EVALUATING THE IMPACTS OF SEA LEVEL RISE AND STORM SURGES ON SEYCHELLES' CRITICAL INFRASTRUCTURE

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Acknowledgements

This research would not have been possible without the assistance of various individuals and groups inside and outside the Seychelles. The researchers would like to say thank you to all of those who helped in assisting them in completing this project, and they would like to extend particular thanks to the following:

Avik Basu
Rojina Manandhar
Chad Tudenggongbu
Laura Kavanaugh
Michele Martin
Rowana Walton
Cynthia Adrienne
Justin Prosper
Seychelles Ministry of Environment, Energy, and Climate Change
University of Seychelles
Public Utilities Corporation
University of Michigan School for Environment and Sustainability (SEAS)
University of Michigan Rackham Graduate School
United Nations Framework Convention on Climate Change
And all individuals who were willing to be interviewed

Executive Summary

It is well known that low-lying coastal communities are particularly vulnerable to changes in sea level and storm surges. Nevertheless, specific impacts on particular geographies, namely the Indian Ocean region, remain unclear. The Seychelles, a small island developing state, is particularly vulnerable to these impacts. This project aims to narrow the existing knowledge gap on potential impacts of sea level rise and storm surges on critical infrastructure. To carry this out, a literature review was completed to understand the current state of critical infrastructure and adaptation in the Seychelles. Stakeholder interviews were conducted with government officials, local and international nongovernmental organizations, and private sector parties to understand the social, economic, and cultural importance and vulnerability of critical infrastructure. In addition, interviews assessed current adaptation strategies to protect this infrastructure and barriers to implementing those measures. Historical sea level data was combined with Geographic Information Systems (GIS) data to generate a hazard map illustrating the geographic distribution of sea level rise and storm surge impacts on the main island of Mahé. These maps, along with images and interview findings were compiled in an ESRI-hosted, interactive Story Map. The report concludes with a list of recommendations to better protect the Seychelles' critical infrastructure from sea level rise and storm surges. The final report will become part of the United Nations Framework Convention on Climate Change's (UNFCCC) Lima Adaptation Knowledge Initiative (LAKI) where it will serve to guide not only the Seychelles Government's approach to climate change adaptation but also other island nations facing similar climate risks.

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Acronym List

AHP = Analytic Hierarchy Process

CBA = Cost Benefit Analysis

EBA = Ecosystem Based Adaptation

ESRI = Environmental Systems Research Institute

DEM = Digital Elevation Model

GCCA+ = Global Climate Change Alliance+

GDP = Gross Domestic Product

GEF = Global Environment Facility

GIS = Geographic Information System

INDC = Intended Nationally Determined Contribution

IPCC = Intergovernmental Panel on Climate Change

IRB = Institutional Review Board

ITCZ = Inter Tropical Coververgence Zone

JICA = Japan International Cooperation Agency

LAKI = Lima Adaptation Knowledge Initiative

MEECC = Ministry of Environment, Energy, and Climate Change

MHILT = Ministry of Habitat Infrastructure and Land Transport

MHW = Mean High Water Level

NDC = Nationally Determined Contribution

NGO = Non-Governmental Organization

PCU = Programme Coordination Unit

PUC = Public Utilities Corporation

RCP = Representative Concentration Pathway

SEZ = Seychelles International Airport

SPA = Seychelles Port Authority

TWI = Topographic Wetness Index

UNFCCC = United Nations Framework Convention on Climate Change

Chapter 1

INTRODUCTION

For island nations, rising sea levels and more frequent extreme weather events resulting from climate change are a major concern (IPCC 2018; Hallegatte 2011). Because the Indian Ocean is warming at a faster rate than any other tropical ocean region (Roxy et al. 2014), island nations located there are increasingly at risk of these climate change impacts. The Seychelles archipelago, spanning 115 islands, is one such nation.

The archipelago's largest island, Mahé, contains over 90% of the country's infrastructure, more than 75% of the population, and serves as the primary driver of the Seychellois economy (Figure 1.1) (Chang Seng & Guillande 2008). This research focuses on assessing the risk posed by climate change to infrastructure in Mahé. Unlike many other islands in the Seychelles, Mahé is characterized by extreme changes in terrain and has a peak elevation of 905 m. Therefore, most of the infrastructure on the island is situated along the flat, narrow coastal plains that are vulnerable to damage from sea level rise and storm surge (Chang Seng & Guillande 2008). Guidelines for development in these areas is often lacking or poorly enforced (The Seychelles National Climate Change Committee 2009) and infrastructure has not been constructed to withstand severe natural disasters (Cheasty et al. 2017).

Figure 1.1: Victoria as seen from Copolia Trail

In order to help nations adapt to the impacts of climate change, the United Nations Framework Convention on Climate Change has developed a program called the Lima Adaptation Knowledge Initiative (LAKI). This initiative aims to narrow the existing knowledge gaps that are preventing the implementation and scaling up of climate adaptation (Lima Adaptation Knowledge Initiative 2016). Small island nations in the Indian Ocean subregion, such as the Seychelles, identified their top priority gap as *"insufficient information on the impacts of storm surges and other extreme events on coastal areas...and impacts on infrastructure, and drinking water supply"* and their third highest priority as *"insufficient information on the impacts of sea level rise on coastal areas...and impacts on infrastructure, and drinking water supply"* (Lima Adaptation Knowledge Initiative 2016). In line with the mission of the LAKI, this research aims to close the knowledge gaps regarding the impact of storm surges and sea level rise on the Seychelles' critical infrastructure.

Previous research for assessing sea level rise and storm surge impacts on infrastructure has focused on scoping stakeholder perspectives and hazard modeling (U.S. Department of Energy 2016). Scoping stakeholder perspectives is integral to a climate resilience assessment to improve the transparency of the assessment process and buy-in from relevant parties, understand local values, and inform desired outcomes. Therefore, semi-structured interviews with representatives in the Seychelles were conducted. Determining which areas and infrastructure types are most exposed and vulnerable to sea level rise and storm surges is necessary for prioritizing management efforts. Thus, modeling of sea level rise and storm surges was also conducted using data from a local tidal monitoring station and GIS data provided by the Seychelles government. This research was compiled in an ESRI story map in order to disseminate it to a broader audience in a narrative and visual format.

Chapter 2

LITERATURE REVIEW

A great deal of research has been published on the impacts of climate change on Seychelles' tourism, water resources, fisheries, agriculture, industry, human habitation, health, and coastal zones (The Seychelles National Climate Change Committee 2009). Although sea level rise, storm surges, and infrastructure are frequently mentioned, this information is dispersed throughout many different documents and organizations, and coherent research on these topics is lacking. Therefore, consolidating existing information on Seychelles' critical infrastructure, how sea level rise and storm surge has impacted them, and the strategies that have been employed to alleviate some of these impacts is a major step towards a clearer understanding of this situation and consequently properly managing it. While this literature review covered only a portion of the available information, synthesizing this information provided some background to guide this research (Appendix A).

2.1 Characteristics of Infrastructure in the Seychelles

Definitions of what is reported as critical infrastructure in the Seychelles varies. For example, the definition of critical infrastructure as stated by the Seychelles Intended Nationally Determined Contribution (INDC), the document countries submit to detail their intended contribution to achieve the goals set out in the Paris Climate Accord, is *"roads, ports, government buildings, electricity, water and sewerage management systems"* (Government of Seychelles 2015). However, this differs from other documentation such as the Seychelles Technology Needs Assessment Report-Adaptation where critical infrastructure was considered to be *"power stations and any power network over 25kV, trunk telecoms infrastructure, television and mobile phone masts, primary roads, reservoirs and high pressure water mains, oil terminals and associated pipeline, airports and offsite navigation aids"* (Government of Seychelles 2017a). This ambiguity of how critical infrastructure is defined sheds a light on the need for a more robust understanding of what pieces of infrastructure are most socially, culturally, and economically vital to the Seychelles.

Interviews with experts for the purpose of this analysis largely identified these same pieces listed above; however, various others were also identified as critical. Based upon these interviews, the researchers believe the definition of critical infrastructure should be expanded. For the purpose of this paper, critical infrastructure can be defined as *roads, ports (sea ports and airport), energy generation and distribution, water supply and distribution, sewage systems, agricultural land, economically vital infrastructure (i.e. those serving fisheries and tourism establishments), and government buildings, which include but are not limited to, food storage, public housing, educational institutions, medical facilities, and transportation hubs*. A more detailed description as to why these particular pieces of infrastructure were chosen as critical and the resulting interview findings can be found in Chapter 3.

Much of the infrastructure in the Seychelles is reaching capacity and unable to keep up with projected growth. To combat this, the Seychelles government has recently committed to investing $520 million in physical infrastructure and economic development projects (African Development

Bank 2015). Funding for these infrastructure projects is a major concern as a $215 million funding gap has been identified for completion of the desired projects (African Development Bank 2015). In addition, the total amount the Seychelles' Nationally Determined Contribution (NDC) allocates to infrastructure adaptation is $70 million, but costs of climate proofing this infrastructure could be several orders of magnitude more (Cheasty et al. 2017). Prior to funding these projects, it is important to take into account the characteristics of the specific types of infrastructure.

