Is the Application of a Vulnerability Framework Effective in Determining Patterns of the Incidence of Dengue Disease on the Island of Dominica?
The Water Associated Disease Index (WADI) Model

Heather Richards, PhD

Table of Contents

Description **Page Number**

Appendices

List of Figures

List of Graphs

List of Tables

List of Photos

Abstract

The goal of the proposed thesis is to identify vulnerable areas of increased risk of transmission to dengue virus as a re-emerging public health threat. Vulnerability will be based on social, ecological, and environmental factors in the Commonwealth of Dominica, a small island nation in the Caribbean.

Using a combination of susceptibility (social) and exposure (ecological / environmental) components, this thesis will aim to provide an evidence base for reducing disease burden from infectious disease outbreaks, by improving the understanding of the susceptibility and exposure drivers of vulnerability and making recommendations for mitigation measures that will minimize the impact of these disease outbreaks.

Methodology The construction of an index model was conducted based on an eco-health model, the Water Associated Disease Index (WADI), using publicly available data sets. Secondary data analysis was carried out to examine the relationship between vulnerability to an increased risk of disease transmission and the incidence of dengue disease cases in Dominica using negative binomial regression. Using the same statistical analysis, an alternative non-index model was used for comparison. Using Geographic Information System (GIS), a visual representation of an increased risk of vulnerability to dengue virus transmission in the form of a map was constructed.

Findings The index model and the non-index model exhibited a moderate fit highlighting that the components of the eco-health model can indicate vulnerable areas to an increased risk of dengue disease transmission in a small island setting.

Discussion An integrative approach to assessing vulnerability, like the WADI model, is an effective tool in determining areas that are more exposed to infectious diseases through an examination of the combined social, environmental, and ecological determinants of health.

Conclusion Dengue virus is a re-emerging threat to public health. As it affects the most impoverished regions of endemic areas disproportionately, low-cost effective tools are needed to neutralize this growing threat. Further research into integrative models that incorporate the vulnerability drivers within the social, ecological and environmental determinants of health is still required to review their linkages and develop effective assessment tools.

Acknowledgements

This thesis could not have been successfully completed without the input, support, and feedback from so many people.

Firstly, for their valuable input in the early development stages of the thesis, I extend a thank you to Drs. Eugenio Zucchelli, Jonathan Read, and Christopher Jewell.

A big thank you to the thesis supervisor, Dr. Mark Limmer, for your consistent support and guidance.

For their time and effort in the viva, thank you to the members of the panel Drs. Corinne Ong, Tony Gatrell, and Katherine Froggatt. As well as, Dr. Guillermo Perez Algorta who performed the 'mock' viva and provided valuable feedback to improve the thesis.

Also, for their advice, feedback, and support throughout thank you to my fellow Public Health colleagues and my fellow Faculty of Health and Medicine students at Lancaster University.

Finally, to my family and my friends, I am especially grateful for your unwavering support, kindness, patience, and solidarity.

Chapter 1: Introduction

Infectious diseases are a constant threat to the health and well-being of the human population. Infectious diseases can not only cause a danger to human health, they can also pose a threat to the stability of a country's national economy by increasing the costs of public health interventions (Morens 2013). In addition, for many developing countries, infectious diseases can be a further threat to their national security, especially during an outbreak, when resources have to be reallocated and government services disrupted, to contain the spread of the disease (Eisenberg et al 2007; Morens et al 2004; Morens 2013).

Despite the fact that there is a global threat of infectious diseases, the threat does not pose the same level of risk to all countries (Fauci and Morens, 2012; Jones et al 2008). The threat of infectious diseases is particularly compelling in developing countries. According to Alsan et al. (2011), the countries of the world where a large portion of the population live on less than two dollars (US) a day experience a higher rate of illness from infectious diseases. The majority of countries in the developing world are in the tropical regions, therefore the aptly named tropical infectious diseases are the infectious diseases associated with a growing global public health concern for increasing morbidity and mortality within a population (Alsan et al 2011; Hurlimann et al 2012).

The World Health Organization (WHO) (2004) stated that infections from any of the major tropical diseases, for example, diarrheal diseases, Chagas disease, African trypanosomiasis and dengue, cause one quarter of the global burden of morbidity and mortality. This global burden of illness from infectious diseases also accounts for 29 out of the 96 leading causes of ill health and death in human beings (Myers and Patz 2009; WHO 2002; WHO 2004). The number of incidences of major tropical infectious diseases globally is continuing to increase, and as also stated by the WHO in 2002, a number of these diseases are emerging or re-emerging by expanding into new territories, thereby increasing the threat to global public health (WHO 2002). Another study also published by the World Health Organization in 2012 found that, during the year 2008, deaths from infectious diseases in countries in the developing world, mainly among children under the age of five, were close to 8 million. Further to this finding, the researchers posit that this figure of 8 million is more likely an underestimate given the inaccuracies in diagnosis and subsequent disease reporting in the developing world (Cassidy-Seyoum 2014; WHO 2002; WHO 2012).

According to Wilcox and Gubler (2005), globally, new and emerging infectious diseases are a rising concern, prompting the public health research community to dedicate substantial effort to combat this issue. The main focus of attention has been through identifying the causes and establishing remedial actions. The identification of and battle against a problem of this magnitude requires a multi- pronged approach which includes exploring all factors pertaining to political, economic, social, environmental, ecological and biological variables (Boischio 2009; Jones et al 2008; Wilcox and Gubler 2005).

Although there is an increased understanding of the connections between the expansion of emerging and re-emerging infectious disease, global environmental change, and the social determinants of health, the research does not yet reflect this knowledge (Dickin et al 2013; Mackey et al 2014). Current research demonstrates gaps in the knowledge of the complexity of these systems and their relationship to human health (WHO 2008; CDC 2005; Dickin et al 2013). In fact, prevailing research approaches have a drawback in their failure to incorporate the multi-faceted relationships that form an increased vulnerability of a population to the risk of infectious diseases. Measures of vulnerability that focus solely on the environmental factors miss an opportunity to explore the other domains which can have a significant impact on the incidence of disease such as the social determinants of health (Boischio 2009; Dickin et al 2013; Fullerton et al 2014; Gubler et al 2012).

Among the 29 tropical infectious diseases contributing to an increased burden to public health in terms of an amplified risk to human illness and death, the disease dengue has been garnering a lot of attention within the public health community (Hurlimann et al 2011; Griffiths and Zhou 2012). Specifically, the WHO scientific paper in 2003 on insect vectors and human health highlighted dengue as a re-emerging and uncontrolled disease globally (WHO 2003). Dengue is spread by the Aedes aegypti mosquito. This is the same vector that also facilitates the transmission of Zika virus and Chikungunya virus that are presently causing large-scale and high profile outbreaks of disease in Central America, South America and the Caribbean (WHO 2016).With dengue virus, there is a need for more research on the local, environmental and susceptibility factors that affect the disease system and more research that explores the relationships between those factors (Boischio 2009; Chadee et al 2012; WHO 2003). According to Griffiths and Zhou (2012), "Research has played a huge role in efforts to understand, control and prevent the spread of infectious diseases", Griffiths and Zhou (2012, page 15). Additionally, research can account for significant changes in the spread of infectious diseases through an improved understanding of the development, clinical management and eventually prevention of the disease (IoMF 2011).

Not only are there emerging and re-emerging diseases that cause deadly infections, to further complicate matters, within that same group there are diseases that the World Health Organization has deemed to be neglected tropical diseases (NTDs) (WHO 2010). The neglected tropical diseases or NTDs have, as the name suggests, long ago fallen by the wayside, and, even though they are well known to the global public health community, they have not been a priority in terms of public health resources or planned interventions (Boischio et al 2009; Cassidy-Seyoum 2014; IoMF 2011; WHO 2012). It is well known that these neglected tropical diseases wreak havoc in the 149 developing countries where large parts of each country's population live in poverty (Cassidy-Seyoum 2014; Hurlimann et al 2011; Mackey et al 2014). In these contexts, instability from large scale catastrophic events such as weather systems, civil unrest or outbreaks of infectious diseases cannot be as easily recovered from, economically, medically or, socially as would occur in countries in the developed world (Amarakoon 2006; Hurlimann et al 2011; WHO 2012).

Most of these developing countries are situated within the Caribbean, South and Central America. As a result the Pan-American Health Organization (PAHO) has called not only for increased research into combating the prevalence of these diseases, but has also suggested beginning research into creating new or improving existing assessment tools and making them a priority for public health service (PAHO 2014). As explained by Griffiths and Zhou 2012, there has been increasing public health interest, but no full investment into combating the NTDs in a manner that would provide a significant decrease in vulnerability for those populations at risk. As a result, for many of the neglected tropical diseases such as trachoma, Buruli ulcer, and dengue there have been no new interventions researched since the beginning of the century (Griffiths and Zhou 2012; IoMF 2011). Public health research into well-funded areas of research, such as malaria, Tuberculosis and HIV / AIDS have determined that there are assessment tools that can highlight vulnerable areas in a given population by expanding the indicators of poverty, morbidity, and mortality that appear to be the key to increasing resource allocation (PAHO 2003).

Dengue is a water-associated insect vector-borne infectious disease that increases the level of morbidity and mortality in the human population, and has long been viewed as a disease that relies on a combination of social and environmental conditions to spread within a population at risk (Boischio 2009; WHO 2008; CDC 2005). Currently, many endemic countries report an increasing number of incidences of dengue cases each year, especially in tropical and subtropical countries. In these regions, both the social and environmental conditions create a favourable situation for dengue transmission (WHO 2008).

In spite of the efforts to control and to eradicate the *Aedes aegypti* mosquito vector which transmits the dengue virus to humans, dengue is a re-emerging disease in the Caribbean (Boisochio et al 2009; Chadee et al 2012). According to the WHO 2009, all regions in the Caribbean are susceptible to circulating dengue virus, with large outbreaks occurring cyclically every three to five years (WHO 2009). In this thesis, Dominica, a small island nation in the Caribbean in which dengue is endemic, will be used as a "proof of concept" (Fullerton et al 2014, page 19) to apply an eco-health model, the Water Associated Disease Index (WADI) at the national level. Dominica is one of the one hundred countries identified by the WHO as highly vulnerable to dengue virus transmission (WHO 2000). Due to its location, climate conditions and a host of anthropological factors, Dominica has, along with the rest of the islands in the Caribbean, remained endemic to dengue since the transatlantic slave trade, with a marked increase in outbreaks for the last 36 years and it is expected that the intensity of dengue outbreaks is on the rise (Amarakoon et al 2006; Chadee et al 2012). Additionally, due to its measured poverty level at 30 percent of the population and the subsequent factors related to poverty that identify key infectious disease determinants such as unplanned high density urbanization and inadequate infrastructure, Dominica is potentially under the threat of a large scale dengue outbreak (Commonwealth of Dominica 2010). As a result, Dominica was chosen as a representative of the island nations in the Caribbean.

The WADI model was developed as a tool by researchers (L Fullerton, S Dickin and C Schuster Wallace) at the United Nations University in Hamilton, Ontario, Canada to identify and visualize vulnerability to different water-associated infectious diseases by incorporating a collection of environmental and social determinants in a map format (Fullerton et al 2014). The efficacy of WADI has been tested by the researchers on two large dengue endemic countries Indonesia and Brazil. The creators of WADI assert that water-associated diseases such as schistosomiasis, cholera and dengue have the potential to negatively affect the health of billions of people across the world and can be found in developing countries (Fullerton et al 2014). The WADI was developed to use the ecological health model which incorporates the environmental / ecological and the social determinants of health, integrating these components in order to detect and visualize vulnerability using a map format (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014).

Specifically, the ecological health model creates a framework that integrates the environment, health and the characteristics of the specific population being researched in order to further understand vulnerabilities with the sole purpose of continually contributing to public health interventions and strategies that can reduce the burden of illness from water associated diseases. (Boischio et al 2009; Fullerton et al 2014; Hurlimann et al 2011)

The spread of water associated diseases are exacerbated by: an inadequate infrastructure that does not support appropriate water and waste management; dense populations; uncontrolled rapid urbanization; and environmental conditions related to climate and precipitation (Boischio et al 2009; Fullerton et al 2014; Hurlimann et al 2011; Natuzzi et al 2016). The WADI tool will also allow for exploring the spatial and temporal relationship of the incidence of dengue disease in Dominica (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014).

For this thesis, the measure of vulnerability to an increased risk of infection will include the conditions of exposure components (environmental / ecological determinants of health) and susceptibility components (social determinants of health) to dengue transmission at the population level in Dominica (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014). By assessing the environmental and social components of vulnerability of a population to the risk of water associated infectious disease (in this case dengue), the WADI tool is intended to present public health officials with an integrated representation of vulnerabilities to dengue infection and to provide information for public health promotion strategies that will aim to decrease the risk of transmission, and thereby reduce the burden of the disease (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014).

The objective of this thesis is to construct and validate the WADI tool in a setting in which it has not heretofore been tested by applying it to the incidence of dengue disease within the population of Dominica a small island nation in the Caribbean .The WADI incorporates the links between people, the environment and health. It will be built from a set of components including climate conditions, land use, poverty, age, population density, education status and access to water / water use practices. These components will be derived from secondary datasets. The use of the WADI framework allows for creating a visual representation of vulnerability to a water associated disease like dengue. Using a geographic tool, Geographic Information System (GIS) tool such as QGIS, the WADI values can be linked to geographic areas and presented visually as a map. In the construction of the WADI, the components derived from the secondary datasets will be combined to create amalgamated indicators of both exposure and of susceptibility with each component contributing to either exposure or susceptibility. During the analysis, these amalgamated indicators of exposure and susceptibility will be weighted by their contribution to dengue vulnerability, and the final output will include an overall disease index in a map layout (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014).

The value of the WADI tool lies within its practicality; it is a disease specific tool applied in assessing vulnerability at a range of different temporal and spatial measures using publicly available data (Fullerton et al 2014). Social /ecological/ environmental threats and triggers for infectious disease outbreaks identified in the study can be used in disease modelling to determine and project locations with high risk of infection, hotspots of epidemics and pandemic planning, as well as determining the areas which are most at risk to an above-average infectious disease burden (McMichael 2004). With limited resources available to reduce the burden of illness or to eradicate the spread of dengue, any mitigation measures require accurate identification of regions most vulnerable to the disease (Nathan 2006; Fullerton et al 2014; Suaya et al 2007). To summarize, the purpose of thesis is to construct and validate the WADI tool as it relates to the incidence of dengue disease on the island of Dominica. However, the vulnerability index can have implications for the incidence of dengue disease that also can be translated into other infectious diseases that are of public health significance in Latin America and the Caribbean (Chadee et al 2012).

Additionally, this thesis aims to generate practical information for public health authorities that can help them to either incorporate new strategies and interventions or improve older strategies that are focused on reducing the burden of infectious disease by directing new initiatives related to public health policy (Boischio et al 2009; Chadee et al 2012; McMichael 2004).

There may also be an opportunity for the results of this thesis to inform the allocation of disaster management resources, the strengthening of infrastructure, and targeting of interventions aimed at reducing infection risk as well as the overall burden of outbreaks of infectious disease (Lau 2010; McMichael 2004; Nathan 2006; Suaya et al 2007).

The thesis is organized into six chapters. Following chapter one, the introductory chapter, chapter two is the literature review which details the development of an integrative framework and associated index methodology. Chapter three presents the methodology to investigate vulnerability of an increased risk to dengue disease in Dominica by using the Water Associated Disease Index (WADI). Chapter four will be the results chapter, describing in detail the data analysis. This analysis is followed by chapter five, a discussion of the findings. The concluding chapter, chapter six, is a summary of the research outcomes achieved and a discussion of the contributions to the literature in understanding vulnerability to a water-associated infectious disease in a small island nation setting.

Chapter 2: Literature Review

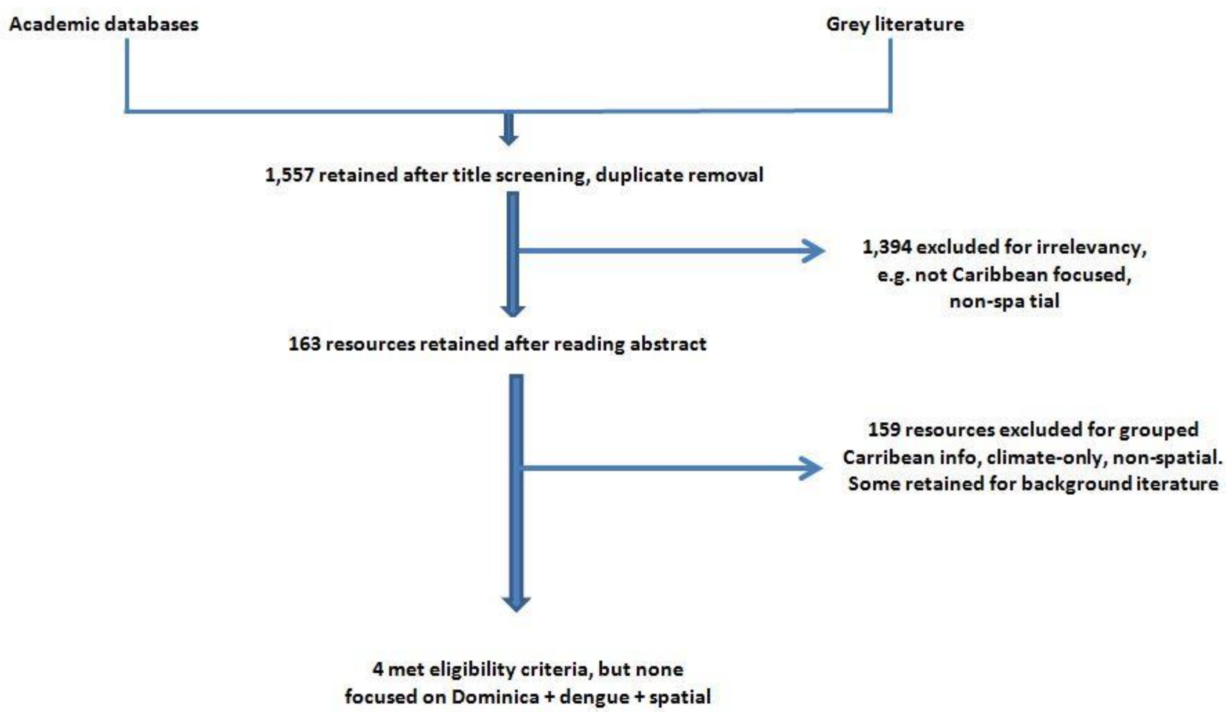
Dengue is a virus that causes an infectious disease in human beings. It is an re-emerging infectious disease that has been deemed by global public health authorities to be part of the Neglected Tropical Diseases (NTDs), which have a negative impact on the morbidity and mortality levels in the developing world (Aagaard Hansen and Chaignant 2010; Hotez et al 2008; Hotez 2013). The premise of this thesis is to determine the predictive value of the Water Associated Disease Index (WADI), using the island of Dominica and its incidence cases of dengue as a proof of concept to demonstrate the WADI's viability as a vulnerability assessment tool. For reasons stemming from health inequities, global public health resources are not allocated to combat the NTDs like dengue; therefore, cost-effective tools that rely on publicly available data may be helpful for countries in the developing world to assess their vulnerability to an increased risk of infection.

The literature review begins by summarizing the impact of infectious disease from a global public health perspective. It continues by incorporating the characteristics of the history of dengue in the Americas, including the aetiology of the diseases, highlighting its pathogenicity and its impact on at risk populations in the developing world. The second section of this review speaks to the health inequities created by the increased occurrence of the neglected tropical diseases in the developing world. This is followed by a review of the environmental and social determinants of health which compound the increased risk of vulnerability to the NTDs. Finally, this literature review concludes by discussing the study area, the Commonwealth of Dominica, as well as the impact of dengue in the region.

Although there are differing schools of thought regarding the types of index models that can appropriately predict patterns in infectious disease outbreak or highlight areas for public health intervention, the results of the literature review support the need for further exploration of the eco-health model that incorporates the environmental, ecological and the social determinants of health as components for an increased risk of infection to the dengue virus. This is the underlying rationale that supports the thesis in evaluating the WADI as a vulnerability assessment tool.

2.1 Search Methods / Strategy

Flow Chart of Search Strategy



The following search strategies were developed for electronic searching and the specific sources searched for the review are listed below. Hard copies of journals were hand searched. Journals were also electronically searched by browsing the contents page for relevant key words incorporating first dengue in the island of Dominica and then expanding the search to the rest of the Caribbean. The search focused on the period from 1999 to 2015. A total of 9 databases were searched including key public health / social science databases, as well as databases for related disciplines in public health research, and those covering grey literature. Hansard was also searched for evidence cited in government sources. Only some databases were sophisticated enough to run a complex search. The remaining databases were searched using a simplified version of the search strategy.

The search for documents included the English keywords, drawing out themes in the title, abstract, and discussion which focused on: public health, infectious diseases, water-borne infectious diseases, social determinants of health, public health intervention, and environmental health. Using all keyword combinations the first wave of searches in the databases returned between nine and ten thousand results. The search was further narrowed by included the terms Caribbean and dengue which placed the results at under four hundred. There were a number of studies which merely had a reference to Caribbean, either through a funding agency or mentioned in the biography of the researcher. A number of these studies were useful in developing the background section of the review and were referenced in that section. There were no studies specific to the island of Dominica, dengue, environmental health and the social determinants of health.

Search strategies developed for electronic searching were planned by the researcher with the help of public health librarians. These searches were compared, combined and revised to improve retrieval. An activity report feature embedded in the library services software helped to keep track of the results and monitor the search strategy by recording any modifications or transitions in the data searched. The websites searched in this review covered a range of national and local government sites, academic research institutes, professional organizations, and research funders.

The reference lists of all retrieved literature for additional references, including unpublished material. Each new reference identified in this way was also searched in turn for new references until this process was exhausted.

Electronic Sources Consulted

●MEDLINE

●EMBASE

●CINAHL

●Toronto Public Health Library

●University of Toronto Library

●Lancaster University Library

●RIC

●Sociological Abstracts

●Dissertation Abstracts

●EPHPP Database

●American Journal of Public Health

●Canadian Journal of Public Health

●Health Promotion International

●Bibliographies references of studies rated relevant

Websites and other sources for Grey Literature

●National Collaborating Centre for Infectious Diseases

●National Collaborating Centre for Social Determinants of Health

●Google

●Google Scholar

●World Health Organization

●Centers for Disease Control

●Pan American Health Organization (PAHO)

●Caribbean Public Health Agency (CARPHA)

2.2 Themes Identified from Literature Review

The literature review served to determine gaps in the research regarding dengue on the island nation of Dominica: developing small island nations were effectively excluded from the research into dengue in regions that are endemic for the disease. However, a number of themes unfolded as a result of the focused review, which supported the thesis: new and emerging infectious disease as a public health threat; the advent of the term 'neglected tropical diseases'; dengue as an economic and medical burden to communities; the relevance of the social determinants, the environmental determinants and the ecological determinants of health in infectious disease research; and, lastly, public health research veering toward a more comprehensive approach of an ecohealth model to measure vulnerability to infectious disease in a population. Through the literature search all of these themes proved to be pivotal to explaining the queries raised by exploring the research question, specific to infectious disease research in countries of the developing world. As a result, all of these themes will be discussed in detail in the literature review.

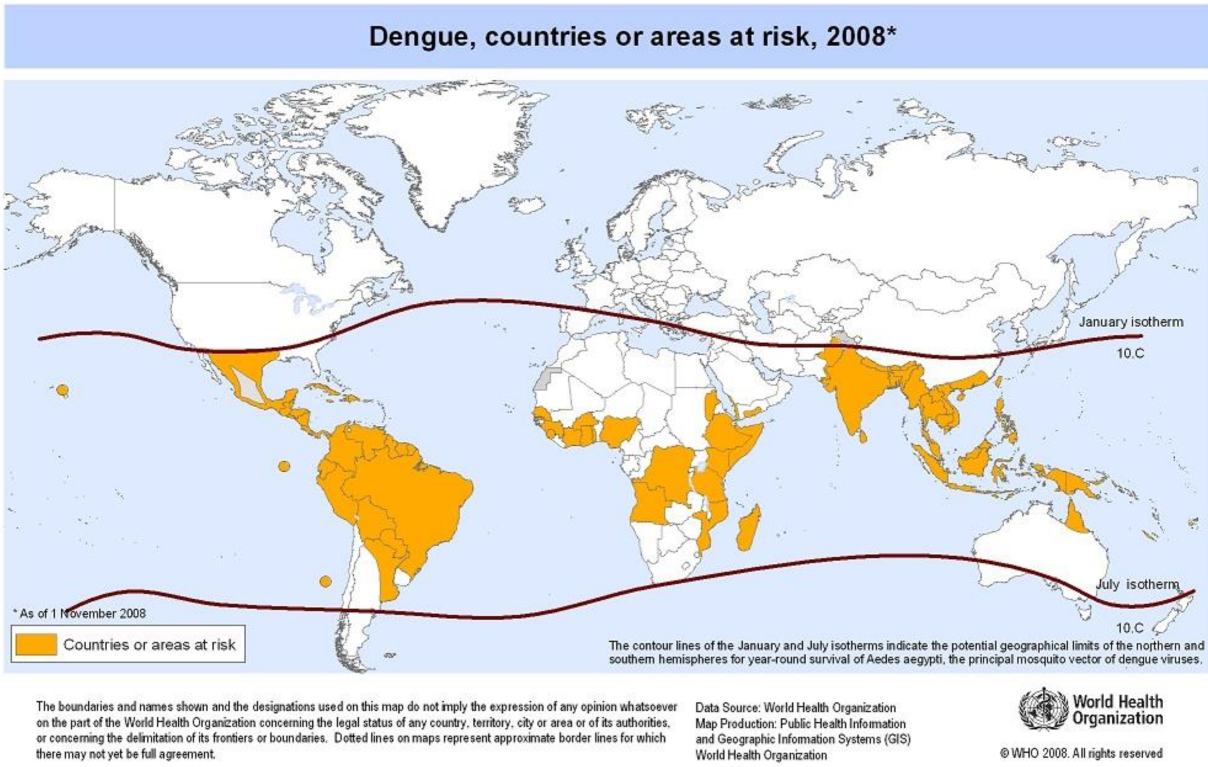
2.3 Dengue

Dengue is a disease that affects millions of people worldwide. It is estimated that each year 50 million people in over 100 countries become infected with dengue, and between 250 000 to 500 000 have their infection escalate to the more severe dengue haemorrhagic fever. As a result of this escalation, up to 200 000 people are hospitalized each year due to dengue (Bhatt et al 2013; Simmons et al., 2012; Fullerton et al 2014).

Dengue is mainly a tropical and subtropical disease affecting countries mainly in the developing world (Zhou and Griffiths 2010). The mosquito species is spread extensively around the world; however, they are mainly found between the latitudes 35ºN and 35ºS, situated in a tropical and subtropical areas (figure 1).

According to Nathan et al (2007), dengue is considered to be re-emerging disease as, since 2000, it has shown an exponential increase in the number of reported cases and epidemic outbreaks. During the 18th and 19th centuries globally, dengue epidemics were seen sporadically, in intervals and over several decades, mainly in Asia and the Americas (Montath 1994; Nathan et al 2007). Based on epidemiological evidence (World Health Organization 2008), the burden of disease is mainly concentrated around the equator reaching no farther than within the lines of the Tropic of Capricorn and the Tropic of Cancer (figure 1) (WHO 2008; Messina et al 2013).

<u>Figure 1 Countries Endemic to Dengue</u>



The pathogenic microorganism that causes dengue disease in human beings is a single stranded, positive sense, RNA flavivirus (Simmons et al 2012). The reservoirs for the virus are human beings, and non-human primates; however, humans are the main amplifying hosts, with transmission of the infection from passing from human to human (WHO 2000). The disease is characterized as anthropod-borne (or vector borne), as transmission from human to human occurs from the bite of a female mosquito (similar to many other anthropod-borne viruses significant to public health, such as yellow fever and West Nile Virus). The most important mosquito species for the transmission of dengue is the *Aedes aegypti*, and to a much lesser extent, mosquitoes of the Stegomyia species such as S. albopictus, S. polynesiensis, as well as, S. scutellaris (WHO 2009). Eight to ten days after being infected with the dengue virus, the female mosquito can transmit the virus during its lifetime to many individual people, while probing their skin and feeding on their blood (WHO 2009). Feeding on blood promotes ovi-position (movement of the eggs within the female mosquito to be laid) (Monath 1994). As a result, the mosquito can also pass on dengue virus to the next generation of progeny (Monath 1994, PAHO 1999; PAHO 2014; WHO 2000).

The dengue virus consists of four distinctive but closely associated serotypes, identified as dengue 1, dengue 2, dengue 3, and dengue 4. Within each serotype there are multiple genotypes with subtle genetic differences that are not clinically important to the manifestation of the disease (Simmons et al 2012). All four distinct serotypes are the causative agents of the same disease, and are transmitted to the human population via the bite of the mosquito. In other words, each serotype can cause an infection in human beings. The distribution of the dengue serotypes circulating in an area is particular to the geographical region; however, some regions that are endemic to dengue virus can have more than one serotype circulating at the same time (PAHO 1999; PAHO 2014; Simmons et al 2012).

2.4 Public Health Significance of Dengue

In agreement with the Centers for Disease Control, the World Health Organization stated that due to the combination of the frequency of the epidemic cycles, the increasing number of cases, the geographical distribution of the disease, and the potentially lethal medical complications, dengue has become a major global public health concern (CDC 2016; WHO 2000; WHO 2009; WHO 2012).

When surveying epidemiological data for dengue cases from 1955 to 1998, the same WHO 2000 documents noted an increase in the global number of annual cases (on average) from 908 cases per year from 1955 to 1959 to a sharp increase of 514,139 global cases of dengue per year after 1960 (WHO 2000). With its increasing rate of infection to over 30-fold since the 1950s, dengue is considered to be the fastest spreading mosquito-borne viral disease in the world including, an expansion into non-endemic regions countries (Gubler 2006; WHO 2000, WHO 2009).

The international public health agencies make the case for an increased risk of dengue prevalence; however, the improved sensitivity of new technologies, improved bedside diagnostics, and improved reporting may also be a contributing factor for the increased amounts of dengue cases worldwide. Notwithstanding, the evidence of disease burden with high morbidity rates was adequately compelling and dengue was marked as a high priority by the World Health Organization in 2004, highlighting the high risk of dengue haemorrhagic fever and dengue shock syndrome in the impoverished urban centres of tropical countries (Patz et al 2009; Simmons et al 2012; WHO 2004).

The noted increased risk in dengue infections led to a 2005 World Health Assembly resolution (WHA 58.3 2005) on the revision of the International Health Regulations. The resolution includes dengue as an example of a disease that has the potential to cause a public health emergency of global concern. This emergency, the WHA resolution states, has the potential to pose a health security risk due to its ability to disrupt an affected country and its rapid spread beyond a country's borders (WHA 2005, page 49). This is due to the fact that large outbreaks of dengue persist each year in endemic countries, which place serious financial costs and health burdens on the individuals, and communities within a country (WHA 2005; WHO 2009; WHO 2013).

