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Climatic Risk Factors and Social Determinants of Dengue in the Caribbean and Central America: A Scoping Review

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2021

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
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## Abstract

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The Caribbean and Central America are highly endemic for dengue virus and experience periodic oscillations in relative incidence of dengue and dengue hemorrhagic fever. In recent years, the number of cases of dengue in this region has become alarming to public health officials as the number of reported cases of dengue has surpassed previous years' case numbers. The periodic severe outbreaks of dengue and dengue hemorrhagic fever in this region disproportionately affect the most vulnerable populations in this region. Major contributors to the transmission of this mosquito-borne viral disease include overpopulation, extreme weather events, urbanization, and poor sanitary conditions and public health infrastructure. There is growing literature around the potential association of climate change and the increasing transmission of vector-borne diseases including dengue and in some parts of the world. Climate change is expected to affect the known social determinants of dengue infection. This review seeks to summarize the literature around how climate change may affect the incidence of dengue in the Caribbean and Central American region.



**Key Words:** Dengue, Climate change, Social Determinants of Health, Central America, The Caribbean

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# Acknowledgements

I would first like to acknowledge and express my profound appreciation to my thesis advisor Dr. Saria Hassan of the Rollins School of Public Health and School of Medicine at Emory University. Thank you for your time spent instructing me and for your endless encouragement and wise counsel as I worked toward completing my MPH. Dr. Hassan’s counsel was always available whenever I ran into any difficulties or had question’s concerning my research, writing, career, and future goals. She consistently allowed this paper to be my own work but steered me in the right direction whenever needed. Thank you for your insightful conversations and invaluable advisement that will benefit me throughout my life.

I would like to acknowledge and thank the expert, Dr. Uriel Kitron, who was involved in the formation of this Thesis. Thank you for agreeing to participate in this project and for providing your invaluable experience, guidance, and passionate feedback and input. Thank you for pushing me to develop as a writer and researcher.

I would like to acknowledge and thank the friends I was so lucky to find at Emory for their never-ending encouragement and support throughout the entirety of my MPH journey; especially through the process of writing this thesis.

Lastly, I would like to give a special thank you to my mother, Adella Barnard, for her unconditional support, motivation, and love. Thank you for giving me the strength to reach for the stars and chase my dreams. This endeavor would not have been possible without you, thank you.

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## Acronym List

CDC: Centers for Disease Control

DENV: Dengue

DHF: Dengue Hemorrhagic Fever

ENSO: El Niño Southern Oscillation

EUCDC: European Centers for Disease Control

NTDs: Neglected Tropical Disease

PAHO: Pan American Health Organization

WHO: World Health Organization

UNECLAC: United Nations Economic Commission for Latin America and the Caribbean

## Chapter 1: Introduction

### *1.1 Rationale: Background & Significance*

Dengue is a vector-borne viral disease that is most spread through the bite of an infected female Aedes aegypti mosquito. Dengue virus continues to be a persistent and growing public health challenge. Since the 1960s, dengue has emerged as a worldwide problem, with almost half of the globe's population at risk (Centers for Disease Control and Prevention [CDC], 2023). The incidence of dengue has increased significantly worldwide with 100-400 million dengue infections every year. In 2019, dengue infections reached the highest global case count ever (CDC, 2023; World Health Organization [WHO], 2022). Although an individual can gain limited immunity to the dengue virus after being infected, an individual can be infected up to four times by the four different dengue serotypes (CDC, 2021). Dengue virus strains (DENV-1, DENV- 2, DENV-3, and DENV-4), usually one or two at a time, can co-circulate in a region simultaneously at any given time. Dengue virus mostly circulates during wet rainy seasons in endemic regions like the Caribbean and Central America. Although there is potential for cross-immunity to other strains of the dengue virus, it is only partial and temporary (WHO, 2022). Subsequent infections of the dengue virus significantly increase the risk for potentially life-threatening conditions: dengue hemorrhagic fever (DHF) or dengue shock syndrome (DSS). While dengue fever can present similarly to severe flu-like symptoms (nausea, vomiting, rash, and body pain), DHF can result in shock with internal bleeding, bleeding gums or nose, persistent vomiting, and even death (CDC, 2021). Approximately 1 in 20 individuals who become infected with dengue will develop DHF (CDC, 2009). According to one of the latest Pan American Health Organization (PAHO) epidemiological updates concerning dengue in the region, during the first 7 months of 2019, more than 2 million people contracted the disease and 723 died (PAHO/WHO, 2019).

Those living in tropical and subtropical climates are most at risk for dengue infection as Aedes aegypti thrive in regions with frequent rainfall, warm temperatures, and humid conditions. Since 2015, there have been over one million reported cases of dengue in the Caribbean and Central America, with some countries reaching incidence rates as high as nearly 3,000 per 100,000 in 2019 (Pan American Health Organization [PAHO], 2023). Although, in 2019, there was an observed overall spike in dengue cases across the region, recent literature has attributed the changes in dengue to previous Zika outbreaks in 2017 and 2018 which possibly suppressed dengue during these years leading to the spike in dengue cases in 2019. Recent literature has indicated that the changes seen in dengue incidence in the region may be due to cross-population immunity from Zika virus epidemics (Mugabe, *et al.*, 2020). Cases counts of dengue have been shown to substantially decrease following Zika outbreaks as Zika virus immunity has been shown to protect against dengue virus for about 2 years. The future trends of dengue are unknown as some countries in the region are presenting upward trends, while some are not.

Every Central American and almost every Caribbean country is considered to be at a frequent/continuous level of risk as this region is highly endemic for dengue and continues to experience periodic oscillations in the relative incidence of dengue and DHF (CDC, 2023). In recent years, the number of cases of dengue in this region has become alarming to public health officials as the incidence of dengue has exhibited a general trend of statistically significant increases as the number of reported cases of dengue has surpassed previous years' case numbers (See figure 1 and figure 4).

In recent decades, the incidence of dengue has increased significantly across the world. Dengue has spread to new regions including non-endemic countries who have never reported local transmission before (Codeco *et al.*, 2022; European Centre for Disease Prevention and Control (ECDC), 2021; WHO, 2023). According to WHO, dengue causes an estimate of 390 million infections and 20,000 to 25,000 deaths per year, primarily in children (Bhatt, 2013; WHO, 2023). In 2019, the highest number of dengue cases ever were reported worldwide with all regions being affected and 3.1 million of these cases were reported in the American region (WHO, 2022). In Central America and the Caribbean, countries like Nicaragua (186,173 cases), Honduras (132,143), Dominican Republic (20,183), and Jamaica (7,555) were the most affected (WHO, 2023).

Globally, WHO has associated dengue with various social factors including population density, access to reliable water sources, and community knowledge, attitudes, and practice (WHO, 2022). Social determinants of health can best be described as the social circumstances an individual may be born, grow, live, work, and/or play (WHO, 2023). These circumstances are shaped by access to resources, money, and power which largely shape one's health and health disparities. Dengue is often considered a disease of impoverishment as it is often closely associated with populations living in poverty and affects populations with low visibility and little political voice. Dengue is classified as one of the 17 neglected tropical diseases (NTDs) of the world by the WHO. NTDs are considered to be proxies for poverty and disadvantage, relatively neglected by research, and can be controlled, prevented, and possibly eliminated (WHO, 2010). Understanding the non-biological, socio-economic factors involved in the transmission and risk of dengue, is critical for public health intervention for dengue as about 30 percent of Central American and Caribbean populations live below the national poverty line and are at increased risk for infection (World Bank, 2020). The periodic and severe outbreaks of dengue and DHF disproportionately affect the most vulnerable communities in this region since the major contributors to the transmission of this mosquito-borne viral disease include overpopulation, extreme weather events, urbanization, poor sanitary conditions, and poor public health infrastructure (WHO, 2022). Aedes aegypti, the primary vector of dengue virus, has adapted well to urban environments, due to the improper disposal of containers, plastic/cement tanks, rubber tires, storm drains, mud pots, etc. Dengue thrives in dense urban areas with poor sanitation and still water containers. These habitats largely advance the abundance and transmission potential of this vector, putting those living in these areas at higher risk for infection. Political and social challenges in the Caribbean and Central America should also be considered with dengue transmission as political conflict can often hinder access to reliable water, sanitation, and health services.

Climate change refers to long term changes in temperature and weather patterns globally. Climate change outcomes encompass warmer temperatures, rising sea levels, more severe storms and natural disasters, increased drought, and more. Similar to social determinants of health, climate change negatively affects human health. The risk of dengue transmission is expected to shift as climate change continues to affect the globe. Vectors are expected to adapt to the new climate environment and expand their geographical range (Greer, 2008; Houtman *et al.*, 2022;

WHO, 2015). The WHO estimates that increasing temperatures across the globe and altered humidity and rain patterns are likely to increase the intensity and frequency of vector-borne disease outbreaks (WHO, 2015). It is also estimated that infectious disease epidemics, i.e., dengue, will become much more difficult to predict, prevent, and control (CDC, 2022).

There is growing literature on the potential association between climate change and the increasing transmission of vector-borne diseases, including dengue (Bouzid *et al*., 2014; Colón-González *et al*., 2013; Colón-Gonzalez *et al*., 2018; Greer, 2008; Houtman *et al*., 2022; Mweya *et al*., 2016; WHO, 2015). Recent literature conveys evidence that the Caribbean and Central American region is currently being impacted by climate change as tropical regions are more susceptible to excessive rainfall, rising sea levels, hurricanes, flooding, drought, El Niño Southern Oscillation (ENSO), and other precursors for mosquito habitats, contributing to vector-borne disease outbreaks (Lo-Yat *et al*., 2011; IPCC, 2014; L'Heureux, 2014; Nicholls and Cazenave., 2010; Herrera-Martinez and Rodríguez-Morales., 2010). With global temperatures rising, ice sheets and glaciers are melting causing sea levels to rise, and hurricanes are being fueled by the release of heat as water evaporates from the surface of the ocean. As the oceans warm and produce more evaporation, there is more water in the atmosphere leading to increased rainfall and less water on the surface causing soil and vegetation to dry out (Barlow *et al*., 2022; Center for Climate and Energy Solutions, 2023). Increased rainfall is expected to result in flooding which increases mosquito density and landing rates. This increase contributed to the prevalence of Aedes aegypti carrying the dengue virus, which ultimately increases the risk of human exposure to dengue (CDC, 1993). ENSO is a significant climate phenomenon that irregularly occurs that influences temperature and precipitation across the globe. ENSO's opposite states, El Niño (warming of the ocean surface) and La Niña (cooling of the ocean surface) have strong effects on the weather as it has the ability to change the global atmospheric circulation.

