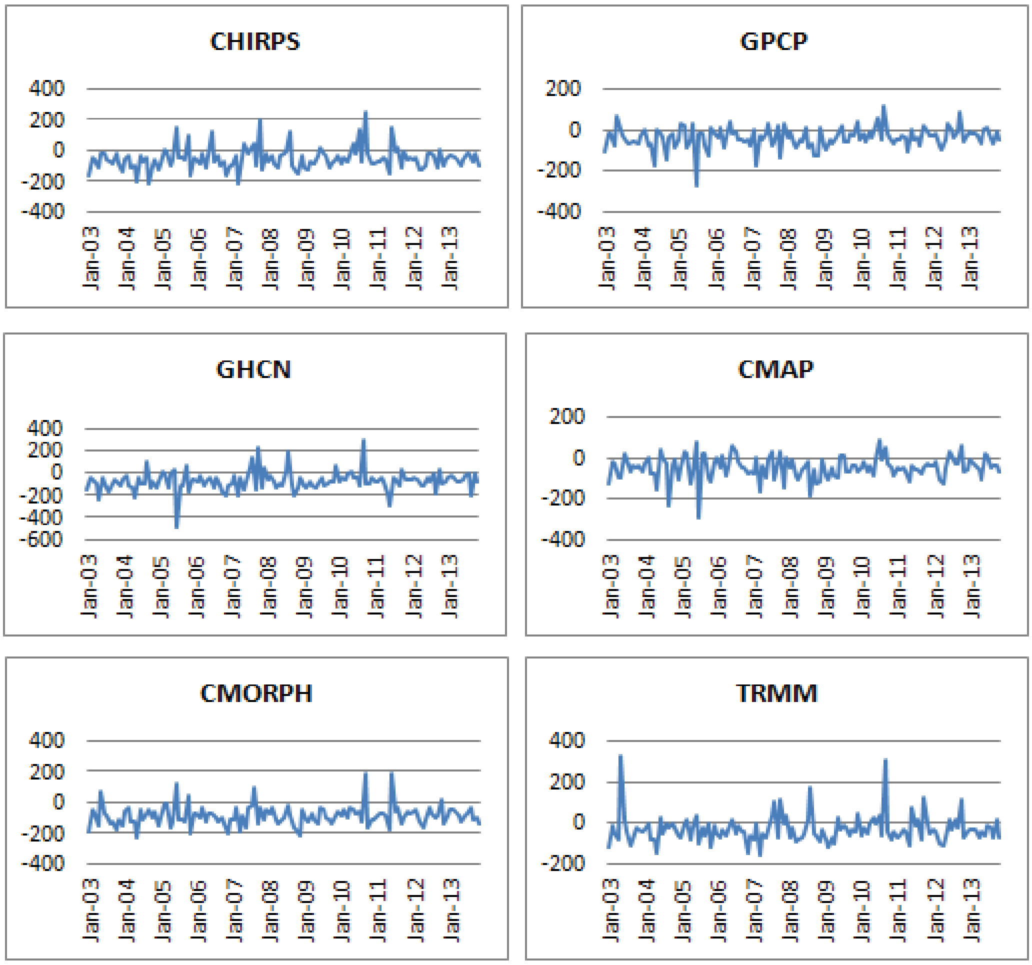
| **Dataset** | **Correlation** | **Mean Error** | **Root Mean Square Error** |
|---|---|---|---|
| CMAP | 0.7854309 | -47.95801542 | 73.65109269 |
| GPCP | 0.8286026 | -38.2166324 | 63.58587026 |
| CMORPH | 0.7972674 | -86.8002086 | 108.7614902 |
| TRMM | 0.8306412 | -31.2443134 | 74.96800763 |
| GHCN | 0.6854019 | -37.57064885 | 115.9705719 |
| CHIRPS | 0.8107591 | -53.68575534 | 89.40794665 |

SOURCE: IRI DATA LIBRARY; Adapted by: Author (2017)

Table 25 shows that all the satellite derived products including GHCN underestimated the extreme events based on the negative ME. Nevertheless, TRMM achieved the strongest correlation and lowest negative bias. Figure 23 shows the level of disparity within the precipitation products between January 2003 and November 2013 using MSJ as reference.

Even though GHCN is based on in situ measurements gathered from the same weather station obtained from MSJ, it demonstrated the weakest correlation (0.69). Also, GHCN was the only product with 11 months of missing data (May 2003, June 2004, July 2004, July 2005, April 2008, January 2009, March 2009, June 2011, July 2012, September 2012 and September 2013). The overall results indicated a better fit for the TRMM product followed by the CHIRPS dataset (Figure 54).

FIGURE 54 - MONTHLY MEAN ERROR OF SATELLITE RAINFALL PRODUCTS FROM 2003 TO 2013 WITH MSJ AS REFERENCE

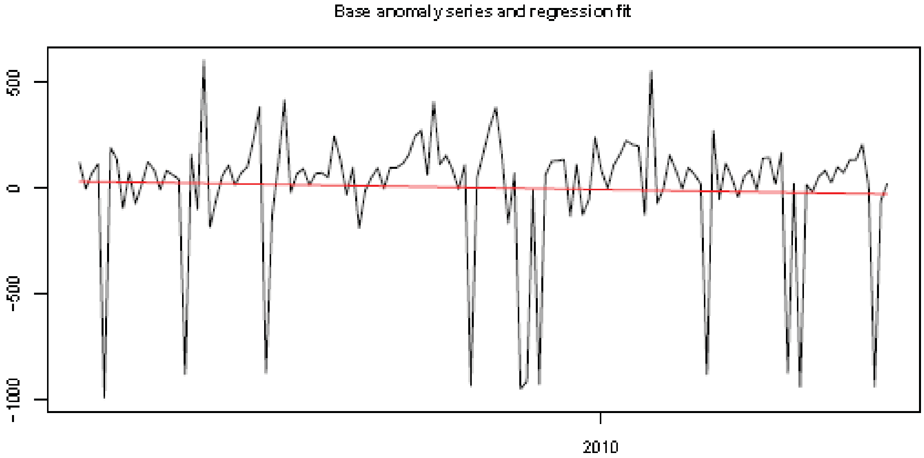



SOURCE: IRI DATA LIBRARY; Adapted by: Author (2017)

A comparison of the GHCN data with the station data obtained from the MSJ revealed a completed dataset for the latter for the same time frame. The missing data in GHCN could be as a result of the quality checks done to remove outliers from the dataset before it is made available to users (LAWRIMORE et al. 2011; MENNE and WILLIAMS 2009).

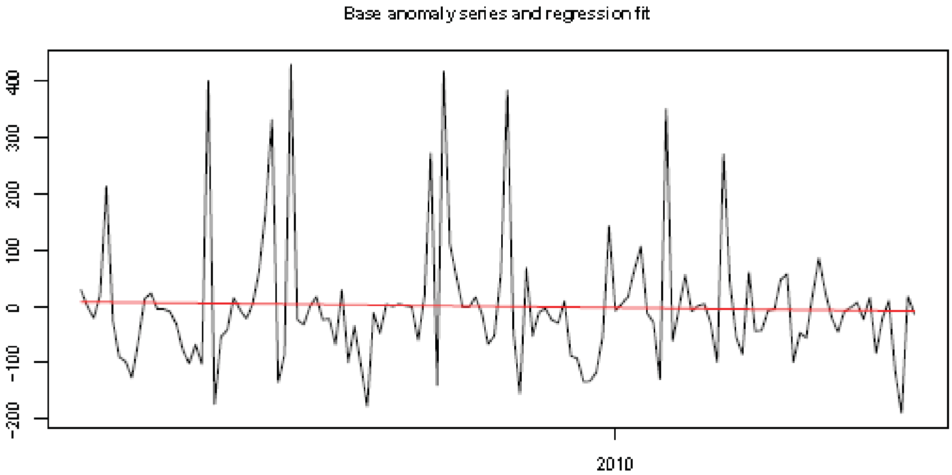
Following this observation, homogeneity analysis was conducted to see if there were any change points within the two station dataset as there have been previous reports regarding coding errors in the software used to detect inhomogeneity in GHCN (MENNE and WILLIAMS 2009). According to NOAA (2015), the presence of bugs within the software generated numerous errors for several stations in Algeria which has since been rectified. However, both data from GHCN and MSJ were compared using RHtest4 and did not exhibit change points (continuous red line) which implies that the data is homogenous (Figures 55 and 56).

FIGURE 55 - RAINFALL HOMOGENEITY ANALYSIS OF GHCN




SOURCE: Wang & Feng (2013); Adapted by: Author (2017)

FIGURE 56: RAINFALL HOMOGENEITY ANALYSIS OF DATA FROM THE METEOROLOGICAL SERVICE OF JAMAICA.




SOURCE: Wang & Feng (2013); Adapted by: Author (2017)

Subsequently, the two sets of station data for the Norman Manley International Airport provided by the MSJ were evaluated which indicated some amount of discrepancy between them from May 2005 to September 2013 (Table 26).

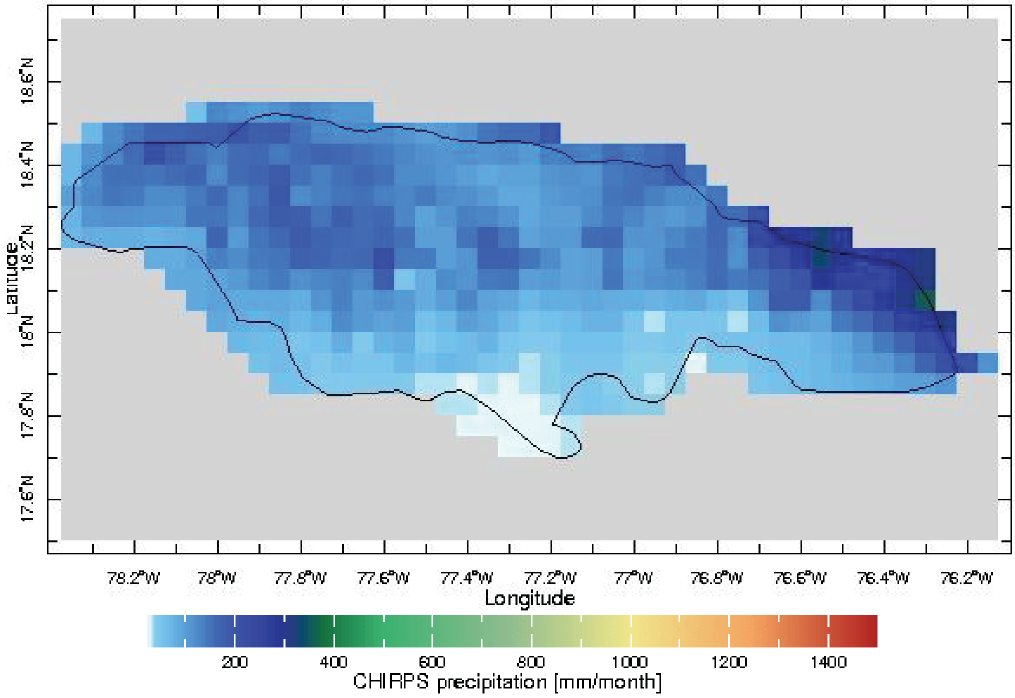
TABLE 26 - DIFFERENCE IN RAINFALL DATA FOR NORMAN MANLEY AIRPORT RECIEVED FROM THE METEOROLOGICAL SERVICE OF JAMAICA.

| Date | **Rainfall value 1 (mm)** | **Rainfall Value 2 (mm)** |
|---|---|---|
| May 2005 | 176.8 | 223 |
| March 2006 | 0 | 1.1 |
| April 2006 | 12.4 | 14.2 |
| July 2006 | 5.5 | 11.5 |
| December 2007 | 106.4 | 107.4 |
| August 2008 | 553.8 | 548.8 |
| April 2009 | 4.3 | 1.2 |
| September 2009 | 12.7 | 54 |
| September 2013 | 29.1 | 111.9 |

SOURCE: IRI DATA LIBRARY; Adapted by: Henry (2017)

Based on the inconsistencies among the data supplied by the MSJ and the performance of the satellite products, further analysis will incorporate the CHIRPS dataset (using the following extent: 78.5W - 76W longitude and 17.5N - 18.75N latitude) from January 2003 to November 2013 (Figure 57). Even though, the Caribbean Catastrophe Risk Insurance Facility[4] (CCRIF) and the Swiss Re excess rainfall policy for the Caribbean is based on parametric analysis from TRMM using rainfall values aggregated over a 5 day period (CCRIF, 2012), it will not be utilized for further analysis as it is no longer in operation. Hence, the CHIRPS product becomes relevant.

FIGURE 57 - JAMAICA - EXTENT FOR CHIRPS DATASET




SOURCE: IRI DATA LIBRARY; Adapted by: Author (2017)

## 7.2 THE SPATIAL AND TEMPORAL PATTERN OF DENGUE CASES AT THE NATIONAL LEVEL

### 7.2.1 Temporal Pattern of Dengue Cases at Different Scales

Annual dengue data gathered from PAHO (2017) illustrates that six dengue outbreaks occurred in Jamaica between 1995 and 2016. In 1995, there were about 1,884 cases while in 1998 about 1,551 cases were reported. Between 1999 and 2006, the total

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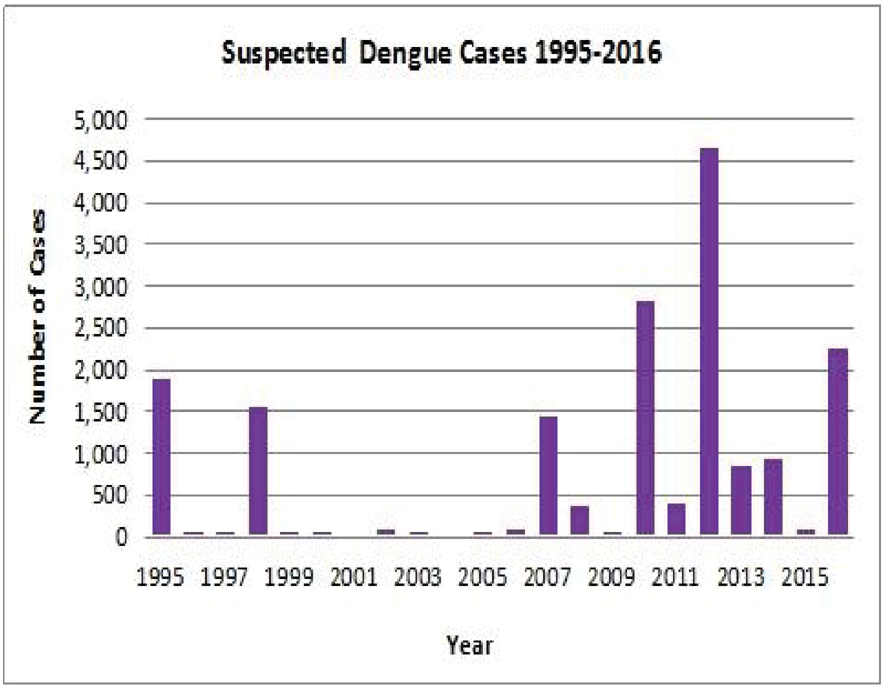
[4] CCRIF is a non profit insurance scheme operated within the Caribbean for Governments within the region since 2008.

number of dengue cases reduced significantly. However, in 2007, the number of cases recorded increased to 1,448 and decreased between 2008 and 2009. By 2010, there was another outbreak of 2,827 cases followed by a decline in 2011. The number of cases later skyrocketed to 4,670 in 2012 but decreased in 2013 up until 2015. In 2016, an additional 2,269 dengue cases were registered (Figure 58).

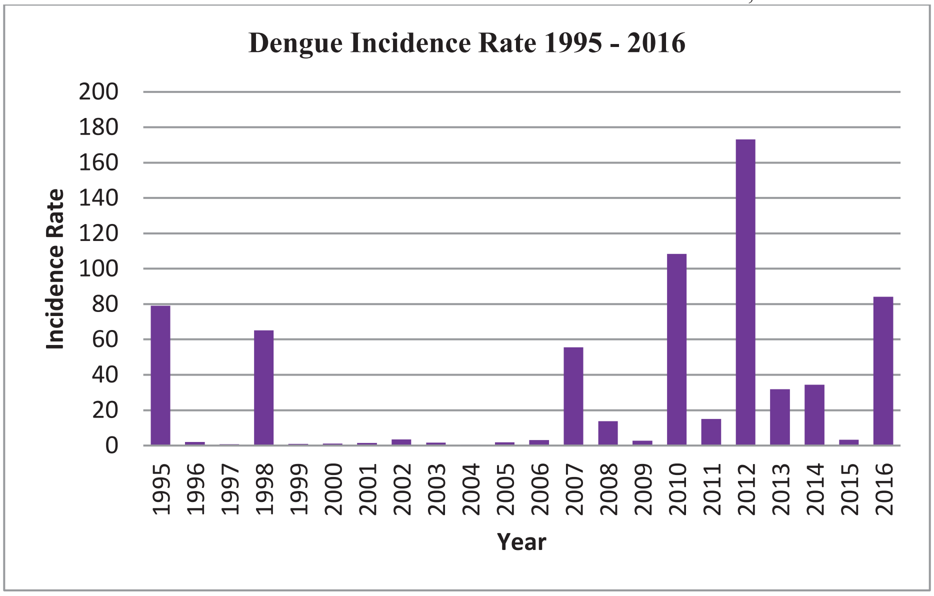
FIGURE 58 - JAMAICA – SUSPECTED DENGUE CASES 1995 – 2016




SOURCE: PAHO, 2017; Adapted by: Author (2017)

Likewise, from an incidence rate perspective, the dengue outbreak years remain the same as highlighted above (Figure 59). However, the rate seems to be low because of the small population on the island.

FIGURE 59 - JAMAICA - DENGUE INCIDENCE RATE PER 100, 000 FOR 1995-2016




One explanation for the occurrence of dengue could relate to the lack of immunity of the population to a particular serotype or the introduction of several serotypes (MONATH, 1994). Brown et al., (2011) and PAHO, (2008) have indicated that the following serotypes: DENV-1, DENV-2 and DENV-4 were responsible for the 2007 outbreak in Jamaica (Table 27). Even though DENV-1, 2 and 4 were identified in the 2007 outbreak, DENV-2 and DENV-4 were the more dominant serotypes (Brown et al. 2011). Notwithstanding that, DENV-3 was detected only in three infants below three years old in 2006 while the other serotypes were discovered in different cohort. Other serotypes detected in outbreak years included DENV-2 in 2010, DENV-1 in 2012 and DENV-3 and 4 in 2016. Between 2013 and 2014, DENV-1, DENV-3 and DENV-4 were being circulated on the island.