The public health concern with an infection from the dengue virus, and potential escalation to dengue haemorrhagic fever or dengue shock syndrome (DHF and DSS), pertains to the extent to which the disease range is expanding across the globe; the specific virulent features of the virus; and, the alarming rate at which the number of infections from dengue are occurring (Brathwaite et al 2010; Murray et al 2013; WHO 2009). The virulence factors can be strongly affected by the complex relationship between the environment and the endemic population (Gubler 2011).

The majority of viruses affecting human health have the ability to shift or drift their DNA, thereby changing their virulence factors. Dengue virus also has the potential to do so but based on the current global dispersal of dengue virus serotypes the shift and drift are relatively infrequent, especially when compared to the constant change in virulence factors of a virus like the influenza virus (Gubler 2006; Gubler 2011; Guzman et al 2010; Messina et al 2014; Murray et al 2013). Sessions et al purports (2015) that dengue viruses are genetically constrained in their ability to mutate at a rapid rate (Sessions et al 2015). The study is limited due to the number of replicates that were available for research, and requires further research to determine the extent to which this will have an effect on dengue control in the future.

A further threat is the newly discovered fifth dengue virus that has been confirmed in South-East Asia. This discovery has increased the concern of the growing global public health threat from dengue (Normile 2013; Mustafa et al 2015). As the discovery is recent, it is unknown the full impact of the new serotype. Global public health officials are on alert as it may be the first indication of dengue virus shift or drift, increasing its virulence factors (Normile 2013; Mustafa 2015). The first outbreak from dengue serotype V has been reported in Malaysia, as a result, there are emerging new challenges to dengue control worldwide (Normile 2013; Mustafa 2015). However, the reporting and subsequent diagnostic tools for the new dengue serotype are very limited and the results are speculative at this time. As a result, further surveillance and investigation will be required to determine the extent of the threat globally.

There is also another growing public health concern relating the risk to vulnerable populations. In any scenario where there is endemic dengue in a region, children are always at a higher risk of developing severe dengue. Young children, when compared to other ages, are less able to compensate for capillary leakage and therefore have a greater risk of developing dengue shock (Aagaard-Hansen and Chaignant 2010; Anderson 2007). Individual risk factors also establish the risk of severity of the disease and include underlying chronic illness such as sickle cell anaemia, diabetes mellitus and asthma; ethnicity, age; and, secondary infection (Bhatt et al 2013). Epidemiological reports have shown that severe dengue is also often seen as a primary infection of infants born to mothers who have immunity to one of the serotypes of the dengue virus (Pouliot et al 2010).

There is evidence of an antibody-dependent enhancement of infection may be the cause, that the infant has acquired passively at birth (WHO 2009). A systematic review into maternal health and dengue in 2010 found higher rates of pre-eclampsia, preterm birth, caesarean delivery in babies born to mothers with a dengue infection (Pouliot et al 2010).

According to the WHO the risk of contracting DHF/DSS subsequent to an initial dengue virus infection is expanding on a global scale, as those who have had their first infection with one of the four serotypes of dengue are at greater risk than the rest of the population for a subsequent infection of another serotype (WHO 2009). Stanaway et al 2013 also conducted a similar calculation, the risk assessment concludes that based on the number of people at risk for dengue, the final number of people at risk of DHF /DSS could potentially be in the millions (Stanaway et al 2013). As a result, the burden of disease may constitute an important threat to public health. Based on this epidemiological data, the PAHO also concluded that dengue is the most significant vector-borne disease in the Caribbean region (Guzman et al 2010; PAHO 1999; PAHO 2014;

WHO 2009). Quantifying risk of an infectious disease is an increasingly complex endeavour which the researchers confirm as difficult as it can be subject to interpretation. However, it is a clear track towards an increased risk of transmission that has been validated through research despite being subject to interpretation.

Further to the other public health challenges of dengue, there is also no approved pre-exposure or post-exposure vaccine widely available, as it is still in phase III of its clinical trials. The vaccine will be pre-exposure, consisting of a live attenuated tetravalent inoculation of three doses, over one year, at the interval of months 0, 6 and 12. There are also 5 other vaccines in the development phase (WHO 2009; Simmons et al 2015; Wilder-Smith et al 2010). This is positive information in the development of methods to combat the global threat of dengue virus, especially in the developing world (Simmons et al 2015). However, as with all pre-exposure vaccines against viruses, the issue of complete protection is a problematic one as viruses are known increase their pathogenicity through antigenic drift or shift rendering the vaccine ineffective (Murray et al 2013; San Martin et al 2010). Also, the vaccine will be available in the early stages for those living in endemic areas only between the ages of 9 to 45, missing a majority of those who are most vulnerable to increased morbidity and mortality at less than 9 years of age and greater than 45 years of age (Simmons et al 2015). Therefore, as a stable vaccine marks remarkable progress in the fight against the dengue virus, the WHO acknowledges, that the vaccine is, "…to be an integrated part of the Global dengue prevention and control strategy" (WHO 2012 page 16). Part of the integrated prevention and control strategy for dengue includes cost effective and pragmatic tools to assess vulnerable regions for targeted public health interventions (Simmons et al 2015). Recent reports state that the trials of the vaccine has had a set back with lower than anticipated efficacy rates (Mustafa et al 2015). Initial trials of the most advanced pre-exposure vaccine have found that the vaccine may not offer full protection against all four serotypes which would be required to be an effective public health initiative in preventing the burden of disease from dengue (Mustafa et al 2015; Simmons et al 2015).

2.5 The Social Determinants of Health

The social determinants of health are the factors related to an increased exposure to illness. According to Mikkonen and Raphael 2010, "(T)he conditions in which people live and work directly affect the quality of their health," page 5. Susceptibility to ill health can be viewed in relation to the social determinants such as unplanned urbanization and socio economic status, where certain segments of the population are at an increased vulnerable risk to not only being ill but also to having the illness having a long term impact on the quality of their life (Mikkonen and Raphael 2010).

The social determinants of health that play a pivotal role in the impact of the effects of infectious disease often overlap. It is not poverty alone that perpetuates the impact of the morbidity and the mortality of illness from infectious diseases; it is also not having access to viable resources to provide integrated methods to combat infectious diseases (Aagnaard and Chaignant 2012; Amarakoon 2006, LeBeaud, 2008). However, underneath it all, poverty, is the leading social determinant of health with regards to an increased level of exposure to infection. Secondary to poverty, as intermediary social determinants of health are housing and clustering, as well as, water and sanitation (Bircher and Kuruvilla 2014).

Social Determinants of Health -Poverty and Dengue

In 2009 the WHO added dengue as the first arbovirus of the NTDs (WHO 2009; WHO 2010). Dengue does fulfill the criteria as an NTD. The WHO documents, while pivotal in re-establishing global interest in dengue does fail fully analyze the exclusivity of the diseases affecting the poor. Like most health issues with negative health outcomes, the poor are disproportionately affected but not solely affected by an increased risk of transmission (Horstick et al 2015). There is also a link to poverty and dengue risk in the developed world; however, the transmission of the disease can easily encroach on wealthier communities, especially during an outbreak (Dean et al 2013).

Mulligan et al 2015 also researched into the poverty dengue link conducting a systematic review. The researchers found in equal measure the number of studies able to draw a significant link of dengue to poverty as those that did not. Unfortunately, only a small sample size of the sample met the research criteria used to determine whether there was an exaggerated risk of dengue among the poor was not sufficient to draw a significant conclusion. No other research studies demonstrated positive associations between measures of dengue and poverty. The measurements are hard to compare as the metrics are applied inconsistently through socioeconomic status/ income, education, structural housing condition, overcrowding in each of the study. The conclusion from the research stated the need for further research into to determine the consistency of the associations and a definitive relationship (Mulligan et al 2015).

In the developed world, public health researchers are noting a trend of dengue in regions where there areas of poverty (LaBeaud 2008; Weaver and Reisen 2010). For example, the Centres for Disease Control (2001) which studied dengue infection in Laredo, Texas, found that the majority of people affected were living in impoverished communities. Most of these impoverished communities do not have the resources to advocate for themselves in terms of implementing adequate vector control and developing other measures which can reduce their risk (CDC 2001). Epidemiologically, this falls in line with the current state of public health research which links dengue to poverty, socio-economic status and unfavourable living conditions (WHO 2014).

From the analysis of secondary data obtained in a research study regarding dengue fever in Belo Horizonte, Minas Gerais, Brazil, the researchers determined poverty to be a significant predictive indicator of clusters of high rates of dengue fever (Pessanha et al 2012). In fact, the majority of the cases of dengue were found in underprivileged areas (Pessanha et al 2012). Further research is also required to determine if this is a limitation of using secondary data from national surveillance systems due to the presentation of non-specific symptoms of dengue, which can lead to over-reporting during an outbreak.

In order to capture the risk to the public and to have a comparable measure as to the extent to which an NTD can have an effect on a country, the concept of the 'disability adjusted life year' or DALY was devised. A DALY specifically measures the burden of disease and the harm to an individual to fully understand the impact an infection from the NTDs. One DALY accounts for the equivalent loss of one year of healthy life due to disease or disability. It also captures the complex combination of the number of years lost from early deaths and the partial years lost when a person is disabled by illness or injury (Murray et al 2012; Vox et al 2012). According to the WHO 2008, Page 18, the DALY gauge is used to capture "the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability." (WHO 2008)

Globally, the agreed upon approximate disability-adjusted life years or DALYs lost to dengue in the year 2001 is 528 years. In comparison, the Caribbean island of Puerto Rico had an estimated yearly mean of 580 DALYs that were lost to dengue between 1984 and 1994. This number of DALYs is equivalent to the combined total of DALYs lost to malaria, tuberculosis, intestinal helminths and the childhood disease clusters in all of Latin America and the Caribbean within the same time period (Bhatt et al 2013; WHO 2008; Murray et al 2012).

A prospective study from 2005-2006, outlining the costs of the cost of dengue, were conducted by researchers in order to embark into the public health significance of the disease through a health economics lens. The results were published by Suaya et al in 2009. Of the eight countries involved in the study, there were three in Southeast Asia (Cambodia, Malaysia, Thailand) and five countries in Latin America (Brazil, El Salvador, Guatemala, Panama, Venezuela). On the whole, the cost of a non-critical ambulatory case averaged US$ 514, while the cost of a non-fatal hospitalized case averaged US$ 1491. As expected, a critical hospitalized dengue patient costs approximately three times what a non-hospitalized patient would cost (Suaya et al 2009). In their study in 2011 Shepard et al concurred with the same conclusion, however not all components such as control of the mosquito vector were included in the estimate. As a result, these high numbers may be an underestimate of the actual economic burden of dengue (Shepard et al 2011; Suaya et al 2009; Vox et al 2012).

As the burden of dengue illness also has an effect other family members who assisted in caring for the dengue patient, a typical episode of the illness represents 14.8 lost work days for non-critical patients and 18.9 lost work days for critical patients (Vox et al 2012). By merging the cost of the non-critical with the critical / hospitalized patients and accounting for the chance that the case could be fatal, the overall cost of one dengue case is estimated at US $828 per day.

Combining this number with the average annual number of officially reported dengue cases from the eight countries studied in the period 2001 – 2005 (532 000 cases) gives a cost for officially-reported dengue of US$ 440 million. Recent research into the DALYs for Colombia during 2010 to 2012 found the economic burden based on the DALYs to each family affected was twice as high as the cost to the state (Rodriguez et al 2016).

From the dengue costing research studies such as Suaya et al 2009, Bhatt et al 2013, and Rodriguez et al 2016 results have often been conflicting because of information gaps. It is clear from the research that prioritizing public health research, policy, and allocation of funds to dengue control requires a more innovative metric. The categories including health care cost savings, the burden of morbidity and mortality are not sufficient to capture the economic burden. It is too narrowly defined and does not incorporate costs linked to vector control, outbreak control spending, income from tourism, and long-term economic productivity. These are all significant factors to consider in economic evaluations of dengue disease and potential future vaccination implementation that was not explored in any of the studies into the economics of disease burden of dengue.

At this stage in public health research into the economic burden of disease, these numbers provide a good framework for future research (Suaya et al 2009). The World Health Organization in a 2014 report still cites the same numbers as the most recent information as accurate to evaluating the considerable economic burden of dengue as do the researchers Bhatt et al 2013 (Bhatt et al 2013; WHO 2014).

Social Determinants of Health -Water, Sanitation and Dengue

Dengue has the potential to afflict all segments of society; however, the disease represents a higher burden to people who live in communities with an inadequate water supply and lack of a solid waste infrastructure (Spiegel 2011; Dom et al 2013a; Sharp et al 2017). This due to the fact that water plays an important role in the Aedes aegypti's life cycle (Bhatt et al 2013; Brathwaite et al 2010).

In a research study based in Brazil by Caprara et al 2009, a bio-social approach was adopted to identify both the biological and socio-behavioural factors that have contributed to the re-emergence of dengue fever including: poor housing and basic sanitation, lack of adequate water supply, the use of unprotected reservoirs for potable water, and lack of public garbage collection. From the research, it was determined that the water supply was irregular in households from both the under-privileged and the privileged areas; however, there were clear differences. In the privileged areas, where households were of the upper and middle class, the researchers found that the irregularity of supply did not have an impact on the number of dengue cases in the area as they had access to bottled water for drinking and cooking. Households in the under-privileged blocks, where the water supply was also irregular without resources for bottled water, the frequent use of water containers such as water tanks, cisterns, barrels and pots, to collect rain water created environmental conditions that increased the number of breeding areas which thereby increased the mosquito population (Caprara et al 2009; Torres et al 2017).

The same findings were determined by researchers in Vietnam; Schmidt et al 2011, confirming the increased number of domestic water storage containers increased the breeding sites for the *Aedes* mosquito. From the bio-ecological perspective, the researchers determined that the presence of the vector mosquito and the quantity of breeding sites are the most important factors of dengue occurrence (Schmidt et al 2011). The main preventive measure against dengue virus transmission is often based on actions to control the *Aedes aegypti* reproduction cycle by targeting water containers of clean and stagnant water (Spiegel 2011; Stanaway et al 2013).

An interesting fact was uncovered during the research study Caprara et al 2009, and may be indicative of the water supply problem in impoverished areas in the developing world. Although the public system supplies water to over 80% of the dwellings in the under-privileged blocks, the people there face daily water supply problems (Caprara et al 2009). This situation is often aggravated by the fact that some inhabitants have no plumbing in their homes, whether due to the absence of public services in the dwelling or because not all families can afford it (Garcia Betancourt et al 2015; Pruss et al 2016). This irregularity (or non-existence, in some cases) of water supply from the public sphere leads the population to store water in various containers such as water tanks, cisterns, barrels, drums, bowls, pots, water filters and others (Aagnaard and Chaignant 2012; Garcia Betancourt et al 2015; Schmidt et al 2011). The sealing of water tanks is a practice that has been implemented by the dengue fever eradication programme, but not all households can afford tanks with a lid or mesh covering (Pruss et al 2016). In some homes with running water, people often use drums and pots for drinking or bathing to reduce the cost (Aagnaard and Chaignant 2012; Garcia Betancourt et al 2015; Schmidt et al 2011). All of the current cases of dengue disease were found in the under-privileged areas that were being studied and, as expected, evidence of the mosquito larvae providing further evidence that lack of an improved water source leads to an increase in the risk of dengue transmission but lack also lack of infrastructure of a state run water supply (Caprara et al 2009).

2.6 The Environmental / Ecological Determinants of Health

Gnanakan 2004 defines determinants, in the environmental health sense, as the circumstances that increase the propensity for disease and promote ill health. Environmental/ecological determinants of health are now being considered by public health researchers to be a definitive factor in research and they are beginning to develop mitigation measures in policy and practice that include the environmental determinants of health (Bircher and Kuruvilla 2014; Gnanakan 2004). Environment refers to the built / physical environment such as urban land use and population density including overcrowding in residential areas and poor unplanned community design (Pruss-Ustun et al 2016). Dean et al 2013 suggest that the social determinants of health cannot give the full assessment when evaluating implications for effective public health practice and policy without examining the associated environmental determinants of health (Dean et al 2013).

There is also an ecological component which includes temperature and precipitation. Research has shown that in the developing world, an examination into environmental and ecological related infectious diseases requires placing environmental and ecological factors at the forefront (Pruss-Ustun et al 2016). The developing world is especially affected negatively from a deterioration in the environment or change in the ecology in which the populations live, and from the increase in global climate change. The ecological and environmental factors emphasize transmission routes of infection from a more holistic perspective (AFMC 2007; Gnanakan 2004; Jones et al 2008; Pruss-Ustun et al 2016).

Additionally, research studies into the study of the determinants of health have begun to uncover an undeniable link that intricately weaves environmental/ecological determinants with social determinants to understand all the pivotal factors that contribute to the propagation of infectious diseases in a population. (AFMC 2007; Gnanakan 2004; Jones et al 2008; Pruss-Ustun et al 2016) Most opportunistic species, which are also amplifiers of infectious disease—particularly rodents—can thrive in disturbed habitats. One theory surmises that if pathogen host species are generalists in terms of their preferred ecological niche, and the newly formed habitat is suitable, the potential for pathogen transmission to human can increase significantly (Guernier 2004; Keesing et al 2010).

According to Murray and Daszak (2013), human influence on the landscape has increased over the last century in direct relation to population increase. Human beings, when compared to other animals on earth, are unequalled in their ability to exploit and alter the landscape to suit their needs (Murray and Daszak 2013). This influence on the landscape has led to a disturbance of the biotic structure, mainly in the form of biological invasions and biodiversity loss (McMichael 2004). From data collection beginning in 1940, 20% of the emerging infectious, especially infectious diseases of animal origin, are believed to be attributed to change of land use (McMichael 2004; Murray and Daszak 2013). Yet a significant amount of research is focused on identifying the reservoirs of the causative agent and its capacity to spread once in the human population. This focus of research has been valuable in revealing mitigation measures in the control of infectious diseases in the form of vaccine development or quarantine measures (Aron & Patz 2001; Smith 2012). Further research such as Jones et al 2008, Morens and Fauci 2013 into travel, trade and globalization on the spread of infectious disease has also been of value to public health promotion, education and controlling disease spread (Jones et al 2008; Morens and Fauci 2013). However, the precursor conditions which begins the process of emerging infectious diseases are much less developed and requires further exploration through research (Eisenberg et al 2007; Jones et al 2008; Morens and Fauci 2013; Weiss 2004).

According to McMichael (2004), a review of unpublished data and an examination of global public health statistics suggest that a change of land use and changes in the environment may be a significant precondition to the emergence of disease outbreaks in the human population (McMichael 2004). Even without significant mortality rates, the outbreak of infectious diseases among the human population can have high morbidity issues thereby leading to high social and economic issues within a population. As suggested by Patz et al (2009), "Infectious diseases are a product of the pathogen, vector, host and environment," (Patz et al 2009, page 394).

Environmental Determinants of Health - Urbanization and Dengue

Demographic changes occurring in underdeveloped countries due to intense rural-urban migration since the 1960s have resulted in overcrowded cities with multiple deficiencies, particularly in housing and basic sanitation (Gubler 2011). Approximately 20% of the population globally in large and medium-sized cities live in slums or under similarly overcrowded, low income conditions (Neiderud 2015).

According to Morens and Fauci 2013, dengue serves as an excellent example of an important re-emerging infectious disease that has endured at a low endemic level, and managed to re-emerge as a pivotal player among the neglected tropical diseases (Morens and Fauci 2013). It has been posited by Laughlin et al (2012) that the lack of any other supplemental hosts has forced the species of mosquitoes that are vectors of the dengue virus, to adapt to the lifestyle of their only urbanized hosts, humans. As a result, urban environments, especially poverty ridden, overcrowded, unplanned urban environments provide the perfect environmental niche for the

Aedes aegypti (Laughlin et al 2012; Gubler 2011). This fact conforms to the knowledge that dengue transmission is highly focal in space, as the vector`s range stays within 100 meters (Chao 2013).

A research study into dengue in Malaysia contradicts the 'urbanization only' theory that has been developed by public health researchers such as Gubler 2011 and Morens and Fauci 2013. The results were derived from a thousand randomly selected adults between the ages of 35 to 74 years old, where the human being / mosquito /landscape connections were analyzed, through a widespread data collection over three years in seven villages (Muhammad Azami et al. 2011). The researchers concluded that there was no significant distinction between the seroprevalence rate of dengue infection of adults living in either urban or rural settings (Muhammad Azami et al, 2011). In other words, any landscape where there were human settlements in the endemic country showed the presence of larval habitats which would lead to the subsequent risk and exposure to infection for human beings (Muhammad Azami et al, 2011).

The authors used IgG serotype as an indicator of dengue exposure, which can determine presence of the disease within the country but not the origin of where the disease was acquired. viraemic subjects may have facilitated the spread of the illness from urban to rural. Therefore, other methods of increased spread of the disease will need to be examined for accurate surveillance data.

The general consensus among researchers such as Dickin et al 2013, Schmidt et al 2011, and Stanaway et al 2012 who study dengue assert that extremely dense, urban human settlements have been identified as being highly associated with a higher incidence of dengue cases (Dickin et al 2013; Gubler, 2011; Schmidt et al 2011; Stanaway et al 2012; WHO 2009). In fact, according to Horstick et al (2015) dengue remains an NTD even though it can affect both the rich and the poor. However, dengue will disproportionately affect the impoverished, in more densely populated urban areas of a region or nation (Horstick et al 2015).

Environmental Determinants of Health - Climate and Dengue

Dengue is an infectious disease that in which transmission is sensitive to temperature and rainfall. Nearly a third of the global population resides in regions where the temperature and rainfall are adequate for transmission of the dengue virus (Gubler 2011; IPCC 2007).

Water, in this case rainfall, is a fundamental element of the mosquito's life cycle. The *Aedes aegypti* mosquito has a lifecycle that was originally specific to existing in the forest landscape. More specifically, *A. aegypti* would use holes in forest trees as its main habitat. The tree holes would act as a natural vessel for collecting rain water. As the human population began to grow and the need for resources became increasingly demanding in the forest areas, human habitats began to encroach on the niche areas inhabited by the *A. aegypti* (Amarakoon et al 2006). As a result, the *A. aegypti* mosquito began to adapt to its changing landscape from forest to urban and peri-urban areas adapting their life cycle to the ubiquitous plastic containers found around most households in an urban setting (Brathwaite et al 2010).

In fact, according to the Pan American Health Organization, with the proliferation of external plastic containers near to most homes, which collect water after a rainfall increases hospitable spaces for larvae growth (PAHO /CAREC 1999). This situation is also better suited for the *A. aegypti* mosquito as adapting to live in urban and peri-urban centres allows for a unique access to its preferred hosts, human beings. A household survey in Trinidad and Tobago found breeding sites in urban areas in cans, clay pots, drums, buckets, tires, and bottles. This practice is seen throughout the islands of the Caribbean, especially among the urban poor (Chadee 2012).

When adult forms of the mosquito remain inside homes, the most important factor for their survival is an increased relative humidity. The kind of home environment that best favours the process of colonization by adult forms of is not yet known or understood, requiring further research to determine its relevance in an increased risk of dengue transmission. This may include un-plastered walls, un-lined floors, especially bathrooms, or other factors that increase the humidity indoors, aiding reproduction of the mosquito (Aagnaard and Chaignant 2012). Climate also highlights the inextricable link between the ecological / environmental and the social determinants of health (Amarakoon 2006; Dean et al 2013). In homes of sound construction or outfitted with air conditioning, relative humidity is not an issue. In poorer regions however, relative humidity is a factor due to the poor infrastructure of the housing unit (Aagnaard and Chaignant 2012; Amarakoon 2006).

Additionally, in the Caprara et al 2009 study of under-privileged socio sanitary blocks, the following were observed (i) a significantly smaller percentage of homes with plastered walls; (ii) a significantly higher percentage of homes with cement floors; (iii) a significantly lower percentage of homes with less porous floors (ceramic); (iii) a significantly lower percentage of homes with tiled bathrooms with an increased risk of dengue transmission (Caprara et al 2009). In other words, the type of home construction in under-privileged neighbourhoods seems to allow a higher relative humidity and thus a more appropriate environment for survival of adult mosquitoes (Amarakoon 2006; Caprara et al 2009)

Temperature also plays a pivotal role in the life cycle of the mosquito in terms of, “adult vector survival, viral replication, and infective periods,” (Murray et al 2013, page 303). The optimal temperature for the mosquito`s life cycle is between 18 to 34 degrees Celsius. This is one of the least disputed issues in the knowledge of dengue transmission in the literature. The *Aedes aegypti* mosquito is bound to geographical boundaries of regions that experience a winter temperature of 10ºC or higher (Bhatt et al 2013). There has been evidence of *Ae. aegypti* as faraway north as 45 ºN but only for brief periods in the summer months, the species has not been known to survive over the winter months or at altitudes that have colder temperatures, above 1000 metres (Bhatt et al 2013; Halstead 2007).

According to Hales et al 2002, by 2080, with projected climate change predictions of increased temperature would put up to 6 billion people at risk to an infection from dengue virus. If the temperature maintains its current status, the number of people at risk would remain at 3.5 billion (Hales et al 2002; Murray et al 2013).

2.7 Study Area – Dominica

Figure Number 2 Island of the Caribbean

Dominica is one of the Windward Islands in the Caribbean (see figure number 2). The island nation lies mid-way in the arc of the Lesser Antilles of the Caribbean archipelago, which starts at the Virgin Islands and ends just before the South American coast. The original name of Dominica is *Wai'tukubuli* which means tall is her body, in the native language of the Carib Indians, the original settlers of the island (Commonwealth of Dominica 2010; DHTA 2000). The population is approximately 71 000, the majority of which are descendants from Africa, with five percent of the population comprised of the Carib Indians. Dominica has an area of approximately 750 km^2 (289 square miles), it is 26 kms (16 miles) across its widest point and 47 kms (29 miles) long, with 150 kms (91 miles) of coastline. Dominica has very rugged, steep terrain with a mass of peaks, ridges, valleys and ravines. The backbone of mountain ridges runs from the north to the south through the centre of the island, with the average peek at an elevation of three thousand feet (see Appendix 3). Due to the nearly impenetrable mountainous interior, the majority of the residential sprawl is along the coastline (see Appendix 4) (Commonwealth of Dominica 2000; Commonwealth of Dominica 2010; DHTA 2000).

Photo Number 1 Commonwealth of Dominica

Photo Credit: **emilykilpatrick.files.wordpress.com**

The Dominican Tourism Association has cleverly marketed the island as the *Nature Island of the Caribbean* due its extensive rainforests, deep river gorges, waterfalls, and one of the world's largest boiling lakes (DHTA 2000). Dominica also boasts a diverse variety of marine and terrestrial life, as well as, an impressive array of flora and fauna. It is a volcanic island with volcanic activity monitored in specific regions of the island such as the Valley of Desolation (DHTA 2000).

Photo Number 2 Commonwealth of Dominica

Photo Credit: Abenteuer.net

The island experiences a humid tropical climate with little seasonal variation in temperature, with strong trade winds. The climate in Dominica is tropical and with very little variation in its daily temperature, hovering at 30 degrees C / 86 degrees F. Daily there is often a short-lived trade wind shower. Similar to most tropical countries, Dominica has two seasons: a dry season with the months of December to January being the driest, and June to July are the wettest months during the wet season (Commonwealth of Dominica 2010; DHTA 2000).

Photo Number 3 Commonwealth of Dominica

Photo Credit: Double-BarelledDevil.com

Dominica is divided into ten regions called parishes: St. Andrew, St. David, St. George, St. John, St Joseph, St. Luke, St. Mark, St. Patrick, St. Paul, and St. Peter with a population of approximately 70 000.

Dominica and the Neglected Transmitted Diseases

Similar to the rest of the developing world, in Dominica the NTDs have been a significant cause of morbidity and mortality among its population (Cassidy-Seyoum 2014). The impact rate with regards to morbidity and mortality is similar to the rest of the smaller countries in the Caribbean at 0.5 to 1.1 deaths per 100 000, with the elderly and the very young at an increased risk of death.

In terms of years lost to disability (Disability Adjusted Life Years), there is a significant health burden at 58.7 healthy years of life lost per 100 000 (WHO 2014; IHME 2013).

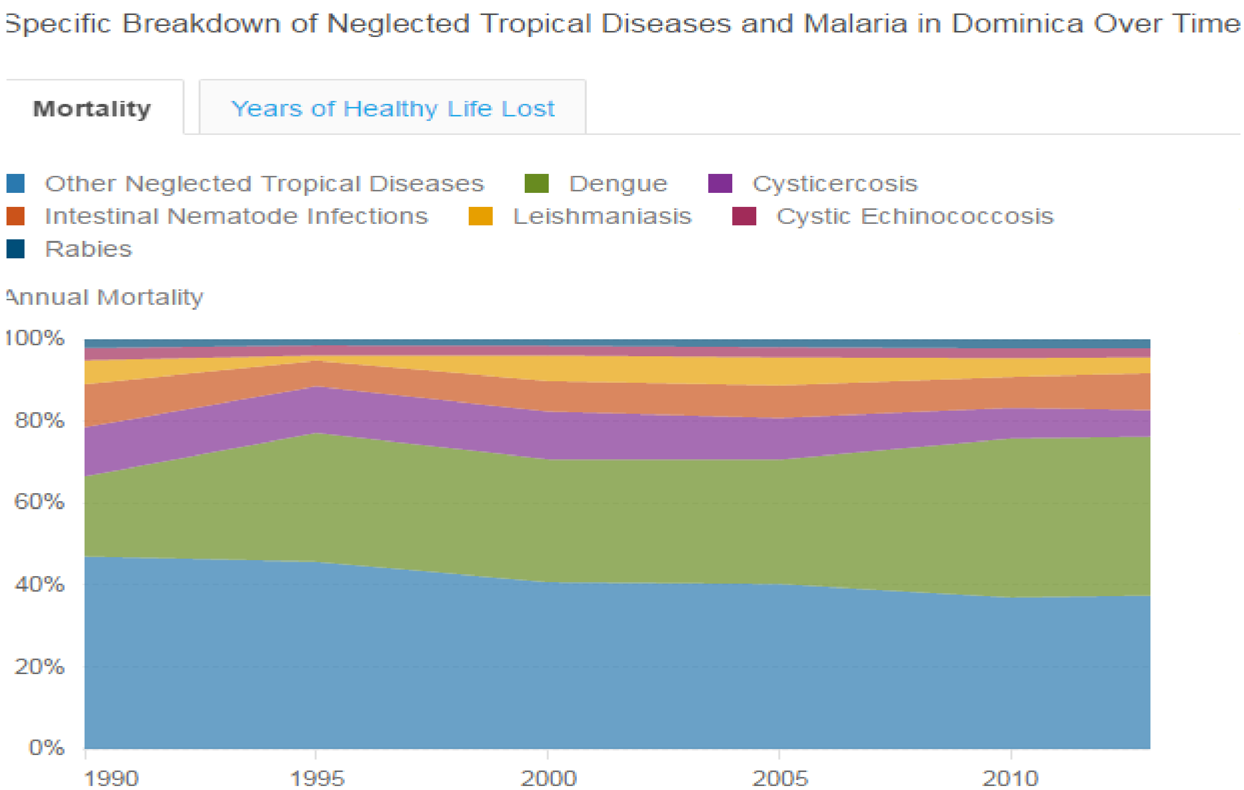
Dominica and Dengue

The island of Dominica is situated directly between the two islands of Martinique and Guadeloupe, both of which had one of the first epidemics of dengue in the Caribbean in the year 1635 (Dick et al 2012). Given the history of the disease in the Caribbean, all four dengue virus epidemiological serotypes are present in the Caribbean. Dominica is considered by the World Health Organization, the Centers of Disease Control and Prevention and the Pan American Health Organization to be endemic for dengue virus, due to the consistent prevalence of the disease within the country. World Health Organization conducted a study from 1975 to 1996 to determine the endemic status of dengue globally (WHO 2000). The island of Dominica is listed as an endemic country with only two countries in the Caribbean and South America region-- Uruguay and Chile-- as having no documented cases of dengue (Appendix 1). However, as early as 1905, from results of research into mosquitoes in the Caribbean, it is clear that dengue and its vector for transmission of the disease, the Aedes aegypti mosquito, were well established on the island (Stone 1969). This paper by Stone 1969 has a strong entomological focus on the classification and identification of mosquitos in the Caribbean but serves to account for the presence of the mosquito vector on the island. Further research (Moreira 2002) into a survey of the Aedes type of mosquito on the island confirmed the findings of the continued presence of the species on the island (Stone 1969; Moreira 2002; WHO 2000)

Dominica is a member of the World Health Organization and as a result is required to follow their recommendations for dengue virus surveillance for all countries which are endemic for dengue (WHO 2014). Dengue is a reportable disease in Dominica. The case definition is presentation of a patient with, a fever lasting more than 2 days as well as, "…2 or more of the following: headache, retro-orbital pain, myalgia, arthralgia, rash, haemorrhagic manifestations, leucopenia." (WHO 2014 page39) In a study researching the seroprevalence of zoonotic diseases in the Caribbean, researchers found the seroprevalence of dengue in Dominica to be 98% (CI of 3.9%) (Wood et al 2014). While seroprevalence alone does not establish a public health threat of dengue, it aids in establishing a trend on the emergence and presence of the disease on the island.