2.1.1 Roads

The Seychelles maintains a 508 km road network, the bulk of which is on Mahé (Figure 2.1). Between 2010 and 2015, vehicle ownership grew at 8.4%, compared to the population that grew at approximately 0.7%. Existing traffic volumes on roadways within Victoria range from 300 to over 900 vehicles per hour during peak periods. Furthermore, few roads cross Mahé given the terrain and steep elevation. The Seychelles' public bus system, a frequent user of the road network, is comprised of over 600 bus trips per day that services as many as 60,000 residents. Buses are accessible to the majority of the island's population, with most of the residents living within 10 to 15 minutes of a bus stop (African Development Bank 2015).

Figure 2.1: East Coast Road heading south from Victoria

2.1.2 Sea Port

The Seychelles Port Authority (SPA) oversees the Port of Victoria which is used primarily for fishing, imports, and exports. The Port of Victoria operates 365 days per year, 24 hours per day. The quay of Victoria was built in the 1970s and is 370 meters long. The port handled over 6 million tons of freight in 2011 (Figure 2.2). The port handles 80% of tuna from the nearby tuna processing plant with refrigerated units for export (African Development Bank 2015). In fact, Port Victoria is the principal tuna transshipment port in the region with around 80% of the tuna catch in the southwest Indian Ocean coming through the port (Jesús 2011). The SPA generated revenues of 27 million in Seychelles Rupee in 2011 (African Development Bank 2015).

Figure 2.2: Port Victoria with a cruise ship and freighter docked

2.1.3 Airport

The Seychelles International Airport at Mahé (SEZ)(Figure 2.3) was built in the 1970s. The average capacity of the terminal is estimated to be 1,000,000 passengers per year. The runway can accommodate at least 10 aircraft landings or take-offs per hour. Currently, the airport handles approximately 8,000 tons of cargo and close to 500,000 passengers annually. However, the airport faces a limitation in the number of peak passengers that can be handled. Between 2007 and 2011, traffic increased between 10-27%, while the number of domestic passengers declined (African Development Bank 2015).

Figure 2.3: Runway at Seychelles International Airport at Mahé

2.1.4 Energy Generation and Distribution

The country has a total of three power plants, two of which are located on Mahé and one on Praslin. Mahé's power plants operate on heavy fuel oil, while Praslin's plant uses light crude oil. Oil to power these facilities is imported and stored in the Seychelles Petroleum Depot. The total power generation capacity in the Seychelles is 79.3 MW, while the safe generation capacity is 53.4 MW (African Development Bank 2015). Transmission and distribution networks cover approximately 400 km and 97% of the households in the Seychelles are connected to electricity (World Bank 2019b). Recently the Seychelles has been attempting to expand their use of renewable energy (African Development Bank 2015). For this study's hazard analysis, energy generation and distribution infrastructure were comprised of electricity lines, fuel stations, power plants, and transformers.

Figure 2.4: Exposed pipes adjacent to Bel Ombre Road

2.1.5 Water Supply and Distribution

The Seychelles water infrastructure is managed by the Public Utilities Corporation (PUC). Water supply in the Seychelles is primarily from river sources, combined with groundwater extraction, and four desalination plants. The country's water system is comprised of about 600 km of pipes (Figure 2.4). Water storage is a challenge with droughts and increasing demand putting a strain on supplies. The water is stored and fed by 3 dams at La Gogue, Rochon, and Cascade (African Development

Bank 2015). For the hazard analysis, water supply and distribution infrastructure were comprised of dams, water pipes, pumping stations, pressure filter houses, and distribution houses.

2.1.6 Sewage System

Sewerage services are also managed by the PUC in the Seychelles. There are approximately 120 km of sewage pipes throughout Mahé. In the Seychelles there are also four sewage treatment plants located in Victoria, Beau Vallon, Point Larue, and Anse Aux Pins (Government of Seychelles 2013). For the sake of the hazard analysis sewage system infrastructure was comprised of dams, water pipes, pumping stations, pressure filter houses, and distribution houses.

2.1.7 Agricultural Land

There are approximately 400 farms comprising nearly 900 acres on Mahé. Agriculture comprises 3% of the Seychelles' GDP. Commonly grown foods include bananas, coconuts, and cassava (Seychelles Agricultural Agency 2011). Agricultural land cover data could not be obtained for this project and therefore could not be included in the hazard analysis.

2.1.8 Economically Vital Infrastructure

There are six ice plants on Mahé, producing an average of 35–40 tons of ice per day (Food and Agriculture Organization of the United Nations 2005). Due to the increase in fishing effort and the effect of large semi-industrial vessels entering the fishery (Figure 2.5), there is often a shortage of ice (Jesús 2011). Furthermore, a recorded 323 tourism establishments—hotels, bed and breakfasts, and self-catering facilities—are found throughout Mahé (Centre for GIS 2019). These tourism establishments were used in the hazard analysis to represent economically vital infrastructure.

Figure 2.5: Fishing vessel enters the Seychelles Fishing Port

2.1.9 Government Buildings

There are many types of government buildings throughout the Seychelles. Although the researchers' interviews resulted in government buildings to be considered food storage, public housing, educational institutions, medical facilities, and transportation hubs, data constraints required the researchers to supplement instead with police stations, bus terminals, schools, district administration buildings, fire stations, and medical facilities in the hazard analysis.

2.2 Climate Impacts on Seychelles' Infrastructure

There are many implications for the country with regard to the economic impacts of damaged infrastructure. The Seychelles benefits from a relatively high GDP due to profitable tourism and fishing industries (World Travel & Tourism Council 2017). However, these industries stand to be severely damaged by the negative impacts of climate change in part because of their reliance on critical infrastructure, such as roads and ports. Adverse economic impacts could also arise from a limited capacity to import food and energy, most of which come through the country's airports or seaports (Abdychev et al. 2017). Furthermore, the costs of natural disasters to the Seychellois economy is roughly 1% of GDP, or roughly $15 million (The World Bank Group 2019b), which is nearly double the cost to other Sub-Saharan African nations (Abdychev et al. 2017).

Rising sea level is already having some degree of impact on the Seychelles through flooding, inundation, coastal erosion, and increased salinization of the soil and aquifers (Cheasty et al. 2017). This encroachment of the sea has been gradual; however, impacts have already been notable such as in May 2007 when high tides combined with current sea level rise resulted in flooding as far as 50 meters inland, in turn, causing damage to public infrastructure, including roads (Cheasty et al. 2017). Storm surges cause extreme flooding and erosion of coastlines and poses considerable risk to the foundations and stability of coastal structures and transportation facilities (Rajan & Saud 2018). Presently, tropical cyclones reaching the Seychelles are rare and the Seychelles has little history of taking damage due to a storm surge event (JICA 2013). This is due to the Seychelles' close proximity to the equator, which means this region falls outside of the Inter Tropical Convergence Zone (ITCZ) that is known for prolific cyclones (The Seychelles National Climate Change Committee 2009). However, there are some indications that the ITCZ may be shifting its range further north as a result of climate change. This, in turn, could result in increased tropical storms and storm surges in the Seychelles in the future (Jean-Louis et al. 2011). Therefore, assessing the potential impacts of storm surges on the Seychelles' critical infrastructure is important in guiding adaptation plans.

Despite a historic lack of storm surges, the Seychelles is still vulnerable and has been affected by several natural disasters in recent decades (Khan & Amelie 2014). For example, the impacts from the notable 1997 and 2013 flooding events provide some insight into what natural disaster induced damage to the country's infrastructure can entail. In September 1997, the entire airfield of the Seychelles International Airport was flooded, causing the asphalt to lift from the sub-base and the new surfaces to crack. A total of 44 sites on the Seychelles' roads were damaged, requiring closure of the roads and long periods of time to clear and repair. Many of the country's water supply pipes were broken, and one reservoir even needed to be demolished and rebuilt. Also, electrical substations were flooded and power lines were brought down by landslides. Repairs took extensive time and exhausted the supplies of many of the country's maintenance stores (Chang Seng & Guillande 2008).

Intense rainfall in 2013 overwhelmed the Seychelles' drainage systems and retaining walls, resulting in floods, rockfalls, and landslides. Impacts to infrastructure were so extensive that it prompted the development of Seychelles' Damage Loss and Needs Assessment (Government of Seychelles 2013). The road network was again impacted by this flooding event, affecting approximately 18 km of road through stripping off of the asphalt, forming potholes, and damaging bridges, culverts, and retaining structures. Water treatment systems in Mahé were also impacted. Intake systems were blocked with soil and debris washed down by increased river flows, water quality at the treatment plants was significantly deteriorated, and filters were subjected to large amounts of muddy and turbid water. Furthermore, seven of the Seychelles' schools sustained an estimated $256,400 in damage mainly to science equipment, furniture, gutters, and building walls (Government of Seychelles 2013). These events indicate the Seychelles' infrastructure susceptibility to flooding and erosion which will increase as climate change increases the frequency of intensive rainfall events and natural disasters in the Seychelles (The Seychelles National Climate Change Committee 2009).

