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Vulnerability of Caribbean Island-nations to Future Climate Change

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VULNERABILITY OF CARIBBEAN ISLAND-NATIONS TO FUTURE CLIMATE CHANGE

By

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Vulnerability of Caribbean Island-nations
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The Caribbean is predicted to be one of the most impacted regions by climate change. However, the impacts of climate change will not be uniformly felt across the region due to the inherent geographic properties and unique socioeconomic characteristics that define each nation individually. This thesis has two goals. First, the vulnerability of thirteen island-nations in the Caribbean to future climate change is estimated by combining indicators of green infrastructure, socioeconomic infrastructure, and future climate change risks. Second, the contribution of five explanatory variables (GDP per capita, population density, land area size, political stability, and years of independence) to the variation in climate change vulnerability among island-nations across the Caribbean is evaluated.

The study reveals that none of the Caribbean island-nations are well prepared to face the challenges of future climate change. The most vulnerable Caribbean nation to climate change is Trinidad & Tobago and the least vulnerable nation is Cuba. The study also found that the five explanatory variables are weak predictors of vulnerability among Caribbean island-nations, a result that challenges some generalizations proposed at the global scale.

Overall, the findings demonstrate that geographic location is a major driver of each nations' vulnerability to climate change rather than the presence of adequate green and

socioeconomic infrastructure. Island-nations in the Caribbean should move quickly to incorporate climate change concerns into their national policies if they aim to increase their resilience to an ever-changing climate.

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CHAPTER 1

INTRODUCTION

The Challenge of Climate Change

In recent decades, global climate change has posed serious implications for both natural and human systems (Field et al., 2014b). The past three decades have been warmer than any preceding decade since 1850, with increases in average land and ocean temperatures from 0.65° to 1.06° Celsius from 1880 to 2012 (Field et al., 2014b). Additionally, glacial melting from rising temperatures has resulted in an increased global mean sea level, which rose at a rate of 3.2 mm yr^{-1} in the 17 year period from 1993 to 2010 (Wong, 2014). Other observed changes in the global climate include increases in extreme weather events, coastal erosion and changes in precipitation patterns (Field et al., 2014a).

Recent changes in the global climate are not solely attributed to the natural variations in the atmosphere (Burkett et al., 2014). Concentrations of greenhouse gases are at unprecedented levels, driven by global economic and population growth (Field et al., 2014b). Since 1750, there have been increases in atmospheric levels of carbon dioxide by 40%, methane by 150% and nitrous oxide by 20% due to increased fossil fuel combustion (Field et al., 2014b). Therefore, global climate change is most influenced by the presence of anthropogenic stressors and the interaction of these stressors with the natural environment (Burkett et al., 2014). As a result, human and ecological systems are exposed to climate change impacts such as decreases in the availability of freshwater sources, disruption of food production, population displacement and loss of natural resources (Bishop & Payne, 2012; Field et al., 2014a).

To minimize the negative impacts of climate change, there are two fundamental options a society has to respond: mitigation and adaptation (Füssel, 2007a). Mitigation reduces the underlying cause of climate change through the act of reducing the accumulation of greenhouse gases in the atmosphere (Laukkonen et al., 2009; McKibbin & Wilcoxen, 2003). On the other hand, adaptation is the ability to *cope* with the impacts of climate change, with the objective of moderating harm from climate change (Füssel, 2007a; Laukkonen et al., 2009). Traditionally, mitigation receives more focus than adaptation, both from a scientific and policy perspective (Füssel, 2007a).

Greater attention is focused on mitigation because it is an easily monitored, straightforward approach that provides actual long-term benefits by directly reducing the root of climate change (Füssel, 2007a). A defining characteristic of mitigation is that it recognizes the reduction of greenhouse gases as a global responsibility. In contrast with mitigation, adaptation requires policies and actions designed at the local and regional levels, where the impacts of climate change are actually felt (Bedsworth & Hanak, 2010; Laukkonen et al., 2009). Adaptation approaches account for a variety of factors that contribute to climate change vulnerability of societies. These include economic development, governance systems, public infrastructure and resource availability (Fazey et al., 2010). For example, adaptation policies can guide the development of new laws and regulations required to respond to issues intensified by climate change including habitat protection and public safety (Bedsworth & Hanak, 2010).

While mitigation is necessary, it is widely recognized that the past consumption of fossil fuels are and will continue to threaten society (Hewitson, 2014; Laukkonen et al., 2009). Even if global emissions are reduced to significant levels through mitigation, the effect of climate change and its associated impacts will continue to impact the global community (Bedsworth & Hanak, 2010). To successfully manage and respond to the unprecedented changes in the global atmosphere, adaptation is critical in enabling human societies to effectively deal with the environmental conditions brought about by climate change (Fazey et al., 2010). Therefore, adaptation is a necessary response to the realities of climate change.

Adaptation strategies must account for the uncertain evolution of climate change impacts in the future. Adaptation of a system should incorporate how a system evolves at different sets of stages, or trajectories (Rougé et al., 2015). Each potential future climate change scenario yields a different trajectory, producing a suite of potential harm scenarios that societies must account for when implementing adaptation policies (Rougé et al., 2015). Characteristics of effective long-term adaptation strategies consist of processes that strengthen human capacity and awareness of adaptation options, reduce the main drivers of climate change and provide a variety of options for future adaptation (Füssel, 2007a).

The continuous stream of adaptation actions and attitudes is shaped by the social, economic and ecological elements of societal systems, specifically the interactions between socioeconomic infrastructure and green infrastructure (Adger et al., 2005; Silva & Prasad, 2017; Tonmoy et al., 2014). Green infrastructure is defined as "network of natural, semi-natural and restored areas designed and managed at different spatial scales (from local to global), that encompass all major types of ecosystems (marine, terrestrial and freshwater), and that aims to conserve biodiversity, mitigate emissions of greenhouse gases, enable societal adaptation to climate change, and deliver a wide range of other ecosystem services" (Silva & Wheeler, 2017, p. 33). It directly provides environmental services that cannot be imported, such as clean air and water, in addition to supplying natural resources that are extremely valuable to humans (Collados & Duane, 1999; Silva & Prasad, 2017). Green infrastructure contributes significantly to social, economic and environmental health and improves the quality of life (Collados & Duane, 1999; Dias et al., 2016; Silva & Prasad, 2017). The loss of green infrastructure decreases biodiversity and ecosystem services, ultimately increasing sensitivity to climate change (Capistrano et al., 2005; Schröter et al., 2005)

Socioeconomic infrastructure provides the physical building blocks that enable the development of complex economies and social systems (Dias et al., 2016; Silva & Prasad, 2017). This type of infrastructure is understood through the services which are provided through the use of public infrastructure (Snieska & Simkunaite, 2009). This infrastructure promotes the health, education, cultural standards and economic activity that directly and indirectly impacts the welfare of societal systems (Snieska & Simkunaite, 2009). Examples include critical infrastructure such as schools, libraries, universities, hospitals, airports, electricity, telecommunications, water supply, sanitation facilities and roads (Snieska & Simkunaite, 2009). For instance, improving water systems reduces the presence of disease, while better roads reduce accidents and improve public safety (Aschauer, 2000). The delivery of services such as water, energy and sanitation directly benefits households, improving their welfare and productivity (Snieska & Simkunaite, 2009). Socioeconomic infrastructure is the underlying factor for quality of life (Aschauer, 2000). Societies that have strong green and socioeconomic infrastructure and effectively manage the tradeoffs are likely to adapt to climate change better, compared to those with weaker infrastructure and inefficient management (Silva & Prasad, 2017).

Vulnerability Assessment as a First Step Toward Adaptation

The application, design and purpose of adaptation polices focus on the social and economic determinants of vulnerability (Burton et al., 2002). Therefore, the first step toward a sound adaptation strategy at any spatial scale is an assessment of the society's vulnerability to future climate change. This step is critical because although climate change is a global phenomenon, the extent of atmospheric processes, ocean circulation, bioclimatic zones, daily weather and long-term climate trends are regional or local in occurrence (Hewitson, 2014).

The Intergovernmental Panel on Climate Change (IPCC) fifth assessment defines vulnerability as "the propensity or predisposition to be adversely effected, encompassing a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (Field et al., 2014b, p. 5) . However, this concept is criticized by scholars (Füssel, 2007b; Wolf et al., 2013). For instance, Wolf et al.'s (2013) formal analysis of the term vulnerability suggest that the minimal definition of vulnerability should be simply "a measure of potential future harm" (p. 66).

Because the IPCC's concept is broad enough to accommodate different ways to assess climate change vulnerability, different methods have emerged to evaluate an entity's vulnerability to climate change through the combination of natural and social science perspectives (Füssel & Klein, 2006). In general, these assessments seek to identify geographic "hot-spots" of vulnerability by analyzing a set of attributes of the system (Tonmoy et al., 2014). Füssel & Klein (2006) review several of these assessments and identify three major sets of policy recommendations: a) specification of long-term targets for the *mitigation* of global climate change; b) identification of particularly vulnerable groups and/or regions to prioritize *resource allocation* for research and adaptation; and c) recommendation of *adaptation* measures for both region and society's sectors (p. 308).

From the multitude of existing assessments, the literature reveals that indicator-based vulnerability assessments (IBVA) are widely used when evaluating climate change vulnerability (Tonmoy et al., 2014). Indicator-based vulnerability assessments integrate biophysical and socioeconomic components of vulnerability, while having the ability to communicate information to policy makers in a relatively easy manner (Tonmoy et al., 2014). They are used to monitor change over time, which is useful in determining the effectiveness of adaptation measures that have been implemented (Vincent & Cull, 2014). Although vulnerability indicators are widely accepted as a way to minimize the gap between the academic community and policy makers, they have been increasingly criticized (Hinkel, 2011; Tonmoy et al., 2014). Hinkel (2011) examines the use of vulnerability indicators to help clarify the concept in the science-policy interface and argues that this dichotomy results from two sources of conceptual confusion. First, there is confusion about what indicators are and what they can accomplish. Second, there is confusion regarding the purpose of assessing and indicating vulnerability. Hinkel (2011) reveals that there are no general theories or models available when developing climate change vulnerability indicators.

Initial development of vulnerability indexes is traced back to Briguglio's (1995) examination of small island developing states (SIDS) and their economic vulnerabilities. The study identifies the most important vulnerabilities that contribute to the special economic disadvantages of SIDS. The disadvantages are classified into five topics: small size, remoteness and insularity, disaster proneness, environmental fragility and other factors (Briguglio, 1995). First, individual indexes are developed through the collection of indicators, based on the three variables of the special economic vulnerability of SIDS: exposure to foreign economic conditions, insularity and remoteness and proneness to natural disasters. Then, all indicators are standardized and weighted, producing three sub-indexes that represent different dimensions of vulnerability. Finally, the combination of the three sub-indexes form a single, composite index.

Yusuf and Francisco (2009) conduct a study that maps climate change vulnerability for Southeast Asia. The objective of their study is to identify which regions in Southeast Asia are most vulnerable to climate change. A "quick" assessment is generated using specific indicators as proxies to create the following sub-indexes: 1) future climate risk based on exposure using historical records of climate related hazards, 2) human sensitivity using population density as an indicator, 3) ecological sensitivity using biodiversity as the proxy indicator and 4) adaptive capacity as a function of socioeconomic factors, technology and infrastructure. The final vulnerability map displays the average of normalized indicators for exposure (multiple risk hazard exposure), sensitivity (human and ecological) and adaptive capacity. The index values are divided into four equal parts and ranked to identify which areas are vulnerable. Although Yusuf and Francisco (2009) successfully develop a general vulnerability index, it is only based on very few indicators and does not take into account future climate change impacts, which is essential in climate change adaptation.

More recent papers incorporate projections of the future climate into vulnerability assessments. Kim et al. (2016) identify key vulnerable municipalities within the Republic of Korea (ROK) using a climate change indicator-based vulnerability assessment. First, a vulnerability index for each municipality is developed. This involves the selection of indicators, establishment of data and assessing vulnerability using the IPCC's definition of vulnerability, which includes variables of climate exposure, sensitivity and adaptive capacity. Vulnerability variables are selected through literature review and in-depth interviews with experts. These data are normalized and weighted using the Delphi method (Kim et al., 2016). Second, municipalities are classified to identify key vulnerable areas, generating key vulnerability maps. Future climate change conditions are simulated using a model that applies the representative concentration pathways (RCP) 8.5 climate change scenario. This scenario represents the worst future climate scenario that assumes a lack of effort toward reducing greenhouse gas emissions (Kim et al., 2016).

Using a similar approach at a smaller political scale, Corobov et al. (2013) assess climate change vulnerability at the local spatial scale, using administrative units of the Dniester river basin in Moldova as the spatial unit of analysis. Exposure is determined with projected temperature and precipitation predictions from 2021-2050. Sensitivity is based on specific indicators representing physiographical and socioeconomic characteristics. Adaptive capacity is analyzed through economic and agricultural indicators. The vulnerability of each unit is calculated with a ranking approach based on the combination of the primary indicator ranks, using equal weights (Corobov et al., 2013). This study supports adaptation to climate change because it provides a vulnerability assessment at the local level where the impacts of climate change are actually felt, while providing the necessary information needed for local communities to adapt.

Tonmoy et al. (2014) review the literature on indicator-based climate change vulnerability assessments, demonstrating that they account for only 6% - 7% of the general vulnerability literature. This indicates a considerable shortfall of sound and integrated vulnerability assessments in some of the most critical regions of the planet.

Vulnerability Assessments in the Caribbean

The Caribbean is identified as one of the most sensitive and exposed regions to the impacts of climate change (Bishop & Payne, 2012; Nurse et al., 2014; Rhiney, 2015). Even though many Caribbean island-nations have already experienced the effects of climate change, there is little understanding of how societies should deal with the effects of future climate change. Lack of sound adaptation strategies to cope with climate change is a major concern in the Caribbean. Adaptation is critical in the Caribbean because it contains the highest number of small island developing states (SIDS) in the world, and the island-nations in the region share distinctive characteristics that increase vulnerability to climate change, such as small size, minimal land available for development, strong socioeconomic dependence on the coastline, and limited resources (Bishop & Payne, 2012; Karmalkar et al., 2013; Turvey, 2007). It is predicted that the impacts of climate change will not be uniformly felt within the region due to the high level of diversity among the islands related to their geography and historical influence that guided societal development. However, this hypothesis has not been formally evaluated (Bishop & Payne, 2012; Rhiney, 2015). Despite the differences among countries, the region is broadly united by the looming reality of climate change and its associated impacts (Bishop & Payne, 2012).

There are multiple gaps in the academic literature that assesses Caribbean climate change vulnerability (Bishop & Payne, 2012). Although climate change research in the Caribbean has progressed over the last years, focus is lacking on the regional impacts of social and economic systems (Rhiney, 2015). There is an urgent need for robust studies of climate change vulnerability in the region and of the mechanisms that contribute to the vulnerability of social, economic and ecological systems (Rhiney, 2015).

The first 'big picture' analysis of climate change politics in the Caribbean was conducted by Bishop & Payne (2012). This study reveals that the politics required to effectively respond to climate change are not sufficiently developed to cope with consequences of future climate change. This is partly attributed to the structure of global climate change politics and its tendency to marginalize smaller, developing nations in comparison to larger, developed nations (Bishop & Payne, 2012).

Rhiney (2015) examines how the region's geography has influenced its exposure to unique multi-scalar drivers of social and economic vulnerability to climate change. Specific social and economic drivers identified in this review include rising input costs of raw materials, changing levels of government support, uneven access to markets and unequal distribution of natural resources (Rhiney, 2015). The review identifies gaps in existing knowledge, highlighting key areas for future academic research. The later include the uncertainty of future climate change predictions, minimal climate change research and its incorporation into policy, and the challenges of defining the concept of vulnerability (Rhiney, 2015). Although there are increases in the number of impact studies that identify the regional threat of climate change, the study indicates that there will be a disproportionately negative effect on the poorest and most vulnerable in the region (Rhiney, 2015).

The limited amount of Caribbean climate change vulnerability assessments can be attributed to the technical inability of climate change models to capture key climate data at a spatial scale specific to the Caribbean region (Karmalkar et al., 2013). Karmalkar et al. (2013) assess the ability of the General Circulation Model (GCM) data used in the Coupled Model Intercomparison Project Phase 3 (CMIP3) and the UK Hadley Centre Regional Climate Model (RCM), to accurately provide present-day and future scenarios of precipitation and temperature for individual Caribbean island-nations. The findings reveal that the RCM and GCM's used in the CMIP3 successfully capture large-scale atmospheric circulation features in the Caribbean, but exhibit difficulty in capturing the bimodal nature of the seasonal precipitation cycles, which is a defining climatic feature of the region (Karmalkar et al., 2013). Although climate change models identify large-scale atmospheric features, the study identifies the need for high-resolution climate model simulations specific to the spatial extent of the region, in order to fully understand climate change and its effect on small Caribbean nations (Karmalkar et al., 2013). Increasing the quantity and quality of accurate climate change models for the region will help minimize the uncertainty surrounding Caribbean climate change models, ultimately enabling the development of more accurate vulnerability assessments.

Existing Caribbean vulnerability assessments of the region have been conducted at multiple spatial scales, using several methods (Boruff & Cutter, 2007; CAF, 2014; Lam et al., 2014; Tonmoy et al., 2014; Turvey, 2007; Weis et al., 2016). Turvey et al. (2007) examine vulnerability in the case of small island developing states (SIDS), which is applicable to the Caribbean due to the high number of SIDS located in the region (Bishop & Payne, 2012). The index ranks 100 developing nations on a scale of 0 to 1 and reveals that eight of the nine nations with the highest geographic vulnerability are SIDS, three being the Caribbean island-nations of Dominica, Antigua & Barbuda and the Bahamas

(Turvey, 2007). The results confirm the hypothesis that small island states, including those with high per capita incomes, are more vulnerable than low income large countries (Turvey, 2007). Overall, the study also confirms that the geographic characteristics of SIDS including remoteness, insularity and coastal length provide valuable information when determining climate change vulnerability of regions like the Caribbean (Turvey, 2007).

The Development Bank of Latin America (CAF) (2014) propose a climate change vulnerability index specifically for the Latin American and Caribbean region (LAC). This is one of the most comprehensive vulnerability assessments for the region aiming to improve the understanding of how and why climate change vulnerability varies across the entire LAC region (CAF, 2014). In the absence of a consistent framework to analyze climate change vulnerability, the study provides up-to-date indexes that describe the relative state of climate change vulnerability at the national and subnational level (CAF, 2014). Climate change vulnerability is quantified by evaluating the risk of exposure, current human sensitivity to exposure and the capacity of a nation to adapt to the climate change impacts (CAF, 2014). The final climate change vulnerability index (CCVI) is composed of three component sub-indexes of exposure, sensitivity and adaptive capacity, with the exposure index being the most influential. Indexes for 33 sovereign nations are based on a scale from 0 to 10, where values closer to 0 represent higher risk and are divided into four risk categories: extreme risk, high risk, medium risk, and low risk (CAF, 2014). Exposure is quantified by evaluating the current risk of a region being impacted by extreme climate related events and the risk of projected changes in the climate, identifying geographic hotspots for extreme events (CAF, 2014). Sensitivity measures a population's susceptibility to climate change impacts as a function of existing physical, social and livelihood circumstances (CAF, 2014). Adaptive capacity is evaluated based on the ability of a nation's institutions and the presence of an economic and societal framework that can adjust to the projected stresses associated with climate change. The resulting exposure index reveals that seven of the top ten nations with the highest risk of exposure are located in the Caribbean, identifying Jamaica as the country at most risk, followed by Dominica and then Cuba (CAF, 2014). The sensitivity index demonstrates that Mesoamerican and Caribbean nations exhibit the greatest relative level of population sensitivity to climate change, with the Caribbean nations of Haiti, Dominican Republic, Jamaica, Cuba and Barbados demonstrating the highest sensitivity (CAF, 2014). Additionally, the adaptive capacity index reveals that the ten riskiest nations within the adaptive capacity index are located in the Caribbean and Mesoamerican region, with only two Caribbean nations of Haiti and Dominican Republic constituting the highest risk group (CAF, 2014). Using these three component indexes, a final index of climate change vulnerability index is developed. The final index demonstrates that within the LAC region, extremely vulnerable nations are located in agriculturally dependent Mesoamerican countries and large Caribbean islands that have high levels of exposure (CAF, 2014). The final index reveals that three of the top ten most vulnerable nations are located in the Caribbean and include Haiti, Dominican Republic and Jamaica. Additionally, the indexes suggest that nations with low socio-economic development exhibit the highest levels of vulnerability (CAF, 2014).