The Pan American Health Organization (PAHO) and the Caribbean Public Health Association (CARPHA) provide publicly available data on rates of dengue in the Caribbean and Latin America. Per 100, 000 on average Dominica has greater than 30 cases of dengue per year, indicating a high burden of disease. Dengue in Dominica accounts for less than four deaths per year 100, 000, more than the expected number of deaths from the rest of the NTDs combined. However, it is the morbidity, expressed in disability adjusted years that accounts for the public health hazard. As seen in the graphic below (Figure Number 3), dengue accounts for over 60% of the disability adjusted life years /years of healthy life lost in Dominica (IHME 2013; PAHO 2014).

Figure Number 3- Years of Healthy Life Lost Due to Dengue and other Infections



Years of Healthy Life Lost Due to Dengue and Other Infectious Diseases Over Time Source IHME 2013

Despite the consistent public health threat of dengue in Dominica and the other small island nations of the Caribbean, very little research has been conducted in this area. In the literature, the 24 small island nations of the Caribbean are often not listed as an individual country as are the larger island nations of Puerto Rico, Cuba, Jamaica, Haiti or Trinidad. Instead they are grouped together under the headings other Caribbean islands; islands of the Lesser Antilles; or, several Caribbean countries (Dick et al 2012).

The results of the literature review yielded four research studies that met the initial criteria for inclusion to the literature review focus on the parameters of Caribbean island + dengue + spatial search. There were no studies specific to the Commonwealth of Dominica; however, four other small island nations were the subject of research. First is a study by Chadee et al in 2005 which explores the first major outbreak of dengue on the island in 1998 using geographical information systems mapping of the vulnerable areas to an increased risk of viral transmission per each of the eight administrative counties. Temporal results from the study found that the rainy season had a higher incidence of dengue cases, with the spatial results there was a link between the more densely populated counties areas of the island to a higher incidence of dengue cases. The study presents a comprehensive view of spatial and temporal distribution to dengue risk per county using GIS technology which will inform this thesis; however, the study fails to broach the risk associated and supported by the literature, which includes the social determinants of health. Poverty, the uptake of health education / health promotion tools, age and access to health care were not factored in to the increased risk of transmission, which play a pivotal role in dengue transmission (Chadee et al 2005).

The Depradine and Lovell 2005 study into the risk of dengue in the 11 parishes in the small island nation of Barbados also focused on the link between climatological data and increased risk to the disease. As with Chadee et al 2005, the research paper provided invaluable information regarding further insight into climatological data and its link to increased vector propagation which further links to an increase in the risk of dengue virus transmission which is discussed further in the literature review section of the thesis. The researchers acknowledge that dengue has been increasing in the Caribbean at an alarming rate since 1995. They also state that the drivers which affect an increase in transmission risk are complex and not well understood, but the focus is still solely on the effect of precipitation on the rates of dengue over a five year period, from 1995 to 2000. The research study does not find any insight into the vulnerability to an increased transmission into any of the 11 parishes using GIS technology. In fact, the researchers found that the areas with less rainfall were the parishes which had more incidence of the disease but were unable to deduce the relationship.

The researchers stated on page 440, “The predictive equations using the climatic variables explain at most 35% of the variance. The total number of cases will therefore depend largely on other non-meteorological and biological factors,” (Depradine and Lovell 2005, page 440). There is also further acknowledgement into the serious knowledge gaps that stem from the 1997 Public Health Symposium in Jamaica. The results of discussions from the symposium, according to the researchers, outlined the human, vector and infectious agent factors that could lead to an increase in dengue cases and may improve the risk analysis (Colwell and Patz 2005). Despite this revelation, the researchers did not focus on the complexity of the drivers of an increased risk to dengue transmission. As a result, the study is lacking depth into vulnerability to an increased risk of transmission by failing to incorporate the social, environmental, as well as, the ecological components.

In the research study conducted by Matheus et al 2012, St. Martin and its sister island St. Barthelemy surveillance and spatial distribution of the dengue virus is studied only within the context of serology by the researchers. Over a two year period blood samples are drawn and analyzed to determine and subsequently map the serotype during the inter-epidemic phase. The importance of research into the serology of dengue on the islands is to improve surveillance of the circulating dengue serotypes through DNA sequencing. The researchers fail to link the acquisition of this knowledge in terms of disease dynamics. Specifically, there was no shift in serotype that proved useful to combating the risk of dengue on the islands through vulnerability to an increased risk of disease transmission. This led further into an exploration of the impact of serotypes on an increased risk to dengue transmission. This line of thought was quickly refuted by the research. For instance, according to Bennett et al 2010 and another Schioler and MacPherson 2009, nations of less than 200, 000 do not have hyperendemicity as found in nations with larger populations, each outbreak will be linked to one of the four known dengue virus serotypes. This also provided background into the low endemicity years found in the nations with small populations which will be discussed further in the literature review.

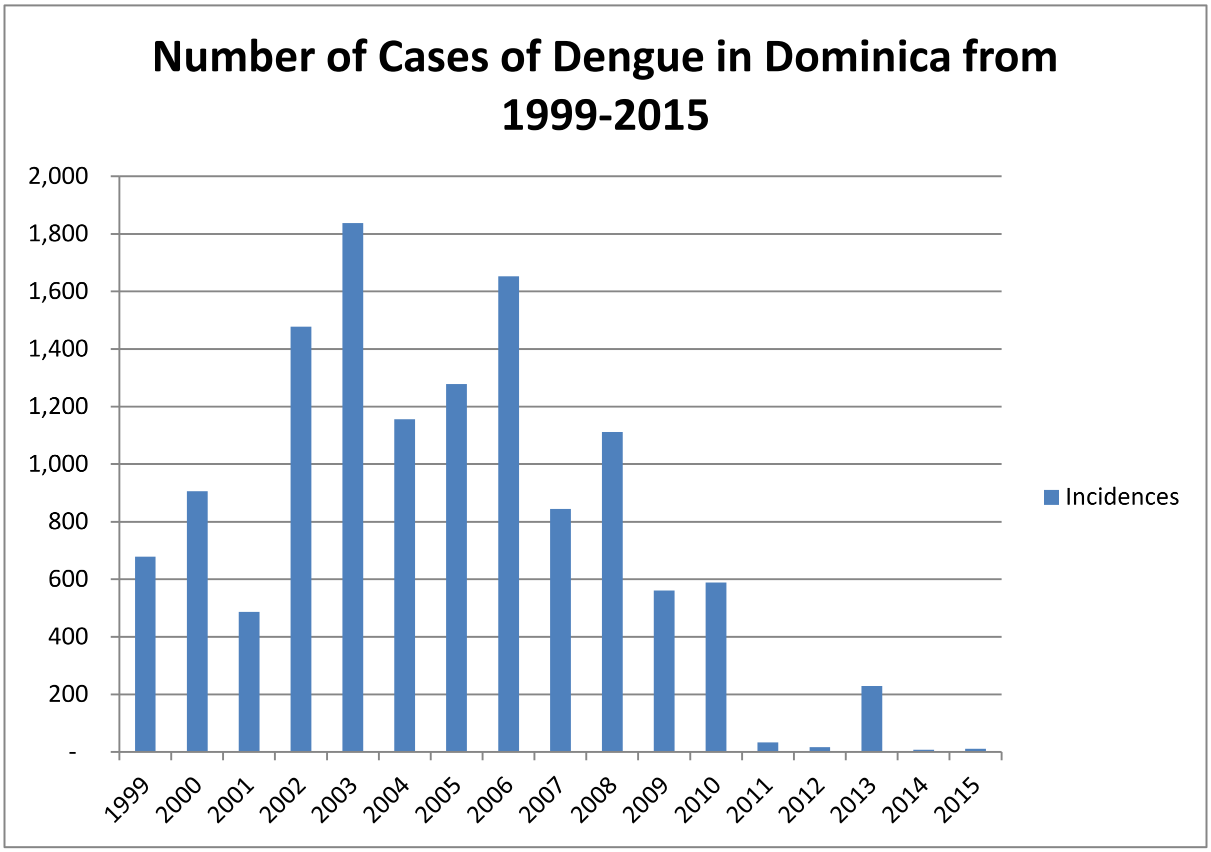
The researchers Matheus et al 2012 did glean some insight into the use of filter paper for laboratory testing in remote areas such as the island nations of the Caribbean but nothing further of relevance to this thesis. The relevance of the study appeared to be farther reaching than exploring the spatial distribution of dengue on the islands, in favour of linking travel –related transmission to visitors who are diagnosed once they return to their home country of France or the Netherlands.

The above mentioned Schioler and MacPherson 2009 research paper is a pivotal study into the increased risk of dengue virus transmission on a small island nation. The researchers uncovered a major research gap, in line with the results of this thesis's literature review, namely, research being conducted on dengue in the Caribbean is mainly confined to the larger islands, each of which hold populations greater than one million. In their research they posited that the 24 small island nations of the Caribbean (including Dominica) due to their size and population of less than 400 000 were not being researched into their unique challenges with the infectious disease.

The researchers highlight that the population base of the other 24 islands is between 10, 000 to 400, 000 (with an average population of 143, 000), while occupying no more than ten percent of the total land mass of the archipelago. Available data from the smaller islands are very limited but do indicate a general pattern of single serotype outbreaks followed by periods of low or undetected transmission in less than 200, 000.

An accurate assessment of the extent of the threat of an increased risk to dengue virus transmission and general epidemiological factors of the disease, on the smaller island nations, remains unclear due to inadequate systems of surveillance, reporting and research.

Graph 1 Dengue Cases in Dominica from 1999 - 2015



Source Department of Health – Commonwealth of Dominica

Between 1999 to 2015, the 16 year period that is the focus of this thesis, Dominica experienced over 13 000 reported cases of dengue. The pattern of disease with large spikes in number of cases of disease with irregular patterns that include 2 to 5 years of low endemicity is typical of countries endemic for dengue (Bennett et al; 2010; Murray et al 2013). There have been a number of theories posited as to why dengue follows such a pattern in endemic countries. Amarakoon et al 2006 and Johansson et al 2009 suggest it is due to climate variability; Strickman and Kittayapong 2002 have conducted research into potential vector variability; and, Adams et al 2006; Ooi et al 2006; as well as, Recker et al 2009 all have suggested in their research that the answer may lie within the immune response and subsequent interactions within serotypes of dengue. Schioler and MacPherson 2009 also noted in their research study that small islands in the Caribbean had the same pattern, "(D)ata from smaller islands are very limited but do indicate a general pattern of single serotype outbreaks followed by periods of low or undetected transmission in a population of less than 200 000," (Schioler and MacPherson 2009, page 280). To add further complexity to the issue, researchers have found evidence that may suggest that there is not a lifelong immunity after recovery from a dengue infection to a specific serotype, as previously believed. According to Waggoner et al 2016, their research in Nicaragua found patients with repeat infections within 2 years from dengue virus of the same serotype, causing a low number of cases in off years (Waggoner et al 2016). This area of dengue transmission is still under-researched, due to the complexity of the disease and disease transmission; it may be interplay of all the factors that have been hypothesized: a combination of circulating serotypes, vector presence in the community, and ecological factors (Bennet et al 2010).

2.8 The Ecological Health Model

Traditionally public health research, policy, and practice focused on environmental and societal issues separately. Public health research that explored the parameters of the social determinants of health often came to the conclusion that health inequities were a significant part of ill health which appeared to exemplify the social determinants of health as the root cause. Very little consideration was given to the physical, environmental, and ecological systems when conducting public health research (Mikkonen and Raphael 2010; Parkes 2010).

As a result, public health research was conducted through a lens which focused on the biomedical or social determinants of health model solely (Ruderman 2013). The biomedical model can inform population health indicators that public health is concerned with; however, unlike the medical model, population based models take a much extensive view of population health over a lifespan span. According to Fielding et al 2012, the ecological health model "…emphasizes the importance of the social and physical environments that strongly shape patterns of disease and injury as well as our responses to them over the entire life cycle," (Fielding et al 2012, page 175).

Research in public health that focused solely on environmental conditions that had the potential to affect human health in terms of increased morbidity or mortality was skewed heavily towards environmental health. For example, toxic chemicals or contaminants that could be present in our food, water or in the soil were at the foreground of this research. The goal of this research was to determine effective mitigation measures to reduce the impact of environmental contaminants from the soil, from water or from food (Parkes et al 2003). According to Parkes (2010), this traditionally held view overlooked the societal processes that had the potential to augment health impacts and to prompt environmental change (Parkes 2010). Greenwood and de Leeuw (2009) believed that the simplification reduced the understanding of the synergistic effect of both the environmental and social factors that can have an impact on health (Greenwood and de Leeuw 2009).

From the fields of human development and psychology is the foundation of the ecological health model, exploring in research the link between the individual and the environment in human behaviour in the 1980s (Fielding et al 2012; Ruderman 2013). Theories within public health research also began to shift at the same time, from individual-based theories such as the health belief model and the trans-theoretical model to the multi-layered ecological health model (Ruderman 2013). The individual factors, for example age, were still integral to understanding disease from a public health standpoint; however, with the ecological health model, broader social, ecological and environmental issues are part of the landscape that has the potential to affect health outcomes (Fielding et al 2012; Frieden 2010).

Public health research, policy, and practice currently aim to address the established divide between environmental and social views on health (Bircher et al 2014). This is to highlight the connection between ecosystems, equity, and health (Parkes 2010, CSDH, 2008). There has been a recognition of the combination of environmental /ecological and social determinants of health as interconnected determinants of health (Parkes 2003; Ruderman 2013) The ecological health model is what many in public health believe to be the original intent of the Ottawa Charter for health promotion a more integrative approach to public health (Fielding et al 2012; De Plaen and Kilelu 2004). This is a systemic progression from traditional concepts that places health inequities with regards to social and environmental conditions at the forefront (Fielding et al 2012; De Plaen and Kilelu 2004).

Dean et al (2013) and Watt (2002) also suggest that implementing any action on social determinants of health requires the understanding of the behavioural and environmental / ecological determinants of health. The ecological health model has evolved from health knowledge that has begun to understand the multiple interconnections that exist, and include both the social and the biophysical determinants of health and their disparities. As a result, public health researchers are beginning to revise their conceptual framework models and adjust their research methods (Arredondo and Orozco 2012; Barkin and Schlundt 2011; Bircher et al 2014). Nowhere is this more pertinent in public health research than in the study of infectious diseases. The majority of infectious diseases, especially those belonging to the neglected tropical diseases, have a component of the risk of transmission that includes social and ecological/ environmental components. As a result, public health researchers into dengue are beginning to revise their conceptual framework models and adjust their research methods (Arredondo and Orozco 2012; De Mattos 2007; Hagenlocher et al 2013; IDRC 2010).

In the past public health researchers found that studies into mitigation measures, such as integrated vector management and routine interventions against the larval stages of the mosquito, can reduce the mosquito vector and thereby reduce the transmission risk to the population but it is not an always an effective approach (Murray et al 2013). In fact, standalone interventions often have short-lived success (Hagenlocher et al 2013). This is due to the fact that the variables that influence vector breeding of the *Aedes aegypti* mosquito can be quite complex and can be due to several different factors (Aruncachalam et al 2014).   The ecological health model is essentially a systems approach to uncover vulnerabilities to disease within a population. Its fundamental premise is to be inclusive by analysing these components based on the intersection of these three elements. The benefit for research of generating interventions and health program based on the evidence under the ecological health model is to provide a more cost-effective and preventative public health intervention (Arredondo 2012; Aruncachalam et al 2014; Bircher et al 2014).

2.9 Vulnerability in Public Health

Vulnerability is the predisposition to have an adverse effect from any condition that falls outside the norm for a population. In public health policy and practice the main objective with regards to the control of infectious disease is to minimize exposure of the infective agent to an already vulnerable population (Blas and Kurup 2010; Eisenberg 2007; Hinkel 2011). A vulnerability steered approach examines the underlying social, economic, institutional, environmental, and ecological factors that determine how a population may be at an increased risk of transmission of an infectious disease (Adger 2006; Bircher and Kuruvilla 2014; Fussel 2007). Vulnerability can be assessed at many levels of the research concerned with a specific system or geographic area. In this thesis, quantitative indicators specific to the increased risk of transmission to dengue disease will be analyzed as the factors that increase vulnerability (Adger and Brooks 2004; Hinkel 2011).

Vulnerability was already a long standing theory within the climate change research community (IPCC 1998) and has emerged as a tool for assessment within the public health community, especially with regards to infectious diseases (IPCC 1998; Hagenlocher et al 2013). Vulnerability is a holistic approach that measures the sensitivity of a system to a negative occurrence and when applied to public health research into infectious diseases, using an ecological health model, the emphasis is on the important mechanisms that affect the whole system. With vector-borne diseases, such as dengue, the mechanisms that affect vulnerability of a given population is an assessment between the interaction of the host, the vector and the pathogen and how these drivers have the potential to increase the risk of transmission of the disease (Sutherst 2004). This assessment will give an indication of the impact to the system, how well it will adapt to a change or an imbalance to the norm.

Vulnerable regions in Latin America and the Caribbean are seeing an expansion of vector-borne diseases like dengue due to environmental/ecological factors such as climate change and rapid urbanization as well as a number of social factors usually related to poverty (Amarakoon 2006). The re-emergence of dengue in these regions has prompted research into efforts to reduce the burden of illness (Brathwaite et al 2010). Using vulnerability tools to determine risk is slowly becoming established within the public health research community when studying infectious diseases like dengue. The hope is that these vulnerability assessments will provide a space for exploration for cost-effective measures to combat the risk of transmission. This will help identify the factors that increase the risk of transmission to aid in proactive public health policies and practices that will decrease existing health vulnerabilities (Adger and Brooks 2004; Birkmann et al 2013; Brooks et al 2005).

Vulnerability Assessment Models

Studies on vulnerability and the risk of the incidence of dengue disease have been conducted. A number of the vulnerability assessment research studies have been based in Southeast Asia—mainly Thailand and Malaysia—and formed the basis for creating a conceptual framework specific to addressing dengue and vulnerability such as Bates et al 2004. Researchers similar to Chang et al (2009) began to look into developing combining Geographic Information System (GIS) with Google Earth to begin to map vulnerable areas to dengue in developing countries (Chang et al 2009).

In Latin America and the Caribbean researchers began to follow suit with de Mattos et al 2007 assessing vulnerability to dengue to the interconnectedness of the social and built environments. Along with Martinez et al (2003) who conducted a research study focused on mapping vulnerability in the Caribbean on the island of Cuba. These research studies provide a clear direction for mapping the incidence of disease using new technologies such as GIS and Google maps; however, the vulnerability assessment appears to be inadequate in its scope and not reproducible. In essence, vulnerability was not integrated into the conceptual framework, for example the research study conducted by Getis et al 2003.

The Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) framework appears to be a comprehensive tool that focuses on exposure susceptibility and lack of resilience. Lack of resilience was defined as lack of access to resources combined with community reaction to the proposed threat. MOVE was created to study natural hazards and adjustments to climate change. It was not intended for research into infectious diseases and was adapted by the researchers Hagenlocher et al (2013) assessing dengue in Colombia. The researchers appear to have difficulty incorporating the lack of resilience as part of the data analysis, thereby making the model extremely complex and difficult to reproduce.

Models are important to public health research in order to organize ideas, determine vulnerable areas and approaches to combat vulnerability, as well as, determine whether the methods are effective (Fielding et al 2012; Ruderman 2012). A strong ecological model in assessing vulnerability to disease is one that has a strong understanding of public health outcomes within the determinants of health (Ruderman 2013). One research study that which had incorporated a comprehensive conceptual framework on vulnerability assessment using an ecological model which included exposure, as the ecological and environmental determinants of health, and susceptibility as the social determinants of health, both to the incidence of dengue disease was the Water Associated Disease Index (WADI) (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014). The WADI had a clear concept of a vulnerability framework and a validation tool using GIS to map vulnerability. The index could be constructed from readily available public accessible data. Since its development, the WADI been tested in two research studies in countries endemic for dengue, Malaysia and Brazil (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014).

Water Associated Disease Index (WADI) and Dengue

The rising incidence of dengue disease, and the threat of the incidence of the more severe forms of the illness, poses an increased the risk of morbidity and mortality in the developing world (Guzman et al 2010; Murray et al 2013). The island of Dominica is no exception and is vulnerable to the rise of dengue cases in the Caribbean. Underreporting of the illness can largely be attributed to the misdiagnosis (Chadee 2012). This fact presents a challenge in terms of surveillance of the risk of the disease and an accurate measurement of its impact. Although protective measures can be used to decrease the burden of disease, most are costly and time consuming (Dom et al 2013). As a result, any mediating initiatives must be suitably targeted, to not only have the maximum impact, but to also be the most cost-effective (Aagnaard and Chaignant 2012; Sharp et al 2017).

Many infectious diseases are deeply entrenched in environmental / ecological conditions and are exacerbated by the social determinants of health (Jones et al 2008; Morens and Fauci 2013). Dengue disease is no different. When compared to the regions in the developed world, vulnerable regions in developing countries commonly do not have disease prevention policies and programs that can safeguard them against the threat of the disease (Aagnaard and Chaignant 2012).

This thesis makes use of the vulnerability framework incorporated in the Water Associated Disease Index (WADI). The WADI was designed by the United Nations University Institute for Water. The authors of the WADI assert, “With limited resources to treat or combat the spread of water associated disease in many endemic regions, preventive interventions must be appropriately targeted and times to maximize their efficacy” (Fullerton et al 2014, page 3). By examining the vulnerability to dengue virus and the potential for Dengue Haemorrhagic Fever and Dengue Shock Syndrome to occur subsequent to the initial infection, ecological and social determinants that allow an increased risk of transmission can be placed in the forefront of public health research (Sutherst 2004; Dom et al 2013). The WADI allows for not only calculating vulnerability to disease incidence, but also to have a visual communication tool to display the vulnerability. As a result, researchers have the ability to measure vulnerability to the incidence and spread of dengue virus in a region (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014).

Additionally, mapping vulnerability allows for bridging the gap that exists between science and policy by placing it in a visual format (Hinkel 2011). With limited public health resources allocated to fight or develop treatments for dengue, the WADI tool provides evidence to allow for targeted and timed interventions (Dickin et al 2013 ; Dickin and Schuster 2014; Fullerton et al 2014).

In this thesis, the conceptual framework of the WADI, designed as a practical tool, will be used to assess vulnerability, “at a range of different spatial and temporal scales,” (Fullerton et al. 2014, page 3). Secondary publicly available data sets will be used to demonstrate clear patterns of vulnerability of the population to the increased risk of the transmission of dengue virus on the Island of Dominica.

Chapter 3 Methodology

3.1 Methodology Overview

Dengue is considered by the World Health Organization to be the most important arborvirus globally, and they have also designated it as one of the Neglected Tropical Diseases (NTDs) (WHO 2009). It is a vector borne disease, transmitted by the Aedes aegypti mosquito, with human beings along with non-human primates, as the hosts. Dengue can wreak havoc on the public health system with periodic large scale outbreaks that increase the risk of morbidity and mortality of the affected population (WHO 2009). Therefore, there is a complex relationship between the human host and the mosquito vector which includes environment / ecological factors, as well as the social determinants of health.

Research into public health measures to combat this threat is vital, as the threat of dengue and other NTDs continue to expand into previously unaffected regions. In those regions, the most vulnerable populations will likely be the areas that experience the most negative impact (Hales et al 2002; WHO 2014; Wilder-Smith and Gubler 2008).

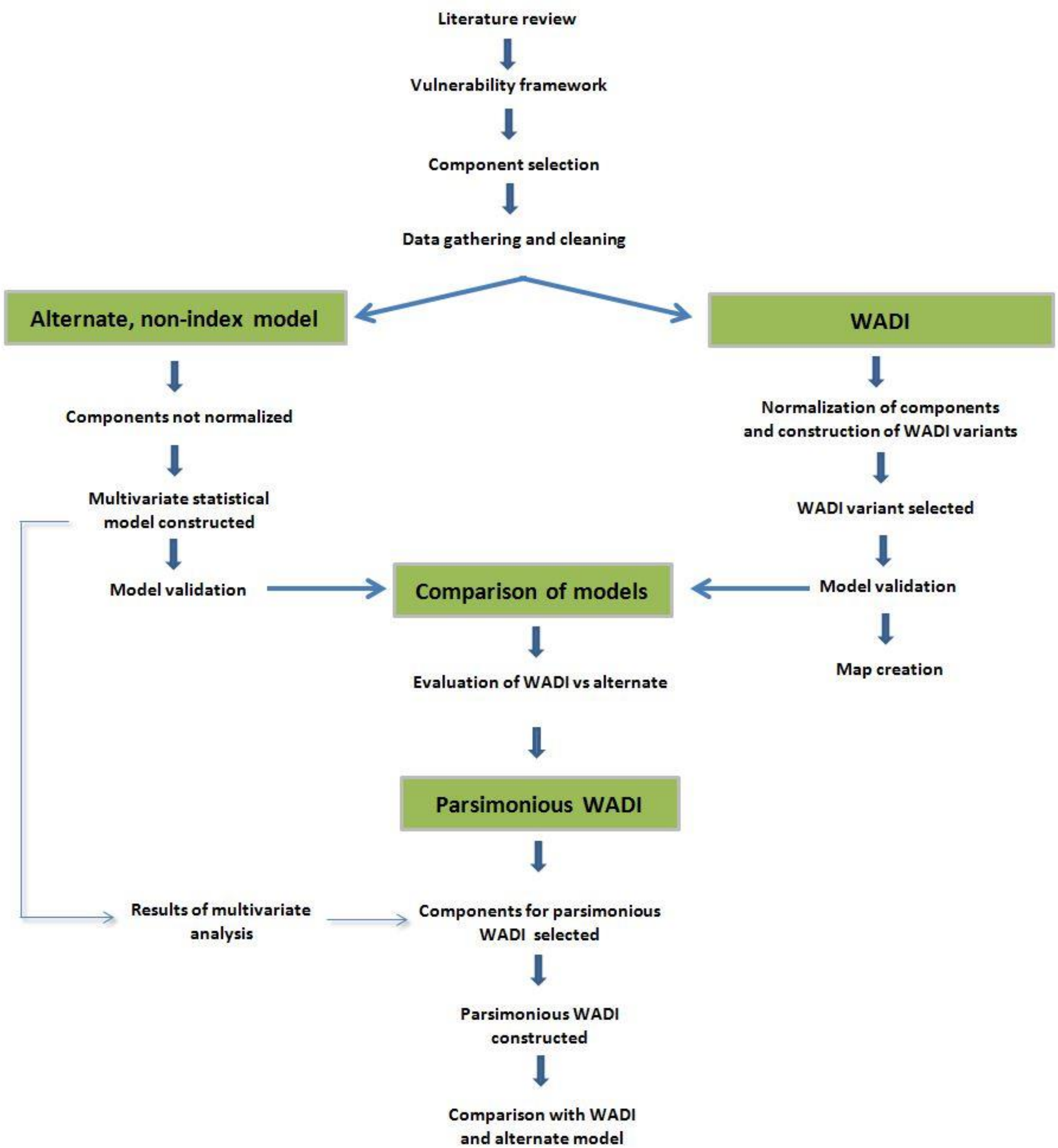
The Water Associated Disease Index (WADI) is an index model that uses an ecological health approach to assess vulnerability to an increased risk of transmission of water associated diseases, which takes into account the interdependent relationship between human beings, the infectious disease vector, as well as the environment (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014). Due to the fact dengue virus's vector, the female Aedes species of mosquito, spends the majority of its life and reproductive cycle around water, dengue is classified as a water-associated infectious disease, making WADI an appropriate framework for researching disease vulnerability, namely, an increased risk of transmission.

This thesis applies the Water Associated Disease Index (WADI) to the island nation of Dominica in order to determine its efficacy as a tool in determining geographic vulnerability to dengue. In order to test the tool, the index was constructed using publicly available secondary datasets of known exposure (environmental /ecological) and susceptibility (social) components. The secondary data sets were used as the source for creating a set of components that were combined to form index values. Geographic Information System (GIS) software, QGIS, was then used to create a map displaying the index values, coded by colour, per geographic location (per parish). The index values were regressed against incidence counts of dengue cases in Dominica, and the model was validated for goodness of fit. On the island of Dominica, the WADI was found to have a statistical association for indicating vulnerable regions to an increased risk of dengue virus transmission. An alternate, non-index model was also constructed and used for comparison and further validation. The non-index model was also determined to statistically have an association of indicating vulnerability to dengue virus transmission per parish.

This thesis was based on the positivism paradigm to both answer the research question, and also to reach the objective of the thesis. The positivism paradigm holds to the principle that only factual knowledge gained through observation, including measurement is valid. This thesis will aim to evaluate a vulnerability assessment tool. The data for this thesis will be publicly available secondary data sets. As a result, the author of this thesis`s role is restricted to finding and cleaning of the data sets, creating the index model, analysis and interpretation of the data analysis through an objective approach. Also, from the results of this thesis the author will draw conclusions and make recommendations for public health research, policy and practice.

Figure Number 4, below, is a flow chart outlining the multi-step process.

