Hurricanes, Climate Change and Small Islands: An Investigation of Vulnerability to Climate-Related Stressors in The Bahamas

By

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LIST OF ABBREVIATIONS

SIDS	Small island developing state
GDP	Gross domestic product
SLR	Sea-level rise
AIMS	Atlantic and Indian Oceans, Mediterranean and South China Sea
SAT	Surface air temperature
SST	Sea surface temperature
ASL	Above sea level
LECZ	Low-elevated coastal zones
CVI	Composite vulnerability index
IDB	Inter-American Development Bank
NDVI	Normalized difference vegetation index
SVI	Social vulnerability index
ED	Enumeration district
BEiNGS	Bahamians Engaged in Natural and Geospatial Sciences

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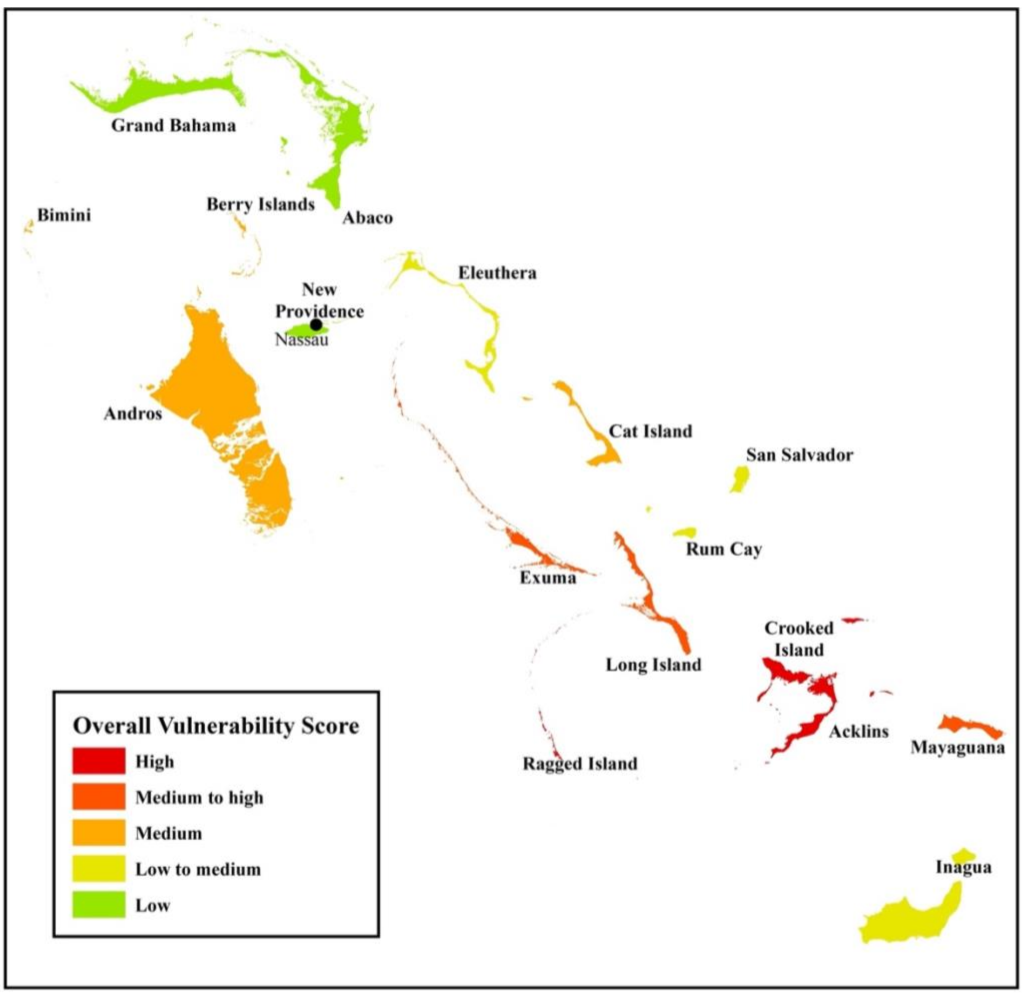
ABSTRACT

Among other small island developing states and nations worldwide, The Bahamas is considered highly vulnerable to various stressors from climate change and tropical cyclone activity. Previous vulnerability assessments rarely focus on the specific characteristics of The Bahamas accounting for its vulnerability, and even fewer considering the discrepancies in vulnerability across individual island populations within the archipelago. The aim of this thesis is to investigate vulnerability in The Bahamas to climate-related coastal stressors, including impacts of climate change and tropical cyclones. This takes a local approach to vulnerability assessment by focusing on individual islands in the country rather than comparing it to other nations at a global scale. Through multiple methods of assessment, I discuss the factors accounting for enhanced vulnerability in the country, assess the relative vulnerability of different islands and highlight perceptions of vulnerability according to Bahamians.



CHAPTER 1: INTRODUCTION

Hurricane Dorian (2019) was one of the most powerful Atlantic storms ever recorded, with maximum sustained winds recorded at 185 mph, wind gusts exceeding 220 mph, and a 20-25-foot storm surge. These conditions made landfall over two major islands in The Bahamas for a three-day period (Deopersad, 2020; Shultz, Sands, Kossin, & Galea, 2019). This was the fourth major hurricane in The Bahamas in the last five years, following Joaquin (2015), Matthew (2016) and Irma (2017), all of which caused substantial damage in different locations across the country. While The Bahamas is no stranger to hurricanes, Hurricane Dorian was particularly devastating, costing $2.5-3.4 billion in damages, and the lives of at least 67 people (Deopersad, 2020). Dorian highlighted an unfortunate trend being seen in tropical cyclone activity: an increased frequency of higher intensity storms, with evidence suggesting they are brought on by a changing climate (Holland & Bruyère, 2014; Meehl, 2007). These stressors are beyond the control of Bahamians, and leave the islands highly vulnerable to future harm.

Researchers have approached the concept of vulnerability to natural disasters and climate change at both regional and global scales. When ranking nations according to their vulnerability, The Bahamas frequently approaches top spots. In an assessment of 100 developing countries, The Bahamas was deemed the third most vulnerable nation to external stressors, determined by a combination of coastal zone area, degree of remoteness, urbanization level and susceptibility to natural disasters (Turvey, 2007). Simpson et al. (2009) then found The Bahamas to be the most vulnerable nation to loss of land-area with a one-meter rise in sea-level. Alongside Montserrat, St. Kitts and Nevis, and Turks and Caicos, The Bahamas also ranked as one the most vulnerable Caribbean nations to climate-related coastal hazards (Lam, Arenas, Brito, & Liu, 2014). Non-exhaustively, these studies highlight The Bahamas as a particularly vulnerable nation that is worthy of its own assessment.

While previous research often looks assesses the vulnerability of different countries and regions, little research to date has taken a particular focus on The Bahamas or its individual islands and communities in regards to large-scale stressors. Given the challenges brought on by climate change and potential future hurricanes, the aim of this research thesis is to investigate the concept of vulnerability to climate-related coastal stressors in The Bahamas and better understand its causes and implications for residents and ecosystems. The research questions I wish to answer include:

1. What are the fundamental factors accounting for vulnerability in The Bahamas to climate change stressors and hurricanes?
2. Which islands may be considered the most vulnerable to climate-related coastal stressors?
3. What are the public perceptions of vulnerability in The Bahamas?

I begin this investigation by providing a conceptual framework of key definitions for vulnerability and its related concepts in Chapter 2, along with an introduction to small island developing states (SIDS), their vulnerable characteristics and the climate-related stressors impacting them. In Chapter 3, I apply this background information to the study area of The Bahamas, discussing previous vulnerability research done in the country, and provide a case study of Hurricane Dorian to contextualize these ideas. In Chapter 4, I describe my methodology, modelling work by Cumberbatch et al. (2020), to build a multi-dimensional vulnerability index for the islands of The Bahamas based on proxy data from the last decade. I also explain the process of conducting a series of interviews with key informants and distributing an online survey to Bahamian residents and citizens. I then share the results of these mixed methods in Chapter 5, before discussing the findings in relation to previous research, the limitations of my investigation, and the overall conclusions arising from the research in Chapter 6.

CHAPTER 2: UNDERSTANDING VULNERABILITY AND ITS IMPLICATIONS FOR SMALL ISLAND DEVELOPING STATES

This chapter begins by discussing the background theory and definition(s) of vulnerability, its associated concepts, and the dominant methods of assessment. This is followed by an introduction to SIDS and the characteristics that leave them highly vulnerable to climate-change impacts and tropical cyclones. Finally, the chapter summarizes the key points and restates the research aims.

2.1: Vulnerability

Broadly defined, vulnerability is an entity's "susceptibility to be harmed" from some stressor (Adger, 2006, p. 269). The entity may fit into one or more different categories, including geographic regions, ecosystems, communities, enterprises or individuals. Vulnerability can then be better understood by providing context: what is susceptible to harm and what is the stressor. Context, however, can add additional complexity to vulnerability assessments. Vulnerability is an interdisciplinary and multidimensional concept (Boruff & Cutter, 2007), open to interpretations based around the background and objectives of the assessors (Lupu, 2019). It is also spatially and temporally variable (Boruff & Cutter, 2007), which requires dynamic and adaptive assessment. Vulnerability encompasses three sub-components; exposure, sensitivity, and adaptive capacity (Adger, 2006; Cinner et al., 2013; Okey, Agbayani, & Alidina, 2015). Simultaneously, vulnerability is a sub-component of risk, alongside hazard (Flanagan, Gregory, Hallisey, Heitgerd, & Lewis, 2011). It should be recognized that these terms are related and act together, but may also contrast with one another (Smit & Wandel, 2006), providing a richer understanding of the status of an entity. Distinguishing these critical terms is the first step towards understanding vulnerability.

2.1.1: Definitions and interpretations

Table 2.1. lists the definitions of terms associated with vulnerability in the context of this investigation. These apply in situations across multiple fields of research, and will guide the understanding of the concepts going forward.

Table 2.1: Definitions of key terms

Term	Definition
Vulnerability	"the degree to which a system is susceptible to, and unable to cope with, adverse effects" (IPCC, 2007, p. 89)
Risk	"the possibility of adverse effects in the future" (Cardona et al., 2012, p. 69)
Hazard	"a condition posing the threat of harm" (Flanagan et al., 2011, p. 1)
Exposure	"the inventory of elements in an area in which hazard events may occur" (Cardona et al., 2012, p. 69)
Sensitivity	"the degree to which a system is modified or affected by perturbations" (Adger, 2006, p. 270)
Adaptive capacity	"the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope" (Adger, 2006, p. 270)
Resilience	"a quality that enables an organisation, ecological system, household or nation to recover quickly from disaster shock" (Pelling & Uitto, 2001, p. 52)

Exposure is a requirement of vulnerability, though an entity may not always be vulnerable despite being exposed (Cardona et al., 2012). Degree of exposure is a result of the magnitude and frequency of the stressor (Patton, 1993 as cited in Watts and Teel (2003)). The sensitivity of an entity is then a product of its characteristics (Scandurra, Romano, Ronghi, & Carfora, 2018), which can be unfavourable to a given external stressor. Exposure and sensitivity may then be balanced by the entity's adaptive capacity, its ability to to change for the better as a response to stress (Smit & Wandel, 2006). Resilience plays a key role in adaptive capacity, yet is often considered alongside vulnerability as two sides of the same coin (Scandurra et al., 2018). These three sub-components are distinct features, but can often be utilized individually to study vulnerability across academic disciplines (Cardona et al., 2012; Smit & Wandel, 2006). While risk may not be the focus of this research, it should be noted that vulnerability is a separate concept, yet makes up a component of risk along with hazard. How these concepts relate to each other can be seen in Figure 2.1.

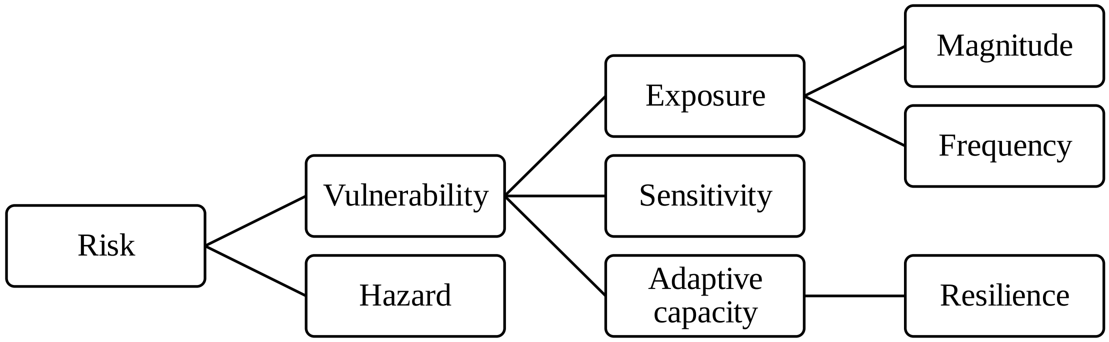


Figure 2.1: Conceptual diagram of the vulnerability and related terms

As vulnerability is interdisciplinary, the concepts discussed can be approached differently across various fields of research (Siagian, Purhadi, Suhartono, & Ritonga, 2014). For example, studies of vulnerability occur in disaster management, social impact assessments, ecological studies and economic analyses. In disaster management, researchers aim to understand how given social dynamics and discrepancies in vulnerability affect overall risk (Flanagan et al., 2011). Other studies of social vulnerability can communicate exposure to unexpected changes and interruptions to livelihoods (Neil Adger, 1999) and is determined by the social status and structure of populations (Cumberbatch et al., 2020). In some ecological assessments, vulnerability is quantifiable, and calculated as the ratio of exposure and sensitivity (collectively referred to as potential impact) to adaptive capacity (Okey et al., 2015). This approach measures the response of organisms and ecosystems to changing environmental regimes and hazards, whether natural or anthropogenic. An economic perspective depicts vulnerability as exposure of a population, country, or business to external shocks or stress (Briguglio, Cordina, Farrugia, & Vella, 2009; Ram, Cotton, Frederick, & Elliott, 2019). While seemingly different assessments, these fields of research overlap and have impacts on one another. As discussed in greater detail in Section 2.2, environmental and economic aspects may contribute to a greater understanding of social and overall vulnerability of a population.