Even more specific to the geographical context of the Caribbean, Boruff & Cutter (2007) assess the environmental vulnerability of island-nations. The objective of this study is to provide a consistent method to compare hazard vulnerability at multiple scales, through the comparison of two Caribbean islands of St. Vincent and Barbados (Boruff &

Cutter, 2007). Through literature review, 17 indicators were selected and tested to evaluate if they are spatially and statistically relevant to analyze the two islands. In summary, the article indicates that most of St. Vincent's landmass is at risk of landslides and populations are most exposed to landslides and volcanic eruptions, while Barbados has much greater population exposure as a result of almost half of the population living in moderately vulnerable areas, especially areas prone to fire (Boruff & Cutter, 2007). Barbados is identified as the more vulnerable island due to the high percentage of the population living in vulnerable locations, as well as the percentage of land in each hazard category (Boruff & Cutter, 2007). Additionally, the comparison suggests that on both islands, high levels of social vulnerability correlate almost entirely to housing unit density and high percentages of older, retired or disabled persons, revealing potential indicators to analyze social vulnerability in the Caribbean (Boruff & Cutter, 2007). The study illustrates that the combination of social and physical indicators is required when evaluating vulnerability, to determine if certain factors increase or decrease vulnerability of the islands, rather than the domination of one indicator (Boruff & Cutter, 2007). In addition, the study provides a method to identify and compare vulnerability at multiple scales by first assessing the local level variation of vulnerabilities within each island, and then at the regional scale by comparing the two islands in the extent of the Caribbean.

Lam et al. (2014) conduct an assessment of vulnerability and adaptive capacity to coastal hazards in the Caribbean region. Using the IPPC's definition of vulnerability as a function of exposure, sensitivity and adaptive capacity, an index-based vulnerability assessment is developed and analyzes hurricane hazards for the nations in the Caribbean (Lam et al., 2014). Refined vulnerability indexes are produced for 25 Caribbean nations, finding that small island-nations were generally more vulnerable than large nations (Lam et al., 2014). Nations with the highest vulnerability indexes include the Bahamas, Montserrat, St. Kitts and Nevis and the Turks and Caicos. Initially, hurricane exposure is considered a key driver of vulnerability, but the resulting higher weights indicate that the variables of low adaptive capacity in the form of socioeconomic status, high electricity consumption and low infrastructure development contribute more to the overall vulnerability index (Lam et al., 2014).

In comparison to the previously described regional level Caribbean vulnerability assessments, Weis et al. (2016) assess vulnerability at the local level using an integrated approach for mapping adaptive capacity, sensitivity and exposure for the Eastern Caribbean island of Grenada (Weis et al., 2016). Guided by the IPCC's definition of vulnerability, the final composite index is the result of the combination of three sub-indexes representative of exposure, sensitivity and adaptive capacity. These data are spatially represented at the local scale through the use of geospatial information system (GIS) methods, which map the specific degree of vulnerability for each of Grenada's 287 districts (Weis et al., 2016). The results indicate that total vulnerability is very dependent on the elevation and slope in an area, due to the fact that an area is not vulnerable in the model unless it is exposed to flooding (Weis et al., 2016). Additionally, the study reveals that vulnerability is not driven by all the same indicators in all areas of the nation (Weis et al., 2016). Sensitivity and adaptive capacity have different spatial patterns across the Grenada, with sensitivity having a high degree of variation across the island, while there are concentrated regions of low adaptive capacity (Weis et al., 2016). Areas of low adaptive capacity roughly correlate with areas of high exposure to the flooding scenarios used in the study (Weis et al., 2016). This study applies an integrated approach that provides a single spatial framework, allowing for the exploration of the different components of vulnerability at the national and sub-national scale (Weis et al., 2016). The resulting indicator based vulnerability index and indicator maps reveal the relationship of elements that contribute to climate change vulnerability, providing a mechanism to inform decision-makers on the most effective pathways to reduce community vulnerability today and in the future (Weis et al., 2016).

The Socio-Climatic Vulnerability Index (SCVI)

To improve communication between climate scientists and policymakers, a Socio-Climatic Vulnerability Index (SCVI) is proposed by Torres et al. (2012) and is currently applied only in Brazil. This approach combines information about a specific region's magnitude of climate change and the social factors that could impact the vulnerability of a local population, revealing the most relevant human and social components to be impacted by future climate change (Figure 1.1) (Torres et al., 2012). The SCVI provides information that enables the identification of areas where adaptation actions should be prioritized, minimizing the gap in the science-policy interface (Torres et al., 2012).

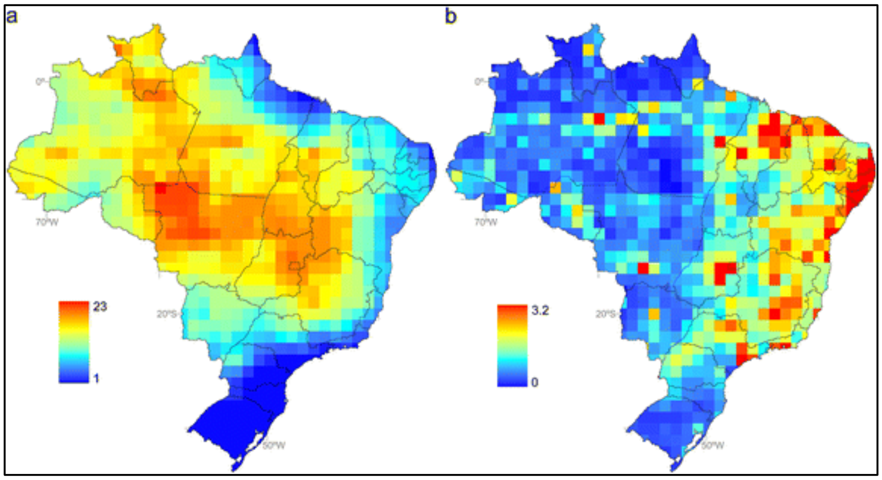

Figure 1.1. RCCI and SCVI Index Maps for Brazil. (a) Final map displaying the Regional Climate Change Index (RCCI) and (b) Socio-climatic Vulnerability Index (SCVI) for Brazil (both dimensionless) developed by Torres et al. (2012).

A benefit of the SCVI is its applicability to multiple spatial scales. It is a relative index that focuses on how vulnerability compares from one place to another by ranking vulnerability on a comparative basis (Torres et al., 2012). Another benefit is the use of climate change projections, rather than the use of observed climate data of the past. SCVI's incorporation of future projections enables the development of effective adaptation polices because the index accounts for the evolution of climate change in the future. In addition, the SCVI can include as many social variables required to characterize the local social conditions (Torres et al., 2012). These benefits are incorporated into Torres et al.'s (2012) definition of the index:

$$SCVI = CI * \sqrt[n]{\prod_{i=1}^{n} F_i},$$

where CI represents any climate change index suitable for the region, and the second element on the right hand side of the equation represents the geometric mean of the normalized social vulnerability factors (F_i) to determine local social conditions (Torres et al., 2012, p. 601). The resulting SCVI analysis identifies major socio-climatic hotspots of specific areas. The SCVI is a spatially explicit evaluation of social vulnerability to climate change and can be applied to different nations and regions. Ultimately, the simplistic and empirical nature of the SCVI can be used as a tool to improve communication between policymakers and the scientific community.

Silva and Prasad (2017) propose a modification of the SCVI. First, they assess vulnerability by combining indicators of ecological infrastructure, socioeconomic infrastructure, and future climate change. Similar to the SCVI equation proposed by Torres et al. (2012), indicators used to estimate green and socioeconomic infrastructure are normalized, rescaled and aggregated using the geometric mean (Silva & Prasad, 2017). Finally, the resulting infrastructure scores are spatially combined with indicators of future climate change to determine the vulnerability of a place. Two benefits of Silva and Prasad's SCVI adaptation are: (a) the incorporation of green infrastructure indicators, that are usually not included in most vulnerability assessments; (b) the visual, geographic representation of the combined infrastructure index overlaid with future climate change index allowing for prioritization of places for adaptation action. This approach also helps identify specific weaknesses that should be targeted (Silva & Prasad, 2017).

Correlates of Vulnerability to Climate Change in the Caribbean

The differences of political, economic and environmental characteristics among nations are critical in explaining how well they are currently prepared to face the negative effects of climate change (Barnett et al., 2008). However, there are very few studies that analyze what the major determinants of current socio-environmental vulnerability are.

Within the Caribbean, independent indicators such as GDP per capita, population density, size of land area, political stability and sovereignty are usually suggested as explanatory variables for differences of climate change vulnerability among nations (Pantin, 1994; Yohe & Tol, 2002).

GDP per capita is a common metric representative of a nation's economic wealth (Bueno et al., 2008; Ludena & Yoon, 2015; Yohe & Tol, 2002). Using climate change models, several authors hypothesize that a poor nation is more vulnerable than a rich nation (Diffenbaugh et al., 2007; Füssel, 2010; Vincent, 2004; Yohe & Tol, 2002). However, this relationship is not always true. For instance, Rhiney (2015) mentions that Cuba had a very low number of deaths during a period of frequent, high intensity natural disasters, despite having one of the largest populations and lowest GDP per capita in the region at the time (Rhiney, 2015). Therefore, the evidence surrounding the use of GDP per capita as a vulnerability indicator for the small island-nations in the Caribbean is uncertain (Bueno et al., 2008; Yohe & Tol, 2002).

Small land area size of Caribbean islands is suggested as a characteristic that increases climate change vulnerability. Briguglio (1995) demonstrates that small size often implies poor natural resource endowment, resulting in a high dependence on foreign resources. Small land area size is also identified by Rhiney (2015) as exacerbating the vulnerability of Caribbean island-nations due to its influence on the limited amount of natural resources, limited infrastructure, and limited human resources. On the other hand, Easterly & Kraay (2000) reveal that small size may not be disadvantageous from a social viewpoint because on average small states have higher incomes and productivity levels than larger states.

Places with the high population densities are hypothesized to be more vulnerable to climate change (Briguglio, 1995). For instance, Yohe and Toll (2002) demonstrate that more densely populated areas are more vulnerable to climate change, which is concerning for Caribbean nations because the majority of their populations are highly concentrated along the coast (CAF, 2014; Yohe & Tol, 2002). Torres et al. (2012) also imply that places with high population density have the highest vulnerability. However, Garschagen and Romero-Lankao (2015) reveal that denser populations have better access to resources and assets that give them the ability to lessen or avoid the negative consequences of climate change.

When considering the role of sovereignty (years of independence), literature suggests that there is no particular advantage or disadvantage regarding the performance of Caribbean small economies, requiring further investigation of its influence on vulnerability to climate change (Ramkissoon, 2002). Bishop & Payne (2010) found that the larger Caribbean island-nations of Jamaica, Cuba and Trinidad & Tobago, which experienced previous periods of substantial economic growth from bauxite and oil production, ascended to independence successfully. In comparison, Bishop & Payne (2010) reveal that Barbados' attempt to become independent shortly after Jamaica and Cuba failed due to confusion of how to function as an independent country. Ramkissoon (2002) argues that colonial status limits the development of domestic capabilities, but there are significant benefits of being associated with a nation of developed world status. This argument is supported by Briguglio's (1995) claim that "many SIDS may not have survived as independent states in the absence of their artificial props" (p. 1622). Additionally, Armstrong & Read (2000) demonstrate that dependent territories have done better economically than independent states.

As for political stability, it is generally assumed that nations with a greater degree of political stability are likely to demonstrate better economic performance, hence less vulnerability (Ramkissoon, 2002). But there is much difficulty of identifying indicators of economic or political processes, resulting in vagueness surrounding the influence of political stability on climate change vulnerability in the Caribbean (Eriksen & Kelly, 2007). Additionally, corruption is an important determinant of political stability but is a difficult, complex phenomenon to observe and even more difficult to quantify (Vincent, 2004). However, Vincent (2004) reveals that the institutional nature and strength of public infrastructure can indicate the stability of the current political regime.

As a result of the diverse and varying conclusions within literature, the ability of these indicators to predict Caribbean vulnerability is ambiguous. Due to the uncertainty surrounding these factors, there is a need to identify their applicability of predicting climate change vulnerability of Caribbean island-nations and their ability to account for the geographic scale and unique characteristics that make the region extremely diverse.

Objectives

There are two primary objectives of this study. The first is to estimate the vulnerability of a selection of thirteen independent island-nations in the Caribbean to future climate change. This is achieved by combining indicators of green infrastructure, socioeconomic infrastructure, and future climate change risks. As a consequence, it addresses some of the shortcomings of the previous regional assessments. The second objective is to evaluate how well five explanatory variables (GDP per capita, population density, land area size, political stability, and sovereignty) explain the variation in vulnerability among Caribbean island-nations. The working hypothesis is that none of these factors will explain vulnerability among Caribbean nations because of the large differences in the history and geographic settings existing among them.

CHAPTER 2

THE CARIBBEAN REGION

Vulnerability to climate change is a product of the unique physical and socioeconomic features that define a region. These features are determined by the Caribbean's geographical characteristics, historical legacy and cultural influences. To examine climate change vulnerability it is necessary to explore the factors that define the region and its uniqueness. This chapter identifies the geographical, physical and socioeconomic characteristics that contribute to the diversity of the Caribbean region.

Geographical Location and Geology

The Caribbean is estimated to cover a total of 2,754,000 square kilometers, spanning the Gulf of Mexico, Caribbean Sea and Atlantic Ocean. The diversity of physical features of Caribbean islands is attributed to the interactions of geological, atmospheric and oceanic processes. Tectonic activity between the Caribbean and North American plates formed the shape of the Caribbean Sea and the resulting arc formation of islands within the region (Figure 2.1). With the exception of the Bahamas, all islands lie close to the boundary of the Caribbean plate. Coastal form varies as a result of either plate collision or subduction. For instance, coasts adjacent to more stable plates are generally flat and are formed through the accretion of sediments such as coral rock, giving rise to coastlines of wider, coastal plains (Agard et al., 2007; Bishop & Payne, 2012; Boruff & Cutter, 2007). Coastal configuration owing to volcanic processes exhibit mountain ranges and steep cliffs, resulting from magma rising to the surface during plate subduction (Agard et al., 2007; Bishop & Payne, 2012; Boruff & Cutter, 2007).

These geological interactions result in the region’s high level of diversity of topography and geological composition.

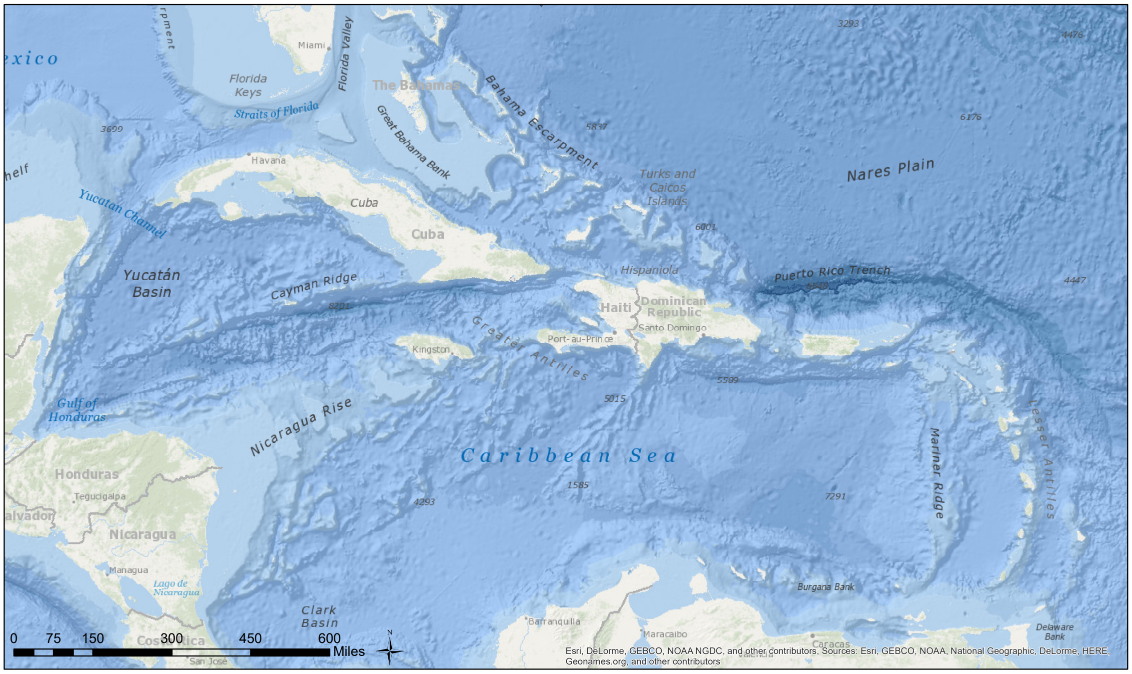

Figure 2.1. Map of Caribbean region. This displays the Caribbean island arc formation and distribution.

Climate

One of the most defining characteristics of any region is its climate. The Caribbean has a dynamic, tropical climate due to the region’s latitudinal position, and the interactions between atmospheric and oceanic processes. With very little seasonal variation, the average temperature is approximately 25° Celsius (77° Fahrenheit) and provides the physical characteristics required for the development of unique tropical ecosystems (Barros et al., 2014). Throughout the year the varying degree of rainfall in the region results in a distinct wet season and dry season. Typically, wet season occurs from June to December and is related to the seasonal northward migration of the Inter-tropical convergence zone (ITCZ) and the movement of major weather systems such as tropical storms and hurricanes (Agard et al., 2007). It is estimated that as much as 65% of total annual rainfall happens during the wet season (Pulwarty et al., 2010). In addition, the region is periodically influenced by sea surface temperature and salinity changes caused by the El Nino/Southern Oscillation (ENSO), as a result of changes in South America's rainfall pattern (Agard et al., 2007).

Oceanic Properties

Sea temperature, salinity and ocean circulation are important physical characteristics that define the region. Sea temperatures range from 21 to 31 degrees Celsius and are the result of the interactions between warm Atlantic ocean currents and the vertical movement of other water masses (Barros et al., 2014). The salinity of the sea surface ranges from 24 parts per thousand (ppt) to 37 ppt and receives little input of freshwater from the surrounding islands, with the exception of rainfall during the wet season (Agard et al., 2007). Ocean circulation in the region is caused by the equatorial currents of the Atlantic Ocean, winds and intensity of wave action. Waters of the South Equatorial Current flow from a major upwelling area near southern Africa, flowing across the Atlantic and along north-eastern South America into the Caribbean Sea (Agard et al., 2007). This circulation pattern determines water quality, in particular salinity and turbidity. In addition, the resulting current systems formed by the Earth's rotation cause the vertical displacement of water masses, which ultimately defines the bottom and coastal features of the Caribbean (Barros et al., 2014). Physical circulation patterns are important to identify because anthropogenic impacts such as pollution that are concentrated near coastal settlements can have a cumulative effect, impacting the entire region (Lewsey et al., 2004).