2.3 Current Adaptation Strategies

The Seychelles' has utilized several approaches to protect their infrastructure from the impacts of climate change including hard and soft engineering approaches, ecosystem-based adaptation (EBA), education and outreach, planning, and policy. Hard engineering approaches include highly visible, man-made structures, such as rock walls, retaining walls, and groynes. Soft engineering approaches utilize ecological practices and principles to cause less of a negative impact on the natural environment. Examples include timber piling and dune nourishment. Both approaches are utilized in Mahé with the intent to protect the coast by buffering waves and providing structure to the coastline. The Seychelles' sea walls have been constructed of stone, timber piling, and rock armoring. Sea walls made of stone were mostly constructed during the colonial era, are low in height, and currently compromised by wave action and, therefore, rarely used today. Timber piling has been a more recently utilized strategy, and it is often coupled with dune restoration and replanting of native coastal vegetation. The success rate for this type of strategy is inconsistent. Most of the recent reclamation work in Mahé has been equipped with rock armor sea walls. This method has proved to be useful in preventing coastal erosion; however, it is frequently considered an eyesore (Government of Seychelles 2017a). Retaining walls are 2m to 3m in height and can be seen throughout at Au Cap, North East Point, and the coral reef along the east coast of Mahé (Ministry of Home Affairs, Environment, Transport and Energy 2011). Groynes, which are long structures that run perpendicular to the shoreline and extend into the ocean, have been used extensively in the past to slow down coastal erosion. However, these structures have had negative impacts such as beach degradation, as areas down-drift become exposed to greater erosion. Groynes are often used to protect the ports in the Seychelles and have proven to be effective when designed to consider currents and allowing for sand movement (Government of Seychelles 2017a).

Ecosystem based adaptation (EBA) is another commonly implemented strategy for adapting to the impacts of climate change. For example, there have been several coral reef restoration projects in the Seychelles. Coral restoration often entails the utilization of species that are resistant to bleaching and is considered a promising technology by many stakeholders. There has also been wetland restoration work around Port Launay, Roche Caiman, and the freshwater marsh at North East Point. This work often entails the cleaning and replanting of mangrove areas. Dune restoration is another EBA strategy implemented on Mahé which has been done through replanting of natural vegetation and restricting vehicle access on the dunes (Government of Seychelles 2017a).

Education and outreach efforts are usually intended to educate the Seychellois public about climate change more broadly and, therefore, indirectly protects the country's infrastructure from sea level rise and storm surge. For example, Sustainability 4 Seychelles, a local NGO, has taken the lead on many of the country's environmental education and outreach efforts, including climate change, through hosting workshops and training programs (Sustainability for Seychelles n.d.). The Wildlife Clubs of Seychelles is another prominent environmental education organization in the country. This NGO focuses their efforts on engaging children and youth in the Seychelles and increasing their knowledge regarding biodiversity and conservation, often times incorporating climate change impacts into lessons and workshops (Wildlife Clubs of Seychelles n.d.). In addition, many television, radio, and newspaper items have been produced in recent decades to educate the public in the country about adapting to the impacts of climate change like water shortages, flooding, and drainage issues (Jean-Louis et al. 2011).

The Seychelles has three frequently listed strategic documents for guiding climate change planning: Seychelles Sustainable Development Strategy, Seychelles Climate Change Strategy, and The Environmental Management Plan of Seychelles (Khan & Amelie 2014; Jean-Louis et al. 2011; JICA 2013). Each of these documents describe the current state of affairs related to climate change, assess recent progress that has been made, establish climate change related priorities, and suggest future actions. Vulnerability to both sea level rise and storm surges are listed as concerns in the Seychelles Sustainable Development Strategy and Seychelles Climate Change Strategy while only sea level rise is mentioned in the Environmental Management Plan of Seychelles. In addition, there are several policies in the Seychelles that regulate coastal and flood management. For example, the Environment Protection Act (1992) allows the Ministry of Environment to designate a "coastal zone" which can then be regulated through preservation and conservation initiatives. In addition, flooding in the Seychelles is managed through the State Land & River Reserves Act (1903) which makes provision for a 10 m setback on both sides of rivers. Further, the Town & Country Planning Act (1972) has recently been under revision in order to incorporate a 25 m setback from high tide as well as increase standards for building codes and climate proofing. The Seychelles National Wetland Conservation and Management Policy (2005) attempts to conserve flood-reducing wetlands by establishing their presence and value through an environmental impact assessment process. However, these policies often serve as guidelines, and are not enforceable laws (JICA 2013; Government of Seychelles 2017). While the Seychelles strategic documents are reasonably comprehensive, implementation and enforcement of policies remains a concern.

Chapter 3

STAKEHOLDER INTERVIEWS

3.1 Background

Previous research on climate change in the Seychelles sought to identify which coastal adaptation strategies were most useful in protecting the nation's coasts, what some of the barriers in using those strategies were, and recommendations surrounding where the country should focus their efforts. The Seychelles' 2017 Technology Needs Assessment employed Likert scale questions with expert stakeholders to prioritize a set of coastal adaptation strategies which could be utilized to protect critical infrastructure such as roads, power stations, and food storage (Government of Seychelles 2017a). Of the eight identified strategies, mapping coastal zones using remote sensing received the highest priority and was followed by EBA strategies and sea-wall construction (Government of Seychelles 2017a). The research also identified a set of vulnerable regions in the country, but did not specify what infrastructure was located in these regions (Government of Seychelles 2017a). Finally, they assessed several barriers to adaptation, which included social (e.g. community engagement) and institutional (e.g. number of stakeholder agencies involved) barriers for each of the strategies. Sea-walls and other hard engineering techniques scored very poorly in terms of community engagement and enhancing governance (Government of Seychelles 2017a).

Building upon these findings, the Government of Seychelles Barrier Analysis & Enabling Framework (2017b) assessed the barriers to implementing various adaptation strategies in the country's coastal zone sector. Using stakeholder engagement and a review of national policy, the three main adaptation strategies identified were coastal mapping and monitoring, wetland restoration, and integrated coastal rehabilitation (Government of Seychelles 2017b). These strategies were being utilized to protect critical infrastructure. However, their characterization of critical infrastructure differed from the Seychelles INDC (2015). In particular, these discrepancies included additions of private and tourism-based infrastructure (Government of Seychelles 2017b). The study found adaptation barriers to include several categories: economic and financial, policy, institutional and coordination, information and awareness, and human capacity barriers (Government of Seychelles 2017b).

A review of national documents and conversations with the then Seychelles National Climate Change Committee yielded a set of recommendations for various sectors, notably fisheries, tourism, and infrastructure (Jean-Louis et al. 2011). For the two main economic sectors, the study recommended updated mapping technologies and increasing technical capacity of those in the sector. For infrastructure, the recommendations centered around better enforcement and implementation of laws surrounding land use planning and new developments (Jean-Louis et al. 2011). In addition, it underscored the challenges in adaptation stemming from gaps in funding, coordination, and knowledge among those in the country (Jean-Louis et al. 2011). While this analysis occurred in 2011, similar outcomes were reached from the country's 2018 Technology Action Plan which identified the need to increase education and outreach and increase enforcement of policies on climate related matters (Government of Seychelles 2018a). However, they also recognized the Seychelles as having various policies seeking to protect the environment, many of which are challenging to implement because of costs, reduced information capacity, and a host of legal challenges (Government of Seychelles 2018a).

An analysis which conducted 70 household surveys and 25 interviews discussed the perception of resilience versus vulnerability by those in the Seychelles (Philpot et al. 2015). The authors identified four categories—ecology, economy, society, and governance—that exemplified resilience (Philpot et. al. 2015). For instance, the governance structure was highlighted as being a resilient area because the small population allowed the government to consult with communities on many decisions. However, a tight knit community meant that there was a lack of enforcement of the laws because everyone knows people in the government (Philpot et al. 2015). Community interests also presented a challenge for the tourism industry because the interests of the two groups were often not aligned. While the tourism industry provides jobs and economic gain for the Seychelles, the reliance on tourism made the country more vulnerable to global economic changes that impact the number of tourists visiting the country (Philpot et al. 2015).

There appears to be a great deal of variability about how stakeholders characterize vulnerability and resiliency. Furthermore, none of these studies focus specifically on critical infrastructure in the country. Thus, this study aimed to better understand how stakeholders characterize "critical" infrastructure and its vulnerability. Instead of identifying specific adaptation strategies currently utilized to protect infrastructure, the researchers allowed interviewees to envision possible strategies and the barriers that might exist to implementing them.