### *1.2 Statement of the Problem*

#### *1.2.1 Dengue in Central America*

In recent years, Central America has experienced severe dengue outbreaks with each strain of dengue, including with DENV-2 the deadliest of the strains of dengue virus, circulating its population (PAHO, 2019). In 2019 the Central American region alone reported over 400,000 cases of dengue (see figure 1) and almost 300 dengue-related deaths; a number higher than the previous 6 years combined and the highest numbers of dengue-related deaths in the previous 20 years (see figure 3; PAHO, 2023; IFRC, 2019). The significant increases seen in this region in 2019 may have been an aberrancy as a result of prior Zika outbreaks, but the observed spikes in some countries in the region, overall, have been higher (Mugabe, *et al*., 2020). As the region continues to face periodic oscillations in the relative incidence of dengue, recorded outbreaks in some countries are becoming more severe. The outbreaks have largely been attributed to rapid urbanization, migration, and lack of financial resources exacerbated by poor sanitation, extreme poverty, and population growth/density. With optimal conditions for vector breeding, the most vulnerable populations in this region continue to be disproportionately affected by dengue.

Central America is expected to double its urban population within the next 35 years, increasing the concentration of climate and social issues that influence human health (Acero *et al*., 2017). Issues of conflict, lack of access to clean water, sanitation, and hygiene all typically arise with the increasing size and concentration of a population. The region's population growth and urbanization have largely contributed to dengue transmission as these factors are known to lead to inadequate civic resources such as water supply, waste disposal, and heightened sites for mosquito breeding (Acero *et al*., 2017). In addition, globalization, travel, and tourism have facilitated the importation of dengue throughout Central America and other regions endemic to DENV viruses through the importation of Sri Lankan/Indian DENV-3 strains and south-east Asian strains of DENV-2, the deadliest dengue serotype. These compounding social issues have largely been attributed to an increase in vulnerability to climate change.

Recent literature associates the diverse effects of climate change with the recent dengue outbreaks seen in this region (Houtman *et al*., 2022). With an increasingly dense population, El Niño events, and shifting rainfall patterns, linked to climate change, the epidemiology of dengue and other vector-borne diseases is expected to change and become more difficult to predict and control in tropical regions at risk for vector-borne diseases (Lowe *et al*., 2021; WHO, 1999; WHO, 2015). Mosquito biting rates are expected to increase, and the mortality rates and the time required for viruses to replicate within Aedes aegypti are expected to decrease (Caminade *et al*., 2017; IPCC, 2014). A recent disease projection model combined with climate indicators predicted that by 2030, more individuals will be at risk for dengue as a result of an increase in mosquito abundance and their larger geographic range (Ebi *et al*., 2018). Another recent projection model also suggested that increases in mean temperature could double the burden of dengue by 2100 in some regions (Teurlai *et al*., 2015).

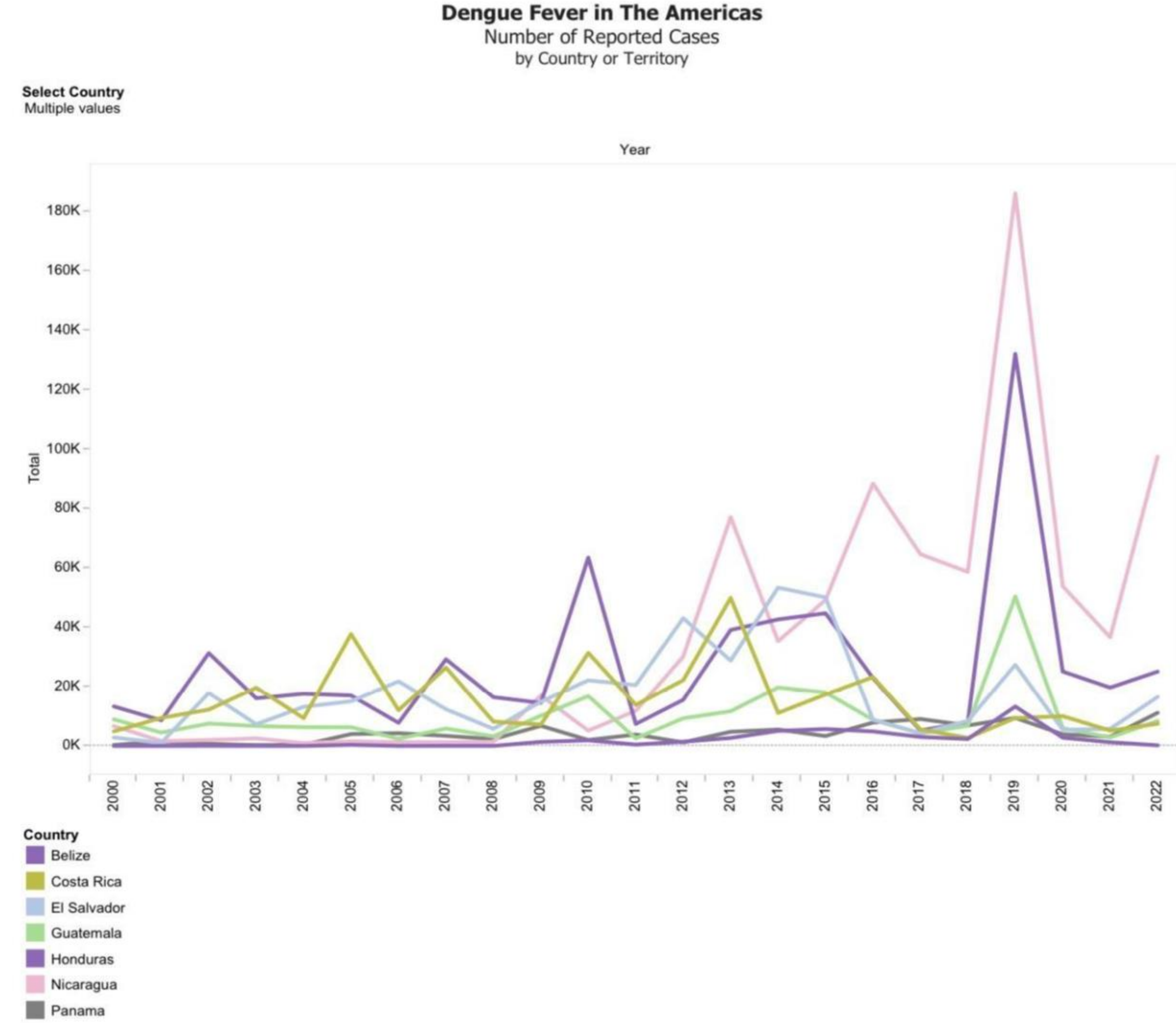



***Figure 1***: This figure illustrates the trend of reported cases of dengue fever in Central America

## Dengue Fever in The Americas
Number of Reported Cases
by Country or Territory

**Select Country**
Multiple values

**Select Year**
Multiple values

| Country | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Belize | 5,691 | 4,899 | 3,042 | 2,326 | 13,316 | 2,785 | 1,251 | 207 | 33,517 |
| Costa Rica | 17,394 | 23,319 | 5,561 | 2,735 | 9,400 | 10,056 | 5,174 | 7,485 | 81,124 |
| El Salvador | 50,169 | 8,789 | 4,297 | 8,448 | 27,470 | 5,450 | 5,752 | 16,542 | 126,917 |
| Guatemala | 18,058 | 8,844 | 4,214 | 6,830 | 50,432 | 5,983 | 2,861 | 8,407 | 105,629 |
| Honduras | 44,834 | 22,961 | 5,217 | 7,942 | 132,143 | 25,180 | 19,753 | 25,162 | 283,192 |
| Nicaragua | 49,326 | 88,463 | 64,712 | 58,746 | 186,173 | 53,953 | 36,741 | 97,541 | 635,655 |
| Panama | 3,347 | 7,884 | 9,077 | 6,908 | 9,448 | 3,939 | 3,095 | 11,172 | 54,870 |
| **Total** | 188,819 | 165,159 | 96,120 | 93,935 | 428,382 | 107,346 | 74,627 | 166,516 | 1,320,904 |

***Figure 2***: This table displays the number of reported ***cases*** of dengue in Central America.

## Dengue and Severe Dengue
Cases and Deaths
for countries and territories of the Americas

**Select Country**
(Multiple values)

**Select Year**
(Multiple values)

**Select indicators**
Deaths

| | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|
| Country | Deaths | Deaths | Deaths | Deaths | Deaths | Deaths | Deaths | Deaths |
| Belize | 0 | | 0 | 0 | 0 | 0 | 0 | 0 |
| Costa Rica | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| El Salvador | 6 | 1 | 0 | 8 | 14 | 0 | 0 | 0 |
| Guatemala | 9 | 1 | 24 | 22 | 66 | 10 | 6 | 16 |
| Honduras | 5 | 3 | 0 | 3 | 180 | 10 | 8 | 9 |
| Nicaragua | 15 | 16 | 2 | 6 | 30 | 1 | 0 | 0 |
| Panama | 4 | 9 | 2 | 3 | 6 | 6 | 2 | 5 |
| **Total** | 39 | 30 | 28 | 42 | 296 | 27 | 16 | 30 |

***Figure 3***: This table displays the number of reported ***deaths*** from dengue in Central America.

### *1.2.2 Dengue in the Caribbean*

The Caribbean islands have experienced similar burdens to Central America with over 120,000 cases of dengue reported (see figure 4) and 384 reported dengue-related deaths (see figure 5), from 2015 to 2022 (PAHO, 2023). Dengue virus continues to cause devastating consequences, magnifying the transmission rate in this region as all four dengue virus serotypes circulate regularly (PAHO, 2023).

Because of the Caribbean's equatorial climate, the region is vulnerable to frequent dengue outbreaks as mosquitos thrive in warm temperatures, humid conditions, and excessive rainfall. Many eastern Caribbean countries have reported increases in dengue cases above the seasonal threshold since the beginning of the 2020 rainy season (PAHO, 2020). Regional changes like storm surges, flooding, intense cyclones, droughts, and extreme heat have been reported (IPCC, 2015). Consequently, these changes are expected to further exacerbate dengue activity, particularly in urban populations predisposed to being adversely affected by the virus (Henry and Mendonça, 2020).