Figure Number 4 **Methodology Flow Chart**



3.2 Methodology Outline

Following the flow chart outlined in Figure Number 4, the methodology will be as follows:

- Develop a vulnerability framework based on the literature review, establishing the ecohealth model
- Select components based on publicly available data sets
- Collect and clean secondary data sets
- Create a Water Associated Disease Index (a vulnerability index) model using the selected components
- Construct and test WADI model
- Construct and test non-index model for validation of and comparison with index model
- Construct revised WADI model based on results of multivariate regression for validation and comparison
- Create vulnerability maps using GIS technology to visualize the WADI

3.3Water Associated Disease Index Model (WADI)

For this thesis the WADI was constructed as an amalgamated indicator composed of exposure and susceptibility components, where susceptibility represents the existing social determinants of health, economic or cultural conditions that render a population sensitive to a water-associated pathogen, and exposure represents conditions conducive to the presence and transmission of the pathogen within the environment (Dickin et al 2013; Fullerton et al 2014). The WADI tool examines links between humans, the vector, the virus, the environment and health by using indicators of susceptibility and exposure, each comprised of components that are identified using a combination of the social determinants of health with ecological / environmental determinants of health placed in a conceptual framework as an index model (Birkman et al 2013; Few et al 2013; Folke 2006).

The dengue virus contributes to the equation through the specificity of the strain and the virus's particular virulence factors. Human beings have an increased risk and vulnerability in urban areas with the infrastructure of their environment: housing types, education level, municipal services that are available. The mosquito vector links both humans and the dengue virus together in a confluence of events through its adaptation to living in urban environments, its ability to transmit dengue to humans, and its vertical transmission of the virus from female mosquito to her progeny (Rodriguez and Roche 2011).

According to Dickin et al (2013, "This framework applies an eco-health approach which recognizes the inextricable links between humans and their environment and the ways these influence health." (Dickin et al 2013, page 4) In fact, WADI the framework provides a frame of reference for the implication of vulnerability to dengue by highlighting explicit facets of the social and natural environment that is sensitive to an increased incidence of disease transmission. These weak spots in the social, natural and ecological environment have the potential to generate prime circumstances for disease in the areas where humans live, work and play. This occurs not only from a marked increase in the areas where the mosquito breeds but also in a heightened exposure to the mosquito vector. Highlighted in this conceptual framework are the environmental conditions such as land use, rainfall and temperature, and the social conditions such as educational level, age of the person infected and socio-economic status. The components of this conceptual framework attempt to explore vulnerability and have been explained by its creators as follows: "While by no means comprehensive, this framework identifies the key components that can be used to populate the WADI-Dengue," (Dickin et al 2013, page 3). Additionally, the creators assert while all the exposure/environmental components are crucial to populating the index model, data selection of the susceptibility/social components should be based on the quality and availability of the data sets. The list is a guideline of the potential components of the social/susceptibility factors. There is also room to manoeuver within the indicator components, based on what the researchers describe as the ideal indicator and the actual indicator. The ideal indicator is the data sets which will capture the vulnerability component but may be difficult to quantify. The actual indicator is a proxy which will serve as a measure closest to the ideal indicator. The two research studies that tested the WADI did not incorporate the ideal indicator with the researchers opting for the actual indicator. They were also unable to incorporate all of the suggested susceptibility components. The inclusion of the components was based on availability and quality of the data (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014). The inclusion of data in this thesis was also determined by available data sets. Data sets for the ecological / environmental component of the index were available as public information; the social data sets components were also publicly available information.

Table Number 1 - The WADI Process

The process for the WADI is described in four steps:
1) Evidence assessment of the conceptual framework
2) Data assessment and collection of freely available public data
3) Development of the construction of the vulnerability index which combines the susceptibility and the exposure factors
4) Creation of the vulnerability index in the visual format of a map

An index value indicating vulnerability was created for a geographical location for each of the ten parishes in Dominica by the combination of an exposure component value and a susceptibility component value. The WADI framework is comprised of these two main components, with each comprising four components. The first are the exposure components of climate (temperature and precipitation), land use and population density. The second are the susceptibility components which include the social determinants of health age, socioeconomic status, quality of potable water, and level of education among females in a population (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014). Jointly, the exposure and the susceptibility components make up the vulnerability index. The vulnerability index can be plotted on a map using GIS, giving a visual rendering which uncovers the areas within a country or region that are vulnerable to an increased risk of dengue virus transmission(Fullerton et al 2014). In this thesis the parishes within Dominica that are vulnerable to an increased risk of dengue virus transmission were plotted on the map.

Figure Number 5 - The Vulnerability Index

Environmental/Exposure Components			
Temperature	Precipitation	Land use	Population Density

+

Susceptibility/Social Components			
Age <15 and >60	Water and Sanitation	Female Progression to Secondary School	Poverty

=

Vulnerability Index

3.4 Limitations of the WADI Model

Model criticism is central to public health research involving statistical analysis, and particularly in infectious disease research, as the models usually involve a multiplicity of datasets that are used to inform the model (De Angelis 2015). The WADI model is based on an index model framework that is not without its faults.

The first critique is centered on how the methodology specifies the data should be weighted (De Angelis 2015). It is a common criticism of index models that weighting is often arbitrary (Qin et al 2017). The WADI methodology specifies combining the components of susceptibility and those of exposure with equal weighting. This choice is entirely arbitrary and therefore open to the criticism that alternate weightings based on the nature of the data could be better (De Angelis 2015). However, the methodology does allow for some broad adjustments to weighting, between the susceptibility and exposure components, and this procedure has been followed in this thesis as well.

There is a related issue regarding the disparate nature of the data sources. Commonly, and in the case of this particular index model, a multiplicity of datasets is used to inform the model. The various sources of datasets will inevitably be of different quality and a natural question is how to account for this diversity in the model (Ypma 2012; Dorigatti 2012). It might be possible to assign a quality ranking to each data source to either increase or decrease its influence in the model, for example, reducing its weight if its quality is considered to be poor. However, this would raise the issue of how to accurately determine the quality/reliability of each data source and how to normalize quality measurement across very different data sources (De Angelis 2015; Ypma 2012; Dorigatti 2012).

Another associated issue with weighting is that correlations among the components of exposure and susceptibility or even between components across the two measures are not accounted for. The creation and analysis of an alternative model developed in this thesis corrects for both of these issues, and will be discussed further in both this section and the Results chapter of the thesis.

3.5 The Vulnerability Components

The exposure component value is derived from a combination of subcomponents: temperature and precipitation (which are the climate components), land use and population density. All social and environmental component values are assigned a score in the range of 0 to 1, as per the WADI framework, and the values are weighted such that the resultant index value is also between zero and one (Dickin et al 2013; Fullerton et al 2014).

Table Number 2 - Vulnerability Components – Environmental Determinants of Health

Category	WADI Indicator	Ideal Indicator	Actual Indicator
Climate	1.Temperature	Temperature	Maximum Temperature
	2.Precipitation	Precipitation	Maximum Rainfall
Land Environment	Type of Land Use	Distribution of urban land use	Distribution of urban land use
Human Environment	Population Density	Population Density	Population per square kilometer

Table Number 3 - Environmental / Ecological Determinants of Health Data Sets – Exposure Components

Vulnerability Factor	Indicator Gauge	Underlying Principle for Inclusion	Data Source
Temperature	Maximum Temperature by Month	A high temperature range is necessary for the mosquito vector to complete its lifecycle.	WorldClim Data http://www.worldclim.org/
Precipitation	Average Precipitation by Month	The mosquito completes part of its life cycle in water; water is used as a breeding site.	WorldClim Data http://www.worldclim.org/
Land Use	Percentage of Urban Land Use	The mosquito vector has adapted to live in human environments, principally the areas of land use designated as urban and peri-urban areas.	Google Earth
Population Density	Population Density (Amount of population per square kilometer)	The rate of transmission of dengue virus increases with the amount of human beings residing in a densely populated area.	CARICOM Commonwealth of Dominica Census

3.6 Environmental/Exposure Components

All index components were assigned a value between zero and one, to a determined low (zero) to high (one) value, according to the WADI methodology. For the exposure components, thresholds based on general dengue thresholds identified in the WADI conceptual framework were used, except for the land-use value, for which the percent of land urbanized was normalized using the Human Development Index approach. This approach is also as outlined in the WADI conceptual framework. The strength of the WADI is that it uses publicly maintained and available data sets that are global in scope. Therefore, if the developing country is unable to generate or maintain this data set, there are global organizations that do so. As a result, in data poor regions such as the Caribbean, the data sets needed for the exposure components, temperature, precipitation, land use and population density are, if not as rich as those in other regions, still publicly accessible. Dominica is divided into 10 parishes and exposure values are determined by parish for the purposes of analysis as the data for incidence of dengue is at the parish-level.

Environmental / Exposure Component - Population Density

According to the literature review for this thesis, it is widely accepted in public health that there is a strong association between an increased population density and an increased rate of the incidence of dengue disease. Exposure to dengue is higher in extremely populated areas. The main hosts for the virus are human beings; as a result, highly dense human habitats increase the risk of transmission of the virus (Braga et al 2010; De Mattos et al 2007).

The density of human habitation is important, as mosquitoes require human beings (and in some cases, animals) as their host for a blood meal. The mosquito has effectively adapted to be able to sense the presence of its host from their expiration of carbon dioxide and the emanation of body heat. Mosquitoes have the ability to locate their hosts' position in space. A mosquito can then identify the most optimal surface on its host's body, preferably one that is rich in its distribution of capillary beds, from detecting the minute variations in the host body's surface temperature Rodriguez and Roche 2013).

The population per parish was divided by the square kilometre per parish to calculate the population density for each of the parishes. A value between zero and one was assigned for each parish based on thresholds in the WADI framework. With increased population density in regions of Dominica, the WADI value assessing vulnerability also increases.

Table 4 - Population Density

Exposure	Dimension	Value
Population Density thousand people per square kilometre	<0.1	0
	≥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

To organize the sets of data for index construction, each of the values in the dataset of the environmental components were designated a score between 0 and 1, representing a high or low value of exposure.

Environmental/Exposure Component - Land Use - Percentage of Urbanization

As it is an extremely mountainous island, with some of the highest peaks in the Caribbean, Dominica's urban areas are concentrated along the flatter, more habitable coastline. There are planned urban areas but also a significant amount of unplanned urban areas in the main city of Roseau. In order to determine values for the land-use/percent urbanized component, satellite imagery from Google Earth was imported into GIS software, and GIS tools were used to calculate the total square kilometre of urbanized land use in each of the 10 parishes. To normalize the data, the Human Development Index technique $(x-x_{min}) / (x_{max} - x_{min})$, as prescribed by the WADI framework, was used. This approach normalized the urbanized land use data to a value of 0 to 1.

Table 5 - Urbanized Land Use

Exposure	Dimension	Value
Urbanized Land Use	Percent Urbanized Area	$(x-x_{min}) / (x_{max} - x_{min})$

Environmental / Exposure Component -Temperature

Temperature has a significant effect on the life of the Aedes mosquito thereby having a similar effect on the rate of dengue transmission (Chen and Hsieh 2012). In other words, if the temperature supports the propagation of a number of mosquitos, the number of carriers of the disease from human to human has also increased (Jury 2008). The optimal temperature range for the mosquito is 20˚ C to 34˚ C. In temperatures that register below 20˚ C the Aedes species of mosquito is not able to reproduce and will not survive (Chen and Hsieh 2012; Depradine and Lovell 2004). The rate of breeding also substantially decreases in temperatures that register above 34˚ C (Focks et al 2000; WHO 2009).

Warm temperature will ensure that any accessible water pooling outside will also be warm which will facilitate the mosquito's life cycle transitioning from the egg stage to the adult stage quite rapidly (Arcari 2007; Chadee et al 2007). Warm air determines the length of the mosquito's life span; the longer a mosquito survives in its adult phase the more time it has to increase the amount of blood meals it consumes, and subsequently lay and develop its eggs in warm water (Chadee et al 2007; Chen and Hsieh 2012).

According to the literature, this higher temperature range is associated with a longer lifespan for the mosquito vector, increased travel range, increased number of biting incidents, and it has a positive impact on virus and mosquito survival rates. (Chadee et al 2007; Chen and Hsieh 2012;

Dickin et al 2013; Jury 2008; Wu et al, 2007)   As a result, there is a definitive linear pattern of an increased rate of dengue transmission with increased temperature. Due to the nature of the development of the virus in the vector and the rate of survival of the vector during the optimal temperature range, the recommendation is to have the temperature value as an exposure indicator lagged by two months (Dickin et al 2013; Gomes et al 2009). The temperature range for Dominica was consistently within the optimal range for each month's maximum value; therefore, lagging the temperature range by two months did not change the value of the data (WordClim).

The temperature component value was assigned according to the thresholds described in the WADI framework, as in the table below. Monthly maximum temperature and monthly cumulative data sets of precipitation were accessed from WorldClim which obtains world climate data from databases networks. These networks include organizations such as Global Historical Climatology Network (worldclim.org).   The datasets consist of a weather station-produced monthly climate data set, which creates climate grids with a spatial resolution of 1km^2 (worldclim.org). As explained in the previous section, WorldClim mines data on precipitation from databases networks. The temperature component value was assigned according to the thresholds described in the WADI framework, as in the table below.

Table 6 - Temperature

Exposure	**Dimension**	**Value**
Temperature (maximum monthly temperature)	≤20˚ C	0
	>20˚ C to ≤34˚ C	1
	> 34˚ C	0

<u>Environmental/ Exposure Component -Precipitation</u>

Similar to the range of optimal temperature, the rate of precipitation plays a pivotal role in the rate of dengue transmission. The optimal range of precipitation is between 75mm to 300 mm. Also similar is the linear association between increased rainfall and increased rate of the incidence of dengue due to the increased availability of water-based reproduction sites. As previously mentioned, water is necessary to the Aedes mosquito's lifecycle (Fullerton et al 2014). However, it is not rainfall alone that factors into an increased reproduction rate. Increased rainfall also increases the level of humidity in the air which augments the level of fertility of the mosquito vector (Caprara et al 2009). Extreme rainfall events in which the levels are above 300 mm can act as a detriment by overflowing breeding sites and destroying any mosquito larvae. In fact, there has been a direct association between the impact of rainfall events greater than 300 mm and a decreased risk of the rate of transmission of dengue (Dickin and Schuster 2014).

The precipitation component value was assigned according to the thresholds described in the WADI framework, as in the table below.

Table Number 7 - Precipitation

Exposure	**Dimension**	**Value**
Precipitation (cumulative monthly rainfall)	<75mm	0
	$\geq$ 75 mm to $\leq$300 mm	1
	> 300 mm	0

Table Number 8 - Thresholds Used to Create the Environmental / Ecological Indicator Component Values

Exposure indicator component	Dimension	Exposure value
Population density (thousand persons / sq.km)	<0.10	0
	≥ 0.10 - < 0.25	0.25
	≥ 0.25 - < 0.5	0.5
	≥ 0.5 - < 1.0	0.75
	≥ 1.0	1
Land cover component	Urban	1
	Agricultural/plantation	0.50
	Mixed vegetated/agricultural	0.25
	Forest	0
Temperature	Maximum monthly temperature, lag of 2 months	>20^{o}C and ≤34 ^{o}C : linear increase in exposure up to 1; ≤20 ^{o}C or >34 ^{o}C : 0 exposure
Precipitation	Monthly cumulative precipitation, lag of 2 months	<300mm precipitation: linear increase in exposure up to 1; >300mm monthly precipitation: 0 exposure

Climate Data and Spatial Resolution

The data used to build the components of the WADI was not all available at the same spatial resolutions, leading to some challenges and compromises. The data for the social/susceptibility components are not available for a smaller geographic unit (higher spatial resolution) than the parish level, the ten (10) local regions the island of Dominica is divided into as they were sourced from census data, which is at the parish or country level. The incidence count data was also at the parish level. The data for the environmental/ecological components temperature and precipitation, on the other hand, were sourced from the WorldClim data sets and were available at the 1 km^2 spatial resolution. In order to perform the regression analysis all the variables had to be at the same spatial resolution. Therefore a value is needed for each parish for the climate variables. This parish-level value was derived by taking an average of the values in that parish.

As noted, the climate data, sourced from WorldClim was at the 1km2 spatial resolution. A value for each parish was needed, and was derived by taking an average of the values in that parish. This value was calculated using the zonal statistics plugin in QGIS. This plugin allows for calculating values across pixels of a raster layer that fall within a shape defined contained within the boundaries of a polygon (QGIS 2016). This feature manages the issue of pixels that are intersected by the boundary of the parish by calculating a proportional mean of the underlying pixel area (QGIS 2016). A shape file from the GADM spatial database of administrative boundaries was used here as it provided a polygon per parish in Dominica (GADM 2015).

Although it was necessary to transform the climate data to the parish level resolution, it must be noted that this is a crude transformation which may involve the loss of information. Small geographic areas with small populations present these kinds of challenges to analysis. However, if data were available at the square kilometre resolution for all of the components there would be another challenge in that incidence counts per square kilometer would be much less meaningful given the number of people in each square kilometre as they would be in, for example a densely populated city.

Fortunately, when constructing the WADI maps it was possible to use the climate data at their original finer resolution as there was no need to match the resolution of other data sets. For any given square kilometre within a parish the parish-level data is the same, but the climate values are specific to that square kilometer and the computed WADI value can be allowed to vary with the climate variable variation. This allowed for building maps at the highest resolution available of the factors, which was the square kilometer resolution of the WorldClim dataset.

3.7 Social/ Susceptibility Components

The factors used for the susceptibility components of WADI for dengue included poverty, female progression to secondary school, unimproved water source and age, as listed in Table 11. The list of the components of the social determinants of health provided by WADI is a guideline (Fullerton et al 2014). During their research into WADI in Malaysia and Brazil, researchers did not employ all components listed as a potential for populating the index model. On average, 4 to 5 of the components were utilized based on the datasets which were publicly available and accurate (Dickin and Schuster 2014; Dickin et al 2013). The island of Dominica is no different with the lack of available comprehensive data; however, relevant and up to date data sets for 4 of the most important social determinants of health were captured in their census data.

The components for the susceptibility / social determinants of health (household education level; unimproved water source, age and poverty level) component scores were created by normalization of the data, to a value between 0 and 1, using the Human Development Index approach as outlined in the WADI conceptual framework. To prepare the sets of data for index construction, each of the values in the dataset which represented the susceptibility components were designated a score between 0 and 1. The range from 0 to 1 represented an assigned high or low value of susceptibility.

Table Number 9 - Vulnerability Components – Social Determinants of Health

Category	WADI Indicator	Ideal Indicator	Actual Indicator
Individual	Age	Population <15 and >60	Population <15 and >60
Community	1.Water Access	Access to affordable, reliable drinking water	Unimproved drinking water source.
	2.Household Dengue Control	Female knowledge of dengue prevention	Female progression to secondary school
	3.Socio-economic status	Poverty rate	Poverty rate

Table Number 10 Social Determinants of Health Data Sets – Susceptibility Components

Vulnerability Factor	Indicator Gauge	Underlying Principle for Inclusion	Data Source
Age	Age (children less than 15 years and adults greater than 60 years)	Both age groups, children and seniors, have a greater susceptibility to dengue infection.	CARICOM Commonwealth of Dominica Census
Poverty	Socio-Economic Status	Dengue, similar to other NTDs, is known as a disease of poverty.	CARICOM Commonwealth of Dominica Census
Education	Percentage of Female Attendance in Secondary School	Level of education is strongly believed to be associated with uptake of public health promotional materials.	CARICOM Commonwealth of Dominica Census
Water / Sanitation	Unimproved Water Source	With no state run water piped into a residence, residents are more likely to store water in containers around their home.	CARICOM Commonwealth of Dominica Census

Social /Susceptibility Component - Household Education - Female Progression to Secondary School

The Human Development Index associates low education levels, especially in females, with an increased susceptibility to infectious disease. In terms of health promotional materials, it has been posited that uptake of the crucial prescriptive information is lacking in a household when the head female occupant has a low education level (Hinkel 2011; Pena 2000; United Nations, 2013)

These public health promotional materials contain specific guidelines and precautions necessary to reduce the risk of transmission of the dengue virus from the mosquito bite. There may also be information on the aetiology of the disease, as well as common symptoms with instructions about when to visit a physician. Research posits that adapting from regular routine to an amended one with a multiple number of new concepts requires a level of understanding that has not been demonstrated among those who do not progress from primary to secondary school (Hinkel 2011; Pena 2000; United Nations, 2013).

Social / Susceptibility Component - Socio-Economic Status – Poverty level

From the extensive work completed on the Neglected Tropical Diseases (NTDs), of which dengue is one, poverty is listed as playing a pivotal role to the increased rate in transmission in countries of the developing world (Hurlimann 2011). Specifically in terms of the spread of dengue, poverty in the developing countries such as Dominica increases risk of transmission by of creating an environment that is perfect for increased mosquito breeding sites. Expanding slums and squatter settlements in urban and peri-urban areas are typically densely populated spaces, lacking structure resulting poor quality housing. Poverty in the developing world can also be an indicator for lack of effective state run services or lack of infrastructure (Braga 2010; Hurlimann 2011; Johansson et al 2009; WHO 2012).

<u>Social / Susceptibility Component - Age (<15 and >60 years of age)</u>

Every human being is susceptible to the risk of dengue transmission. Human beings are the main known carriers of the disease. According to Egger 2007, "these findings provide strong empirical evidence that age is an important factor in determining risk for disease severity after primary dengue virus infection" (page 925). Children have always been associated with an increased risk of becoming being bitten by a mosquito from their school and play activities outdoors, especially in the morning when the Aedes species of mosquitoes are most active. Due to the fact that their circulatory system is underdeveloped and has fragile capillaries, children thereby are also at an increased of developing the advanced stages of dengue, dengue haemorrhagic fever and dengue shock syndrome. According to the WHO an estimated 500 000 patients, 90% of them below the age of 15, are hospitalized with DHF / DSS every year. Children are more than likely to be hospitalized. These facts explain the inclusion of those who are under the age of 15 as an indicator for susceptibility (Egger 2007; Valdez et al 2002). However, there is also an increased risk among the senior members of the population who may have an underlying condition (such as diabetes milletus and hypertension) associated with advanced age. Hospitalization and rates of morbidity and mortality for the more severe forms of dengue infection were seen to be high among not only those below 15 with also an increased for those whose age was greater than 60 years (Guzman et al 2002; Lee et al 2006; Malavige 2006; Valdez et al 2002).

Social / Susceptibility Component -Unimproved Water Source

Water use for drinking and other household activities is a significant element of the susceptibility indicators. Dengue is considered a water-associated disease due to the female mosquito's link to water throughout its lifecycle (Tran et al 2010). When there is no water piped into the domestic dwelling, residents will resort to collecting and storing rainwater in multiple synthetic and plastic containers outside of the home (Caprara et al 2009; Tran et al 2010). The Aedes species of mosquito has adapted their life cycle from the sylvan stage of breeding in tree holes to breed in these containers. As a result, an unimproved water source with no piped water into the housing unit for drinking or sanitation (including bathing and toilets) could provide an increased risk by increasing the number of breeding sites for the mosquito vector (Bunch et al 2011; Pruss-Ustun et al 2008;Tran et al 2010) .

Table Number 11 - Thresholds Used to Create the Social / Susceptibility Indicator Component Values

Exposure indicator component	Dimension	Exposure value (Normalized from 0 to 1 using HDI)
Female Progression to Secondary School	% females not moving on from primary to secondary school per parish	Between 0 to 1
Socio-Economic Status	% of households living below the poverty line per parish	Between 0 to 1
Age < 15 years old and >60	% population per parish that were aged at<15 and > 60	Between 0 to 1
Unimproved Water Source	% households with no water source piped into their home per parish	Between 0 to 1

Table 12 - Final Components of the WADI for Dengue on the Island of Dominica

Indicator	Component	WADI Dengue Factor	Source of the Data
Environmental/ Exposure	Climate	Precipitation	WorldClim
	Climate	Temperature	WorldClim
	Land Environment	Population Density	Dominican Census
	Human Environment	Urbanized Areas	LandCover QGIS
Social/ Susceptibility	Individual	Age <15 and > 60	Dominican Census
	Community	Female Education	Dominican Census
	Community	Access to Potable Water	Dominican Census
	Community	Socio-Economic Status	Dominican Census

Dengue Cases in Dominica

The up-to-date and accurate rates of dengue disease are publicly available on the Pan American Health Organization (PAHO), as well as the Caribbean Public Health Agency (CARPHA). The total number of confirmed dengue cases per year from 1999 to 2015 was accessed on their websites (see number of cases in the table 14, below). However, as a geographic component is necessary to complete the WADI through a GIS, the location and epidemiological week of occurrence of the cases of dengue was confirmed by the Health Department in Dominica by parish in detailed Excel spreadsheets. Datasets of the incidence cases were received from Dominican Public Health authorities, in the form of lists of individual dengue cases along with the place, year, epidemiological week (no identifying information). For example, if a year had an incidence rate of dengue cases of 145 nationwide, the Health Department in Dominica provided the details of the month and the parish attributed to each case. The data included over 2000 data points attributed to a city or region within a parish. Each data point has an incidence count per month, per year with a corresponding WADI value. Every place had to be searched via maps on the internet for the associated parish. Datasets corresponding to the location of each case required extensive cleaning. There were a number of cities, regions and general areas that were given colloquial names which were searched on local websites and local newspapers on line.

The epidemiological week listed in the data sets was converted to calendar month of the related year. With that level of detail, the incidence of disease cases was added to the map of vulnerability, as points on the map for comparison to non-vulnerable areas, per year, per parish, per month. When the incidence location was given as a location other than a parish, the appropriate parish was mapped according to the city/town/village of each case as the analysis would be by month and by parish due to the fact much of the data for the components is at the parish level, due to the fact it gives a reasonable level of granularity, and also it is not possible to determine a more precise location for an incidence report when only the parish is given. The incidence of dengue cases per parish data in Dominica will be used to determine if there is a significant association between identified by the WADI as being vulnerable areas of risk and incidence counts of dengue cases, using GIS technology.

The city/town/village/hospital was linked to the correct parish as required to build a geospatial database of place and the parishes they belong to in Excel. The geospatial databases and geographical lists of places in Dominica were built from various open source GIS tools. The place/ parish mapping was created and imported into Excel and finally, a lookup table was constructed to connect place to parish for all dengue cases.

3.8 Construction of GIS maps for the WADI

Geographic Information System (GIS) mapping was used to demonstrate differences in disease prevalence and distribution in the ten parishes of Dominica which is endemic for dengue virus. The goal was to correlate environmental and social risk factors with infectious disease rates; estimate current disease burden based on infection rates and disease outbreaks; and produce a visual map of disease hot spots (Lau 2010; Yang et al 2012).

Once the values for the social and exposure components were been calculated to determine the vulnerability index values, a GIS map was created to provide a visual representation of the parishes on the island of Dominica that are vulnerable to an increased transmission risk for the dengue virus.

All component values of the index were conformed to values between zero and one. These values were calculated either through the application of the threshold rules, or by unity-based normalization through the Human Development Index approach. In each of the component values, a value of zero represents lowest vulnerability, and a value of one represents the highest vulnerability.

The exposure components were weighted and totalled up to produce an exposure value between zero and one, and the susceptibility components were weighted and totalled up to produce a susceptibility value between zero and one. For the final step, the susceptibility and exposure components are weighted and totalled up to produce the WADI index value, also to range between zero and one.

Following the original WADI paper, three weightings of exposure to susceptibility were tried:

1) 0.25 exposure/environmental components and 0.75 susceptibility/social components

2) 0.50 exposure/environmental components and 0.50 susceptibility/social components

3) 0.75 exposure/ environmental components and 0.25 susceptibility/ social components

3.9 Validation of the Water Associated Disease Index (WADI)

All data sets were saved as *csv files* and loaded into *Stata* for the analysis. A Water Associated Disease Index was constructed. The component values were calculated from the raw data value within Microsoft Excel – for example, the application of the HDI methodology to raw values to normalize them was done in Excel, and calculation of population density was performed in Excel.

Excel was then used to generate csv (comma separated value) files that were analysed using the statistical software, Stata. These files were in the format of: year, month, Parish, Incidence Count, Actual Population (for offset of population differences), WADI value.
Since the nature of the dependent variable in the analysis is count data (number of incidences) a variant of a Poisson model was used as it is the standard practice for count data (Cameron and Trivedi 2013).

The WADI was constructed in the original manner of Fullerton et al (2014) and Dickin et al 2013, with the exposure and the susceptibility components combined and weighted to make the vulnerability index. Following the methodology as listed in Fullerton et al (2014), three different weightings of exposure to susceptibility were tested by a regression analysis. The weightings of environmental components (exposure) and social components (susceptibility) that produced the best fit to the data were chosen for constructing the WADI. The three weighted versions of the WADI were 25/75, 50/50, 75/25. The best of these was the WADI 50/50; however, the results for all three of the versions were used for further comparison.

A parsimonious multivariate model was also created and its regression results were compared to those of the WADI to determine whether predictive power was lost by transforming the inputs into an index according to the methodology of the WADI (deciding a priori to normalize and weight elements within a component evenly) versus a traditional multivariate regression model.

As an extension/innovation to the WADI, a new version was constructed using the findings of the multivariate regression. Components whose raw inputs were found to be not significant were not included in this new WADI.

Log likelihood, Akaike information criterion (AIC) and Bayesian information criterion (BIC) values were used to compare goodness of fit among the models (Fullerton et al 2013; Dickin et al 2013). Fullerton et al (2013) employed OLS regression for their analysis. However, negative binomial regression was used in this thesis due to the fact that the literature supports that it is more appropriate for regression analysis of count data (Cameron and Trivedi 2013).

The source data were at varying resolutions, ranging from per-square-km for climate data from WorldClim, to values that are at the parish level, such as those derived from the Census data source. The regressions were performed with index values at the parish level to in order to match the incidence data, which was also aggregated to the parish level. Index values were computed using the software Microsoft Excel.

The WADI was validated by measuring its goodness of fit and by comparing it to an alternate, non-index / alternative model constructed via multivariate regression of the same components that were used to build the index.

The WADI also allows for constructing a vulnerability map where pixel colours indicate WADI values geographically. A raster layer of index values was created for each month of the year, showing the vulnerability geographically on a map. Further processing of the selected index formulation was completed in the geographic information system software, QGIS. The completed raster layers represent a map of the vulnerability as an image, with each pixel representing a WADI value between 0 and 1, representing the range from low to high social components (susceptibility) or environmental components (exposure) values. The map will facilitate in allowing public health practitioners to visualize dengue vulnerability on the map of Dominica.

3.10 Ethics

This thesis used only secondary, publicly available data for the data analysis. Even though participants were not directly recruited, each of the over 13,000 cases of dengue from 1999-2015 is linked to a person living in Dominica. Ethical practice in research requires consideration of benefits and harms when conducting research to ensure that no harm is done to the participants. In this case an ethical concern could be raised in terms of identifiers that would have the potential to link a person to the incidence case. There are a number of debates concerning which pieces of information represent identifying data (AGENS 2008; Law 2005). The most apparent identifiers are name and address; however, occupation, religious affiliation or ethnicity can also be distinct identifiers in certain communities.

The type of secondary data set that causes the most concern with regards to ethical situations is the data set that is collected with regards to an interaction with or intervention on the human subject (CPHS 2014). Ethical concerns regarding secondary use of this data set can include the potential harm to the individual people of the original research study in not having informed consent, especially among vulnerable populations (AGENS 2008; Tripathy 2013). The consent of the individual must be particular to a specific researcher as well as for a specific purpose. The idea of informed consent can get quite complicated as the researcher cannot plan which research project may request their dataset, and thereby will not be able to inform the individuals about possible future uses for the data that was collected originally (CPHS 2014; Law 2005).