TABLE 27 - JAMAICA -DENGUE SEROTYPES 2003 – 2016

(Continues)

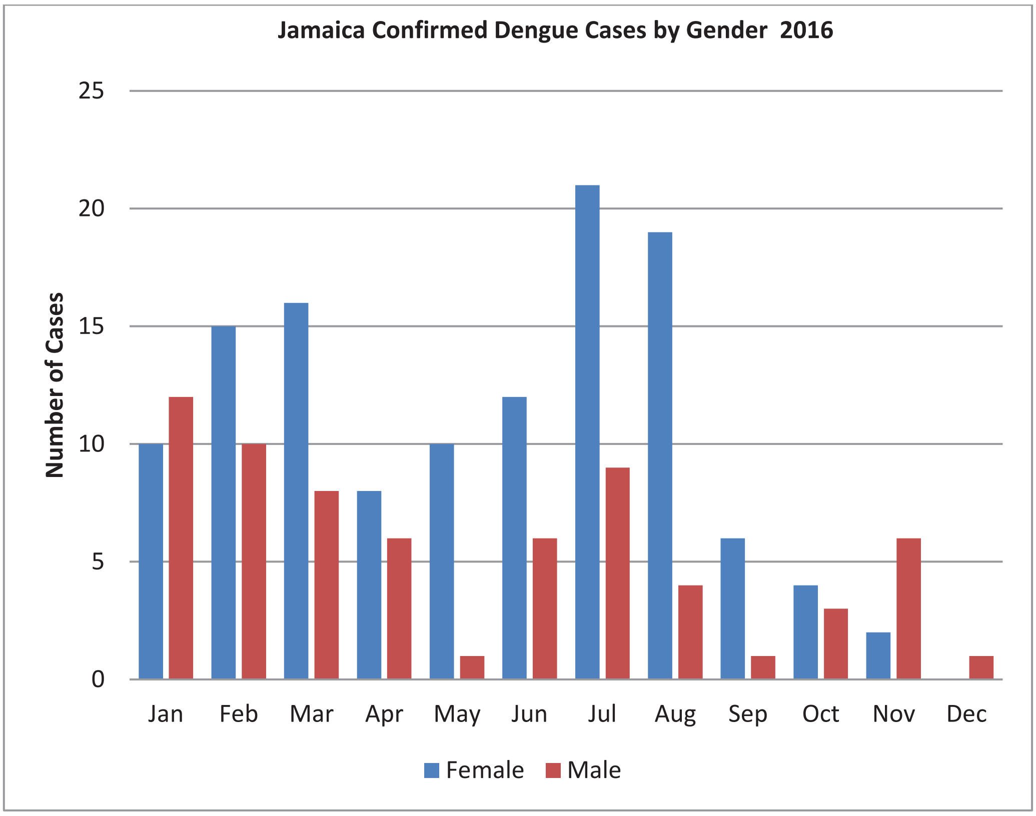
| **Year** | **Serotype** | **Source** |
|---|---|---|
| 2003 | DENV-1 | Brown et al., 2011 |
| 2004 | DENV-2 | Brown et al., 2011 |
| 2005 | None identified | Brown et al., 2011 |
| 2006 | DENV-3 | Brown et al., 2011 |
| 2007 | DENV-1, DENV-2, DENV-4 | Brown et al., 2011<br>PAHO, 2008 |

TABLE 27 - JAMAICA -DENGUE SEROTYPES 2003 - 2016
(Concludes)

| Year | Serotype | Source |
|---|---|---|
| 2008 | DENV-2, DENV-4<br>DENV-3 | MoH, 2007<br>PAHO, 2009 |
| 2009 | None identified | PAHO, 2010 |
| 2010 | DENV-2 | PAHO, 2011 |
| 2011 | DEN | PAHO, 2012 |
| 2012 | DENV-1 | PAHO,2013 |
| 2013 | DENV-1 | PAHO, 2014 |
| 2014 | DENV-3 | PAHO, 2015<br>&ARS, 2015 |
| 2015 | DENV-4 | PAHO, 2016 |
| 2016 | DENV-3, DENV-4 | PAHO, 2016 |

The next analysis involves confirmed dengue cases by gender for 2016. Figure 60 shows that for each month, females accounted for majority of the confirmed dengue cases in 2016 except for January and November. The figure also shows that while both males and females were infected with dengue each month, only males were notified with dengue in December. Additionally, majority of the outbreak took place between July and August.

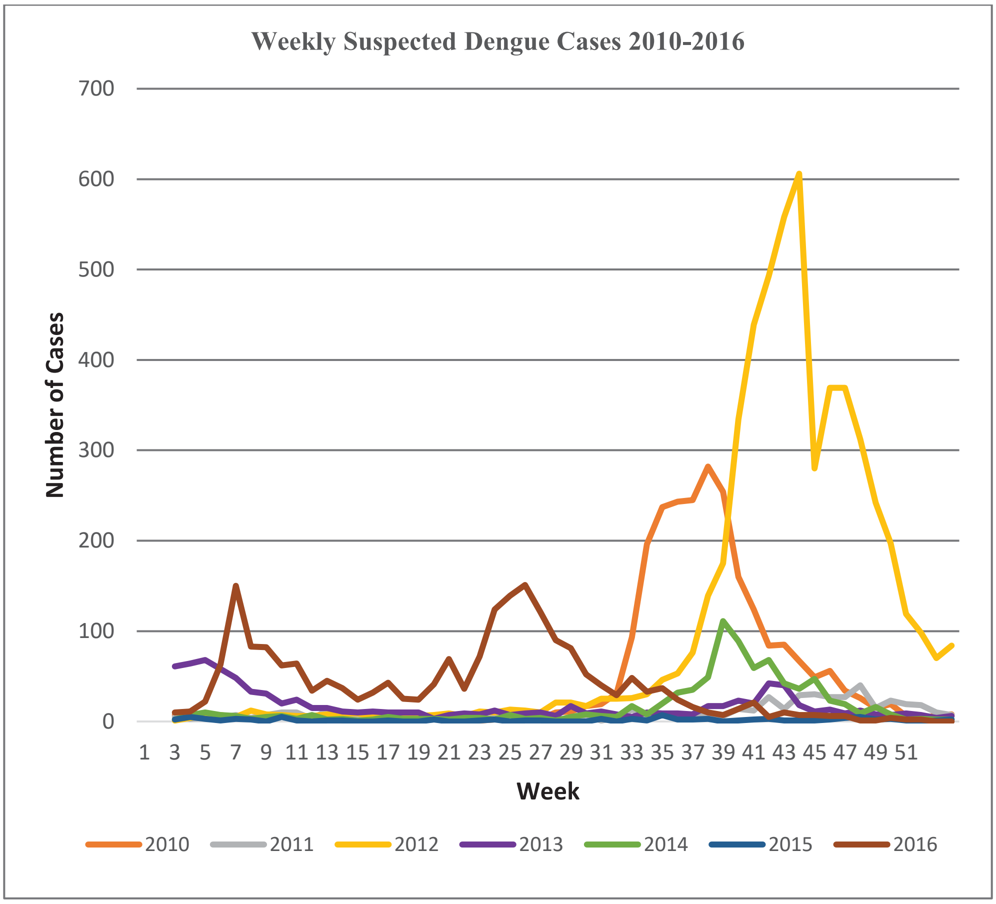
FIGURE 60 - JAMAICA - CONFIRMED DENGUE CASES BASED ON GENDER 2016




When analysis is conducted in weekly format between 2010 and 2016, the maximum peak in dengue cases varies yearly but three distinct outbreaks are observed (Figure 61). For 2010, the dengue outbreak curve occurred between week 32 and 42 with a peak at week 38. However, in 2012, the cases began to rise at week 39 although dengue peaked at week 44 before declining in week 45. Following this, a smaller peak emerged at week 46. In the 2016 outbreak, the first peak was observed at week 7 with about 150 cases followed by fluctuations and another major peak during week 26.

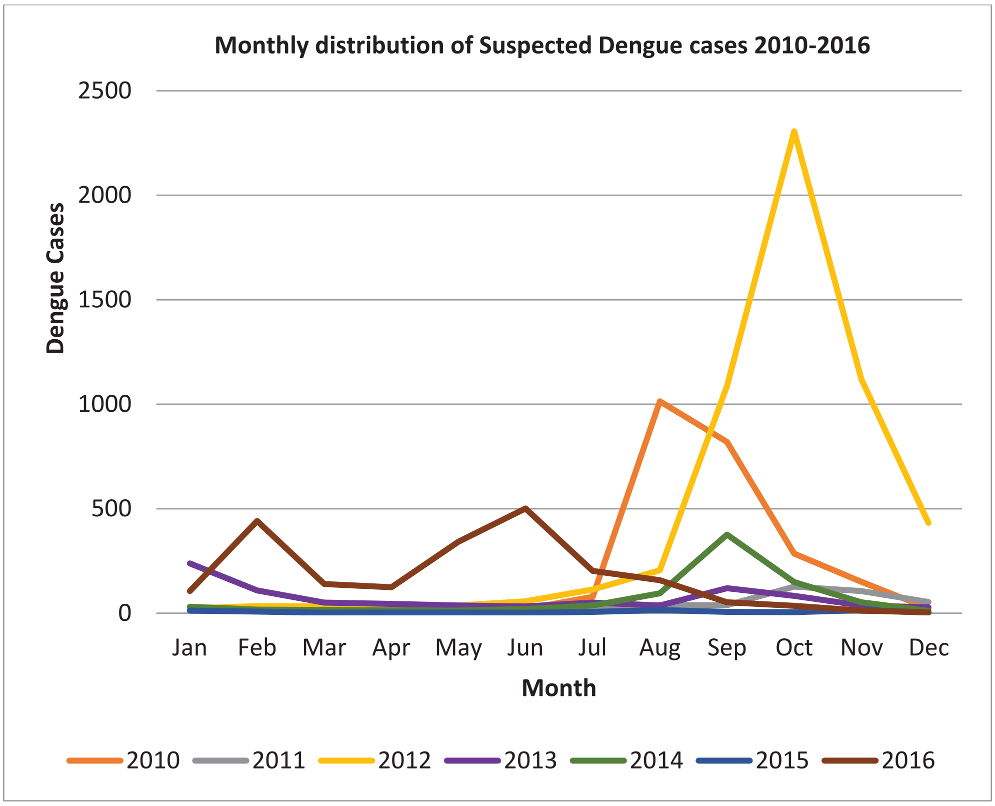
In general, aggregated weekly data between 2010 and 2016 shows that majority of the dengue cases (764) were recorded in week 42 while the lowest cases (46) occurred during week 17.

FIGURE 61 - JAMAICA - WEEKLY SUSPECTED DENGUE CASES 2010-2016




To identify seasonal pattern, the monthly dengue cases were examined. It is evident that outbreaks vary per month. Figure 62 shows that few dengue cases were reported between January and June however, by July, the number of cases increased. In 2012, dengue cases increased between August and December and peaked in October before it declined in November. On the other hand, the 2010 outbreak curve occurred between July and October with a peak in August. In 2016, the first dengue peaked is observed in February and the second in June.

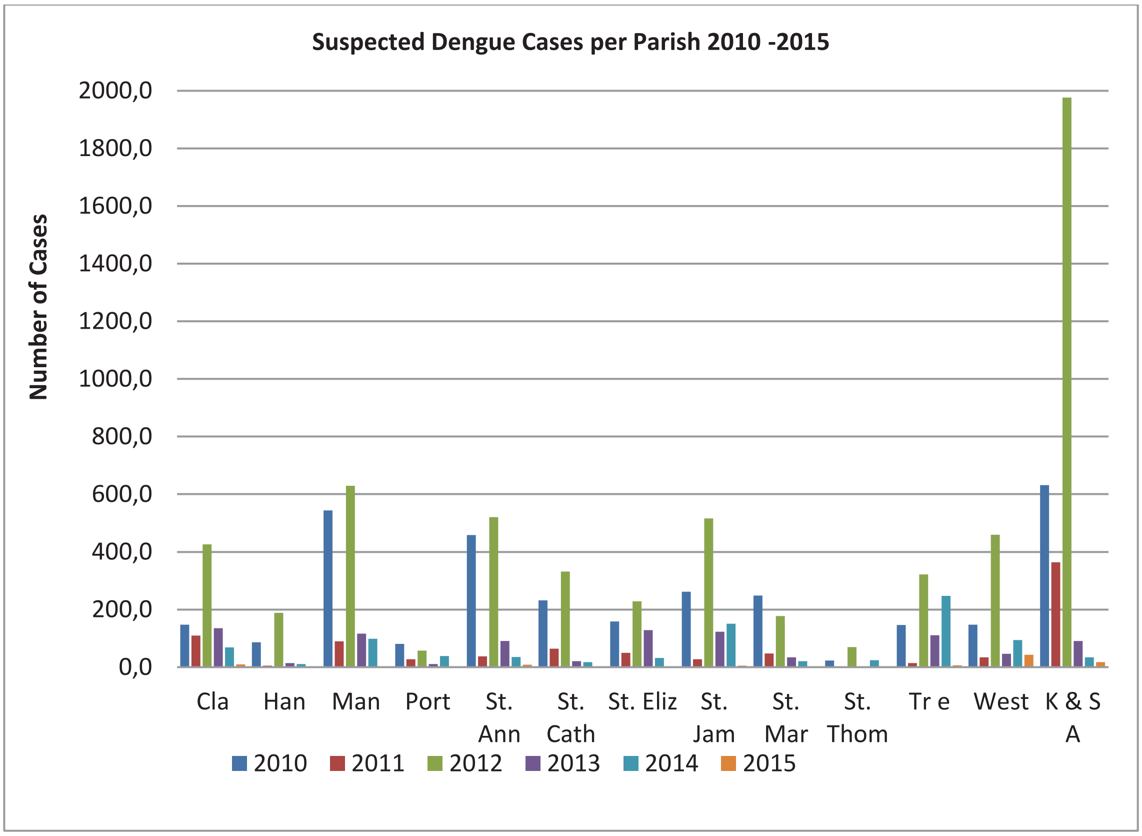
FIGURE 62 - JAMAICA - MONTHLY SUSPECTED DENGUE CASES 2010-2016




7.2.2 Spatial Distribution of Dengue

At the parish level, regions with high population density, infrastructure that promotes mobility and economic opportunities tend to record high amount of dengue cases. Between 2010 and 2015, majority of the suspected dengue cases were registered in Kingston and St. Andrew (K&SA) followed by Manchester (Man), St Ann and St. James (Figure 63). For the foregoing period, Kingston and St. Andrew recorded about 3,114 cases while dengue cases in Manchester were estimated at 1,480. While about 1,151 cases were notified in St. Ann, St. James had around 1,085 cases. St. Thomas was the parish with the least number of cases (121) followed by Portland (218) and Hanover (307). It is also evident that 2010 and 2012 exhibited majority of the epidemic, with Kingston and St. Andrew having the most cases.

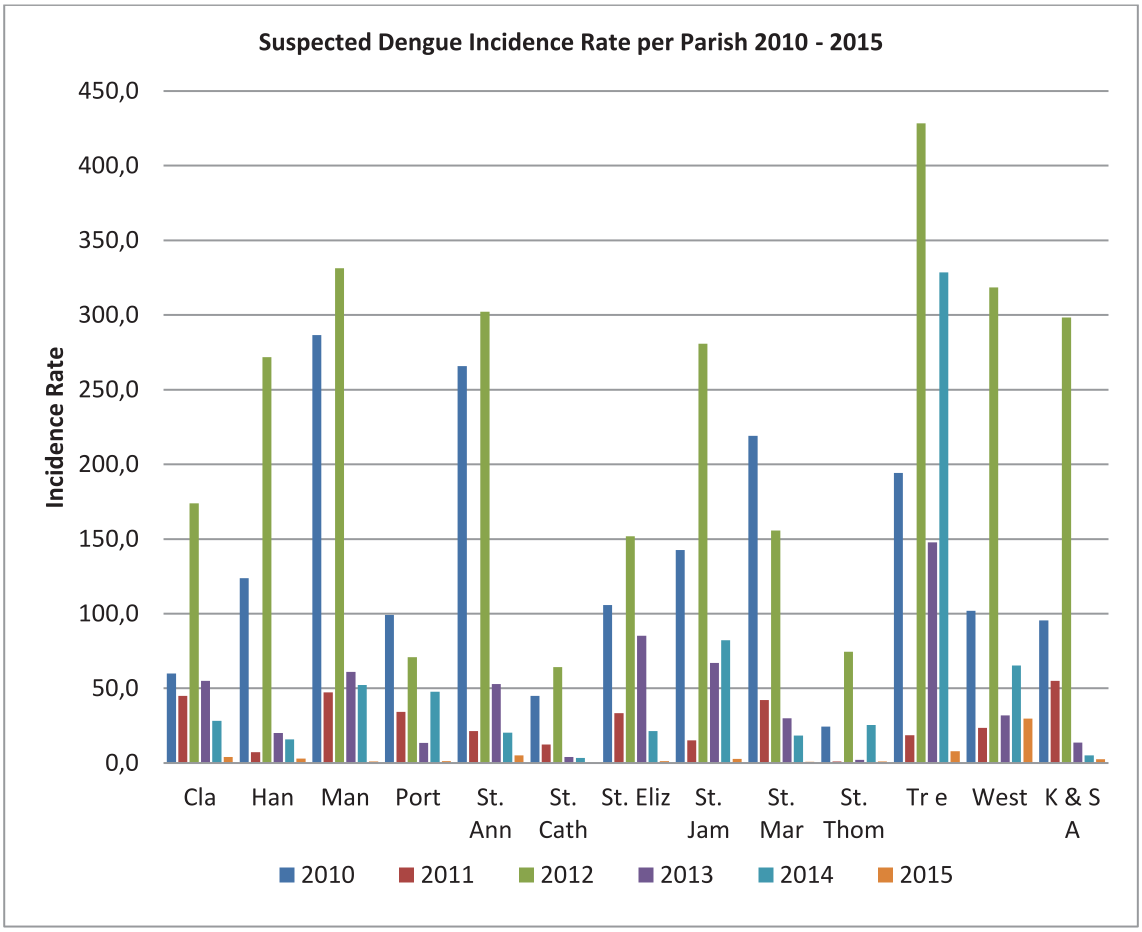
FIGURE 63 - JAMAICA -SUSPECTED DENGUE CASES PER PARISH 2010-2015




SOURCE: MoH, 2016; Adapted by Author (2017)

From an incidence rate stand point, Kingston and St. Andrew seem have a lower rate in comparison to other parishes. The highest incidence rate (1,125) was recorded in Trewlany (Tre). Manchester (Man) had the second highest incidence rate (779.8) and St. Ann accounted for the third highest rate (667.8) which might be due to the difference in population and number of cases. The lowest incidence rate was recorded in St. Thomas (128.9) followed by St. Catherine (129.6). Therefore, even though some of the parishes recorded fewer cases, proportionally, the epidemic amount to the same or more than the number of cases in Kingston and St. Andrew. Figure Figure 64 shows the suspected dengue incidence rate per 100,000 at the parish level for the period 2010 to 2015.