2.1.2: Assessments of vulnerability

Vulnerability and its linked components can be evaluated in different ways. Smit and Wandel (2006) identify four main bodies of literature on methods of assessment in their analysis of adaptive capacity and vulnerability. The first looks at modelled future stressors, particularly in the context of climate change, and the hypothetical adaptations needed to mitigate or offset the predicted impacts. The second body reviews potential adaptation strategies to conclude a best option to move forward, such as the work done by Cinner et al. (2018) on tropical coastal communities. They put forward multiple domains of adaptive capacity towards climate change to improve on in these regions, including assets and resources, flexibility in strategies, social organization, learning, and agency. A third area of study compares vulnerability of geographical areas or populations based on criteria defined by the researcher. This generally involves proxy data and ranking countries, regions or communities as most vulnerable and highlighting where adaptation measures are most necessary. Finally, a fourth body of literature documents responses to direct implementation of adaptation strategies aimed at reducing vulnerability in location-specific case studies (Smit & Wandel, 2006). Assessments may also vary across different scales: global, regional, local or individual. Factors as large as the Sustainable Development Goals or as small as individual day-to-day lifestyle changes can be considered, which yield different results from different interpretations (Robinson, 2020). Larger scales can cover more area in a single assessment, while losing resolution and detail in factors accounting for vulnerability at smaller scales (L. Nurse et al., 2014). The complexity of vulnerability also indicates it is unlikely to be perfectly described by simple indicators. Despite some over simplification of the concept, vulnerability assessments do assist in provide policy planners with guiding information on who and what is in most need of assistance (Villa & McLEOD, 2002).

In the third body of literature mentioned by Smit and Wandel (2006), multiple indices have been proposed using proxy data for vulnerability of different populations to various stressors at global or regional scales. These stressors often include natural disasters and climate change. Peduzzi, Dao, Herold, and Mouton (2009) created a vulnerability index for natural disaster risk, represented by attributed deaths between 1980 and 2000, and found China, India and Indonesia had the highest total values, but Vanuatu, Dominica and Mauritius had the highest per capita per year. Briguglio (1995) conducted one of the first global economic vulnerability assessments and highlighted Antigua and Barbuda, Tonga, Seychelles, Vanuatu, and St. Kitts and Nevis as the most vulnerable nations to external shocks. Blasiak et al. (2017) ranked Kiribati, Solomon Islands, Maldives and Micronesia as most vulnerable to future impacts of multiple climate-change models on marine fisheries. As a percentage of gross domestic product (GDP), Micronesia, Palau and The Bahamas were most vulnerable to damage from sea-level rise (SLR) according to Anthoff, Nicholls, and Tol (2010). An emerging pattern from these studies is the high proportion of small island nations topping the rankings.

2.2: Small island developing states (SIDS)

SIDS consist of 38 United-Nations-member and 20 non-member island nations and states spread across three main geographic regions: the Caribbean; the Pacific Ocean; and the Atlantic and Indian Oceans, Mediterranean and South China Sea (AIMS) (UN-OHRLLS, 2015). Situated largely in the tropics, these island nations are generally characterized by their small physical size, remoteness, and plethora of coastline surrounded by ocean, which plays a large role in their physical, natural and socioeconomic structures. Many have dense and increasing populations, and are often isolated from large markets or resource bases, and have extremely open economies (Gheuens, Nagabhatla, & Perera, 2019; L. A. Nurse et al., 2001). They are also the site of unique and attractive endemic marine and terrestrial ecosystems (L. Nurse et al., 2014).

As described in the studies mentioned previously, SIDS are defined by their high vulnerability to stressors associated with climate change and natural disasters (Gheuens et al., 2019; L. Nurse et al., 2014). Briguglio (1995) describes SIDS as having five major components that account for their vulnerability; small size, remoteness and insularity, disaster proneness, environmental fragility, and additional minor factors that can include dependence on foreign finances and social demographics. They often have low adaptive capacities due to “poorly developed infrastructure; and limited funds, human resources, and skills” (L. A. Nurse et al., 2001, p. 845). This vulnerability can sometimes be masked by per capita GDP values (Briguglio, 1995), which can give false representations of economic prosperity among the larger population. Both environmental and socioeconomic factors of small islands interact and contribute to their overall vulnerability.

The status and quality of the ecosystems providing services to a small island population has a great impact on their vulnerability. This environmental vulnerability emanates from features like disaster proneness; a combination of exposure frequency and magnitude. Many SIDS are located in tropical cyclone belts and along tectonic plate boundaries, where they are exposed to large storms, earthquakes and tsunamis (Briguglio, 1995), in addition to droughts and flooding from precipitation patterns. The Caribbean is the most disaster-prone of the three regions, with nearly 60% of disasters due to storms and the remainder largely due to flooding. Storms also make the largest contribution to disaster in both the AIMS region and the Pacific (41% and 52% respectively), but these regions are more prone to drought and tsunamis than the Caribbean. SIDS are also at risk of threat to biodiversity loss, soil degradation and erosion, salinization of soils and water supplies, forest fires in some cases, coastal erosion, and desertification (Gheuens et al., 2019). They have fragile local ecosystems, many endemic to specific islands (L. Nurse et al., 2014), which influences their sensitivity to stressors and decreases resilience. Natural disasters contribute both directly to the vulnerability of a population or indirectly by damaging vulnerable ecosystem services the population is dependent on, such as groundwater supplies, fisheries, and tourist attractions.

Economically, SIDS are vulnerable to external shocks beyond their control due to their structural characteristics (Ram et al., 2019). The concentration of economic activity in small and remote areas accounts for increased susceptibility to shock. Their small size limits the availability of natural and skilled human resources, prompting higher import content from international markets and an increased dependence on foreign trade, without reaping the benefit of economies of scale (Briguglio, 1995). Remoteness leads to higher transport costs of resources to isolated communities (Encontre, 1999), which may cause delays in shipment (Briguglio, 1995) or prove unfeasible to transport. Economic implications of disasters are further exacerbated by their small size and remoteness. Limited financial, technical and institutional capabilities affect their recovery (Simpson et al., 2009) and those most in need of aid are difficult and expensive to reach. Globalization trends further marginalize SIDS, as trade systems expand and become more efficient. Products traditionally produced by SIDS can be obtained in larger quantities for cheaper elsewhere in the world, and competing with larger countries is difficult (Encontre, 1999). Low resource availability prompts enhanced import rates to offset deficits (Briguglio et al., 2009). This openness to external economies leave them further exposed to shocks (Encontre, 1999). A lack of diversification is also responsible for vulnerability to external shocks, as changes in demand for a homogenous export product, most notably tourism for many SIDS, can prove costly, as adaptive capacity is low when falling back on a weaker sector (Ram et al., 2019).

In addition to these factors, the composition and dynamics of an island population may enhance their social vulnerability. Non-exhaustively, characteristics like health status, level of wealth, education, and lifestyle play a role in determining the susceptibility of SIDS to hazards and stress, and potential for loss (Cutter, Boruff, & Shirley, 2003). An article published by the United Nations states as many as a quarter of Pacific Islanders live below the poverty line (UN News, 2019). Low financial status indicates heightened sensitivity and low adaptive capacity to recover from loss. Differences in dwelling structure and strength also account for differences in vulnerability, seen in the substantial damage during the 2010 earthquake in Haiti, where no building code had been established (Charles, 2020). Similarly, informal settlements are fragile and built in areas generally more exposed to stressors (Doberstein & Stager, 2013). Aims to try and reduce vulnerability in SIDS can threaten the cultural ways of living, such as losses in agriculture, tourism and fisheries, and is an expensive task to undertake, limiting its feasibility (Robinson, 2020). Increasing stress in remote areas may drive population drift towards urban, economic centers, furthering exposure to large-scale stressors with larger populations in the same area (L. Nurse et al., 2014).

2.3: Climate change, tropical cyclones, and the implications for SIDS

It is clear that SIDS are susceptible to many of the negative effects of current and predicted trends in climate change and tropical cyclones. While annually occurring storms are natural, as are gradual changes in climate conditions, anthropogenic emissions and land-use changes have been shown to exacerbate these stressors (Holland & Bruyère, 2014; Meehl, 2007). SIDS contribute negligible greenhouse gas emissions, less than 1% of global amounts (Simpson et al., 2009), yet are at the frontlines of succumbing to their consequences (L. Nurse et al., 2014). Despite variations between global models of climate change, mean predictions consistently show an increase in global surface air temperatures (SAT) in the coming decades and throughout this century, provided even a stabilizing of greenhouse gas emissions rates to current values (Meehl, 2007; Simpson et al., 2009). This has implications for multiple climatic processes and environmental regimes, increasing risks for the most vulnerable areas. The 2014 Intergovernmental Panel on Climate Change (IPCC) report devotes a full chapter to the knowledge of climate change and its potential impacts and response for SIDS. It notes that not all SIDS are equally impacted by climate change, and that there is diversity in effects between island regions and within the countries in a given region. The impacts of climate change on SIDS in recent years can often be masked by the large-scale changes occurring within the SIDS themselves, such as urban development, settlement-pattern change and globalization factors. Additionally, the size of SIDS can often be lower than the resolution of global climate models, which can make determining vulnerability more difficult. Regardless, many, if not all SIDS will have to deal with one or more of the following stressors more directly in the coming decades, as the forcing from anthropogenic emissions and biodiversity loss prompt major global changes (L. Nurse et al., 2014).

2.3.1: Sea-level rise and implications for coastlines

A well-known factor of climate change, SLR provides major negative consequences for SIDS. While not uniform globally, the rate of SLR has increased to nearly double 20th century rates since 1993, now currently between 2.8 and 3.6 mm yr^{-1} (L. Nurse et al., 2014). This is the result of both increased major ice-sheet melt and the thermal expansion of oceans (Simpson et al., 2009). Accumulated, net SLR of one meter could be expected by the end of the century, though it is unclear whether SLR will be as linear as often predicted. If not the case, many regions could see several meters of SLR in the next century (Simpson et al., 2009). While the Caribbean region is not expected to have SLR rates any higher than global averages, the western Pacific has predicted rates up to three times the global average (Simpson et al., 2009).

SLR poses many challenges for SIDS, which have long coastlines relative to their land area that create more exposure to coastal-stressors than in larger land masses. Issues from inundation and increased rates of erosion are exacerbated by the majority of populations and infrastructure being concentrated along coasts (L. Nurse et al., 2014; Simpson et al., 2009). Livelihoods dependent on tourism may be hindered by coastal erosion, as property is lost and sites of attraction, namely beaches, are reduced in quality. Efforts to mitigate impacts can be costly to implement for SIDS, and may still be futile in some cases (Powers, 2012). Freshwater resources may also be compromised as SLR increases salinity in groundwater aquifers. Vital ecosystems such as mangroves contribute to the resilience of small-island coasts as a natural barrier against wave action. SLR poses a significant threat to mangrove welfare should saltwater depths rise beyond their tolerance level (L. Nurse et al., 2014), and would leave populations more exposed to hazards. A notable example of vulnerability to SLR is Tuvalu, with an average elevation of one-meter above sea level (ASL). Coastline submergence from SLR over the next century has major implications for its inhabitants: forcing migration, loss of livelihoods and a further decline in limited resources. Consequences may go as far as reducing the area of their economic exclusive zone as land area recedes (Powers, 2012).

2.3.2: Air and ocean temperature change and implications for natural resources

Regional SAT changes are predicted to impact precipitation patterns, which further effect water availability and proneness to disaster. Decreases in rainfall by 5-10%, predicted for all SIDS regions (Simpson et al., 2009), are associated with contractions of freshwater lenses, which draw saltwater inland and can affect vegetation sensitive to salinity levels (L. Nurse et al., 2014). Periods of drought are expected to increase in frequency and duration of dry periods as well. This can reduce an island's agricultural yields, adaptive capacity and self-sufficiency. Despite this, rainfall intensity is expected to increase outside of lengthened dry seasons, prompting short-term flooding of some areas (Meehl, 2007).

As SATs are expected to increase, so are sea surface temperatures (SST). There are many uncertainties associated with the timing and extent of temperature change, but multiple models have shown with little uncertainty that temperatures can be expected to rise in the future (Simpson et al., 2009). SSTs are closely linked to SATs, as energy transfers between the two mediums and has implications for marine species and biodiversity (Simpson et al., 2009). Coral reefs are important ecosystems for island nations, and are also extremely vulnerable to increasing temperature. Reefs protect coastlines from large-scale damage from wave action, and help enable economic prosperity by providing food sources and tourist attractions (L. Nurse et al., 2014). Their loss is a further reduction of the limited resources and resilience SIDS have to reduce their vulnerability from other climate-related stressors. Increases in peak SSTs in summer months cause more frequent mass coral bleaching events, and subsequent loss of marine biodiversity (Reaka, O'Connell, Regan, & Wicklund, 1994). The mortality of coral reef environments can be costly and increase vulnerability for small island populations in numerous ways.