Ecosystems

The atmospheric, oceanic and geological characteristics that define the region's climate also provide the platform for the development of unique ecosystems. Major coastal and marine tropical ecosystems include tropical forests, beaches, seagrass beds, coral reefs and mangroves. The development of marine ecosystems are a result of the interactions between sea surface temperatures, salinity and the currents that are specific to the Caribbean Sea (Agard et al., 2007). Coastal features such as pristine beaches and coral reef ecosystems play a vital role in the tourism industry, which most island economies are dependent on (Lewsey et al., 2004). Ecosystems such as mangroves, wetlands, forests and dunes serve as natural shock absorbers for protecting coastal infrastructure and are a strategic necessity for limiting vulnerability to climate change (Lewsey et al., 2004).

Tropical broadleaf and coniferous forests support a high level of species richness and contain species found nowhere else. Terrestrial ecosystems contain approximately 11,000 plant species, with 72% being endemic to the region (Anadón-Irizarry et al., 2012). In addition, vertebrates in the region exhibit a high level of species endemism, with endemics species comprising 100% of 189 amphibian species, 95% of 520 reptile species, 74% of 69 mammal species and 26% of 564 bird species (Anadón-Irizarry et al., 2012). The Caribbean region is considered a biodiversity hotspot, representing 2.6% of the worlds 300,000 plant species and 3.5% of the world's 27,298 vertebrate species (Anadón-Irizarry et al., 2012; Wege & Pérez-Leroux, 2010).

The dynamic nature of beaches is important to the configuration of coastlines, and provide important habitats for species such as sea turtles. The constant accretion and erosion of sand is heavily influenced by storms, currents, offshore reefs, sand shoals and onshore dunes (Agard et al., 2007). Apart from its ecological role, beaches are one of the most important elements of the tourism industry, which is one of the largest economic sectors of Caribbean societies (Barros et al., 2014).

Seagrass beds have many important roles regarding Caribbean Sea ecosystems. The beds provide sediment stabilization, wave energy reduction as they approach the shore and nursery habitats for multiple marine species. Seagrass also plays an important role in the food chain due to its high net productivity (Barros et al., 2014).

Coral reefs are one of the most productive and valuable ecological features of the Caribbean. This resource supports the livelihoods of almost 40 million inhabitants and is a large contributor to the tourism and employment sectors of most economies in the region (UNEP, 2011). The presence of healthy reef ecosystems also provides shoreline protection from storm events and coastal erosion (UNEP, 2011). It is estimated that 90% of corals in the Caribbean are threatened from stressors that include coastal development, marine & land-based pollution, overfishing and a warming climate (UNEP, 2011). The loss of this resource is extremely destructive to coastal communities and will continue to degrade as a result of climate change impacts (Agard et al., 2007).

Mangroves are another extremely valuable ecosystem within the region. These tropical, deep rooted trees are found in estuaries and provide a variety of ecosystem services including habitats for spawning grounds and nurseries for many marine organisms (Agard et al., 2007). Mangroves and seagrass beds are expected to tolerate projected sea level rise through soil stabilization and decreasing energy from wave action, protecting the coastal infrastructure of many communities (Lewsey et al., 2004).

Socioeconomic Development

The historical influences imposed by varying colonizing powers is a large contributor to the diversity of the region (Bishop & Payne, 2012). Rapid internal changes in demography, economy, social culture, politics and environments have dictated the development of many societies in the Caribbean (Beckford & Rhiney, 2016). The region's dependency on outside foreign resources, markets, aid and governance can be attributed to the historical legacies imposed by the colonizing powers of England, Spain, France, the Netherlands and the United States (Beckford & Rhiney, 2016; Klak, 2000). During the early days of European colonization, the plantation era was the driving force for the domination of the Caribbean (Timms, 2008). The imperialistic nature of many colonizing powers perpetuated the development of close ties to Africa and Asia, which supplied labor in the form of slaves from Africa and indentured labor from South Asia. This shaped the demography of modern Caribbean societies (Beckford, 2013). Demographically, the region is largely composed of people of African, Asian and European descent, with very few remnants of the first peoples in Caribbean populations due to the genocide of indigenous populations during the early days of European colonization (Beckford & Rhiney, 2016).

Historically, Caribbean economies were based on agriculture (Beckford & Rhiney, 2016). External pressures from global forces resulted in an economic shift from agriculture to service-based industries in the Caribbean (Beckford & Rhiney, 2016). Post-war development policies of trade liberalization and increased privatization resulted in a shift away from agriculture, removing support to local farmers and transitioning domestic markets to food imports (Beckford & Rhiney, 2016). As a result of this transition, many nations are highly dependent on food imports and experience a decreased market for their few traditional exports. To balance the loss of the agriculture industry, the region experienced an increased reliance on the services sector (Beckford & Rhiney, 2016). In 2016, tourism and travel accounted for 14.9% of the region's gross domestic product (GDP), supporting an estimated 2,319,500 jobs in the region (WTTC, 2017). As a result, the tourism sector is the staple for economic growth in the Caribbean and provides employment opportunities and foreign currency flow. The impacts of historical globalization in the Caribbean contribute significantly to the current distribution and diversity of the region, helping understand the socioeconomic foundations that contribute to vulnerability to climate change.

The region's historical legacy and unique geographic characteristics largely contribute to the diversity of Caribbean island-nations. Therefore, there is a varying degree of unique economic, political and social systems throughout the region. In addition, islands differ significantly in population size, land area and GDP (Table 2.1). Overall there is a total of 26 island nations and dependent territories in the region with a total population of 43,782,373 inhabitants.

Table 2.1. Caribbean nation characteristics of land area, population and GDP per capita

Nation	Land Area (km^2)	Population Size	GDP per Capita ($US)
Anguilla	90	14,906	$21,493
Antigua & Barbuda	440	94,700	$13,715
Aruba	180	104,588	$25,751
Bahamas	10,010	330,000	$22,817
Barbados	430	292,300	$15,429
British Virgin Islands	150	31,200	$30,502
Cayman Islands	257	61,557	$58,808
Cuba	104,020	11,100,000	$6,790
Curaçao	444	159,987	$20,282
Dominica	750	73,900	$7,116
Dominican Republic	48,310	10,700,000	$6,468

Nation (cont.)	Land Area (km^2) (cont.)	Population Size (cont.)	GDP per Capita ($US) (cont.)
Grenada	340	111,700	$9,212
Haiti	27,560	10,600,000	$818
Jamaica	10,830	3,000,000	$5,232
Martinique	1,060	396,071	$24,118
Montserrat	100	5,179	$12,384
Puerto Rico	8,869	3,679,086	$28,123
St. Barthélemy	25	7,209	$27,700
St. Kitts & Nevis	260	52,700	$15,772
St. Lucia	610	165,000	$7,736
St. Maarten (Dutch)	34	41,486	$28,084
St. Martin (French)	54	31,949	$19,300
St. Vincent & Grenadines	390	102,100	$6,739
Trinidad & Tobago	5,130	1,200,000	$17,322
Turks & Caicos Islands	951	35,442	$23,615
United States Virgin Islands	350	106,574	$36,351

Major Climate Change Threats in the Caribbean

The characteristics that define the unique nature of the region also enhance sensitivity to future climate change impacts (Karmalkar et al., 2013). Major impacts of climate change for the region include changes in precipitation, soil moisture budgets, variation of sea level at the local and regional scale, frequency of extreme weather events, rising temperatures, and patterns of wave action (Lewsey et al., 2004). Each of these impacts will negatively affect coastal infrastructure and economic development (Barros et al., 2014).

Sea level rise (SLR) is projected to be one of the most serious threats for the Caribbean. It is predicted that sea levels will rise 0.5 to 0.6 meters (20 to 24 inches) by 2100, and for each centimeter of SLR, the United Nation's Caribbean Environment Programme (CEP) projects a shoreline retreat of up to several thousand hectares in coastal areas (Barros et al., 2014; Lewsey et al., 2004; UNEP-CEP, 1989). Problems associated with sea level rise include coastal erosion, the contamination of freshwater aquifers, loss of essential coastal infrastructure, and population displacement (Lewsey et al., 2004). These impacts will significantly hinder economic development because the concentration of populations, major facilities, and key services are located in coastal zones that are vulnerable to flooding from sea level rise and extreme weather events (Lewsey et al., 2004).

Overall, the Caribbean is predicted to become a much drier and warmer region (Pulwarty et al., 2010; Rhiney, 2015). Climate simulations predict that sea surface temperatures are expected to have a median annual increase of 1.8° to 2.3° Celsius (35.2° to 36.1° Fahrenheit) by 2100 (Barros et al., 2014). In addition, annual precipitation is expected to decrease by about 12%, signaling challenges for agriculture and water availability (Barros et al., 2014). Severe impacts will arise from these changes, drastically altering the livelihood of local communities throughout the region (Karmalkar et al., 2013). A decrease in precipitation will result in the lengthening of dry seasons, increasing drought and demand for water, thereby negatively impacting the agriculture and utility sectors (Nelson et al., 2009). Increasing temperatures will facilitate coral bleaching and result in loss of marine biodiversity, thereby devastating valuable coastal resources important to Caribbean economies (Bernal et al., 2004; Rhiney, 2015). Other impacts include the increase of northerly swells, increases in seasonal damage to beaches, widespread flooding, increases in the movement of invasive species and an increase in climate related diseases (Field et al., 2014b).

All Caribbean nations are united by the commonalities of climate change (Bishop & Payne, 2012). Despite regional similarities, climate change impacts will be disproportionately felt throughout the region due to the diversity of geophysical characteristics and socioeconomic development that are unique to each nation (Bishop & Payne, 2012). Therefore, it is expected that the impacts of climate change will vary among island-nations due to the unique societal, economic and ecological characteristics that are specific to each Caribbean island-nation.

CHAPTER 3

SPATIAL ASSESSMENT OF CARIBBEAN VULNERABILITY TO FUTURE CLIMATE CHANGE

This chapter estimates the vulnerability of the thirteen island-nations in the Caribbean to future climate change. This is achieved by combining indicators of green infrastructure, socioeconomic infrastructure, and future climate change risks. From this information, the level of vulnerability for each island-nation is determined. The results of this analysis are compared with the results of previous assessments of the region. The policy implications of the findings of this analysis are also discussed.

Methods

Study Site Selection

The study area includes 13 sovereign, island-nations located in the Greater and Lesser Antilles of the Caribbean. Initially, the study area included 25 nations and territories throughout the region, but due to limited data availability, the number of study sites was reduced. Territorial islands that belong to larger, distant sovereign nations, such as the United Kingdom, France and the Netherlands, either had no data available, or had data values that were grouped with their larger, mother nations they are dependent on. These territories were therefore excluded because they lack accurate data that represent the unique characteristics of the Caribbean societies.

Each nation was selected as the spatial unit of analysis due to the lack of data at local, finer scales. The final selection of 13 independent island- nations represents 88.24% of the entire Caribbean population and encompasses approximately 209,080 square kilometers of land, spanning the Greater and Lesser Antilles distributed throughout the Caribbean Sea (Table 3.1) (Figure 3.1).

Table 3.1. List of the 13 Caribbean island-nations selected for this study.

Caribbean Island-nations
Antigua & Barbuda
Bahamas
Barbados
Cuba
Dominica
Dominican Republic
Grenada
Haiti
Jamaica
St. Kitts & Nevis
St. Lucia
St. Vincent & the Grenadines
Trinidad & Tobago

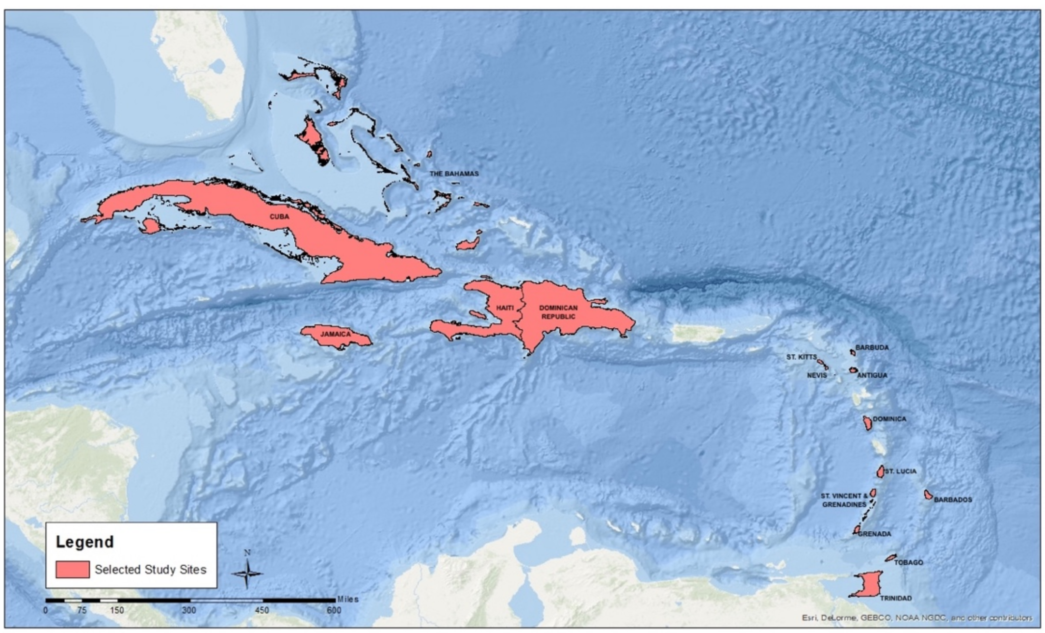

Figure 3.1. Selected island-nations. Map displaying the 13 Caribbean island-nations selected for this study.

Socioeconomic Infrastructure

Socioeconomic Indicators

Socioeconomic indicators represent the physical infrastructure that supports the social and economic systems of societal life in Caribbean nations. Selected indicators are separated into seven groups, that represent the core components of socioeconomic infrastructure. The seven core components are representative of (1) health, (2) access and availability of freshwater, (3) food, (4) energy, (5) communication, (6) transportation and (7) human capital. Even though each core element is examined individually, it is important to note that these components are correlated and are heavily influenced by one another.

Climate change is linked to increases in disease prevalence as a result of changes in climatic factors such as temperature, precipitation and extreme weather events (Tong et al., 2010). Indicators of health are important because they assess the current status of a community's health infrastructure and indicate a community's ability to prevent and/or cope with the adverse health impacts associated with climate change (Tong et al., 2010).

Water is an essential element to human survival. Climate change will impact the availability and quality of freshwater sources accessed by human populations. This is relevant for the Caribbean due to the region's lack of freshwater resources (Barros et al., 2014; Tong et al., 2010). Indicators of freshwater are chosen because one of the major impacts of climate change on the human population is likely to be the depletion of freshwater resources (Field et al., 2014b; Tong et al., 2010; UNDP, 2007).

Agricultural systems and food production will be heavily impacted by climate change, ultimately threatening food security (Stern & Taylor, 2007). Changes in mean daily temperature and rainfall can result in lower yields of stable food crops, or cause events such as plant disease epidemics. Food indicators reveal which nations will face an increase in threats to food security.

Energy is necessary for generating conditions for human prosperity, societal development and economic growth (World Bank, 2016a). Access to electricity is one of the most indispensable resources within a society and indicates a nation’s energy poverty status (World Bank, 2016a). Climate change can have positive or negative impacts on the energy sector in a variety of ways, depending on which resources a nation depends on for its energy needs (Schaeffer et al., 2011). Therefore, indicators of energy are extremely important in assessing socioeconomic infrastructure of a nation.

Communication is a key element in keeping a society connected, informed and prepared for responding to the impacts of climate change. Communities that have stronger communication infrastructure have the ability to implement strategies such as hazard warning systems (Lynn, 2011). Additionally, communication technologies provide opportunities for better service delivery, economic growth as well as social and cultural advances (World Bank, 2016a).

Climate change impacts pose serious threats to transportation infrastructure (Lynn, 2011). The majority of Caribbean nations have a strong dependence on imports, making transportation infrastructure such as ports, extremely important when dealing with the impacts of climate change. Transportation infrastructure also provides routes for vital amenities that include the distribution of food and medical services (Lynn, 2011). Indicators that identify the presence of transportation infrastructure are critical when examining vulnerability to future climate change.

Human capital involves indicators that reveal certain features of a population, such as education attainment and employment. Communities with minimal access to educational opportunities are considered to be vulnerable to climate change impacts (Busby et al., 2013). For example, populations that are undereducated may have less information and lack the skills to lessen the impacts of climate change (Busby et al., 2013). Indicators of this type of infrastructure shed light on a population's ability to respond to climate change.

Selection of Indicators

Selection of each indicator is conducted through literature review, identifying the level of consistency of data collection and analysis methods, in addition to the indicators relevance to the unique characteristics of Caribbean society. Raw data collection of socioeconomic indicators is compiled from a variety of sources that include the World Bank, Food and Agricultural Organization of the United Nations, United Nations Energy Statistics Division, World Port Index, CIA World Factbook, International Telecommunications Union and United Nations Educational, Scientific and Cultural Organization. Original data values for each indicator are the actual values of physical infrastructure or a proxy indicator that represents physical infrastructure. Actual values of physical infrastructure include, for instance, number of hospital beds or the percent of total roads that are paved, while proxy indicators include data such as physician density or percent of the population with access to improved sanitation facilities.

A database is developed, which compiles all raw data of the potential indicators and organizes indicators into their relative component groups of health, freshwater, food, energy, communication, transportation or human capital. Quantitative values of each indicator are either the original, pre-calculated values that came directly from the source, or are data that required further calculations to make them more applicable to the study region.

A Spearman correlation is conducted among the indicators using the statistical program SPSS. The correlation identifies if an indicator is redundant, within their respective core group. Indicators having a correlation coefficient of 0.8 or higher are considered redundant and one is removed. A total of 24 socioeconomic indicators are selected for the analysis (Table 3.2).

Table 3.2. The 24 socioeconomic indicators selected for this study.