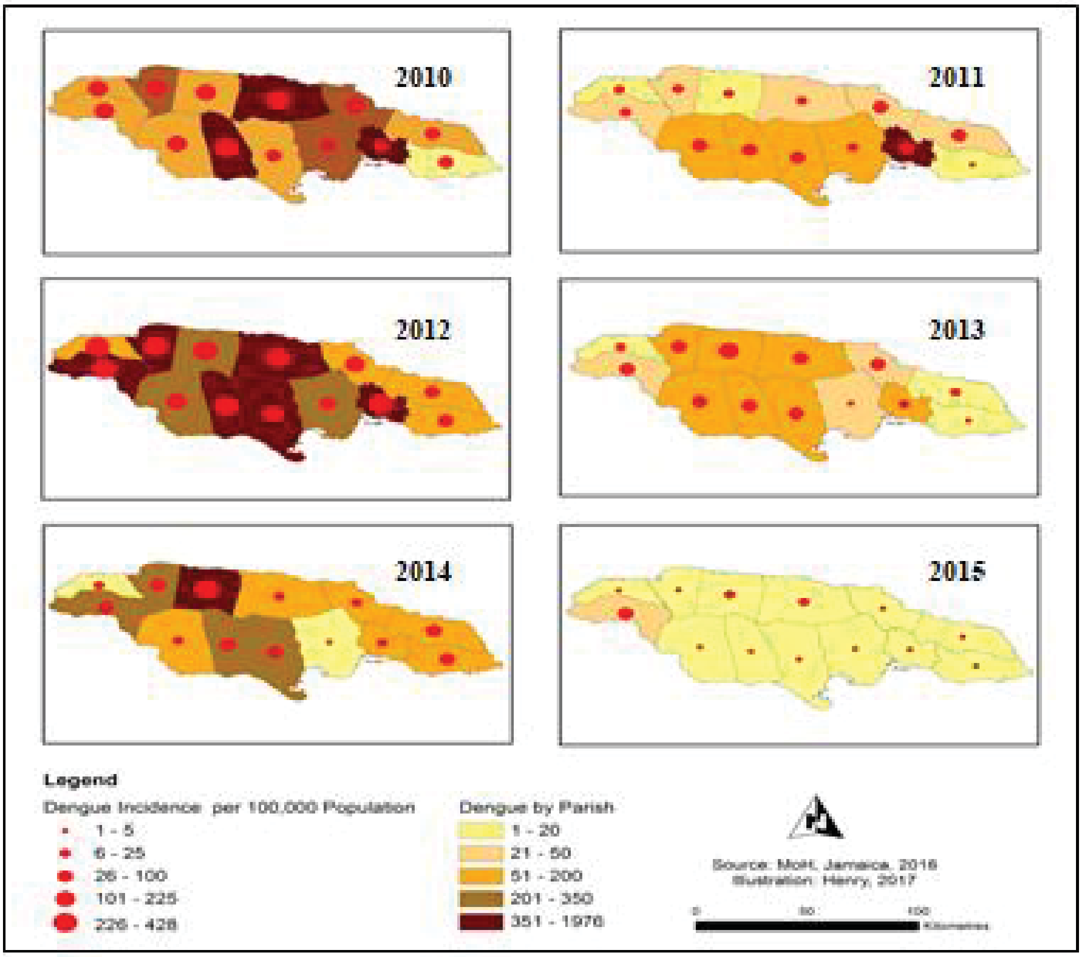
FIGURE 64 - JAMAICA - SUSPECTED DENGUE INCIDENCE RATE PER100, 000 PER PARISH 2010-2015




SOURCE: MoH, 2016: Adapted by Author (2017)

To gain a better perspective of the geographical distribution of dengue between 2010 and 2015, the data was mapped (Figure 65). The figure highlights fluctuation in the number of cases with records of high incidence rate in all parishes for some of the years. Even though Hanover is the least populated parish as per the 2011 census, the incidence rate was higher than Kingston and St. Andrew in 2012 though it had few cases. By 2015, all the parishes registered fewer dengue cases than the normal amount.

FIGURE 65 - JAMAICA - DENGUE INCIDENCE PER 100, 000 PER PARISH 2010-2015




SOURCE: MoH, 2016: Adapted by: Author (2017)

## 7.3 RELATIONSHIP BETWEEN DENGUE AND CLIMATE VARIABLES

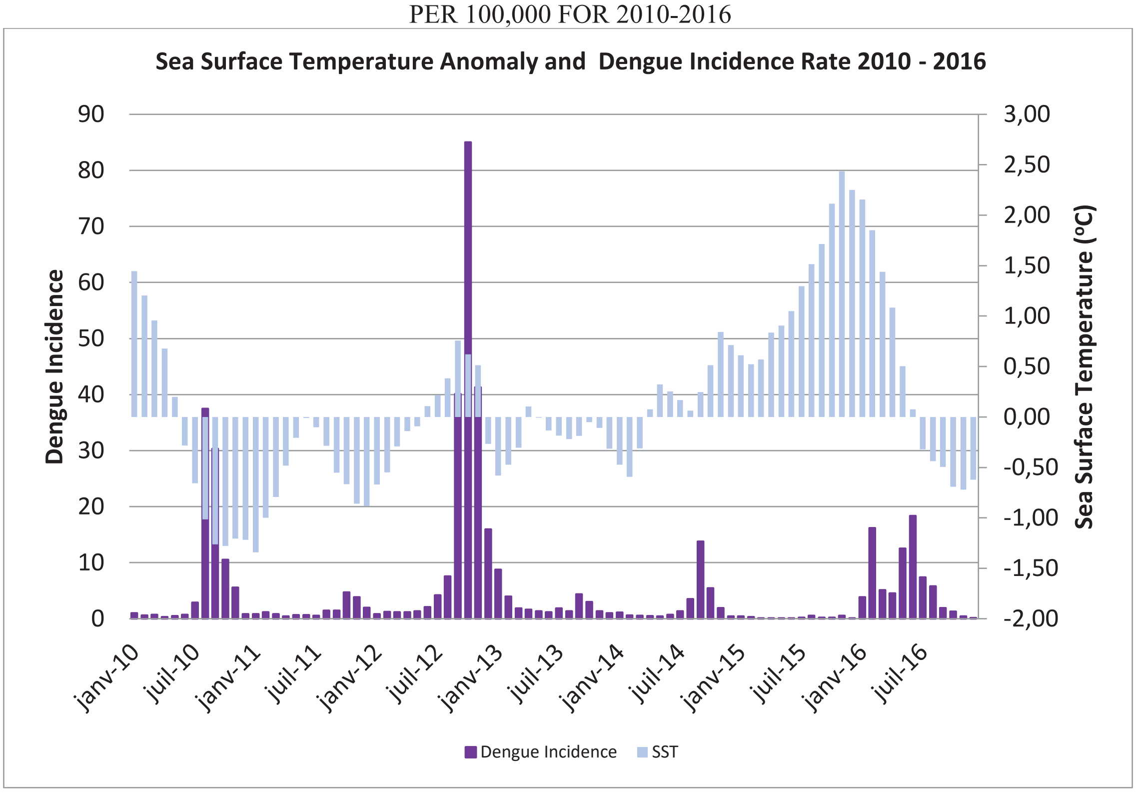
Some outbreaks seemed to be influenced by the ENSO phenomenon. Based on the NIÑO 3.4 index, the 1998, 2007 and 2010 outbreaks were periods with strong La Niña episodes. On the other hand, the 1995 and 2016 outbreaks took place during moderate and weak La Niña respectively.

Even though a number of dengue outbreaks occurred during ENSO events, there was no significant correlation between the SST in the Niño 3.4 Index and dengue fever in Jamaica (Table 28). Since the Niño 3.4 Index impacts the weather pattern in Jamaica, a more significant relationship might be obtained with other climate anomaly data (rainfall and climate). Figure 66 shows the SST anomaly with dengue incidence at a lag of 0 to 3 months.

TABLE 28 - CORRELATION BETWEEN DENGUE INCIDENCE AND SEA SURFACE TEMPERATURE WITHIN NINO 3.4 INDEX LAGGED AT 0 TO 3 MONTHS

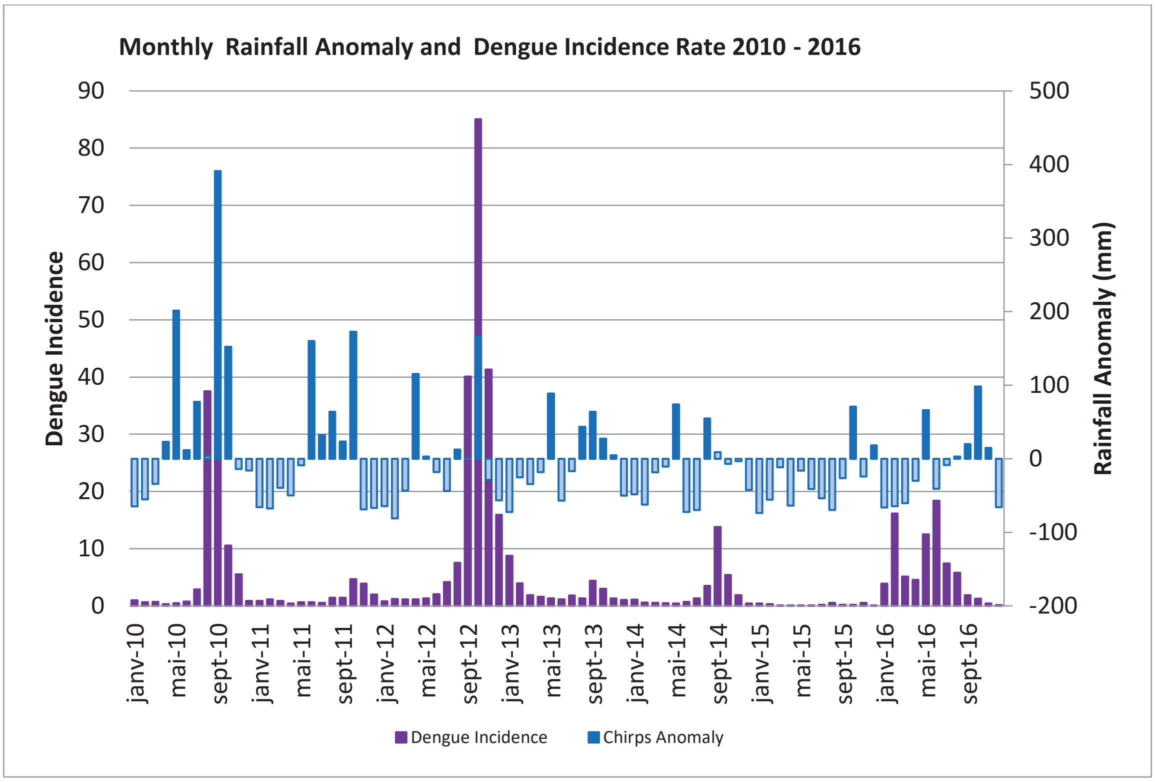
| **Parameter** | **0 Lag** | **1 month lag** | **2 month lag** | **3 month lag** |
|---|---|---|---|---|
| Lag | -0.10 | -0.10 | -0.10 | -0.10 |

FIGURE 66 - SEA SURFACE TEMPERATURE ANOMALY AND DENGUE INCIDENCE RATE PER 100,000 FOR 2010-2016




Analysis of dengue incidence with monthly rainfall anomaly from CHIRPS illustrates fluctuation with the variables between 2010 and 2016 (Figure 68). The variability in rainfall is an indication of extreme events (drought for negative values and heavy rainfall for higher values). Interestingly, the highest dengue peak can be observed on October 2012 which corresponds to one rainfall event above normal conditions and high dengue incidence. Even though 2012 was an outbreak year and was affected by hurricane, the rainfall amount was relatively low. Figure 67 also indicates some dry conditions below normal with a spike in dengue cases especially in 2016.

FIGURE 67 - MONTHLY RAINFALL ANOMALY AND DENGUE INCIDENCE RATE PER 100,000 FOR 2010 - 2016




To gain a better understanding of the driest and wettest month, the monthly rainfall percentile between 2010 and 2016 was calculated. Table 29 shows that October is the wettest month followed by May. In general, the rainfall reveals the rainfall pattern for Jamaica with two wet and one the dry season.

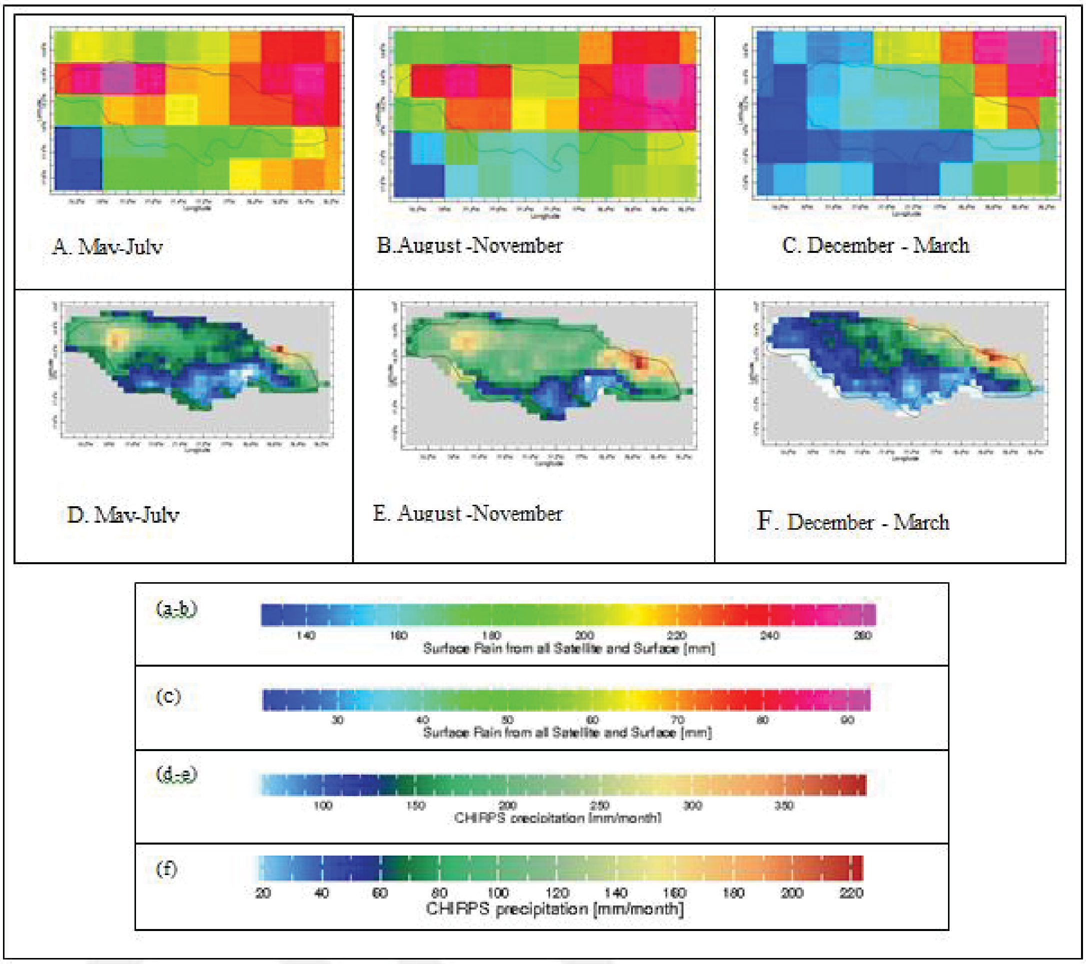
TABLE 29 - JAMAICA - CHIRPS MONTHLY RAINFALL PERCENTILE FOR – 2010-2016

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | 0CT | N0V | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5% | 34.85 | 31.03 | 52.88 | 48.63 | 94.21 | 40.40 | 43.21 | 60.27 | 89.63 | 111.52 | 51.40 | 41.60 |
| 25% | 38.81 | 42.17 | 66.84 | 68.31 | 105.14 | 59.15 | 59.37 | 111.34 | 112.48 | 157.20 | 81.85 | 46.96 |
| 50% | 42.34 | 45.87 | 73.77 | 90.05 | 174.53 | 67.31 | 91.25 | 120.89 | 128.00 | 206.54 | 94.27 | 58.05 |
| 75% | 34.54 | 33.56 | 48.73 | 45.31 | 92.46 | 36.69 | 39.37 | 42.83 | 83.39 | 103.29 | 57.93 | 41.74 |
| 95% | 56.25 | 51.22 | 105.48 | 93.76 | 180.75 | 67.27 | 91.53 | 152.71 | 125.83 | 201.01 | 119.31 | 114.51 |
| 100 % | 42.34 | 52.56 | 109.40 | 90.05 | 174.53 | 67.31 | 99.56 | 120.89 | 128.00 | 206.54 | 122.90 | 126.69 |

To further comprehend the seasonal variation in precipitation for the island and its representation by the products, comparisons were also done for the two rainy seasons and the dry season. The spatial variation in seasonality can be visualized in Figures 68

(A-F) based on data obtained from TRMM and CHIRPS. This further reiterates the observation made about wetter conditions experienced over the north-eastern region of Jamaica during the two rainy seasons (May to July and August to November) and even in the dry periods (December to March). As usual, the southern section of Jamaica receives less rainfall which worsens during the dry season. Another highlight is the overestimation of precipitation values during drought conditions for CHIRPS (68F) in comparison to TRMM (68C).