Urban areas in the Caribbean are highly vulnerable to climate conditions that favor the presence of Aedes aegypti (i.e., humidity, vapor pressure, inadequate waste management, etc.; IPCC, 2014). As this region is now considered to be the most urbanized developing region in the world, many of the countries in the Caribbean lack the resources to support additional pressure placed on their healthcare systems as a result of rapid urbanization (UNECLAC, 2022; IPCC, 2014). Many of the islands are experiencing an inability to meet the needs of its urban populations with more than 81% of its population now living in cities (UNECLAC, 2022). The poor communities in these urban areas have an increased risk of infection with research showing an association between the incidence of dengue and social inequality (Mol *et al*., 2020). Populations vulnerable to poverty often reside near locations of poor waste management where vectors carrying the dengue virus are able to thrive (Mol *et al*., 2020). Solid waste management has been shown to have an inverse association with poorer populations as these areas often consist of garbage improperly disposed of (i.e., tires, plastic containers, tins, etc.) which creates a prime habitat for mosquitos (Mol *et al*., 2020).

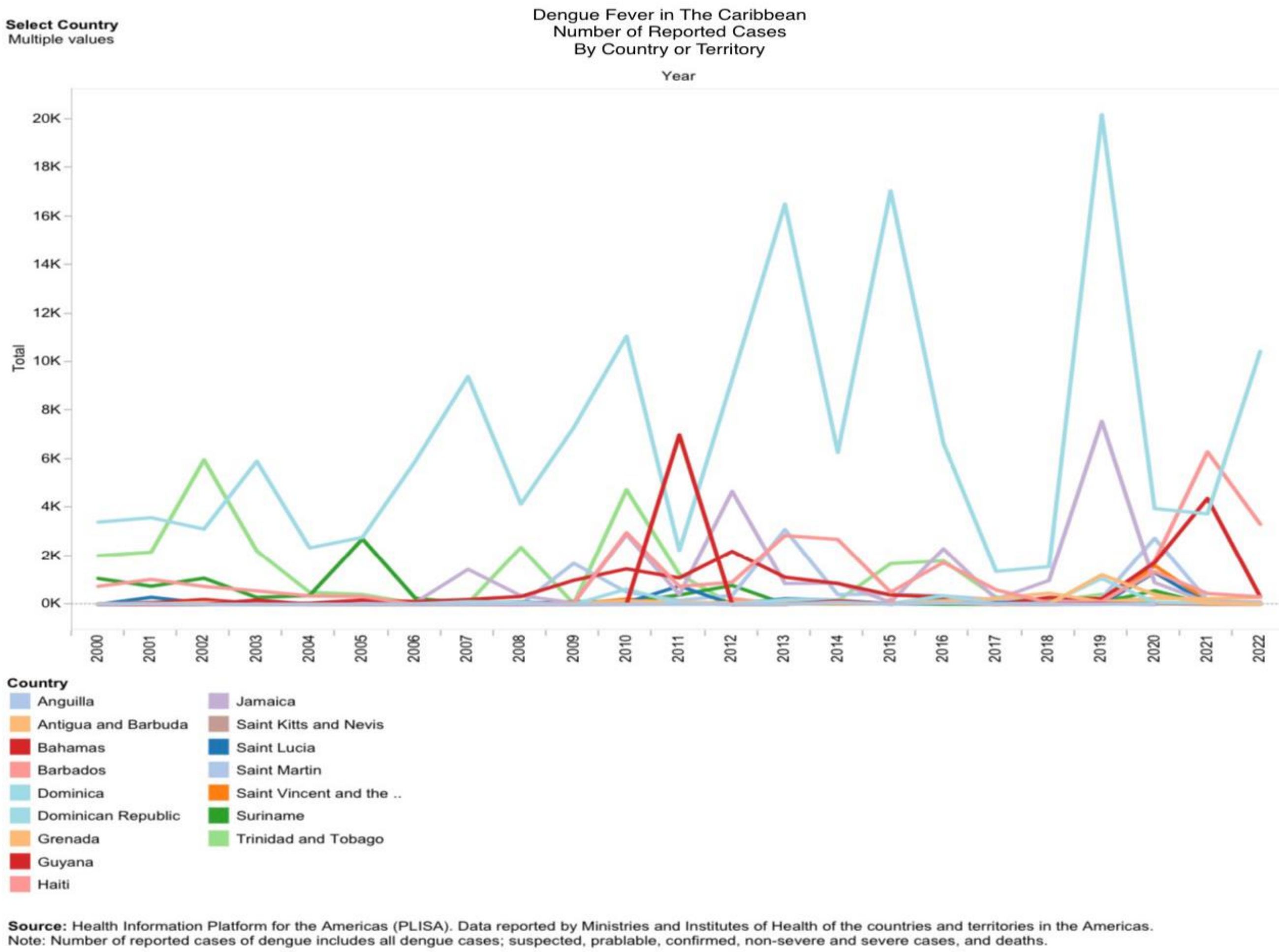



***Figure 4***: This figure illustrates the trends of reported cases of dengue fever in the Caribbean

Dengue Fever in The Caribbean
Number of Reported Cases
By Country or Territory

**Select Country**
Multiple values

**Select Year**
Multiple values

| Country | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Anguilla | 8 | 50 | 22 | 1 | 6 | 6 | | | 93 |
| Antigua and Barbuda | 14 | 103 | 1 | 8 | 1,223 | 407 | 46 | 4 | 1,806 |
| Bahamas | 10 | 82 | 14 | 10 | 27 | 3 | | | 146 |
| Barbados | 503 | 1,732 | 597 | 67 | 117 | 1,352 | 448 | 313 | 5,129 |
| Dominica | 38 | 351 | 33 | 45 | 1,066 | 88 | 65 | 28 | 1,714 |
| Dominican Republic | 17,048 | 6,645 | 1,363 | 1,558 | 20,183 | 3,964 | 3,746 | 10,439 | 64,946 |
| Grenada | 25 | 151 | 239 | 463 | 106 | 253 | 230 | 286 | 1,753 |
| Guyana | 388 | 303 | 4 | 286 | 230 | 1,724 | 4,380 | 311 | 7,626 |
| Haiti | 130 | | | 90 | 93 | 1,783 | 6,298 | 3,316 | 11,710 |
| Jamaica | 88 | 2,297 | 215 | 986 | 7,555 | 898 | 96 | 100 | 12,235 |
| Saint Kitts and Nevis | 5 | 136 | 10 | 6 | 46 | 20 | 0 | 1 | 224 |
| Saint Lucia | 25 | 196 | 66 | 90 | 20 | 1,318 | 39 | 15 | 1,769 |
| Saint Martin | 436 | 350 | 197 | 104 | 260 | 2,736 | 172 | 35 | 4,290 |
| Saint Vincent and the Grenadines | 13 | 89 | 3 | 4 | 11 | 1,603 | 152 | 16 | 1,891 |
| Suriname | 15 | 6 | 1 | 123 | 86 | 563 | 10 | 13 | 817 |
| Trinidad and Tobago | 1,687 | 1,801 | 300 | 123 | 416 | 59 | 20 | 52 | 4,458 |
| **Total** | 20,433 | 14,292 | 3,065 | 3,964 | 31,445 | 16,777 | 15,702 | 14,929 | 120,607 |

***Figure 5***: This table displays the number of reported ***cases*** of dengue in the Caribbean.

Dengue and Severe Dengue
Cases and Deaths
for countries and territories of the Americas

**Select Country**
(Multiple values)

**Select Year**
(Multiple values)

**Select indicators**
Deaths

| | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|
| Country | Deaths | Deaths | Deaths | Deaths | Deaths | Deaths | Deaths | Deaths |
| Anguilla | 0 | 0 | | 0 | 0 | 0 | | |
| Antigua and .. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bahamas | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Barbados | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Dominica | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Dominican R.. | 107 | 39 | 3 | 1 | 53 | 36 | 26 | 39 |
| Grenada | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Guyana | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Haiti | 0 | | | 0 | 0 | 0 | 0 | 0 |
| Jamaica | 0 | 2 | 6 | 13 | 24 | 1 | 0 | 0 |
| Saint Kitts an.. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Saint Lucia | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| Saint Martin | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Saint Vincent .. | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 |
| Suriname | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trinidad and .. | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 111 | 41 | 9 | 14 | 78 | 50 | 26 | 39 |

***Figure 6***: This table displays the number of reported ***deaths*** from dengue in the Caribbean.

### *1.2.3 Intersection of Climate and Social Determinants of Health*

The relationships between social determinants of health, climate change, and dengue have not been deeply investigated in recent literature, yet social determinants of health and climate change are inextricably linked as they both worsen human health. It is important to study social determinants of health and climate change both together and separately to comprehensively support human health through the control and prevention of dengue. Vulnerable populations, such as communities of color, those experiencing poverty, lower levels of education, urbanization, and other known factors of health disparities, are more likely to be affected by climate change as these populations lack the capacity or resources to adapt to or cope with the adverse effects of climate change. Populations in tropical regions of the world, i.e., the Caribbean and Central America, typically rely on climate-sensitive natural resources such as fishing, agriculture, and forestry to sustain their livelihoods, making them disproportionately at higher risks to the impacts of climate hazards. These adverse effects of climate change will make it even more difficult for communities to reach economic and development goals, which further exacerbates food and water insecurity, poor health, poverty, displacement and involuntary migration, and other inequalities in the most vulnerable populations of the region (United Nations, 2016).

## *1.3 Statement of Purpose*

The purpose of this scoping review is to summarize and understand what is known about how climate change and social determinants of health will affect the transmissibility of dengue across countries in Central America and the Caribbean. This review will provide insight into the association of climatic factors such as temperature, rainfall, and relative humidity, and social determinants such as poverty, education, housing, gender, and socioeconomic status, with the epidemiology of dengue and dengue hemorrhagic fever across this region. This review will help inform potential practices and planning to limit the risk of dengue transmission and amplify control and prevention measures with consideration for how climate change may affect dengue in Central America and the Caribbean. Understanding the relationship between climate, social determinants, and dengue can help inform public health interventions through more informed predictive, control, and preventive measures.

### *1.4 Research Question and Focus*

Research question: How are climatic and social risk factors affecting dengue transmission and infectivity in the Caribbean and Central America?