3.2 Methods

3.2.1 Interview Questions

For stakeholder interviews, the researchers adapted a set of questions from a similar study done in Tanzania (Pilato et al. 2018). While there are large differences between Tanzania and Seychelles—including the size of the countries, livelihoods of those in the region, and the climatic challenges faced by each, among others—the questions employed by Pilato et al. are relevant to the Seychelles' context because they seek to better understand the role of the individual in their organization, the current strategies being employed by their group, and the importance of climate related challenges on livelihoods. These questions were used when speaking to various stakeholders in the island nation to better elucidate the state of adaptation of the Seychelles' critical infrastructure and their vulnerability to sea level rise and storm surges. The list of interview questions can be found in Appendix B.

3.2.1 Participants

To identify stakeholders, the research team consulted with the UNFCCC's LAKI team and the University of Seychelles for relevant contacts, which resulted in individuals at the Seychelles Ministry of Environment, Energy, and Climate Change (MEECC) and the Global Climate Change Alliance Plus Initiative (GCCA+).

The team then interviewed individuals from the Climate Change Division, Coastal Management Team, and policy analysts at MEECC, as well as a Seychellois educator who also serves as a consultant on the GCCA+ project. During interviews, researchers requested contact information for any other relevant stakeholders, leading to subsequent interviews with individuals from various sectors in the country. This "snowball" sampling technique was utilized until no new names were given, however, not all individuals mentioned were available for interviews. The final set of interviewees are listed in Table 3.1.

Semi-structured interviews were conducted with 31 individuals in October and November 2018. The majority were completed with only one individual, while others were conducted with two or more representatives from an organization. The majority were completed in person in the Seychelles between November 18th - 28th, 2018, while the rest were conducted via online video chat. Twenty of the 25 interviews were recorded, and following University of Michigan Institutional Review Board (IRB) approvals, files were sent to be transcribed by Rev.com and then stored securely in the University of Michigan's system. For the five interviews not recorded, detailed notes were taken by interviewers and compared to ensure consistency amongst reporting.

3.2.3 Interview coding

Using NVivo software, two members of the team coded the same interview and compared results to ensure intercoder reliability. From the resulting codes, themes were drawn (Table 2). Each time a code (e.g. roads or financial barriers) was mentioned, it was marked in the NVivo software. When drawing conclusions, the researchers compared findings between stakeholders to understand claims and their accuracy.

3.2.4 Limitations

One limitation of this study was its relatively small sample size. Local communities, particularly those on the coasts and where adaptation strategies have been employed, were notably underrepresented in the sample. Finally, the focus of this project is around Victoria; thus, the researchers likely have not adequately represented the needs and desires of those living in other areas of the island of Mahé.

Table 3.1: Individuals interviewed by the research team organized by organization, sector, and roles.

Agency / Organization	Division	Sector	Number of Interviewees (Female/Male)	Roles of Interviewees
Ministry of Environment, Energy, and Climate Change	Climate Change Division - Climate Adaptation and Management System	Government	4 (2/2)	Director-General, Senior Policy Analyst, Coastal Coordinator, Coastal Management Support Staff
Seychelles Planning Authority	N/A	Government	2 (0/2)	Chief Executive Officer, Consultant
Ministry of Habitat, Infrastructure, and Land Transport	Infrastructure Department, Centre for GIS	Government	4 (1/3)	Principal Secretary, Director for Design, GIS Specialists
University of Seychelles	Blue Economy Research Institute	Academia	3 (3/0)	Director, Senior Lecturer, Lecturer
Economic Planning Ministry		Government	1 (1/0)	Principal Secretary
Public Utilities Corporation	Energy, Water	Private	2 (0/2)	Engineer, Principal Engineer
Seychelles Port Authority	N/A	Government	1 (0/1)	Secretary
Local Environmental NGO	N/A	NGO	1 (1/0)	N/A
Mason's Travel	Public Relations, Branding, & Communications	Private	1 (1/0)	Manager
Programme Coordination Unit	N/A	NGO	3 (2/1)	Project Manager
Indian Ocean Tuna Ltd.	Environmental Health and Safety	Private	1 (0/1)	Manager
Seychelles Fishing Authority	Fisheries	Government	1 (0/1)	Chief Officer
Wildlife Club of Seychelles	N/A	NGO	1 (0/1)	Educator
Friends of Mont Buxton	N/A	Community	1 (1/0)	Chairperson
GCCA+	N/A	Private	1 (1/0)	Consultant
Independent Consultant	N/A	Private	1 (0/1)	Consultant
allspatial	N/A	Private	1 (0/1)	Consultant
Ministry of Local Government	Anse Aux Pins	Government	1 (0/1)	District Administrator
Seychelles Public Transport Corporation	Unknown	Private	1 (0/1)	Manager

3.3 Results

Stakeholder interviews highlighted a variety of vulnerable infrastructure, a few strategies for adaptation, and numerous barriers inhibiting their protection. Coding of the interviews led to the following categories: vulnerability, importance of infrastructure, adaptation strategies, barriers to adaptation, and other climate change effects (Table 3.2).

3.3.1 Importance and Vulnerability of Infrastructure

With regard to infrastructure, various pieces were highlighted as critical to the country's social, cultural, and economic well-being. Principal among these pieces was the ***road system***, which was mentioned by nearly 90% of interviewees. As the Director General of the Climate Change Division of the Ministry of Environment, Energy, and Climate Change remarked,

> *"Public coastal infrastructure, the coastal road and utilities, they all go around the island, and this is our main artery for all the residents … to go to work, to go to school, for all of our activities."*

Their importance is further recognized during times when they are most vulnerable. The Director continues on,

> *"[storm surges come] with waves over the top, crashing on the road, and this creates traffic congestion."*

These comments were reiterated by interviewees who intertwined discussions of ***social vulnerability*** with those of roads. Here social vulnerabilities are challenges that derive from the reliance on existing social, economic, and cultural frameworks of the Seychelles, and the inability to adapt to challenges which threaten these current frameworks (Dow 1992). In this context, the damage to a road would directly impede an individual's ability to access food, medical care, or their professions; thus, damage to roads would greatly impact their access to necessary services. A researcher at the University of Seychelles remarked,

> *"[The East Coast Road is] the only road. So if something happens to that road, I have no way of getting home…".* (Figure 3.1)

This is particularly challenging with the Seychelles Public Transit Corporation representative's claim that more than half the population uses the bus system daily. These discussions characterize the need to protect roads, and various other infrastructure, to protect the Seychellois.

Along with roads, ***seaports*** and ***airports*** were also frequently mentioned. A third of respondents mentioned both. As one University of Seychelles' faculty member explained,

> *"Where the generators are, obviously the port as well, the airport, all of that is on reclaimed land or adjacent to reclaimed land. It's just above sea level. That's quite vulnerable."*

Figure 3.1: East Coast Road south of Seychelles International Airport

This is particularly concerning because of the importance of these pieces of infrastructure to the country's economic and social well-being. Nearly all goods come through either the sea or airport, and many pieces of infrastructure that are critical to the fisheries and tourism industries are held there, including the tuna factory and ice plants, which are critical to the country's main export: tuna. If this infrastructure is damaged by rising sea level or storm surges, it will have significant implications for the economy. A similar economic challenge is faced by traditional fishing communities around the island.

While not traditionally making use of the port facilities, various communities around the island are vulnerable to sea level rise and storm surges. As one expert put it,

> *"Around Victoria there's a lot of ... fishing facilities in the port, but also there are a few other fishing areas around the three main islands that are kind of critical to the local economy even for the artisanal fisheries."*

The implications for the livelihood of Seychellois are also evident from the various mentions of ***housing*** vulnerability. Experts specifically named concerns about public assistance housing, elderly homes, and many private homes, as vast numbers of them are situated on the coasts and reclaimed lands, as are many of the tourism establishments.

Tourism infrastructure was also an area of concern for interviewees. Hotels, restaurants, and beaches lie almost entirely in low-lying coastal areas and are pivotal to the Seychelles' economy. As an individual from Mason's Travel explained,

> *"... there's a pizzeria called Baobab, for example, and there [have] been times when the waves have actually almost come into the restaurant."*

Such challenges are typical for many coastal tourism establishments.

Table 3.2: Interview themes and subthemes with numbers of mentions and interviewees mentioning, along with illustrative examples of each subtheme.