2.3.3: Tropical cyclones

Tropical cyclones can be an annual dilemma for SIDS, as their nearby open oceans heat past 26° C in summer months and fuel storm growth (Lugo, 2000). Evidence suggests that though the frequency of storms forming in a given year is not expected to increase with climate change, the intensity may increase, and result in a higher frequency of major storms (Holland & Bruyère, 2014; Meehl, 2007; Simpson et al., 2009). Major storms are considered a category three or higher on the Saffir-Simpson scale, which indicates extremes of sustained windspeeds and even higher gusts, substantial rainfall amounts, and destructive wave action and storm surges. Increased intensity is derived from higher SSTs providing energy for their development (Meehl, 2007).

The consequences for SIDS are likely to be enhanced with increased intensity of storms. The costs of damage can be more substantial (Lugo, 2000), with increased loss of property, infrastructure and life. Factors as simple as the perceptions of a nation post-storm can deter tourists from visiting, reducing their ability to recover from the disaster (L. Nurse et al., 2014). As an immediate concern during tropical cyclones, the health and safety of inhabitants is ever more at risk in higher intensity storms (Lugo, 2000). Should the frequency of higher intensity storms increase, people may be more vulnerable with each event as they have yet to recover from previous ones (Lugo, 2000). Storm surges and flooding impacts may be greater with increased SLR, putting larger proportions of populations at risk. Category one cyclones can bring a storm surge of nearly two meters above high tide level, which is damaging to low-elevated SIDS (Simpson et al., 2009). Immediate and delayed loss of vegetation result from substantial damage from winds, debris and flooding (Meehl, 2007), which reduces an island's ability to provide ecosystem services for its inhabitants.

2.4: Vulnerability of SIDS

This chapter has introduced and discussed the many facets of vulnerability and its relationship with factors of risk. Elements involved in understanding vulnerability — exposure, sensitivity and adaptive capacity — are inherently dynamic and are often specific only to the given systems being studied (Smit & Wandel, 2006). SIDS have been consistently shown to be more vulnerable to stressors than many large countries due to a combination of socioeconomic characteristics and the physical environments they encompass (Anthoff et al., 2010; Blasiak et al., 2017; Briguglio, 1995; Peduzzi et al., 2009). Climate-related coastal stressors, including tropical cyclones, SLR and changing air and ocean temperatures pose massive threats to the wellbeing of an island's populations and ecosystems (L. Nurse et al., 2014), and the interactions between them further influence their vulnerability to subsequent stresses. These concepts provide the basis of this research going forward, with the objective of addressing the following questions:

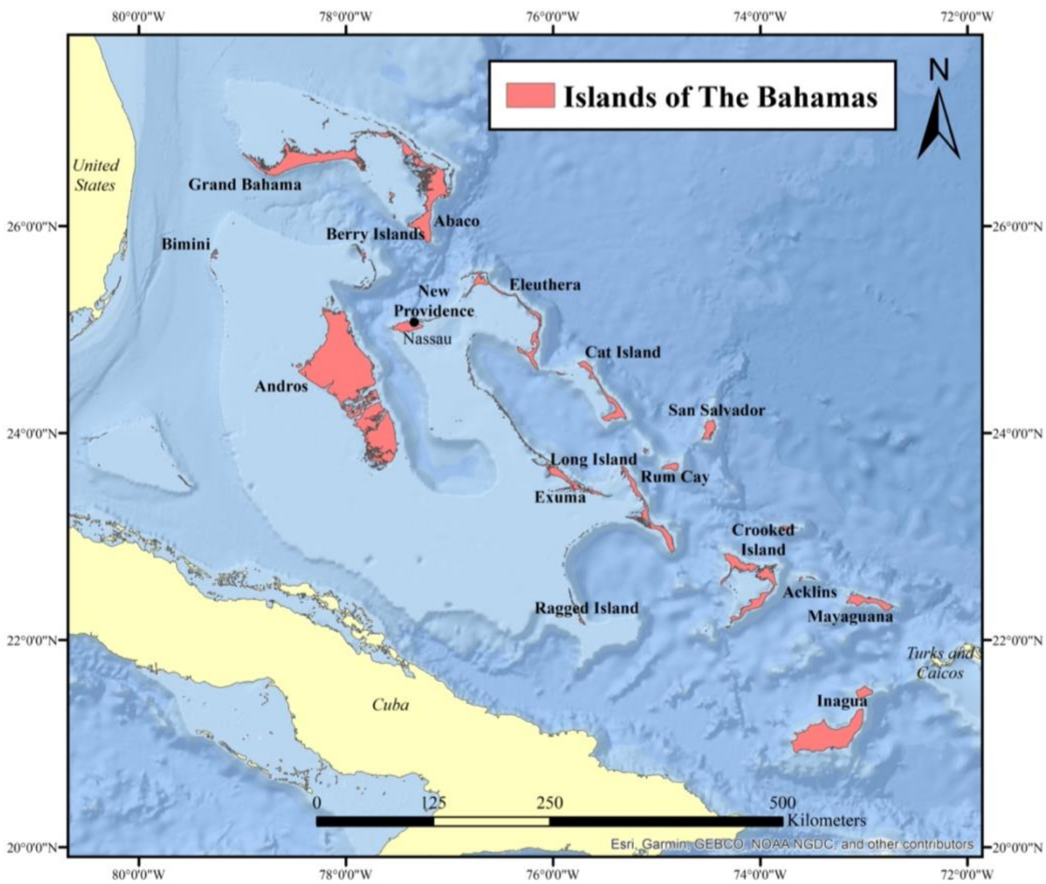
1. What are the fundamental factors accounting for vulnerability in The Bahamas to climate change stressors and hurricanes?
2. Which islands may be considered the most vulnerable to climate-related coastal stressors?
3. What are the public perceptions of vulnerability in The Bahamas?

CHAPTER 3: VULNERABILITY IN THE BAHAMAS

This chapter describes relevant background information and research on the characteristics of The Bahamas that make it particularly vulnerable among SIDS. A case study of the 2019 Hurricane Dorian disaster in the northern Bahamas is then presented and the reasons the impacted islands were vulnerable to the hazard are discussed.

3.1: Factors of vulnerability for the islands of The Bahamas

With over 3000 islands, cays and land masses spread some 1400 km in the western Atlantic (ICF Consulting, 2012; Johnson, 2020), The Bahamas has a firm status among SIDS as a region highly vulnerable to climate-related coastal stressors. Previous research illustrates vulnerability largely as a product of the country's situation and physical geography, though social and economic factors have also been shown to play a role. Map 3.1 provides an overview of the archipelago's long chain of islands. The capital city of Nassau is located on the northern coast of New Providence.



Map 3.1: Overview of the islands of The Bahamas (Source: Author)

3.1.1: Physical geography and environments

Aspects of its physical geography leave The Bahamas highly vulnerable to multiple climate-related stressors. Atlantic tropical cyclones originating from the central Atlantic Ocean, Gulf of Mexico and the west African coast largely curve northeast in and around the Caribbean region, albeit with a degree of variability (Kossin, Camargo, & Sitkowski, 2010). This leaves The Bahamas prominently exposed to the dominant movements of these atmospheric hazards. The karst, limestone islands are very low-lying, with the highest point being 63 meters ASL. on Cat Island. Modelled three-meter SLR found The Bahamas at the highest flood risk of any Caribbean country (Silver et al., 2019), where 80% of land mass is less than 1.5 meters ASL. (Deopersad, 2020). In a global estimate of urban area and populations within low-elevated coastal zones (LECZs), McGranahan, Balk, and Anderson (2007) found that, per share of population in the LECZs, The Bahamas ranked number one, being the only small island state within the top ten countries. This study used population data from 2000, when the population stood at 267,000. Today, that value has nearly doubled as the population approaches 400,000 (Worldometers.info, 2021), yet land area and elevation remain constant. One meter of SLR was also predicted to cost The Bahamas approximately 1.2% of its GDP when modelled for 2100, a value eclipsed only by Micronesia and Palau worldwide (Anthoff et al., 2010). Elevation therefore has major implications for both future storm activity and changing climate regimes.

Additional research conducted in The Bahamas found that coastlines situated near extensive shallow-water banks are the most exposed to coastal hazards, most notably storm surges (Silver et al., 2019). This was determined using a coastal vulnerability model that accounted for type of shoreline, relief, wave action and protective ecosystems present, in addition to SLR scenarios. The nation, which derives its name from the Spanish translation of shallow waters “bajamar”, is famous for these banks (Hannau, 1977). The northern coast of Grand Bahama, western coast of Abaco, Andros, Acklins and Crooked Island were considered particularly exposed regions of the country due to their proximity to large offshore banks (Silver et al., 2019).

Natural ecosystems in The Bahamas provide a great deal of critical services to the Bahamian population (L. Nurse et al., 2014; Silver et al., 2019), and their susceptibility to harm therefore has implications for Bahamian vulnerability. Terrestrial ecosystems include coppice forests, shrublands, mangroves distributed across the entire archipelago, and pine forests on

Abaco, Andros, Grand Bahama and New Providence. These provide resources for industry, habitats for ecologically important organisms, sources of food, employment, and attractions for tourism. Mangroves also provide an enhanced coastal protection from high-energy waves and storms while reducing erosion, making them a crucial barrier for coastal populations (Silver et al., 2019). Despite this, they themselves are vulnerable to increased intensity of storms, storm surges and SLR (L. Nurse et al., 2014). Marine ecosystems, including sea grass beds and coral reefs, are similarly important to the well-being of Bahamians, and their loss would prove destructive for Bahamian ways of life and prosperity. As discussed in Section 2.3.2, coral reefs are particularly sensitive to stress from increased SSTs, which can lead to bleaching and the subsequent loss of marine habitats (L. Nurse et al., 2014).

Limited water resources provide another aspect of the physical environment influencing vulnerability in The Bahamas. With porous, limestone islands, all rainfall accumulates in sub-surface freshwater lenses, leaving negligible surface runoff (L. Nurse et al., 2014). These sources of water are highly susceptible to pollution from anthropogenic waste (Deopersad, 2020) and salinization from inundation of occurring with the onset of storms, SLR, or lens contraction during reduced rainfall periods. A rainfall gradient exists across the islands, with the southern islands having less annual rainfall and being much drier than the north (ICF Consulting, 2012). This leaves them more susceptible to drought-like conditions.

3.1.2: Socioeconomic structure

In addition to being physically vulnerable, there are a number of social and economic factors that increase exposure and sensitivity to stressors while reducing adaptive capacity in The Bahamas. New Providence, with 70% of the population, is densely populated. The remainder of the population is spread across Grand Bahama (15%), Abaco (5%) and the other settled islands and cays, collectively known as ‘the Family Islands’ (Bahamas Department of Statistics, 2017). In total, 29 islands are inhabited (Johnson, 2020). While impacts in New Providence may be strongly felt by a larger number of people, challenges are then raised for residents of the Family Islands in terms of development and recovery after disaster, described here by the Inter-American Development Bank (IDB):

> Settlements are usually dispersed and contain small populations, which increases the costs associated with the provision of public utilities and the development of infrastructure which needs to be extended for long distances to supply communities. Dispersion of population also contributes to inequitable access to social services of varying quality (Deopersad, 2020, p. 16).

Those of lower economic status and health suffer more during storms and can lack resources to be resilient (Shultz et al., 2019). Large informal settlements exist on New Providence, Abaco, Eleuthera, Andros and Exuma (Department of Environmental Health Services, 2013) and hurricanes in The Bahamas disproportionately impact these marginalized communities (Shultz et al., 2019).

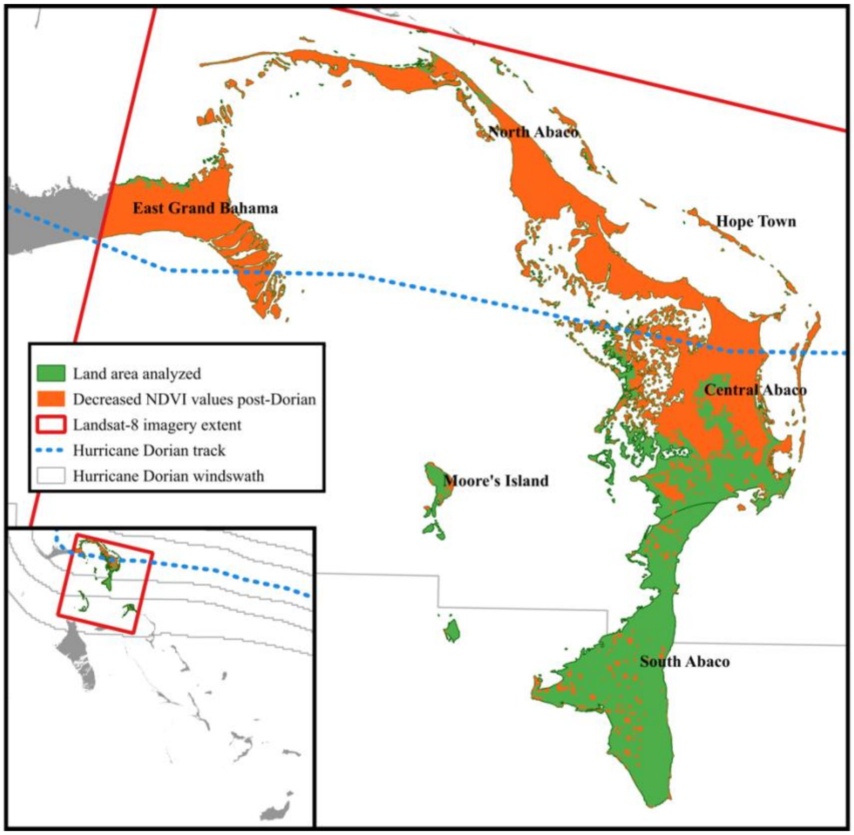
Employment of most Bahamians is provided through tourism and fishing (Deopersad, 2020), both industries being dependent on the prosperity of the natural environment. Prior to the COVID-19 pandemic, tourism accounted for the country's largest industry and source of income, making up 50-70% of GDP and directly employed 65% of the workforce (Rolle, 2020). This makes The Bahamas highly reliant on foreign sources of income, which are susceptible to change according to stressors external to the country. GDP per capita was at $32,933.50 USD in 2019, making The Bahamas one of the richest nations in the Caribbean (World Bank, 2020). However, this is offset by the relatively high cost of living for residents, as it also ranked globally as the sixth most expensive country to live in 2020 (Allen, 2020). As mentioned previously in Section 2.2, GDP per capita does not represent the distribution of wealth in the country and masks disparities that question whether the population as a whole can be considered affluent (Briguglio, 1995). Poverty levels were referenced at 14.8% in 2019 (Pratt, 2019).