The focus of this scoping review is to understand how interrelated climatic and social risk factors might be affecting dengue transmission and infectivity in the Caribbean and Central America. This review aims to systematically map the current literature, investigate research done surrounding this topic, and identify any knowledge gaps. Little research has been conducted in this region concerning dengue and climate change. This scoping review aims to inform planning and potential practices to limit the risk of dengue transmission and amplify control and prevention measures in this region. This review will provide information from the available literature and highlight research in this region concerning climate and social determinants of health regarding dengue. Further understanding of this research topic will aid in the reduction of the impact of dengue on vulnerable populations in this region and other comparable regions.

# Chapter 2: Methods

## *2.1 Protocol*

This protocol was drafted using the Preferred Reporting Items for Systematic Reviews and Meta-analysis extension for Scoping Reviews (PRISMA-ScR). This methodology was developed and revised by the researcher. Full text of the PRISMA-ScR explanation and checklist is available at the following web address: http://annals.org/aim/fullarticle/2700389/prisma-extension-scoping- reviews-prisma-scr-checklist-explanation.

## *2.2 Eligibility Criteria and Search Strategy*

This scoping review applied precise inclusion and exclusion criteria to peer-reviewed articles in PubMed, Web of Science, and Embase databases. A scoping review was conducted to identify knowledge gaps, investigate research conducted, and allow an understanding of the scope of available documented research evidence in this region concerning climatic risk facts and social determinants of dengue fever. This approach allows for a broad assessment of the scope of research discovery regardless of the rigor of the design of the research study.

A comprehensive search of the literature using the Participants, Interventions, Comparators, Outcomes, and Study Design (PICOS) model was conducted to produce research studies relevant to the Caribbean and Central American region and the relationship between dengue transmission, climate change, and social determinants of health (Riva *et al*., 2012). The search was limited to articles in the English language concerning the Caribbean and Central American Region between January 2000 and December 2022.

Each Caribbean and Central American country was considered for this search. The following specific variables were used as search terms for this review. For the Caribbean region: (Caribbean OR Anguilla OR Antigua and Barbuda OR Barbados OR Bahamas OR Dominica Or Dominican Republic OR Grenada OR Guyana OR Haiti OR Jamaica OR Saint Kitts and Nevis OR Saint Lucia OR Saint Martin OR Saint Vincent and the Grenadines OR Suriname OR Trinidad and Tobago). For the Central American region: (Central America OR Belize OR Costa Rica OR El Salvador OR Guatemala OR Honduras OR Nicaragua OR Panama).

The following search terms were used to address dengue: (dengue virus OR severe dengue OR dengue hemorrhagic fever OR breakbone fever OR dandy fever OR DENV-1 OR DENV-2 OR DENV-3 OR DENV-4 OR Dengue transmission OR dengue infectivity)

Lastly, the social determinants and climate change search terms included: ("Social determinants of health" OR gender OR sex OR race OR ethnicity OR socioeconomics OR poverty OR wealth OR income OR education OR access OR housing OR sanitation OR urbanization OR infrastructure OR Ecology OR Meteorology OR urbanization OR ecosystem OR landscape OR environment OR Climate Change OR Climate OR temperature OR rainfall OR humidity OR weather OR heat OR global warming OR global heating OR climate crisis OR environmental destruction).

The following inclusion and exclusion criteria were designed using the Population, Interventions, Comparison, Outcome, Type of Study, and Type of Question (PICOTT) method.

| | **Inclusion Criteria** | **Exclusion Criteria** |
|---|---|---|
| **Population** | Adults, adolescents, and children in the Caribbean and Central America | Non-Caribbean/Central America based |
| **Intervention** | Dengue transmission/infectivity | None |
| **Comparison** | Social determinants of health and climate change | N/A |
| **Outcome** | Dengue infection outcomes | N/A |
| **Type of Study** | All | NA |
| **Human and/or Animal Studies** | Human | Animal |
| **Publication Type** | Peer-reviewed literature | Grey literature and conference proceedings |
| **Publication Years** | January 2000 to December 2022 | >2000 |
| **Language(s)** | English | Non-English |

### *2.3 Data Extraction Process*

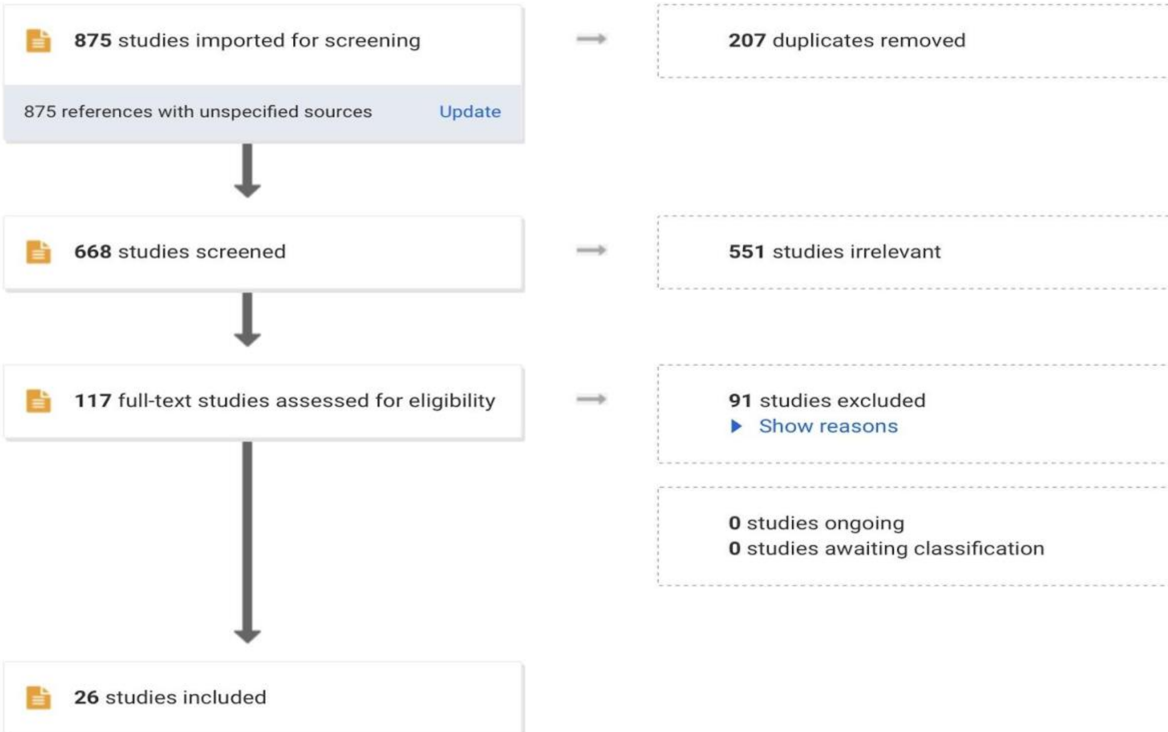
The data extraction process for this scoping review was completed through COVIDENCE by one reviewer. Relevant studies from PubMed, Embase, and Web of Science were imported for screening with all duplicates being removed. To further determine the relevance of each imported study, title/abstracts were screened and then the full text of each source was screened for eligibility by the reviewer. After the removal of the studies that were deemed irrelevant to the research question, the remaining studies were selected to be included in the scoping review to be extracted into Microsoft Excel. Key information from each eligible study was charted into an Excel spreadsheet. The key information included from each source includes the Study Title, Study Location, Reference Year of Publication, Social Determinant(s) considered, Climate variable studied, Significant Results and/or Conclusions, Study Type, and Dengue-Related Outcome.

## Chapter 3: Results

### *3.1 Selection of Articles*

The selection of the sources for this scoping review was completed through COVIDENCE. Figure 1 illustrates a flowchart detailing the screening and selection process of including articles eligible for inclusion in this study. A total of 875 studies from PubMed, Embase, and Web of Science were imported into COVIDENCE for screening. Of the 875 research papers that were imported, 207 of them were removed for being duplicates. The title and abstract of 668 studies were screened and 551 of these studies were deemed irrelevant for reasons such as wrong setting, risk factor, outcome, region, date of publication, and non accessibility through university. The full text of 117 studies was assessed to determine final eligibility for inclusion in this study. Finally, ninety-one studies were excluded in this final step leaving 26 studies left for inclusion in this scoping review based on the aforementioned criteria (see figure 7; table 1). Of the 26 studies included in this review, 9 studies were from the Caribbean region, 15 studies were from Central America, and 2 of the studies encompassed research on both regions. Thirteen studies' research focus was on social determinants of health, 9 studies had a climate focus, and 5 studies examined both social determinants of health and climate.

**Figure 7: PRISMA Flow Diagram**




### *3.2 Synthesis of Results*

#### *3.2.1 Social Determinants of Dengue*

Of the 26 studies included in this scoping review, 17 studies examined social determinants of dengue. The key themes that emerged concerning social risk factors and dengue were housing, education, and poverty. The majority of studies were from countries in Central America (n=13) while fewer studies came from the Caribbean region (n=4).

#### *Housing*

Housing emerged in the literature as one of the determinants of dengue infection. Household air pollution, environmental capital, and water supply were investigated to determine the different ways in which housing factors may affect the transmission of dengue. The studies by Madewell *et al.*, examined the association between household air pollution from cooking with firewood and arboviral infection (Madewell *et al*., 2020); air pollution and environmental capital with larvae/pupae (Madewell *et al*., 2019). Globally, an estimate of 2.9 billion individuals uses biomass fuel for household cooking and heating, causing the death of about 1.6 million individuals yearly from household air pollution-related diseases, yet the study team found household air pollution from cooking with firewood to be inversely associated with arboviral infection (Madewell *et al*., 2020). As public health leaders now call for a transition from biomass fuel, an effective mosquito repellent, to clean fuels for household cooking and heating, there is heightened concern for increased risk of arboviral infections, i.e., dengue, in urban and rural households, that depend on the arboviral-protective benefit of smoke exposure (Madewell *et al*., 2020).