Theme	Subtheme	Number of Interviewees Mentioning	Number of Mentions	Example
Vulnerability and Importance of Critical Infrastructure	*Roads*	19	39	*"So I think obviously with the Seychelles, the first thing I think of are the roads...there's only one main road on each side of the island."*
	Social Vulnerability	12	42	*"[Fisherman] leave their boats by the sea, by the beach, and whenever [storm surges] happen, it impacts their livelihoods."*
	Seaports	9	17	*"For example, our fishing industry, that's also located by the coast: the tuna factory, the ice plants, the port. We have a major port here."*
	Utilities	8	18	*"It's the electricity because desalination will not work without electricity. Sewage treatment plants will not work without electricity."*
	Homes	8	10	*"And many people live right along the coastal strip."*
	Airport	7	10	*"[W]e are connected mostly via the airport internationally, and the airport is actually on the coastline, and it was flooded during the tsunami I think as well."*
	Ecological Assets	7	13	*"So if there is too much rock or seagrass, a lot of [hotels] will submit a request to remove this, but if you do this, it also increases your risk of erosion."*
	Tourism Infrastructure	7	9	*"I mean obviously tourism is the main pillar of the economy, and the majority of the tourism infrastructure, hotels and restaurants, they're all in that [coastal] area too."*
	Farming	7	9	*"Most of the farming is done on the lowlands, on the coastal areas, and it appears that more and more...well, as the sea level rises, the lowlands are becoming more and more salinated."*
	Food Storage	4	7	*"In terms of food storage, it's been pointed out for a long time that these sites are on the threat and could be impacted by climate change, but as of yet, I've seen no move to actually relocate these..."*
	Hospitals	3	5	*"[T]hey play a critical role into the social development, and a lot of the common infrastructures be it in your education, in your health sector, and also your road structure, they've been here for a long time and probably maintenance has not necessarily been high on the agenda…"*
	Schools	3	5	*"Well, we have schools, community centers, I mean all of those places, those gathering places."*
	Bus Terminal	1	1	*"When we had the tsunami in 2004, all this place got flooded, so even the bus terminal got affected and that's by the coast."*
	Government Buildings	1	1	*"The government administration is located in low-lying areas as well."*

Theme	Subtheme	Number of Interviewees Mentioning	Number of Mentions	Example
Barriers to Adaptation	*Lack of Action / Political Challenges*	22	121	*"None of us thought about sea-level rise, or your issue of storm surges or anything related to climate change. It didn't necessarily exist when we were planning for these infrastructures."*
	Information Capacity	22	82	*"But we're a small country. We have our human resource constraints. So maybe we could explore how to get that technical capacity or how to really actually disseminate that technical capacity once it's there so that other people can really understand the issues at hand."*
	Financial Capacity	21	60	*"But the government doesn't have money to build [another runway]. They're looking for funding from elsewhere."*
	Space Constraints	18	30	*"Yes, and then also you see, there's a conflict in space. We've got such small land and such a small land that can be developed and so many interests and uses."*
	Human Resource Capacity	14	36	*"We need to have a little bit more of local people to undertake. I believe some institutions are too diluted, they're doing so many things that they cannot really focus in a particular area."*
	Other Priorities	11	20	*"SUBIOS, conferences, Environment Day are days when climate change is discussed, then dies out, just as on January 1, Christmas day has died out."*
	Community Push Back	11	28	*"Maybe this property is for Mr. X. Mr. X can abstain, not giving your part of the road. Although you can propose compensation, he might say no."*
	Technological Needs	9	11	*"How easy is it to get that data to build into a design model. Sometimes we do not have that and we are just guessing. So if there is a possibility to do that remote sensing or mass surveying, that would help in the design, that would help us with our planning."*
	Aesthetics	3	3	*"[T]he thinking is it will help to accumulate sand. It's pretty ugly and we are seeing it more and more, and, you know, if the country is relying on tourism, it really diminishes the aesthetic appeal of these, of the beaches."*
	Timing	2	5	*"But it's also, we're trying to look for the quick fix because we are very reactive and people call and they're in trouble, and we need to sort something out very quickly. That's why there's a lot of hard engineering techniques that are taking place right now."*

Theme	Subtheme	Number of Interviewees Mentioning	Number of Mentions	Example
Adaptation Strategies	*Identifying and Securing Financing*	21	54	*"It is on everybody on the island. Government should give direction, steer, possibly put in some money and also try to motivate the private sector to participate and to contribute."*
	Education & Outreach	20	84	*"It's a little bit more than that, also in the sense that people still need to be sensitized about the effect of climate change because until we really understand that, and we really see the damage that can cause, then it's difficult for you to convince somebody that you really need to adapt, have some adaptation measures, or you really need to take that into account when doing construction of developing infrastructure."*
	Hard Engineering	19	60	*"But there've been a lot of manmade or artificial walls built to sort of prevent increased wave energy from destroying the infrastructure."*
	Ecosystem-Based Adaptation	17	62	*"[T]hey're, in coastal, in marine and terrestrial [systems], looking at ecosystem-based adaptation approaches, doing a lot of invasive species removal and planting and engineering of streams and culverts to prevent flooding. There's also been some coral restoration under that project as well."*
	Policy Changes	15	45	*"Nationally I think what we need is for everyone to actually sit down and to come up with a real national strategy as to say, 'Yes, agriculture is doing this, fishery is doing that.", and the way you do NDS, National Development Strategy, the way you do your stakeholder consultation is important."*
	Land Use Planning	11	23	*"Well, I think they need to move a little bit faster with the planning guidelines for sure. To be able to, ya know, limit development on the coast or insist that they're designed with certain features in mind…"*
	Raising Infrastructure	9	14	*"Well with housing, it's raising of the plane, so if you do have flooding, the buildings will not be flooded."*
	Relocation	9	16	*"We may do some proposal as well to whereby we can shift certain essential buildings [and] avoid big impact when calamity comes."*
	Altering Landscapes	5	8	*"I know there has to be a balance, like land reclamation I suppose is part of that. It's creating space for people."*
	Repurposing Infrastructure	1	1	*"Okay I'll give an example. Instead of planting crops, which they did, they go for chicken farming."*
Who Drives Adaptation?	*N/A*	22	49	*"Well I think the different actions can be owned by different departments, and some can be done as partnerships with the private sector as well."*
Other Climate Change Effects	*N/A*	15	30	*"With climate change, as we have been noticing that either the rainy period is longer or, what do you call it, the drought period is longer. We are already noticing change with the various seasons, our seasons, our kind of seasons changing like this year."*

A quarter of stakeholders mentioned the vulnerability of ***utilities***—water, energy, and waste. As a researcher from the University of Seychelles explained,

> *"I don't know what the percentage is, PUC would be able to tell you, it must be about 90% of the energy of the Seychelles that is used comes from those generators. Without that, there would be no power here."*

This discussion characterizes the social vulnerability inherent in damage to these pieces, or the challenges any damage to them would pose in allowing local Seychellois to access vital services which rely on electricity. Similar sentiments were shared when talking about water and waste. As the Seychelles Planning Authority explained,

> *"For example, at the Northeast Point sea level rise could damage water distribution pipelines because it's under the road…And this road will likely be underwater in the next 50 years."*

This is not only relevant to water distribution systems, as energy and waste ***distribution systems*** are often beneath roads as well. Regarding waste, a member of Ministry of Habitat, Infrastructure, and Land Transport (MHILT) explained,

> *"[W]e do not have municipal sewer in a lot of the place, so you do have a lot of the plateau areas where we are using septic tanks. So definitely when you have flooding, you have contamination and risk from that."*

Similarly, interviewees expressed concern about ***storage facilities*** such as waste, fuel, and water storage facilities that are often located at vulnerable, low-lying coastal regions.

3.3.2 Barriers to Adaptation

Based on the interviews, current barriers to adaptation include financial barriers, a lack of political action, and information capacity. Most interviewees discussed space constraints, human resource capacity, competing priorities, and community pushback. Less commonly mentioned were technological needs, aesthetic challenges, and timing. Each of these subthemes is explored in greater detail below.

Of the 25 interviews conducted, 22 mentioned a ***lack of action or political issues*** as a barrier to adaptation; one portion of this barrier stems from a lack of coordination in adapting critical infrastructure to sea level rise and storm surges. The Chief Executive Officer from the Seychelles Planning Authority explained,

> *"A lot of friendly people like you have come and have discussed, but when it comes to implementing, like for instance we have JICA [Japan International Cooperation Agency] that came in to study of our coast, and we are implementing it like a teaspoon of sugar."*

This failure to implement the plans of those coming to the island is more often described as a failure of those coming to do research, however. A member of the University of Seychelles' Blue Economy Research Institute explained, *"[A] consultant comes in and gives us a plan, and then they leave, and then I'm stuck with a plan. Well what do I do with this?"*

The lack of coordination can be seen when focusing on the relationship between consultants and the government, but it is also illustrated through the government's internal interactions.

A ***lack of coordination*** amongst agencies to make climate change adaptation work hand in hand with development also seems to contribute to inaction. A member of the Ministry of Energy, Environment and Climate Change put it best when they said:

"*We are encouraging that climate change become central to our development plans, it's climate change proof, but in addition to that, maybe it should be extended. We should be looking at adaptation measures and mitigation measures being across the board rather than just being seen as something for the Ministry of Energy, Environment and Climate Change to handle.*"

There seems to be a larger concern around the inability to access information. Two members of the MHILT's Centre for GIS specifically mentioned the lack of data sharing amongst agencies, in turn, increasing the challenges associated with accessing the work of consultants. As a result, many projects are often reproduced. However, data sharing is only one portion of the current lack of action.