In an economic focused vulnerability assessment in the Caribbean, Ram et al. (2019) computed a composite vulnerability index (CVI) which combined economic factors with social and environmental factors to rank nations on their overall vulnerability to climate change and natural disasters. Using proxy indicators in six sub-categories — export concentration, export destination, strategic imports, external financing, social susceptibility, and natural hazards and climate change — they provided a static score and rank of Caribbean nations. When separated by category, economic vulnerability was highlighted as the area needing the highest reduction in order for The Bahamas to be more resilient.

3.2: Abaco, Grand Bahama and Hurricane Dorian 2019

The northern islands of Abaco and Grand Bahama were hit directly by Dorian in September 2019. Inhabitants of Grand Bahama faced these catastrophic conditions for 40 hours as the eye stalled its movement overhead, while Abaco received the most damage over all. Post-storm assessments of the impacted areas found half of all surveyed coral reefs suffered structural damage, with a quarter being severely damaged (Dahlgreen, 2020). Pine forests were damaged on two of their four endemic islands. These contain larger amounts of biodiversity than the more resilient coppice forests, but Post-Dorian surveys then found less biodiversity in the slower-to-recover pine forests (Watson, 2020). Mangroves were also severely impacted, with 40% and 74% of trees being damaged or destroyed on Abaco and Grand Bahama respectively (Lewis, 2020). The damage and loss of these fragile ecosystems further exacerbates the island's vulnerability, as critical ecosystem services have been reduced overall.

Map 3.2 provides a view of the environmental impact of Hurricane Dorian on Abaco and the eastern end of Grand Bahama. It depicts a change detection analysis of a normalized difference vegetation index (NDVI) using two Landsat-8 Level 2 images: one taken on March 23rd 2019 and the other on November 15th 2019. The NDVI provides a measure of the overall health of green vegetation: higher values can be associated with healthier vegetation while lower values indicate sparse and stressed vegetation in poorer health. Areas with decreased NDVI values after Hurricane Dorian compared to before are shown in relation to the path of the storm. The damaged areas cover the major settlements in Abaco, and a large range of the country's inland pine forests and coastal mangrove swamps. This analysis shows the stress applied on natural environments by large-scale storms and highlights a majority of the island of Abaco as substantially weaker from an ecological perspective rather than from a social or economic perspective alone.



Map 3.2: NDVI change detection analysis in Abaco following Hurricane Dorian (2019)
Source: Author (Landsat-8 imagery courtesy of the U.S. Geological Survey)

While exposure to this high-magnitude event played a critical role in the vulnerability of these two islands, other factors discussed previously in Chapter 2 can also be considered. Populations are dispersed across Abaco and Grand Bahama, with small, remote settlements being difficult and expensive to reach in times of disaster. The city of Freeport on Grand Bahama had a dense population hit by the storm. Situated on the Little Bahama Bank, which may have contributed to Dorian's storm surge of up to 25 feet, these islands with a majority of their population living in LECZs were highly sensitive to the negative impacts (Deopersad, 2020). Due to the predominant role of tourism in the islands, a feedback loop formed: lost infrastructure and damage deterred foreign visitors, which in turn led to the islands having limited ability to financially recover and rebuild in order to attract visitors again. Between September 2019 and January 2020, Abaco and Grand Bahama saw an average 82% and 77% reduction in mean monthly arrivals by air (Ministry of Tourism, 2020).

CHAPTER 4: METHODOLOGY AND DATA

In this chapter, I describe the methodology used to construct a multi-dimensional index to assess vulnerability in The Bahamas to climate-related coastal stressors. I also outline the process of conducting interviews with key informants, and an online survey to understand Bahamian perceptions of vulnerability.

4.1: Composite vulnerability index

To assess vulnerabilities to climate-related stressors across individual islands, I constructed a CVI using data indicators specific to The Bahamas. This assessment falls under the third body of literature discussed by Smit and Wandel (2006) in Section 2.1.2, where proxy indicators may be used to rank the vulnerability of a region. The procedure closely follows that described in Cumberbatch et al. (2020), which outlined a social vulnerability index (SVI) for risk and disaster management in Barbados. Using enumeration districts (ED), data were georeferenced and sorted from highest to lowest in each of eight indicators across five social categories, including socioeconomic status, gender, age, special needs and property. Percentile rankings were used to assess the performance of EDs in each indicator, and those scoring in the 75th percentile or higher were flagged, indicating a high relative performance in that indicator. They determined the most vulnerable areas by then summing category percentiles for each ED, and noting the number of flags, before mapping their results.

I took a similar approach to in this assessment to Cumberbatch et al. (2020), with modifications to increase applicability to The Bahamas. Island groupings as listed in the 2010 Bahamas Census of Housing and Population served as ED substitutes. In addition to social vulnerability, I also included categories of economic vulnerability, environmental vulnerability and remote vulnerability, which were utilized by Scandurra et al. (2018) in their assessment of SIDS. I determined the percentile ranks of the island groups for indicators in all four categories, flagging those in the 75th and above percentiles, and mapped the overall results. Some particular indicators were sorted from lowest to highest to indicate high vulnerability. For example, a lower mean household income suggests higher vulnerability to stress as there is less capital available to provide resilience, therefore the lowest scoring island was ranked in the highest percentile. All indicators were weighted equally, a choice I discuss the limitations of further in Section 6.3.

4.2: Data collection

At this scale of assessment, data accounting for all aspects of vulnerability described for every island group are limited, as some islands are remote with very small populations. To conduct this research, I used a series of proxy datasets available for all islands. A full list of the 35 indicators selected is shown in Table 4.1. The data sources used aim to highlight vulnerability in The Bahamas based on characteristics over the last decade. The justification for data use and limitations are described following Table 4.1.

Table 4.1: List of indicators used in composite vulnerability index

Direction of vulnerability indicates whether high values (+) or low values (-) increase vulnerability in an indicator.

Category	Indicator	Definition	Data source	Direction of vulnerability
Social (1)	Population	Total number of individuals residing on a given island	(Bahamas Department of Statistics, 2017)	+
Social (2)	Population Density	Population of a given island divided by the area of that island in km^2	(Bahamas Department of Statistics, 2017)	+
Social (3)	Mean Household Size	Total population of a given island divided by the number of dwellings on that island	(Bahamas Department of Statistics, 2017)	+
Social (4)	Non-Home Ownership	Percentage of island's population that do not own their home	(Bahamas Department of Statistics, 2017)	+
Social (5)	Dependant Population	Percentage of island's population below 15 or above 65 years of age	(Bahamas Department of Statistics, 2017)	+
Social (6)	No Health Insurance	Percentage of island's population with health insurance	(Bahamas Department of Statistics, 2017)	+
Social (7)	Non-black Population	Percentage of island's population considered white or non-black	(Bahamas Department of Statistics, 2017)	-
Social (8)	Highschool Education	Percentage of island's population with high school or lower grade being their highest educational attainment	(Bahamas Department of Statistics, 2017)	+
Social (9)	Female Head of Household	Percentage of island's households with a female head	(Bahamas Department of Statistics, 2017)	+
Social (10)	Disability	Percentage of island's population that is disabled	(Bahamas Department of Statistics, 2017)	+
Social (11)	Informal Settlements	Number of informal settlement structures on a given island	(Department of Environmental Health Services, 2013)	+
Economic (1)	Stop-over Visits	Ratio of stop-over visitors to a given island to the population of that island	(Ministry of Tourism, 2020)	+
Economic (2)	Mean Household Income	Total household income of a given island divided by the number of dwellings on that island	(Bahamas Department of Statistics, 2018)	-
Economic (3)	Mean Import per capita	Ratio of mean imports from 2013-2017 for an island to the population of that island	(Bahamas Department of Statistics, 2019)	+

Economic (4)	Distance from Capital	The straight-line distance between a given island and the capital city of Nassau in km	Google Earth Pro	+
Economic (5)	International Flights	Number of direct flights from international locations to a given island	(Ministry of Tourism, 2020)	-
Economic (6)	Unemployment	Percentage of island's working force population unemployed	(Bahamas Department of Statistics, 2018)	+
Economic (7)	Political Coverage	Number of members of parliament for a given island based on the number of constituencies within the island	Government of The Bahamas	-
Environment (1)	Mean Rainfall	Mean annual precipitation in mm for a given island	Weather Atlas; WeatherBase; World Weather Online	-
Environment (2)	Renewable Water Resource	Renewable freshwater resources in million m^3 per year for a given island	(FAO, 2015)	-
Environment (3)	Coastline to Area Ratio	Ratio of coastline in km for a given island to the area in km^2 of that island	(Bahamas Department of Statistics, 2017)	+
Environment (4)	Area Below 5 Meters Above Sea Level	Percentage of an island's total area in km^2 that is less than 5 meters above sea level	Google Earth Pro	+
Environment (5)	Hurricane Impact	Sum of the Saffir-Simpson storm categories for hurricanes at closest point to an island within the storm's wind swath between 2010 and 2019	NOAA	+
Environment (6)	Direct Hurricane Conditions	Sum of the Saffir-Simpson storm categories for hurricanes at closest point to an island within hurricane conditions between 2010 and 2019	NOAA	+
Environment (7)	Proportion of Mangroves	Ratio of area in km^2 of mangroves on a given island to the area in km^2 of mangroves in The Bahamas	The Nature Conservancy	+
Environment (8)	Mangrove Protection	Ratio of area in km^2 of mangroves on a given island to the area in km^2 of that island	The Nature Conservancy	-
Environment (9)	Proportion of Coral Reefs	Ratio of area in km^2 of coral reefs surrounding a given island to the area in km^2 of coral reefs in The Bahamas	The Nature Conservancy	+
Environment (10)	Marine and Terrestrial Protected Areas	Area of protected marine and terrestrial environments in km^2 for a given island	Bahamas National Trust	-
Remoteness (1)	Internet Access	Percentage of island's households with internet access	(Bahamas Department of Statistics, 2017)	-
Remoteness (2)	Household Computer	Percentage of island's households with a computer and internet services	(Bahamas Department of Statistics, 2018)	-
Remoteness (3)	Television	Percentage of island's households with a television	(Bahamas Department of Statistics, 2018)	-
Remoteness (4)	Fixed Telephone	Percentage of island's households with a fixed telephone	(Bahamas Department of Statistics, 2018)	-
Remoteness (5)	Cell Phone	Percentage of island's households with at least 1 cell phone	(Bahamas Department of Statistics, 2018)	-
Remoteness (6)	Radio Stations	Number of radio stations based on a single island	(URCA, 2017)	-
Remoteness (7)	Medical Facilities	Number of medical facilities and hospitals on a given island	Government of The Bahamas (n.d.)	-

4.2.1: Social vulnerability

Similar to Cumberbatch et al. (2020), these 11 indicators provide data on the social structure of a given island's population. The data includes indicators of education level, household size and ownership, gender of household head, disability, health insurance and ethnicity. These are based on research by Cutter et al. (2003), who list these as prominent factors of social vulnerability to environmental hazards. Additionally, population and population density were considered, as these account for increased exposure to hazards. Female heads of households may increase sensitivity to stressors, as women are often paid less than men and have familial responsibilities (Cutter et al., 2003). A lack of higher education, ownership of home, or health insurance then reduces adaptive capacity to changes from disaster. Non-white ethnicities also tend to be more vulnerable to hazards (Cutter et al., 2003). In the context of The Bahamas, a predominantly black nation, a higher proportion of non-black people in the population may account for reduced vulnerability on a given island, being more affluent. Also considered are the number of shanty town structures on an island, as these settlements are often built in exposed areas, are not up to building codes and highly sensitive to climate stressors, and their inhabitants may be financially incapable of recovering quickly (Doberstein & Stager, 2013). While census data provide a standard method of comparison between islands, the demographics described are from 2010, and likely outdated for an assessment of current conditions. At the time of writing, there had been no public release of the 2020 Bahamas Census of Housing and Population.

4.2.2: Economic vulnerability

This category included seven proxy indicators for economic vulnerability, which are representative of the economic structure of an island and its susceptibility to economic loss and stress (Ram et al., 2019). Factors considered include unemployment, household income, and imports per capita. The role of tourism is expressed in number of stop-over visits per capita and number of international flights, and relates to that island's dependence on an individual sector of the economy. The distance from the capital city to an island was measured, representing barriers to development and resource allocation post-disaster, in addition to the number of political figures overseeing a given island, who may provide a higher adaptive capacity in larger numbers with a greater degree of autonomy (Roberts, 2017). These were chosen largely on the basis of data availability for all islands. Unemployment and household income, however, were reported as an aggregate number for all those considered a part of the Family Islands. Individual islands were therefore assigned the same value and could only be assessed as having a higher or lower performance compared to islands with unique values.