A study undertaken in Guatemala evaluated household environmental factors as attributes of mosquito abundance and socioeconomic status. In this study, higher environmental capital served as an indicator of higher socioeconomic status which included access to running water, sewage systems, and sanitation/trash disposal services. It was found that households that had the lowest and highest environmental capital had significantly fewer larvae or pupae than households with middle environmental capital (Madewell *et al*., 2019). The researchers found that households that were in proximity to paved roads and other houses or structures were inversely associated with higher levels of larvae or pupae and mediated the association of environmental capital and abundance of larvae or pupae. Decreases in distance to paved roads and other houses indicated greater population density, which consists of greater availability of productive habitats for mosquitoes to thrive in, i.e., more containers and availability of blood meals in areas closer to roads. It is likely that households that have greater environmental capital own more barrels and water storage containers that encourage increased levels of mosquito populations, however great environmental capital was found to be protective as it indicates higher levels of income, education, occupation, and other socioeconomic factors that are associated with mosquito prevention measures. For example, households with greater socioeconomic status are more likely to remove containers with standing water. Households with lower environmental capital had increased distances from paved roads and were noted to have fewer large water storage containers and barrels making their households less desirable for mosquito productivity. The researchers deemed it probable that the distance to low environmental capital households exceeded the typical flight range of mosquitoes. The results also reinforced the importance of community-wide control and prevention efforts, rather than individual, as households closer to other houses and structures had significantly more larvae and pupae which puts each community member in proximity at risk of infection (Madewell *et al*., 2019).

A secondary analysis of a Nicaraguan study investigating community mobilization for dengue prevention in households with and without regular water supply confirmed findings that irregular water supply is a risk factor for dengue. The study indicated that households with an irregular water supply were about twice as likely to have Aedes aegypti infestations than households with a regular water supply. The study results depict that access to a regular water supply is critical in vector control. The study also informed that although communities without regular water supply should be prioritized, households with a regular water supply should not be excluded from control and prevention interventions as these households had similar impacts from the community mobilization interventions. Some households that reported having regular water supply were found to still have water storage barrels. These households conceivably still kept these barrels for emergencies as a result of lack of confidence in their water supply (Cárcamo *et al*., 2017). Results from Veras-Estevez *et al*. also highlighted issues of access to water supply. Participants described having poor access to adequate household plumbing infrastructure and having to store water without proper protection which results in frequent Aedes aegypti infestations in their community (Veras-Estevez, 2017).

***Education***

Education also emerged as a key determinant of dengue infection. Recent literature from Peru, Costa Rica, Panama, Dominican Republic, Jamaica, and Honduras examined the association between education and dengue prevention/control. Knowledge, attitudes, perceptions, and practices related to dengue was investigated to determine the different ways in which educational factors may affect the transmission of dengue.

Egedus *et al*. designed a qualitative survey to investigate knowledge, perceptions, and practices related to dengue prevention in Costa Rica. The results conveyed that households with more breeding sites for dengue had lower education levels and less knowledge of the symptoms, dangers, and importance of preventative measures concerning dengue (Egedus *et al*., 2014). Participants of the study who had previous dengue infection, had greater risk perception of dengue; they were more likely to consider and support prevention measures. These findings indicate that increased education to support dengue awareness can support dengue prevention and control (Egedus *et al*., 2014).

Whiteman *et al*., compared the levels of Aedes infestation in socioeconomically different neighborhoods in Panama. The results indicated that infestation levels for both Aedes aegypti and Aedes albopictus mosquitoes were significantly higher in neighborhoods with a lower percentage of residents with a bachelor's degree and lower household income. Higher education level and wealth proved to be protective against dengue infection. The study also found that the proximity between contrasting socioeconomic neighborhoods can indicate infestation level by species of Aedes. Aedes aegypti breeding sites were found to increase with proximity between neighborhoods while Aedes albopictus decreased. The presence of Aedes albopictus was found to decrease with proximity between neighborhoods as this species typically breeds in natural habitats in suburban locations. Aedes aegypti's breeding habits are more reliant on man-made containers in urban areas. The increased presence of Aedes aegypti in lower socioeconomic neighborhoods indicated an abundance of accumulated water in unmaintained artificial containers (Whiteman *et al*., 2019).

Whiteman *et al*. (2018), previously conducted a study on the exact same neighborhoods as Whiteman *et al*. (2019) and found that households in the low socioeconomic neighborhoods were less knowledgeable of and had fewer preventative practices related to dengue and other Aedes-borne diseases. Participants with primary school being their highest completed education had significantly less preventive practice than those with higher education levels completed. This study also revealed widespread misinformation, lack of concern, and relative knowledge regarding dengue and other Aedes-borne diseases. More than half of the respondents thought vaccines for each Aedes-borne disease, DENV, CHIKV, and ZIKV, existed and were available for their use in Panama and about two-thirds of participants thought each disease was curable.

Low socioeconomic status communities, elderly residents, and residents with low education were highlighted in this study to be in the most need of health education campaigns since they had the lowest relative knowledge and prevention practices of dengue and other Aedes-borne diseases. The degree of concern for infection was higher among high socioeconomic neighborhoods, even though they reported less mosquito biting which illustrated a need for low socioeconomic neighborhoods to be the focal point of outreach and health education campaigns.

Veras-Estevez & Chapman (2017), conducted a qualitative study in the Dominican Republic to identify health workers' perceived challenges for prevention and control strategies of dengue. The results found that individual lack of education, awareness, and action was a perceived challenge for dengue prevention and control. Although most of the respondents reported community health seminars from representatives of the ministry of health concerning dengue in local communities, there were still some community members that believed dengue transmission by mosquitoes to be a myth. Another respondent described that non-adherence to dengue prevention and control measures was not for lack of understanding of dengue as a health threat, but that community members were apathetic. Some participants described that educating the community led to a sense of shared responsibility among community members. Knowledge that individual non-adherence to preventative measures can affect their surrounding community, as mosquitoes can fly from one home to another, has led to more adherence. Moreover, these results illustrate that community-level risk awareness, knowledge, and understanding of dengue can influence prevention, control, and health-seeking behaviors.

Alobuia *et al*. (2015) conducted a cross-sectional study in western Jamaica to assess residents' knowledge, attitudes, and practices concerning the control and prevention of dengue and other vector-borne diseases. The study found that knowledge of the dangers of dengue infection significantly influenced the practices of participants, with knowledge scores significantly predicting the practice scores of participants. The study illustrated poor knowledge and practices among participants with low literacy levels. Most study participants had secondary education as their highest level of education. Overall, the results expressed a need for government intervention to improve and provide access to educational materials and programs for citizens to understand the risks and prevention practices of dengue to control and prevent infection.

In Honduras, a pilot education campaign to identify risk factors associated with container mosquitos provides a framework for creating sustainable community-based vector control programs. Parker *et al*. (2019) created an educational campaign that trained participants on how to inspect residential properties for mosquito development sites and reduce the sources producing mosquito larvae in an underserved community. The results of this education campaign showed a significant improvement in community knowledge of dengue and other vector-borne diseases after the training workshops. The study highlighted that individuals without knowledge of dengue or other vector-borne diseases had an average of nine more containers at their residences than individuals who knew of or heard of these diseases. Some of the factors associated with the highest number of containers per residence included: not having a complete primary education, storing drinking water in containers, and not having their children up to date on vaccinations, which supports the generally known positive association of education level and poverty with dengue infection.

***Poverty***

Poverty also emerged as a key theme in literature for determinants of dengue infection. Poverty status and lack of education are closely related as the two often intersected in the literature with positive correlations. Recent literature examined the associations between poverty and dengue prevention and control. These results highlight the role and factors of having little access to resources, lack of funds, and living in dense urban populations play in the transmission of dengue fever in the region.

Some of the main barriers to the prevention of dengue infection are inadequate access to resources and funding (Warner *et al*., 2016). A study investigating the knowledge and impact of dengue in a rural population in Honduras found that participants with lower incomes had the largest knowledge deficits regarding how the dengue virus is transmitted and knowledge that mosquitoes lay their eggs in still water. Most participants reported practices of emptying their standing water around their residents to prevent mosquito bites (Warner *et al*., 2016).

Vera- Estevez's (2017) qualitative interviews on perceived challenges for prevention and control of dengue in the Dominican Republic depict the realities of some families living in poverty while also under the burden of dengue. Participants described wanting to protect themselves from dengue but could not afford recommended prevention measures like bed nets and repellent. A participant described his need to feed his family with his daily wages of about RD$150-$200, equivalent to US $4-$5, and that mosquito repellent costs about RD$100, a significant proportion of his daily income. The same sentiments were shared by many participants in the community with similar incomes.

A review by Hotez *et al.* (2014) found that individuals living under $2 per day, particularly in Guatemala, Honduras, Nicaragua, and El Salvador, were most at risk for dengue and other neglected tropical diseases. An estimate of 10.2 million individuals lived on less than $2 per day in Central America. There is a significant contrast between wealth and poverty in this region, as almost every country in the region has Gini indices exceeding 50%. This disparity leaves about 13.8% of the population in this region in extreme poverty. The study describes that neglected tropical diseases represent stealth causes of poverty as dengue has caused a significant economic impact of almost $700 million in Central America. Along with being a health burden, dengue and other neglected tropical diseases have economic impacts as they affect the livelihood of individuals by decreasing work productivity, reducing wage earnings, and adversely affecting human development.

A case-control study in El Salvador investigated the association between nutritional status and the severity of dengue in children and found a significant difference in socioeconomic status between the different groups. The study team found that children that had dengue infection had a higher socioeconomic status than healthy controls. Children included in the upper or middle class had a greater proportion of dengue hemorrhagic fever and dengue fever than healthy controls. The authors suggest that this discrepancy in socioeconomic class does not necessarily reflect the children's risk for infection, but their access to healthcare, pools, fountains, flowerpots, and vases, which are commonly known as symbols of wealth. The author also suggested that children in households with lower income were more likely to store rainwater in containers for future use (Maron, 2010). This study's results differ from findings from Whiteman *et al.*'s 2019 study, which found infection levels to be significantly higher in neighborhoods with lower household income as a result of an abundance of accumulated water in unmaintained artificial containers.

### *3.2.2 Climatic Risk Factors of Dengue*

Key themes that have emerged in this region concerning climatic risk factors of dengue are rainfall, temperature, and drought.