While experts mentioned a general understanding of climate change in the country, this did not always materialize into actions, which was often ascribed to oversight by those with jurisdiction. One member of the Programme Coordination Unit (PCU) explained,

"No one's doing anything about [roads] because land transport will tell you I take care of the road. When my road gets damaged, I fix my road. I'm not going to move it because you're saying climate change or whatever."

Another member of a local NGO explained,

"We've had a climate change strategy since 2009...However, there are lots of things in there that we have implemented, and I think the biggest issue is that there is not a coordinated approach to it."

Both of these quotes characterize the lack of action on climate adaptation stemming from the government, yet this may also be a result of the oversight coming down from the political system in place. A researcher at the University of Seychelles explained,

"I think the practicality of getting buy-in, and also because the political situation, having to do things quickly that are making a difference and that are being seen as making a difference."

An economic minister continued on,

"The political set of Seychelles, we're a very small population, and we go to election every five years. Everybody wants to do tangible things so when you next go to election, you will be reelected and climate change you do not see that much."

On short election cycles and with continual changes in government ministers, there seems to be a ***lack of prioritization*** of climate change action that has driven some of the barriers to adaptation; however, there is also a perceived lack of information in the country.

Lacking ***information capacity*** was identified as a challenge for adapting critical infrastructure to sea level rise and storm surges in 22 of 25 interviews. As the Seychelles Planning Authority explained,

"We need a lot of people in the field of research to provide that data so that we can then…make decisions, effective decisions based on data."

It is not only the government who makes note of these challenges, as one consultant used more specific examples saying,

"Yeah in terms of knowledge gaps there is quite a lot. I would say on how do we deal with climate change, possible impacts in terms of the port environment or airport environment, or our food security. I would say there is a major gap in knowledge and technology."

Knowledge gaps often coincided with reduced decision making, and participants regularly associated this with the lack of sharing the knowledge between agencies. However, even if information were available, it is unclear the country would have the funds to enact the necessary adaptation strategies.

Mentioned in 21 out of 25 interviews, ***financial barriers*** were a concern in adapting vulnerable infrastructure to sea level rise and storm surges. This lack of finances was presented as a fear of losing international financing that the country relies on to implement adaptation strategies to protect critical infrastructure. As one consultant told the researchers,

"We have increasingly limited access to grants or to… funds to be able to help us, or preferential loans because Seychelles is being classified as a high income country now. It doesn't really reflect the reality. So they have a limited pool of finance options compared to some other small island states that are poorer."

The high-income classification here refers to the country's place on the World Bank's Income Level Indicators, where the Seychelles moved into the highest income category in 2015 (Amla 2015). This challenge was referenced by numerous parties as a major point of fear about the future of funding for adaptation, one NGO explained,

"We are only considered high income because we're compared to Africa, the mainland continent and whatever, but...It's only the economics, calculations. A lot of the interventions that's been done here, were done as a result of donor funded projects so if that's taken away, the government would struggle."

Yet, most of these mentions came in conjunction with the issue of major reductions in national budget allocations for climate adaptation on the coasts.

For government, academic, and NGO stakeholders, funding challenges involved discussion of the reduction in government budgets allocated to addressing climate change. In fact, it often is presented as perpetuating the reliance on international funding mechanisms as one NGO explained,

> *"We have seen also that the budget for environment has reduced over the years. One reason for that is they rely on grants and donor funds."*

Another individual from Indian Ocean Tuna, Ltd. mentioned that this financing barrier must be overcome by placing a higher priority on adaptation projects, but government actions seem to come in direct opposition to this. Members of the MEECC informed us that their budget had been cut from over $5 million a few years ago to a current $1.6 million, where one project alone costs nearly $1.5 million. This helps explain the Director-General of the MEECC's insight,

> *"Because right now I have, as you can see, about $30 million of adaptation projects, but it's dead. No funding."*

However, it also seems this lack of priority funding links back directly to the political constraints and the country's place among the high-income countries.

The country's priority setting has helped address the everyday social problems affecting its citizens; however, this often means fewer resources for adaptation. As one member of the MEECC put it,

> *"[I]f we were to try to fund all of our adaptation projects by ourselves, it just could not happen because we have to fund everything else...education which is free, health which is free, and the cost of transportation which is 7 rupees which is nothing…"*

One consultant characterized the need for a change in decision structure as,

> *"So if we act now, spend the money now, and we fix our roads, plan ahead for the future, then, you know, we're going to save money down the road."*

However, she went on to recognize,

> *"So, those people that are in those positions, they don't have access to that kind of information to guide their decisions."*

Thus, it seems the financial barriers coincide with barriers of action and knowledge, yet regardless of these barriers, there are a host of challenges associated with being a small-island developing state.

The very ***mountainous terrain*** of Mahé (Figure 3.2) causes problems with constructing infrastructure outside of the low-lying coastal zones. This is evident in discussions with stakeholders, as it was mentioned by individuals from every sector. A researcher from the University of Seychelles characterized the issue when she explained,

> *"So yeah I think the infrastructure is quite vulnerable and also the houses from flooding. Where do people go? Cause we can't move higher because the forests are and there and the granite's quite hard to build on."*

Similar sentiments were illustrated by individuals discussing roads, energy distribution, and infrastructure associated with tourism and fisheries. Not only is there a lack of space, there also seems to be a limited number of individuals in the country who can devote time to these issues.

Figure 3.2: Terrain of Mahé as seen from the eastern side of Victoria

The issue of ***human resource capacity*** is another example of a two-fold challenge, one relating directly to a limited number of people living in the country and the second being a perceived lack of commitment to professions which seek to address climate change. The former challenge was mentioned by all members of the government who were interviewed, and it was ascribed not only to a lack of people with the understanding to implement projects, but also a lack of staff to support them in implementing their expertise. As a member of the MEECC put it,

> *"The problem is, sometimes we have individuals that are trained in, for example, adaptation, but they don't have the necessary support, as in people power to help them with their projects. So they end up working alone…"*

She continues on to explain that this leads to projects not getting the necessary follow-up. Nonetheless, these challenges seem to be exacerbated by the lack of commitment shown by employees in the country, which was often ascribed to young Seychellois. Mentioned by both the private sector and government individuals, it was framed as a reluctance to work and a desire to quickly reach great positions. In terms of the latter, the Director-General at the MEECC explained,

> *"[N]owadays, the young generation, they are on a mission. As soon as they leave school, they want to go on the super highway."*

This desire for success translates into continued staff turnover and the loss of talented people in the government, but a host of challenges associated with getting the community on board with adaptation also exists.

Mentioned in nearly half of the interviews conducted, the ***pushback from communities*** is an additional barrier to adaptation. Some interviewees mentioned the cultural elements of those on the island being a large barrier. For instance, the MEECC placed bollards on the road to stop people from driving on the beach, but when originally announced it was met with strong opposition from those in the community who spent their weekends on the beach. Nonetheless, the strategy was implemented and has seen success. However, a larger challenge comes when the government attempts to move infrastructure such as roads. As a minister of local government explained,

> *"Maybe this property is for Mr. X. Mr. X can abstain, not giving you part of the road. Although you can propose compensation, he might say no."*

This pushback on providing land to move infrastructure was mentioned by two government officials, one researcher, and a member of the Public Utilities Corporation. These "not in my backyard" type interactions are challenging, but even if they were to be solved, it seems there is a challenge in the technology available to the country.

The ***technological challenges*** discussed were strongly linked to those of human resource capacity. As one community group representative explained,

> *"There is a lack of technical capacity in the area of climate change itself. We have to consult out the work, bring in experts from outside the Seychelles to get the work done."*

This outsourcing has led to some challenges, including an inability to make decisions without sufficient mapping and survey data.

3.3.3 Adaptation Strategies

Of the 25 interviews conducted, 21 presented a strategy involving ***finding financing*** for adaptation strategies. These financing strategies can be characterized as partnerships, tapping into international funding mechanisms, and monetizing the country's natural resources. In regard to partnerships, stakeholders referred mainly to finding financial agreements between the Seychelles government and the private sector. As one consultant explained, *"[I]t should be both government and private [sector] because the private sector, they also have a lot to lose if these strategies are not implemented...Government should give direction, steer, possibly put in some money and also try to motivate the private sector to participate, to contribute."*

This same sentiment was reiterated by others who tapped into the importance of tourism for all of those in the country and the power in trying to use this framing to increase partnerships with private sector groups. These partnerships were also mentioned by tourism and fishing industries (Figure 3.3), who discussed strategies they themselves already instituted, including the Sustainable Tourism Label. However, it was also common for these mentions to come with the recognition that these partnerships are not the only funding strategy utilized.

There was also an expressed need to finding financing in the international community. As members of the PCU explained,

"*They can do something nationally, but I think internationally in terms of foreign affairs, they need to start, I don't know, lobbying because statistically [we are] going back to the higher income..."*

The need is furthered by the Director-General of MEECC noting that the country

"depends very much on external funding…"

However, the country has found success in finding international funding. Frequently mentioned examples were funding from the European Union, Global Environment Fund, and Japanese government for adaptation. Though this funding is available and has been employed in the past, there is a need for staff focused on identifying, securing, and monitoring it.