4.2.3: Environmental vulnerability

The 10 selected environmental indicators focus on the influence of hurricanes and climate change stressors on ecosystems, resources and the physical landscape, which in turn have implications for an island's inhabitants. Issues of change in water availability were represented by average annual precipitation and the freshwater lens volume for each island. Lower values in these indicators suggest higher vulnerability. Exposure to storms was represented by historical hurricane track data between 2010 and 2019, and risk of flooding and inundation from SLR was assessed by accounting for the area of land below five meters ASL. Coastal areas are also more exposed to stressors, meaning the coastline length of an island also plays a role. Natural barriers may reduce the impact of storms on small islands (L. Nurse et al., 2014). This was considered by estimating mangrove and coral reef ecosystem areas for each island through habitat map digitization. To account for these natural ecosystems also being vulnerable to stressors, the proportion of the country's mangroves and reefs attributed to a given island was also assessed. Finally, the total area of protected terrestrial and marine parks was included to represent the ability of the natural environment to adapt and recover without the enhanced damage from human appropriation.

4.2.4: Remoteness vulnerability

These eight indicators aim to show an island's vulnerability as a result of remoteness and isolation from large population centers and urban areas, as well as a lack of connectivity to the global economy. They were chosen as similar indicators to those used in the remote vulnerability category in Scandurra et al. (2018). Indicators included the proportion of population with internet, computer, cellphone and television access, representing the available infrastructure of connectivity on an island. Due to limited data, the Family Islands have been attributed an aggregate value in these reports. The values considered therefore are the representative population of each island in that number, and can only be considered higher or lower than islands with accurate values. This category also includes the number of radio stations per island, as they provide emergency alerts during a disaster and sense of connectivity to an island's inhabitants, as well as the number of medical facilities and hospitals per island.

4.3: Key informant interviews

In addition to the CVI assessment, a series of interviews was conducted with key informants in The Bahamas on climate change, hurricanes, and the social structure of The Bahamas. The interviews provided an informed perspective on the subject that differed from my own, and highlighted aspects of vulnerability I had yet to consider in my prior research. Interviewees were chosen based on their field of work, such as natural sciences, marine biology and climate change research. I reached out directly to the candidates through email, where I provided them all relevant information about the research, what their participation would entail and a consent form. These interviews were semi-structured and carried out using video conference platforms to accommodate COVID-19 restrictions. Four interviews were completed in total: two in November 2020 and two in January 2021. All interviews were recorded with the informants prior informed consent, and recordings were stored securely until transcribed, and were deleted afterwards. The informants are listed in Table 4.2 according to how they consented to be named in writing. They were interviewed using a similar list of prompts, with slight modifications based on the informant's field of expertise. A list of discussion prompts can be seen in Appendix B. From these interviews, I derived my findings by coding responses according to their relevance to my three research questions and the frequency of mention across multiple conversations.

Table 4.2: Description of key informants

Name	Description	Affiliation	Interview Date
Michael Brindle-Selle	Bahamian Geography Teacher	N/A	November 4th 2020
Dr. Nick Higgs	Director of Science and Engineering	The Cape Eleuthera Island School	November 11th 2020
Informant 3	Expert in climate change specializing in renewable energy	N/A	January 27th 2021
Shenique Smith	Northern Caribbean Program Director	The Nature Conservancy	January 29th 2021

4.4: Survey of public perception

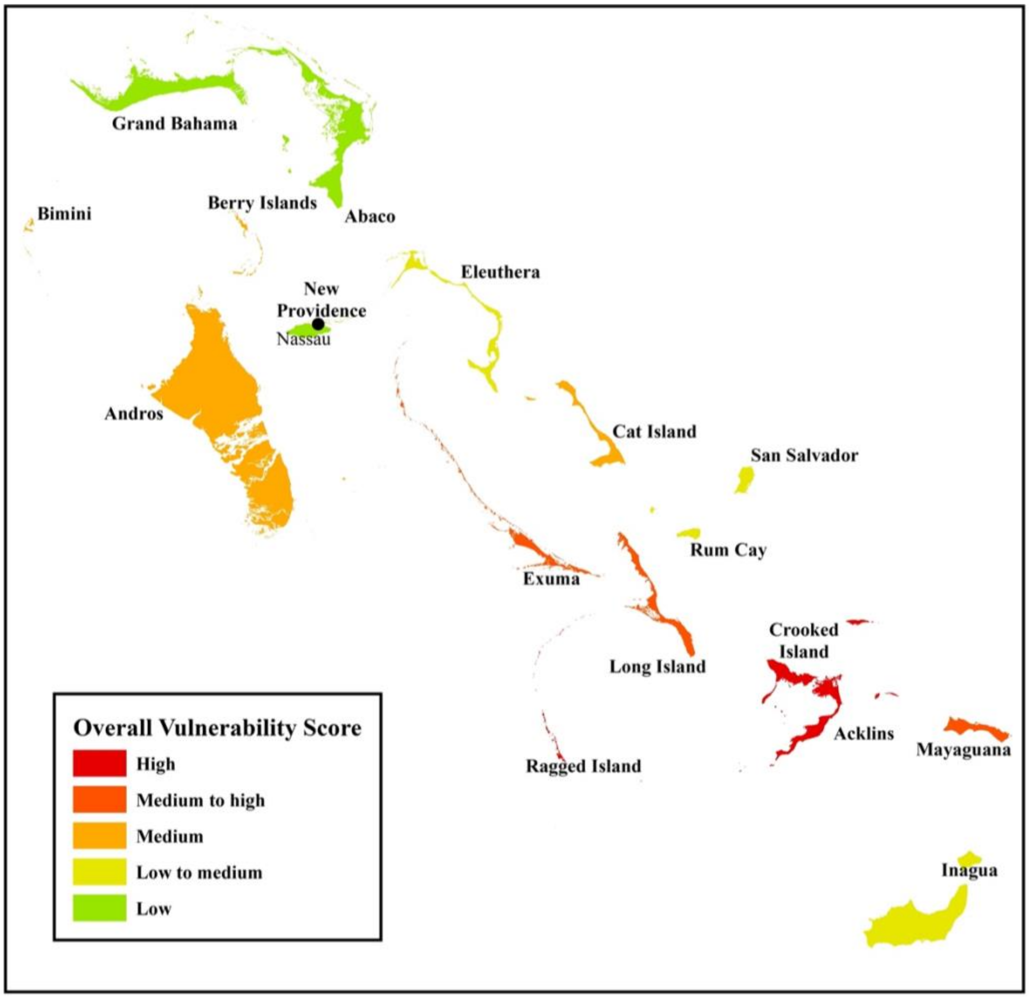
The final component of the research was an online survey, undertaken to highlight perceptions of vulnerability within The Bahamas according to its citizens and residents. This was done using the McGill LimeSurvey platform and distributed to potential participants through Facebook. The online format reached participants without in-person research, which was not possible due to the COVID-19 restrictions. The survey was open between October 30th 2020 and November 13th 2020, and again from January 18th-24th 2021. A description provided information on the purpose of the survey in the context of climate-related vulnerability, and what participation required. Respondents completed the survey anonymously and were encouraged to share it with others after completion, resulting in a snowball sampling method. The sample population is unlikely to be representative of all Bahamians as I shared primarily with family and colleagues, as well as in a Facebook group entitled 'Bahamians Engaged in Natural and Geospatial Sciences' (BEiNGS) to reach more participants. This group had a greater understanding of the topics discussed than an average citizen. The first section of the survey contained a total of 16 questions where participants were asked to select islands and ecosystems they believed were most vulnerable to both climate change and hurricanes, give their opinions of climate change adaptation, and provide any other feedback they wished to share. The second section included five questions regarding the participants' age, gender, island of residence, employment and history with hurricanes, which helped to analyze the differences in perceptions of participants. The full list of questions can be found in Appendix C.

CHAPTER 5: RESULTS

In this chapter, I describe the results of the various methods employed in the investigation, including the CVI, interviews with key informants, and the online survey.

5.1: Output of composite vulnerability index

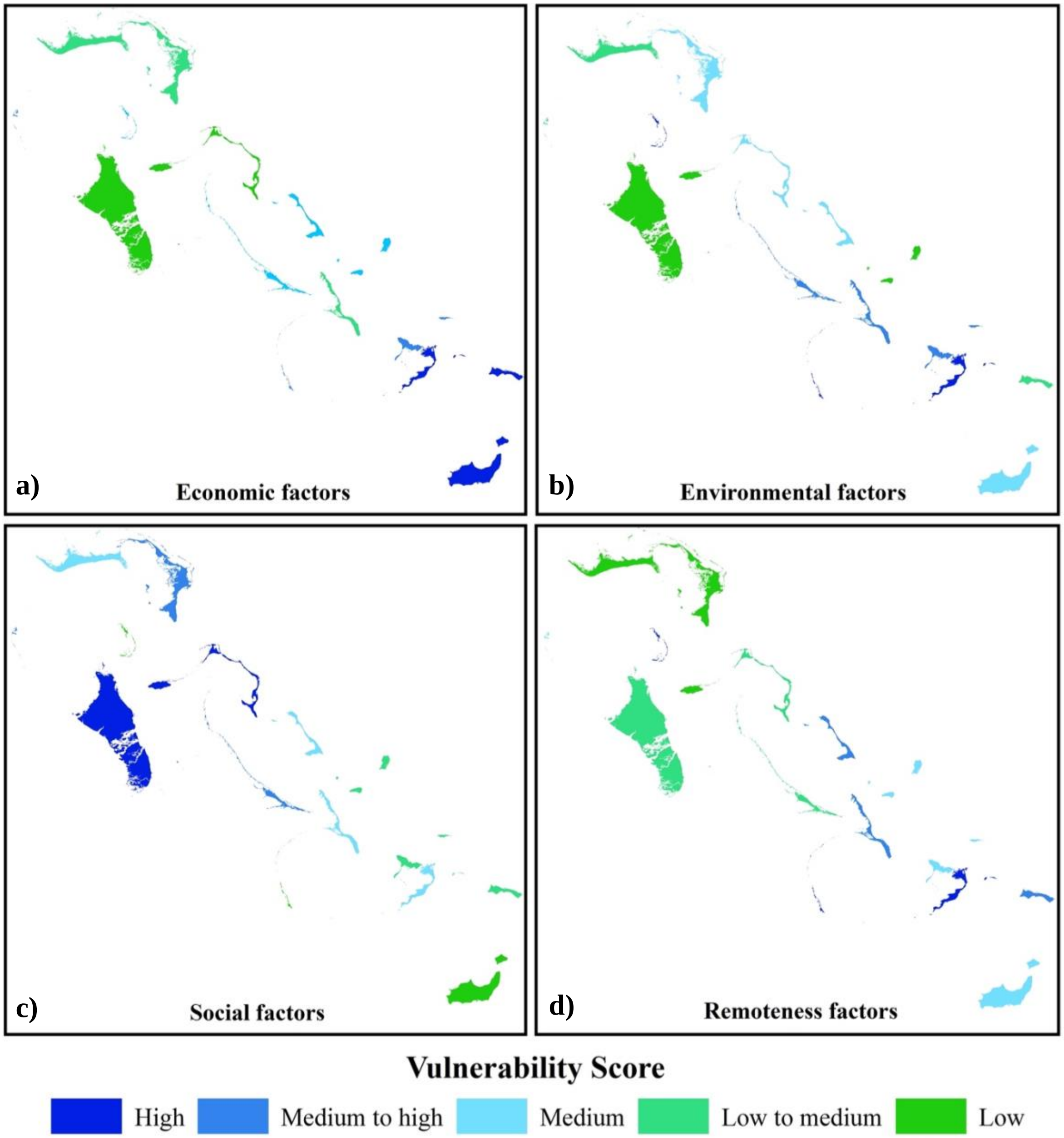
These values represent the sum performance in all four of the individual vulnerability categories. Following the steps described in Section 4.1, Acklins was ranked as the most vulnerable island to climate-related coastal stressors, with the largest sum of percentile ranks across all indicators (s=2247%). Ragged Island (s=2112%) was ranked second, followed by Crooked Island (2030%). Abaco (s=1488%), New Providence (s=1335%) and Grand Bahama (1323%) were determined to be the least vulnerable islands to these same stressors using this method. The distribution of overall vulnerability scores can be seen in Map 5.1. Acklins and the Berry Islands received the largest number of flags, with a high performance in 16 out of the 35 indicators. Abaco had the least number of flags with seven. Table 5.1 displays the number of flags received for each island. Vulnerability rankings for individual categories can be seen in Map 5.2, including economic factors (Map 5.2(a)), environmental factors (Map 5.2(b)), social factors (Map 5.2(c)) and remoteness factors (Map 5.2(d)). The top three ranked islands in each category are also shown in Table 5.2.



Map 5.1: Overall vulnerability in The Bahamas using percentile rankings (all categories)

Table 5.1: Number of vulnerability flags by island

Island	Number of flags	Island	Number of flags
Abaco	7	Exuma	12
Acklins	15	Grand Bahama	8
Andros	14	Inagua	12
Berry Islands	16	Long Island	10
Bimini	14	Mayaguana	15
Cat Island	13	New Providence	9
Crooked Island	13	San Salvador & Rum Cay	16
Eleuthera	9	Ragged Island	9



Map 5.2: Relative island vulnerability by category

Table 5.2: Most vulnerable islands by category

Rank	Economic	Environmental	Social	Remoteness
1	Inagua	Ragged Island	New Providence	Ragged Island
2	Mayaguana	Acklins	Andros	Acklins (tied-2)
3	Acklins	Berry Islands	Eleuthera	Berry Islands (tied-2)

5.2: Key informant interview responses

The nature of coastal development, dependence on foreign resources and capital, frequency of storms, limited access to research and data, adaptation and recovery struggles, physical geography and dependence on fragile ecosystems and environments were factors of vulnerability discussed in the interviews. A number of regions and specific islands were highlighted as particularly vulnerable due to social and economic factors, environmental conditions and status, as well as issues associated with remoteness. Finally, opinions on public understanding and perceptions of these vulnerabilities, hazards and risk were also discussed.