In the recent literature, researchers are modeling and discussing climate change with concerns for increases in vector-borne illnesses and preparation for public health response. Stewart-Ibarra *et al.* developed a study to understand stakeholders' needs and perceptions for the development of climate services, such as climate-driven early warning systems and models to forecast arbovirus outbreaks, and control and prevention measures for Aedes-borne diseases in the Caribbean region. The results found that national health sectors reported limitations concerning geographic information systems, funding, modeling, and statistics that limited the ability to implement climate services. Stakeholders reported the need to improve relationships with the private sector, academia, and civil society and the national climate sector reported a lack of staff. The participants also reported gaps in local research linking climate to arboviral diseases as a barrier to making informed decisions. The study found that a climate-informed early warning system for arboviruses would benefit the Caribbean health sector in public health decision-making, but partnerships, local capacities, and investment in local research linking climate and health need to be strengthened to successfully develop climate services in this region (Stewart-Ibarra *et al.*, 2019). Iwamura *et al*. developed a global mechanistic phenology model to apply to Aedes aegypti to predict the number of life-cycle completions based on biophysical responses to environmental conditions. The model broadly reproduced the known distribution of Aedes aegypti globally and suggested that there will be a consistent increase in suitability for the life-cycle completion of Aedes aegypti. The model projections suggested that global suitability for Aedes aegypti will accelerate from 1.5% per decade between the 1950s-2000s to 3.2% per decade by the 2050s. The model also highlights the way in which changing environmental conditions will promote vector invasion among specific regions. The researchers suggest that climate change along with other social-environmental changes, like increased human movement and land-use change, are expanding the distribution and abundance of vectors, increasing the risk of vector-borne disease (Iwamura *et al*., 2020).

***Rainfall***

Rainfall emerged as a key determinant of dengue infection in this region. Recent literature from Honduras, Barbados, and Trinidad investigated the relationship between rainfall, climate variation, and El Niño Southern Oscillation with dengue infection.

Zambrano *et al*., (2012) conducted a study in the main hospital of Honduras to investigate the potential associations between climatic variations and dengue hemorrhagic fever. This was the first study out of Honduras to link El Niño Southern Oscillation and climatic variation to dengue incidence and epidemics. The study found that higher rain probability, rain accumulation, humidity, and the Oceanic Niño Index were the most significant factors influencing dengue incidence in Honduras. Parker and Holman's study in Barbados also found that precipitation affected the occurrence of dengue, however, their findings only showed a .14% increase in the monthly odds of a dengue outbreak. In Trinidad, another study on the effects of climate on dengue incidence found rainfall to be significantly associated with dengue incidence (Torres *et al.,* 2017). Although Chadee *et al.*'s study found a significant correlation between rainfall and dengue incidence, their results found no significant correlation between temperature and dengue incidence (Torres *et al.*, 2017; Chadee *et al*., 2007).

***Temperature***

Two studies from Trinidad identified temperature as one of the factors influencing dengue. Polson *et al*. (2012) found that because of increased temperatures, mosquito life cycles and the extrinsic incubation period of the virus will be shortened. With shortened life cycles, mosquitos will become smaller in size and feed more frequently. This study also found that the geographical range of mosquitos will likely expand. Chadee and Martinez (2016) investigated the evidence for Aedes aegypti adapting to climate change and discovered high temperatures are leading Aedes aegypti mosquitoes to move to underground breeding sites as a result of high temperatures. The study results revealed that Aedes aegypti's adaptive behavior of changing breeding sites from drums to underground drains and septic tanks demonstrates the complexities of dengue transmission in different ecosystems. The authors recommended targeted vector control and transdisciplinary approaches to control the growing Aedes aegypti population.

Increased mean monthly temperature was found to hasten the onset of dengue outbreaks and increase the duration of dengue outbreaks in Barbados, Brazil, and Thailand, and while drought conditions were discovered to increase the time in between outbreaks (Parker and Holman, 2012). Parker and Holman used event history analysis to investigate meteorological and demographic factors possibly impacting the duration of dengue outbreaks and found that an increase in monthly temperature of just 1°C caused a 72% increase in the monthly odds of an epidemic occurring. The researchers associated longer durations of outbreaks with increased numbers of infections.

El Niño Southern Oscillation (ENSO) and vegetation dynamics were found to be predictors of dengue cases in Costa Rica (Fuller *et al*., 2009). Fuller *et al*. developed a climate-based model to depict the influence of climate and vegetation dynamics on dengue cases and found that the model can predict dengue outbreaks as early as 40 weeks in advance. Temperature variations were noted to possibly explain the variance between seasons in dengue cases as the incubation period decreases when temperatures are between 32°C and 35°C in Costa Rica. La Niña also appears to be inversely related to dengue cases. This model is potentially scalable to the broader region and can be used to warn public health leaders to inform prevention and control measures for potential outbreaks.

***Drought***

Two studies from Barbados found that drought influences the occurrence of dengue. Parker and Holman (2012) found that drought conditions significantly increased the time between dengue outbreaks. The model suggests that the monthly odds of an outbreak decrease by 66% under drought conditions. Lowe *et al*., (2018) coupled distributed lag nonlinear models and a hierarchical mixed-model framework to investigate the association between the relative risk of dengue and key climate indicators. The model result found that drought conditions were associated with a higher incidence of dengue and that drought periods followed by intense rainfall provide optimal conditions for a dengue outbreak.

***Overlap of Social determinants of dengue and Climatic Risk Factors***

Of the 26 eligible studies, 4 papers discuss both social determinants and climatic risk factors of dengue. Population density, urbanization, poverty, rainfall, and temperature were the common themes discussed in these papers.

In Nicaragua, researchers investigated the association between rainfall, population density, and dengue transmission. Theodorakos *et al*. used spatiotemporal compartmental simulations to investigate which areas in the region are at high risk for dengue infection and uncover factors influencing dengue in the country. The study results found that densely populated areas with low altitudes and mild rainfall are at high risk for dengue (Theodorakos *et al*., 2017). The results suggest that areas experiencing increased population density, influenced by urbanization, in addition to the presented climate factors, significantly impact this region and add to the cumulative risk of dengue infection in Nicaragua. The paper demonstrates an approach to looking at the combined effect of social determinants such as population density and climate factors such as rainfall on dengue infection.

In Jamaica, researchers Henry and Mendonça investigated the intersection of economic drivers of migration and urbanization with climatic factors in urban environments. The study found that urban areas have higher vulnerability to dengue than rural areas and that the geographical range of dengue will expand in higher altitudes under climate change conditions based on maximum temperature and rainfall under the Representative Concentration Pathway (RCP; IPCC, 2014). The authors suggest the high vulnerability of dengue in urban areas is a result of inequality of public health policies, environmental conditions, and socioeconomics between urban and rural areas. As a result of inequalities, rural populations migrate to urban areas that are already strained with health resources. The authors also suggest that the predominance of dengue in urban areas is attributed to climatic factors in this region such as humidity, vapor pressure, and temperature (Henry and Mendonça, 2020).

A study from a metropolitan region of Panama City assessed the effects of climate variables and population density on dengue incidence in the region (Navarro Valencia *et al.*, 2021). The study found that urban regions, with increasingly higher population density influenced by urbanization, have higher rates of dengue than rural areas because of the greater availability of breeding sites during the rainy season. The researchers used Spearman and Pearson's correlation coefficients to measure the strength of these relationships in different moments or lags in terms of weeks and found climatic factors such as accumulated precipitation, increased air temperature, and relative humidity to be indicators for dengue. Dengue incidence increased around 7–8 weeks after the beginning of rainy seasons, 2 weeks after the hottest months, and relative humidity maintained its strongest relationship with no lag. In addition, the researchers also suggest the dispersed distribution of objects by humans that serve as breeding grounds for mosquitos and water collection in containers or tanks for human consumption as a result of limited access to drinking water, also influences dengue cases. The study highlighted the importance of understanding human-vector interaction in addition to climate variables to aid in local vector control and eradication strategies (Navarro Valencia *et al.*, 2021).

A correlational epidemiologic study of 81 cantons, a type of administrative division of a country, of Costa Rica identified higher temperature, lower altitude, and a high human poverty index ranking as the main factors influencing the cumulative incidence of dengue across Costa Rica (Mena *et al*., 2011). The study investigated demographic, socioeconomic, housing, geographical, and climatic variables as indicators for dengue incidence. To determine the association and degree of influence of each of the included variables with dengue incidence, the research team analyzed each independent variable against the incidence in the cantons through simple and multiple Poisson regressions. Each variable that was deemed most relevant in each category, was introduced in a new multiple analysis to obtain a final model that combined the climate and social variables. The demographic indicators included population density, percentage of the urban population, demographic dependency ratio, fertility rate, and male/female ratio. Of these indicators, only the male/female ratio was found to be significantly associated with dengue incidence. The socioeconomic indicators included the human development/poverty index, illiteracy rate, education, uninsured rate, and unemployment rate. Of these indicators, the human poverty index, illiteracy rate, and unemployment rates were associated with dengue incidence. The housing indicators included overcrowded housing, housing conditions, and housing with sanitation and aqueducts. The results found that none of the housing indicators were significantly associated with dengue incidence. Some of the climatic and geographical indicators included temperature, altitude, precipitation, and improved vegetation index. All of these indicators were found to be significant, except for precipitation. These study results depict that climate and socioeconomic indicators have the greatest relationship with dengue incidence.

## Chapter 4: Discussion

### ***Social Determinants of Health***

The social factors of housing, education, and poverty emerged as key risk factors for dengue infection among the investigated studies. There was significant overlap and intersection between these three key themes that emerged as each variable can be linked to issues of systemic poverty. Generally, the literature displayed the landscape of characteristics of low socioeconomic status that are proxies for increased dengue distribution. Research displayed that densely populated urban areas often consisted of lack of access to regular safe drinking water (Navarro Valencia *et al.*, 2021), sanitation/hygiene measures (Madewell *et al*., 2019; Mena , 2011), adequate housing conditions (Madewell *et al*., 2019; Madewell *et al*., 2020; Veras-Estevez., 2017) , and higher levels of education (Egedus *et al*., 2014; Whiteman *et al*., 2018; Whiteman *et al*., 2019).; all of which also function as indicators for increased mosquito abundance and dengue virus (Cárcamo *et al*., 2017; Jetten, 1997; Knudsen, 2005; Madewell *et al*., 2019; Madewell *et al*., 2020; Maron, 2010; Vera- Estevez, 2017). These results align with other parts of the world where researchers also found poverty and its subsequent consequences to be associated with dengue infection rates. The poverty indicators that were often investigated included income, education, housing, access to water, sanitation, and hygiene, and socioeconomic status (Carnmo, *et al*., 2020; Mulligan *et al*., 2015; Zellweger *et al*., 2017).