FIGURE 68 - JAMAICA - SEASONAL AVERAGE OF RAINFALL 2010 - 2016 FROM TRMM (A-C) AND CHIRPS (D-F)




SOURCE: IRI DATA LIBRARY; Adapted by: Auhtor (2017)

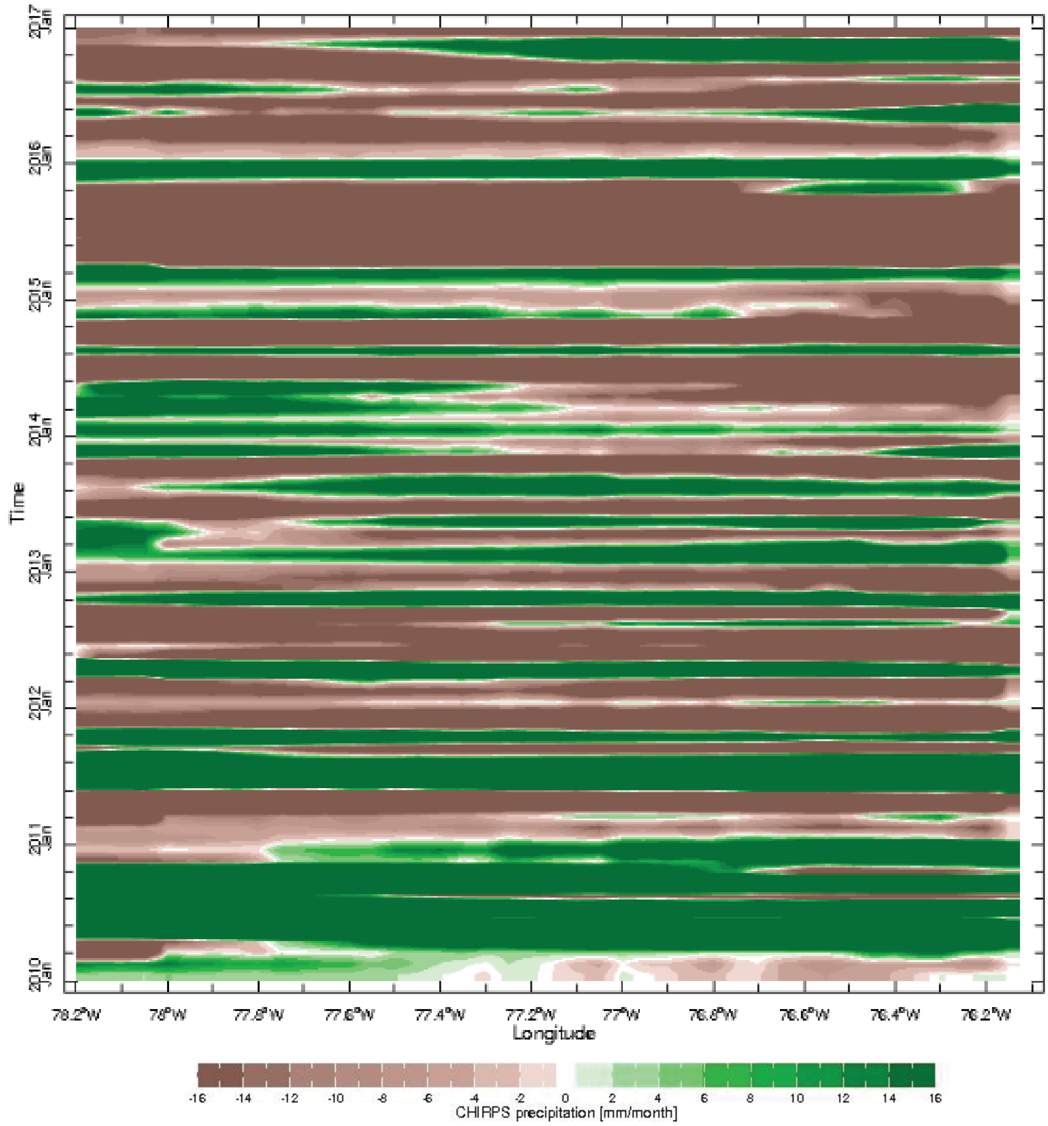
Further analysis indicated that rainfall anomaly and dengue cases are positively correlated (Table 30) with and without monthly lags. This relationship varies from 0.30 to 0.31 from one month lagged to three months lagged and even with zero months lagged. However, the relationship was proven to be tatistically insignificant.

TABLE 30 - CORRELATION BETWEEN DENGUE AND MONTHLY LAGGED RAINFALL FROM 0 TO 3 MONTHS

| Parameter | 0 Lag | 1 month lag | 2 month lag | 3 month lag |
|---|---|---|---|---|
| Lag | 0.31 | 0.30 | 0.31 | 0.31 |

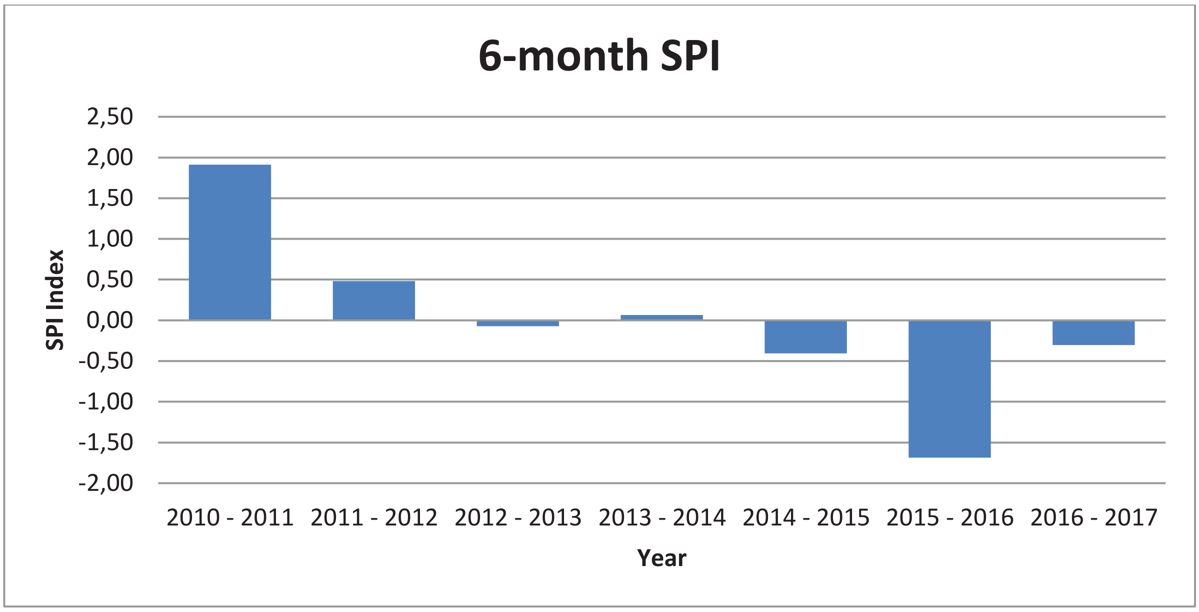
In order to better understand the rainfall pattern on the island, spatial representation of rainfall anomaly using CHIRPS is presented in Figure 69. Wet conditions are shown in green and dry conditions in brown. As depicted, periods with heavy rainfall are followed by episodes of dry conditions which explain the haphazard nature of the graphs with the rainfall presented earlier. This type of activity seems to be homogenous in longitude (76ºW to 78º W) which is a representation of the island of Jamaica from east to west. It must be noted that 2010 accounts for a greater number of wet periods in comparison to the other years. Specifically, the earlier months of 2010 commenced with rainfall in the west while dry conditions were over eastern section of the island. However, wet conditions were homogenous across the country by April with a return of the dry spells in early 2011. In mid-2011, the wet periods were observed until the latter part of the year when the dry period emerged. This fluctuation continued until 2017. However, the driest phase seems to have occurred in 2015. Also, there seems to be continuous drought in the east in 2014 relative to the west.

FIGURE 69 - JAMAICA - CHIRPS RAINFALL ANOMALY 2010 - 2016




Notwithstanding, a positive relationship (0.61) was established between dengue and the 6-month SPI. Figure 70 shows the 6-month SPI for Jamaica Jamaica using CHIRPS. From the figure, it can be seen that 2010 was the wettest period while 2015 was a major drought period.

FIGURE 70 - JAMAICA - 6-MONTH SPI 2010 - 2016



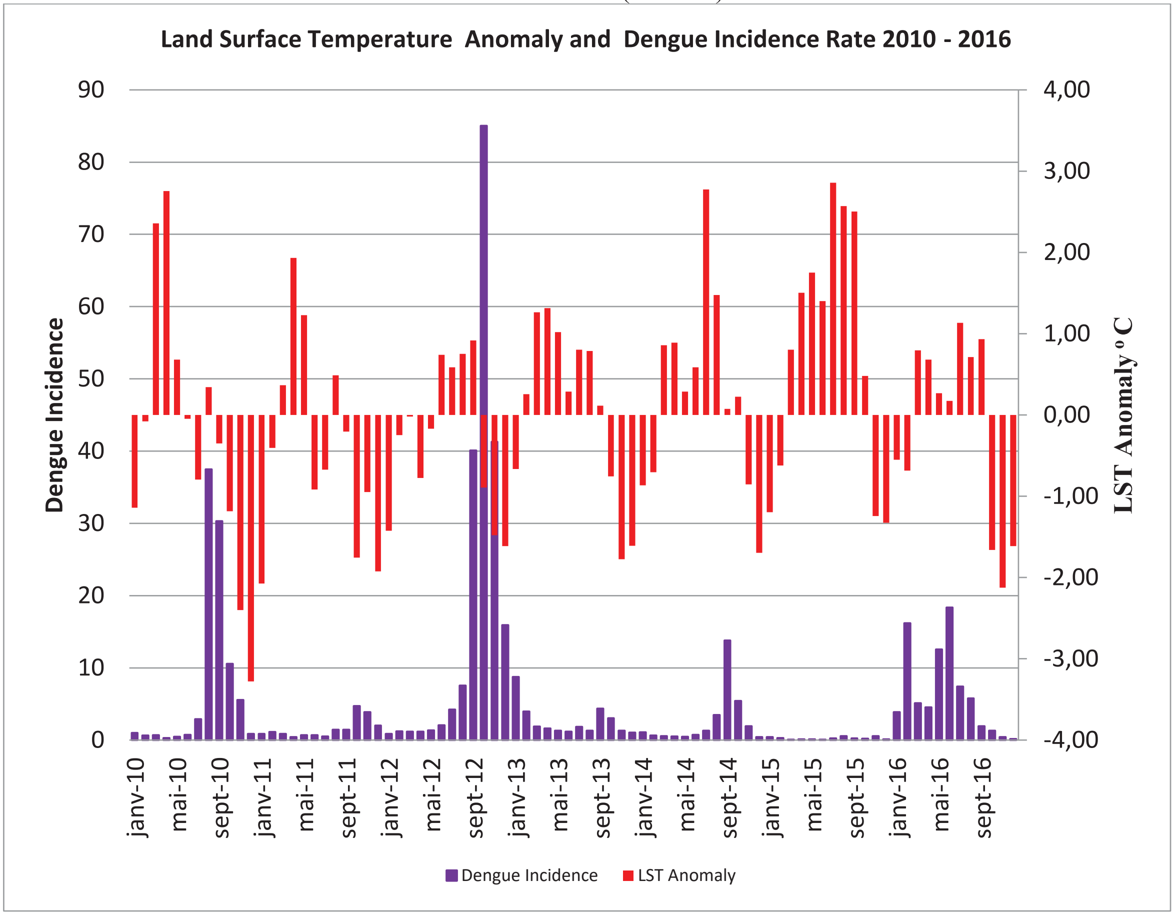

In terms of dengue incidence and LST anomaly, no significant relationship was obtained between the two variables. Table 31 shows the results from the correlation analysis between dengue and LST at 0, 1, 2 and 3 monthly lags.

TABLE 31 - CORRELATION BETWEEN DENGUE FEVER AND MONTHLY LST ANOMALY FROM ZERO TO THREE LAGGED MONTHS

| Parameter | 0 Lag | 1 month lag | 2 month lag | 3 month lag |
|---|---|---|---|---|
| Lag | -0.11 | -0.12 | -0.13 | -0.13 |

The LST anomaly and dengue cases can be observed in Figure 71. While the figure shows no apparent pattern for the spread of dengue and LST anomaly, it can be seen that the LST anomaly was negative during the major peak in 2012.

FIGURE 71 - JAMAICA DENGUE INCIDENCE RATER PER 100,000 AND MEAN ANNUAL LAND SURFACE TEMPERATURE (MODIS) 2010-2016




The NDVI value range (0.52 – 0.82) in figure 72 shows an estimate of the vegetation greenness which is considered high and suggest the presence of dense vegetation which is a typical characteristic of tropical forest (JENSEN, 2007). The figure also highlights variability in the values implying fluctuation in the vegetation greenness or other environmental variables such as rainfall, evaporation or soil moisture (PETTORELLI, 2013) which can have an impact on disease transmission such as dengue. However, the correlation analysis did not reveal any significant relationship between dengue and NDVI (Table 32).

FIGURE 72 - JAMAICA - MONTHLY NDVI AND DENGUE INCIDENCE RATE PER 100,000 FOR 2010-2016

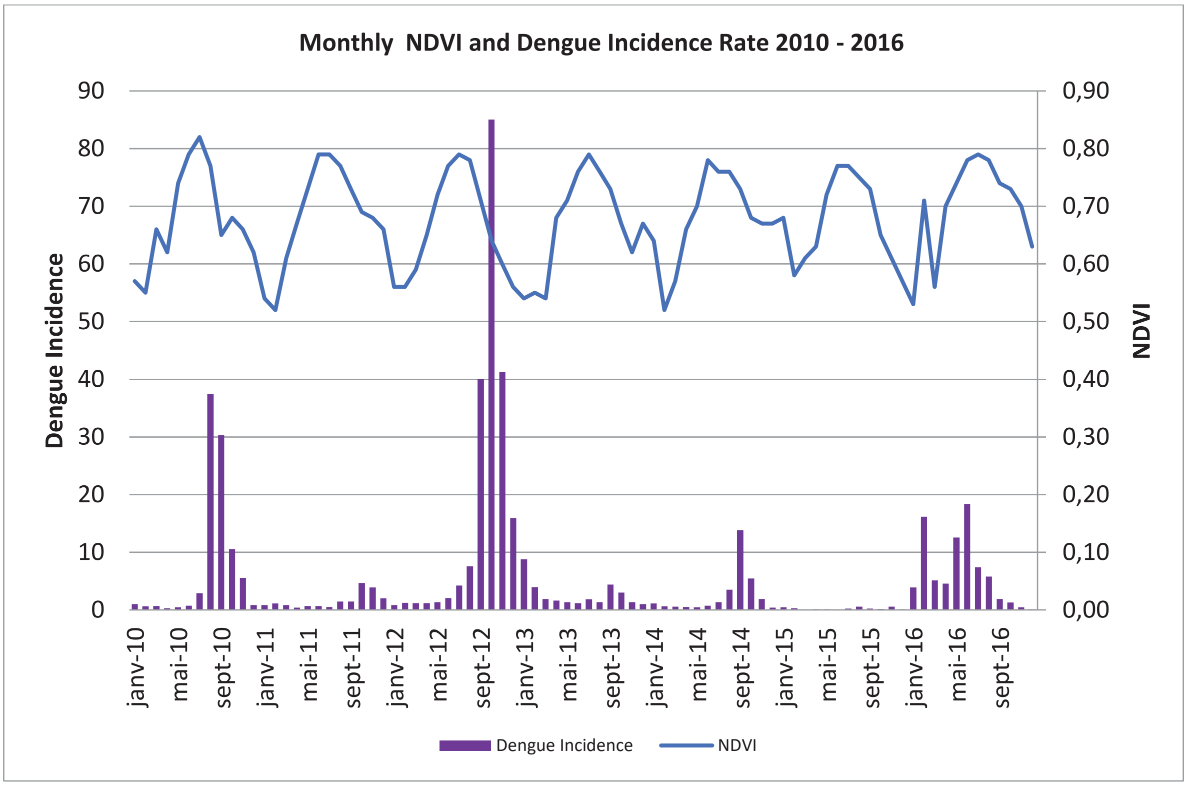
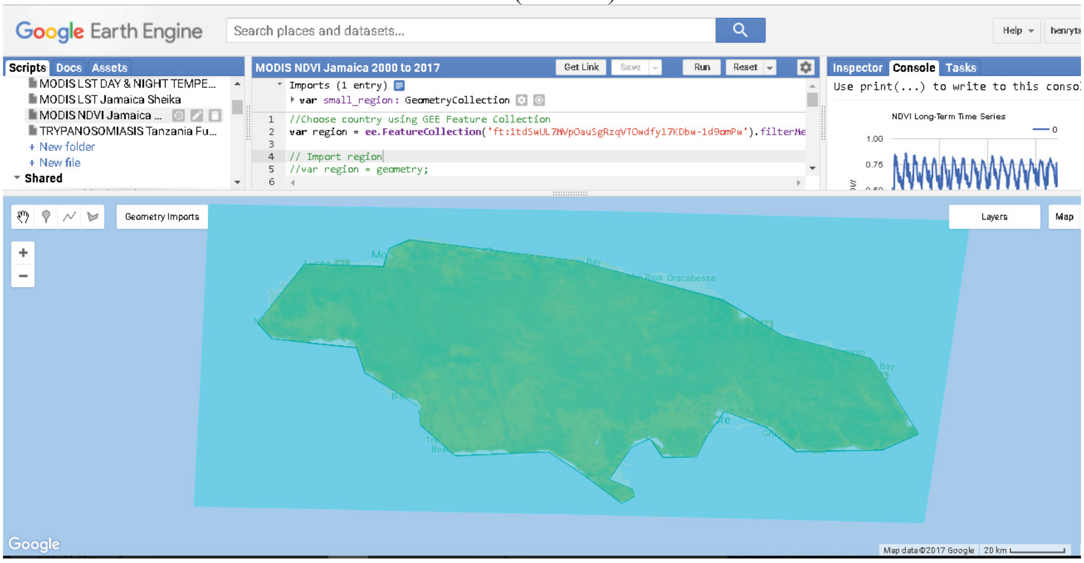



TABLE 32 - CORRELATION BETWEEN DENGUE FEVER AND MONTHLY NDVI FROM ZERO TO THREE LAGGED MONTHS

| Parameter | 0 Lag | 1 month lag | 2 month lag | 3 month lag |
|---|---|---|---|---|
| Lag | 0.01 | 0.00 | -0.01 | 0.00 |

In Figure 73, the spatial distribution of NDVI across Jamaica is dominated by vegetation in green and to a lesser extent, built up areas in brown. This contrast provides an intriguing observation as it relates to the impact of land use on the spread of dengue in Jamaica which needs to be explored further.

FIGURE 73 - JAMAICA - EXTRACTING NDVI (MODIS) FROM GOOGLE EARTH ENGINE




SOURCE: Google Earth Engine; Adapted by: Author (2017)

## 7.4 VULNERABILITY ASSESSMENT

Figure 74 shows the results from the vulnerability assessment with the World Clim rainfall and temperature dataset for 1970-2000. Areas with low vulnerability are indicated in red while regions with higher vulnerability are represented in green. The figure shows that vulnerability to dengue varies spatially and temporally with the lowest vulnerability in October located in the east, central regions and sections of western parishes. May was another period with low vulnerability particulary in the some section of Westmoreland (west). In each scenario, sections of the Blue Mountain, which is the highest point on the island (2,256m), seems to be less favourable to dengue. Likewise, in all the scenarios, the areas with higher vulnerability are located within urban areas.