Dengue is a reportable disease in Dominica and the data is collected by the state, as well as by the international agencies such as PAHO and CARPHA for surveillance purposes in public health research, this thesis does not represent a deviation from its original intended use. Public data sets for this thesis such as dengue cases per year, per parish from PAHO, CARPHA and the Health Department of Dominica were prepared with the assertion that the data set would be made available to the public and, as a result, are not independently identifiable and their analysis would not engage human subjects directly. As the data set was also without any identifying information such as name, age or address, or even identifiers which fall in the grey area, such as religious affiliation or ethnicity. Therefore, risk to the direct identification of any individual dengue case was minimal and not an ethical issue for this thesis.

The data sets regarding the social determinants of health such as socio-economic status, progression to secondary school, as well as age were all part of the Dominican census data. This data was presented as publicly available data sets in aggregate form with no direct link or identifier to an individual person within each parish. As a result, the secondary data sets that was be accessed for the purpose of this thesis presents a minimal risk to the human population they were derived from and do not constitute an ethical issue (AGENS 2008; CPHS 2014; Law 2005). Using a quantitative research method, Geographic Information Systems (GIS) was used to combine multiple data sources to develop and create a visual representation of vulnerability, as outlined in the Water Associated Disease Index (WADI) framework. Using GIS has its own set of ethical issues, as GIS, "…allows for closer identification of geographic data through the availability of differing degrees of granularity," (Trainor and Dougherty, 2000, page 135). The ability to triangulate or to combine the data is what constitutes the possible ethical issue, thereby allowing precise identification of individuals even if standard identifying information had been removed from the data set. A methodology that would allow the researcher to triangulate identity via information procured from GIS has been outlined (Trainor and Dougherty 2000; Law 2005). As there are no identifiers attached to each incidence case of dengue, it was not possible to triangulate or combine the data to determine a specific identity within the data set using GIS technology.

This research project was approved by the Research Ethics Committee at Lancaster University in June 2016.

Chapter 4 Results

4.1 Results Introduction

This chapter will begin by briefly reviewing some key points on dengue and the methodology regarding the construction of the Water Associated Disease Index (WADI). Integrated approaches are required in order to be able to reduce vector or pathogen exposure so as to decrease human susceptibility to disease. The aim of this thesis was to test the WADI tool, an evidence-based approach to highlighting areas of vulnerability to dengue disease.

The WADI has been proven to be an effective tool in determining vulnerable areas in large populous, heterogeneous countries endemic for dengue (Dickin et al; Schuster and Wallace; Fullerton et al 2014). The aim of this thesis was to determine if that same level of effectiveness could be demonstrated in a less populous, less heterogeneous dengue endemic region by constructing and validating it for the island of Dominica. These smaller island nations which are also dengue endemic regions have been largely ignored by researchers. The results of the WADI model validation through regression, comparison to a non-index model and then revised using results from the non-index model, indicate that the Water Associated Disease index model may also be a useful tool for less populous and less heterogeneous regions, such as the 24 island nations in the dengue endemic region of Latin America and the Caribbean.

The results show the importance of the ecological and environmental factors in conjunction with the social factors to the increased risk of transmission of the dengue virus, and that the WADI can be used to highlight vulnerable areas to that risk in an endemic area. By using Geographic Information Systems software the WADI value can provide a visual representation of the vulnerable areas in an endemic region Dominica by creating colour coded maps of the area.

Following will be an exploration of the data set in terms of incidence counts and the components generated from the indicator data. The results of the model validation through regression and comparison to the non-index model and the revised WADI model will be reported in detail and the findings outlined.

4.2 Discussion of Results

Dengue is an infectious disease caused by the dengue virus. Dengue is classified as a vector-borne disease, meaning that its transmission is facilitated by a vector, in this case the Aedes aegypti mosquito. As the Aedes aegypti mosquito spends the majority of its lifecycle dependent on water, dengue is also considered to be a water-associated infectious disease. Despite the fact that there is increasing knowledge of the links between vector-borne water-associated infectious diseases and the social, environmental and ecological determinants of health, there are still gaps in the understanding of the intricacy of these systems and their relationship to a population's vulnerability to disease transmission (WHO 2009). According to Schioler and MacPherson 2009, there is also a gap in research in the regions being studied with the majority of dengue research taking place in large populous regions, ignoring the unique less populous homogenous regions of the endemic areas (Schioler and MacPherson 2009).

It has been proposed by researchers that a trans-disciplinary approach works well for a water associated-disease like dengue (Arunachalam et al 2014; Arrendondo and Orozco 2012; Blas and Kurup 2010) due to the complex relationship between the main amplifying host (human beings), the vector insect / mosquito and the environment. Using such a comprehensive approach, all the complexities which precipitate an outbreak of dengue in a region, including the ecological / environmental and social factors, can be assessed for their impact using a vulnerability framework instead of a predictive framework (Bircher and Kuruvilla 2014). A vulnerability framework can be used to evaluate and interpret data sets providing an approach to simplify the relationship that includes human beings and the disease vector through the ecological / environmental / social determinants of health lens (Arunachalam et al 2014; Arrendondo and Orozco 2012; Blas and Kurup 2010) .

The Water Associated Disease Index (WADI) is a tool that incorporates a vulnerability framework through a combination of environmental and social determinants of health lens. The WADI allows the researcher to populate its vulnerability assessment model with data sets that are divided into two sets of components: susceptibility components and exposure components (Fullerton et al 2014). Currently, the WADI has been validated on large populous diverse regions such as Malaysia and Brazil, the aim of this thesis was to confirm its efficacy on small homogenous regions. As the framework for the WADI incorporates a comprehensive view of the drivers from the environmental, ecological and social determinants of health, all relevant data sets were incorporated into the disease index for dengue disease on the island of Dominica. One of the main advantages of the WADI methodology is that it allows for public health research into water associated infectious diseases in areas of the world that are data-poor. All the proposed components for the vulnerability framework are sourced from free data sets available on publicly accessible sources (Fullerton et al 2014).

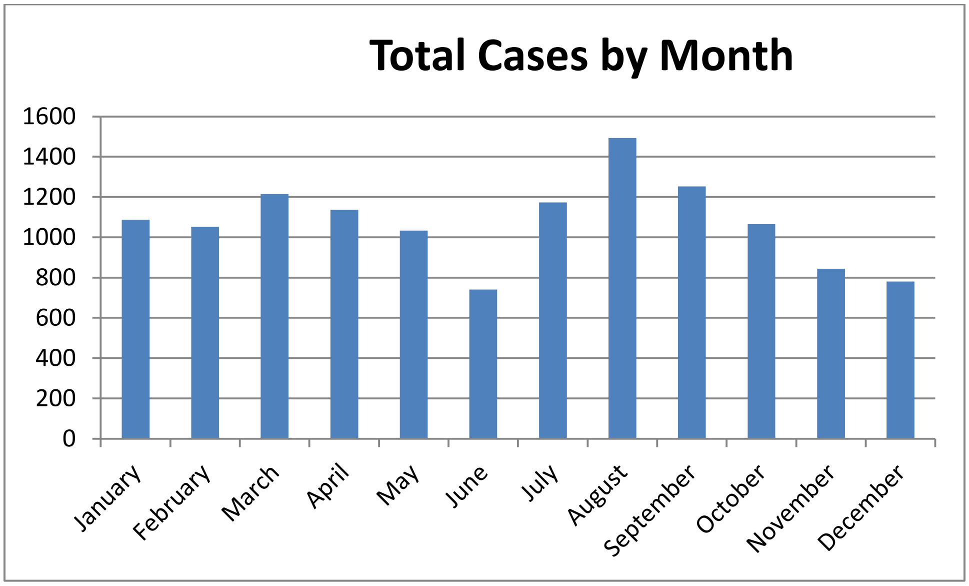
The first stage in applying the WADI process was to develop a conceptual framework that included a comprehensive inclusion of the ecological, environmental and social determinants of health. This framework gives prominence to the natural and social interconnectedness between the dengue virus, the mosquito, human beings and the environment, in order to demonstrate vulnerability. This thesis attempted to populate the WADI with components of exposure to the mosquito vector, such as measures influencing the development of breeding sites for initiating its life cycle; and, with susceptibility factors reflecting the social determinants of health that increase vulnerability at the community and individual level. The environmental/ecological exposure components included temperature, precipitation, land use and population density (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014). The social /susceptibility components included demographic and socio-economic variables. Each of these components has a role to play in increasing the likelihood of an increased risk of transmission of the dengue virus. Education level, age, water and sanitation, and poverty were incorporated into the WADI as susceptibility factors. (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014)

4.3 Exploration of the data

The years with the highest counts of incidences, representing major outbreaks were 2002, 2003 and 2006. The years with the smallest incidence counts were 2014 and 2015. The spike in 2013 argues against complacency with the low counts of the most recent years.

By summing cases by month across the years, the seasonality of disease transmission becomes evident: the number of cases is significantly greater in August than any of the other months, with the second-highest month being September, after which there is a steady decline month by month through December. There is a significant drop in the average number of cases from May to June, dipping slightly below the lows of December. This is a typical pattern for dengue disease in endemic countries, regardless of serotype, will show periodic peaks in transmission (Bennet et al 2010).

Graph 2 Total Cases of Dengue in Dominica by Month



Source: Department of Health, Commonwealth of Dominica Health Information Unit

Ranking the parishes by number of cases across the years studied, one can see that the greatest number of cases were in the parish of St. George, which contains the capital city of Roseau. However, as can be seen in Table Number 17, the next two parishes in terms of number of cases are not the next two largest parishes in terms of population. In fact, St. Joseph, the third ranked in terms of number of cases had more than twice as many cases as the next ranked, St. John, which is 15% larger by population. The parish had six times as many cases as St. Paul, whose population is almost 50% larger.

Saint Andrew, the second by rank, has high values for unimproved drinking water source, temperature, and has the highest score in terms of proportion of the population who are in the most vulnerable age range.

Table Number 13 - Ranking by Total Number of Cases

Parish	Total number of cases	Average Incidence rate	Population	Unimproved drinking water source	Vulnerable age value	Poverty	Household dengue control	Land-use value	Temperature	Precipitation	Population density value
Saint George	6101	0.15%	21241	0.099	0.000	0.127	0.588	1.000	0.642	0.475	1
Saint Andrew	2358	0.11%	9471	0.702	1.000	0.273	0.000	0.037	0.693	0.359	0
Saint Joseph	1671	0.14%	5637	0.458	0.391	0.362	0.647	0.219	0.663	0.412	0
Saint John	635	0.06%	6561	0.230	0.333	0.273	0.671	0.237	0.706	0.324	0.25
Saint Luke	518	0.16%	1668	0.099	0.435	0.000	0.835	0.105	0.700	0.410	0.25
Saint David	515	0.04%	6043	1.000	0.833	1.000	0.776	0.000	0.689	0.398	0
Saint Patrick	491	0.03%	7622	0.667	0.877	0.616	0.353	0.173	0.656	0.463	0
Saint Paul	268	0.02%	9786	0.000	0.054	0.240	1.000	0.140	0.655	0.443	0.25
Saint Peter	232	0.08%	1430	0.337	0.444	0.064	0.624	0.013	0.672	0.381	0
Saint Mark	82	0.02%	1834	0.367	0.187	0.593	0.294	0.094	0.728	0.380	0.25

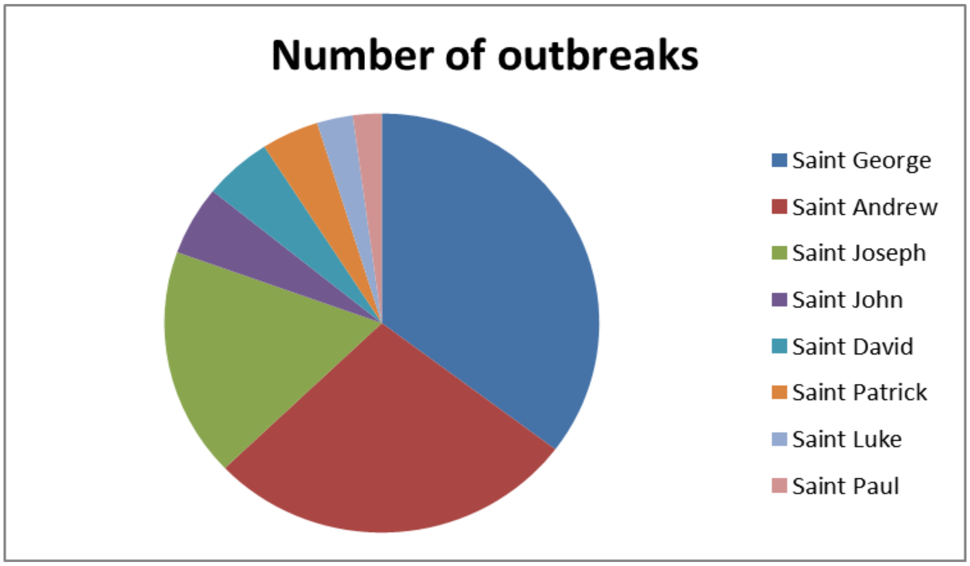
Source: Department of Health, Commonwealth of Dominica Health Information Unit

Ranking the parishes by average incidence rate also provides some insights. St. George remains in the top two, coming in second with an average incidence rate of 0.15%. St. George, containing the capital city Roseau, which is the largest and most developed, has the highest ranking in terms of land use (percent urbanized), and it has been shown in the literature that the increase in population density that comes with urbanization (both planned and unplanned) aids in the spread of the transmission of dengue virus (Gubler 2011; Hales et al 2002; Messina et al 2014; Pessanha et al 2012). St. George, St. Joseph, and Saint Andrew are near the top in both of these rankings. Saint Luke, which was ranked first, scored highest in terms of household dengue control risk. It did not score high on population density. This exposes an area of possible future improvements of the WADI in that the accuracy of the population density component can be improved upon.

The population density could possibly be better calculated by taking into account how much of the land area of the parish is settled at all. In the case of St. Luke, almost all of the population is in a small land area, the city of Pointe Michel, and the population density calculation is not ideally comparable to that of neighbouring St. George where the population is spread across most of the parish. Further research could look into ways of taking this factor into account to produce a better population density value.

In table number 13, it is apparent that the parish of St. David, which has some of the highest WADI values in Dominica, is only in the middle of the ranking for number of cases and for incidence rates. Further research could explore the salient features of that particular parish which may make it relatively resilient to the spread of dengue virus transmission. Two interesting features of Saint David that may be relevant are that a large portion of the parish is undeveloped, and that the inhabited areas have dwellings lining long roads, rather than clumping in areas such as harbours, as in other cities or densely packed in a grid as they are in much of the capital, Roseau. As with the population density calculation, there is a concession made between how precise the component value can be made to be, when compared to the extensive amount of work needed to create the values.

Graph 3 Number Percentage of Number of Outbreaks of Dengue per Parish in Dominica



Source: Department of Health, Commonwealth of Dominica Health Information Unit

Graph number 3 provides a review of the aggregate number of outbreaks condensed per parish over the 16 year study period 1999 to 2015, indicating the areas of concern. By far the highest counts are in St. George, as the majority of dengue cases occur in the capital of the parish, Roseau. The parishes of St. Andrew and St. Joseph have also had some of the largest outbreaks, with an average of 50 to 60 incidences of transmission in a month range. The highest counts of the outbreaks took place in the months of May, August, and September.

4.4 Analysis and Validation of WADI Dominica

The first step in the analysis was building the index model according to the procedure prescribed by the authors of the WADI (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014). Each component of the WADI was compiled and transformed into the 0 to 1 range. Each component within the exposure and susceptibility categories was given an equal weighting, proportioned so that the exposure and susceptibility values would both be between 0 and 1 (i.e., the four susceptibility components would each receive a ¼ weighting). However, following the procedure of the original WADI construction, the weighting of susceptibility versus exposure for the data analysis was explored for the best fit. Three variations of the index were computed using three different weightings of exposure and susceptibility components:

- Index1: 25% exposure and 75%'s susceptibility
- Index2: 50% exposure and 50% susceptibility
- Index3: 75% exposure and 25% susceptibility

The version that provided the best model fit of the three was to be chosen as the representative WADI model. Only trying three rough variations on the composition strikes a balance between over-fitting and not using any information from the data at all to influence the composition, and therefore seemed a reasonable approach to use for this analysis.

The WADI is meant to be a measure of vulnerability. To validate its performance of this function it was regressed against incidence counts of dengue, with the incidence counts standing in as a measurable proxy for vulnerability. The index was evaluated based on data for the island of Dominica for the years 1999 through 2015. Index values were computed using each of these three weightings.

The data for incidence counts consists of 2040 data points, each one a count for a particular parish-month-year tuple. For example, one observation could be: 21 counts of dengue in the parish of St. John in January of 2006.

Across this data set, the mean incidence count was 6.3; the minimum was zero and the maximum 184 incidences, occurring in 2003 in the parish of St. George (Table Number14).

Table Number 14 –Descriptive Statistics of Incidence of Dengue Counts

Observations	Mean	Standard deviation	Min	Max
2040	6.309314	14.71974	0	184

Negative binomial regression was used for the analysis, rather than linear regression as used by Dickin et al. (2013). As the incidence data is in the form of count data, ordinary least squares is not suitable, given assumptions it makes about the dependent variable being continuous. Count data can only be integral and greater than or equal to zero. As in the literature, a Poisson or negative binomial regression is deemed to be a more adept model to analyze count data.

Negative binomial regression was indicated rather than Poisson due to over dispersion in the data, as a Poisson regression assumes that the mean and variance of the count data are equal. In particular, a random-effects negative binomial model was used since it is panel data that was analysed. Panel data is multidimensional data usually involving a set of measurements over time, in this case, incidences in each parish over time. The population of each parish was used as an offset in the binomial regression to account for the effect of differing population sizes among the parishes on the incidence counts. For example, with all else equal, there is a high probability that there would be a greater number of incidences of dengue that would occur in a parish with a large population size, when compared to a parish with a smaller population size.

All three index models were regressed individually on the incidence counts. In each case the p-values for the coefficient of the index indicated that the index was significant with the highest p-value, for the 25% exposure +75% susceptibility formulations, having a value of 0.002. The other two formulations of the index had p-values that were low enough to be rounded to 0.00 by the statistical software used to run the test, Stata. Log likelihood, Akaike information criterion (AIC) and Bayesian information criterion (BIC) values were used to compare goodness of fit among the models. The comparisons showed that the 50% exposure + 50% susceptibility model provided the best fit, slightly better than the 75% exposure +25% susceptibility model, and markedly better than the 25% exposure 75% susceptibility model (Table Number 15). This was a different finding than the Dickin et al (2013) paper, which found a weighting of 75% for exposure and 25% for susceptibility to be the best for the regions in which the authors tested the WADI.

Table Number 15 – Regression Analysis of WADI Variants

	Log likely-hood	Wald	p-value of coeff	AIC	BIC	95% confidence	interval
Index1	-4668.09	9.31	0.002	9344.176	9366.659	-1.697559	-.369818
Index2	-4644.99	53.72	0.00	9297.989	9320.472	-4.584626	-2.650047
Index3	-4646.17	51.41	0.00	9300.343	9322.826	-3.140726	-1.79229
Revised WADI	-4659.77	25.45	0.00	9327.538	9350.021	-2.957115	-1.30224

As a comparison tool to aid in assessing the WADI, an alternate, parsimonious model was built using multivariate regression and forgoing normalization of the variables and the construction of an index. The results of a multivariate regression of all the variables on the incidence counts were used to identify the most parsimonious set of variables that should be included in the model. As the objective of the parsimonious model is to be as succinct as possible, only the variables found to be significant predictors of the incidence of dengue in Dominica in the regression were included. A 5% p-value significance level was chosen as the threshold for inclusion in the model. As with the index model, random effects negative binomial regression was used as was the offset variable of population values per parish.

The predictor variables used for the non-index model where the same inputs that were normalized and used in the construction of the WADI. For example, precipitation was included as an independent variable, but not normalized to a value between zero and one. Building this alternate model allowed for a comparison to evaluate whether the transformation of the inputs into a human-readable index resulted in a meaningful degradation of goodness of fit. It also provides for what can be thought of as a standard model to compare against the novelty of an index model. Index models are becoming more and more established in the literature and in practice, but it was expected that it would be useful to the analysis to make this comparison between index and non-index for this specific situation - measuring vulnerability to dengue in Dominica.

The WADI inputs were chosen a priori based on the body of knowledge of factors that influence the incidence of dengue. They were chosen because they have been shown in the literature to be contributors to the spread of dengue. With this alternate model inclusion in the model is not decided a priori but by whether or not the variable meets chosen significance level for this data set. Multiple regression analysis was performed and the results analysed, with the aim of removing from the model any inputs that are not significant at the 5% level. The first step consists of regressing all the variables against the incidence counts. This model was found to be significant as evidenced by the p-value for the Wald chi-squared of 0.00 (Table Number 16). Temperature, land use, age and poverty were found to be the most significant predictors. However, three of the components were found to be not significant at the 5% level. These were precipitation, population density and education. The P values for their coefficients were 0.098 for precipitation 0.073 for household education (female progression to secondary school), and 0.152 for population density (Table Number 17). Possibly a 5% cut off for a p-value is unduly stringent given the variability in incidence counts of dengue. If a 10% level was used only population density would be excluded. However, the parsimonious model was constructed without these three variables to complete the comparison as the 5% level had been chosen a priori.

Table Number 16 – Regression Analysis of Multivariate Model

	Log likelihood	Wald	p-value for chi2	AIC	BIC
Multivariate regression	-4547.5966	240.52	0.00	9117.193	9179.021

Table Number 17- Results of Multivariate Regression for Variable Selection

Multivariate regression	Coeff	Std.Err	z	P>|z|	95% Conf Intvl	
Temperature	2.011995	0.667084	3.02	0.003	0.704534	3.319455
Precipitation	0.165553	0.100147	1.65	0.098	-0.03073	0.361837
Land use	-7.50936	2.343329	-3.2	0.001	-12.1022	-2.91652
Population density	-1.58592	1.10788	-1.43	0.152	-3.75732	0.585489
Age	-19.6733	6.610222	-2.98	0.003	-32.6291	-6.71746
Poverty	-5.66835	0.914682	-6.2	0	-7.46109	-3.87561
Household	0.055914	0.031214	1.79	0.073	-0.00527	0.117093
Water source	0.032965	0.01395	2.36	0.018	0.005623	0.060306

The parsimonious non-index model included the remaining variables - temperature, land use, age, poverty, and water source. The model was tested using the same statistical methods. The model as a whole was found to be significant as evidenced by the Wald chi-squared statistic p-value (Table Number 18).

Table Number 18 –Regression Analysis of Parsimonious Non-Index Model

	Log likelihood	Wald	p-value for chi2	AIC	BIC
Parsimonious non-index model	-4551.5726	231.89	0.00	9119.145	9164.111

Table Number 19 – Variables Included in the Parsimonious Non-Index Model

Parsimonious non-index model	Coeff	Std.Err	Z	P>|z|	95% ConfIntvl	
Temperature	1.722447	0.656806	2.62	0.009	0.435131	3.009763
Land use	-11.7992	1.018725	-11.58	0	-13.7959	-9.80252
Age	-27.3517	6.008719	-4.55	0	-39.1285	-15.5748
Poverty	-5.62898	0.777825	-7.24	0	-7.15349	-4.10447
Water source	0.039693	0.011897	3.34	0.001	0.016375	0.063011

The revised WADI was created using the variables which were deemed essential in the non-parsimonious model- temperature, land use, age, poverty, and water source. The model was tested using the same statistical methods. The model as a whole was found to be significant as evidenced by the Wald chi-squared statistic p-value (Table Number 20).

Table Number 20 – Regression Analysis of Revised WADI Model

	Log likelihood	Wald	p-value for chi2	AIC	BIC
Revised WADI	-4659.769	25.45	0.00	9327.538	9350.021

The model as a whole was found to be significant as evidenced by the Wald chi-squared statistic p-value of 0.00

Goodness of fit was further examined by comparing predicted counts from the models against actual incidence counts, considering the mean, minimum and maximum predicted values generated by each model versus the actual incidence count values (Table Number 21). This allowed for comparing each model to actual incidence counts and for comparing the models to each other.

Table Number 21 - Comparison of Actual to Predicted Incidence Counts

Variable	Observations	Mean	Std.Dev.	Min	Max
Actual Incidences	2040	6.309314	14.71974	0	184
Index1	2040	7.104198	5.792707	1.549954	22.80055
Index2	2040	8.124561	5.808196	1.895408	24.39306
Index3	2040	7.753167	4.686235	1.636382	17.75274
Parsimonious	2040	8.718156	5.202432	2.631982	20.00717
Revised WADI	2040	8.679183	6.653007	1.50763	25.50405

Statistical significance was found with respect to all formulations of the index as well as to the five of eight inputs included in the alternate non-index model and the revised WADI. All the models showed a moderate fit with the data as evidenced by similar minimum and mean predictions versus actual incidence counts. The alternate, parsimonious by this measure was the lowest performer with both its mean and minimum values furthest from the actual values.

All the models predicted a higher mean than was found in the actual incidence data. The formulation of the index which showed the best fit according to the other model comparison methods, Index 2 (50% exposure and 50% susceptibility), fit less well by this measure, making the highest predictions (aside from the parsimonious model), farthest from the mean and minimum of the actual counts, although not very different from the next-best index model formulation, Index 3.

None of the models predicted the large outbreaks as evidenced by their lower maximum values compared to the actual counts. This is not a cause for concern as the aim is to measure vulnerability, not to predict exact counts or to predict the outbreaks represented by the outliers which set the maximum value in the actual incidence counts.

Log likelihood and AIC/BIC comparisons suggest that the alternate model provides a better fit than the WADI model. However, for any given data set a better fit should be expected from the parsimonious model versus the WADI given their methods of construction.

The question is whether there is a material loss of fit when using the WADI rather than the alternate, non-index model that would be relevant to a public health practitioner, and whether the benefits of having a WADI style tool outweigh the cost of the loss of fit. Given that the non-index model did not provide a meaningfully better fit, the conclusion was that there is no meaningful cost to the use of the index model from the perspective of the public health practitioner's planning needs.

Regardless of the fit of the models, index-based or traditional, actual counts of incidences of dengue cannot be predicted with much accuracy given the variability in the factors that contribute to the spread of dengue and to outbreaks. For example, a powerful rainstorm can wash away Aedes aegypti breeding sites in an afternoon, even if every other contributing factor is at its most impactful value and conditions would suggest a large outbreak was imminent. Given the intrinsic unpredictability of incidence counts, it is arguably more useful to the public health practitioner who needs to make plans and allocate prevention resources to know the relative vulnerability of a geographic area than to have a prediction of actual incidence counts, and a tool such as the WADI allows for this. The traditional multiple regression model provides a prediction per geographic area, which is constant for any tuple of parish-month between iterations of updates of the component data, which will not occur frequently. These predictions will generally be incorrect, although they could be considered indicative of vulnerability as well. However, the WADI provides an intuitive and visual measure of vulnerability, and furthermore one that is directly comparable across disparate geographic areas - a zero value is a zero value in any location and has the same interpretation.

An extension of the WADI which excluded from the list of components used for susceptibility and exposure that were found to be not significant in the alternate, non-index multiple regression was completed. This revised, parsimonious WADI model's predicted mean is almost as far from the actual mean as the parsimonious non-index model, but the minimum and maximum predicted values are closest to the actual values. The parsimonious WADI seems to perform better than the parsimonious multivariate model, but not as well the best version of the index model, index2.

4.5 Geographic Information System Maps

Using Geographic Information System in public health, specifically in infectious diseases is relatively new and currently expanding as the technology improves. In this thesis, GIS was incorporated as raster layers of environmental / ecological factors and social factors were combined to create colour coded maps which indicates the areas of vulnerability to increased risk of transmission of dengue virus in Dominica. The results imply that there is a vulnerability to the increased risk of transmission to the dengue virus in both spatial and temporal terms. In terms of spatial circumstances it is consistent with the outbreak data suggesting the hardest hit parishes are Saints David, George and occasionally St. Joseph. With regards to temporal conditions, there is seasonality to dengue outbreaks occurring in the wetter months July through October. The maps also highlight the homogeneity of the spatial and temporal indicators, the whole region has some level of vulnerability; however, there is increased vulnerability from the human controlled environmental factors such as urbanization.

In order to validate the WADI value, a substantiation approach using the incidence counts of reported dengue disease was used. Validation was applied to index values using regression coefficients to evaluate the associations.