5.2.1: Physical geography & environmental dependence

The nature of the geography and physical environments were clearly stated to be a large factor affecting Bahamian vulnerability. Low-elevated islands were frequently highlighted as a crucial issue. This was believed to enhance vulnerability to SLR associated with climate change and storm surges. Susceptibility to hurricanes was then described as heavily due to the location of The Bahamas in the western Atlantic. The shallow-water banks offshore of many islands were highlighted as a potential enhancer of stress from large storm events by Shenique Smith: “in terms of the force of wind and the waves that can be gathered and brought onshore, it's actually places with shallow water offshore, it's actually a little bit more risky than places with deeper water right offshore” (January 29th 2021). Also discussed, was the area covered by The Bahamas compared to the size of the islands. According to Informant 3: “Hurricanes hardly recognize us as landmass. So they just tend to swoop over us” (January 27th 2021). Dr. Nick Higgs also had this to say:

> If you compare The Bahamas to the southern Caribbean islands, like the British Virgin Islands, we cover a huge area that is the size of multiple countries in the southern Caribbean, but all under one country, one government, one response strategy. And in some particular areas, it's hard to manage that and keep that going. (November 11th 2020)

These comments indicate that how and where the islands are situated accounts for the vulnerability of their inhabitants.

The Bahamas’ cultural dependence on fragile ecosystem was also believed to increase vulnerability. Both marine and terrestrial environments were considered very sensitive to disturbance. Marine ecosystems such as coral reefs are sensitive to rising SSTs, noted to be occurring faster in the Caribbean region, which increases their likelihood of bleaching. Culturally important food sources including spiny lobsters and queen conch may also be affected by limiting the availability of calcium in their body. Dr. Nick Higgs discussed his concerns about the impacts of stressors on ecosystems the population depends on. He elaborated that, particularly in the Family Islands, Bahamians turn to the environment for artisanal food and sources of income in times of crisis, such as during a disaster or the COVID-19 lockdowns. Bahamians are left vulnerable as the health of these environments decline and resources deplete. “I worry about the ability to bounce back, well, the ability of the environment to support the bounce back and to provide that insurance” (November 11th 2020). The quality of water across the islands’ freshwater lenses was also discussed. Given their relative importance despite more recent shifts to reverse osmosis as a source of potable water, Bahamians are dependent on these lenses, which are at risk to saltwater intrusion during storms, inundation from SLR and pollution from landfill leaching and other heavy metals unable to be properly handled in the country.

5.2.2: Foreign dependence

The issue of further dependence on foreign resources and sources of income was prominently discussed. As described by Informant 3:

> We get our food from outer country, we got fossil fuels that run the economics from out of the country. Until recently, even the communications that we get a lot of people get their news, believe it or not from outside of the country. We are very vulnerable to any two things are very exposed dependent on things that are outside of the Bahamas. (January 27th 2021).

With an economy built largely around tourism, a changing climate reduces the attractiveness of The Bahamas to visitors, who will opt to remain at home in their fairer weather conditions, thereby reducing access to wealth and prosperity for Bahamians. Additionally, food imports, which were stated to supply more than 90% of food consumed in the country, may become more cumbersome to maintain with shifts in climate regimes requiring new suppliers.

5.2.3: Issues of adaptation and recovery

In regards to recovery practices post-disaster versus mitigation, the informants considered the two areas unbalanced in focus. Attention is given almost exclusively to recovery and reconstruction, which is distinguished from lacking efforts to pre-plan for future stresses in The Bahamas. Shenique Smith highlighted the abandonment of recovery and restoration of ecosystems providing protection to coastal stressors, as efforts are instead focused towards human recovery. She believed this stemmed from a high cost for mitigation that could instead be put towards helping individuals directly. With more frequent storm occurrences, the cost of recovery is high, and will continue to rise. This was contrasted with the fact that the nation receives minimal foreign aid from Overseas Development Assistance funding due to The Bahamas being classified as a rich nation based on GDP, leaving them on their own to recover. Shenique Smith concluded any form of adaptation or recovery in the country is limited by the availability of financial capital, and no improvements or changes will move forward without it.

5.2.4: Coastal development and built environments

Considering the whole nation to be a coastal state, issues of development in exposed locations were highlighted. SLR, wave action and storm surges are stresses impacting the islands. Some communities exist in areas that frequently flood during large precipitation events. The strength of infrastructure during storm events was described Informant 3:

> The Bahamas has one of the strongest building codes on this side of the planet. But we're also dealing with storms that we've never had to deal with before. So our hurricane building code is for category three. We have not had a category three hurricane in The Bahamas in quite some time, we've had fours and fives. So our building code is deficient, for serving its purposes. It's strong, but it is deficient at this time. (January 27th 2021)

Michael Brindle-Selle also elaborated on this concept, noting that the building code has not been updated since 2006 despite talks of doing so. According to Dr. Nick Higgs, efforts to try and reduce losses in property or income through coastal erosion are only making the issues worse. The hardening of coastlines with development and infrastructure like seawalls disrupts natural cycles of sediment transport and extreme event buffering, enhancing their susceptibility to damage in the future.

Dr. Nick Higgs also shared his concerns with development across New Providence in comparison to the Family Islands, where there is an imbalance of critical infrastructure around the capital compared to other regions in the country. Most islands function on the infrastructure of New Providence, notably its international airport. He believed this puts the country in a highly vulnerable position, with "all our eggs are in one basket" (November 11th 2020). The status of all islands in The Bahamas is therefore dependent on Nassau, New Providence alone. He added:

> So right now we are in a situation where we have a low probability, high severity risk in that all of our forms of government are dependent on one island in the country. So yes, low probability of the island being hit, but if it is hit, it will be very severe. (November 11th 2020)

This dependency stems from the cost of further development in more remote locations with limited connections to larger markets and populations, which must be put in place in order for critical infrastructure, resources and services to be dispersed across the country.

5.2.5: Limits arising from data accessibility and lack of prior research

A point frequently mentioned during interviews was the notion of limited accessibility to critical data needed to better prepare for disasters and reduce vulnerability. Research across The Bahamas involving climate models and future prediction scenarios are sparse due to the spread of the islands over a large area of ocean, which can be too small to be represented accurately in models. Issues like these and other limits in data for research in The Bahamas make it difficult to assess the future implications of these stressors on the islands. Shenique Smith mentioned not having access to research on the effects of saltwater inundation on soils across the islands, which could be a potential issue for endemic vegetation and agricultural prospects. She described the benefits in having more data, which are needed to improve predictions of storm surges to plan accurate evacuation strategies and aid decision makers in other areas.

5.2.6: Frequency of exposure

In relation to hurricanes, the frequency of exposure of the islands was a large concern across the interviews. Shenique Smith discussed the increased frequency of more intense storms on the natural environment:

> So normally, you're talking about these storms [that] would have been a one in 50 year, one in 100 year, maybe one in 10. And for us now, it’s almost a one in two, one in three year. So how is that affecting long term? We don't know, in terms of when an ecosystem that was severely damaged [had] maybe 10 years, 15 years to recover now only has two or three. (January 29th 2021)

Beyond wind damage and flooding associated with flooding, these environments are exposed to saline conditions from inundation more frequently, making their recovery more difficult. From a community perspective, it was made clear that storms have a cumulative impact on the mental health of those having to rebuild every few years, or losing family members. The storm frequency poses major challenges to economic recovery in The Bahamas, as the shock to the economy can be too much to cope with. Dorian was given as an example of a cumulative financial burden on a country that had yet to recover from previous disasters, namely Hurricane Joaquin in 2015. Dr. Nick Higgs went on to discuss the implications of storms for the more remote southern islands; “And then if storms become more intense and an airport or island gets wiped out every other year, but it takes several years to rebuild, you see a slow decimation of some of the islands” (November 11th 2020). Ragged Island was given as an example, being severely damaged in 2017 by Hurricane Irma, and not being fully restored by the government of The Bahamas.

5.2.7: Vulnerable islands and regions

As for the particular areas in The Bahamas most vulnerable to climate-related stressors, there was no overall consensus across interviews. Grand Bahama was frequently depicted as a very vulnerable island to future storms, referred to by the climate change expert as “one of the top three, if not the top, the most frequently hit places for hurricanes in the world” (January 27th 2021). Shenique Smith similarly discussed how the history of storms on the island over the last 20 years and believes this has had a cumulative impact on the island and its population. The north was considered more vulnerable to storms due to historic tracks, with Grand Bahama and Abaco were highlighted in particular with references to Dorian. Beyond these locations, Michael Brindle-Selle discussed Andros, and the difficulties in trying to fortify and protect its coastlines simply due to its large size. Shenique Smith referenced research highlighting Lowe Sound in northern Andros because of the influence of offshore shallow water banks on storm surges, noting that “it's easier to move water that shallow than deeper water” (January 29th 2021). For climate change vulnerability, the central and southern islands were believed to be more at risk of extremes of weather, including both flooding and drought. While there was not an agreement on a particular location most vulnerable, there was agreement with the words of Michael Brindle-Selle: “I would say all of the islands of The Bahamas are very vulnerable to climate change, as are many other island nations in the world. But yes, we are very very vulnerable” (November 4th 2020).

5.2.8: Perceptions of vulnerability

Opinions were mixed on how aware and concerned the general Bahamian public are on these coastal stressors. All agreed that concern about future hurricanes is very high among the population due to its direct, tangible impacts, but had different beliefs regarding concern and understanding of climate-change impacts on The Bahamas. Michael Brindle-Selle believed awareness is limited, highlighting the actions of fishers seen in local news sources as an example: “[they] go out there and a lot people do not have, or seem to have, a great concern for the environment. They fish illegally and out of season, and things like that” (November 4th 2020). He and Shenique Smith expressed their doubts that many are concerned with future environmental changes with SLR and rising SSTs, and believed more research on this subject needs to be done. Dr. Nick Higgs shared similar points in regard to ocean environments:

> One thing is that people don’t really believe how precarious the marine ecosystem is, in that there is a perception it will always provide, that is limitless and humans can exalt, I can tell you several studies that have picked up these recurrences in interviews. (November 11th 2020)

Informant 3 believed that people know these stressors and issues are occurring, but lack the full understanding to describe them. Fishers and farmers are seeing the impacts through reduced yields, and overall “there are people connecting the dots” (January 27th 2021). They note that Bahamians are most aware of issues that may impact them financially.

5.3: Bahamian perceptions of vulnerability

This section describes the quantitative results found from multiple-selection responses and qualitative results from open-answer responses by participants who completed the online survey.

5.3.1: Summary of results

Of the 123 respondents who attempted the survey, 71 participants completed the survey in full. Table 5.1 summarizes the demographics and hurricane experience of the participants. A large majority of participants originate from New Providence, have experienced a hurricane in the past and suffered personal injury or loss as a result.

Table 5.3: Demographic summary of survey participants

Category	Count	Percentage	Category	Count	Percentage
Gender			**Island(s) previously or currently live on**		
Male	28	39%	Outside Bahamas	9	N/A
Female	42	59%	Abaco	9	N/A
No answer	1	1%	Andros	3	N/A
Age			Cat Island	3	N/A
18-24	11	15%	Crooked Island	1	N/A
25-34	18	25%	Eleuthera	5	N/A
35-44	17	24%	Exuma	1	N/A
45-54	17	24%	Grand Bahama	7	N/A
55-64	5	7%	Long Island	2	N/A
65+	3	4%	New Providence	61	N/A
Experienced a hurricane in The Bahamas			**Suffered personal loss/injury during a storm**		
Yes	66	93%	Yes	45	63%
No	5	7%	No	22	31%
No answer	0	0%	No answer	4	6%

Participant levels of concern about future hurricanes and climate change in The Bahamas is shown in Table 5.2, and their selections for the most vulnerable islands are plotted in Figure 5.1. Table 5.3 then summarizes how important each individual vulnerability category, as described in Chapter 4, are to determining overall vulnerability according to the participants.