The Seychelles has long utilized its land and resources to better its economic standing, and many stakeholders expressed the need for similar methods to secure additional funding for adaptation. One member of the PCU expressed that the country has been a place for organizations to try out new approaches, explaining,

"I think that something they've done also is that...because Seychelles, we're quite good with innovative ideas and implementing things on the small scales, so they always kind of...not always, but they tend to us Seychelles as… 'Let's try [this there]'."

In a similar vein, the Indian Ocean Tuna Ltd. representative mentioned that the Blue Economy can be a selling point in the international market. This focus on the blue economy is also prevalent in their continued research on coral restoration and using biodiversity to increase their economic standing internationally. However, just as this took immense education and outreach inside and outside the country, the adaptation strategies mentioned by nearly all stakeholders also called for educational campaigns.

The discussion of ***education and outreach*** to characterize the impacts of sea level rise and storm surges on critical infrastructure was present in 20 of 25 interviews. This can be further broken down into the need for education among government agencies and the general public. In terms of the latter, more than half of mentions referred to education occurring, or needing to occur, in schools. As members of the Planning Authority explained,

> *"And education, in our schools, it's the future generation that needs to be more prepared."*

However, it was recognized that this must also occur outside the classroom. One researcher at the University of Seychelles remarked,

> *"And I think in terms of climate change, the challenge is people know it, but they don't understand it. You know people talk about it all the time on the news, people talk about it in the newspaper, 'But what does it actually mean to me? And I don't know if I can really have an impact. It's the government's job.'"*

Several strategies were suggested to overcome this barrier including a local government official's suggestion to utilize the television and radio to explain the benefits of protecting critical infrastructure for all and the need to do so now.

The need for education and outreach around climate adaptation for critical infrastructure with those in the government is often intertwined with justifying the increasing costs of projects and resetting the priorities of those currently in decision-making positions. A member of MHILT remarked that data should come from respected international agencies so that,

> *"when we build it in, there is more acceptance on the costing and the justification of the results."*

Moreover, a member of the PCU recognized,

> *"We stay in our little bubble instead of trying to custom fit the final product to policy makers, to people, the everyday person…"*

There was both a lack of trust in data created in the country and a failure of data to be communicated in a way that makes sense to those in decision making roles. Similar points were made about doing outreach into the international community to share out and receive additional data for decision making processes.

In terms of currently employed adaptation strategies, ***hard engineering techniques*** were mentioned in 19 of the 25 interviews. Among the 60 mentions of a hard engineering solution, more than 40 referenced rock armoring, bollards, and groynes. As a member of the MEECC explained, *"The [adaptation strategies] we do have, we are following a lot of hard engineering techniques. So we have groynes, sea walls, rock armoring--a lot of rock armoring, especially."*

Images of the latter can be seen in Figure 3.1. These strategies were explained as being heavily utilized as "quick-fix" solutions when people are in trouble. This ties into the need for immediate progress faced by politicians and government agencies. This is why ecosystem-based adaptations have been a challenge.

Figure 3.3: Rock Armoring found along Anse A La Mouche. (Reguero et al. 2018)

Referenced across 17 interviews by representatives from all sectors, stakeholders often mentioned the importance of ***ecosystem-based adaptation*** because the country's economic standing and culture is centered around its surroundings. As one local consultant put it,

"I would say there is some adaptation happening but as Seychelles is a small country which is highly dependent on the quality of its environment for both the tourism and fisheries industry, I would say ecosystem-based adaptation is getting the priority."

He then continued on to mention,

"But the government also does understand that ecosystem-based adaptations have limitations."

Nonetheless, interviewees called upon several specific strategies which they understood were being implemented and believed should continue. These included coral restoration, and using sea grasses and other vegetation to reduce erosion and increase water uptake by the land. However, with the realization of the slow progress of such approaches, there was recognition for it to go hand-in-hand with new policies for adaptation.

The focus on ***policies*** across the 15 interviews in which it was referenced can be sorted into two categories; first, the need to mainstream climate adaptation across all ministries and the second, the need for stronger enforcement of current and new policies. Regarding the former, individuals in the academic and NGO sectors made note of a new GCCA+ report that suggested climate change be included in all ministries and there be a stronger focus on it. A member of the PCU even alluded to the success of this recommendation, explaining,

> *"Now even Economic Planning, which is part of the Ministry of Finance, has...they call it Vision 2033...And they recorded climate change as one of the issues and they're trying to integrate it into fisheries, into agriculture, into education, health."*

This success was recognized by those in the government as well. The representative from the Economic Planning Ministry specifically said,

> *"I think it's the notion that whatever policies we come up with now, or the plans we come up with now, it has to be climate-proof. We need to have that as a central part in it."*

However, the mention of current policies, particularly those dealing with where buildings can be placed and their required protections, was almost always accompanied with a discussion of the currently insufficient accountability. As one local NGO put it,

> *"Well, there's talk of developing this climate change adaptation policy, but it's still in the development, and the old climate change strategy, as I said, hasn't been implemented as such."*

This was a sentiment among many groups outside of the government. However, the government representatives focused their discussions of new policies heavily around land use planning.

Inside the government, there was a recognition of the work being done to ensure ***land use planning*** incorporates climate change, but several stakeholders outside the government focused on the government's lack of planning as a challenge for climate adaptation. Government representatives mentioned their current work on raising the required level of buildings, increasing the coastal setback policy, and creating and managing reclaimed lands. A member of MEECC explained the current workings to the researchers,

> *"Well we have the coastal management plan that is being formulated in...alongside the coastal setback policy, and that's supposed to mitigate the effects of natural hazards on the coastal infrastructure and the people and their livelihoods by protecting them from it."*

However, these policies seem unknown or less hopeful for those outside the government. Members of each of the other stakeholder groups claimed a lack of coordination among ministries, a lack of urgency, and failure to incorporate data and community consultation into decision making when it comes to land use planning.

A strategy mentioned in 9 of the 25 interviews detailed ***raising infrastructure***, and much of which focused on reclaimed land. The country has utilized reclaimed land off the main island to create more space to fit a growing population, and as one interviewee underscored,

> *"I think that new reclamation already offers an advantage in [that] the level is a little bit higher than the coastline. So maybe concentrating more of the new developments on that area could be a strategy, but again, it depends on what the forecast is."*

These reclamations were noted by both MHILT and the Planning Authority, which deserves mention because they hold jurisdiction over planning decisions for critical infrastructure. A member of MEECC explained that they were placing recommendations around raising infrastructure in their new plans. This has already been heeded by some ministries, notably the Seychelles Port Authority's extension of the port which will be built at a higher level to accommodate a rising sea level. Yet, there are also aesthetic and usage challenges associated with raising this infrastructure, just as there are with relocating infrastructure.

Mentions of ***relocating infrastructure*** predominately involved moving roads. Although every stakeholder group recognized the importance and vulnerability of the roads, several people illustrated the challenges in implementing this strategy. As the representatives from MHILT explained,

> *"It is very difficult, not just topography, land tenure as well. You have a lot of strips which are private and cut up inland. So shifting roads is difficult, and the terrain is difficult as [you] go further up."*

Yet, the challenges of land tenure may be an extension of the current issues around who drives adaptation in the country.

3.3.4 Who Drives Adaptation

Questions surrounding who was responsible for adaptation yielded almost across the board mention of the ***MEECC***; however, there was also continued expression of the need for ***more partnerships*** in this area. As one consultant explained it,

> *"And that little division, the Climate Change Division (of MEECC), ya know, the ones that deal with...Selvan Pillay's division, I mean most of this stuff falls on their shoulders. They're the ones who would be identifying the problems, hearing it from the districts, and suggesting solutions."*

More specifically, the Coastal Adaptation and Management System (CAMS) was the most common answer. However, members of this division did explain that the strategies they implement are a result of consultations with or calls from local communities. The director-general explained,

> *"[E]ach and every project we do communicate with [the local government]."*

This local community engagement is certainly necessary. Nonetheless, there is room and a need for greater partnerships with others in the country.

When the question of who drives adaptation strategies was asked of private sector companies, namely that of the Indian Ocean Tuna, Ltd. and Mason's Travel, their responses focused on their actions as private sector groups and the need for a more ***collaborative approach*** to protecting critical infrastructure from sea level rise and storm surges (Figure 3.4). The representative from the latter group detailed a project they had implemented on an island the group owned, and then explained how, while the government should be responsible, if actions require large investments, there may not be enough funding for the government to implement any strategy.