GIS Maps

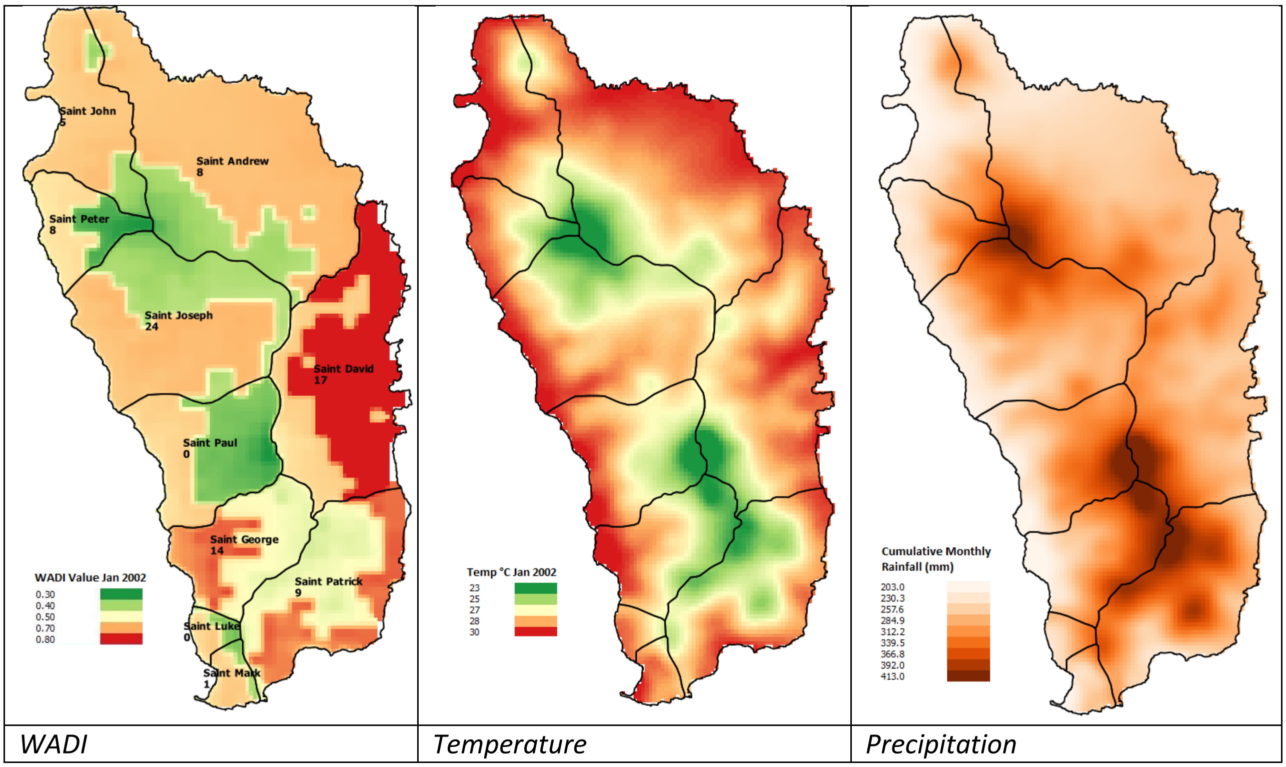
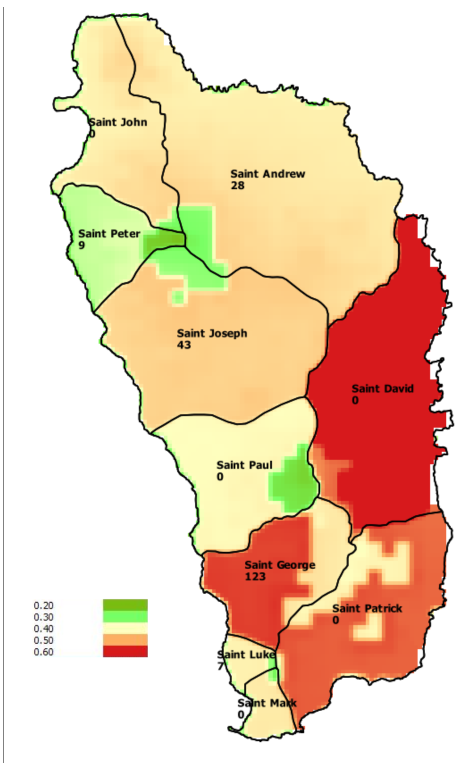


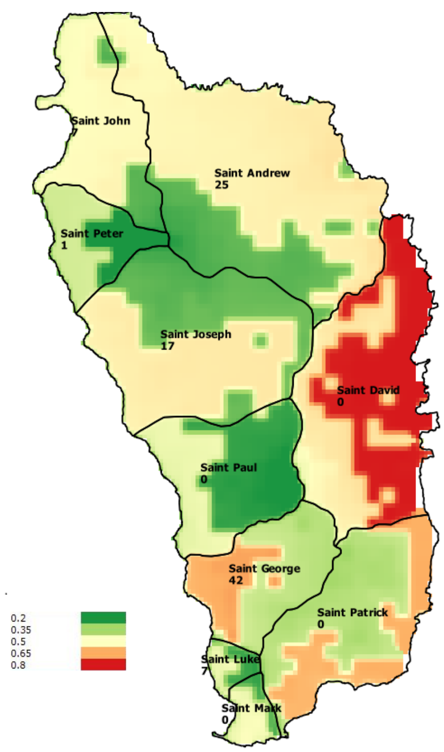
Figure Number 6 - Dominica WADI Vulnerability Assessment - January 2002

Vulnerability to an increased risk of dengue transmission was assessed for every month of every year in each parish from 1999 to 2015. A visual representation of the WADI value per month, per parish can be generated through GIS. The actual incidence of dengue cases in the parish during the particular month provides validation of the WADI value. Figure Number 6 is an example of January 2002. The highest vulnerability as indicated by the red colour is in the parish of St. David, it also corresponds to the highest number of dengue cases for that month at

17. Second to St. David is the parish of St. George which also links to the second highest number of cases at 14. The parish with lowest number of cases at 0 or 1 are also visually represented with yellow or green, the parishes of Saints Mark, Luke and Paul.

Figure 7 also shows alongside of the WADI map are the maps for temperature and precipitation related to January's WADI values. As explained, all of the social components (age, poverty, education, access to water) as well as two of the environmental components (population density and land use) are fixed throughout each parish. The components that vary within a parish are the ecological ones (temperature and precipitation) that were sourced from the WorldClim data set, which vary per square kilometre. The effect can be seen in the three maps and can be thought of as a fixed baseline WADI value in a parish (for a given month) with variations in the climate variables comprising the changing portion of the WADI value.





August 2003 December 2003

Figure Number 7 WADI Vulnerability Assessment August 2003 Figure 8 WADI Assessment December 2003

Comparing two months within the same year visually there is a shift in vulnerability based on the WADI value (Figure Number 7 and 8, page 111). The social components of health remain the same throughout the period of 1999 to 2015; however, the changes are due to the change in the environmental determinants of health that do change: the precipitation and the temperature. Therefore, increases will be observed in some areas and can provide valuable insight into changes in vulnerability for planning for public health interventions.

4.6 Summary of Findings

- The WADI model was found to be a significant assessment of the vulnerability proxy of incidence counts, with a moderately good fit using a negative binomial regression
- As a comparison model and validation tool, an alternate, non-index model was created and also found to be significant, with a moderately good fit using a multivariate regression
- All but one of the components (population density) of the alternate parsimonious non-index model was found to be significant at the 10% level. Five (temperature, urban land use, age, unimproved water source, poverty level) out of the eight components were found to be significant at the more stringent 5% level (precipitation, female progression to secondary school and population density were below the mark)
- A new WADI was created using the components that were identified as essential in the non- index model for further validation of WADI was tested and found to be significant
- The original WADI derived the most statistically significant result
- Geographic Information System (GIS) temporal and spatial visual output of the vulnerable areas in the region to an increased risk of dengue transmission in the form of a map per parish per month over the period of the research study 1999-2015

Chapter 5 Discussion

5.1 Introduction Discussion

At this time, the most important arborvirus as a threat to global public health is the dengue virus (WHO 2009). Dengue has been recorded in Latin America and the Caribbean as far back as the seventeenth century, and was relegated to the background of health hazards after an aggressive public health campaign to eradicate the disease was deemed successful. The eradication process is no longer an effective option and, currently, dengue poses a threat to human health as a re-emerging infectious disease. Presently, no effective vaccine is available to combat an infection from the virus and, as a result, only supportive therapy can be used to alleviate the symptoms. This lack of options for medical intervention can lead to increased risk of morbidity and mortality in dengue endemic countries which disproportionately affect the poor, elderly and children and has an even more of a negative impact on countries in the developing world (PAHO 2014; WHO 2009).

Much-needed public health research into dengue has been limited. The WHO has deemed dengue one of the Neglected Tropical Diseases highlighting the need for evidence based public health approaches to resolve the issue (Aagnaard and Chaignant 2012). Research into dengue in the Caribbean has been limited; however, there has been some research into the larger islands of the Caribbean and also countries in Latin America. Small island nations in the Caribbean are also under constant threat from an increased risk of transmission of the dengue virus, yet the level of research has been inadequate (Schioler and Macpherson 2009). The Water Associated Disease Index (WADI) was created in order to service areas of the world that not only had a surge in re-emergent water associated diseases like the dengue virus, but also in the developing world where resources and access to data to aid in public health research may be lacking (Dickin 2013; Dickin and Schuster 2014; Fullerton et al 2014).

Previously, the WADI has only been tested on comparatively large and populous countries such as Brazil and Malaysia. The objective of this thesis was to assess the WADI in the context of a country that is smaller, with a more homogeneous land area and a smaller population, than the countries for which it has already been assessed. The island of Dominica was chosen for this purpose. Dominica is a small island, 751 km^2 with a population of approximately 73,500 people in which dengue is endemic and as such was a suitable location for this evaluation. The WADI has been promoted by its creators as a vulnerability assessment tool. Given the restricted amount of public health resources available in many countries, including Dominica, the aim of the study was to explore a low cost effective measure that could be used to determine areas of vulnerability to aid in public health decision making. The WADI for Dominica was developed to determine whether or not there was an association with health outcomes on the island, namely the number of dengue cases. The research question sought to explore, through the known incidence of cases of dengue per parish, whether this tool could be informative in mapping vulnerable areas at the parish level on the island of Dominica.

In this thesis's statistical analysis, the dependent variable was the number of reported dengue disease cases per parish, per month. The independent variable was the synthesized WADI index value, a composite of susceptibility and exposure components, designed to measure vulnerability to an increased risk of transmission of dengue. A non-index model was also tested with a composite of the susceptibility and the exposure factors with certain components notable as essential to the vulnerability assessment. A new WADI was created with these notable components and tested. The results of both the index models and the non-index model yielded a significant outcome which will be discussed in detail, as well as, the visual output of vulnerability per parish, the Geographic Information System (GIS) derived maps.

5.2 Discussion of Findings

The results from the analysis of the WADI on the island of Dominica show that there is a significant relationship between the dengue incidence counts and the WADI values, demonstrating a confirmation of specific vulnerability at the parish level. The WADI has highlighted areas on the island that are vulnerable and are thereby at an increased risk to dengue virus transmission, which corresponds to the number of known dengue cases in each parish. The measure of vulnerability in this thesis was challenging due to the fact that the only measure to validate the tool was an association between the WADI value and the presence of cases in each parish. For example, whether the level of vulnerability described in a parish (spatial) for a month (temporal) would have an actual epidemiological link. If the vulnerability was high for the described space and time (an example could be February 2012 in St. Paul parish), there would be a corresponding increased number of cases of dengue when the WADI value was high, or a decreased number of cases (or no cases) of the disease when the WADI value was low.

The association between the WADI value for vulnerability of an increased risk of disease transmission and the corresponding incidence of disease was generally matched over the research period from 1999 to 2015. As a vulnerability assessment tool for the island of Dominica, there is a positive association between the calculated WADI value of an increased risk of dengue virus and the corresponding number of cases signifying presence of the disease in per parish, per month. However there were a few anomalies detected. A high WADI value of vulnerability and an increased risk of disease transmission were often demonstrated; however, there could also be the phenomenon of an indicated high vulnerability value in a parish without any known dengue cases.

Research into dengue has often focused on the lack of reporting due to lack of resources to maintain a database of reportable diseases, especially in countries of the developing world. Studies have also concluded that due to its similarity in terms of non-reportable diseases like the viruses of the common cold or the flu could also result in under-reporting or a misrepresentation of the reports. Even in the literature this can be conjecture, as it is difficult to determine retrospectively the reasoning behind the discrepancy and this thesis relies on historical data with the research period from 1999 to 2015.

Results from this thesis may be able to infer that from the WADI of Dominica there can be vulnerability based on elevated social, ecological and environmental determinants of health captured by the WADI value without an epidemiological risk of disease transmission. This may also be an area in which requires further research to determine that if the vulnerability is high in one region yet there is no elevated risk in health outcomes is due to a parish specific element. The WADI value may be high but the ability to adapt or manage the health hazard could be due to one or to a number of different drivers that have not been identified in the index. These indicators may be within or outside the scope of the identified components; however, they are significant enough to warrant further exploration.

These anomalies can also be attributed to the nature of WADI as a confirmation of risk but not an interpretation of risk. The value of WADI is to highlight areas in which the social, ecological and environmental determinants of health has the potential to increase the level of risk to dengue transmission among its inhabitants, and can be a priority for public health intervention. Dengue, like many other infectious diseases that present with flu-like symptoms is often underreported (WHO 2012). Dominica may also have data sets related to incidence rates of dengue that are incomplete or not representative of the true scope of the number of cases, therefore it is difficult to assess the risk when conducting research into data-poor area when accurate reporting is necessary for accurate results (Ayukepi et al 2017).

Additionally, the results from the regression indicate that the relationship is significant but the WADI model provides only a moderate fit to the incidence data and cannot be used as an accurate predictor of incidences of disease transmission. However, prediction of actual incidence counts is not its purpose, and prediction accuracy is measured for insight into the model. Instead, the WADI is meant to be a measure of vulnerability that can be used as a tool for planning purposes, and its level of fit with the data is adequate for this task. The implication of this finding is that the WADI can be used in a country like Dominica, which is representative of a set of countries for which the model had been untested and unproven.

From results of this thesis, the parishes within the small island nation of Dominica, which have proven to have an increased risk of incidence of dengue, have now been identified both spatially and temporally on the island. With large countries, the different regions will have different climates affecting the value of the ecological components within the index model; risk will differ from region to region. Not all regions will have the ecological value which supports proliferation of the disease vector, a major component of the disease cycle. With small island nations in the Caribbean, the risk will more than likely fit the pattern of Dominica due to their homogenous climate pattern. Vulnerability is equal across the island from the ecological components. All regions have the potential to support the mosquito's lifecycle. As a result, the social determinants of health such as poverty and unimproved water source play a much larger role and can have a more negative impact in a vulnerable region of the island's ability to cope with the health hazard.

Additionally, from the WADI Dominica, a potential new avenue has emerged for the exploration of low incidence counts of data in what the literature describes as the 'off' years (Bennet et al 2010). Schioler and MacPherson 2009 in their research study alluded to the fact that a small island setting with seroprevalence of one dengue serotype may be the reason for the low incidence years, where a small of number of dengue were reported (Bennet et al 2010; Schioler and MacPherson 2009). In larger countries with larger populations and higher incidence rates of the disease, these years may be less evident than in the small island setting where the levels reach near undetectable levels. The difference between off and on years are more drastic and easily seen when plotted on a graph (for example Table Number14, page 91). Whereas in a more populous region, and with the prevalence of multiple serotypes, during the 'off' years of much lower numbers, there would still be detectable levels. The distinction would not be as evident or the phenomenon may be theorized differently, as per Johansson et al 2009 and Strickman and Kittayapong who suggest either vector variability or climate variability.

The importance of this finding may give support to the Adams et al 2006; Ooi et al 2006; and, Recker 2009 who have suggested in their research that the answer may lie within the human body's immune response to the dengue virus. In conjunction with recent findings in Nicaragua by Waggoner et al 2016, contradicting the long held theory of long term immunity dengue virus, continued research into dengue in the small island setting, like Dominica, may be the type of endemic countries that can illuminate this emerging theory further (Adams et al 2006; Ooi et al 2006; Recker 2009; Schioler and MacPherson 2009; Waggoner et al 2016).

The WADI constructed according to the methodology of the creators of this index model for the island of Dominica. By comparing the WADI to a non-index multivariate regression model in this thesis, further validation of the WADI for Dominica was achieved. The analysis showed that the non-index model had only slightly better fit than the index model WADI. The data sets for the non-index model were not normalized or otherwise transformed. These results shows that for the purposes of measuring vulnerability, a complex index model like WADI can be used without meaningful loss of information through the transformation of the raw data sets into the components, fitting them to an assigned value of zero to one through normalization, and adding further complexity of the combination of the components to form the index.

A comparison of the WADI to an alternate non-index parsimoniously constructed multivariate regression model had not been made with previous research of the WADI in Malaysia and Brazil. Confidence in the WADI's use required investigation of the possible information loss - does it cost too much in terms of lost fit to be worth the benefits of the index? For the island of Dominica at the least, it does not. This finding builds the case for the usefulness of the WADI model in a small island setting.

An important finding of the analysis was that all but one of the indicators, population density, chosen to be components of the WADI was significant at the 10% level. At the p value level, it does not explain any of the variation in the dengue incidence counts. On the island of Dominica, living in a densely populated parish was not a factor as a predictor of increased risk to transmission to dengue. This finding is contrary to the literature which states that population density is a key component to dengue transmission (Braga et al 2010; De Mattos et al 2007). This may be attributed to being unable to utilize the component for population density listed as the ideal indicator. Due to availability of data, the actual indicator was an approximation, the population per square kilometer. Or, it may be for a small island setting with less populous regions, population density is not an indicator which contributes to an increased risk of disease transmission.

The final result of the non-index model does indicate that a priori selection of components based on a review of the literature can confirm vulnerability to an increased risk of the disease. The majority of the components of the non-index model were still deemed to be key to building a complex eco-health model to assess vulnerability. This is especially relevant in countries where public health manpower and financial resources that can be devoted to researching candidate components are limited, similar to Dominica. The WADI components have been clearly outlined, based on the literature and on validation of the model, can serve as a template for developing public health initiatives in vulnerable regions.

5.3 Comparison to the Other WADI Research Studies

The creators of the WADI have tested the index model in dengue endemic countries of Malaysia and Brazil, both large populous countries with very diverse regions. This thesis represents the first test of the WADI on a country with a small population size, less than 1 000,000 with a relatively environmentally homogeneous and a small land mass. Prior to this thesis it had only been tested for larger countries with much larger populations. The WADI is potentially very useful to smaller countries and the analysis and validation show that it is a tool that can be used in that context.

The validation performed was more rigorous and thorough than had been performed on the previous WADI studies. The comparison of the WADI with an alternative, parsimonious non-index model also provided a novel and vital test of the index and is also a deviation from the methodology as outlined by the WADI creator. For this thesis, it provided further validation of the WADI. Additionally, the WADI was tested again using the new list of components outlined by the alternative, parsimonious non-index model. Also, more appropriate form of regression was used: a negative binomial panel regression rather than a linear regression which was used in the original WADI research papers (Cameron and Trevedi 2013).

The process of conducting a lag in temperature by the creators of the WADI was not necessary as the average temperature in Dominica remains virtually unchanged with no temporal or spatial difference to account for any major variation in the temperature. In smaller areas, there is less climate variability, as was demonstrated in Dominica, and would be similar in countries in the region of a similar size. Therefore, conducting this extra step would be unnecessary and can be removed from the process if the region being researched is similar in size and climate.

For the WADI for Dominica, there was a finding of less fit with vulnerability as measured by incidence counts of dengue, than was found in the original WADI locations, where each had a near perfect fit. This may suggest that it is less precise of a tool for places like Dominica which have less seasonal, regional and population variability, than it is for larger countries like Brazil or Indonesia.

For example, in Dominica, the vulnerability as described by the index model predicts that St. David's exposure to conditions that support the presence and transmission of dengue and is susceptible to social determinants that increase their sensitivity to the disease. Yet there are some months that despite the increased risk and the threat of an outbreak, there are no cases in the parish. Parishes, such as St. Joseph, with a lower WADI reading, also have an increased susceptibility as determined by the assessment of correlation to vulnerability, an increased number of dengue cases in the parish. This finding will be a significant factor in public health authorities' decision on whether to use it for their particular country or region. The tool is less precise, but does provide some indication for areas of concern and begin the conversation focusing on best practices in public health to combat dengue transmission.

5.4 The Non-index Model

The alternate parsimonious non-index model allowed for further comparison and validation of the WADI model by producing a regression coefficient that was significant. The non-index model consisted of all the components of the WADI from the social, ecological and environmental factors at equal value, unlike the WADI model which weighted each of the components. The non-index multivariate model highlights whether by use of an index model explanatory power is lost as the index uses a methodology which takes each component and normalizes them. As a result, with all of the inputs are combined within exposure and susceptibility, it is difficult to determine which component or components can explain the results. Using a non-index multivariate regression produces a coefficient for each independent variable and which uncovers significant components and the level of the significance. The results from the regression also suggested a moderate fit of the non-index model, there was an association between the index values which evaluated vulnerability using the incidence of disease as a proxy for vulnerability, like the WADI model. As all the components in the non-index were weighted equally, they were not all of equal value to the outcome.

The non- index model provided further information regarding the components that were non-essential to assessing vulnerability in Dominica. The components such as temperature, land use, age, poverty, and unimproved water source were deemed to be essential in the literature (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014) and creators of the WADI to assessing vulnerability to an increased risk of dengue transmission in Dominica, whereas the precipitation, population density, household dengue control (education), were deemed to be non-essential (Dickin et al 2013; Dickin and Schuster 2014; Fullerton et al 2014). The model was tested using the same statistical methods as the WADI and was found to also be moderately significant with the new configuration of the social, ecological and environmental factors.

The non-index model was created to serve as a comparison to the index model, as mentioned above. The main critique of index models like the Water Associated Disease Index is in the computing of the index, which places the variables into a normalized or categorized value between zero and one and in the a priori selection of variables without analysing the data. This may seem like it does not allow for determining which factors are actually the major players and the categorization and normalization may be seen as altering the data.

The results of the multivariate regression of the non-index model gave a number of revelations that were contrary to the literature with the values for land use, population density, age, and poverty having negative coefficients. The negative coefficients convey that as there is an increase in the value of these variables, there would subsequently be a decrease in the number of cases of dengue.

This indicates that rural areas with low population density should have the largest number of dengue cases, as opposed to the expected high density, highly urban areas posited by researchers into the dengue virus. As a result, this is contrary to the findings in the literature and, interestingly, the actual number of cases per parish in the study area. The answer to the anomaly may be due to the data sets used to populate the models. The percent urbanization data set was the proxy indicator for the land use per parish component and was calculated using GIS technology. This process, as mentioned in the methodology section, is well documented in research papers for health geography such as Chang et al 2009**.** Drawing a polygon over the Google Earth image to determine the size of a populated area is a widely accepted practice for generating land use data sets also according to Sherman et al 2014; however, the data set is only as accurate as the Google Earth image. The numerator of the equation for percent of urbanized area per parish was the total urbanized square kilometers, the sum of urbanized polygons in that parish. The denominator was the total square kilometers for the parish. For parishes where a large portion of the area is uninhabited, the number would be more correct if the uninhabited square meters could be excluded from the denominator. Population density may also be improved by a more sophisticated denominator due to the fact it also incorporates the total square kilometers of the parish. As GIS technology continues to improve with further refinement, data sets computing population density and percent urbanized can also be improved. (Chang et al, 2009; Sherman et al, 2014.)

As discussed, age is a parameter which is seen as a social determinant of health that can increase the risk of dengue transmission and progression to the more severe states of dengue infection including dengue haemorrhagic fever and dengue shock syndrome, which can be fatal if there is inadequate medical intervention. The results of the non-index regression suggested that as the per cent of people inside of the vulnerable age range decreased, so would the number of cases of dengue per parish. The literature states that a vulnerable age definitely entails increased risk to developing serious symptoms. However, increased risk of serious symptoms may be conflated with risk of infection/dengue transmission. This requires further exploration in general and in this setting in particular.

The multivariate coefficient for poverty was also found to be contrary to what the literature traditionally states, with the results suggesting that lower poverty is associated with a lower number of incidence counts of dengue per parish. However, lately the notion of a link between dengue and poverty has become contested. For example, a research study by Muhmmad Azami et al 2011 and a systematic review by Mulligan et al 2015 attempt to challenge the inclusion of this social determinant of health as a driver for increased rate of infection with the idea of the 'urbanization only' theory, a point of view that was included in the literature review. Neither research paper was able to make a convincing case but suggested switching the narrative from poverty to opportunity. However, the literature overwhelmingly states that although there are cases in wealthy densely populated areas, the areas of lower economic status with an infrastructure that does not promote an improved water source, with low uptake of public health promotional material are at greater risk. In fact, the Horstick et al in 2015 study determined that dengue was still a threat to public health as the number of infections continues to increase worldwide, especially in the developing world where poverty is a major risk factor for transmission of the Neglected Tropical Diseases (Horstick et al, 2015; Muhmmad Azami et al, 2011; Mulligan et al 2015)

In the end, the results of the thesis showed that the WADI, which provided equal weighting to the social and the environmental/ecological determinants, was more effective at determining vulnerability as measured by comparing actual versus predicted cases of dengue per parish than the multivariate model. However, the value of examining the issues raised by the results of the multivariate regression of the non-index model provides the impetus for further exploration and for challenging the accepted tenets of risk factors in the literature.

5.5 The Revised WADI model

In this thesis, the first WADI model was constructed by choosing the components a priori based on the literature and availability of data sets. After constructing the non-index parsimonious model, a revised version of the WADI was created using the components that were selected as essential from the multivariate regression of the non-index model. This was a modification of the original WADI methodology by using the results of a multivariate regression to exclude components whose significance does not meet the p-value at 10%. There were three components that had P values of higher than 0.10: precipitation, female progression to secondary school and population density. As a result, a reconstruction of the index incorporated the five components rather than the original eight; all weighted equally within the exposure and susceptibility factors. The components that were constructed in the revised WADI were temperature, land use, age, unimproved water source, and poverty.

The result of the regression of the revised WADI using the combination of the above five components was better than the parsimonious model; however, the original WADI outperformed them both in significance. The original WADI model construction was the most significant result of this thesis and the best fit of the data to the actual incidence counts of dengue disease. In other words, WADI with the original eight components of social ecological and environmental determinants of health, normalized to a value between zero to one and weighted based on the literature proved to be the best at assessing vulnerability to increased risk of dengue virus transmission on the island of Dominica.

The WADI is premised on a priori inclusion of components that are known from the literature to be relevant to the spread of dengue. One of the complaints about eco-health index models, like the WADI, is they can appear to be cumbersome by including all of the components which have the potential to increase vulnerability represented by the social, ecological and environmental determinants of health. It can be argued that some of these components may not be strong enough contributors in a particular location. For example, precipitation was found to not be significant in the alternate non-index model at 10%. The WADI for Dominica could be built without including precipitation as a component based on this finding. However, care must be exercised as the finding of non-significance for the component is based upon a specific sample of data. Water, or in this case precipitation is essential to the lifecycle of the mosquito vector. Even if the virus was circulating in the human population, its presence would die out without the aid of the mosquito in the spread of the virus from person to person. Dengue was not a public health issue in the Caribbean during a vector control campaign, regaining a toehold in the region once the mosquito vector was no longer controlled by pesticides (WHO 2009; WHO 2012).

In this particular analysis the data set was quite large, spanning 16 years and that would tend to support accepting this finding. However, the literature does not support the claim that precipitation is not essential to any research exploring vulnerability to the risk of dengue transmission.

5.6 Geographic Information System

The use of GIS in public health research specific to infectious diseases is essentially providing a spatial framework to address ecological, social and environmental issues. The role of GIS in public health research is to establish where areas in need of public health intervention. In this thesis the GIS map provides a visual representation of the WADI values. A map can be produced for each month of the year in each parish with an associated WADI value. The WADI values ranged between zero and one, with zero being least vulnerable, and one being the most vulnerable. The range of index values is represented by a colour gradient from green to red rising with the index value. The GIS-constructed maps for the island of Dominica show at a glance that there is some level of vulnerability in each of the ten parishes at any given time throughout the year. Dominica is not a zero risk country in terms risk of transmission to the dengue virus.

The whole island has some vulnerability. Spatially, there is no particular parish that does not have some risk of dengue and in fact, temporally, there is no month of the year or season in which no cases have been reported in at least one parish of the island. The index for Dominica mostly ranges in value from 0.28to 0.66. The WADI value is noteworthy spatially and temporally for vulnerability on the island of Dominica which allows for greater insight into the patterns of the increased incidence of the transmission of dengue virus.

Areas that are affected by an increased risk of dengue transmission are essential to public health intervention, especially in resource –strapped areas of the world. GIS use in public health provides a visual representation of vulnerable areas of an affected region. The GIS derived maps that highlight vulnerability on the island of Dominica, gave a visual representation of the increased risk of dengue transmission at any given month, in each of the parishes during the period of 1999 to 2015. There is always some risk as indicated by the WADI value on the map, the visual representation is clear that there is not a lot of variation spatially and temporally; however, there is still some regions that are on the higher range of vulnerability (closer to the value of 1). That subtle difference can prove to be indicative of an increased risk level. When the map is paired with the incidence of dengue there is a display in the patterns of variations in the disease rates. Despite the fact that there is vulnerability in all parishes of the island the strength of the vulnerability does associate with the number of cases.

Possibly one of the first explanations for the lack of a stronger relationship between the WADI value for vulnerability and the incidence counts is the fact that the climate values for temperature 20° C and 34 ° C (68 ° F to 93 ° F) and precipitation (between 75mm to 300mm) are both almost consistently within the ranges that are optimal for the disease vector throughout Dominica. The temperature has a significant effect on the *Aedes aegypti* mosquito, allowing for the completion of its lifecycle, thus also increasing the number of bites each mosquito can make and increasing its spatial range for biting. Due to its consistency in temperature, seasons in Dominica are marked not by temperature but by precipitation. The months with the most amount of precipitation are July through October, and the WADI value corroborates this with an increase in the value. As a waterborne disease vector, the mosquito's breeding sites proliferate with an increase in steady precipitation. Although, there is still a risk of dengue transmission during the drier months December through May as the island will experience rainfall throughout those months well within the range to promote mosquito breeding and support its lifecycle.

The homogeneity of the climate data may be a contributor to the lack of greater variation in WADI values. As with other research studies which employed the WADI variations within the regions climate data from temperate to tropical, this one did yield corresponding WADI values of the expected vulnerability. For example, the Dickin et al (2013) outputs found a positive correlation with WADI in areas where the temperature and precipitation had a large impact on the exposure value and very little vulnerability in areas where the climate data did not support what is known in the research to support the growth and propagation of the disease vector (Dickin et al 2013).

In order to contrast the WADI with a non-index traditional model, and to investigate whether any of the variables that were transformed to components were or were not contributors to vulnerability a parsimonious non-index model was built and a analyzed through a multivariate regression. The same variables that were transformed into components of the vulnerability index were analyzed. As with the analysis of the WADI, an offset was included for population, to account for the variation in populations per parish.

Temperature, land use, age, poverty and water source appeared to be the most significant contributors to the incidence count of dengue disease in the non-index model. The relevance of the climate data to increasing the incidence of life cycle, life span, the biting incidents and the areas in which the vector can travel has been discussed. The significance of land use can begin a discussion on urban versus rural areas and the risk of transmission but it can also speak to the unplanned, uncontrolled urban sprawl that is widespread in the developing world. This also has links to another one of the susceptibility components - water and sanitation. With unplanned urban sprawl, the infrastructure that supports urban development lags behind in providing for basic utilities, forcing the population to fashion their own by collecting water on site. Household education is similar as it is usually linked to poverty. Household education was significant at the 10% level. Most female led households in the developing world tend to live below the poverty line and the head female is usually uneducated or undereducated. Further to that, the responsibility of all the other things in the home, especially child-rearing does not leave the time and energy needed to read, understand and implement any of the directives outlined in the public health promotion tool regarding infectious disease prevention.

Removing the variables whose coefficients were not significant at the 5% p-value level, an alternate, parsimonious model was tested, using only the variables temperature, land use, age, poverty, and water source to determine whether or not these variables were the crucial to assessing vulnerability to an increased risk of dengue transmission in Dominica. By removing the superfluous variables the model should have been better equipped to match vulnerability to the increased dengue cases per parish. This parsimonious model did not perform better than the original multivariate model, the WADI. Comparisons of the non-index models to the WADI showed that the WADI is as efficient as a vulnerability assessment tool, as a traditional non-index model, for practical purposes.

The literature states that the social determinants, the environmental determinants and the ecological determinants of health play a vital role in vulnerability to disease incidence with the dengue virus. The value of the WADI is in synthesizing all the factors that populate a comprehensive model that incorporates the ecological, environmental and social determinants of health that the research has shown to contribute to a high risk of dengue transmission.

The WADI was established to detect and visualize vulnerability to an infectious disease like dengue that is water-associated. This approach has value to the public health community to in that it provides a pragmatic tool that can be used for developing more innovative and long term solutions to public health policy and practice. A model that integrates environmental, ecological and social determinants of health similar to the WADI tool yet borrowing a page from parsimonious model development and pruning components based on multivariate regression could be the key to further understanding the role of each of the social, environmental and ecological determinants of health. Clearly, they are inextricably linked to understanding a nation's vulnerability to the threat of increased incidences of dengue disease. Thereby, it is vital that these the determinants of health are also linked to the proposed public health policy and practices that will reduce vulnerability to the disease.

The global public health community cannot combat the threat of the dengue virus to human health from one angle. A multipronged approach is necessary to fight a complex disease that considers and incorporates the drivers of humans, the vector and the environment/ecology.