Likewise, the scenario with CHIRPS and LST (Figure 75) shows variation in vulnerability. From a temporal perspective, the month of May has the the lowest vulnerability. Spatially, regions with high vulnerability are concentrated in urban areas for January and May. However, from Jun onwards, vulnerability to dengue increases even in non urban areas. In this scenario, the lowest vulnerability to dengue in the Blue Mountain only occurs in January, February, March, April, May and December.

FIGURE 74 - JAMAICA - MONTHLY VULNERABILITY TO DENGUE WITH WORLD CLIM RAINFALL AND TEMPERATURE DATA 1970-2000

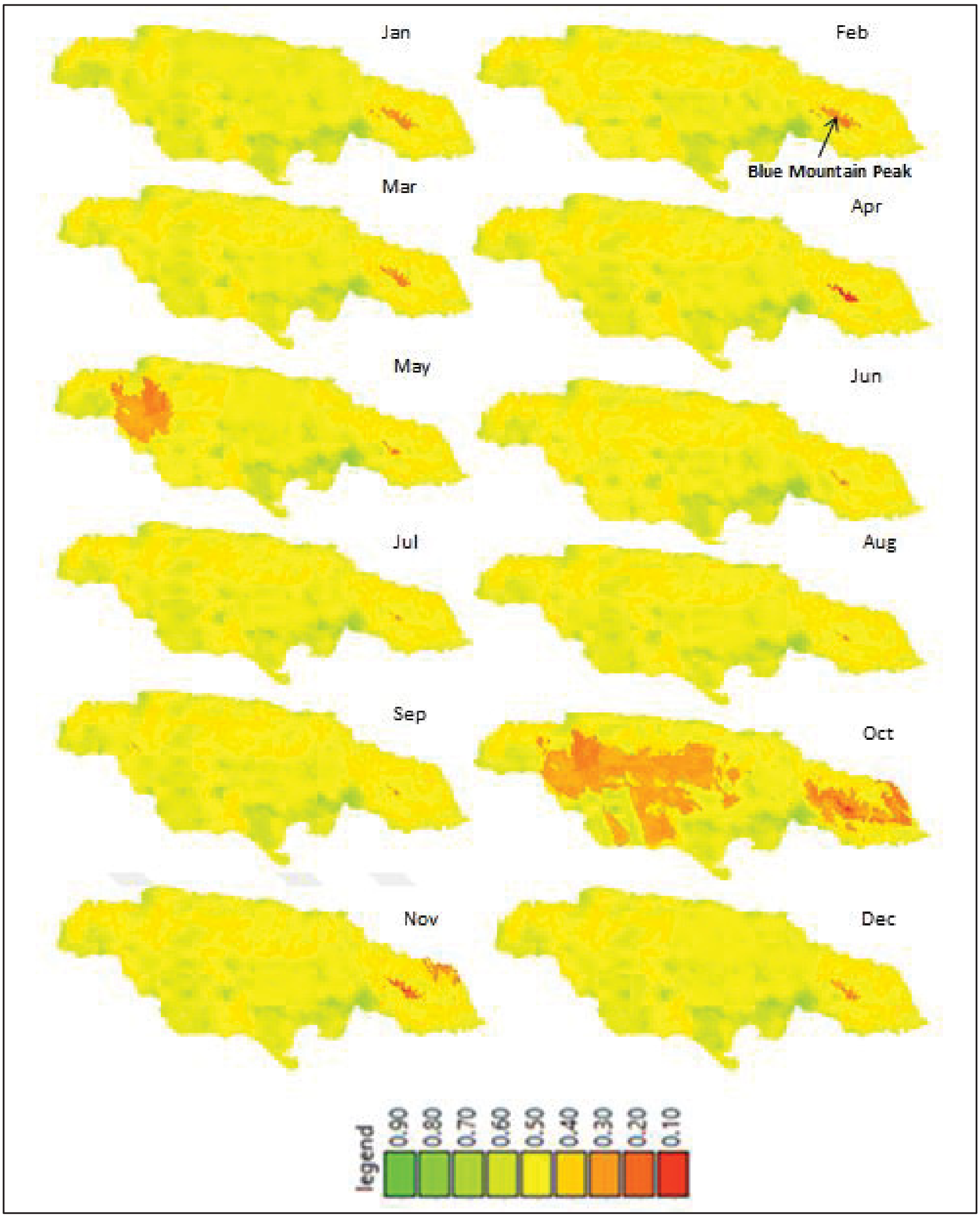
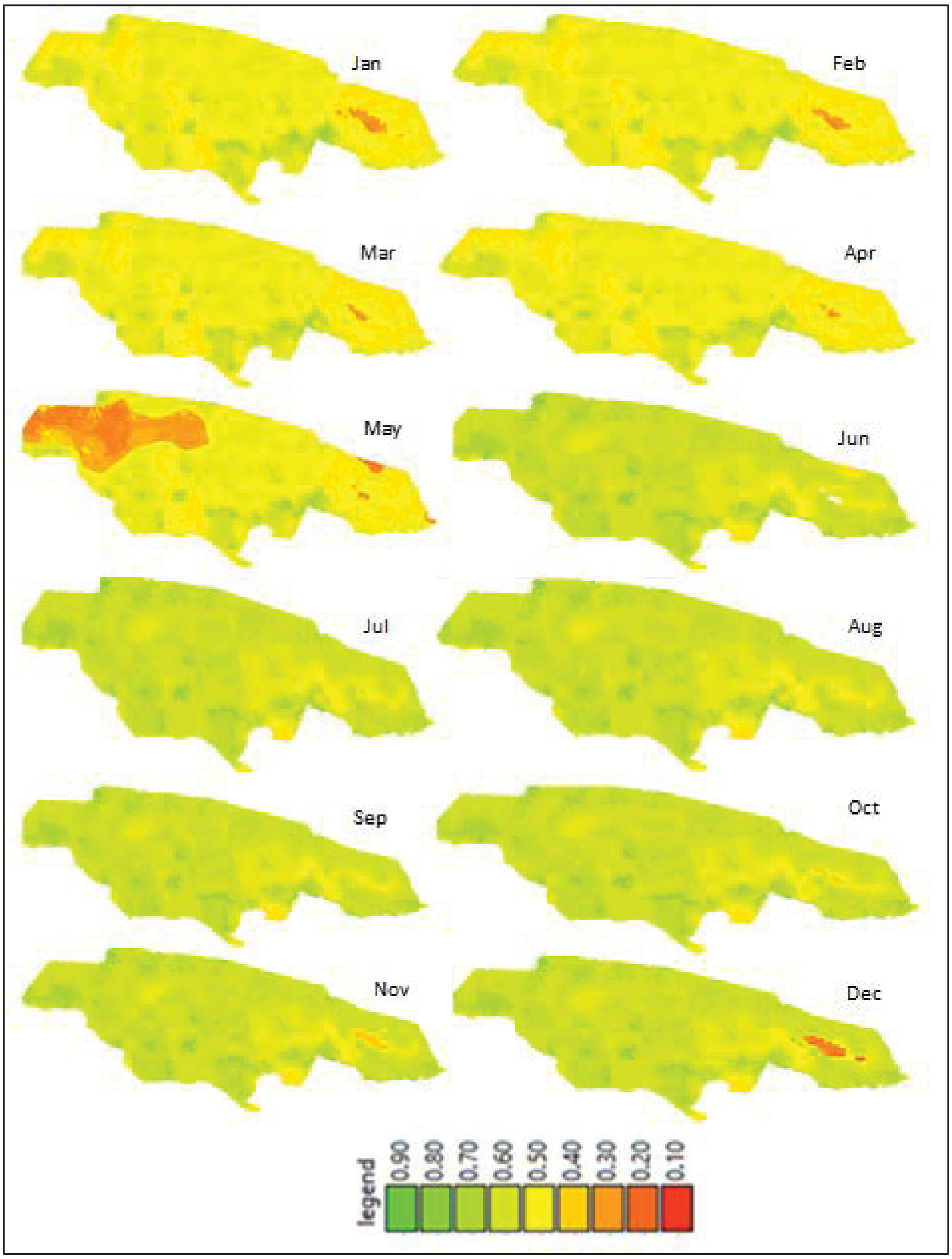
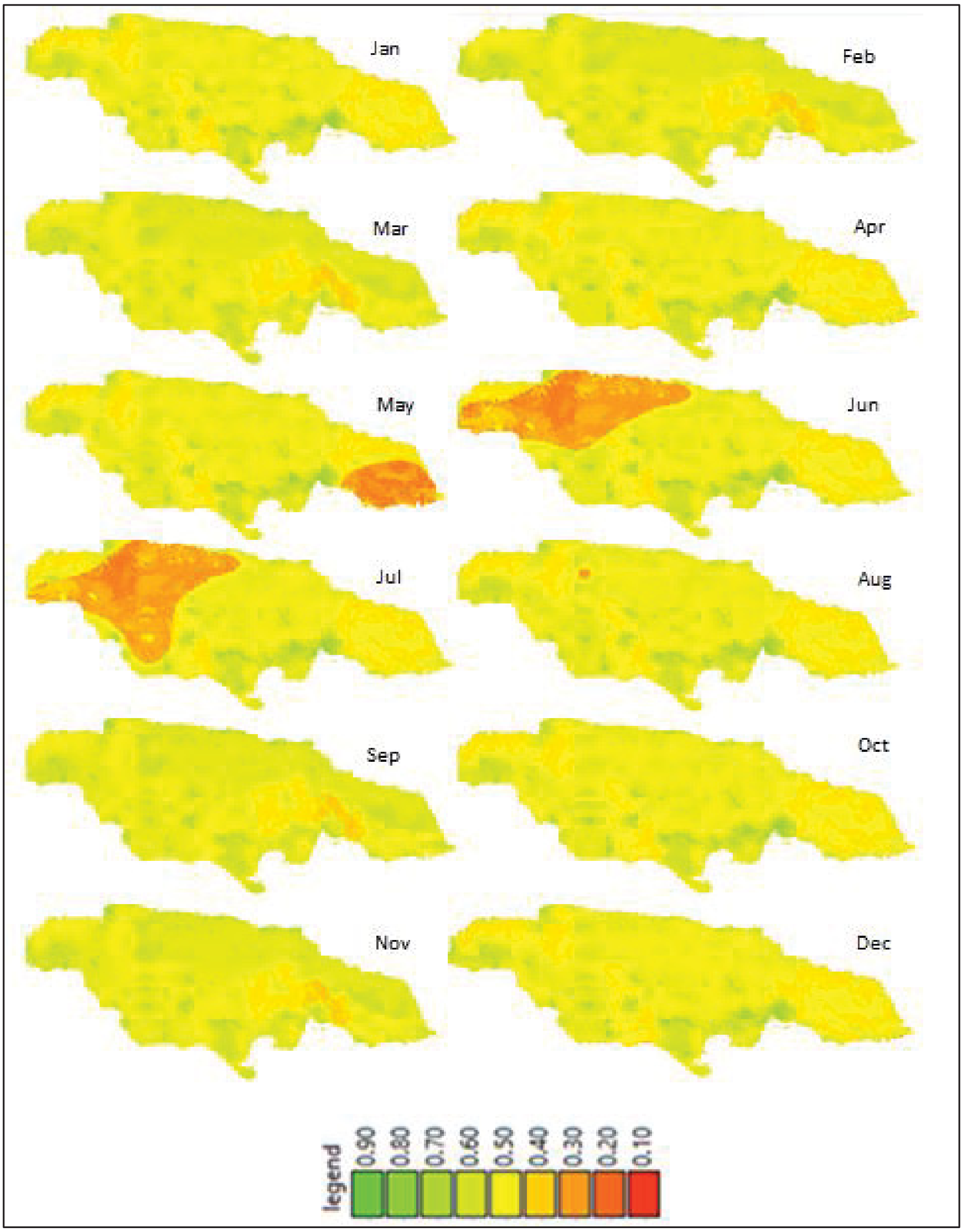


FIGURE 75 - JAMAICA - MONTHLY VULNERABILITY TO DENGUE WITH CHIRPS RAINFALL AND MODIS LST FOR 2002 TO 2016



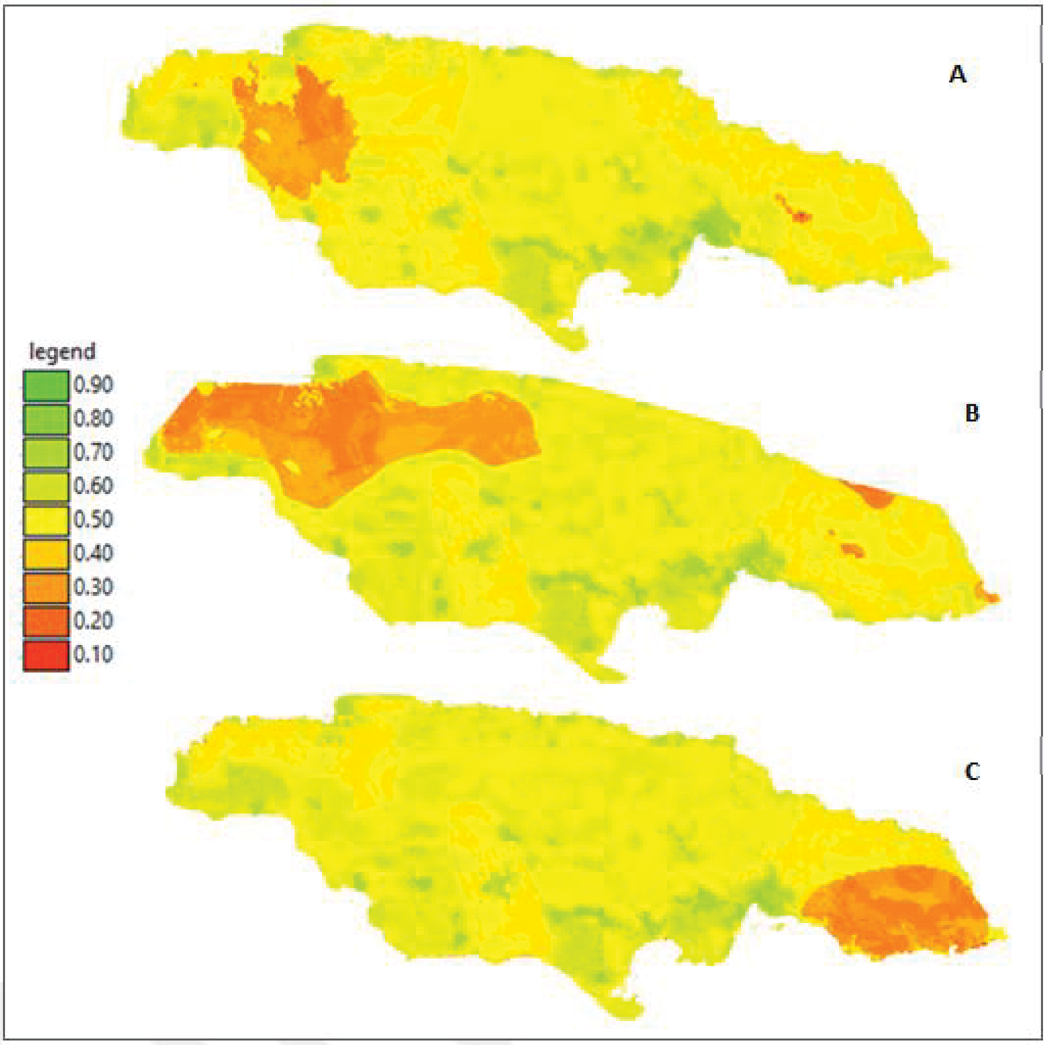

For the RCP 8.5 Climate Change Scenario for 2030, higher vulnerability is also more pronounced in urban areas (Figure 76). From the figure, it appears that some months will have the same amount of vulnerability (1) January, April, August, October and December (2) May and June (3) February, March, September and November. Vulnerability to dengue is likely to be highest for February, March, September and November.

FIGURE 76 - JAMAICA - MONTHLY VULNERABILITY TO DENGUE SCENARIO WITH RCP 8.5 CLIMATE CHANGE PROJECTION FOR 2030




Comparison of the following three scenarios for the month of May is presented in Figure 77 (1) World Clim rainfall and temperature dataset for 1970-2000 (A); (2) CHIRPS rainfall and LST from MODIS for the period 2002 to 2016 (B); (3) Climate change scenario using RCP 8.5 for 2030 (C).