Socioeconomic Infrastructure Component Group	**Socioeconomic Indicator**	**Description**	**Source**	**Year Range for Available Data**
Health	Physician Density	Physicians per 1000 population	World Bank World Development Indicators [a]	1999 - 2011
	Hospital Beds	Number of hospital beds	World Bank World Development Indicators [a]	2007 - 2012
	Health Expenditure	Expenditure per capita in US$	World Bank World Development Indicators [a]	2014
Freshwater	Improved Sanitation Facilities, Rural	Percent of rural population with access to improved sanitation facilities	World Bank World Development Indicators [a]	2007 - 2015
	Improved Sanitation Facilities, Urban	Percent of urban population with access to improved sanitation facilities	World Bank World Development Indicators [a]	2007 - 2015
	Improved Water Source, Rural	Percent of rural population with access to improved water sources	World Bank World Development Indicators [a]	2007 - 2015

Socioeconomic Component Group (cont.)	Socioeconomic Indicator (cont.)	Description (cont.)	Source (cont.)	Year Range for Available Data (cont.)
Freshwater (cont.)	Improved Water Source, Urban	Percent of urban population with access to improved water sources	World Bank World Development Indicators [a]	2015
	Freshwater Resources	Renewable internal freshwater resources per capita in cubic meters	World Bank World Development Indicators [a]	2014
= Food	Food Production Variability	Variability of net food production value in constant 2004-2006 per capita in US$	FAO Suite of Food Security Indicators [b]	2013
	Food Import Quantity *	Total tonnage of food imports	FAO Food Balance Sheets [c]	2013
	Per Capita Food Supply	Food supply in kilocalories per capita	FAO Food Balance Sheets [c]	2013
Energy	Access to Electricity, Rural	Percent rural population with access to electricity	World Bank World Development Indicators [a]	2012
	Access to Electricity, Urban	Percent urban population with access to electricity	World Bank World Development Indicators [a]	2012
	Renewable Energy *	Percent of total electricity production that uses renewable energy sources	2014 UN Energy Statistics Yearbook [d]	2014
Transportation	Ports	Total number of marine ports	2016 World Port Index [e]	2016
	Airports	Total number of airports with paved runways	CIA World Factbook [f]	2013
	Road Density	Density of roads per 100 square kilometers of land area	FAO Suite of Food Security Indicators [b]	1999 - 2011
	Paved Roads	Percentage of total roads that are paved	CIA World Factbook [f]	2001 - 2015

Socioeconomic Component Group (cont.)	Socioeconomic Indicator (cont.)	Description (cont.)	Source (cont.)	Year Range for Available Data (cont.)
Communication	Mobile Cellular Subscriptions *	Subscriptions per 1000 population	International Telecommunications Union [g]	2015
	Fixed Telephone Subscriptions *	Subscriptions per 1000 population	International Telecommunications Union [g]	2015
	Fixed Broadband Subscriptions *	Subscriptions per 1000 population	International Telecommunications Union [g]	2015
	Internet Access *	Percent of population with access to the internet	International Telecommunications Union [g]	2015
Human Capital	Education Expenditure	Percent government expenditure on education as percent of GDP	United Nations Educational, Scientific and Cultural Organization [h]	1999 - 2015
	Pupil-Teacher Ratio	Pupil-teacher ratio for primary education (headcount basis)	United Nations Educational, Scientific and Cultural Organization [h]	1998 - 2015

* Additional indicator calculations. [a] World Bank (2016b). [b] FAO (2016b). [c] FAO (2016a). [d] UN Statistics Division (2014). [e] National Geospatial Intelligence Agency (2016). [f] CIA (2016). [g] International Telecommunications Union (2015). [h] UIS (2016).

Additional Indicator Calculations

From the 24 selected socioeconomic indicators, 6 socioeconomic indicators require further manipulation in order to calculate the indexes.

Food Import Quantity

Total tonnage of domestic supply of food imports is calculated by adding the individual food and crop import tonnage values from the FAO's Food Balance Sheets.

Renewable Energy

The percentage of renewable energy used in total electricity production is calculated by aggregating the total electricity production values of hydro, nuclear, wind and solar power. This value is divided by the total electricity production to reach the final percentage.

Paved Roads

The percentage of paved roads is calculated by acquiring the total, overall length of paved roads in square kilometers. To get the final percentage, the paved roads total length is divided by the total length of all road, in square kilometers.

Mobile Cellular Subscriptions

This is calculated by dividing the total mobile subscriptions value by the total population. This value is multiplied by 1000 to reach an indicator value that represents mobile subscriptions per 1000 population.

Fixed Telephone Subscriptions

This is calculated by dividing the total fixed telephone subscriptions value by the total population. This value is multiplied by 1000 to reach an indicator value that represents fixed telephone subscriptions per 1000 population.

<u>Fixed Broadband Subscriptions</u>

This is calculated by dividing the total fixed broadband subscriptions value by the total population. This value is multiplied by 1000 to reach an indicator value that represents fixed broadband subscriptions per 1000 population.

Green Infrastructure

Environmental Indicators

Indicators of green infrastructure represent physical elements of different ecosystems and environmental features that supply essential natural resources and services required for human development (Dias et al., 2016). Direct services supplied by green infrastructure cannot be imported and include things such a clean air and clean water (Collados & Duane, 1999). Green infrastructure contributes significantly to social, economic and environmental health, and improves the overall quality of life (Collados & Duane, 1999; Dias et al., 2016).

Selection of Indicators

Indicators of green infrastructure are selected through reviewing literature, identifying the integrity and consistency of data collection and analysis methods, and its relative ability to capture the specific and unique characteristics of Caribbean island-nations. Raw data collection of environmental indicators originates from a variety of sources that include the United Nations Environment Program, Food and Agriculture Organization of the United Nations, the Status and Trends of Caribbean Coral Reefs: 1970 – 2012, NASA MODIS/ Terra Vegetation Index and ReefBase Global Information System for Coral Reefs. As a result, a selection of five environmental indicators are chosen for the analysis (Table 3.3).

Table 3.3. The five green infrastructure environmental indicators selected for this study.

Environmental Indicator	Description	Source	Year of Data
Change in Mangrove Coverage	Percentage of change in mangrove coverage in hectares	World Atlas of Mangroves [a] & FAO The World Mangroves 1980-2005 [b]	1988 - 2012
Mangrove Area	Percent of total land area covered by mangroves	ReefBase Global Database [c]	2000-2007
Coral Reef Cover	Average percentage of most recent coral cover	Status and Trends of Caribbean Coral Reefs: 1970-2012 [d]	2003 - 2012
Reef area	Percent of total marine area covered by reefs	ReefBase Global Database [c]	2004
Vegetation Cover	Percent of land covered by natural vegetation	MODIS/Terra Vegetation Indices [e]	2016

* Additional indicator calculations. [a] Spalding et al. (1997). [b] FAO (2007). [c] ReefBase (2016). [d] Jackson et al. (2014). [e] NASA (2016).

Additional Indicator Calculations

All five environmental indicators for green infrastructure indicators require further manipulation in order to be used in the calculation of the indexes.

Change in Mangrove Coverage

This indicator represents the percent change in mangrove coverage using a combination of the oldest and most recent data available. The most recent mangrove coverage data are calculated using ESRI's ArcMap geospatial system. The raw data are in the form of a shapefile that contained global mangrove distribution. In order to calculate mangrove extent for each of the 13 study sites, a single shapefile is created using data from the Global Administrative Boundaries database, which contains all boundary data for each island-nation. The mangrove distribution shapefile and study site shapefile are each separate individual layers in ESRI's ArcMap and are added to the data-frame. Mangrove data for each individual study site are acquired using "select by location" tool and the spatial selection method "are within a distance of source layer feature", with a search distance of 2 miles. These selected data are exported to create a new, separate Caribbean mangrove distribution shapefile in order to analyze and process the data more efficiently. The attribute table of this new shapefile contains mangrove extent in square kilometers, which is transformed into hectares by adding a field in the attribute table and calculating the new value using the field calculator tool. To get the final total mangrove extent in hectares for each individual study site, mangrove distribution data are aggregated through the summarize tool and selecting "sum" as the output statistic.

The oldest mangrove extent data come from the "North and Central America Status and Trends in Mangrove Area" section of "The World's Mangroves 1980-2005", a joint collection project involving the FAO and UNEP-WCMC. Both the recent and past data used in the calculation of this indicator are comparable, because they both were collected by the same organizations, through consistent methodologies. The final indicator value represents the percent change in mangrove extent, as a function of the oldest mangrove extent in hectares, through the following formula:

$$\% \text{ increase} = (\text{newest value} - \text{oldest value})/(\text{oldest value}) * 100$$

A negative percent change value indicates loss of mangrove ecosystems, where positive values represent an increase in mangrove coverage.

Mangrove Area

Mangrove area is calculated by dividing the total mangrove extent in square kilometers by each nations total land area in square kilometers. This value was multiplied by 100 to produce the final percentage of mangrove extent for each nation.

Coral Reef Cover

This indicator is calculated with the most recent percent coral cover values of reef locations from Jackson et al.'s (2014) *Status and Trends of Coral Reefs 1970-2012*. The time period of data collection for each island-nation occurred between 2003 to 2012. For each nation, the coral reef study provides data for either multiple coral reef locations, a single reef location, or none at all. The final value for coral reef cover is the mean across the individual coral cover percentages for reefs located in each of the 13 island-nations.

Reef Area

Reef area is calculated by dividing the total reef area in square kilometers and the total marine area for each nation, in square kilometers. This value is multiplied by 100 to produce the final percentage of reef area for each of the 13 island-nations.

Vegetation Cover

Vegetation coverage is calculated as a percentage using ESRI's ArcMap geospatial information system. Using the Land Cover geotiff product data from the MODIS/Terra Vegetation Indices, data are downloaded in the raster format via the MODIS subset data tool for each of the 13 island-nations. The Land Cover geotiff product classifies each nation’s land surface into 17 land cover types that include different forms of vegetation, water, urban build-up and croplands. Smaller island-nations are able to fit into a single raster data subset, while island-nations covering a larger spatial extent require multiple raster subsets. Larger nations requiring multiple raster datasets are combined using the “mosaic” tool in ESRI’s ArcMap to produce a single raster file. Land cover raster data are produced for each nation individually. These data are symbolized and classified into a set of unique values ranging from 0 to 17, with each value representing one of the 17 types of land cover. Each raster is clipped to the boundary of each nation so the remaining pixels solely represent the land area of each nation, excluding pixels representative of the surrounding coastal waters. Excluding of pixels is necessary because the raster subset download includes pixels representing each island-nation’s land area, but also all the pixels of the surrounding coastal waters of the Caribbean Sea. As a result, the majority of pixels in each raster are classified as water. Since this indicator is representative solely of vegetation cover for each island, there is no use for the water pixels that constitute the majority of the raster. To accurately calculate vegetation cover, all the pixels must fall within the land boundary of each nation and exclude all pixels that are outside this boundary. This step is necessary because otherwise, the final indicator would be skewed. The final land cover classification data for each island-nation are exported to create a table that contains the 17 land cover types and the number of pixels constituting each type. For each nation, the number of pixels for each land cover type are aggregated to produce a single value of the total pixel count. The number of pixels constituting each of the 17 land cover types is divided by each nation’s total pixel count to achieve the percentage for each individual, land cover type in the raster. The final indicator value is calculated by aggregating all land cover types designated as natural vegetation to produce the final vegetation cover percentage for each of the 13 island-nations.

Future Climate Change Risk

Future Climate Change Indicators

Each nation's risk to future climate change is assessed through the combination of a Regional Climate Change Index (RCCI) and the percentage of land area that is below 5 meters. The two indicators used in this index are normalized, rescaled and aggregated using the geometric mean to produce a final value that determines a nations risk to future climate change. Both are based solely on physical and climatic factors, excluding the human element.

Selection of Indicators

The Regional Climate Change Index (RCCI) is a comparative index that identifies which regions may experience more pronounced impacts of climate change, through the combination of multiple climate model projections (Giorgi, 2006; Torres & Marengo, 2014). The RCCI uses reliable general circulation models (GCM) and forcing scenarios from the Coupled Model Intercomparison Project phase 5 (CMIP5) (Torres & Marengo, 2014). RCCI-CMIP5 uses 24 general circulation models from the CMIP5 to generate data for the present climate and projections for climate in the future. Monthly precipitation and surface air temperature data are analyzed to simulate the present climate (1961 – 1990) and future climate (2071 – 2100) (Torres & Marengo, 2014). The CMIP5 uses Representative Concentration Pathways (RCP) 2.6, 4.5, 6.0 and 8.5 W m^(-2), that correspond with radiative forcing by the end of the century (Moss et al., 2010). The RCP forcing scenarios 2.6, 4.5, 6.0 and 8.5 correspond to CO_2 concentrations of roughly 490, 650, 850 and 1,370 parts per million (ppm) by 2100 (van Vuuren et al., 2011).

Sea level rise is expected to be one of the more severe impacts of climate change in the Caribbean. The insular nature of most Caribbean nations makes them particularly sensitive to changes in sea level, in addition to the high concentration of coastal populations. The percentage of total land area that falls below 5 meter is a valuable indicator of climate change vulnerability because there is a varying degree of topography in the region. As a result of plate tectonics, some Caribbean island-nations are more low-lying than others, which makes the threat of sea level rise even more severe. This indicator data is acquired from the World Bank Development Indicators database and did not require further calculations to achieve the final value used in the index.

Additional Indicator Calculations

<u>RCCI-CMIP5</u>

The RCCI-CMIP5 indicator is generated using ESRI's ArcMap geospatial information system. First, the RCCI-CMIP5 raw global data are transformed into 1 degree latitude and longitude spatial resolution. To display the spatial extent of the 13 study sites, the global RCCI-CMIP5 is transformed into a raster dataset and clipped to the boundary of the extent of the Caribbean region. The initial raster cell size is resampled to a smaller size of 0.125 due to the small, geographic size of the island-nations. The final indicator is calculated using the zonal statistics tool that produces the mean value of the RCCI-CMIP5 cells that compose each individual island-nation.

Analysis

Index Composition

Normalization

The resulting indicator data collected for socioeconomic infrastructure, ecological infrastructure and future climate change risk are normalized in order for the data to be comparable to one another. For each individual indicator, the following min-max normalization formula is applied:

$$X_{normalized} = (X - X_{minimum})/(X_{maximum} - X_{minimum})$$

where X represents a single nation's indicator value, $X_{minimum}$ represents the value of the nation with the lowest indicator quantity, and $X_{maximum}$ represents the value of the nation with the highest indicator quantity. Using this formula all data are transformed so indicator values range from 0 to 1.

Rescaling

Each indicator has either a positive or negative effect on climate change vulnerability. Therefore, each indicator is rescaled based on their direct or indirect impact on socioeconomic or green infrastructure, in regards to future climate change. An indicator with a positive effect on vulnerability to climate change is rescaled using the following formula:

$$X_{rescaled} = X_{normalized} * (1.0 - 0.1) + 0.1$$

An indicator with a negative impact on climate change vulnerability is rescaled using the following formula:

$$X_{rescaled} = X_{normalized} * (0.1 - 1.0) + 1.0$$

Aggregation

Once all indicator data for each of the 13 island-nations are transformed and rescaled accordingly, indicators within each group are aggregated using the geometric mean formula:

$$\sqrt[n]{x_1 \, x_2 \dots x_n}$$

For socioeconomic infrastructure, the output value from aggregation represents a nation's score for each of the seven socioeconomic core groups including health, freshwater, food, energy, transportation, communication and human capital. The overall socioeconomic infrastructure score is calculated by aggregating the seven group scores into a single value, using the geometric mean formula. The final green infrastructure score for each nation is calculated by combining the geometric means of the five environmental indicators. The final climate change risk score is calculated by combining the geometric means of the two future climate risk indicators. The two resulting infrastructure indexes are combined through aggregating the geometric means to produce a current Composite Infrastructure Index for each island-nation.

Map Composition

To visualize the geographic variation of the final index scores, all data are transformed into maps using ESRI's ArcMap geospatial information system. All final index values are compiled into one database and added to ArcMap. These data are joined with the Caribbean boundary shapefile, using the "ISO" attribute as the common field for both datasets. All indexes are converted into individual maps, using the final scores for each island-nation as the quantitative value to be displayed. The world's oceans are used as the base map due to the important role the Caribbean Sea has in the region. Within each map, each island-nation is categorized into three groups using a quantile classification method. For every individual infrastructure index developed, each nation is symbolized as either red to indicate the lowest scores, yellow to indicate scores in the middle, and green to indicate nations with the highest scores. Low scores represent weaker infrastructure which increases their vulnerability to climate change, while high scores represent strong infrastructure which makes them less vulnerable to climate change. For the future climate change risk index, the high scores represent a high risk of climate change impacts, while lower scores indicate a lower risk of future climate change. Nations with higher scores will experience future climate change impacts more severely, while lower scoring nations will be less impacted. Future climate change risk scores were symbolized as red for high, yellow for medium and green for low.

Final Vulnerability Chart

To identify which of the 13 island-nations are most vulnerable to future climate change, each nation's composite infrastructure index is plotted with the future climate change risk index. In excel, a scatter-bubble chart allows for the input of three variables – composite infrastructure score, future climate change risk score and population size. The size of each point in the chart is proportional to each nation's population size, and the composite infrastructure score and future climate risk score are the x and y axis. The minimum score of the top 25% of the composite infrastructure scores and future climate change risk scores is used as a threshold value to separate the nations into their respective quadrants. This threshold is selected because it complements the division of the chart into 4 individual quadrants. Each quadrant is representative of the following 4 vulnerability groups that each nation falls under: high infrastructure & high climate risk (medium-high vulnerability), high infrastructure & low climate risk (low vulnerability), low infrastructure & high climate risk (high vulnerability), and low infrastructure & low climate risk (medium-low vulnerability). The color of each point represents the vulnerability group each nation falls under: red as high vulnerability, orange as medium-high vulnerability, yellow as medium-low vulnerability and green as low vulnerability.

Comparison to Different Reports

The scores of the composite infrastructure index and future climate risk index are correlated with general vulnerability indices from other publications (CAF, 2014; Lam et al., 2014; Wheeler, 2011) using the statistical program SPSS to perform a Spearman correlation due to the nature of the data. A correlation is considered significant if $p < 0.05$. Specifically, the indexes used in the correlation are: CAF's(2014) Vulnerability Index to Climate Change for the LAC Region, David Wheeler's (2011) quantification of vulnerability for 233 nation-states, and Lam et al's. (2014) vulnerability and adaptive capacity assessment to coastal hazards in the Caribbean region

Results

Health Infrastructure Index

Health infrastructure scores have a minimum of 0.11 and a maximum of 0.75, with an overall average of 0.35. Cuba has the highest score, while Haiti has the lowest (Table 3.4). Low infrastructure scores range from 0.11 to 0.24, medium from 0.25 to 0.36 and high from 0.37 to 0.75 (Figure 3.2).

Table 3.4. List of health infrastructure scores for each selected nation.

Nation	Health Infrastructure Index Score
Antigua & Barbuda	0.24
Bahamas	0.57
Barbados	0.61
Cuba	0.75
Dominica	0.36
Dominican Republic	0.22
Grenada	0.31
Haiti	0.11
Jamaica	0.17
St. Kitts & Nevis	0.32
St. Lucia	0.17
St. Vincent & the Grenadines	0.36
Trinidad & Tobago	0.39

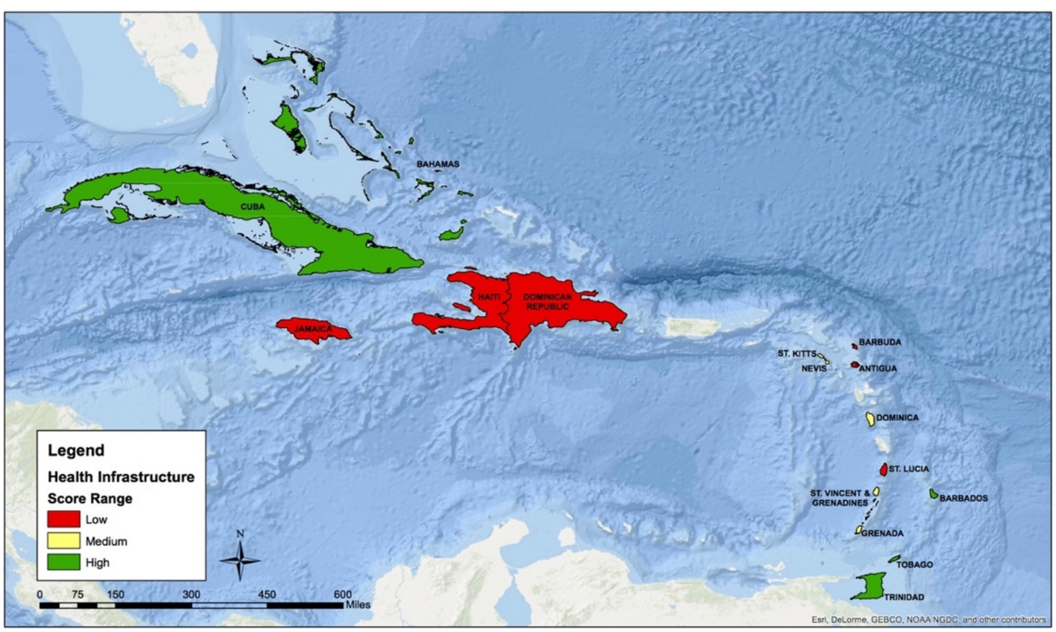

Figure 3.2. Health Infrastructure Index Map. Geographic variation in health infrastructure scores.