### ***Climate***

The included studies displayed general consensus of dengue being a climate-sensitive disease. Generally, the studied sources identified rainfall, temperature, and drought as the climatic risk factors that most impact dengue transmission and incidence in this region. These findings align with studies in other parts of the world as researchers also found that shifting rainfall patterns

(Bhatia *et al*., 2022; Colón-González, 2013; Griggs and Noguer, 2006;), warmer ocean/air temperatures, humidity (Cheng *et al*., 2021; Fuller *et al*., 2009; Houtman *et al*., 2022), and drought conditions are having impacts on dengue epidemiology causing generally significant increases worldwide (Lowe *et al*., 2021; Lowe *et al*., 2018). These climate factors have contributed to the expansion of the traditional geographical range and breeding grounds of mosquitos, increasing the relative risk of dengue infection. As these and other weather events are exacerbated by climate change, dengue cases are expected to surge and expand to areas outside of typical tropical areas. For example, prior to 2010, France reported no local transmission, but in 2022, France reported 65 cases of dengue, due to the expanded range of the vector carrying the dengue virus (Cochet *et al*., 2022). Other previously unaffected countries or areas recently reporting their first dengue case and/or local transmission include Niger and Afghanistan (WHO, 2022)

In addition, global model projections predict a consistent increase in global suitability for Aedes aegypti and dengue virus (Bhatia *et al*., 2022; Iwamura *et al*., 2020; Messina *et al*., 2019). Although various models have projected increased global suitability for Aedes aegypti, consideration for human behavior should be recognized as human social and behavioral aspects influence dengue transmission. Increases in global suitability does not necessarily mean there will be increased transmission of dengue. As aforementioned, social determinants of health have proven to play a major role in differential risk of dengue infection. For example, comparing two bordering cities Laredo, Texas and Nuevo Laredo, Mexico, dengue transmission is significantly higher in the Mexican city as there is more opportunity for mosquito/human contact than in the Texas city because of access to housing factors such as air-conditioning and vaporative coolers

(Reiter *et al*., 2003).With increasing global temperatures, the prevalence of air-conditioning in countries with higher socioeconomic status is expected to increase which is likely to decrease dengue transmission. In all, these highlighted conditions display the need for improved early warning systems, improved public health infrastructure, and local government and ministry of health support to prevent and control dengue.

### *The Intersection of Climate and Social Determinants*

The intersection of the climatic risk factors of rainfall, temperature, and drought, as well as other climate change conditions, and social determinants including population growth/density, socioeconomic status, education, urbanization, and globalization, are predicted to create an increased cumulative risk for dengue infection. These conditions as a collective are expected to significantly influence the prevalence of mosquito breeding sites, life cycles of mosquitoes, mosquito range and distribution, and vector-human migration to urban areas. This is an issue of inequity; with differential risk and impact, vulnerable populations are expected to suffer at magnified levels. The predominance of dengue in urban areas was frequently discussed in recent literature with most studies attributing to dengue infection in these populations to climatic factors such as humidity, vapor pressure, temperature, and greater availability of breeding sites, especially during rainy seasons (Chang *et al*., 20214; Mena, 2011; Theodorakos *et al*., 2017).

## Chapter 5: Conclusion and Recommendations

Recent literature seems to generally agree with the association of social determinants of health and climate change factors with increasing dengue infection rates. The general consensus among studies across the globe suggests that the influence of climate change and social determinants on dengue is real. Improved public health infrastructure, through local government and ministries of health support, and community empowerment/mobilization, particularly focused towards areas with lower socioeconomic status, is needed to address the inequitable impact of dengue virus and provide adequate prevention, control, and eradication measures against dengue virus.

**Recommendation 1**: Address critical social determinants of health that increase the risk of dengue infection

- Improve access to education concerning dengue virus transmission and preventative measures.
- Improve access to regular water supply, sewage systems, and sanitation/trash disposal services.
- Mitigate/adapt to urbanization: Improving job opportunities and health services in rural areas. This would reduce the need to migrate to urban areas. Reducing costs of and providing environmentally sustainable public transportation. This decreases the use of fossil fuels improves the urban ecological footprint with the use of environmentally friendly transportation.

**Recommendation 2**: Adapting to and mitigating climate change

- Improve storage of household water supply. The effects of climate change may cause households to increase their storage of water. Correctly cover and clean containers frequently, maintain running water in and/ or place fish (guppies, betas) in ornamental fountains that always contain water, repair broken septic tanks and cover vent pipes with wire mesh, and throw away, empty, or turn over any container that may accumulate water to reduce the risk of dengue infection (CDC, 2023).

- Improve local laws, policies, regulations, and resources to provide vector control services such as WASH, bed nets, mosquito repellants, air conditioning, insecticides, and other health services to support national level dengue responses.

**Recommendation 3**: Mitigating both climate and social risk factors

- Improve access to climate friendly affordable housing
- Improve access to education concerning vector-borne diseases to encourage preventative behaviors at the individual and community level
- Mitigate/adapt to urbanization through: Sustainable and environmentally friendly cities. Cities that are planned, designed, and developed with regard to urbanization and climate change lessen their impact on the environment and contribute to the bettering of human health through improved public health services and infrastructure, productivity, efficiency, and economic growth

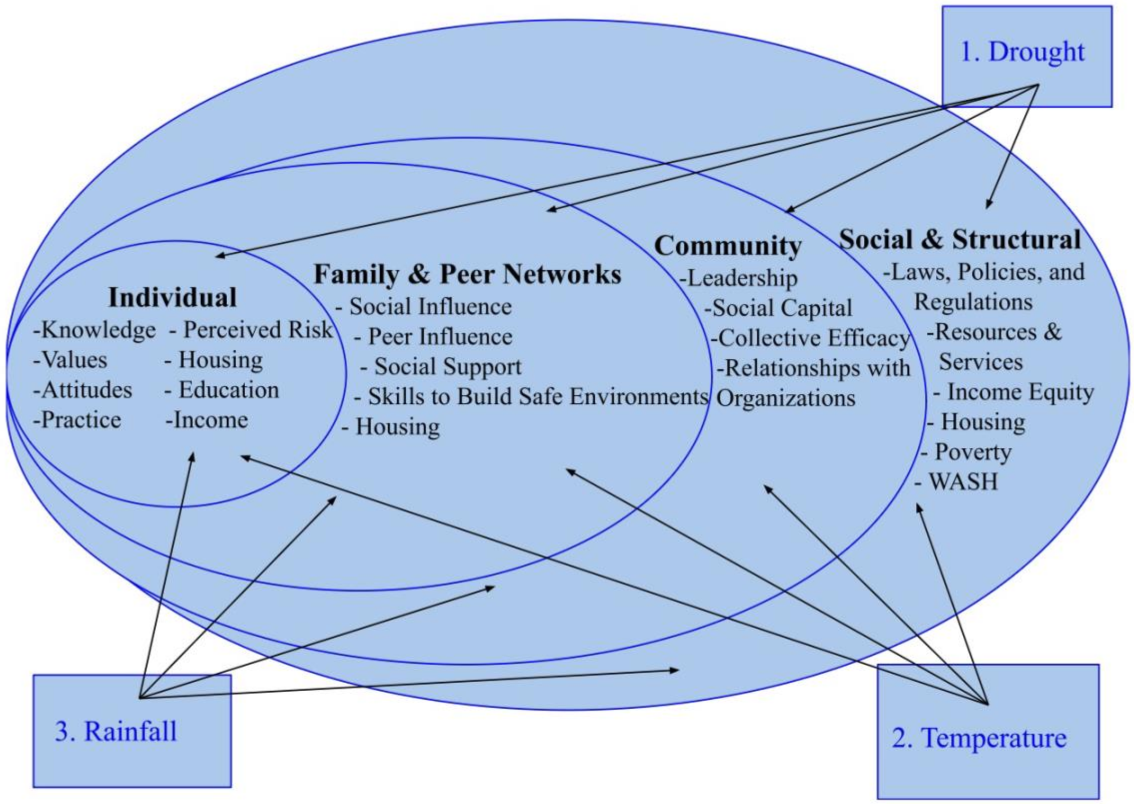
### *5.1 Socio-ecological Model*

The socio-ecological model illustrates the ways in which social determinants of health at the individual, family, community, and social structural levels interact and influence health in regard to dengue virus transmission and prevention. The individual level of the socio-ecological model depicts that individual knowledge, attitudes, perceptions, practice, etc. concerning dengue influences risk, transmission, and control of dengue virus. The family and peer networks level include social interaction with family and peers and how these factors influence prevention behaviors, such as reducing breeding sites near homes, actions to prevent mosquito bites, and social support for those impacted by dengue. The community level involves local leadership and organizations, collective efficacy, etc. This level involves local community groups mobilizing to prevent/control dengue and offer support systems for those impacted by dengue. The social and structural level includes state level laws, policies, regulations, resources, etc. to provide vector control services such as WASH, bed nets, mosquito repellants, insecticides, and other health services to support national level dengue responses (see figure 8).

Drought, rainfall, and temperature was shown in this scoping review to interact with each level of the socio-ecological model.

1. **Drought**: Drought as a slow onset climate hazard results in irregular water supply and water scarcity. These conditions lead to households storing water in containers which provides increased larval habitats for Aedes aegypti, which ultimately increases the risk of dengue infection (Lowe *et al.*., 2018). These conditions require intervention at each level of the socio-ecological model with individual, family and peer network, community, and structural interventions needed to properly control and prevent dengue infection.
2. **Temperature**: With increasingly warm global temperatures, there is increasing evidence of Aedes aegypti adapting to climate change with observed behavioral changes of breeding sites, life cycles, and geographical range. Prevention and control measures from the individual level to the social and structural level of the socio-ecologic model is needed to adequately control dengue virus (Polson *et al*., 2012; Chadee and Martinez, 2016).
3. **Rainfall**: With increasing intensity and frequency of global precipitation, targeted vector control and trans-disciplinary approaches are needed to control the growing Aedes aegypti population at each level of the socio-ecologic model (Zambrano *et al*., 2012; Chadee *et al*., 2007)

Figure 8: The Socio-ecologic Model




The socio-ecological model illustrates the ways in which complex systems of individuals, family and peer networks, community, and social relationships interact and influence health in regard to dengue virus.