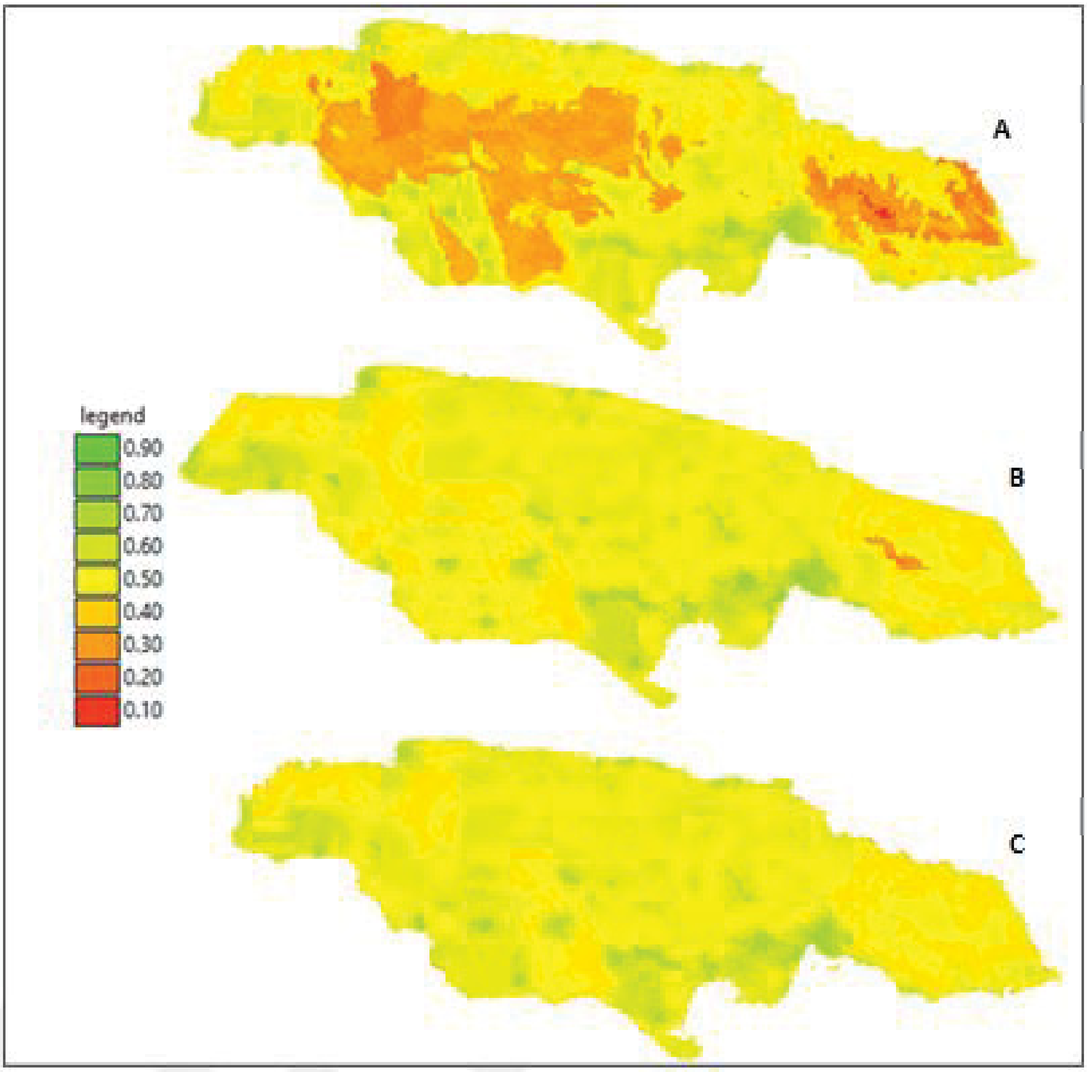
FIGURE 77 - JAMAICA - VULNERABILITY WITH WORLD CLIM DATASET (A), CHIRPS RAINFALL AND LST FROM MODIS (B) AND RCP 8.5 CLIMATE CHANGE PROJECTION FOR 2030 (C) FOR THE MONTH OF MAY




While Scenarios A and B show low vulnerability in the west, low vulnerability is displayed in the east for 2030 (C) for the month of May. The highest vulnerability to dengue is present mainly in urban areas while the lowest vulverability differs across the region in each scenario. Scenario A shows a similar pattern to B with low vulnerability to dengue however, scenario B covers a wider extent. On the contrary, lowest vulnerability to dengue will likely take place in the east specially, in St. Thomas.

For the Month of October, vulnerablility to dengue is more favourable in urban areas while forested areas tend to be less favourable (Figure 78). In Scenario A, areas with less suitability to dengue are mostly concentrated in the east, some central parishes and a small portion of the western end of the island.

FIGURE 78 - JAMAICA - VULNERABILITY WITH WORLD CLIM DATASET (A), CHIRPS RAINFALL AND LST (B) AND CLIMATE CHANGE PROJECTION FOR 2030 (C) FOR THE MONTH OF OCTOBER




For scenario B, only the Blue Mountain seems to be the least vulnerable to dengue. However, in the climate change scenario (C), the area in the Blue Mountain that is normally least favourable to dengue in all the other scenarios is non-existent.

# CHAPTER 8

In this section, the results obtained form the analysis will be analysed with the use of case studies from other regions. This approach will therefore provide an overview of the occurrence of dengue in Jamaica and across the world.

## 8 DISCUSSION

In this study, sporadic cases of dengue outbreaks have been observed over the years. One example for fluctuation in cases could be due to resistance to the disease as lack of immunity of the population to a particular serotype or the introduction of several serotypes, can significantly impact the spread of the disease (MONATH, 1994). Savargaonkar et al., (2018) has shown how multiple serotypes in India caused a major outbreak in 2015. In Trinidad and Tobago, reduction to dengue in 2002 was due to serotype immunity (CHADEE, 2007). This shows how herd immunity can lead to a decrease in dengue transmission even without vector control activities.

The number of epidemics in Jamaica is consistent with other regions. On the Caribbean island of the Dominican Republic, dengue peaked five weeks (week 33) before the outbreak in Jamaica in 2010. However, Columbia and Honduras experienced major peaks during week 11 and week 24 to 34 respectively in the same year (BRAITHWATE-DICK et al., 2012). In 2012, like Jamaica, dengue was also registered in Madeira, Portugal with over 2,000 cases notified and about 81 cases recorded in other European countries through travelling (LOURENÇO & RECKER, 2014). In both countries, dengue peaked in October. However, while the cases peaked in week 44 in Jamaica, the dengue virus peaked in week 43 in Madeira. Also in Rio de Janeiro, Brazil, about 113,000 cases were notified in 2012 (SABINO et al., 2016).

From the data examined, most of the dengue cases in Jamaica took place after July, especially in the two major outbreaks (2010 and 2012), which were after the Mid Summer Drought on the island. Likewise, this period corresponds with the second rainfall season and also the period with hurricane activity. The occurrence of dengue outbreaks in the second wet season has also been observed on other islands in the Caribbean, such as Trinidad and Tobago (ENFIELD & ALFARO, 1999). Likewise, Savargaonkar et al., (2018) realized that peak rates of dengue cases in India from 2012 to 2015 occurred between September and October especially after the monsoon period. However, in Brazil, seasonal pattern of dengue takes place between January and April (BRAGA & VALLE, 2007).

Research indicates that four of the six outbreaks occurred during the years in which Jamaica was affected by severe flood events from tropical storms or hurricanes. The year 2007 was demarcated by Hurricane Dean whereas in 2010, Tropical Storm Nicole was responsible for an increase in rainfall. In 2012, Hurricane Sandy resulted in severe infrastructural damages. However, the flooding in 2016 was caused by the impact of hurricane Matthew within the Caribbean basin which did not pass over Jamaica directly.

Dengue cases might have also been influenced by ENSO as a number of episodes took place during La Niña. While the 1998 outbreak was associated with La Niña in this research, in contrast, Taylor (1999); Chen & Taylor (2001) attributed this outbreak to El Niño +1 year. According to the authors, two of the effects emanating from El Niño+1 year in the West Indies are increases in temperature and rainfall in the first rainy season (May to July) which provide favourable conditions for mosquito habitats. Specifically, the epidemics in the earlier part of the year tend to occur during El Niño + 1 year if higher temperatures are present (ENFIELD AND ALFARO, 1999).

It is important to note, that, the dengue cases presented in this research could also be less than the actual scenario because there are many instances where co-infection occurs and misdiagnosis takes place. Research has shown that co-infection of dengue with other types of diseases caused by the chikungunya (Savargaonkar et al., (2018) and leptospirosis (Suppiah et al., 2017), can impact dengue analysis. In 2016, Zika and Chikungunya were also circulating in Jamaica though Zika dominated with 6,731 suspected cases in comparison to 396 suspected cases. As it relates to Chikungunya, about 2,116 cases were notified (MoH, 2016). Therefore, due to similarity of the symptoms, there is a possibility for misdiagnosis.

Jamaica also has a culture of using home remedies for treating illnesses instead of visiting hospitals. Therefore, all the dengue cases might not be recorded. According to Bourne (2010), 18 out of every 100 Jamaicans in a study concerning care-seeking behavior of uninsured Jamaicans preferred traditional remedies over other types of treatment.

Furthermore, underreporting is known to take place in Jamaica. During the Chikungunya outbreak in 2016, some doctors mentioned the disparity between the number of cases reported by MoH and the actual cases at health facilities (JAMAICA

GLEANER, 2016). This level of inconsistency was later confirmed in the third Jamaica Health and Lifestyle Survey - JHLS (2018) for 2016 -2017 which indicated that over 80% of Jamaicans were infected with the Chikungunya virus (ChiK V) in contrast to the initial reports provided by MoH. Furthermore, this epidemic was not recorded in the EMDAT database for Jamaica. Besides, research by Fletcher et al., (2013) indicated that the national surveillance system did not reflect the true magnitude of the Acute Gastroenteritis cases for 2009 based on the underreporting factor of 58.9. Since the Zika epidemic on the island, public health stakeholders have called for a more modern protocol for reporting and divulging information about diseases such as Zika due to underreporting by the Ministry (JAMAICA GLEANER, 2016).

One of the hypotheses in this research is that precipitation has a greater effect on the occurrence of dengue in Jamaica in comparison to other climate variables. While precipitation was the only variable that responded positively with dengue, this relationship was statistically insignificant. Though this relationship was insignificant, the impact of rainfall should not be dismissed as extreme rainfall or a lack thereof, plays a role in the creation of mosquito breeding sites (Heslop-2006) that leads to the spread of dengue. Furthermore, in other studies in the Caribbean such as Puerto Rico, the positive relationship between rainfall and dengue was statistically significant (JOHANSSON, DOMINICI & GLASS, 2009a). Likewise, rainfall corresponded with dengue in Barbados (Dephradine & Lovell, 2004) and Trinidad (CHEN, 2006). However, like this study, Roseghini (2013) found no significant correlation between dengue and rainfall anomaly in central and southeast Brazil. In Sao Luis, Brazil, a significant correlation was only obtained with three months lagged rainfall and dengue (SILVA, MIRANDA DOS SANTOS, CORREA & CALDAS, 2015).

LST was used as a proxy for air temperature because the data is sparse for the island. Even though LST was insignificantly correlated with dengue in this research, air temperature has been known to have an influence on the presence of the vector from an ecological perspective. For example, in Trinidad and Tobago, air temperature had a more significant positive relationship with dengue than rainfall (ENFIELD AND ALFARO, 1999). Also in Puerto Rico, the relationship between air temperature and dengue was statistically significant (JOHANSSON, DOMINICI & GLASS, 2009b). Amarakoon et al., (2008) also found a stronger relationship with dengue and temperature than rainfall in some countries in the Caribbean such as Trinidad and Tobago, Barbados and Jamaica.

It must be noted that the data used, especially the climate change data and those obtained from satellites, might contain some amount of bias which might impact the results obtained in this study. This was indicated in the bias analysis with the rainfall products (each dataset recorded some amount of inconsistency). The results showed that the TRMM dataset out-performed the other products followed by CHIRPS based on the statistical analysis conducted. However, since TRMM is no longer in operation, CHIRPS was utilized. Likewise, the inconsistencies identified in the in situ rainfall data collected at the Norman Manley International Airport highlights the need for error assessment of input data to be incorporated before analysis is conducted. Therefore, care should be taken with the interpretation of the results.

The second hypothesis was that higher vulnerability to dengue would occur in urban areas compared to non urban areas. In agreement, greater propensity for dengue transmission has been observed in urban areas in this study. This finding seem to coincide with other studies that utilized the WADI Framework (Fullerton, Dickin and SCHUSTER-WALLACE et al., 2014; PHAM, NGUYEN and NAKAMURA (2018); RICHARDS (2018). Specifically, Pham, Nguyen and Nakamura (2018) applied the WADI framework in Vietnam and found a correlation of 0.5 between dengue rates at the provincial level and the vulnerability index obtained in their study. Similarly, positive correlation with WADI and dengue cases was obtained in Malaysia by Schuster-Wallace and Elliot (2013) in areas where exposure was strongly influenced by climate. In the Caribbean, Richards (2018) utilized the WADI method on the small island of Dominica with a population size less than 100 thousand people and discovered a strong relationship between dengue incidence and the WADI values.

Validation of the WADI values using the same technique as the abovementioned studies was not possible due to inaccessibility to time series dengue data. However, since the goal of this research is to demonstrate how different scenarios will lead to variation in results, and not to necessarily produce a validated index, the results presented can be useful for vector control as it shows how the dengue vector responds under different conditions.

Access to dengue seems to be a major challenge across the globe as inaccessibility to the data beyond state level was also reported in Malaysia (DICKIN, SCHUSTER-WALLACE & ELLIOT, 2013). As a result, many studies have analyzed dengue using 1 year of data (KOOPMAN et al., 1991; CHOWELL & SANCHEZ, 2006). Others such as Koopman et al., (1991) used 8 months of dengue data to ascertain factors that that lead to the spread of the infection. Ramírez, Lee and Grady (2018) used weekly data for two different years (1998 and 1983) to map spatial distribution of multiple diseases with El Niño using suspected cases without confirmations due to data issues.

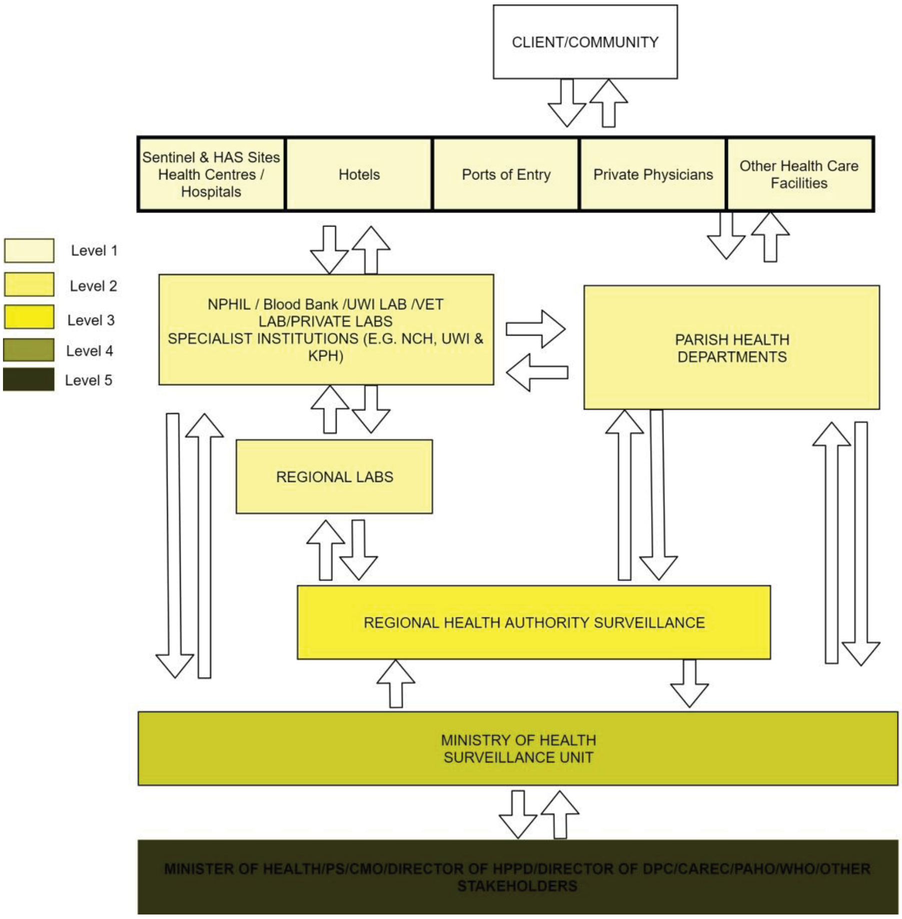
The National Surveillance Manual of Jamaica (2009) has two of its objectives as (1) to provide data to support systematic programme planning, monitoring and evaluation (2) to provide data and information to support priority-setting, guidelines, policies and leglislation towards disease prevention and control. The manual also highlighted the dissemination of weekly and annual reports in digital forms to international and regional organizations (WHO, PAHO and the Caribbean Epidemiology Center, CAREC) along with local stakeholders. Likewise, the manual states that the data can be utilized for research purposes and to determine endemic levels for a communicable disease. However, even with the aforementioned, access to time series dengue data at the community level is a major challenge.

Lack of access might be due to the system in place for reporting, as diseases under surveillance in Jamaica, are given the following classes: Class 1, Class 2 and Class 3. The goal of the surveillance system on the island is to prevent and control the occurrence of class 1 diseases and so, they are given a higher priority. Currently, dengue falls within the category of Class 2 and so it is of less priority even though health officials are required to provide weekly reports to Medical Officers of Health at their Health Departments islandwide (NATIONAL SURVEILLANCE MANUAL, 2009).

Even so, health data for the surveillance system are collected at five levels which suggest the availability of data such as dengue at different scale. Level 1 includes health centres and hospitals which are classified as Sentinel and Hospital Active Sites (HAS). Data collected at hotels, ports of entry, private physicians and other health facilities are also a part of Level 1. level 2 encompasses the National Public Health Laboratory (NPHL), Blood Bank, Univeristy Hospital of the West Indies (UHWI), Vet, Labs, specialist institutions for example Kingston Public Hospital (KPH), Parish Health Departments and regional labs where data are collected, analysed and disseminated. At Level 3 (Regional Health Authority Surveillance Units), data from levels 1 and 2 are collated, analysed and disseminated. At Level 4 (Ministry of Health Surveillace Unit), data from levels 1, 2 and 3 are collated, validated and transformed into information. Level 5 is comprised of personnel who are responsible for the formulation of policies and dissemination of information such as The Minister of Health, Permanent Secretary, and etcetera. Figure 79 shows the flow of surveillance information in Jamaica at different levels.

Despite the various levels of data collection mechanism in place, the database utilized by the RHAs, hospitals and MoH are not linked (Jamaica, 2009). In fact, PAHO & WHO (2010), referred to the current information system of Jamaica as fragmented due to the lack of collaboration between sectors within the Ministry that hinders the generation of vital statistics. However, the Ministry has formulated the National Health Information System Strengthening (NHIS) and E-Health Strategic Plan 2014-2018 in 2013 with assistance provided by PAHO to address this issue. This NHIS and E-Health system will replace the paper based system with the Jamaica Electronic Patient Administration System (EPAS) with the use of the electronic health record. Experimental projects began in 2016 at the Saint Elizabeth Health Department and the Black River Hospital. The objective of the system is to provide access to reports on morbidity and mortality and other socio-economic data rapidly that can provide analysis of disease prevalence (Jamaica, 2016).

FIGURE 79 - JAMAICA - FLOW OF SURVEILLANCE INFORMATION AT DIFFERENT LEVELS




SOURCE: Adapted from National Surveillance Manual (2009)

Based on the foregoing, the lack of access to time series dengue data at the community level implies that the National Surveillance System might not be effective in preventing epidemics at the local level. Hence, the system is not meeting some of its objectives that pertain to access and sharing of data for research and monitoring of dengues. Bearing in mind the potential for outbreaks in light of climate change, access to dengue data by researchers is required in order to mitigate future disaster. The plans for the NHIS and E-Health system seem promising however, there is no information provided regarding the scale at which data will be shared with researchers and other stakeholders.