Freshwater Infrastructure Index

Freshwater infrastructure scores have a minimum of 0.13 and a maximum of 0.89, with an overall average of 0.71 (Table 3.5). Cuba has the highest score, while Haiti has the lowest. Low infrastructure scores range from 0.13 to 0.67, medium from 0.68 to 0.83 and high from 0.84 to 0.89 (Figure 3.3).

Table 3.5. List of freshwater infrastructure scores for each selected nation.

Nation	Freshwater Infrastructure Index Score
Antigua & Barbuda	0.67
Bahamas	0.83
Barbados	0.63
Cuba	0.89
Dominica	0.81
Dominican Republic	0.69
Grenada	0.85
Haiti	0.13
Jamaica	0.87
St. Kitts & Nevis	0.63
St. Lucia	0.79
St. Vincent & the Grenadines	0.64
Trinidad & Tobago	0.87

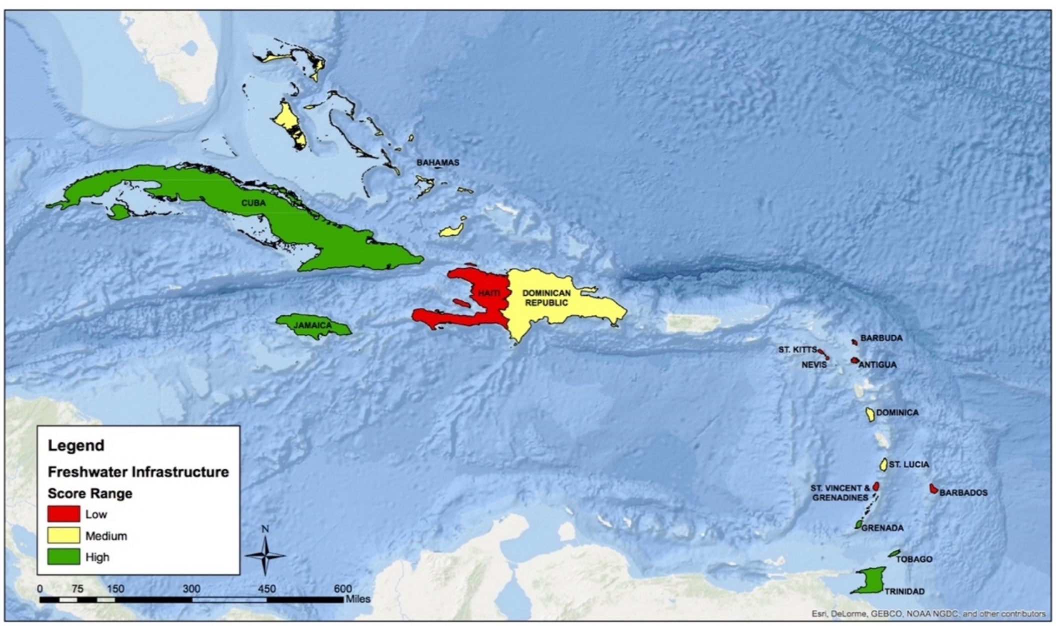

Figure 3.3. Freshwater Infrastructure Index Map. Geographic variation in freshwater infrastructure scores.

Food Infrastructure Index

Food infrastructure scores have a minimum of 0.35 and a maximum of 0.85, with an overall average of 0.64. Barbados has the highest score, while St. Lucia has the lowest (Table 3.6). Low infrastructure scores range from 0.35 to 0.53, medium from 0.66 to 0.73, and high from 0.75 to 0.85 (Figure 3.4).

Table 3.6. List of food infrastructure scores for each selected nation.

Nation	Food Infrastructure Index Score
Antigua & Barbuda	0.66
Bahamas	0.75
Barbados	0.85
Cuba	0.44
Dominica	0.73
Dominican Republic	0.53
Grenada	0.67
Haiti	0.41
Jamaica	0.71
St. Kitts & Nevis	0.53
St. Lucia	0.35
St. Vincent & the Grenadines	0.82
Trinidad & Tobago	0.81

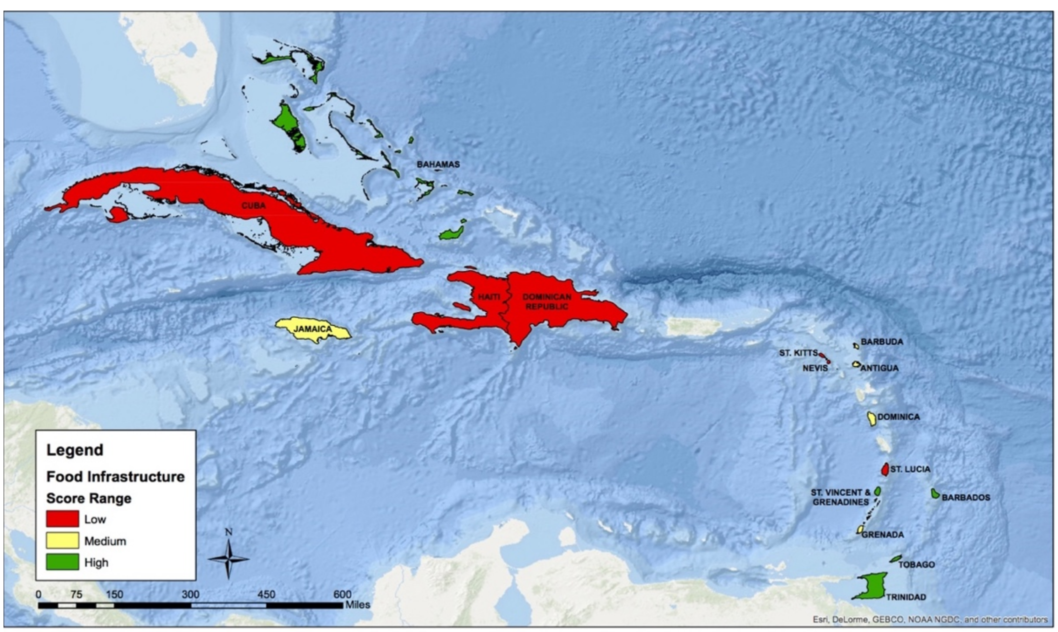

Figure 3.4. Food Infrastructure Index Map. Geographic variation of food infrastructure scores.

Energy Infrastructure Index

Energy infrastructure scores have a minimum of 0.15 and a maximum of 0.91, with an overall average of 0.51 (Table 3.7). Dominica has the highest score, while Haiti has the lowest. Low infrastructure scores range from 0.15 to 0.43, medium from 0.46 to 0.56 and high from 0.59 to 0.91 (Figure 3.5).

Table 3.7. List of energy infrastructure scores for each selected nation.

Nation	Energy Infrastructure Index Score
Antigua & Barbuda	0.43
Bahamas	0.46
Barbados	0.43
Cuba	0.48
Dominica	0.91
Dominican Republic	0.68
Grenada	0.43
Haiti	0.15
Jamaica	0.61
St. Kitts & Nevis	0.56
St. Lucia	0.43
St. Vincent & the Grenadines	0.59
Trinidad & Tobago	0.46

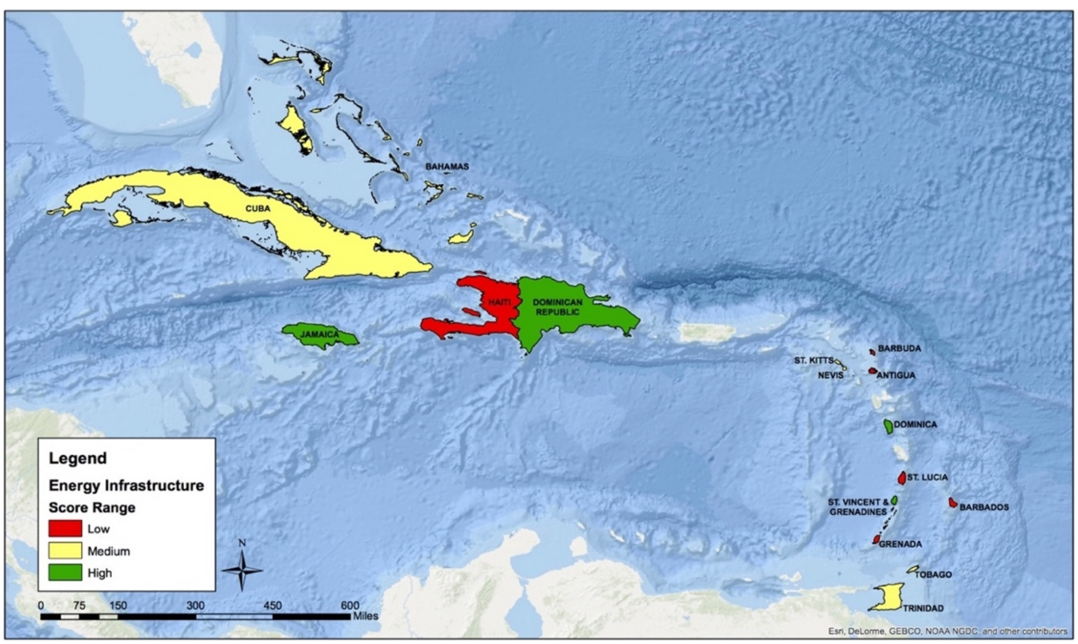

Figure 3.5. Energy Infrastructure Index Map. Geographic variation in energy infrastructure scores.

Transportation Infrastructure Index

Transportation infrastructure scores have a minimum of 0.14 and a maximum of 0.55, with an overall average of 0.30 (Table 3.8). Cuba has the highest score, while Haiti has the lowest. Low infrastructure scores range from 0.14 to 0.28, medium from 0.29 to 0.33, and high from 0.46 to 0.55 (Figure 3.6).

Table 3.8. List of transportation infrastructure scores for each selected nation.

Nation	Transportation Infrastructure Index Score
Antigua & Barbuda	0.22
Bahamas	0.30
Barbados	0.32
Cuba	0.55
Dominica	0.23
Dominican Republic	0.33
Grenada	0.28
Haiti	0.14
Jamaica	0.46
St. Kitts & Nevis	0.22
St. Lucia	0.29
St. Vincent & the Grenadines	0.28
Trinidad & Tobago	0.33

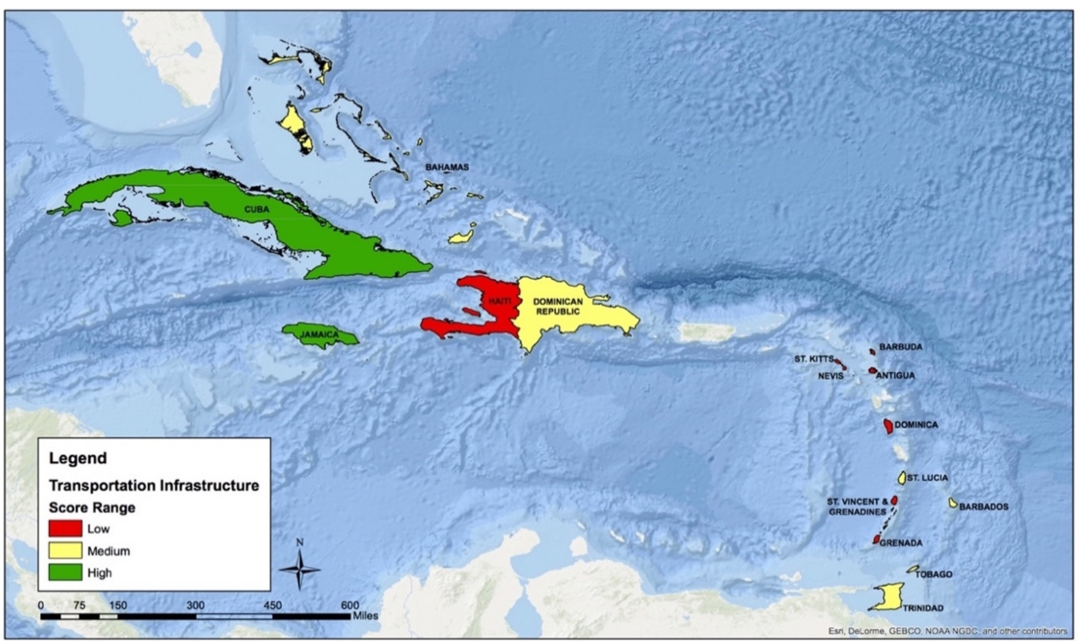

Figure 3.6. Transportation Infrastructure Index Map. Geographic variation in transportation infrastructure scores.

Communication Infrastructure Index

Communication infrastructure scores have a minimum of 0.14 and a maximum of 0.86, with an overall average of 0.56 (Table 3.9). St. Kitts and Nevis has the highest score, while Haiti has the lowest. Low infrastructure scores range from 0.14 to 0.54, medium from 0.57 to 0.66 and high from 0.73 to 0.86 (Figure 3.7).

Table 3.9. List of communication infrastructure scores for each selected nation.

Nation	Communication Infrastructure Index Score
Antigua & Barbuda	0.54
Bahamas	0.73
Barbados	0.85
Cuba	0.19
Dominica	0.66
Dominican Republic	0.40
Grenada	0.59
Haiti	0.14
Jamaica	0.38
St. Kitts & Nevis	0.86
St. Lucia	0.57
St. Vincent & the Grenadines	0.58
Trinidad & Tobago	0.75

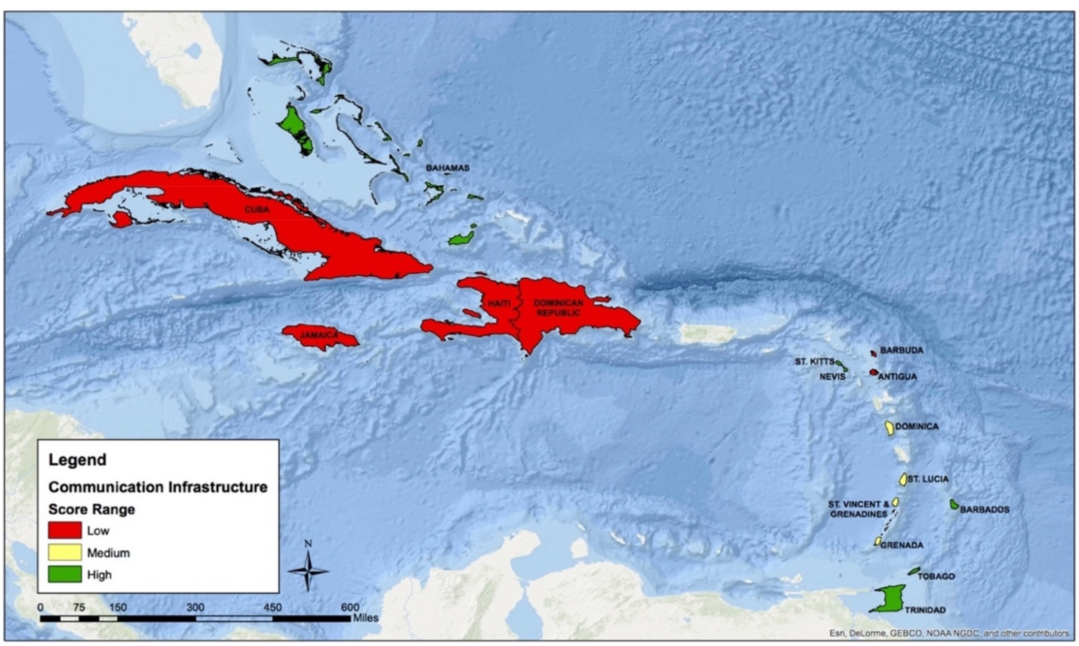

Figure 3.7. Communication Infrastructure Index Map. Geographic variation in communication infrastructure scores.

Human Capital Infrastructure Index

Human capital infrastructure scores have a minimum of 0.10 and a maximum of 1.00, with an overall average of 0.0.49 (Table 3.10). Cuba has the highest score, while Haiti has the lowest. Low infrastructure scores range from 0.10 to 0.42, medium from 0.43 to 0.54 and high from 0.55 to 1.00 (Figure 3.8).

Table 3.10. List of human capital infrastructure scores for each selected nation.

Nation	Human Capital Infrastructure Index Score
Antigua & Barbuda	0.41
Bahamas	0.44
Barbados	0.67
Cuba	1.00
Dominica	0.57
Dominican Republic	0.34
Grenada	0.47
Haiti	0.10
Jamaica	0.48
St. Kitts & Nevis	0.41
St. Lucia	0.54
St. Vincent & the Grenadines	0.56
Trinidad & Tobago	0.42

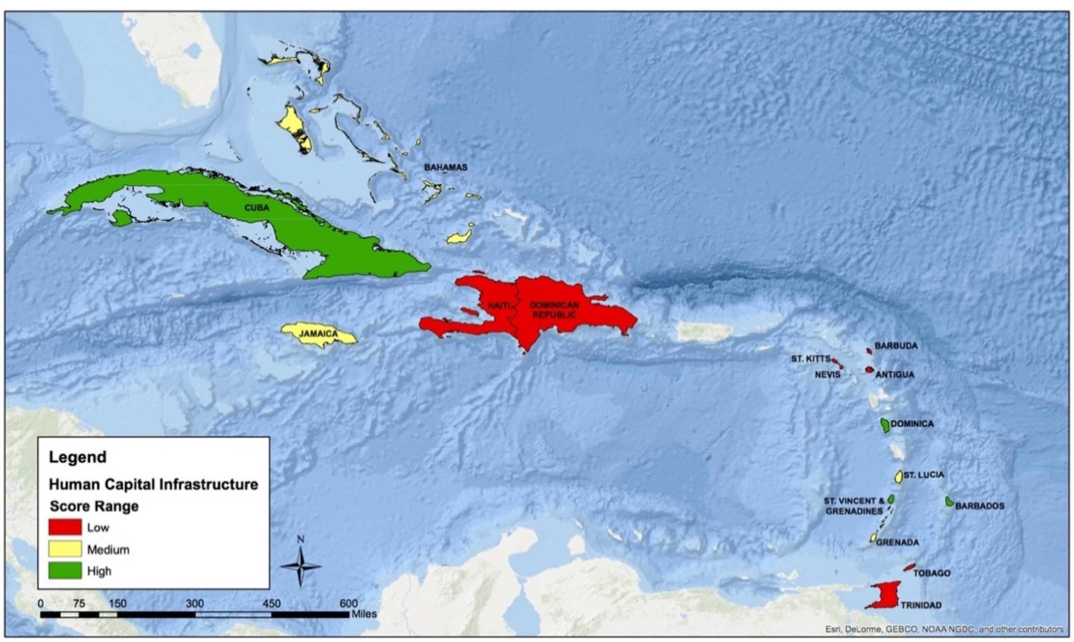

Figure 3.8. Human Capital Infrastructure Index Map. Geographic variation in human capital infrastructure scores.