| TABLE 1: Extraction of Eligible Studies | | | | |
|---|---|---|---|---|
| **Study Title** | **Study location** | **Social Determinant** | **Climate Variable** | **Significant Results** |
| Impact of environmental temperatures on resistance to organophosphate insecticides in Aedes aegypti from Trinidad (Polson *et al,* 2012) | Trinidad | N/A | Environmental temperature impact on organophosphate resistance | "With increased temperatures, the life cycle of the mosquito will be shortened; smaller mosquitoes, which feed more frequently, will be produced; the geographic range of the mosquitoes will expand; and the extrinsic incubation period of the virus will be shortened…The shortening of the mosquito life cycle with increased environmental temperatures will undoubtedly result in the propagation of resistance through selection " |
| Event history analysis of dengue fever epidemic and inter-epidemic spells in Barbados, Brazil, and Thailand (Parker and Holman, 2012) | Barbados, Brazil, & Thailand | N/A | Temperature and drought | "Mean monthly temperature was the most important factor affecting the duration of both inter-epidemic spells…and epidemic spells… drought conditions increased the time between epidemics. Increased temperature hastened the onset of an epidemic, and during an epidemic, higher mean temperature increased the duration of the epidemic… correlation between temperature and the geographic range and vector efficiency of dengue fever" |
| Associations between household environmental factors and immature mosquito abundance in Quetzaltenango, Guatemala (Madewell, *et al*., 2019) | Guatemala | Housing, transportation, paved roads, and environmental capital | N/A | "Proximity to other houses and paved roads was associated with greater abundance of larvae and pupae. Understanding risk factors such as these can allow for improved targeting of surveillance and vector control measures in areas considered at higher risk for arbovirus transmission." |
| Potential impacts of climate variability on Dengue Hemorrhagic Fever in Honduras, 2010 (Zambrano, *et al*., 2012) | Honduras | N/A | ENSO | "Linear regression showed significantly higher dengue incidence with lower values of Oceanic Nino Index… higher rain probability…, accumulated rain… and higher relative humidity... At a multiple linear regression model using those variables, ONI values shown to be the most important and significant factor found to be associated with the monthly occurrence of DHF cases… climate variability is an important element influencing the dengue epidemiology in Honduras" |

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| Informed community mobilization for dengue prevention in households with and without a regular water supply: Secondary analysis from the Camino Verde trial in Nicaragua (Cárcamo *et al.,* 2017) | Nicaragua | Access to regular water supply | N/A | "Our results indicate a roughly twofold increased risk for entomological evidence of Aedes aegypti infestation in households with irregular water supply compared with those that have regular water supply." |
| Neglected tropical diseases in Central America and Panama: review of their prevalence, populations at risk and impact on regional development. (Hotez *et al.,* 2014) | Panama | Poverty and Gini Index | N/A | "Particularly at risk are the 10.2 million people in the region who live on less than $2 per day, mostly in Guatemala, Honduras, Nicaragua and El Salvador. Indigenous populations are especially vulnerable to neglected tropical diseases. " |
| Inverse association between dengue, chikungunya, and Zika virus infection and indicators of household air pollution in Santa Rosa, Guatemala: A case-control study, 2011-2018 (Madewell *et al.,* 2020) | Guatemala | Household air pollution | N/A | "Several primary determinants of HAP [household air pollution] exposure were inversely associated with arboviral infections. Additional studies are needed to understand whether interventions to reduce HAP might actually increase risk for mosquito-borne infectious diseases, which would warrant improved education and mosquito control efforts in conjunction with fuel interventions" |
| Health Workers' Perceived Challenges for Dengue Prevention and Control in the Dominican Republic (Veras-Estevez., 2017) | Dominican Republic | Economics, education, community cohesion, sustainability of government interventions | N/A | "These findings evince the complex interplay of economic, environmental, health, political and social factors that can directly or indirectly influence individual and community adherence to recommended dengue prevention measures." |

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| Association between Nutritional Status and Severity of Dengue Infection in Children in El Salvador (Maron, 2010) | El Salvador | Nutrition and socioeconomic status | N/A | "Excess nutrition does not appear to be a risk factor for severe forms of dengue infection in El Salvador, nor does malnutrition appear to be predictive of good outcomes. " |
| Examination of influencing factors and high-risk regions of dengue in Nicaragua, using spatiotemporal compartmental simulations (Theodorakos *et al*., 2017) | Nicaragua | Rural/urban populations | Rainfall | "High-risk areas in Nicaragua for the dengue disease seem to be isolated rural regions, with increased rainfall and vegetation" |
| Nonlinear and delayed impacts of climate on dengue risk in Barbados: A modeling study (Lowe *et al*., 2018) | Barbados | N/A | Drought, extreme rainfall, and temperature variations | "Drought conditions were found to positively influence dengue incidence rates at longer lead times up to 5 months, while excess rainfall increased the risk at shorter lead times between 1 and 2 months. Therefore, the modeling results suggest that a drought period followed by intense rainfall 4 to 5 months later could provide optimum conditions for an imminent dengue outbreak." |
| Investigating the knowledge and impact of dengue and chikungunya in a rural population in Yoro, Honduras (Warner *et al*., 2016) | Honduras | Poverty and access to resources/funds | N/A | "The poorest respondent group was less likely to know that Dengue is transmitted by mosquitoes… and less likely to know that mosquitoes lay their eggs in standing water…Respondents listed poor access to resources and lack of funds as the main barriers to mosquito prevention" |

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| A Mosquito Workshop and Community Intervention: A Pilot Education Campaign to Identify Risk Factors Associated with Container Mosquitoes in San Pedro Sula, Honduras (Parker *et al*., 2019) | Honduras | Education and housing | N/A | "The most prevalent containers (>50%) were flowerpots, garbage, and toys, which could be targeted in mosquito control programs. This pilot study offers a framework for training community leaders and stakeholders to create a sustainable community-based vector control program for container mosquitoes" |
| Socioeconomic and demographic predictors of resident knowledge, attitude, and practice regarding arthropod-borne viruses in Panama (Whiteman *et al*., 2018) | Panama | Education | N/A | "Lower relative knowledge and fewer practices related to the prevention of Dengue, Chikungunya, and Zika were found in low-SES neighborhoods. There is also a widespread lack of adequate knowledge regarding these diseases as well as low levels of concern in areas of highly reported mosquito biting." |
| Knowledge, perceptions, and practices with respect to the prevention of dengue in a mid-Pacific coastal village of Costa Rica (Egedus *et al*., 2014) | Costa Rica | Education | N/A | "Households with more positive breeding sites were lower education level, higher prevalence of dengue infections in the household, lesser knowledge of dengue symptoms, a lower rating on the dangers of dengue and a lower rating on the importance of preventative actions." |
| Aedes aegypti (L.) in Latin American and Caribbean region: With growing evidence for vector adaptation to climate change? (Chadee and Martinez, 2016) | Trinidad | N/A | Drought, water temperature, behaviors of Aedes Aegypti | "Within LAC countries, A. aegypti mosquitoes are moving to underground breeding sites" & "The increase in extreme events including higher than normal temperatures may be responsible for this shift or adoption by mosquitoes to underground breeding sites and resting places" |

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| Accelerating invasion potential of disease vector Aedes aegypti under climate change (Iwamura *et al*., 2020) | Global | N/A | Temperature, rainfall, and habitat | "The world became 1.5% more suitable per decade for the development of Ae. aegypti during 1950-2000, while this trend is predicted to accelerate to 3.2-4.4% per decade by 2050." |
| Epidemiological Characteristics of DengueDisease in Latin America and in the Caribbean: A Systematic Review of the Literature (Torres *et al*., 2017) | Central America and Caribbean (Trinidad and Honduras) | N/A | ENSO and rainfall | "In Trinidad…Although rainfall was significantly associated with dengue incidence, temperature was not. Indeed, dengue transmission in Trinidad was shown to occur at a variable level based on factors including seroprevalence, mosquito density, and climate" |
| Aedes Mosquito Infestation in Socioeconomically Contrasting Neighborhoods of Panama City (Whiteman *et al*., 2019) | Panama | Education and income | N/A | "Infestation levels for both Aedes species vary between neighborhoods of contrasting socioeconomic status, being higher in neighborhoods having lower percentage of residents with bachelor's degrees and lower monthly household income…proximity between socioeconomically contrasting neighborhoods can predict infestation levels by species, with A. aegypti increasing and A. albopictus decreasing with proximity between neighborhoods." |
| Past, Present, and Future Vulnerability to Dengue in Jamaica: A Spatial Analysis of Monthly Variations (Henry and Mendonça., 2020) | Jamaica | Urbanization | Rainfall and temperature | "A higher vulnerability was depicted in urban areas in comparison to rural areas. The results also demonstrate the possibility for expansion in the geographical range of dengue in higher altitudes under climate change conditions based on scenario" |

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| Co-developing climate services for public health: Stakeholder needs and perceptions for the prevention and control of Aedes-transmitted diseases in the Caribbean (Stewart-Ibarra *et al.,*2019) | Barbados and Dominica | Knowledge and climate/health | N/A | "Climate and health sectors do not feel ready to develop and implement an early warning system or other adaptation measures due to limited institutional capacity (resources and expertise)… we identified strategies and opportunities to initiate a successful process of joint collaboration between the climate and health sectors " |
| El Nino Southern Oscillation and vegetation dynamics as predictors of dengue fever cases in Costa Rica (Fuller *et al.,* 2009) | Costa Rica | N/A | ENSO | "[this model] may be used to predict DF/DHF outbreaks as early as 40 weeks in advance and may also provide valuable information on the magnitude of future epidemic" |
| Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002-2004) (Chadee *et al.,* 2007) | Trinidad | N/A | Temperature and rainfall | "No significant correlations were observed between temperature and DF or DHF incidence, but rainfall was found to be significantly correlated with DF incidence, with a clearly defined 'dengue season', between June and November" |
| Assessing the Effect of Climate Variables on the Incidence of Dengue Cases in the Metropolitan Region of Panama City (Navarro Valencia *et al.,* 2021) | Panama | Population density | Rainfall and temperature | "The result of this study shows that climatic variables could be important factors to predict Dengue incidence behavior, especially those whom affected the Aedes infestation index." |

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| Knowledge, Attitudes, and Practices *Regarding* Vector-borne Diseases in Western Jamaica (Alobuia *et al.,* 2015) | Jamaica | Education | N/A | "Poor knowledge of VBDs and poor prevention practices among participants. It identified specific groups that can be targeted with vector control and personal protection interventions to decrease transmission of the infections." |
| Factors associated with the incidence of dengue in Costa Rica (Mena *et al.,* 2011) | Costa Rica | Human poverty index | Temperature and altitude | "The cantons of Costa Rica with the highest incidence of D/DH were located mainly near the coasts, coinciding with some of the variables studied. Temperature, altitude and human poverty index (IPH) were the most relevant variables to explain the incidence of D/DH, while temperature was the most significant in the multiple analyses." |

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