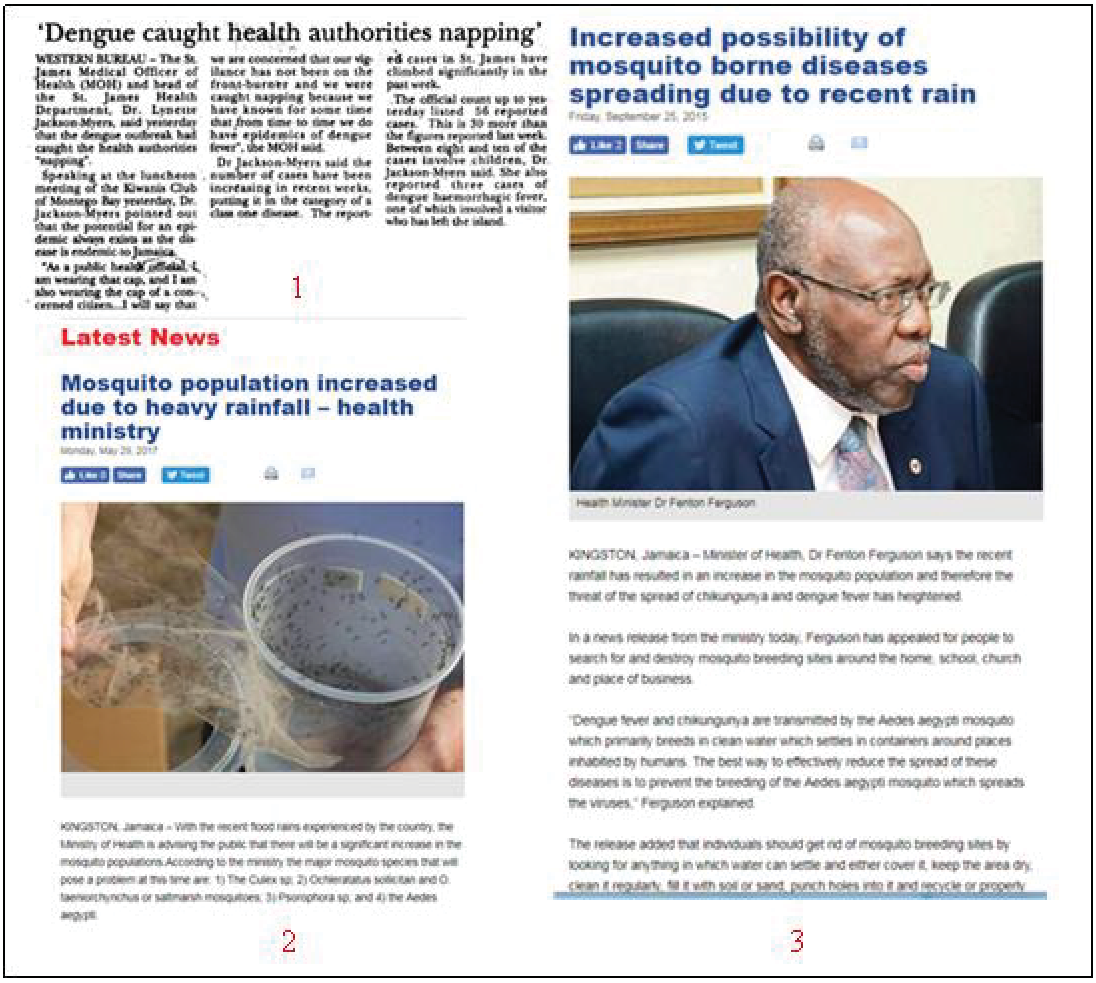
Similar to above, vector control data from MoH is difficult to obtain. Even though JIS (2016) noted the availability of the data in spatial format, there was difficulty regarding the sharing of the data. Specifically, the vector control programme in Jamaica includes the following phases:

- Phase 1: An entomological survey in which field inspectors go into community to identify potential breeding sites for eradication purpose (JIS, 2006).
- Phase 2: The killing of adult mosquitoes by fogging during site inspection. These mosquito habitats are then mapped using GIS for monitoring (JIS, 2006).

These initiatives normally result from collaboration with various agencies and sectors. For example, in 2006, the National Works Agency provided access to areas with difficulties to traverse for treatment. On other occasions, clean-up projects are initiated by the Social Development Commission (SDC) in Portland as part of the national projects geared towards the removal of solid waste (JIS, 2010). National Solid Waste Management Authority, Fire Department, Non-governmental organizations are examples of other organizations that provide assistance to the ministry during vector control activities.

Even though these mechanisms are in place, the surveillance and control system tend to be very reactive. Numerous sources have also indicated how the inadequate mosquito surveillance system in Jamaica led to a major dengue outbreak in 1995 (JAMAICA GLEANER, 1995; CASTLE et al., 1999). The article by the Jamaica Gleaner (1995) provides a clear picture of how 'dengue caught health officials napping' (Figure 80) and highlights the problem with a very reactive dengue control program in Jamaica. According to the sources, vector control commenced after the number of cases (1,884) were reported. These measures included clean-up campaigns, public education and the use of aerial ultra volume malathion spray to eradicate mosquito breeding sites (CASTLE et al., 1999).

FIGURE 80 - JAMAICA - DENGUE RELATED ARTICLES



'Dengue caught health authorities napping'

WESTERN BUREAU – The St. James Medical Officer of Health (MOH) and head of the St. James Health Department, Dr. Lynette Jackson-Myers, said yesterday that the dengue outbreak had caught the health authorities "napping".

Speaking at the luncheon meeting of the Kiwanis Club of Montego Bay yesterday, Dr. Jackson-Myers pointed out that the potential for an epidemic always exists as the disease is endemic to Jamaica.

"As a public health official, I am wearing that cap, and I am also wearing the cap of a concerned citizen...I will say that we are concerned that our vigilance has not been on the front-burner and we were caught napping because we have known for some time that from time to time we do have epidemics of dengue fever", the MOH said.

Dr Jackson-Myers said the number of cases have been increasing in recent weeks, putting it in the category of a class one disease. The reported cases in St. James have climbed significantly in the past week.

The official count up to yesterday listed 56 reported cases. This is 30 more than the figures reported last week. Between eight and ten of the cases involve children, Dr Jackson-Myers said. She also reported three cases of dengue haemorrhagic fever, one of which involved a visitor who has left the island.

1

Latest News

Mosquito population increased due to heavy rainfall – health ministry

Monday, May 29, 2017

KINGSTON, Jamaica – With the recent flood rains experienced by the country, the Ministry of Health is advising the public that there will be a significant increase in the mosquito populations. According to the ministry the major mosquito species that will pose a problem at this time are: 1) The Culex sp; 2) Ochlerotatus sollicitan and O. taeniorhynchus or saltmarsh mosquitoes; 3) Psorophora sp; and 4) the Aedes aegypti.

2

Increased possibility of mosquito borne diseases spreading due to recent rain

Friday, September 25, 2015

Health Minister Dr Fenton Ferguson

KINGSTON, Jamaica – Minister of Health, Dr Fenton Ferguson says the recent rainfall has resulted in an increase in the mosquito population and therefore the threat of the spread of chikungunya and dengue fever has heightened.

In a news release from the ministry today, Ferguson has appealed for people to search for and destroy mosquito breeding sites around the home, school, church and place of business.

"Dengue fever and chikungunya are transmitted by the Aedes aegypti mosquito which primarily breeds in clean water which settles in containers around places inhabited by humans. The best way to effectively reduce the spread of these diseases is to prevent the breeding of the Aedes aegypti mosquito which spreads the viruses," Ferguson explained.

The release added that individuals should get rid of mosquito breeding sites by looking for anything in which water can settle and either cover it, keep the area dry, clean it regularly, fill it with soil or sand, punch holes into it and recycle or properly

3

SOURCE: (1) Jamaica Gleaner (1995); (2) Jamaica Observer (2015); (3) Jamaica Observer (2017)

Since the 1995 incident, the health authorities have become more vigilant and have modified their approach towards monitoring potential epidemic. Emphasis have especially been placed on targeting the *Aedes aegypti* mosquito after heavy precipitation as there have been instances where dengue cases emerge these episodes which is responsible for ponding/stagnant water in some sections of the island and acts as mosquito breeding sites. In other instances, water collected in artificial containers has been found to be habitat for the *Aedes aegypti* mosquito.

The third hypothesis postulated that climate change will change the geographical range of dengue on the island. Similar to the finding in this research regarding the possibility expansion of dengue in highlands, other studies have found comparable results. For example, Acharya et al., (2018) used dengue cases and climate change variables obtained from WorldClim to map suitability for dengue transmission in Nepal based on three RCPs. Results imply that a geographical shift in climatic suitability areas for dengue transmission in highlands will most likely occur. In another study in Nepal, an increase in the distribution of Aedes aegypti mosquito from lower elevation to higher altitude has been reported (Tuladhar et al., 2019). The study also found an increase in larvae during monsoon due to the use of containers that provide breeding habitat. According to Tuladhar et al., (2019), the presence of the Aedes vector differs per geographical location due to micro-climatic impacts.

It must be noted, that, the aforementioned results might contain some level of uncertainty. One of the limitations of vulnerability assessment relates to the application of weights since the decision maker may apply their preference for particular variables resulting in bias (SABAEI et al., 2015). Another disadvantage is the lack of access and quality of the data. Moreover, it has been recognized that the temporal and spatial resolution of data used in vulnerability assessment are not always in unison (WHO, 2013). Therefore, data are often aggregated to a particular level or used based on availability. Besides, the Water-Associated Disease Index (WADI) by Dickin, Schuster-Wallace and Elliot (2013) was specifically designed to make use of this limitation. One of the merits of the WADI framework is the ability to integrate data with different spatio-temporal scale within a geospatial domain (LOUIS et al., 2014).

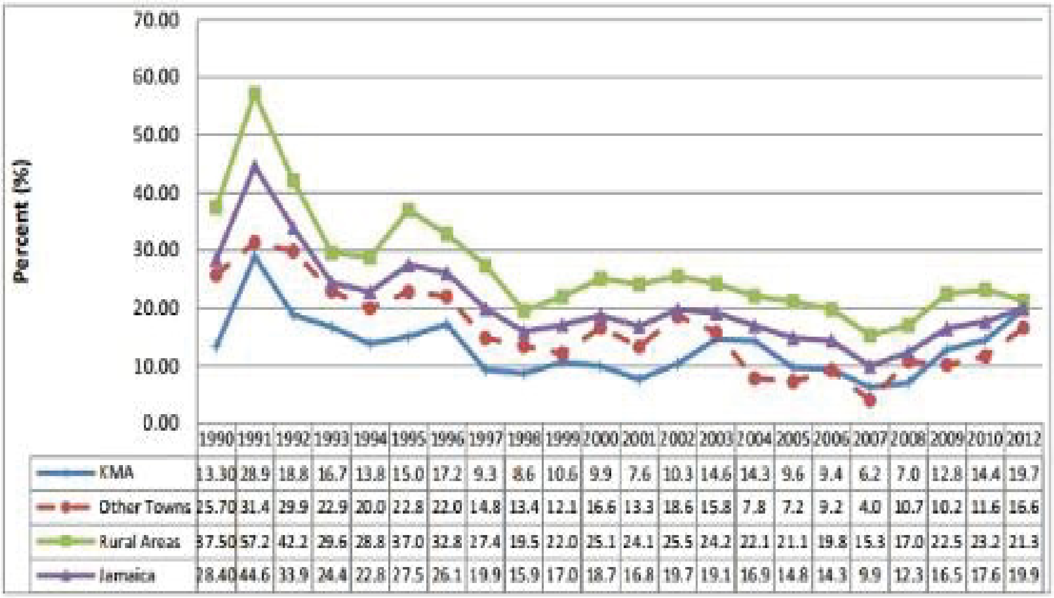
In general, the high vulnerability in urban areas could be as a result of the socio-economic conditions that drive the disease. In Jamaica, planning is done in a haphazard manner that results in many urban related problems. This leads to under-development in rural areas and migration into urban areas. Currently, about 54% of Jamaicans reside in urban areas (PIOJ, 2016), which is almost on par with the global average of 55% (United Nations - UN, 2018). By 2030, urbanization in Jamaica will increase to about 58% (PIOJ, 2016). Kingston is the capital of Jamaica and one of the two cities on the island. It is one of the most urbanized parishes and is well known as a commercial and entertainment hub. The parish was declared a creative city of music by UNESCO in 2015 (UNESCO, 2015). It became occupied in 1664 after the 1962 earthquake in Port Royal destroyed the town resulting in sections being displaced under sea water (JIS, 1990). Apart from its city status, it is home to the Kingston Harbour which is the seventh largest natural harbour in the world (IDB, 2004) and provides the mechanism in place for a port (Port of Kingston) which supports cargo transshipment. The Norman Manley International Airport and the Tinson Pen Aerodrome are also located in the Parish and generate mobility daily. Likewise, The Coronation Market, the busiest market in Jamaica can be found in Downtown Kingston while embassies and head offices for a number of companies are located within Kingston and St. Andrew.

Saint James is the second city, but is well known for tourism from cruise ship passengers to air travel. The parish is the base for numerous call centres that operate within Jamaica and as such promotes migration and rapid urbanization. Further mobility is generated at the other major airport called the Sangster International Airport.

According to Vlahov, Boufford, Pearson and Norris (2010), pressure is placed on health service of middle income due to insufficient resources in middle income countries as urbanization increases. The term "maldevelopment" has been used by Touraine (1992) to describe this inadequacy to meet the needs of population in urban areas. The urban poor are normally the population at risk. According to the United Nations Economic and Social Commission for Asia and the Pacific - ESCAP & UNISDR (2012), urban poverty is a prevalent condition in developing countries and is one of the factors that lead to deaths, property damage and displacement of people. Accumulation by dispossession is a term that has been coined by David Harvey to describe the insufficient resources that are distributed to the poor which makes them inept at mitigating diseases effectively (MAROLLA, 2017).

The level of poverty in urban areas also prohibits the capacity of the government to provide for population in need and puts a strain on planning authorities to provide essential services in the urbanized areas (COHEN, 2006). Since the 1990's, the poverty prevalence rate for the island has fluctuated significantly from 28.4% in 1990. In 2012, the national poverty prevalence rate was estimated at 19.9% (JSLC, 2012). While poverty rates in the KMA have been low for numerous years, the rural areas have a higher poverty prevalence that exceeds the average for the entire country each year. In 1998, there was a decline resulting in prevalence rate of 15.9% but increased in 2002 when 19.7% of the population was estimated to be poor. This number diminished again in 2008 when the rate was recorded at 12.3% followed by an increase in 2012 (19.9%). Between 1992 and 2008, poverty rates were lower in Kingston, St. Andrew, St. Catherine and St. James compared to the rural areas (Figure 81).

FIGURE 81 - JAMAICA - POVERTY PREVALENCE BY REGION (1990-2012)

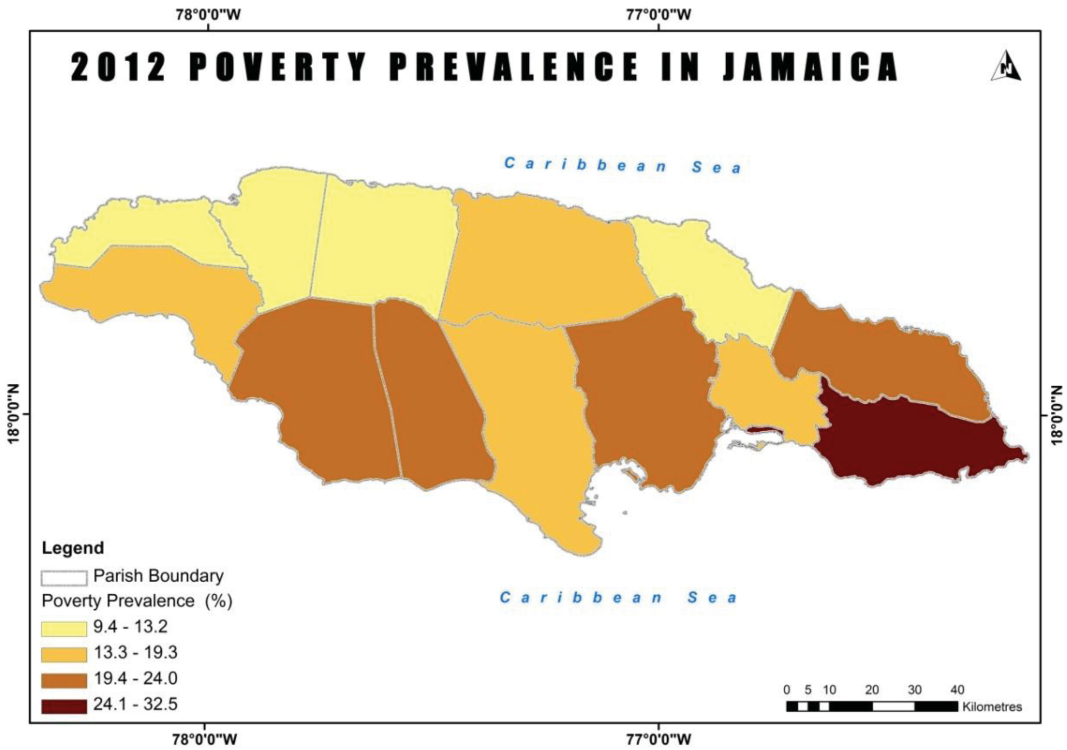



| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KMA | 13.30 | 28.9 | 18.8 | 16.7 | 13.8 | 15.0 | 17.2 | 9.3 | 8.6 | 10.6 | 9.9 | 7.6 | 10.3 | 14.6 | 14.3 | 9.6 | 9.4 | 6.2 | 7.0 | 12.8 | 14.4 | 19.7 |
| Other Towns | 25.70 | 31.4 | 29.9 | 22.9 | 20.0 | 22.8 | 22.0 | 14.8 | 13.4 | 12.1 | 16.6 | 13.3 | 18.6 | 15.8 | 7.8 | 7.2 | 9.2 | 4.0 | 10.7 | 10.2 | 11.6 | 16.6 |
| Rural Areas | 37.50 | 57.2 | 42.2 | 29.6 | 28.8 | 37.0 | 32.8 | 27.4 | 19.5 | 22.0 | 25.1 | 24.1 | 25.5 | 24.2 | 22.1 | 21.1 | 19.8 | 15.3 | 17.0 | 22.5 | 23.2 | 21.3 |
| Jamaica | 28.40 | 44.6 | 33.9 | 24.4 | 22.8 | 27.5 | 26.1 | 19.9 | 15.9 | 17.0 | 18.7 | 16.8 | 19.7 | 19.1 | 16.9 | 14.8 | 14.3 | 9.9 | 12.3 | 16.5 | 17.6 | 19.9 |

SOURCE: JSLC (2012)

From a regional context, the poorest parish in 2012 was St. Thomas followed by Kingston (Figure 82). Only four other parishes had low poverty prevalence (St. James, Trelawny and St. Mary).