Socioeconomic Infrastructure Index

Socioeconomic infrastructure scores have a minimum of 0.15 and a maximum of 0.59, with an overall average of 0.47 (Table 3.11). Barbados has the highest score, while Haiti has the lowest. Low infrastructure scores range from 0.15 to 0.46, medium from 0.47 to 0.54 and high from 0.55 to 0.59 (Figure 3.9).

Table 3.11. List of socioeconomic infrastructure scores for each selected nation.

Nation	Socioeconomic Infrastructure Index Score
Antigua & Barbuda	0.42
Bahamas	0.55
Barbados	0.59
Cuba	0.55
Dominica	0.56
Dominican Republic	0.42
Grenada	0.48
Haiti	0.15
Jamaica	0.48
St. Kitts & Nevis	0.46
St. Lucia	0.41
St. Vincent & the Grenadines	0.52
Trinidad & Tobago	0.54

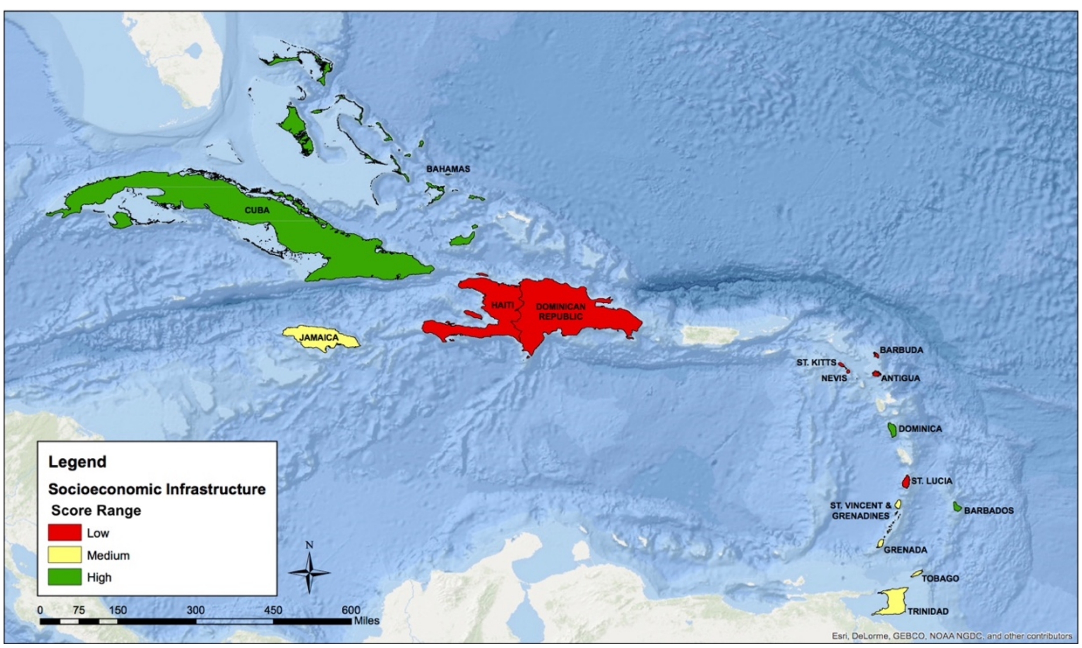

Figure 3.9. Socioeconomic Infrastructure Index Map. Geographic variation in socioeconomic infrastructure scores.

Green Infrastructure Index

Green infrastructure scores have a minimum 0.20 and a maximum 0.47, with an overall average 0.32 (Table 3.12). Cuba has highest score, while Antigua and Barbuda have the lowest. Low infrastructure scores range from 0.20 to 0.30, medium from 0.31 to 0.37 and high from 0.39 to 0.47 (Figure 3.10).

Table 3.12. List of green infrastructure scores for each selected nation.

Nation	Green Infrastructure Index Score
Antigua & Barbuda	0.20
Bahamas	0.40
Barbados	0.22
Cuba	0.47
Dominica	0.39
Dominican Republic	0.31
Grenada	0.30
Haiti	0.21
Jamaica	0.43
St. Kitts & Nevis	0.31
St. Lucia	0.34
St. Vincent & the Grenadines	0.37
Trinidad & Tobago	0.27

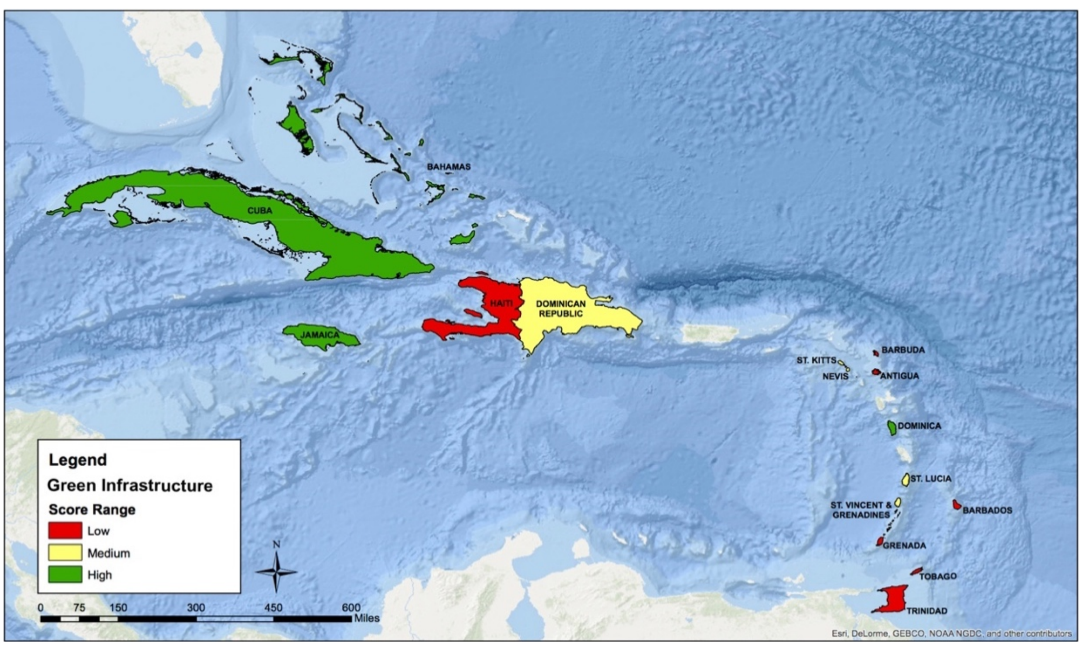

Figure 3.10. Green Infrastructure Index Map. Geographic variation in green infrastructure scores.

Composite Infrastructure Index

Composite infrastructure scores have a minimum of 0.18 and a maximum of 0.51, with an overall average of 0.38 (Table 3.13). Cuba has the highest composite infrastructure score, while Haiti has the lowest. Low infrastructure scores range from 0.18 to 0.37, medium from 0.38 to 0.44 and high from 0.45 to 0.51 (Figure 3.11).

Table 3.13. List of composite infrastructure scores for each selected nation.

Nation	Composite Infrastructure Index Score
Antigua & Barbuda	0.29
Bahamas	0.47
Barbados	0.36
Cuba	0.51
Dominica	0.46
Dominican Republic	0.36
Grenada	0.38
Haiti	0.18
Jamaica	0.45
St. Kitts & Nevis	0.38
St. Lucia	0.37
St. Vincent & the Grenadines	0.44
Trinidad & Tobago	0.38

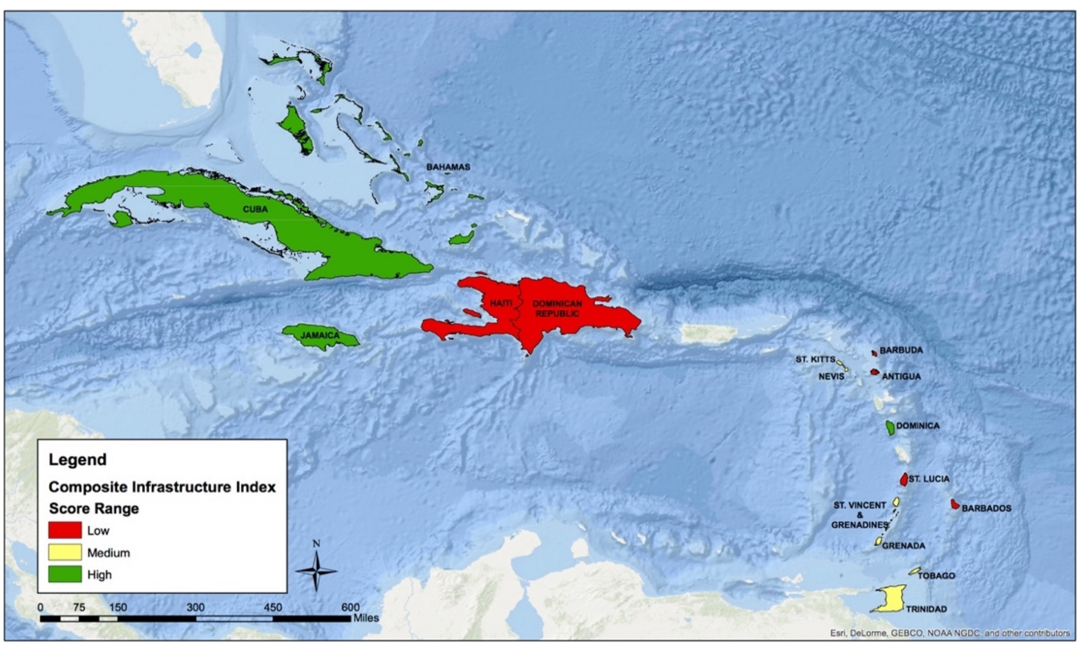

Figure 3.11. Composite Infrastructure Index Map. Geographic variation of composite infrastructure scores.

Future Climate Change Risk Index

Future climate change risk scores have a minimum of 0.10 and a maximum of 0.66, with an overall average 0.32 (3.14). The Bahamas is at most risk for future climate change, while Barbados has the least risk. Low risk scores range from 0.10 to 0.26, medium risk from 0.27 to 0.36 and high risk from 0.37 to 0.66 (Figure 3.12).

Table 3.14. List of future climate change risk scores for each selected nation.

Nation	Future Climate Change Risk Index Score
Antigua & Barbuda	0.38
Bahamas	0.66
Barbados	0.10
Cuba	0.29
Dominica	0.18
Dominican Republic	0.17
Grenada	0.36
Haiti	0.23
Jamaica	0.29
St. Kitts & Nevis	0.26
St. Lucia	0.30
St. Vincent & the Grenadines	0.44
Trinidad & Tobago	0.45

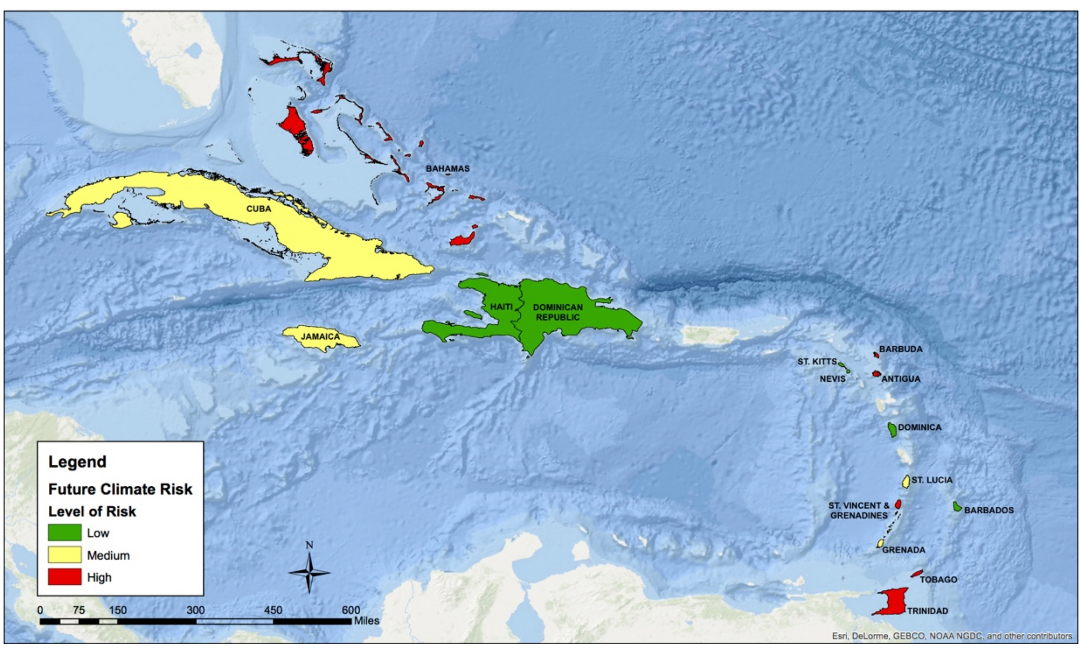

Figure 3.12. Future Climate Change Risk Index Map. Geographic variation of future climate change risk scores.

Variation of Composite Infrastructure Index With Future Climate Risk

Thresholds used to separate each nation into their respective quadrants were 0.9 for composite infrastructure and 0.38 for future climate risk. These values are the bounds that delineate the top 25% of scores and represent the nations with the strongest infrastructure and the nations at most risk to future climate change. Vulnerability is determined through the resulting chart (Figure 3.13). The most vulnerable Caribbean nation to future climate change is Trinidad & Tobago, followed by St. Vincent & the Grenadines and the Bahamas. The least vulnerable nation to future climate change is Cuba, followed by Dominica and Jamaica.

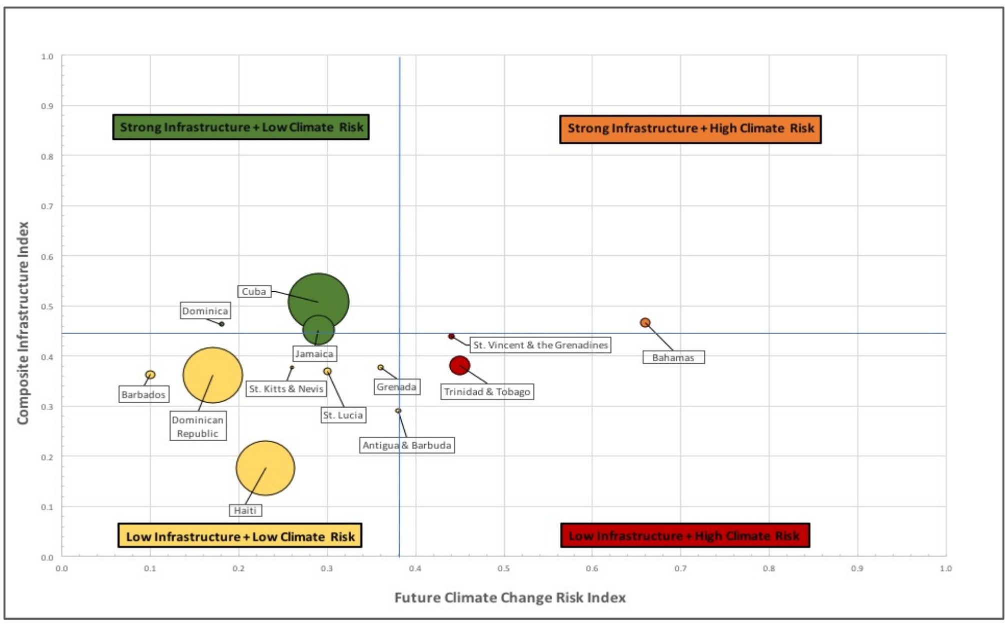

Figure 3.13. Final Vulnerability Chart. Overall vulnerability ranking based on the composite infrastructure index and future climate risk, each point sized proportional to population and point color representative of the vulnerability group a nation is a part of.

Correlation with Previous Vulnerability Indices

The Composite Infrastructure Index (CII) is not correlated with the three existing vulnerability indexes of the region, selected for the analysis. Correlations between the

Composite Infrastructure Index and each report are as follows: CAF General Vulnerability Index ($r_s = 0.182$, $p = 0.552$), Wheeler Vulnerability Index ($r_s = -0.479$, $p = 0.097$) and Lam Vulnerability Index ($r_s = -0.136$, $p = 0.658$) (Table 3.15).

Table 3.15. Results of Spearman correlation of the Composite Vulnerability Index and the 3 existing vulnerability indexes of the region.

	Spearman's Correlation	**CII**	**CAF (2014)**	**Wheeler (2011)**	**Lam et al. (2014)**
CII	Correlation Coefficient	1.00	0.182	-0.479	-0.136
	Sig. (2-tailed)	-	0.552	0.097	0.658
	N	13	13	13	13
CAF (2014)	Correlation Coefficient	0.182	1.00	0.467	0.530
	Sig. (2-tailed)	0.552	-	0.108	0.062
	N	13	13	13	13
Wheeler (2011)	Correlation Coefficient	-0.479	0.467	1.00	0.381
	Sig. (2-tailed)	0.097	0.108	-	0.199
	N	13	13	13	13
Lam et al. (2014)	Correlation Coefficient	-0.136	0.530	0.381	1.00
	Sig. (2-tailed)	0.658	0.062	0.199	-
	N	13	13	13	13

The Future Climate Change Risk Index is not correlated with any of the three existing vulnerability indices for the region, selected for this analysis. Correlations between future climate risk and each report are as follows: CAF General Vulnerability Index ($r_s = 0.396$, $p = 0.18$), Wheeler Vulnerability Index ($r_s = 0.454$, $p = 0.119$) and Lam Vulnerability Index ($r_s = 0.465$; $p = 0.110$) (Table 3.16).

Table 3.16. Results of Spearman correlation of the Future Climate Change Risk Index and the 3 existing vulnerability indexes of the region.

	Spearman's Correlation	**Future Climate Change Risk Index**	**CAF (2014)**	**Wheeler (2011)**	**Lam et al. (2014)**
Future Climate Change Risk Index	Correlation Coefficient	1.00	0.396	0.454	0.465
	Sig. (2-tailed)	-	0.180	0.119	0.110
	N	13	13	13	13
CAF (2014)	Correlation Coefficient	0.396	1.00	0.467	0.530
	Sig. (2-tailed)	0.180	-	0.108	0.062
	N	13	13	13	13
Wheeler (2011)	Correlation Coefficient	0.454	0.467	1.00	0.381
	Sig. (2-tailed)	0.119	0.108	-	0.199
	N	13	13	13	13
Lam et al. (2014)	Correlation Coefficient	0.465	0.530	0.381	1.00
	Sig. (2-tailed)	0.110	0.062	0.199	-
	N	13	13	13	13

Discussion

Spatial Assessment of Climate Change Vulnerability of the Caribbean

The resulting infrastructure scores of the 13 island-nations examined in this study indicate that the Caribbean region as a whole has weak socioeconomic and green infrastructure. Each final infrastructure index scores range from 0 to 1, with nations having the potential to have the highest score of 1, indicating extremely strong infrastructure. However, the resulting 13 nation scores for both socioeconomic and green infrastructure do not have values higher than 0.59. Therefore, it can be concluded that the region has weak infrastructure in general.

Responding to climate change will require each nation to focus on adaptation strategies, rather than mitigation. Adaptation promotes the development of policies and actions that moderate the negative effects of climate change at the local and regional level, where the impacts of climate change are actually felt. However, adaptation is limited in the region because many nations do not have the capacity to manage the multitude of issues associated with climate change. In particular, socioeconomic infrastructure in the region has been identified as one of the most hindering elements to climate change adaptation in other reports such as the CAF's (2014) Vulnerability Index of the LAC. It is apparent that the quality and strength of infrastructure is a key determinant of climate change vulnerability for Caribbean island-nations.