5.7 Limitations

This thesis had a few limitations. First, a number of the islands in the Caribbean have a national spoken and written language other than English, mainly Spanish, French, and Dutch. Although there were no language restrictions which were applied to the search (the search for relevant studies for the literature review was conducted mainly in English only with some French), searching the same key words in other languages may have generated a different result. Additionally, public health terms can be quite ambiguous which could complicate the search for relevant materials. This is especially true when combining public health terms with technical terms in another discipline such geography, ecology and environmental health issues. There is a possibility that some terms were not adequately identified during the many searches for appropriate literature. As a result, different outcomes may have been obtained to produce more relevant studies to this thesis.

Another limitation of the thesis focuses on the strength of the data. The homogeneity of the climate data may be a contributor to the lack of greater variation in WADI values. Other research studies which used the WADI to determine vulnerability in a region, variations within the regions climate data from temperate to tropical, this one did yield corresponding WADI values of the expected vulnerability. For example, the Dickin et al (2013) outputs found a positive correlation with WADI in areas where the temperature and precipitation had a large impact on the exposure value and very little vulnerability in areas where the climate data did not support what is known in the research to support the growth and propagation of the disease vector. Further research could benefit from long term series of climate data which is based on daily temperatures and precipitation; it may yield a more nuanced result of the WADI value.

The construction of the urbanized areas data set was determined through the Google Earth technology. The procedure includes drawing a polygon around the satellite image of the populated area to determine the density to $1km^2$. Even though the process garners an extremely close estimate and its use widely accepted (Sherman et al 2014), it is not an exact measure of the urbanized areas. The technology is improving exponentially and thereby allowing for more accurate measurement of urbanized areas in the future. Therefore, a future iteration of a study incorporating urbanized areas into an index model for dengue in Dominica may be able to rely on more accurate data.

The creators of WADI acknowledge that accessible and accurate data for a number of the components that is used to build the social determinants of health portion of the index would simply not be accessible by any means. There were a number of the social determinants of health components which had to rely on a proxy as an indicator. When the WADI was tested on Malaysia and Brazil, the researchers also had to use a proxy for a number of the social determinants of health, so this is not a limitation which is unusual for building this particular index model; however, it is a limitation for this thesis. For example, the ideal indicator for housing quality is housing construction and solid waste collection; this thesis had to rely on the unimproved water source data set from the Dominican census. As another example, the ideal indicator for household dengue control would be a measure of the head female in the household's knowledge of disease prevention. This thesis used female progression to secondary school which was also readily available in the Dominican census data. By using proxies for the indicators of the social determinant of health components the index model could be populated with components that increased the risk of dengue transmission, as supported by the literature, in a region that is data-poor.

There were a number of data sets that simply were not available and a proxy could not be created for such as immunity level which would use dengue seroprevalence among the residents of Dominica. Seroprevalence data set would entail having blood work drawn from a sample of the population per parish which has not been conducted and therefore is not available. Social capital is a WADI indicator that also could not be captured as it would have required measuring the percentage of people per parish that participate in community dengue activities. The value in the WADI is to take all available data which the literature suggests may be part of the crucial element of the social / ecological / environmental determinants of health components in the model. The issue with accessing data in most of the countries in the developing world is a number of those important data sets are not available, and / or, if available may be incomplete or inaccurate. Actual crucial data may not exist for building an index model. Therefore, based on the data available to construct the index model may not be a precise indication of all the factor that contribute to the region’s vulnerability; however there is value in research which uses this method. The results of the WADI could be seen as the starting point to support policy development into public health interventions and to continue shaping future research into regional vulnerability to an increased risk to infectious diseases.

Chapter 6 Conclusion

The infectious disease caused by the dengue virus takes its toll on the human population. There is morbidity and an economic burden that arises from every case of dengue. There is an estimated 50 to 100 million cases per year of dengue worldwide. The majority of people in those cases will suffer from symptoms of joint pain, general malaise and headache, and will recover without serious incident. However, there is an estimated 500,000 people worldwide who, due to their infection from the dengue virus, will be hospitalized with severe symptoms (WHO 2012). Approximately 12,500 of the 500,000 who will receive hospital care will succumb to their illness if the illness progresses from Dengue Haemorrhagic Fever (DHF) to Dengue Shock Syndrome (DSS). The risk of death increases for those who are aged less than 15 as well as those older than 60; those who are immune-compromised; and, those who are living in poverty. The members of the population who do survive the infection from DSS will likely suffer from major health issues, which will be chronic, disabling and may affect their ability to have gainful employment (WHO 2009; WHO 2011).

Dengue has long been thought of as a disease of the poor. Wherever it manages to get a toehold, especially in the developing world, those who suffer are usually members of the population with a lower economic status (Aagaard-Hansen and Chaignant 2012; Hotez 2013). It is a disease that primarily affects the developing countries located in tropical and sub-tropical regions; however, regions that include countries with intemperate climates such as Europe and North America are beginning to see activity from the mosquito vector and to document of cases of dengue in the human population (WHO 2011).

Despite the fact that there is a genuine threat to public health from the re-emergence and increased incidence of dengue worldwide, the health hazard was not always given priority in terms of public health research and policy development (Hotez 2013). In fact, in 2009 the World Health Organization declared that the threat of dengue was largely ignored in the public health community. As a result, the WHO added dengue to the list of the Neglected Tropical Diseases (NTDs) as they do not receive much consideration from the global public health community in terms of research, advocacy or policy development. Instead, the majority of public health resources are allocated to research, advocacy and policy development for the big three diseases: malaria, tuberculosis and Human Immunodeficiency Virus infection and Acquired Immune Deficiency Syndrome (HIV/AIDS). These diseases do have a huge disease burden worldwide, including in the developing nations; however, in terms of Daily Adjusted Life Years, or lifelong disability after recovery, the Neglected Tropical Diseases play a pivotal role in continuing the vicious cycle of poverty, pain and suffering in the developing world (Horstick 2015; Hotez 2013; San Martin et al 2010; WHO 2009).

Despite the paucity of allocated public health resources there has been research into exploring mitigation measures to combat the threat of dengue worldwide. The majority of the research has been into methods to control the main vector, the Aedes aegypti mosquito (Dom et al 2013; Getis 2003; Ooi et al 2007). The research has included delving into dengue surveillance and developing index models to analyze mosquito density and biting patterns (Bhatt et al 2013; Depradine and Lovell 2004; Dom et al 2013; Schmidt et al 2011). The information gleaned from this research was not very sensitive or reliable; however, it was invaluable in determining that climate conditions, mainly temperature and precipitation, are vital components in the spread of dengue as they both can have positive effects on the life cycle of the mosquito when conditions are optimal (Amarakoon 2006; Jones et al 2008; Messina et al 2014).

Research into risk assessment models was also conducted to aid public health professionals in determining the areas where there was increased risk of dengue transmission. The objective of this research was to determine the areas in which removal of breeding sites and site specific chemical spraying could both be applied to minimize the risk of dengue infection. The number of cases of dengue did not decrease as the researchers discovered that the human-to-vector factor at the household level was also vital to the increased disease burden (Pruss et al 2016). The Aedes aegypti mosquito had adapted its life cycle to be intrinsically entwined with the human urban environment (Schmidt et al 2013). Essentially the mosquito vector created a new niche for a breeding site within the plastic containers ubiquitous around the yards of homes in urban centres in the developing world (Rodriguez-Roche and Gould 2013).

It became evident from synthesizing the empirical findings from public health research on dengue that the complex relationship of vector – environment – human / host needed further exploration to determine new and innovative methods to combat the health hazard (Birkmann et al 2013). The literature showed that a number of factors in combination increased the incidence of dengue disease within a population and that these factors fell within the parameter of the determinants of health that were being researched separately: the ecological, environmental and the social determinants of health. Of the social determinants of health, poverty, education level, housing quality, and access to improved water and sanitation were deemed important to the increased vulnerability to transmission of the dengue virus. Temperature, precipitation, land use and population density were also primary factors influencing the rate of dengue infection in a region. A combination of these factors in their optimal ranges appeared to render a population more vulnerable to an increased risk of the incidence of dengue disease (Dickin and Schuster-Wallace 2014; Dom et al 2013; Eisenberg et al 2007; Fullerton et al 2014; Pruss-Ustun et al 2016).

The objective of this thesis was to determine the validity of the tool for the island of Dominica, a country endemic for dengue disease. The island of Dominica was chosen as it differs greatly from the countries in which the WADI tool has previously been tested (for example, Brazil and Malaysia), as it is a country with a small geographic footprint and a small population. The results of the analysis for the larger countries proved WADI to be an effective tool for synthesizing the various contributors to vulnerability and visually presenting them in map form. However, would the WADI also be effective in determining vulnerability to dengue disease in Dominica, a country which differs significantly in the size of the land mass, population and in incidence of disease? The WADI is an attractive tool for such countries and its effectiveness in such a country due to be validated. Further to that, could the model be more rigorously validated? Does the WADI perform as well as a non-index model? Do indicators chosen via a literature review show them to be significant when regressed on the vulnerability measure? These questions were addressed, extending the body of knowledge on geospatial vulnerability measures in small countries and adding more rigour to the validation of the WADI in particular.

The WADI provided the framework for populating the index. The vulnerability components were divided into two categories: the susceptibility components, essentially the social determinants of health; and the exposure components, which comprised of the ecological and environmental determinants of health. The WADI for the island of Dominica included the four components of the exposure described in the literature: land use, precipitation, temperature, and population density for each of the ten parishes (or districts). These factors support the existence of the vector and transmission of the disease. The indicators for susceptibility were four, chosen from a list provided by the authors of the WADI for dengue and which the literature showed were indicators that were correlated to an increased risk to exposure to infection of the dengue virus. As a result, indicators such as female progression to secondary school / household education, unimproved sanitation facilities / access to potable water, age (<15 and >60) and socio-economic status were included in the WADI for Dominica per parish. The visual maps were generated through QGIS, a GIS software package.

Using negative binomial regression the computed WADI values were analyzed against the incidence of dengue disease per parish as a proxy for vulnerability to determine the best weighting between exposure and susceptibility, and that best candidate formulation of the index was evaluated for goodness of fit. The results of the analysis indicated that the WADI values have a significant relationship with vulnerability although the relationship was not found to be a strong as in the countries where the WADI was originally tested. An alternate, multivariate parsimonious model was built using the same indicators that populated the WADI but without transforming and normalizing them into an index. Similarly, the data sets were analyzed using negative binomial regression and investigated for goodness of fit. The results of the analysis of the alternate model indicated that there was no meaningful loss of fit due to the use of the index methodology versus a traditional statistical modelling approach. Among the components of the index, temperature, land use, age and poverty were found to be the most significant contributors to vulnerability to dengue as measured by the incidence of dengue disease per parish (spatial) and per month (temporal) on the island of Dominica.

A research approach that includes a combination of a vulnerability assessment and mapping using GIS as well as including the complex relationship of the social / ecological / and environmental determinants of health is beginning to be used, to a greater extent, for public health research. As incorporating a more inclusive approach to public health research into infectious diseases is in its infancy stage, dramatic gains can be achieved. As a low-cost, practical tool that uses publicly available data, the WADI can be used as a way to synthesize and explore the determinants of health in various combinations, customized to a specific area or region.

Furthermore, WADI could be used as a tool that complements early signal models for dengue and other water associated diseases. Additional uses could be for planning and prevention methods, which increasingly require incorporating the social with the biophysical determinants of health.

According to both authorities at the World Health Organization and at the Centers of Disease Control, dengue is a re-emerging and uncontrolled disease. As a result, with dengue there is clearly a need for more scientific research on the local, community-level influences that affect the infectious disease cycle and the intricate connections between those factors. Currently, the widespread primary preventive strategies against transmission of the disease include the use of mosquito repellents, mosquito coils, mosquito bed nets, protective clothing such as long sleeves and long pants, and regularly removing sources of stagnant water to destroy mosquito breeding sites. The most effective out of all of those preventive strategies in dengue prevention and control is the removal of stagnant water. According to Mustafa et al 2015 and Simmons et al 2015 their studies report that the dengue vaccine may not be as effective as first hoped and Flash et al 2016 state that the testing of the efficacy rates of Phase III of the vaccine trial is at only at a 25-35% effective level. With the latest information regarding the limits of an immunological response by Waggoner et al 2016 the potential for there to be large scale outbreaks and also, with the discovery of the latest serotype (DENV-V) as described by Mustafa et al 2015, it may be a bit longer than expected for actual pre-exposure prophylaxis. Therefore, the developing countries endemic for dengue still require these inexpensive, effective planning tools (Flash et al 2016; Mustafa et al 2015; Simmons et al 2015; and Waggoner et al 2016).

As a result, preventative interventions must be targeted and timed when there are limited resources to combat or treat dengue in endemic regions to ensure their efficacy (CDC 2016; WHO 2012; WHO 2009).

Attaining any meaningful level of prevention and control of dengue in the community will rely on the effectiveness of initiatives to educate the public about dengue - how it is transmitted, its symptoms - and on delving into control of the mosquito vector breeding sites by removing stagnant water. However, complicating matters further is the need to have an effective household environmental sanitation network that includes an adequate potable water supply, ensuring that storage of standing water in containers, a prime breeding site for Aedes aegypti, is not a vital necessity for the household. Regardless of the solutions chosen to address the factors rooted in the environment / ecological determinants of health, the cause is often also deeply entrenched in the social determinants of health. Further research is needed to develop an understanding of the confluence where all of these factors meet and increase vulnerability in a region.

Similar to many of the infectious diseases that cause an increased risk of morbidity and mortality in the developing world, dengue often occurs with an infection from another NTD simultaneously, rendering the long-term outlook a much bleaker picture. This also highlights the crucial necessity of effective public health interventions. Given the importance of the burden of disease from neglected emerging and re-emerging infectious diseases further research is needed. Exploration requires delving into new and emerging innovative solutions. The development of the WADI signals the beginning of a new holistic approach to public health research into infectious diseases. A research model with an environmental / ecological / social conceptual framework and a mapping tool to generate a visual representation is inventive. However, the model would have to advance further and have a demonstrated fitness in adaptability to various disease contexts.

At the time of submission of this thesis, there is currently no published thesis /research study that has tested the index model, the Water Associated Disease Index, on a small island nation. The key finding of the thesis was the applicability of the WADI for assessing vulnerability to an increased risk of dengue virus transmission. This was significant as in the literature, dengue has been studied in Latin America and the Caribbean on the large islands or mainland Guyana and on four of the small island nations; however, there has been no study into dengue solely in the Commonwealth of Dominica. At present, there is no published thesis / research study that incorporates the eco-health model with regards to dengue research on any of the small island nations of the Caribbean. Lastly, there is currently no published thesis /research study that has explored or created GIS generated maps of vulnerability to an increased risk of dengue virus transmission in any of the small island nations of the Caribbean including the Commonwealth of Dominica.

The value of WADI is its ability to aid researchers to conduct research into water borne infectious diseases in regions that are data-poor. The WADI allows for using proxy indicators for the preferred component indicators that make up the index when ideal data sources are not available. The study has highlighted the need for improvement in this area, as outlined in the limitations sections of the discussion. Moving forward it would be beneficial in terms of increasing the accuracy of the index model to build a more comprehensive picture of what the literature identifies as risk factors. Possibly, a mixed method research study that allowed for the collection of a range of data sets that fall within the umbrella of the social determinants of health might yield better candidate factors. For example, a survey or questionnaire might allow for attaining a more accurate picture of components such as the level of uptake of public health education materials related to dengue. For this WADI, the proxy used was the percentage of female education to secondary school per parish. The assumption is that health promotion to inform residents of ways in which they can reduce their risk of transmission is more likely to be understood when the female head of the family has a post-secondary education. However, there may be a host of other usable factors that may be unrelated to education that can be gleaned from qualitative data analysis.

This thesis has also uncovered that the choice of proxies is not as straightforward as the WADI methodology would indicate at first glance. A finding of the regression analysis of the non-index model was that four of the components which the literature would suggest are a perfect fit for this application showed surprising results in the statistical analysis. Population density, age, land use and poverty, all of which were integral to the other iterations of the WADI and corroborated in the literature were deemed to have the opposite effect according to the analysis. For this thesis, the WADI model outperformed the non-index model in terms of statistical significance and goodness of fit; however, this is still an important discussion to move forward. It may be possible that as research into dengue and other vector amplified water borne diseases continues a number of factors that were thought to be drivers of vulnerability could be put into question and require further research. In particular, it is possible that some of the factors which have worked in other geographies are not as applicable in a small island setting or, perhaps, not applicable for the island of Dominica in particular.

Geographic Information Systems were not designed for public health in particular. GIS maps are relatively still in their infancy in terms of public health research into infectious disease. Within this realm, it provides a valuable way to theorize about factors that could have an impact on negative health outcomes or to identify spatial issues that need to be further investigated. As the technology improves so will the ability to fine tune it to have a more accurate assessment of spatial and temporal data sets. Also, across disciplines there are potentially new ways of conceptualizing and communicating vulnerability to dengue and other infectious diseases which will be a welcome addition to mitigating the morbidity and mortality of the disease. Technology designed for one purpose or discipline might have a beneficial use to public health research. This opens up the dialogue for a multi-disciplinary approach to infectious disease prevention and using emerging technology in innovative ways.

The same insect vector, the Aedes aegypti mosquito, which transmits dengue is also the carrier of the Chikungunya and the Zika virus (and also yellow fever). Both Chikungunya and Zika viruses are currently causing outbreaks in the Caribbean, including Dominica. Therefore any tool that shows vulnerability to one will also be effective for the other infectious diseases and can aid in targeted measures that promote infection control. Further research is needed to characterize the epidemiology of dengue in small island nations and to better understand the factors involved in differences in vulnerability to dengue across small island nations.

There has been a shift in public health research to approaches that are more comprehensive in terms of the ecohealth model. It incorporates the elements of the all aspects that facilitate the interaction between the host, the vector, the disease agent and the environment. Infectious disease propagation, disease control, human actions and public health intervention are all taken into consideration in the research. Further research is needed to study the impact of environmental, social and ecological dynamics on humans, mosquitoes and dengue virus on emergence of dengue outbreaks. This thesis provides an impetus for further investigation of clusters of disease and risk factors in these vulnerable areas. Further studies of the factors that operate at fine spatial scales are vital for understanding of the spatial and temporal patterns of dengue in the study area.

References

Adger, W., Brooks, N., Bentham, G., Agnew, M. (2004). *New Indicators of Vulnerability and Adaptive Capacity*. Technical Report 7 [pdf] Tyndall Centre for Climate Change. Available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.112.2300&rep=rep1&type=pdf. [Accessed 25th April 2016].

Adger, W. (2006). Vulnerability. *Global Environmental Change.* 16 (3), pages 268-281.

Alsan, M., Westerhaus, M., Herce, K., Nakashima K., Farmer, P. (2011). Poverty, Global Health and Infectious Disease: Lessons from Haiti and Rwanda. *Infectious Disease Clinics of North America.* 25 (3), pages 611-622.

Amarakoon, A., Chen, A., Rawlins, S. (2004). Dengue Epidemics: Its Association with Precipitation, Temperature and its Seasonality in Caribbean Countries. *West Indian Medical Journal*. 53(2), pages 60-68.

Amarakoon, D., Chen, A., Rawlins, S., Chadee, D. (2006). Climate Change Impact on Dengue: The Caribbean Experience. *Climate Study Group, University of the West Indies, Mona, Jamaica*. Pages 66-76.

Anderson, K. (2007). Burden of Symptomatic Dengue Infection in Children at Primary School in Thailand: a Prospective Study. *Lancet*. 369 (9571), pages 1452-1459.

Aagaard-Hansen, J. and Chaignant, C. (2010) Neglected Tropical Diseases: Equity and Social Determinants. *Population Health Improvement Research Network*, *World Health Organization*. Pages 135-159.

Arcari, P., Tapper, N., Pfueller, S. (2007). Regional Variability in Relationships Between Climate and Dengue/DHF in Indonesia. *Singapore Journal of Tropical Geography*. Volume 8, Issue 3, pages 251-272.

Arredondo, A. and Orozco, E. (2012). Application of the Eco-health Model to Translate Knowledge into Action in the Health Sciences. *Environmental Health Perspectives*. Volume 120, Issue 3, pages 104-106.

Arunachalam, N, Tana, S., Espino, F., Kittayapong, P., Abeyewickreme, W., Wai, K., Tyagi, B., Kroeger, A., Sommerfeld, J., and Petzold, M. (2014). Eco-bio-social Determinants of Health of Vector Breeding: A Multi-country Study in Urban and Peri- Urban Asia. *Bulletin of the World Health Organization.* Volume 14, pages 173-184.

Ayukepi, J., Oyero, O., Nnukwu, S., Mesumbe, H., and Fobisong, C. (2017). Value of Routine Dengue Diagnosis in Endemic Countries. *World Journal of Virology*. Volume 6(1), pages 9-16.

Barkin, S. and Schlundt, D. (2011). The Challenge Facing Translation of Basic Science Into Clinical and Community Settings to Improve Health Outcomes. *Environmental Health Perspectives.* Volume 119 (10), pages 418-420.

Barrera, R., Amador, M., Clark, G. (2006). Ecological Factors Influencing Aedes aegypti Productivity in Artificial Containers in Salinas, Puerto Rico. *Journal of Medical Entomology*. Volume 43 (3), pages 484-492.

Bates, I., Fenton, C., Gruber, J., Lalloo, D., Medina Lara, A., Squire, S., Theobald, S., Thomson, R., Tolhurst, R. (2004). Vulnerability to Malaria, Tuberculosis, and HIV/AIDS Infection and Disease. Part 1: Determinants Operating at Individual and Household Level. *Lancet Infectious Diseases.* Volume 4(5), pages 267-277.

Batterman, S., Eisenberg, J., Hardin, R., Kruk, M., Lemos, M. (2009). Sustainable Control of Water-Related Infectious Diseases: A Review and Proposal for Interdisciplinary Health-Based Systems Research. *Environmental Health Perspective*. Volume 117, number 7, pages 1023 - 1032.

Bennett, S., Drummond, A., Kappan, D., Suchard, M., Munoz-Jordan, J., Pybus, O., Holmes, E., Gubler, D. (2010). Epidemic Dynamics Revealed in Dengue Evolution. *Molecular Biology and Evolution.* Volume 4, pages 811-818.

Bhatt, S., Gething, B., Brady, O., Messina, J., Farlow, A., Moves, C., Drake, J., Brownstein, J., Hoen, A., Sanko, O. (2013). The Global Distribution and Burden of Dengue. *Nature.* Volume 496 (7446), pages 504-507.

Bircher, J. and Kuruvilla, S. (2014). Defining Health by Addressing the Individual, Social and Environmental Determinants of Health. *Journal of Public Health Policy.* Volume 35(3), pages 363-386.

Birkmann, J. (2007). Risk and vulnerability indicators at different scales: Applicability, usefulness, and Policy Implication. *Environmental Hazards*. Volume 7 (1), pages 20-31.

Birkmann, J., Cardonna, O., Carreno, M., Barbat, A., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M., Alexander, D., Zeil, P., and Welle, T. (2013). Framing Vulnerability, Risk and Societal Responses: the MOVE Framework. *Natural Hazards*. Volume 67 (2), pages 193-211.

Blas, E., and ,Kurup A. (2010). *Equity, Social Determinants and Public Health Programmes.* World Health Organization, Geneva [pdf]. Available at http://apps.who.int/iris/bitstream/10665/44289/1/9789241563970_eng.pdf . Accessed October 8th, 2015.

Bleakley H. (2007). Disease and Development: Evidence from Hookworm Eradication in the American South. *Quarterly Journal of Economics*. Volume122 (1), pages 73-117.

Boischio, A., Sanchez, A., Orosz, A., Charron, D. (2009). Health and Sustainable Development: Challenges and Opportunities of Ecosystem Approaches in Prevention and Control of Dengue and Chagas Disease. *Cadernos de Saude Publica*. Volume 25 (1), pages 149-154.

Brady, O., Gething, P., Bhatt, S., Messina, J., Brownstein, J. (2012). Refining the Global Spatial Limits of Dengue Virus Transmission by Evidence-Based Consensus. *PLoS Neglected Tropical Disease*. Volume 6(8), pages 1760-1768.

Braga, C., Luna, C., Martelli, C., Souza, W., Cordeiro, M. (2010). Seroprevalence and Risk Factors for Dengue Infection in Socio-economically Distinct Areas of Recife. *Acta Tropica*. Volume 113 (3), pages 234-240.

Brathwaite-Dick, O., San Martin, J., Montoya, R., Del Diego, J., Zambrano, B., Dayan, G. (2010). The History of Dengue Outbreaks in the Americas. *American Journal of Tropical Medical Hygiene.* Volume 87(4), pages 584-593.

Brooks, N., Adger, W., Kelly, P. (2005). The Determinants of Vulnerability and Adaptive at the National Level and Implications for Adaptation. *Global Environmental Change*. Volume 15, Issue 2, pages 151-163.

Bunch, M., Morrison, K., Parkes, M., Venema, H. (2011). Promoting Health and Well-being by Managing for Social–ecological Resilience: The Potential of Integrating Eco-health and Water Resources Management Approaches. *Ecological Society* 16(1), pages 81-92.

Camara, F., Gomes, A., dos Santos, G., Camara, D. (2009). Climate and Dengue Epidemics in State of Rio de Janeiro. *Revista Sociedade Brasileira Medicina Tropicale*. Volume 42 (2), pages 137-140.

Cameron, A. and Trivedi, P. (2013). *Regression Analysis of Count Data, Second Edition*. Cambridge University Press, New York.

Caprara, A., Lima, J., Marinho, A., Calvasina, P., Landim, L., Sommerfeld, J. (2009). Irregular Water Supply, Household Usage and Dengue: a Bio-social Study in the Brazilian Northeast. *Cadernos de Saude Publica*. Volume 25(1), pages 125-136.

Cassidy-Seyoum, S. (2014). *Neglected Tropical Disease: Latin America and the Caribbean's Silent Killer*. Council on Hemispheric Affairs, Washington, DC.

Cattand, P., Desjeux, P., Guzman, M., Jannin, J., Kroeger, A., Medic, A. (2006). *Tropical Diseases Lacking Adequate Control Measures: Dengue, Leishmaniasis, and African trypanosomiasis*. In: Disease Control Priorities Project. Washington, DC, International Bank for Reconstruction and Development/World Bank.

Centers for Disease Control. (1990). Case Definitions for Public Health Surveillance. *Morbidity and Mortality Weekly.* Volume 39 (13), pages 10-12.

Centers for Disease Control and Prevention. (2016). *Dengue Home Page*. [pdf]Available from http://www.cdc.ncidod/dvid/dengue/index/htm, [Accessed November 12, 2015.]

Chadee, D., Mahabir, R., Sutherland, J. (2012). Dengue Fever Epidemiology and Control in the Caribbean: A Status Report. *Caribbean Medical Journal*. Volume 74, pages 17-21.

Chadee, D., Shivnauth, B., Rawlins, S. Chen, A. (2007). Climate, Mosquito Indices and The Epidemiology of Dengue Fever in Trinidad (2002–2004). *Annual Tropical Medical Parasitology.* Volume, 101 (1), pages 69-77.

Chang A., Parrales, M., Jimenez, J., Sobieszczyk, M., Hammer, S., Copenhaver, D., Kulkarni, R. (2009). Combining Google Earth and GIS mapping technologies in a dengue surveillance system for developing countries. *International Journal of Health Geography*. Volume 8 (49), pages 1-11.

Chao D., Longini I., and Halloran M. (2013) The Effects of Vector Movement and Distribution in a Mathematical Model of Dengue Transmission. *PLoS ONE.* 8(10), pages 760-769.

Chaterji S., Allen J., Chow A., Leo Y., Ooi E. (2011) Evaluation of the NS1 rapid test and the WHO dengue classification schemes for use as bedside diagnosis of acute dengue fever in adults. *American Journal of Tropical Medicine and Hygiene*. 84(2), pages 224–228.

Chen, S., Hsieh, M. (2012). Modelling the Transmission Dynamics of Dengue fever: Implications of Temperature Effects. *Science of Total Environments*. Volume 431, pages 395-391.

Colwell, R., and Patz, J. (2005). *Climate, Infectious Disease and Health*. American Academy of Biology, Washington, DC, USA.

Commission on the Social Determinants of Health (CSDH). (2008). *Closing the gap in a generation: Health equity through action on the social determinants of health.* Final Report of the Commission on Social Determinants of Health. Geneva: World Health Organization.

Committee for the Protection of Human Subjects Guidelines (CPHS). (2014). *Research Involving the Secondary Use of Existing Data*. University of California, Berkeley.

Commonwealth of Dominica. (2000). *National Census Report.* Caricom Capacity Development Programme, Commonwealth of Dominica.

Commonwealth of Dominica. (2011). *Population and Housing Census*. Commonwealth of Dominica.

Commonwealth of Dominica. (2010). *Country Poverty Assessment*. Commonwealth of Dominica.

Dean, H., Williams, K., and Fenton, K. (2013). From Theory to Action: Applying the Social Determinants of Health to Public Health Practice. *Public Health Reports.* Volume 128, supplement 3, pages 1-4.

De Mattos, A., Caiaffa, W., Assuncao, R., Proietti, F. (2007). Spatial vulnerability to dengue in a Brazilian urban area during a 7-year surveillance. *Journal of Urban Health*. Volume 84 (3), pages 334-345.

De Anglis, D., Presanis, A., Birrell, P., Tomba, G., House, T. (2015) Four Key Challenges in Infectious Modelling Using Data from Multiple Sources. Epidemics. Volume 10, pages 83-87.

De Plaen, R., and Kilelu, C. (2004). From Multiple Voices to a Common Language: Ecosystem Approaches to Human Health as an Emerging Paradigm. *EcoHealth*. Volume 1, supplement 2, pages 73-78.

Depradine, C. and Lovell, E. (2004). Climatological variables and the incidence of Dengue fever in Barbados. *International Journal of Environmental Health*. Volume 14 (6), pages 429-441.

Dickin, S. and Schuster-Wallace, C. (2014). Assessing Changing Vulnerability to Dengue in Northeastern Brazil Using a Water Associated Disease Index Approach. *Global Environmental Change*. Volume 29, pages 155-164.

Dickin, S., Fullerton, L., Schuster-Wallace, C. (2013). Developing a Vulnerability Mapping Methodology: Applying the Water Associated Disease Index in Malaysia. *PlosOne*. Volume 8(5), e36594,pages 1-11.

Dom, N., Ahmad, A., Ishak, A., Ismail, R. (2013). Assessing the Risk of Dengue Fever Based on the Epidemiological, Environmental and Entomological Variables. *Procedia-Social and Behavioral Sciences*. Volume 105, pages 183-194.

Dom, N., Abu Hassan, A., and Rodziah, I. (2013). Habitat Characterization of Aedes Species Breeding in Urban Hotspot Area. *Procedia-Social and Behavioral Sciences*. Volume 85, pages 100-109.

Dominica Hotel and Tourism Association (DHTA) (2000) *Destination Dominica*. Visitor Magazine of the Dominica Hotel and Tourism Association. Commonwealth of Dominica.

Dorigatti, I., Cauchemez, S., Pugliese, A., Ferguson, N. (2012). A New Approach to Characterising Infectious Disease Transmission Dynamics from Sentinel Surveillance: Application to the Italian 2009–2010 A/H1N1 Influenza Pandemic. *Epidemics.* Volume 4(1), pages 9–21.