FIGURE 82 - JAMAICA - POVERTY PREVALENCE RATE 2012




SOURCE: JSLC 2012; Adapted by: Author (2017)

Another result of urbanization is the creation of squatter settlements due to inadequate housing solutions. With 20% of Jamaicans residing in squatter settlements and 82% located in urban areas (Rapid Assessment of Squatting Report, 2008), the issue regarding dengue occurrence arise due to the possibility of inaccessibility to sanitation services. Furthermore, the Rapid Assessment of Squatting Report, (2008) indicated that only 37% of the respondents in squatter communities had access to garbage collection services and a significant amount still dump their garbage (Rapid Assessment of Squatting Report, 2008). Research conducted by Chadee, Huntley, Focks and Chen (2009), indicated that tins, tyres and plastic containers were some of the main breeding site for the *Aedes aegypti* mosquito in Jamaica. Figure 83 shows an example of dumping that takes place in Jamaica.

FIGURE 83 - JAMAICA - DUMPING OF TYRES AND GARBAGE IN CLARENDON

Based on the results from the vulnerability assement, it is evident that Jamaica will most likely be endemic to dengue for a long time due to favourbale climatic conditions. Therefore, adaptation measures might be the only method that can be useful in controlling the spread of the disease. The study by ECLAC (2011) has shown that even though dengue will cost up to US$25 million in the future, improvement in sanitation and access to potable water as adaptation measures could result in a reduction of up to US$5,547,722 and US$5,250,111 under A2 and B2 scenarios. However, as noted by

Mimura et al., (2007); Bueno et al, (2008), adaptation cost might be a hindrance for SIDS due to financial constraints.

# Chapter 9

## 9 CONCLUSION AND RECOMMENDATIONS

This study analysed the spatio-temporal vulnerability to dengue using socio-economic variables and climate datasets for present and climate change scenario for 2030. The vulnerability assessment included the following scenarios: (1) World Clim rainfall and temperature dataset for 1970-2000; (2) CHIRPS rainfall and LST as proxy for air temperature from MODIS for the period 2002 to 2016; (3) Maximum temperature and rainfall scenario using RCP 8.5 for 2030 downscaled at 25km based on RegCM4.3.5 Model. The findings from the study are presented below:

1. **What is the spatial and temporal distribution of dengue in Jamaica?**

Dengue is regarded as a very important vector borne disease in tropical and subtropical countries. In Jamaica, dengue fever outbreak is sporadic although a number of cases have been recorded year-round. Between 1995 and 2016, about 6 outbreaks were recorded on the island (1995, 1998, 2007, 2010, 2012 and 2016).

From the weekly data, the peak in dengue cases varied annually with some outbreaks taking place at week 7 (2016 outbreak), week 38 (2010 outbreak) and week 44 (2012 outbreak). The 2012 outbreak in Jamaica was synonymous with outbreaks in other parts of the world including the Madeira Islands of Portugal that recorded their epidemic one week after Jamaica.

Spatially, majority of the dengue cases were reported in Kingston and St. Andrew. The results show that these areas account for high population density and serve as an important thoroughfare for mobility purposes. Additionally, it was highlighted that Kingston is the second poorest parish which implies that the level of poverty might be a contributing factor for the spread of dengue. However, from an incidence stand point, parishes with low population such as Trelawny and Manchester have reported higher dengue rates in comparison to Kingston and St. Andrew.

2. **How can variation in climatic conditions account for the spread of dengue in Jamaica?**

Rainfall and 6-month SPI Index seemed to be the only climate variables that exhibited a positive correlation with dengue occurrence although they were deemed to be statistically insignificant. This is comprehensible as lack of rainfall normally results in the storage of water in containers that have been identified as a breeding site for the *Aedes aegypti* mosquito. Notwithstanding, the following outbreaks have occurred after major flood events in Jamaica caused by hurricanes: 2007, 2010, 2012 and 2016. Similarly, three dengue outbreaks (1998, 2007 and 2010) took place during strong La Niña episodes while the 1995 and 2016 epidemics were during moderate to weak La Niña events.

3. **How does vulnerability to dengue vary temporally and spatially in Jamaica?**

The WADI Framework was useful in determining the level of vulnerability across the island using different scenarios. In each scenario, high vulnerability to dengue was found mostly in urban areas. In the scenarios with World Clim, CHIRPS and LST for present conditions, the lowest vulnerability was situated in the Blue Mountain which is over 2,000 metres high. However, under climate change conditions with the RCP8.5 for 2030, the level of vulnerability in the Blue Mountains will be increased implying a change in the range of dengue fever due to an increase in favourable climatic conditions for the presence of *Aedes aegypti* mosquito in that regions.

From a temporal aspect, October appears to be the month with the lowest vulnerability followed by May with the WorldClim scenario. In the scenario with the CHIRPS and LST dataset, vulnerability to dengue increases from June onwards even in non-urban areas. Also, low vulnerability to dengue in the Blue Mountain only occurs in February, March, April, May and December under this scenario. For the RCP8.5 climate change scenario, February, March, September and November had the highest vulnerability.

The researcher hypothesized that precipitation had a greater effect on the occurrence of dengue in Jamaica in comparison to other climate variables. The results indicated that while rainfall and the 6 Month SPI were the only variables to have a positive association with dengue, the relationship was statistically insignificant.

The second hypothesis was that higher vulnerability to dengue would occur in urban areas compared to non-urban areas. In agreement, urban areas were shown to be more favourable for dengue transmission due to the socio-economic and climate conditions that are present in these locations.

For the third hypothesis, it was assumed that climate change will alter the geographical range of dengue on the island. Results from this study seem to indicate that the distribution of dengue will expand to high altitudes under climate change which would most likely not ocurr with present climate conditions. Even though climate change might result in changes in the distribution range of dengue, increase in temperature and rainfall intensity might lead to less favourable conditions for the survival of the Aedes aegypti mosquito in some areas.

The vulnerability scenarios presented show how results vary depending on the type of data used in the analysis. When each scenario was compared for May and October, vulnerability to dengue differed temporally and spatially. Results can also be impacted by the weights used in the analysis as a change in standardization or ranking of the variables can lead to a different output. Despite the challenges, the results show Jamaica's vulnerability to dengue which is likely to continue in the future unless adaptation measures are implemented.

## 9.1 RECOMMENDATIONS

There are a number of climate and environmental factors that contribute to the spread of dengue fever in Jamaica. These can be categorized into: social and ecological factors; vector ecology; individual virological and immunological factors; epidemiology and vector control. Even though dengue is impacted by socio-economic and climatic factors that have a spatial component, there is paucity in the application of GIS and remote sensing technology in analysing dengue in Jamaica. Therefore, this research will contribute new information about vulnerability to dengue from a scenario point of view.

Based on the results outlined, it is evident that access to dengue data should be a priority of the MoH. For analysing the impact of climate variables on dengue transmission, the ideal scale should be at least daily and at the community level since this is where the vector reacts to climate and socio-economic conditions. However, such detail time series data is not always accessible at that scale, which is also a major limitation in this study. Fieldwork was conducted in Jamaica between 2017 and 2018 in order to gather data as there is no platform where all the information required for the thesis could be accessed remotely. This experience indicated how challenging and bureaucratic the data collection process for research is on the island. Moreover, due to political factors, only one year (2016) of dengue data was shared at the community level by the Ministry of Health of Jamaica which was accomplished following a lenghty bureaucratic process.

Inaccessibility to time series dengue data prevented the execution of the previous proposal that was based on the impact of flood events on the occurrence of dengue in Jamaica. As a result, the topic was changed to vulnerability to dengue, which permitted the use of data that were available within the public domain. This was a necessary option so that the thesis could be completed within the required time.

To overcome this, there should be a policy that forces public organizations to divulge data via government platforms online in formats that are compatable with Excel and GIS softwares. Other countries such as Brazil could serve as an example where rapid access to government data is concerned. In Brazil, the Brazilian Health Informatics Department (DATASUS) and the Brazilian Institute of Geography and Statistics (IBGE) are two platforms that provide free health and statistical data respectively in formats compatible with GIS. This policy should also allow for accessibility to the data free of charge for research purpose especially to students at all levels. Jamaica produces a lot of data, but if the information cannot be accessed, productivity and contribution to research becomes meaningless.

Surveillance of disease is regarded as the pillar of any effective public health system and makes an important contribution for the monitoring of infectious diseases. Therefore, for future research, an evaluation of the national surveillance policy for monitoring and detecting health problems based on the framework provided by the WHO should be considered. Moreover, there is a need for a surveillance system for individual diseases such as dengue fever.

Other studies could also involve the vector control strategies employed before, during and after major extreme weather events and the cost in the form of a cost benefit analysis. Furthemrore, the vector control system should incorporate a participatory approach where residents can provide inputs since they are the first responders to any public health emergencies. This feedback system will allow the Ministry to respond rapidly thus aiding in preparedness planning for future epidemics. Participatory mapping techniques utilized in other disciplines such as those involved in flood hazard zonation could be used as reference. In this case, residents can delineate areas within their communities that might be vulnerable to dengue on maps for authorities to take action. This information can be collected in town hall meetings, workshops or via crowd sourcing mechanisms.

Additional analysis should be conducted with the use of agent-based models (ABMs). ABMs are computational techniques that are used to illustrate the interactions of agents, places and things in time. Agents in this manner can be represented as people, animals, buildings, cars and many other objects. The models are stochastic and involve the demarcation of individuals or organizations as agents which are given attributes enabling them to behave and interact with the environment in a certain manner. This therefore permits the modelling of complex phenomena or systems compared to the traditional approaches like regression based methods. Currently, there exist a wide range of ABMs. However, some of the open source models include: Repast (Recursive Porous Agent Simulation Toolkit), Swarm, NetLogo and MASON (Multi Agent Simulation Of Neighbourhood).

Likewise, vector capacity models can also be used to show the potential of dengue transmission of the vector and how it responds to different climate and socio-economic factors over time. Vector capacity is the average rate at which the infected mosquito bites after the infected host is introduced. The model includes feeding habits, survival rate and incubation period.

Moreover, the use of the Adaptive Management of vulnerability and Risk at Conservation sites (MARISCO) can be incorporated in the study of dengue in Jamaica since it provides the framework for adaptation to climate change from an ecological perspective. In this case, MARISCO could be applied to interpret the high or increased incidence in dengue fever and the Aedes aegypti mosquito as a change in the condition of the ecosystem or as a failure to regulate ecosystem services due to other conditional changes in the system.

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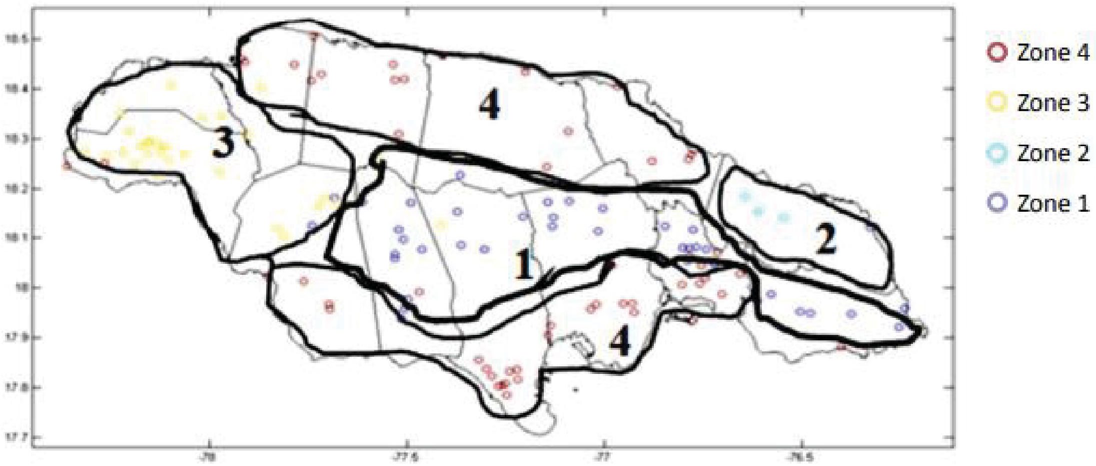
## APPENDIX 1 - COST OF IN ACTION ON CLIMATE CHANGE WITH % OF 2004 GDP WITHIN THE CARIBBEAN

**Cost of Inaction on Climate Change: % of 2004 GDP**

| Islands | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|
| Anguilla | 10.4 | 20.7 | 31.1 | 41.4 |
| Antigua | 12.2 | 25.8 | 41.0 | 58.4 |
| Aruba | 5.0 | 10.1 | 15.1 | 20.1 |
| Bahamas | 6.6 | 13.9 | 22.2 | 31.7 |
| Barbados | 6.9 | 13.9 | 20.8 | 27.7 |
| British | 4.5 | 9.0 | 13.5 | 18.1 |
| Cayman | 8.8 | 20.1 | 34.7 | 53.4 |
| Cuba | 6.1 | 12.5 | 19.4 | 26.8 |
| Dominica | 16.3 | 34.3 | 54.4 | 77.3 |
| Dominican | 9.7 | 19.6 | 29.8 | 40.3 |
| Grenada | 21.3 | 46.2 | 75.8 | 111.5 |
| Guadeloupe | 2.3 | 4.6 | 7.0 | 9.5 |
| Haiti | 30.5 | 61.2 | 92.1 | 123.2 |
| Jamaica | 13.9 | 27.9 | 42.3 | 56.9 |
| Martinique | 1.9 | 3.8 | 5.9 | 8.1 |
| Montserrat | 10.2 | 21.7 | 34.6 | 49.5 |
| Netherlands | 7.7 | 16.1 | 25.5 | 36.0 |
| Puerto | 1.4 | 2.8 | 4.4 | 6.0 |
| Saint | 16.0 | 35.5 | 59.5 | 89.3 |
| Saint | 12.1 | 24.3 | 36.6 | 49.1 |
| Saint | 11.8 | 23.6 | 35.4 | 47.2 |
| Trinidad | 4.0 | 8.0 | 12.0 | 16.0 |
| Turks | 19.0 | 37.9 | 56.9 | 75.9 |
| U.S. | 6.7 | 14.2 | 22.6 | 32.4 |
| TOTAL Caribbean | 5.0% | 10.3% | 15.9% | 21.7% |

Source: Bueno etal., 2008

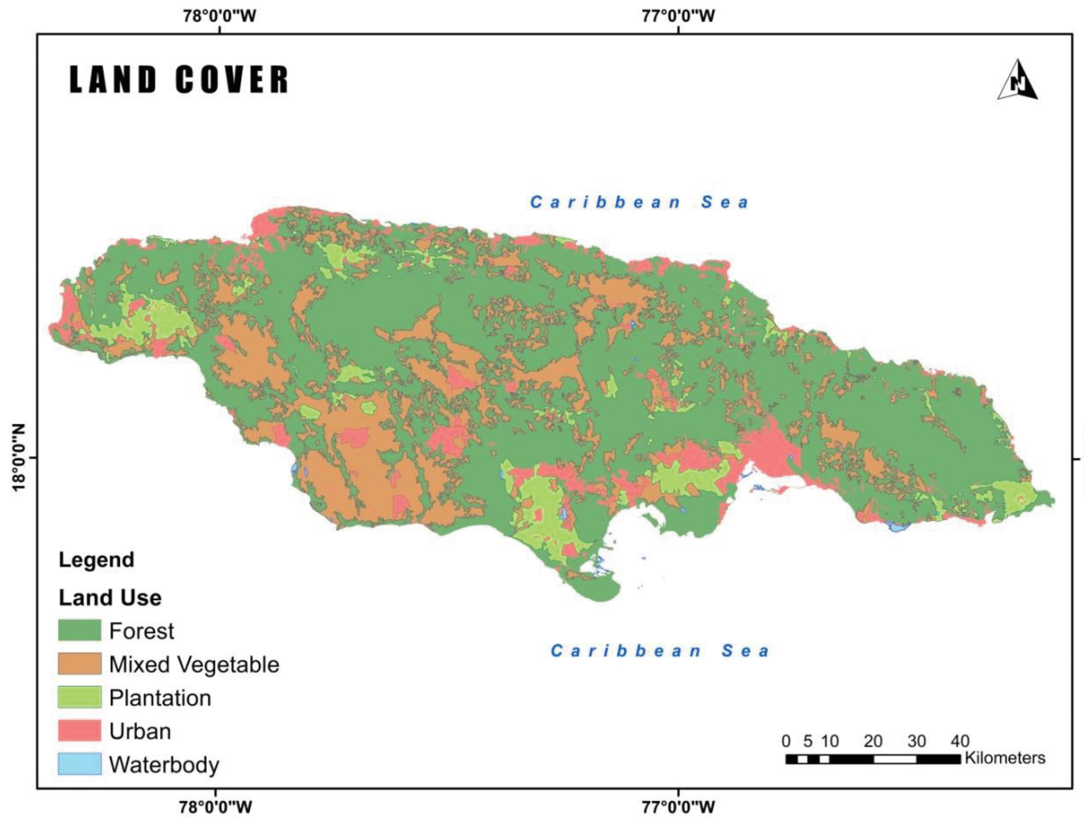
**APPENDIX 2: RAINFALL ZONES IN JAMAICA**




CSGM, 2017

- The characteristic bimodal pattern seen in the all-island index is reflected in the rainfall climatology for three of the four rainfall zones.
- The Interior (zone1) and Coasts (zone 4) follow the all island climatology closely with an early season peak in May but with the late season peak and mid-summer minimum occurring one month earlier in September and June respectively. The Interior also has higher rainfall totals than the Coasts which represent the driest of all the rainfall zones.
- Rainfall in the West (zone 3) peaks in May and September-October and has the least pronounced mid-summer rainfall minimum. The West also shows least variability from month to month and receives the most rainfall of all zones excepting the East (zone 2).
- The East (zone 2) deviates the most from the all-island climatology with highest rainfall occurs in November (and comparable totals in December and January), and a secondary peak in April-May. Like the other zones, the mid-summer minimum first appears in June. The East also receives the highest amounts of rainfall year-round – at all times exceeding the average rainfall of any of the other three zones.
- Both the Interior and the Coasts receive most rainfall during the late rainfall season (August-November). The West receives comparable amounts during the dry and late wet seasons, while the East receives most of its rainfall during the traditional dry season (Table 8).

## APPENDIX 3: LAND COVER FOR JAMAICA



# APPENDIX 4: DEPARTMENTS AT MINISTRY OF HEALTH OF JAMAICA