It is important to recognize that the resulting infrastructure maps, future climate change risk map and vulnerability chart produced are a comparison of infrastructure strength and future climate risk *relative* to the 13 island-nations selected for this study, and are classified as such. For example, even though Cuba is classified as having the highest health infrastructure score on the map and symbolized as green, it is only the highest in the context of the 12 other nations it is compared to. At the broader level, Cuba's resulting health infrastructure score of 0.75 reveals that the nation has moderate infrastructure in the region when compared to the index's highest value of 1. On the other hand, Haiti has the lowest health infrastructure score relative to the 12 other island nations examined, symbolized as red on the map. At the broader, regional context Haiti's health infrastructure score of 0.11 is extremely close to 0, which is the lowest value of the index's score range of 0 to 1. This indicates that Haiti has extremely weak infrastructure in the region, and is the weakest among the nations examined in this study.

Final vulnerability is determined by the relative position of where each nation is placed along the two axes formed by the Composite Infrastructure Index and Future Climate Change Risk Index. Although the most vulnerable nations (Trinidad & Tobago, St. Vincent & the Grenadines and the Bahamas) have relatively higher composite infrastructure indexes compared to other nations in the region, they are clearly not well prepared to face the challenges associated with future climate change because their composite infrastructure indexes are far from 1. These three island-nations should be top priorities for investments in both green and socioeconomic infrastructure within the region.

Although climate change is expected to have serious negative impacts on the Caribbean as a whole, the resulting vulnerability assessment reveals that the impacts of climate change will not be uniformly felt across the region. This variation of climate change vulnerability is a direct reflection of the unique characteristics that define each nation individually. The Caribbean region is comprised of a diverse group of overseas territories and sovereign nations that vary significantly in culture, geographic size, topography and population. Additionally, this diversity is partly due to the region's historical legacy of its colonial past, influencing the distribution of land, location of population settlements and the development of social groups and economic sectors (Rhiney, 2015). These elements contribute to the variation in the type and quality of infrastructure throughout the region, as indicated by each nation's composite infrastructure scores.

The inherent geographic and geophysical properties of each island are important determinants of the spatial variability of climate change vulnerability in the region. The island archipelagos are a result of the tectonic activity of the Caribbean plate, resulting in a diverse range of topographies throughout the region (Agard et al., 2007). Island-nations that are formed by volcanic processes tend be very mountainous and have steep, cliff-like coastlines as a result of magma rising to the surface caused by tectonic plate subduction (Agard et al., 2007; Bishop & Payne, 2012; Boruff & Cutter, 2007). Island-nations with flat topography with low relief are generally formed through the accretion of sediments, such as coral rock, over thousands of years and have coastlines consisting of wider, coastal plains (Bishop & Payne, 2012; Boruff & Cutter, 2007). For example, the volcanic processes that formed the mountains of Dominica also contribute to the high abundance of primordial forests throughout the island resulting from increased rainfall and soil properties (Sarrasin et al., 2012). Due to favorable geographic conditions and effective natural resource management, Dominica has one of the highest scores in both green and socioeconomic infrastructure.

Correlation with Existing Studies

Both the Composite Infrastructure Index and Future Climate Change Risk Index exhibit no correlation with any of the region's vulnerability indexes reported by previous studies. However, both the Composite Infrastructure Index and CAF (2014) vulnerability index reveal Haiti and the Dominican Republic as the most vulnerable nations in the region. Therefore, both of the proposed indexes evaluate vulnerability of Caribbean island-nations to climate change are capturing new dimensions that were not grasped by previous analyses and, consequently, shed some light on different factors that contribute to increased sensitivity of nations in the region. Specifically, the indicators of infrastructure selected for this study proved to be very effective in determining climate change vulnerability as they combined green and socioeconomic infrastructures, something that is not usually taken into consideration in the previous studies.

Shared Characteristics of Nations with Weak Infrastructure Compared to Nations with Strong Infrastructure

Adaptation to climate change is achieved through balancing the socioeconomic and green infrastructure within each nation (Dias et al., 2016). This balance is directly influenced by the governing institutions and policies that moderate the availability of natural resources and adequacy of infrastructure (CAF, 2014). The resulting scores of the socioeconomic sub-indexes and green infrastructure index reveal certain commonalties shared among island-nations that have higher infrastructure scores and certain characteristics shared among island-nations that have lower infrastructure scores.

Nations having lower scores in both green infrastructure and socioeconomic infrastructure are considered more vulnerable to climate change impacts. Lack of climate change adaptation policies and legislation is a common theme found among the lower scoring Caribbean island-nations. Many of these nations lack national land-use plans and building codes, resulting in incompatible land use development when aiming to reduce vulnerability to climate change (USAID, 2013). In addition, many of these nations do not have policies that manage their natural resources in a way that preserves the ecosystem functions required for adaptation to future climate change (USAID, 2013). For example, St. Lucia has no national land use plan or building codes (USAID, 2013). Currently, their policy for climate change adaptation is to build infrastructure, rather than implement better natural resource management and protection policies (USAID, 2013). Although St. Lucia emphasizes infrastructure development, these projects collapse as land is inefficiently allocated and becomes too expensive to maintain as a result of the high costs associated with the nation's improper regulation of natural ecosystems (USAID, 2013). Therefore, the findings in this study support this information, indicated by St. Lucia having one of the lowest infrastructure scores in the Composite Infrastructure Index. Haiti is another example of a low scoring nation that does not have sound climate change adaptation policies. The lack of land-use policies in Haiti results in deforestation as a common practice due to the societal dependence on charcoal and firewood as a primary energy source. This, in turn requires a land management system that establishes protected zones and reforestation zones (Smucker et al., 2007). Lack of green infrastructure has a negative impact on Haiti's societal development, making this Caribbean island one of the least developed nations in the world (CAF, 2014).

Another common theme among nations with low composite infrastructure indexes relates to the low levels of public participation and awareness of climate change. Many of these nations lack the technology and social capacity to increase the public's involvement in climate change adaptation (USAID, 2013). Programs that promote public outreach and education of climate change impacts are critical to decreasing vulnerability to future climate change. Increased public awareness promotes positive relationships between protected natural areas and the people who affect them. This helps preserve the natural ecosystems that are vital to climate change adaptation. Island-nations such as Grenada need improvement on public outreach policies, where other nations such as St. Lucia completely lack a system that involves citizens in the implementation of conservation measures (USAID, 2013). Increased public involvement and awareness of climate change is extremely important in determining the effectiveness of adaptation polices.

Island-nations with low composite infrastructure index scores lack a system to collect and analyze data that can be useful for future climate change adaptation policies. Decisions of how to adapt to climate change and how to manage terrestrial and marine ecosystems should be based on reliable data that are collected by trained specialists. Island-nations with lower scores lack the adequate personnel and systems that are able to provide reliable data essential to the decision-making process. For instance, St. Lucia currently has no established system for collecting, analyzing and distributing data that are required for climate change adaptation, which is the result of political and business leaders viewing ecosystem conservation as unimportant (USAID, 2013). Haiti, Grenada and Antigua & Barbuda have data methods in place, but are in serious need of improvement in the collection, analysis, distribution and use of the data (Smucker et al., 2007; USAID, 2013). In addition, the lack of data collection and analysis contributes to the limited number of vulnerability assessments in the region (Rhiney, 2015).

Finally, the majority of these low scoring nations lack domestic sources of fossil fuels or renewable energy. These island-nations are almost 100% dependent on fossil fuel imports to provide the electricity that allows society to function. Haiti is one of the few low scoring nations that has access to energy resources such as charcoal and firewood, but the lack of natural resource management and rapid deforestation rates results in the destruction of this resource (Smucker et al., 2007). Although these nations heavily depend on imported fossil fuels, some nations are taking steps toward renewable energy production to strengthen their response to the negative impacts of future climate change. For instance, Grenada is 100% reliant on fossil fuels for transport, electricity generation and cooking, but have developed the National Energy Policy of 2011 to achieve their goals of 1) reducing hydrocarbon dependence and 2) to meet 20% of their energy needs using renewable energy (USAID, 2013). Other island-nations such as St. Kitts & Nevis and Antigua & Barbuda are involved in transnational climate change projects such as the Caribbean Renewable Energy Development Program, which aims to minimize barriers of renewable energy use in the Caribbean (USAID, 2013). Retaining a high dependence on imported fossil fuels, coupled with a lack of resources play critical role in the determination of vulnerability to climate change, as indicated by their low infrastructure scores, in particular their low energy infrastructure scores.

Island-nations with higher composite infrastructure scores are considered less vulnerable to the future impacts of climate change. Just as the lower scoring island-nations share common themes, higher scoring island-nations share similar characteristics that contribute to their lower level of vulnerability. First, these nations already have established policies and legislation in response to adaptation to climate change. Many have made progress in understanding and responding to the implications of climate change from a planning perspective (USAID, 2013). As a result, these nations aim to improve current adaptation policies as well as implement new, compatible policies that strengthen their response to climate change. For instance, higher scoring nations focus on allocating resources to specific purposes such as improving the management of marine resources, while lower scoring nations focus on establishing more general land-use development plans before considering the management of other natural resources (USAID, 2013).

Second, higher scoring nations have access to their own energy resources and are not 100% dependent on energy imports. In addition, each of these nations are involved in some type renewable energy plan or program to reduce their dependence on fossil fuels. For example, Dominica's geographic location provides access to natural resources that supports hydro, wind, solar, biomass and geothermal energy production. In addition to the two operating diesel plants on the island, Dominica has three hydropower facilities that provide around 30% of total electricity production (USAID, 2013). The results of the Composite Infrastructure Index demonstrate that these nations have higher scores in energy infrastructure, ultimately contributing to their overall, higher infrastructure scores.

Public involvement and awareness of climate change adaptation is much higher in these nations in comparison to lower scoring nations. Most high scoring nations have some form of climate change awareness and education programs in place. For instance, St. Vincent & the Grenadines have prioritized community participation in the management of marine areas (USAID, 2013). Their effective outreach programs have helped avoid conflict over issues such as the access and availability of marine reserve resources, while providing fishermen with the platform to participate in the management process. In addition, these fishermen provide valuable, detailed knowledge of current and past marine ecosystems, which is crucial for any successful adaptation policy (USAID, 2013). Increasing public perception of climate change enables these island-nations to form positive relationships between the community and their environment.

Trinidad and Tobago as the Most Vulnerable Nation

The resulting vulnerability assessment indicates that Trinidad & Tobago is the most vulnerable to future climate change. It has the fifth highest socioeconomic infrastructure score, but the combined effect of having a weak green infrastructure score and a high future climate change risk score results in this island-nation being the most vulnerable in the region. Trinidad and Tobago (TTO) is considered by some experts as the Caribbean nation with the least amount of climate change adaptation activity and capacity (USAID, 2013). Trinidad and Tobago is the leading Caribbean producer of oil and gas, and is the only industrial-based Caribbean economy due to the focus on petroleum and petrochemical development (USAID, 2013). The nation's primary source of power generation comes from natural gas, with very limited existing renewable energy production. The resulting Socioeconomic Infrastructure Index demonstrates that the nation has adequate energy infrastructure due to the abundance of natural gas, but the absence of renewable energy sources is of particular concern. A major barrier hindering renewable energy development relates to the nation's domestic energy subsidies that make renewable energy less competitive (USAID, 2013).

Trinidad & Tobago has one of the lowest green infrastructure scores. The nation is especially susceptible to coral reef loss, exhibiting one of the lowest percentages of coral reef area, as indicated by the green infrastructure index (USAID, 2013). Additionally, this low score is related to the incompatibility of current government structures in the promotion of social and ecological resilience (Tompkins & Adger, 2004). For instance, the TTO government established a “Green Fund” to finance environmental restoration, conservation and reforestation activities implemented by non-governmental organizations, but the fund has gone unused and has grown to an estimated $US 500 million (USAID, 2013). The nation also requires better land-use planning to guide the construction of infrastructure related to housing, construction, commercial and industrial sectors. Current land use planning practices are insufficient and negatively impact TTO’s climate change adaptation (USAID, 2013). The compounding effect of these hindering factors results in the nation’s low green infrastructure score.

The Socioeconomic Infrastructure Index reveals that transportation is the weakest component of TTO’s socioeconomic infrastructure and should become a priority for climate change adaptation. Transportation is extremely critical to the well-being of this nation’s industrial-based economy, with oil and gas accounting for about 80% of exports and constituting about 40% of GDP (USAID, 2015). Infrastructure investments and expansions have not kept up to pace with the exponential growth of the nation’s economy, while the current infrastructure is highly susceptible to natural disasters such as flooding (Francke, 2013). Priority should be given to improving the quality of road, sea and air infrastructure, while taking into account sea level rise which is predicted to cost an estimated $362 million for 2 meters of sea level rise by 2080 (Francke, 2013; USAID, 2013). Transportation infrastructure must be prioritized due to the nation’s economic dependence on the exportation of oil and gas products. In addition, transportation is extremely influential in the vulnerability of other sectors such as health, reflected in the loss of essential services that become inaccessible due to the nation's lack of viable transportation infrastructure (Shah et al., 2013).

Overall, the most influential factors of climate change vulnerability for Trinidad and Tobago are the nation's lack of green infrastructure, minimal renewable energy production and inadequate transportation infrastructure. TTO needs to prioritize the conservation and restoration of ecological resources, promote better coordination between government agencies, and establish effective land-use planning policies to develop infrastructure that supports climate change adaptation.

CHAPTER 4

EXPLAINING CLIMATE CHANGE VULNERABILITIES AMONG CARIBBEAN NATIONS

This chapter conducts an analysis that evaluates how well five explanatory variables (GDP per capita, population density, land area size, political stability, and years of independence) explain the variation in climate change vulnerability, as measured by the Composite Infrastructure Index of the 13 island-nations across the Caribbean (see Chapter 3). The working hypothesis of this examination is that the selected factors are *not* sensitive enough to determine national vulnerabilities of the region and do not capture the unique and specific features that increase climate change vulnerability of Caribbean small island developing states.

Methods

To analyze how well the five explanatory variables explain the variation of vulnerabilities, each variable is compared to an outcome variable. For this analysis, the outcome variable is the Composite Infrastructure Index (CII) that is calculated in the previous chapter. The CII represents a proxy for vulnerability to climate change as measured by the balance between green and socioeconomic infrastructure. The five explanatory variables are 1) GDP per capita (PPP), 2) population density (people/km^2), 3) land area (km^2), 4) sovereignty (years of independence), and 5) political stability. A multiple regression analysis is conducted in the statistical program SPSS to evaluate the relative contribution of the explanatory variables to the variation of the outcome variable across island-nations.

Results

The raw values for both outcome and explanatory variables for the selected 13 Caribbean island-nations are highly diverse (Table 4.1). It is clear that there is a large variation of the coefficients of land area, GDP per capita, population density, political stability and years of independence, all having varying levels of significance. The multiple regression model was not significant ($R^2 = 0.630$; $F_{5,7} = 2.38$; $p = 0.144$), indicating that none of the explanatory variables explain the variation of the composite infrastructure index across island-nations. Table 4.2 presents the outcome of the regression for each of the explanatory variables.

Table 4.1. Raw values of explanatory variables and outcome variable for each of the 13 Caribbean nations

Country	**Land Area (km^2)**	**Population density (people/km^2)**	**Political stability**	**Sovereignty (Years)**	**GDP per capita**	**CII**
Antigua & Barbuda	440	209	1.07	35	$23,062	0.29
Bahamas	10,010	39	0.96	43	$23,001	0.47
Barbados	430	661	1.32	50	$16,406	0.36
Cuba	104,020	109	0.58	114	$20,646	0.51
Dominica	750	97	1.19	38	$10,865	0.46
Dominican Republic	48,310	218	0.17	172	$14,237	0.36
Grenada	340	314	0.81	43	$13,559	0.38
Haiti	27,560	389	-0.73	213	$1,757	0.18
Jamaica	10,830	258	0.09	54	$8,873	0.45
St. Kitts and Nevis	260	214	0.67	33	$10,944	0.38
St. Lucia	610	303	0.86	37	$11,140	0.37
St. Vincent & Grenadines	390	281	0.86	37	$25,088	0.44
Trinidad & Tobago	5,130	265	0.27	54	$33,309	0.38

Table 4.2. Coefficient results of the multiple regression analysis.

Variables	Unstandardized Coefficient *B*	Standardized Coefficient *Beta*	t	Significance
(Constant)	0.928	-	5.356	.001
Land Area (km^2)	3.383E -6	0.647	1.841	0.108
Population Density (people/km^2)	0.000	-0.140	-0.533	0.611
Political Stability	-0.007	-0.027	-0.068	0.948
Sovereignty (years)	-0.002	-0.930	-1.793	0.116
GDP per capita	-2.394E -8	-.001	-0.005	0.996

Discussion

The findings of this study indicate that variables as GDP per capita, size of land area, population density, sovereignty and political stability do not explain the variation in infrastructure among Caribbean nation-states. A key characteristic of the region is its diversity, which is attributed to the varying geographic, cultural, historical and ecological features that guided societal development of each island nation. This study reveals that the five variables examined are not able to capture the unique heterogeneity within Caribbean island-nations, which is a key contributor to the high level of climate change vulnerability within the region.

The results indicate that GDP per Capita is not an applicable indicator to be used in the determination of Caribbean vulnerability to climate change. The results of this analysis go against several vulnerability assessments that use GDP per capita as a key indicator of climate change vulnerability, based on the untested conclusion that a poor nation is more vulnerable than a rich nation (Brooks et al., 2005; Diffenbaugh et al., 2007; Eriksen & Kelly, 2007; Füssel, 2009; Moss et al., 2010; Yohe & Tol, 2002).

Small size is an inherent property of Caribbean island-nations that is recognized as negatively influencing vulnerability (Briguglio, 1995; Nurse et al., 2014; Rhiney, 2015). This is based on the notion that small size inhibits island-nations from developing economies of scale because their small size prevents them from diversifying into a wider range of activities (Easterly & Kraay, 2000). Based on this assumption, land area is used as an indicator of vulnerability because it insinuates that island economies are small, hence more vulnerable. However, there is a growing view in literature that having small size, economically and in terms of land area, may not be disadvantageous (Easterly & Kraay, 2000). Literature has revealed that certain nations that are small in land area with small economies perform much better than others, finding that small states are nearly 40 percent richer than other states (Armstrong & Read, 2000; Easterly & Kraay, 2000; Ramkissoon, 2002). In addition, advantages of being small in land area are often overlooked, including elements such as their openness to trade and social cohesion (Ramkissoon, 2002; Read, 2002). Therefore, total land area size by itself is not a sufficient explanatory factor to explain the variation of climate change vulnerability of the region, as indicated by the results of the multiple regression analysis.

Population density is also used to determine vulnerability in the Caribbean (Briguglio, 1995; Lam et al., 2014). Islands are likely to be disproportionately impacted by climate change due to their high population densities relative to their size (Bishop & Payne, 2012; Briguglio, 2003). In addition, population density will substantially change in the future due to the variations in socioeconomic vulnerability caused by population growth (Vincent, 2004). However, a well-connected population of high density can deal with hazards effectively and minimize the biophysical effects that translate into human impacts, providing opportunities for vulnerability reduction (Garschagen & Romero-Lankao, 2015; Handmer et al., 1999). Socioeconomic progress of areas with high population density may allow for increased access to key social services such as health care or education (Garschagen & Romero-Lankao, 2015). In contrast to these findings, the results produced in this analysis indicate that population density is not a good proxy for assessing current vulnerability to climate change in the Caribbean.