Table 5.4: Responses to “On a scale of 1-10, how concerned are you about the effects of a future hurricane or climate change in The Bahamas?” (1- least concerned, 10- extremely concerned)

Stressor	**Mean**	**Mode**	**Standard Deviation**
Future hurricane	9.09	10 (n=38)	1.19
Climate change	9.05	10 (n=41)	1.48

Table 5.5: Responses to “Please indicate on a scale of 1-10 how important you think each of these factors are in determining the vulnerability of a given island” (1- least concerned, 10- extremely concerned)

Vulnerability category	**Mean**	**Mode**	**Standard Deviation**
Economic	8.0	10 (n=28)	2.413
Environmental	9.1	10 (n=42)	1.541
Social	7.5	10 (n=17)	2.305
Remoteness	8.3	10 (n=32)	2.196

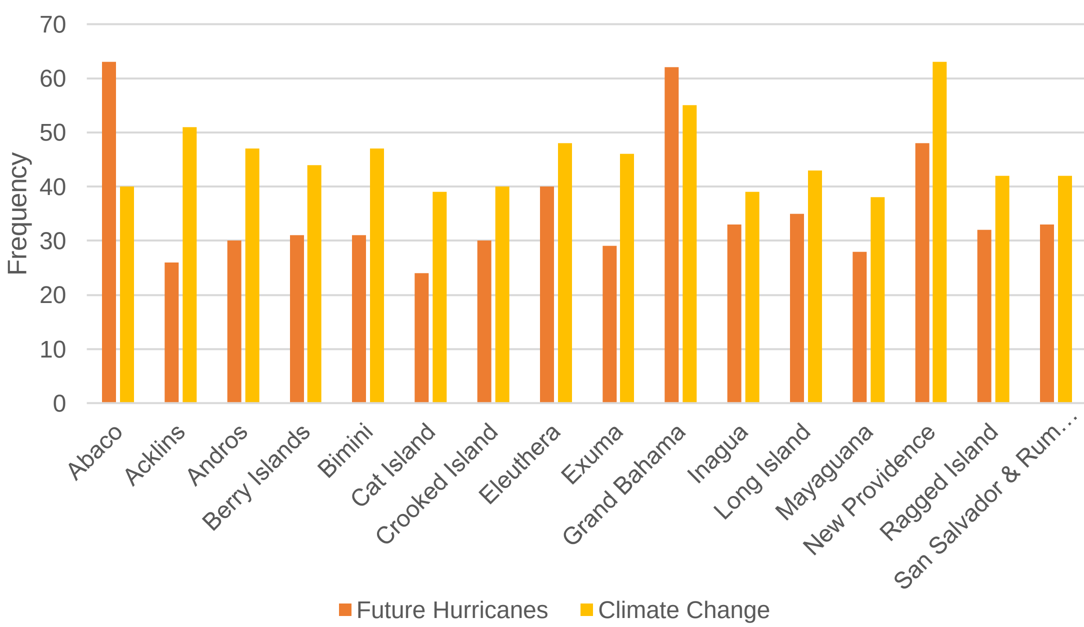
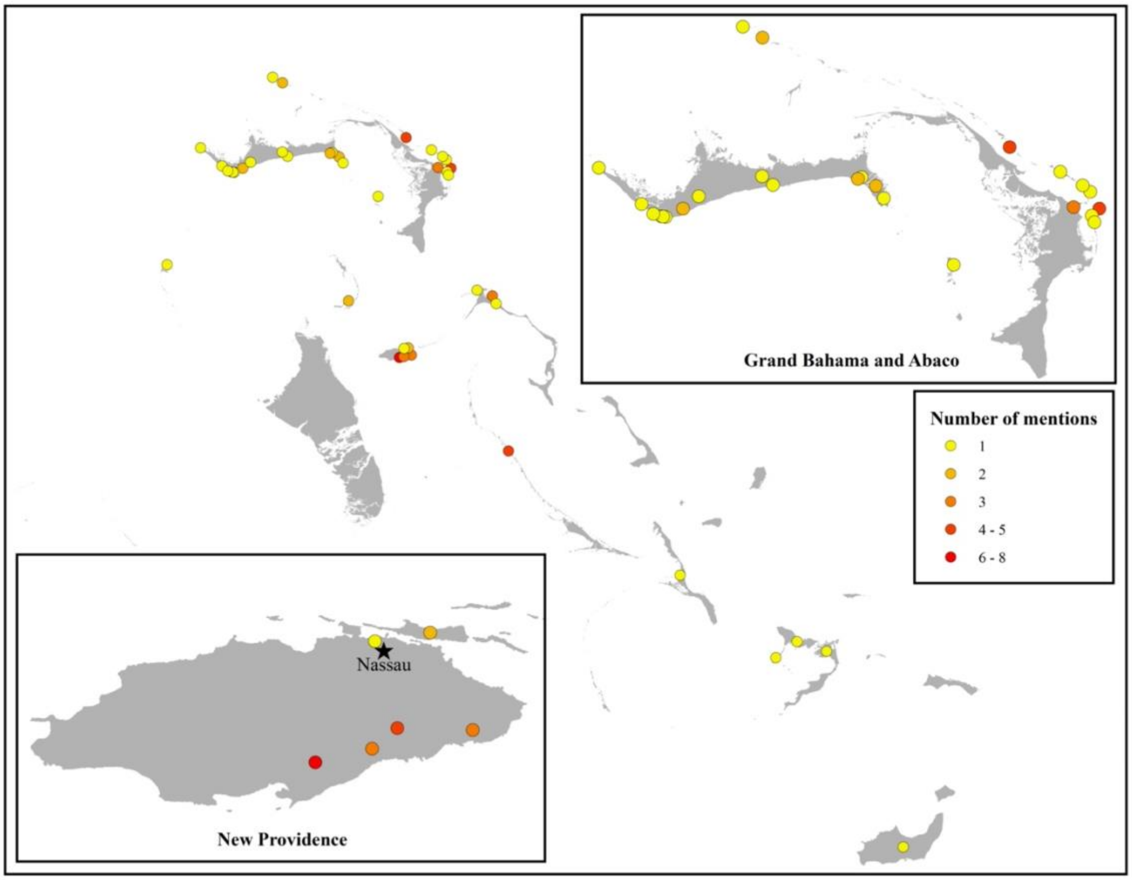


Figure 5.1: Responses to “Which island(s) do you believe are most vulnerable to hurricane and climate change stressors?”

The results shown above indicate that Bahamians were extremely concerned about both future hurricanes and climate change, with no statistically significant difference between stressors in Table 5.2. This held true across all age-groups and gender at a 5% alpha level. All islands received more votes for climate-change vulnerability ($\bar{x}=45$) than hurricane vulnerability ($\bar{x}=35$), excluding Abaco and Grand Bahama. The islands most frequently selected as most vulnerable to future hurricanes were Abaco, Grand Bahama, and New Providence, selected by 89%, 87% and 68% of participants respectively. The islands selected least frequently were Mayaguana (39%), Acklins (37%), and Cat Island (34%). Regarding climate-change vulnerability, New Providence was most frequently selected (89%), followed by Grand Bahama (77%) and Abaco (72%). Inagua and Cat Island were selected least frequently (55%), followed closely by Crooked Island (56%). Environmental vulnerability factors had the highest mean score, while social vulnerability had the lowest. An ANOVA test found these mean values had no statistically significant difference between genders ($p>0.05$), and no difference between age-groups after a Scheffe test. Environmental vulnerability was, however, scored significantly higher than economic and social factors ($p=0.0002$).

Specific locations believed to be particularly vulnerable to either a future hurricane or climate change are shown in Map 5.3 below. Though spread across the archipelago, a majority of the locations can be seen clustered in the northern Bahamas, particularly across Abaco, Grand Bahama and New Providence. Table 5.4 then shows the total number of locations mentioned and their frequency by island.



Map 5.3: Particularly vulnerable locations in The Bahamas according to survey participants

Table 5.6: Frequency of mention of locations by island according to survey respondents

Island	Number of locations/areas mentioned per island	Total number of mentions
Grand Bahama	14	17
Abaco	12	22
New Providence	6	22
Eleuthera	3	5
Crooked Island	2	2
Exuma	1	4
Berry Islands	1	2
Bimini	1	1
Long Island	1	1
Inagua	1	1
Acklins	1	1

A number of different justifications were provided for the chosen locations. The southern side of New Providence was most frequently chosen, with risk of flooding being the dominant reason. These stem from the low-elevation on this coast and in areas such as Pinewood, which frequently flood. After this followed the Abaco Cays, the majority of which are situated offshore of the eastern coast of the main island. These, along with Marsh Harbour; the largest settlement in Abaco, were mentioned due to their susceptibility to rising sea levels, history of storms and their current damaged state post-Dorian. Many locations in Grand Bahama were selected for similar reasons, with those on the east end of the island being described as isolated.

5.3.2: Perceptions of vulnerability to hurricanes

Regarding opinions on vulnerability to future hurricanes in The Bahamas, many participants selected all the islands as most vulnerable, believing that no individual island was more vulnerable than another. Explanations for this choice mainly included the low elevation of all islands which increases potential for flooding during storm events.

> The entirety of The Bahamas is at risk with different risks associated with each island. Some (like Abaco) have demonstrated a propensity for severe flooding and storm surge while others are at risk of being cut off from help simply due to distance from the capital and a lack of transportation infrastructure. (Participant 9, October 30th 2020)

Those who selected specific islands to be highly vulnerable to hurricanes most frequently selected Grand Bahama, Abaco, and New Providence. These islands were highlighted because of their population size and density, particularly in New Providence, and storm history in Grand Bahama and Abaco. A common theme in these responses were references to Hurricane Dorian in 2019 as justification for the selection. They mentioned the recent destruction and lack of recovery. Overall, the northern islands of The Bahamas were believed to be more vulnerable because of their populations and infrastructure, and frequency of hits by storms in comparison to the central and southern Bahamas. A few participants also discussed vulnerability in the Family Islands, one believing San Salvador and Inagua to be particularly vulnerable due to storm tracks coming from the eastern side of the archipelago and Caribbean Sea respectively. Another mentioned the lack of development in comparison to the capital city, Nassau, which leaves the whole country vulnerable to impacts in New Providence:

> Eventually a Cat 4 or 5 storm with massive surge similar to Dorian will strike New Providence, and it will be dire. If and when what happened to Marsh Harbour and Abaco from Dorian happens to New Providence, it is feasible that The Bahamas could collapse as a functioning independent state. (Participant 81, November 3rd 2020)

5.3.3: Perceptions of vulnerability to climate change

As for climate change vulnerability, again the majority believed all islands were vulnerable due to the overall low-lying nature of the islands and coastal proximity: "To my knowledge, most people on all islands live along the coasts. Any erosion and rise in sea levels would affect everyone" (Participant 30, October 31st 2020). Those in the northern region of the country were mentioned most frequently. Many mentioned New Providence for its large population on a relatively small, flat and low-lying island. It is "the economic epicentre of the country" (Participant 50, November 1st 2020), meaning factors affecting it have implications across all islands. One respondent described New Providence as being overdeveloped. Others then discuss the Family Islands, but with little agreement on their vulnerability. Participant 82 noted that: "Andros Island is really a mini archipelago which is covered in vast areas of mangroves and pine forests, channels and lakes. The island is very flat and low lying" (November 4th 2020), believing it to be more vulnerable to SLR as a result. Another participant instead considered Andros alongside Cat Island as more resilient to coastal stressors.

5.3.4: General comments

When asked if they had any additional comments to add to their response about vulnerability in The Bahamas, some provided notable concerns. Multiple people referenced the status of the government and their role in impact mitigation, recovery and sustainable development, which was considered lack-luster. Participant 9 notes:

> As demonstrated post-Dorian in Abaco, the central government's inability to maintain law and order in an area that has been severely impacted would be a threat

> to safety and security of storm survivors. This would be especially true should New Providence ever sustain damage on that level (or if ports, airports, and other vital infrastructure was knocked out for a time following the storm). (October 30th 2020)

Another participant went on to discuss town planning across the islands, namely that the country would shut down should New Providence experience a Dorian-like disaster. One participant noted the lack of self-sufficiency in terms of production and exports from The Bahamas, while others used the COVID-19 pandemic as an example of the economic vulnerability of the country. Overall, many were worried about what is to come in the future and believed that change must occur in perceptions of vulnerability and how disaster situations are handled. Participant 81 described in detail their believed shortcomings in thinking about these risks in the short term and long term:

> the poor quality of education with respect to teaching the population to think clearly ie critical thinking skills; the lack of teaching of the realities of our geography and potential consequences of it, the lack of teaching of local history with respect to hurricanes and their short and long term impacts, and lack of teaching of civics for creating the foundations of strong, meaningfully engaged citizens. (November 3rd, 2020)

CHAPTER 6: DISCUSSION

In this chapter, I will discuss the significance of the results shown in Chapter 5 and their relation to the background research and information provided in Chapter 2 and Chapter 3. I will then address the limitations of these research methods and results before coming to my final conclusions.

6.1: Key findings

6.1.1: Fundamental factors of vulnerability in The Bahamas

Factors attributing to high vulnerability to climate-related stressors in The Bahamas on a global scale were highlighted in interviews with key informants and survey responses. From a physical perspective, there was large agreement that the low elevation of the islands is a critical issue for the country. This leaves essentially all communities and terrestrial ecosystems highly sensitive to SLR and storm surges during hurricanes, regardless of their overall magnitude. Shallow-water banks characteristic to the archipelago provide an increased exposure to these stressors, while the frequent exposure to hazardous tropical storms and hurricanes further influences vulnerability as a result of the country's location in the North Atlantic hurricane belt. The fragility of vital ecosystems and resources then affects sensitivity to climate stressors, as their harm and loss leaves the population dependent on them with reduced economic resilience and adaptive capacity while also being more exposed to the next stressor. The nature of the physical environment and ecosystems were considered the most important factor in determining overall vulnerability, followed by remoteness.

In terms of population dynamics and social structure, vulnerability results from the distribution of the population across the many islands. As all are under one government state, all are dependent on the status of Nassau, New Providence. This island alone houses the majority of the population and critical infrastructure, leaving it heavily exposed to increased stress from climate change and hurricanes. Due to its small size, the population is densely packed in exposed coastal zones and in areas prone to flooding. Simultaneously, several dozen other islands and settlements rely on New Providence to provide their resources and services, being in remote regions with limited connectivity. Applied stress may fracture these connections, proving detrimental to remote communities.

The openness of the Bahamian economy was another component of vulnerability. The country's dependence on external sources of food, products, and wealth through tourism means its prosperity rests on the status and well-being of foreign suppliers of goods and visitors, rather than being a self-sufficient nation. The connections between the Family Islands and New Providence can be considered a microcosm for the connections The Bahamas has to global markets. Should those connections be broken due to some stressor, seen most recently with the almost complete shutdown of tourism during the COVID-19 outbreak, the impacts are felt by all.