Egger, J. and Coleman, P. (2007) Age and Clinical Dengue Illness. *Emerging Infectious Diseases.* Volume 13(6), pages 924-925.

Eisenberg, J., Desai, M., Levy, K., Bates, S., Liang, S. (2007). Environmental determinants of infectious disease: a framework for tracking causal links and guiding public health research. *Environmental Health Perspective.* Volume 115(8), pages 1216-1223.

Fauci, D. and Morens D. (2012) The Perpetual Challenge of Infectious Diseases. *New England Journal of Medicine.* Volume 366, pages 454-461.

Fielding, J., Teutsch, S., Breslow, L. (2010). A framework for public health in the United States. *Public Health Reviews*. Volume 32 (1), pages 174-189.

Focks, D. and Barrera, R. (2007). *Dengue Transmission Dynamics: Assessment and Implications for Control.* Report of the Scientific Working Group Meeting on Dengue. World Health Organization, Geneva, Switzerland.

Frieden, A. (2010). Framework for Public Health Action: The Health Impact Pyramid. *American Journal of Public Health*. Volume 100(4), pages 590-595.

Fullerton, L., Dickin, S., Schuster-Wallace, C. (2014). *Mapping Vulnerability to Dengue Using Water Associated Disease Index.* United Nations University, Hamilton, Canada.

Fussel, H. (2007). Vulnerability: A Generally Applicable Conceptual Framework for Climate Change Research. *Global Environmental Change*. Volume 17, issue 2, pages 155-167.

Garcia-Betancourt, T., Higuera-Mendieta, D., Gonzalez-Uribe, C., Cortes, S., Quintero, J. (2015**).** Understanding Water Storage Practices of Urban Residents of an Endemic Dengue Area in Colombia: Perceptions, Rationale and Socio-Demographic Characteristics. *PlosOne*. Volume 10(6), e0129154.

Global Administrative Areas (GADM) (2015) Available from http://gadm.org [Last accessed November 12, 2017.]

Getis, A., Morrison, A., Gray, K., Scott, T. (2003). Characteristics of the Spatial Pattern of the Dengue Vector, Aedes aegypti, in Iquitos, Peru. *American Journal of Tropical Medical Hygiene*. Volume 69(5), pages 494-505.

Gnanakan, K. (2004). Environmental Determinants of Health. *Global Perspectives in Health.* Volume 1, pages 32-43.

Greenwood, M. and de Leeuw, S. (2009). Teachings from the land: Indigenous people, our health, our land, and our children. *Canadian Journal of Native Education*. Volume 30(1), pages 48-53.

Griffiths, S. and Zhou, X. (2012). *Global Report for Research on Infectious Diseases of Poverty*. World Health Organization, Geneva.

Gubler, D. (2006). Dengue / Dengue Hemorrhagic Fever: History and Current Status. *Novartis Foundation Symposium*. Volume 277, pages 3-16.

Gubler, D. (2002). Epidemic dengue, dengue hemorrhagic fever as a public health, social and economic problem in the 21st century. *Trends in Microbiology.* Volume 10 (2), pages 100-103.

Gubler, D. (2011). Dengue, Urbanization and Globalization: The Unholy Trinity. *Tropical Medicine and Health.* Volume 39 (4), pages 3-11 .

Gubler, D. and Clark, G. (1995*)* Dengue / Dengue Hemorrhagic Fever: The Emergence of a Global Public Health Problem. *Emerging Infectious Diseases.* Volume 1(2), pages 18-21.

Gubler, J. and Ooi, E. (2009). Global Spread of Epidemic Dengue: The Influence of Environmental Change. *FutureVirology.* Volume 4(6), pages 34-39.

Guzman, M., Halstead, S., Astrob, H., Buchy, P., Farrar, J., Gubler, D., Hunsperger, E. (2010). Dengue: A Continuing Global Threat. *National Review of Microbiology*. Volume 8, supplement 12, pages 7-16.

Guzman, M., Kouri, G., Bravo, J., Valdes, L., Vazquez, S., Halstead, S. (2002). Effect of Age on Outcome of Secondary Dengue 2 Infections. *International Journal of Infectious Diseases*. Volume 6(2), pages 118-124.

Hagenlocher, M., Delmelle, E., Casas, I., and Kienberger, S. (2013). Assessing Socioeconomic Vulnerability to Dengue Fever in Cali, Colombia: Statistical vs Expert-based Modeling. *International Journal of Health Geography***.** Volume 12 (36), pages 1-14.

Haines, A., Kovats, R., Campbell-Lendrum, D., Corvalan, C. (2006). Climate Change and Human Health: Impacts, Vulnerability, And Mitigation. *Lancet*. Volume 367(9528), pages 2101-2109.

Halstead, S. (2007). Dengue. *Lancet*. Volume 370(9599), pages 1644-1652.

Hales, S., de Wet, N., Maindonald, J., Woodward, A. (2002). Potential Effect of Population and Climate Changes on Global Distribution of Dengue Fever: An Empirical Model. *Lancet*. Volume 360 (9336), pages 830-834.

Hammond, S., Balmaseda, A., Perez, L., Tellez, Y., Saborio, S. (2005). Differences in Dengue Severity in Infants, Children, and Adults in a 3-year Hospital-based Study in Nicaragua. *American Journal of Tropical Medicine and Hygiene*. Volume 73 (6), pages 1063-1070.

Hijmans, R., Cameron, S., Parra, J., Jones, P., and Jarvis, A. (2005). Very High Resolution Interpolated Climate Surfaces for Global Land Areas. *International Journal of Climatology*. Volume 25, issue 15, pages 1965-1978.

Hinkel, J. (2011). Indicators of Vulnerability and Adaptive Capacity: Towards a Clarification of the Science–Policy Interface. *Global Environmental Change.* Volume 21, issue 1, pages 198-208.

Horstick, O., Tozan, Y., Wilder-Smith, A. (2015). Review: Is Dengue Still A Neglected Tropical Disease? *PlosOne Neglected Tropical Diseases*. Volume 9(4): e0003632.

Hotez, P. (2011). *The Neglected Tropical Diseases and the Neglected Infections of Poverty: Overview of Their Common Features, Global Disease Burden and Distribution, New Control Tools and Prospects for Elimination*. National Library of Medicine, George Washington University.

Hotez, P. (2013). *Forgotten People, Forgotten Diseases: The Neglected Tropical Diseases and Their Impact on Global Health and Development*. American Society for Microbiology Press, Washington, USA, Library of Congress.

Hotez, P., Fenwick, A., Savioli, L., Molyneux, D. (2009). Rescuing the Bottom Billion Through Control of the Neglected Tropical Diseases. *Lancet*. Volume 373 (9474), pages 1570-1575.

Hotez, P., Bottazzi, M., Franco-Paredes, C., Ault, S., Periago, M. (2008). The neglected tropical diseases of Latin America and the Caribbean: a review of disease burden and distribution and a roadmap for control and elimination. *PLoS Neglected Tropical Diseases*. Volume 2 (9), e300.

Hurlimann, E., Schur, N., Boutsika, K., Stensgaard, A., Laserna de Himpsl, M. (2011). Toward an Open-Access Global Database for Mapping, Control, and Surveillance of Neglected Tropical Diseases. *PLoS Neglected Tropical Disease.* Volume 5(12), e1404.

Institute for Health Metrics and Evaluation (IHME). (2017). *Mortality from Infectious Disease Between 1990-2015.* Institute for Health Metrics and Evaluation. Available at http://www.healthdata.org/ [Accessed December 2016].

Institute of Medicine Forum (IoMF). (2011). *Microbial Threats. The Causes and Impacts of Neglected Tropical and Zoonotic Diseases.* National Academy Press, Washington, DC, USA.

Intergovernmental Panel on Climate Change. (2007). *Impacts, Adaptation and Vulnerability*. Cambridge, UK, and New York, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). 2008. *Climate Change 2007: The Physical Science Basis.* Cambridge, UK, and New York, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Cambridge, UK, and New York, NY, USA: Cambridge University Press.

International Development Research Centre (IDRC). (2010). *EcoHealth Works: Infectious Diseases.* International Development Research Centre Publications, Canada.

Johansson, M., Dominici, F., Glass, G. (2009). Local and Global Effects of Climate on Dengue Transmission in Puerto Rico. *PLoS Neglected Tropical Disease*. Volume 3(2): e382.

Jones, K., Patel, N., Levy, M., Storeygard, A., Balk, D., Gittleman, J. (2008). Global Trends in Infectious Diseases. *Nature*. Volume 451, pages 990-993.

Jury, M. (2008). Climate Influence on Dengue Epidemics in Puerto Rico. *International Journal of Environmental Health Research.* Volume 18(5), pages 323-334.

Knock, E. and O'Neill, P., (2014). Bayesian Model Choice for Epidemic Models with Two Levels of Mixing. *Biostatistics.* Volume 15 (1), pages 46–59.

LaBeaud, A.(2008). Why Arborviruses Can be Neglected Tropical Diseases. *PlosOne Neglected Tropical Diseases*. Volume 2(6), e247.

Lau, C. (2010). *Urbanization, Climate Change, and Leptospirosis: Environmental Drivers of Infectious Disease Emergence*. University of Queensland Press, Australia. Pages 83-87

Lau, M., Marion, G., Streftaris, G., Gibson, G. (2014). New Model Diagnostics for Spatio-temporal Systems in Epidemiology and Ecology. *Journal of the Royal Society Interface*. Volume 11 (93), pages 28-39.

Law, M. (2005). Reduce, Reuse, Recycle: Issues in the Secondary Data Use of Research Data. *IASSIST Quarterly*. Spring Volume, pages 5-10.

Mackey, T., Liang, B., Cuomo, R., Hafen, R., Brouwer, K. (2014). Emerging and Re-emerging Neglected Tropical Diseases: A Review of Key Characteristics, Risk Factors. *Clinical Microbiology Review*. Volume 27 (4), pages 949-979.

Malavige, G. (2006). Patterns of Disease Among Adults Hospitalized with Dengue Infections. *Quarterly Journal of Medicine*. Volume 99 (5), pages 299-305.

Marmot, M., Bell, R., Houweling, T., and Taylor, S. (2008). Closing the Gap in a Generation: Health Equity Through Action on the Social Determinants of Health. *Lancet*. Volume 372 (9650), pages 1661-1669.

Matheus, S., Chappert, J., Cassadou, S., Berger, F., Labeau, B., Bremand, L., Winicki, A., Huc-Anais, P., Quenel, P., Dussart, P. (2012) Virological Surveillance of Dengue in Saint Martin and Saint Barthélemy, French West Indies. *The American Society of Tropical Medicine and Hygiene*. Volume 86(1), pages 159–165.

McMichael, A. (2004). Environmental and Social Influences on Emerging Infectious Diseases: Past, Present, Future. *Philosophical Transactions - The Royal Society of Publishing Biological Sciences*. Volume 359 (1447), pages 1049-1058.

Messina, J., Brandy, O., Scott, T., Zhou, C ., Pigott, D., Duda, K., Bhatt, S., Katzelnick, L., Howes, R., Battle, K., Simmons, C., Hay, S. (2014). Global Spread of Dengue Virus Types: Mapping the 70 Year History. *Trends in Microbiology*. Volume (22)3, pages 138-146.

Mikkonen, J. and Raphael, D. (2010). *Social Determinants of Health: The Canadian Facts*. York University School of Health Policy and Management. Pages 3-62.

Molyneux, D. (2010). Neglected Tropical Disease: Beyond the Tipping Point? *Lancet*. Volume 375 (908), pages 3-4.

Moreira, S. (2002). *Survey of the Aedes Mosquito in Dominica, WI*. Texas A and M University, Texas, USA.

Morens, D., Folkers, G., Fauci, A. (2004). The Challenge of Emerging and Re-emerging Infectious Diseases. *Nature*. Volume 430(6996), pages 242-249.

Morens, D. and Fauci, A. (2013) Emerging Infectious Diseases: Threats to Human Health and Global Stability. *PloS Pathogens*. Volume 9(7), e1003467.

Muhammad Azami, N., Salieh, S., Neoh, H., Syed Zakaria, S., Jamil, R. (2011). Dengue Epidemic in Malaysia: Not Predominantly an Urban Disease Anymore. *BioMedical Central Research Notes*. Volume 4(216), pages 1-4.

Murray, C., Vos, T., Lozano, R. (2012). Disability-Adjusted Life Years (DALYs) for 291 Diseases and Injuries in 21 rRgions, 1990–2010: A Systematic Analysis for the Global Burden of Disease Study. *Lancet*. Volume 380(9859), pages 2197-2223.

Murray, K., and Daszak, P. (2013). Human Ecology in Pathogenic Landscapes: Two Hypotheses on How Land Use Change Drives Viral Emergence. *Current Opinion in Virology*. Volume 3(1), pages 79-83.

Murray, N., Quam, M., and Wilder-Smith, A. (2013). Epidemiology of Dengue: Past Present and Future Prospects. *Clinical Epidemiology*. Volume 5, pages 299-309.

Mustafa, M., Rasotgi, V., Jain, S., Gupta, V. (2015). Discovery of fifth serotype of dengue virus (DENV-5): A new public health dilemma in dengue control. *Medical Journal of the Armed Forces India*. Volume 71 (1), pages 67-70.

Myers, S., and Patz, J. (2009). Emerging Threats to Human Health from Global Environmental Change. *Annual Review of Environmental Resources*. Volume 34, pages 223-252.

Natuzzi, E., Joshua, C., Shortus, M., Rubein, R., Dalipandra, T., Ferran, K., Aumua, A., Brodein, S. (2016). Defining Population Health Vulnerability Following an Extreme Weather Event in an Urban Pacific Island Environment: Honiara, Solomon Islands. *American Journal of Tropical Medicine*. Volume 95(2), pages 307-314.

Nathan, M., Dayal-Drager,R. (2006). *Recent Epidemiological Trends, The Global Strategy and Public Health Advances in Dengue.* World Health Organization Report on Dengue, World Health Organization Press, Geneva, Switzerland.

Neiderud, C. (2015) How Urbanization Affects the Epidemiology of Emerging Infectious Diseases. *Infection Ecology & Epidemiology.* (5), pages 402 to 409.

Niemeijer, D., and de Groot, R. (2008). *A Conceptual Framework for Selecting Environmental Indicator Sets.* Ecological Indices, 8.

Normile, D. (2013). Surprising New Dengue Virus Throws a Spanner in Disease Control Efforts. *Science*. Volume 342(6157), pages 415-420.

Ooi, E., Gubler, D., Nam, V. (2007). *Dengue Research Needs Related to Surveillance and Emergency Response.* Report of the Scientific Working Group Meeting on Dengue, Singapore.

Pan American Health Organization. (1999). *Communicable Diseases Program Division of Disease Prevention and Control. A Blueprint for Action for the Next Generation: Dengue Prevention and Control.* Pan American Health Organization, Washington, DC, USA.

Pan American Health Organization (PAHO). (2014). *Key Facts on Vectorborne Diseases*: *Dengue.* Pan American Health Organization, Washington, DC, USA.

Parkes, M. (2010). *EcoHealth and Aboriginal Health: A Review of Common Ground.* National Collaborating Centre for Aboriginal Health (NCCAH), Canada.

Parkes, M., Panelli, R., and Weinstein, P. (2003). Converging Paradigms for Environmental Health Theory and Practice. *Environmental Health Perspectives*. Volume 111(5), pages 669-675.

Pessanha, J., Caiffa, W., de Mattos Almeida, M., Brandao, S., Proietti, F. (2012). Diffusion Pattern and Hotspot Detection of Dengue in Belo Horizonte, Minas Gerais, Brazil. *Journal of Tropical Medicine.* Volume 2012, article ID 760951, pages 1-11.

Peterson, A., Martinez-Campos, C., Nakazawa, Y., Martinez-Meyer, E. (2005). Time-specific Ecological Niche Modelling Predicts Spatial Dynamics of Vector Insects and Human Dengue Cases. *Research in Social Tropical Medicine and Hygiene*. Volume, 99 (9), pages 647-655.

Phuanukoonnon, S., Mueller, I., Bryan, J. (2005). Effectiveness of dengue control practices in household water containers in Northeast Thailand. *Tropical Medicine of International Health*. Volume 10 (8), pages 755-763.

Pouliot S., Xiong, X., Harville , E., Paz-Soldan, V., Tomashek , K., Breart , G., Buekens , P. (2010). Maternal dengue and pregnancy outcomes: a systematic review. *Obstetrical and Gynecological Survey*. Volume 65(2), pages 107-118.

Pruss-Ustun A., Bos, R., Gore, F., Bartram, J. (2008). *Safer Water, Better Health: Costs, Benefits and Sustainability of Interventions to Protect and Promote Health*. World Health Organization Press, Geneva.

Pruss-Ustun, A., Wolf, J., Corvalan, C., Nelville, R., Bos, R., Neira, M. (2016). Disease Due to Unhealthy Environments: An Updated Esitmate of the Global Burden of Disease Attributable to Environmental Determinants. *Journal of Public Health*. Volume 39(3), pages 464-475.

Racloz, V., Ramsey, R., Tong, S., Hu, W. (2012). Surveillance of Dengue Fever Virus: A Review of Epidemiological Models and Early Warning Systems. *PLoS Neglected Tropical Diseases.* Volume 6(5), e1648.

Qin, J., Yu, G., Xia, T., Li, Y., Liang, X., Wei, P., Long. B., Lei, M., Tang, X., Zhang, Z. (2017) Spatio-Temporal Variation of Longevity Clusters and the Influence of Social Development Level on Lifespan in a Chinese Longevous Area (1982-2010). *International Journal of Environmental Research in Public Health*. Volume 14(7), pages 812-819.

QGIS (2016) *QGIS Training Manual*. [pdf] Available from: https://docs.qgis.org/testing/en/docs/user_manual/plugins/plugins_zonal_statistics.html. [Last accessed November 22nd, 2017.]

Reidpath, D., and Allotey, P. (2001). Data Sharing in Medical Research: An Empirical Investigation. *Bioethics*. Volume15(2), pages 125-134.

Rodriguez, R., Carasquilla, G., Porras, A., Galera, K., Yescas, J., Ruella, J. (2016).The Burden of Dengue and Financial Cost to Colombia 2010-2012. *American Journal of Tropical Medicine and Hygiene*. Volumne 94(5), pages 1065-1072.

Rodriguez-Barracher, I., Cordeiro, M., Braga, C., de Souza, W., Marquez, E., Cummings, D. (2011). From Re-Emergence to Hyperendemicity : The Natural History of the Dengue Epidemic in Brazil. *PloS Neglected Tropical Diseases*. Volume 5(1), e935.

Rodriguez-Roche, R., and Gould, E. (2013). Understanding the Dengue Viruses and Progress Towards Their Control. *Biomedical Research International*. Volume 2013, article ID 690835 .

Ruderman, M. (2013). *An introduction to The Ecological Model in Public Health*. John Hopkins Bloomberg School of Public Health, Baltimore, USA.

San Martin, J., Brathwaite, O., Zambrano, B. (2010). The Epidemiology of Dengue in the Americas Over the Last Three Decades: A worrisome Reality. *American Journal of Tropical Medicine and Hygiene*. Volume 82 (1), pages 128-135.

Schioler, K., and MacPherson, C. (2009). Dengue Transmission in the Small Island Setting: Investigations from the Caribbean Island of Grenada. *The American Society of Tropical Medicine and Hygiene*. Volume (81)2, pages 280-286.

Schmidt, W., Suzuki, M., Thiem, V., White, R., Tsuzuki, A., Yoshida, L., Yanai, H., Haque, U., Tho, L., Anh, D., Ariyoshi, K. (2011). Population Density, Water Supply, and the Risk of

Dengue Fever in Vietnam: Cohort Study and Spatial Analysis. *Plos Medicine*. Volume 8(8), e1001082.

Semenza, J., Suk, J., Estevez, V., Ebi, K., Lindgren, E. (2012). Mapping Climate Change Vulnerabilities to Infectious Diseases in Europe. *Environmental Health Perspectives*. Volume120 (3), pages 385-392.

Sessions O., Wilm A., and Kamaraj U. (2015) Analysis of Dengue Virus Genetic Diversity during Human and Mosquito Infection Reveals Genetic Constraints. *Neglected Tropical Diseases*. 9(9), pages 404 to 414.

Sharp, T., Tomashek, K., Read, J., Margolis, H., Waterman, S. (2017). A New Look at an Old Disease: Recent Insights into the Global Epidemiology of Dengue. *Current Epidemiological Reports.* Volume 4(1), pages 11-21.

Shepard, D., Coudeville, L., Halasa, Y., Zambrano, B., Dayan, G. (2011). Economic impact of dengue illness in the Americas. *American Journal of Tropical Medicine Hygiene*. Volume 84(2), pages 200-207.

Sherman, R., Henry, K., Tannenbaum, S., Feaster, D., Kobetz, E., Lee, D. (2014). Applying Spatial Analysis Tools in Public Health: An Example Using SaTScan to Detect Geographic Targets for Colorectal Cancer Screening Interventions. *Preventive Chronic Diseases*. Volume 11, pages 1-15.

Simmons, C., McPherson, K., Chau, N., Hoai Tam, D., Young, P., Mackenzie, J., Wills, B. (2015). Recent Advances in Dengue Pathogenesis and Clinical Management. *Vaccine*. Volume 33 (50), pages 7061-7068.

Spencer, D., Salagwaina, B., Wassenaar, D., Bull, S., Parker, M. (2015). Developing Ethical Practices For Public Health Research Data Sharing in South Africa: The Views and Experience From Diverse Sample of Research Stakeholders. *Journal of Empirical Research on Human Research Ethics*. Volume 10(3), pages 290-301.

Spiegel, J. (2011). *Looking Beyond the Lamp Post: Addressing Social Determinants of Neglected Tropical Diseases in Devising Integrated Control Strategies.* National Library of Medicine, Forum on Microbial Threats, Washington, DC, USA.

Stanaway, J., Shepard, D., Undurraga, E., Halasa, Y., Coffeng, L., Brady, O., Hay, S., Bedi, N. (2013). The Global Burden of Dengue: An Analysis From the Global Burden of Disease Study 2013. *Current Epidemiological Reports*. Volume16(6), pages 712-723.

Stone, A. (1969). *Smithsonian Biological Survey of Dominica: The Mosquitoes of Dominica.* Smithsonian Institution Press, Washington, DC, USA.

Strickman, D. and Kittayapong, P. (2002). Dengue and its Vectors in Thailand: Introduction to the Study and Seasonal Distribution of Aedes Larvae. *American Journal of Tropical Medical Hygiene*. Volume 67(3), pages 247-259.

Suaya, J., Sheppard, D., Beatty, M. (2007). *Dengue: Burden of Disease and the Cost of Illness*. Report of the Scientific Working Group Meeting on Dengue, World Health Organization, Geneva.

Suaya J., Shepard, D., Siqueira, J., Martelli, C., Lum, L., Tan, L., Kongsin, S., Jiamton, S., Garrido, F., Montoya, R., Armien, B., Hui, R. (2009). Cost of Dengue Cases in Eight Countries in the Americas and Asia: a Prospective Study. *American Journal of Tropical Medicine and Hygiene*. Volume 80(5), pages 846-855 .

Sutherst, R. (2004). Global Change and Human Vulnerability to Vector-borne Diseases. *Clinical Microbioliology Review*. Volume 17(1), pages 136-173.

The Association of Faculties of Medicine of Canada (AFMC). (2007). *Primer on Population Health. Public Health Ontario and the Association of Faculties of Medicine of Canada*. The Association of Faculties of Medicine of Canada, Canada.

Torres, J., Orduna, T., Pina-Pozas, M., Vazquez-Vega, D., Sarti, E. (2017). Epidemiological Characteristics in Dengue Disease in Latin America and the Caribbean: A Systematic Review. *Journal of Tropical Medicine*. Volume 2017, article ID 8045435,18 pages.

Trainor, T., and Dougherty, K. (2000). Selected Issues Concerning Disclosure Avoidance in the Context of User-defined Geography. *Statistical Journal of the UN Economic Commission for Europe*. Volume 17(2), pages 133-140.

Tran Van, H. (2011). Application of Mosquito-proof Water Containers in the Reduction of Dengue Mosquito Population in a Dengue Endemic Province of Vietnam. *Asian Pacific Journal of Tropical Disease*. Volume 1(4), pages 270-274.

Tran, H., Adams, J., Jeffery, J., Nguyen, Y., Vu, N. (2010). Householder Perspectives and Preferences on Water Storage and Use, with References to Dengue, in the Mekong Delta, Southern Vietnam. *International Health*. Volume 2(2), pages 136-142.

Tripathy, J. (2013). Secondary Data Analysis Issues and Challenges. *Iranian Journal of Public Health*. Volume 42(12), pages 1478-1479.

Tristao, I., and Cali, J. (2014). *It Can Be Done: An Integrated Approach for Controlling and Eliminating Neglected Tropical Diseases*. Inter-American Development Bank, Felipe Herrera Library.

United Nations. (2014). *Human Development Index.* 2014 Global Human Development Report, United Nations.

United Nations Development Program (UNDP). (2013). *Program Human Development Report Technical Notes*. United Nations Development Program.

Vos, T., Flaxman, A., Naghavi, M., Lozano, R., Michaud, C. (2012). Years Lived With Disability (YLDs) for 1160 Sequelae of 289 Diseases and Injuries 1990–2010: A Systematic Analysis for the Global Burden of Disease Study 2010. *Lancet*. Volume 380(9859), pages 2163-2196.

Waggoner, J., Balmaseda, A., Gresh, L., Sahoo, M., Montoya, M., Wang, C., Abeynayake, J., Kuan, G., Pinsky, B., Harris, E. (2016). Homotypic Dengue Reinfections in Nicaraguan Children. *Journal of Infectious Diseases.* Volume 214(7), pages 986-993.

Waltner-Toews, D. (2001) An Ecosystem Approach to Health and its Applications to Tropical and Emerging Diseases. *Saude Publica*. Volume 17, pages 23-36.

Weaver, S., and Reisen, W. (2010). Present and Future Aborviral Threats. *Antiviral Research*. Volume 85 (2), pages 328-345.

Webb, J., Mergler, D., Parkes, M., Saint-Charles, J., Spiegel, J. (2010). Tools for Thoughtful Action: the Role of Ecosystem Approaches to Health in Enhancing Public Health. *Canadian Journal of Public Health*. Volume 101(6), pages 439-441.

Wilder-Smith, A., and Gubler, D. (2008). Geographic Expansion of Dengue. *Medical Clinician of North America*. Volume 92 (6), pages 1377-1390.

Wilder-Smith, A., Ooi, E., Vasudevan, S., Gubler, D. (2010). Update on Dengue: Epidemiology, Virus Evolution, Antiviral Drugs and Vaccine Development. *Current Infectious Disease Report.* Volume 12(3), pages 157-164.

Wilkinson, P., Close, R., Crabbe, H. (2016). *Environmental Determinants of Disease*. Health Knowledge, Public Health Action Support Team, England and Wales.

Wood, H., Drebor, M., Dewailly, E., Dillon, L., Dimitrova, K., Forde, M., Grolla, A., Lee, E., Loftis, A. (2014). Seroprevalence of Seven Zoonotic Pathogens in Pregnant Women From the Caribbean. *The American Journal of Tropical Hygiene and Medicine*. Volume 91(3), pages 642-644.

Working Group for the Survey and Utilization of Secondary Data (AGENS) (2008). Good Practice in Secondary Data Analysis: Revision After Fundamental Reworking. *German Society for Social Medicine and Prevention*. Volume 70 (1), pages 54-60.

World Health Assembly. (2005). *International Health Regulations*. World Health Assembly. Volume 58(3).

World Health Organization. (2008). *International Classification of Functioning, Disability and Health.* World Health Organization, World Health Press, Switzerland.

World Health Organization .(2009). *Dengue: Guidelines for Diagnosis, Treatment, Prevention and Control.* World Health Organization, Geneva, Switzerland.

World Health Organization. (2009). *Neglected Tropical Diseases*. World Health Organization, World Health Press, Switzerland.

World Health Organization. (2011). *Dengue, Countries at Risk*. World Health Organization, Geneva, Switzerland.

World Health Organization. (2012). *Dengue and severe dengue*. *Factsheet N° 117*. World Health Organization, Geneva, Switzerland.

World Health Organization. (2013). *Sustaining The Drive To Overcome The Global Impact Of Neglected Tropical Diseases. W*orld Health Organization, Geneva, Switzerland.

World Health Organization. (2014). *World Urbanization Prospects.* World Health Organization, Geneva, Switzerland.

World Clim http://www.worldclim.org/WorldClim.

Wu, P., Guo, H., Lung, S., Lin, C., Su, H. (2007). Weather as an Effective Predictor for Occurrence of Dengue Fever in Taiwan. *Acta Tropical*. Volume 103 (1), pages 50-57.

Yang, K., LeJeune, J., Alsdorf, D., Lu, B., Shum, C., Liang, S. (2012). Global Distribution of Water Associated Infectious Diseases. *PLoS Neglected Tropical Diseases*. Volume 6(2), e1483.

Ypma, R., Bataille, A., Stegeman, A., Koch, G., Wallinga, J., van Ballegooijen,W. (2012) Unravelling Transmission Trees of Infectious Diseases by Combining Genetic and Epidemiological Data. *Proceedings of the Royal Society of London B: Biological Sciences.* Volume 279 (1728), pages 444–450.

APPENDIX 1: List of countries endemic to dengue (WHO 2000)

Countries or Territories in Which Dengue Fever or Dengue Haemorrhagic Fever is Known to Occur, by WHO Region, 1975–1996

African Region

Angola Burkina Faso Comoros Côte d'Ivoire Ethiopia Ghana Guinea Kenya Madagascar Mauritius Mozambique Nigeria Réunion Senegal Seychelles Sierra Leone South Africa United Republic of Tanzania Zaire

Region of the Americas

Antigua and Barbuda Aruba Bahamas Barbados Belize Bolivia Bonaire Brazil British Virgin Islands Colombia Costa Rica Cuba Curaçao Dominica Dominican Republic Ecuador El Salvador French Guiana Grenada Guadeloupe Guatemala Guyana Haiti Honduras Jamaica Martinique Mexico Montserrat Nicaragua Panama Paraguay Peru Puerto Rico St Kitts & Nevis St Lucia St Martin St Vincent & the Grenadines Suriname Trinidad & Tobago Turks & Caicos Islands United States of America Venezuela Virgin Islands of the United States

South-East Asia Region

Bangladesh India Indonesia Maldives Myanmar Sri Lanka Thailand Eastern Mediterranean Region Djibouti Pakistan Somalia Saudi Arabia Sudan

Western Pacific Region

Australia Brunei Darussalam Cambodia China Cook Islands Fiji French Polynesia Guam Kiribati Lao People's Democratic Republic Malaysia Marshall Islands Nauru New Caledonia New Zealand Niue Palau Papua New Guinea Philippines Samoa Singapore Solomon Islands Tokelau Tonga Tuvalu Vanuatu Viet Nam Wallis & Futuna Islands

Source: World Health Organization 2000 (Annex 1)

Appendix 2: Satellite Photograph of the Commonwealth of Dominica

Source: Google Maps

Appendix 3 Topographical Map of the Commonwealth of Dominica

Appendix 4 Road Map of Commonwealth of Dominica