The results of this analysis demonstrate that sovereignty (years of independence) does not explain the variation in vulnerability to climate change in the region. Sovereignty has no advantage when determining vulnerability, making it inadequate to indicate vulnerability in the Caribbean region. For instance, Haiti was the first country in the region to achieve independence, but is one of the most socioeconomically and ecologically vulnerable nations in the world (Ramkissoon, 2002). In addition, solely using a nation's years of independence does not account for the political and economic history that shaped the societal development of most Caribbean island-nations. Therefore, sovereignty is not a factor that explains the varying degree of vulnerability.

The last variable this analysis examines is political stability. As the other explanatory variables, it does not explain the variation of infrastructure across the Caribbean. When determining political stability of a nation, there are cases where political issues such as corruption impede access to resources and the distribution of societal privileges (Vincent, 2004). Therefore an important determinant of political stability is corruption, which is an extremely complex concept to quantify, especially due to the difficulty of recognizing the problem in the first place (Vincent, 2004). High levels of corruption lowers public expenditures on key sectors such as healthcare, education and construction of transportation infrastructure. Caribbean societies tend to overlook corruption, even though there is a significant real political corruption problem that hinders the region's development (Collier, 2002). In addition, there is no direct indicator of political stability to determine how climate change influences conflict and instability, especially in regions such as the Caribbean where corruption is widespread (Hsiang & Burke, 2014; Vincent, 2004). As a result, political stability does not accurately represent Caribbean climate change vulnerability and explain variation among island-nations in the region.

The findings in this study confirm the hypothesis that the explanatory variables (GDP per capita, population density, size of land area, years of independence, political stability) are not sensitive enough to determine national vulnerabilities of the region and do not capture the unique and specific features that increase climate change vulnerability of Caribbean island-nations. Explaining variation in infrastructure must incorporate variables that effectively account for the diversity among Caribbean nations at the national *and* local level, attributed to the distinct characteristics that contribute to SIDS vulnerability. Factors similar to the ones examined in this study are not applicable because they do not recognize that climate induced pressures are unevenly distributed within Caribbean nations and are mediated by society (Eriksen & Kelly, 2007). For instance, there is a high level of corruption in Caribbean political governments that influences political stability (Collier, 2002. However) However, many nations do not have the resources to identify these type of political issues, and are therefore unaccounted for by general variables such as political stability (Collier, 2002). In comparison, infrastructure data provides more accurate indications on the level of institutional capacity and strength of governance, due to the maintenance and resources required to effectively maintain physical infrastructure (Vincent, 2004). However, because the Caribbean is an extremely data deficient region, similar types of macro-level explanatory variables as used in this analysis may be the only data available.

CHAPTER 5

CONCLUSION

Significance

This study examines vulnerability to future climate change as a function of socioeconomic and green infrastructure. It is an integrated approach that establishes the current state of each island-nation's socioeconomic and green infrastructure, combining this data with a future climate risk. The combination of each nation's current infrastructure with future climate risk data reveals the necessity of implementing adaptation policies in order to reduce future impacts that will negatively affect Caribbean society. The resulting indexes identify which island-nations in the Caribbean are most vulnerable to future climate change, and reveals the high level of geographic variation among the nations that are evaluated.

Caribbean vulnerability to climate change is a highly complex reality composed of diverse, intangible processes that must be captured by explanatory variables. As a result of this complexity, there is an increased risk that variables may not accurately represent the intended process or conditions of vulnerabilities among Caribbean island-nations, which is the case of the five explanatory variables examined in this analysis. When determining vulnerability to climate change in the Caribbean, these variables lack the ability to accurately capture the unique and specific features of the vulnerabilities among and within the Caribbean region. Variables such as the Composite Infrastructure Index are better suited to explain vulnerabilities among Caribbean nations because they capture issues of internal structure and function, which is essential when determining vulnerability at the national level.

This study demonstrates the critical role infrastructure plays in the determination of climate change vulnerability in the Caribbean. In general, the region lacks adequate infrastructure, resulting in serious implications for socioeconomic development and vulnerability to climate change. Infrastructure assessments are critical because the majority of infrastructure and facilities of Caribbean nations are within 1.5 kilometers of the shoreline, making them extremely sensitive to climate change impacts such as sea level rise, coastal inundation and extreme weather events (Nurse et al., 2014). Assessing Caribbean vulnerability as a function of infrastructure provides new, valuable data when determining climate change vulnerability in the Caribbean.

Overall, the maps this study produces help bridge the gap within the science-policy interface through the visualization of complex, quantitative data that reveals information in a more effective manner for policy makers. From this information, decision makers can identify where they need to allocate their resources to develop stronger climate change adaptation strategies. It is important to recognize that the proposed indexes are relative to the thirteen nations analyzed in this study, and is only valid for comparisons within the Caribbean region. Therefore, the resulting indexes identify if a Caribbean nation should prioritize socioeconomic infrastructure to strengthen their social and economic capacity, or if priority should be directed to protecting and conserving ecological infrastructure.

Recommendations

Overall, each Caribbean island-nation needs to define areas of targeted research on the socioeconomic and environmental elements that heighten vulnerability to future climate change. This is achieved through identifying if a nation has a higher socioeconomic infrastructure score or higher green infrastructure score. Based on the results of this study, recommendations on which type of infrastructure should be prioritized are proposed for each of the 13 Caribbean island-nations (Table 5.1).

Table 5.1. Type of infrastructure that should be prioritized for each individual island-nation.

Nation	Infrastructure to be Prioritized
Antigua & Barbuda	Green
Bahamas	Green
Barbados	Green
Cuba	Green & Socioeconomic
Dominica	Green
Dominican Republic	Green
Grenada	Green
Haiti	Green & Socioeconomic
Jamaica	Green & Socioeconomic
St. Kitts & Nevis	Green
St. Lucia	Green
St. Vincent & the Grenadines	Green
Trinidad & Tobago	Green

At a more detailed level, the study identifies which two components of socioeconomic infrastructure and green infrastructure are the weakest through identifying which components have the lowest scores (Table 5.2).

Table 5.2. List of the weakest green infrastructure components and socioeconomic infrastructure components.

Nation	Green Infrastructure Weakest Components	Socioeconomic Infrastructure Weakest Components
Antigua & Barbuda	Coral Reefs	Transportation
	Mangroves	Health
Bahamas	Mangroves	Transportation
	Coral Reefs	Human Capital
Barbados	Natural Vegetation	Energy
	Mangroves	Transportation
Cuba	Mangrove	Communication
	Natural Vegetation	Food
Dominica	Mangroves	Transportation
	Coral Reefs	Health
Dominican Republic	Mangroves	Health
	Natural Vegetation	Transportation
Grenada	Mangroves	Transportation
	Natural Vegetation	Health
Haiti	Coral Reefs	Human Capital
	Natural Vegetation	Health
Jamaica	Mangroves	Health
	Coral Reefs	Communication
St. Kitts & Nevis	Mangroves	Transportation
	Natural Vegetation	Health
St. Lucia	Mangroves	Health
	Coral Reefs	Transportation
St. Vincent & the Grenadines	Mangroves	Transportation
	Coral Reefs	Health
Trinidad & Tobago	Mangroves	Transportation
	Coral Reefs	Health

Based on this information, the following recommendations are made as to which components of infrastructure increase vulnerability the most and need to be prioritized:

1.) To strengthen Antigua & Barbuda's green infrastructure, the government needs to have strict coastal zone management that rigorously regulates development activity along the coast. Conservation should be the foundation of these policies to minimize the destruction of mangroves and runoff from the sedimentation and pollution that negatively impacts reef health. In terms of socioeconomic infrastructure, all existing transportation infrastructure, especially their single marine port and two airports, should be re-developed or relocated to withstand sea level rise impacts. Paving of all roads should be prioritized to ensure that this infrastructure is not destroyed by the impacts of climate change and limits access to services and resources that are essential to society. To strengthen health infrastructure, government expenditure on health should increase to ensure that existing facilities are equipped to deal with the physical impacts of climate change. In addition, the nation needs to increase the quantity of physicians and qualified health professionals to deal with the varying patterns and types of disease that are brought about by climate change.

2.) The Bahamas must prioritize their green infrastructure by immediately implementing policies that strictly manage and enforce the monitoring of ecosystems and associated biodiversity. These policies are necessary because the impacts of climate change coupled with over-exploitation of their ecological resources will result in the loss of this type of infrastructure. In terms of socioeconomic infrastructure, transportation should be prioritized by allocating resources to the development and improvement of structural protection from sea level rise, such as sea walls. The low density of roads in this low-lying nation will be reduced even further by the negative impacts of climate change, making structural protection extremely important. To strengthen human capital infrastructure, government expenditure on education needs to increase and establish education programs that increase individual awareness on how to adapt to climate change. In particular, health education programs on climate-related diseases should be implemented within all communities throughout the Bahamas.

3.) Strengthening of Barbados' green infrastructure will require strict monitoring of urbanization by the Barbados Planning Authority by making use of their available data to analyze the extent, location and pace of urbanizing and its influence on terrestrial and marine ecosystems. Plans and regulations must be established to manage and protect marine areas, delegating this responsibility solely to the Barbados Coastal Zone Management Unit to minimize confusion at the institutional level. Socioeconomic infrastructure adaptation needs to prioritize energy infrastructure and implement renewable energy technologies, specifically ocean thermal energy systems, household solar technology and photovoltaic panels. Transportation infrastructure needs to be outfitted to handle sea level rise impacts through processes such as increasing the height of cement docks in their single marine port. In addition, plans for infrastructure adjustments should incorporate the different scenarios of future climate projections and be trajectorially based.

4.) Green infrastructure of Cuba can be strengthened through the establishment of firm enforcement policies that protect and manage marine resources, to ensure limited degradation of natural resources as they open the door to millions of Americans and face intense economic development pressures. In addition, there should be strict limitations on the sugar industry's use of mangroves for fuelwood, implementing full protection of certain mangrove areas rather than partial protection. In terms of socioeconomic infrastructure, strengthening of Cuba's communication infrastructure should involve widening their current market by lifting strict regulations that limit the presence of US telecom and internet companies. Opening their market to the US will provide a variety of services that include selling infrastructure equipment and devices and setting up business locations that offer telecommunication and internet services to Cuba's population. Food infrastructure is weak due to the high pressure that food importation has on the national budget. Cuba needs to have serious improvements in their farming technology of domestic food production and identify strains of essential crops that provide the most nutrition such as beans. In addition, strains of the crops selected should be the most resilient to climate change impacts.

5.) To strengthen green infrastructure of Dominica, strict land-use policies that incorporate serious consequences for unregulated development need to be implemented. To minimize loss of mangroves, the government should provide incentives for land owners to maintain natural resources that are located on their property, and provide even greater incentives for property owner's that provide data on the current status of these resources. Strengthening of socioeconomic infrastructure requires prioritization of transportation infrastructure. Restructuring and re-planning of road systems will establish routes that will remain accessible as sea level rise increases and other climate change impacts such as landslides occur. In addition, this restructuring needs to require that all roads are paved and are physically resilient to climate change impacts. In terms of health infrastructure, there needs to be an increase in the quantity of physicians or qualified health professionals that can handle trans-national health issues, due to the nation's concern that increasing migration to the island will complicate climate change circumstances related to human health (USAID, 2013). Increasing government expenditure on health should focus on developing infrastructure that is appealing to outside professionals and establish specific area of health service provision that can address climate change issues.

6.) To strengthen the Dominican Republic's green infrastructure, land-use policies that are based on natural resource conservation need to be developed. In particular, implementing stricter deforestation policies, along with strong enforcement along the nation's border with Haiti, will help minimize the loss of mangrove resources. Transportation infrastructure needs to be prioritized and requires a serious assessment of road infrastructure to identify areas that need to be restructured to maintain accessibility as sea level rise increases. In terms of socioeconomic infrastructure, all aspects of their health infrastructure need to be improved. Health infrastructure must be restructured to withstand the pressures of climate change and have special plans for particularly vulnerable groups including disabled residents, children, sick and bed-ridden residents and pregnant women. Health services and infrastructure should pay particular attention to diseases such as dengue and malaria and the factors that increase transmission.

7.) Grenada's green infrastructure can be strengthened through processes that refinance funds so funding is sufficient to support ecosystem management. To minimize the impacts on coral reef health, a limited or set number of coastal construction projects per year should be established to decrease sedimentation and pollution runoff into adjacent marine areas. Increasing natural vegetation on the island can be achieved through requiring property owners to maintain a certain percentage of natural vegetation on their property to reduce runoff, sedimentation and erosion, rather than the current practice involving complete clearing of all vegetation from their property (USAID, 2013). Strengthening of socioeconomic infrastructure will involve restructuring of transportation infrastructure to equip ports and airports to be resilient to climate change impacts, including the construction of structural protection. In addition, health infrastructure needs to be restructured at the institutional level, increasing government expenditure on health to re-organize the current health system so that key decisions and actions are not delayed at both the institutional and program level.

8.) Green infrastructure of Haiti is in most need of strict deforestation policies on mangroves that are coupled with strict urban development laws. Haiti needs to improve biofuel use and biofuel management, establishing effective replanting programs that monitor seedlings and provide incentives for farmers to invest in long-term reforestation practices. In terms of socioeconomic infrastructure, strengthening of health infrastructure will involve construction of hospitals that are equipped to with stand natural disasters and impacts of climate change. To increase physician density and health care professionals, decision makers should establish a relationship with the National Campus of Health Sciences and develop a program that requires medical students to spend a certain amount of time offering services to the most vulnerable Haitian communities. In terms of human capital infrastructure, Haiti needs to increase education expenditures and allocate resources to develop climate change awareness programs in schools. To increase the number of qualified teaches and education professionals, programs should be implemented that train and certify teaching assistants that are able to assist teachers and help manage large student bodies. In general, Haiti exhibits the weakest infrastructure in the majority of the components of socioeconomic infrastructure. Therefore, it is also recommended that Haiti also prioritizes: 1) rural and urban access to freshwater and sanitation facilities, 2) development of transportation infrastructure that is resilient to flooding and extreme weather events, 3) increasing the availability of communication infrastructure to create a more connected community and 4) development of energy infrastructure and energy policies that make electricity available and accessible to the entire population.

9.) Green infrastructure of Jamaica needs to be strengthened at the financial level, providing the funds required for strict enforcement of ecosystem protection and the hiring of qualified enforcement staff who are knowledgeable about the ecosystems being monitored. In addition, there needs to be coastal development management that does not allow road networks and commercial development to destroy resources such as mangroves. Health infrastructure requires increases in health expenditure to establish mechanisms that specifically deal with increases in food-borne and water-borne diseases, especially chikungunya virus. Prioritization of communication infrastructure is necessary and should involve increasing the number of physical, telecommunication structures to ensure that the entire island has access to fixed telephone lines and broadband connections.

10.) To strengthen green infrastructure of St. Kitts & Nevis, a coastal zone management unit should be developed. This unit should strictly regulate private sector development, especially for projects higher than 1000 feet above sea level because these are the projects that violate the national land use policy the most (USAID, 2013). In addition, a national climate change policy needs to be developed. In terms of socioeconomic infrastructure, transportation should be restructured through increasing road density, paving all roads and ensuring that transportation infrastructure is located in areas that won't be destroyed by climate change impacts. Strengthening of health infrastructure must involve improving the health workforce and quality of infrastructure to attract physicians and nurses.

11.) Green infrastructure of St. Lucia can be strengthened by limiting the development of hotels and golf courses along the coast which have a close proximity to beaches and marine ecosystems. In addition, mapping of all forest ecosystems can identify which areas should receive reforestation funding and increased protection. Strengthening of health infrastructure should be aimed at increasing the shortage of human resources in health care delivery by offering comprehensive remuneration packages that have high salaries, benefits and rewards of being a healthcare professional in St. Lucia. In terms of transportation infrastructure, St. Lucia needs to reconstruct their ports to withstand the impacts of sea level rise. In addition, St, Lucia demonstrated the weakest food infrastructure in the region. This type of infrastructure can be strengthened by minimizing the nation's reliance on food importation by increasing the production of traditional, local crops that are resilient to climate change. This should be coupled with policies that require food retail stores to purchase a certain percentage of domestic crops in to motivate farmers and stimulate production.

12.) To strengthen green infrastructure, St. Vincent & the Grenadines need to establish a financing strategy that is sufficient to cover basic operating costs of managing and protecting marine ecosystems, especially for the creation of programs that allow the community to participate in ecosystem planning procedures. In addition, the nation needs to implement a large scale marine planning model that immediately goes into action. In terms of socioeconomic infrastructure, transportation infrastructure should focus on possible locations for the construction of a second airport, because the current airport will be inaccessible in the future due to sea level rise. In terms of health infrastructure, increasing expenditure on health will strengthen infrastructure and prioritize the accessibility of health services on both islands that constitute the nation.

13.) Trinidad and Tobago can strengthen green infrastructure by implementing more comprehensive land use development regulations with updated building and zoning standards. These regulations should also incorporate policies that preserve forested areas and monitor runoff into marine ecosystems. In terms of health infrastructure, Trinidad and Tobago needs to establish a National Health Service that plans for the increases of disease and health issues caused by climate change. In particular, better ways to access health care services needs to be developed, especially for vulnerable populations such as pregnant women. In terms of transportation infrastructure, assessing the current state of infrastructure will enable decision makers to identify which type of transportation is in most need of restructuring and which areas are prone to natural disasters. A more detailed description of recommendations for Trinidad and Tobago can be found in the discussion section of Chapter 3.

Major Conclusions

In general, major conclusions of this assessment of Caribbean vulnerability to future climate change include the following:

1. Caribbean island-nations present a large variation in both green and socioeconomic infrastructure, with nations of Cuba, Jamaica and the Bahamas exhibiting the strongest green infrastructure, while Barbados, Dominica and the Bahamas exhibit the strongest socioeconomic infrastructure.

2. Caribbean island-nations exhibiting the weakest green infrastructure are Antigua & Barbuda, Haiti and Barbados, while the nations demonstrating the weakest socioeconomic infrastructure are Haiti, St. Lucia and Antigua & Barbuda.

3. Caribbean island-nations exhibiting the strongest composite infrastructure are Cuba, the Bahamas and Dominica, while the nations exhibiting the weakest composite infrastructure are Haiti, Antigua & Barbuda and the Dominican Republic.

4. Common characteristics of nations with weak composite infrastructure scores include lack of climate change adaptation policies and legislation, low levels of public participation and awareness of climate change, lack of data collection and analysis and lack of domestic sources of fossil fuels or renewable energy.

5. Common characteristics of nations with strong composite infrastructure scores include the presence of established adaptation response policies and legislation to climate change,

access to their own energy sources and are not dependent on energy imports, and higher levels of public involvement and awareness of climate change adaptation.

6. The impacts of climate change will not be uniformly felt across the region due to the inherent geographic and geophysical properties and unique characteristics that define each nation individually.

7. Caribbean island-nations must respond to climate change through adaptation rather than mitigation, in order to develop appropriate policies and actions at the local and regional level to effectively manage the negative consequences associated with climate change.

8. Indicators of infrastructure are valuable when determining climate change vulnerability in the Caribbean, providing a new dimension of vulnerability that previous analyses did not capture.

9. The lack of correlation with the Composite Infrastructure Index reveal that the variables of GDP per capita, population density, size of land area, sovereignty and political stability are not sensitive enough to capture issues of internal structure and function and the unique, specific features that contribute to the increased vulnerability of Caribbean island-nations. Therefore, variables similar to the five analyzed in this study do not explain the varying degree of vulnerability of Caribbean island-nations.

Overall, a more nuanced view about the vulnerability of the Caribbean island-nations to climate change is provided. By combining green infrastructure, socioeconomic infrastructure, and predictions about future climate change, this research generated a more holistic perspective about the challenges Caribbean island-nations will experience as a result of global climate change .

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