Finally, additional areas of concern are overall policy and planning in The Bahamas, related to the responses and involvement of government and decision-makers in times of crisis. Poor measures are believed to be taken in comparison to the scope of situations requiring response. Focuses are on reconstruction rather than strategic planning for stressors decision-makers know are likely to occur. This may stem from limited research on these stressors or lack of available data to do so. Table 6.1 summarizes the main components of vulnerability to climate-related stressors in The Bahamas.

Table 6.1: Summary of fundamental factors of vulnerability in The Bahamas

Physical geography	**Social structure**	**Economics**	**Policy and planning**
Low elevation coastal zones and shallow-water banks	Distribution of population across 29 islands	Over-importance of tourism as a source of income	Poor mitigation strategies and pre-planning
Frequency of major hurricanes, fragile environments and local resources	Discrepancies in population size, development and connectivity	Dependence on foreign resources	Limited data availability

6.1.2: Most vulnerable islands in The Bahamas

The results of the CVI analysis show a general increasing gradient in vulnerability with decreasing latitude. The southern islands, particularly Acklins, Ragged Island, Crooked Island, Long Island and Mayaguana were found to have the highest overall vulnerability in The Bahamas. These islands ranked high and received flags in many of the assessed indicators, most frequently in remote vulnerability. These islands out-rank the north in all categories except social vulnerability.

Southern islands are generally more remote than the north, have smaller populations, are less connected to local and global markets, and have experienced multiple storms in recent years with hurricanes Joaquin (2015), Matthew (2016) and Irma (2017).

An interesting finding is the somewhat opposite opinions of the Bahamian public and key informants, who largely believed Abaco, Grand Bahama and New Providence to be the most vulnerable islands. Survey participants selected Mayaguana, Acklins and Crooked Island least frequently as most vulnerable. Reasons for selecting northern islands focused on the population size and development, believing that these islands generally have more to lose in the event of disaster. Responses also frequently referenced Dorian, which left the northern islands weakened and highly vulnerable to the next large stressor. These opinions align more closely with the results of the CVI social vulnerability category, where New Providence in particular out-ranked all islands in score and number of flags. This is surprising given that the social category had the lowest mean concern of the four categories, while environmental and remoteness instead had the highest mean scores. This would suggest an agreement with the CVI scoring of southern islands who had higher performances in these categories, however, as a majority of respondents and key informants noted they live in New Providence, their personal experience with the more populated northern islands may have influenced their opinion on the most vulnerable islands in The Bahamas

6.1.3: Public perceptions of vulnerability

While many islands received significantly more votes for climate-change stressors than future hurricanes when asked to select most vulnerable locations, the open-interpretation question responses suggest a very urgent concern about future hurricanes in the eyes of the Bahamian public. Key informants seemed to agree that a true understanding of climate change is missing from the average citizen, but a clear concern is present for potentially more catastrophic storms and disasters in the near future. Nearly all survey participants had experienced a hurricane in the last five years alone, and almost two thirds have previously suffered personal loss due to a storm. This past experience may mean they know what to expect with a storm, while climate impacts are less clear and familiar, making it worthy of concern to the sampled population and accounting for its larger mean number of votes.

6.2: Significance of results

As no previous research has assessed vulnerability at the inter-island level across multiple categories as in this investigation, the constructed CVI adds a new approach to vulnerability assessment in The Bahamas. Following applied methodology from Barbados carried out by Cumberbatch et al. (2020), the index is simple to interpret and can be updated with more recent data to provide improves its accuracy. Given the discrepancies between results and public opinion, it may be beneficial to consider heavier weighting of indicators considered most important to the investigation, as all 35 indicators described in Chapter 5 were weighted equally.

The factors of vulnerability described previously largely agree with the literature and research outlined in Chapter 2 and Chapter 3. Present in The Bahamas are all factors of vulnerability associated with SIDS according to Briguglio (1995): small size, remoteness and insularity, disaster proneness, environmental fragility, dependence on foreign finances and social demographics. Beyond these factors, the perceived influence of low elevation on SLR vulnerability aligns with Simpson et al. (2009), who noted a one-meter SLR is enough to submerge 10% of the Bahamian land area. References to shallow-water banks influencing storm surges also agree with the work done by Silver et al. (2019). Issues described with the country's population spread across a large area of ocean in small, remote communities echo the quote by the IDB in Chapter 3 (Deopersad, 2020). I had expectations for social aspects like age, health, education and home ownership to play a larger role as noted in Cumberbatch et al. (2020), however, these factors were largely unaddressed by survey participants and in interviews. Social factors also had the lowest mean score of influence on vulnerability, a surprising result given the amount of work focused in that particular area (Cumberbatch et al., 2020; Cutter et al., 2003; Flanagan et al., 2011; Neil Adger, 1999).

Perceptions of climate-change vulnerability according to Bahamian residents and citizens largely agree with the findings of Thomas and Benjamin (2017), who conducted a similar online survey to determine public perceptions of climate-change risk in The Bahamas in order to fill gaps in the research that would be beneficial for policy planners and climate-change communicators. They found that a majority of participants ranked SLR as the most concerning issue, yet did not fully recognize its consequences. This relates to a key point brought up in interviews: Bahamians are aware of climate change stressors but do not fully understand their true implications.

6.3: Limitations

There are a number of limitations to consider in the discussing the results of this investigation. Regarding the CVI, a major obstacle in its construction was the lack of reliable and accurate data at an inter-island scale. While data are relatively accessible to compare The Bahamas to other nations, standardized data representative of dynamics within each island group is limited beyond the Bahamas Census of Housing and Population. The proxy indicators used represent what was available for public-use and could be interpreted by myself as a general indicator of that vulnerability category. Many improvements could be made to the datasets sourced, which could therefore provide a more accurate and representative CVI for the islands of The Bahamas. This relates well to the lack of data availability as an underlying factor of vulnerability, as research towards accurately assessing susceptibility to hazards would help with disaster preparedness, planning and emergency situations. As noted again by the IDB:

> Although there are geographical databases of The Bahamas, they are not available for public use and not easily shared between State entities. For example, The Bahamas National Geographic Information System Centre (BNGIS), which is the technical agency specialized in the subject, does not have a web geoportal to upload the official geo-information of The Bahamas. Therefore, it can be challenging to search, find and download data to perform any analysis related to spatial planning or risk assessment (Deopersad, 2020, p. 161)

Data including elevation, coastal area, mangrove and reef area, international flights and distance from the capital were all extracted from indirect sources through GIS analyses and digitizing maps of previous research with different intended uses, which raises questions of validity in this new context. Having a reliable source of data for the different islands of The Bahamas would improve this investigation, as well as many other areas of future research.

The participants involved in the qualitative aspects of this research may also be considered a limiting factor. As mentioned in Chapter 4.3, the survey sample is not an accurate representation of the Bahamian population, and is instead a product of my own social connections and outreach. Using the ‘BEiNGS’ Facebook platform likely skewed overall concern and understanding of both climate change and hurricane vulnerability towards higher values. This was a limitation of the COVID-19 outbreak: in-person surveying could have provided a more representative sample of the population across The Bahamas. Additionally, while the key informants interviewed all have a high degree of credibility associated with their titles, all can be considered within a similar area of expertise regarding natural environments and climate. To broaden the backgrounds and understanding of vulnerability, future work could benefit from the involvement of informants in government positions, finances or social work. They could then speak more to the social and economic aspects of vulnerability in the country rather than be focused on ecosystems and physical geography.

6.4: Conclusion

In this thesis, I investigated vulnerability to climate-related stressors in The Bahamas. Using a mixed-methods approach, I came to an understanding of the fundamental factors of vulnerability in the country, which areas could be considered most vulnerable, and what some local perceptions of the topic are. While some issues are shared by many SIDS worldwide, the collection of factors discussed is unique to The Bahamas and contributes to its high ranking globally. Determining the most vulnerable parts of the country is dependent upon what aspect(s) of vulnerability are being considered, whether that be economic, environmental, social or remoteness. Finally, a consensus exists among Bahamians that the entire country is incredibly vulnerable to external stressors, and their impacts are growing in potential as climate conditions become ever more unstable and stray away from current regimes. This research may serve as a baseline assessment of the status of The Bahamas and highlights factors to consider in future decision-making processes. There is room to improve its effectiveness, as is the case for the country's resilience to external stressors through adaptation, mitigation and effective planning.

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APPENDIX A: Research Ethics Board Approval

McGill

Research Ethics Board Office
James Administration Bldg.
845 Sherbrooke Street West. Rm 325
Montreal, QC H3A 0G4

Website: www.mcgill.ca/research/research/compliance/human/

Research Ethics Board 1
Certificate of Ethical Acceptability of Research Involving Humans

REB File #: 20-10-004

Project Title: An Investigation of local vulnerability to climate-related coastal hazards in The Bahamas

Principal Investigator: Prof. Thomas Meredith

Department: Geography

Other Researchers: Brandon Taylor

Approval Period: **October 16, 2020 to October 15, 2021**

The REB-1 reviewed and approved this project by delegated review in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.

Deanna Collin, Senior Ethics Review Administrator

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* Approval is granted only for the research and purposes described.
* Modifications to the approved research must be reviewed and approved by the REB before they can be implemented.
* A Request for Renewal form must be submitted before the above expiry date. Research cannot be conducted without a current ethics approval. Submit 2-3 weeks ahead of the expiry date.
* When a project has been completed or terminated, a Study Closure form must be submitted.
* Unanticipated issues that may increase the risk level to participants or that may have other ethical implications must be promptly reported to the REB. Serious adverse events experienced by a participant in conjunction with the research must be reported to the REB without delay.
* The REB must be promptly notified of any new information that may affect the welfare or consent of participants.
* The REB must be notified of any suspension or cancellation imposed by a funding agency or regulatory body that is related to this study.
* The REB must be notified of any findings that may have ethical implications or may affect the decision of the REB.

APPENDIX B: Prompt questions for semi-structured interviews

1. Can you tell me a little about yourself? What is your job title or position? What fields does that cover/do you work in? How did you get to this point?

2. I've mentioned the term vulnerability quite a lot so far, what comes to mind for you when you think of the term? How would you define it? What direction are you approaching it from?

3. What aspects of a hurricane event in The Bahamas are the most concerning for Bahamians and the natural environment?

4. What aspects of climate change in The Bahamas are the most concerning for Bahamians and the natural environment?

5. What regions of The Bahamas, islands, communities and/or ecosystems come to mind as most vulnerable to a future hurricane?
    a. Vulnerable populations
    b. Vulnerable ecosystems
6. And also climate change?

7. What makes that location/ecosystems/population so vulnerable in your opinion?

8. In recent years we have seen multiple major hurricanes wreak havoc among Bahamians (Joaquin, Matthew, Irma, Dorian), are efforts to mitigate their impacts being actively carried out consistently, or are they instead in response to the aftermath of a storm?
    a. Regarding population or ecosystem

9. As mentioned, The Bahamas continuously ranks as one of the most vulnerable nations globally to the adverse effects of climate change stressors. What fundamental factors do you think explain this consistently high ranking on a global scale?

10. What aspects of the physical geography play the largest role in vulnerability to climate-related coastal stressors?

11. What aspects of the socio-economic structure play the largest role in vulnerability to climate related coastal stressors?

12. How do you think the Bahamian general public's perception of vulnerability is in comparison to the reality?
    a. Are the adverse impacts of these phenomena a concern for most Bahamians? Are they aware?
    b. Silent stressors that are lesser known/
13. What is the best plan of action in dealing with these issues in your opinion?

APPENDIX C: Online survey questions

1. Have you experienced a hurricane in The Bahamas before?
   - Yes
   - No

   (if yes, please specify where and when the most recent one was)

2. How concerned are you about the effects of a future hurricane in The Bahamas? (rate from 1-10: 1= not concerned at all; 10 = extremely worried)

3. Which island(s) do you believe are most vulnerable to future hurricanes? (list all options)
   a. Can you elaborate on why you chose that location?

4. How concerned are you about the effects of a climate change in The Bahamas? (rate from 1-10: 1= not concerned at all; 10 = extremely worried)

5. Which island(s) do you believe are most vulnerable to climate change stressors? (e.g. sea level rise, warming air and sea temperatures, reduced rainfall/water supply, erosion, etc.) (list all options)
   a. Can you elaborate on why you chose that location?

6. In your own words, what do you think is the largest factor contributing to vulnerability in the area you have identified?

7. Please indicate how important you think these factors are in determining the vulnerability of the entire country.

   i. Physical geography (amount of coastline, elevation above sea level, location in The Caribbean, etc.) (rank from 1-10: 1= not important at all; 10 = extremely important. Please add any additional information you think is important to this factor.

   ii. Socio-economics (wealth, health, population distribution, access to resources and services, communication, dependency on foreign imports, industry, etc.) (rate from 1-10: 1= not important at all; 10 = extremely important)
   Please add any additional information you think is important to this factor.

   iii. Other (please specify)

8. How would you rate the ability of the country as a whole to adapt to change, whether initiated by climate change, hurricanes or other external stressors? (rate from 1-10: 1= very poorly; 10= extremely well)
   a. Can you elaborate on why you gave this rating?

9. Which Bahamian ecosystem are you most concerned about regarding hurricane damage and/or climate change? Rank the following options from 1 (most vulnerable) to 5 (least vulnerable)

- Pine forests
- Coppice forests
- Mangroves/wetlands
- Coral reefs

Can you elaborate on why you chose that ecosystem?

10. Any general comments or opinions you would like to add?

Finally, to assist in our analysis, would you please let us know

11. Age
- 18-24
- 25-44
- 45-65
- 65+

12. Sex
- Male
- Female
- Other

13. Island you live on (list all options) OR
    a. Outside of The Bahamas

14. What is your job position/industry? (before Covid-19)

15. Have you, or a family member, experienced personal loss or injury as a result of a hurricane or climate change stressor?
- Yes
- No