Figure 3.4: Wastewater Treatment Plant sponsored by Indian Ocean Tuna, Ltd., a company the Seychelles Government owns 40% of the company's operation in the country (Government of Seychelles 2018b)

In addition to private sector partnerships, the need for more cross cutting government actions was also mentioned by several government stakeholders. As the representative from the Economic Planning Ministry explained,

> *"I think the adaptation measures should be across the board, all the ministries, departments and agencies need to identify themselves and see themselves in there and recognize that in their own ways for the specific sectors, they also need to drive adaptation measures."*

Yet, one NGO in the country explained the arguments between which agencies should cover the problem, and continued to explain how it gets settled,

> *"And I guess because there is this department called Climate Change, that climate change is in its name, everybody wants to say, 'Okay, you're the people.'"*

However, there are challenges in this structure which are furthered by other effects of climate change that people are concerned with.

3.3.5 Other Climate Change Effects

While the focus of this analysis is on analyzing the vulnerability of critical infrastructure to sea level rise and storm surges, it serves to mention that more than half of the interviews also discussed other impacts of climate change in the country. Individuals from both the community and MEECC expressed concern about the ***changing weather patterns*** and the ***health impacts*** associated with this change and, more generally, a changing climate. In line with this, members of three government agencies also expressed concerns with the landslides that have been occurring with heavy rains and their impacts on those living on steep inclines. Not only were challenges mentioned, there were also a variety of discussions around the country's solutions to ***mitigation of greenhouse gas emissions***. The discussion of emissions reduction greatly focused on increasing solar energy throughout the island to reduce the reliance on energy production occurring on the coasts.

Chapter 4

HAZARD ANALYSIS

4.1 Background

Reviews of different global sea level rise scenarios often predict sea level rise in the range of 0.5 m to 1.5 m over the next 100 years (Church et al. 2013; Horton et al. 2014; Rosencranz et al. 2018). Some studies, however, have also made predictions of sea level rise as high as 2 to 3 meters, though these are considered extreme scenarios (Horton et al. 2014; Iwamura et al. 2013). Previous research in the Seychelles has utilized global assessments of sea level rise in their analysis (Mendez et al. 2013). However, sea level rise estimates vary widely across the globe and these predictions are far less specific to the archipelago (Nicholls & Cazenave 2010). Therefore, the researchers believe it is important to utilize local data when making sea level rise predictions. Previous studies of sea level rise in the Seychelles have used local sea level monitoring data in their assessment. For example, Chang-Seng (2007 as cited in The Seychelles National Climate Change Committee 2009) suggested an increase of 1.46 mm ± 2.11 mm rise per year from data collected between 1950 and 2001, Church (2006 as cited in The Seychelles National Climate Change Committee 2009) estimated rise would be 0.5 mm ± 0.5 mm from data collected between 1950 and 2001, and Ragoonaden (2006 as cited in The Seychelles National Climate Change Committee 2009) predicted an annual rise of 1.69 mm at Point La Rue between 1993 and 2004. However, these studies utilized sea level data from 2001 and in just the next four years, these projections were exceeded by 10 cm in five separate instances, which, in conjunction with extreme weather events, caused considerable damage to coastal infrastructure (The Seychelles National Climate Change Committee 2009).

Because of a historic lack of storm surges in the Seychelles, minimal modeling for this type of natural disaster has been done. However, one previous study still modeled a hypothetical storm surge in the Seychelles by estimating wave height using local meteorological data such as inverse barometric effect, average bathymetry, cyclone average maximum wind speed, and extreme astronomical tides (Chang-Seng 2008). In turn, the wave height for a hypothetical storm surge in the Seychelles was estimated to fall in the range of 0.4 to 2.8 meters.

Broadly speaking, there are two main types of models that are often used for predictive analysis: data-driven models and process-based models. Data-driven models build predictive equations based on trends in existing data but are ineffective at explaining the underlying mechanisms which create those trends (in this case, climate change). As such, their predictions may be thrown off if an outside driving mechanism suddenly changes (e.g. global greenhouse gas emissions drastically change or ice sheets melt at a faster rate). In contrast, process-based models create predictions based on *a priori* knowledge of the underlying mechanisms which may affect the variable of interest, though they may be calibrated with existing data. However, because it is impossible to consider or gather data for every possible factor which may influence the variable of interest, these models can fail to reflect reality. The aforementioned global sea level rise assessments and storm surge models have typically been process-based while the local sea level rise assessments have typically been done using data-driven models. Both of these types of models have been utilized in some capacity in this report's analysis.

4.2 Methods

4.2.1 Modeling Sea Level Rise

To identify exposed critical infrastructure, an analysis was conducted to predict sea level rise surrounding the main island of Mahé utilizing daily sea level reports from the Pointe La Rue monitoring station (Figure 4.1). This daily data, covering a 24-year period from 1993 to 2017, was made available from the University of Hawaii Sea Level Center (Caldwell et al. 2015).

Using the daily sea level data, the researchers constructed two data-driven models to predict the change in sea level by 2120: one linear and one exponential. The first predictive model is based on a linear regression of the past sea level data and assumes a constant rate of sea level rise. The results of this linear model are the basis of the 'constant' sea level rise scenario, which indicates a sea level rise of 4.82 mm per year. The second predictive model is based on an exponential regression of past sea level data and assumes an acceleration in the rate of sea level rise. The results of this model are the basis of the 'accelerating' sea level rise scenario, which indicates sea level rise accelerates at a rate of 0.47% per year.

Because there was a great deal of variance in the daily sea level reports, a smoother linear and exponential model of sea level rise was created with an annual moving average of the data. This method of smoothing highly variable data has previously been used in other regions to study changes in sea level (Dangendorf 2014). This method entails regressions of a simple moving average of the sea level reports using subsets of 365 data entries. To put it more simply, the first data entry of the moving average would be the mean of the sea level from days 1 to 365, the second moving average entry would be the mean of the sea level from days 2 to 366, the third moving average entry would be the mean of the sea level from days 3 to 367, and so on and so forth. Note that doing so resulted in the loss of the first 364 data entries, though considering the large number of samples (a total of 8841), this number is relatively negligible. The 'constant' sea level rise scenario utilizing the annual moving average data indicates a sea level rise of 5.04 mm per year. The 'accelerating' sea level rise scenario utilizing the annual moving average data indicates the sea level is rising by 0.49% times its current level per year.

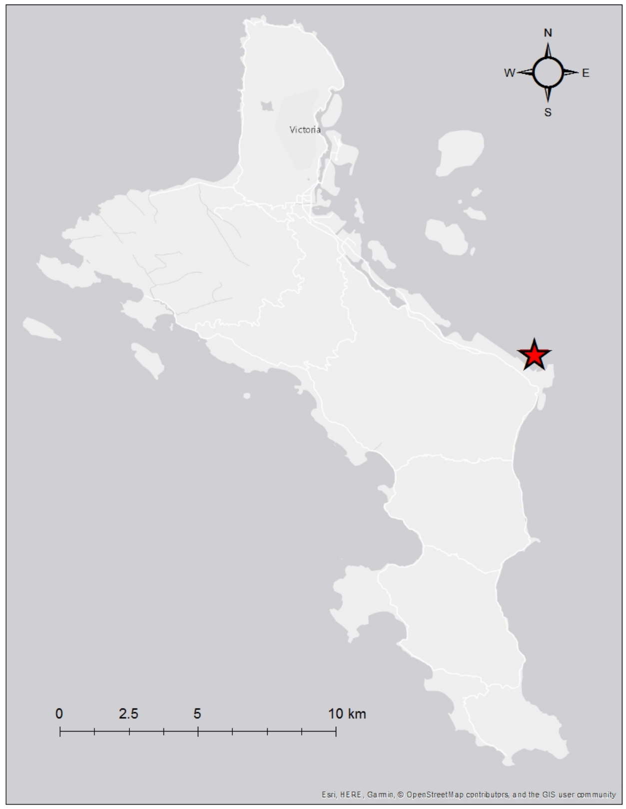

Figure 4.1: Location of Pointe La Rue Monitoring Station off the Coast of Mahé.

The equations derived from these four models can be seen below and representative graphs can be seen in Figure 4.2:

(1) Linear Model: $y_x = (0.0132 * x * 365.25) + y_0$
Whereby:

- y_x= predicted sea level (mm)
- y_0= current sea level (mm)
- x=years from present
- p-value<1E-200, R-Squared=0.1275

(2) Exponential Model: $y_x = y_0 * e^{(365.25*x/0.0000134)}$
Whereby:

- y_x= predicted sea level (mm)
- y_0= current sea level (mm)
- x=years since 1993
- p-value<1E-200, R-Squared=0.1338

(3) Annual Moving Average Linear Model: $y_x = (0.0138 * x * 365.25) + y_0$

Whereby:

- y_x= predicted annual moving average sea level (mm),
- y_0= current annual moving average sea level (mm),
- x=years from present
- p-value<1E-200, R-Squared=0.4736

(4) Annual Moving Average Exponential Model: $y_x = y_0 * e^{(365.25*x*\ 0.0000134)}$

Whereby:

- y_x= predicted annual moving average sea level (mm),
- y_0= current annual moving average sea level (mm),
- x=years since 1994
- p-value<1E-200, R-Squared=0.4837

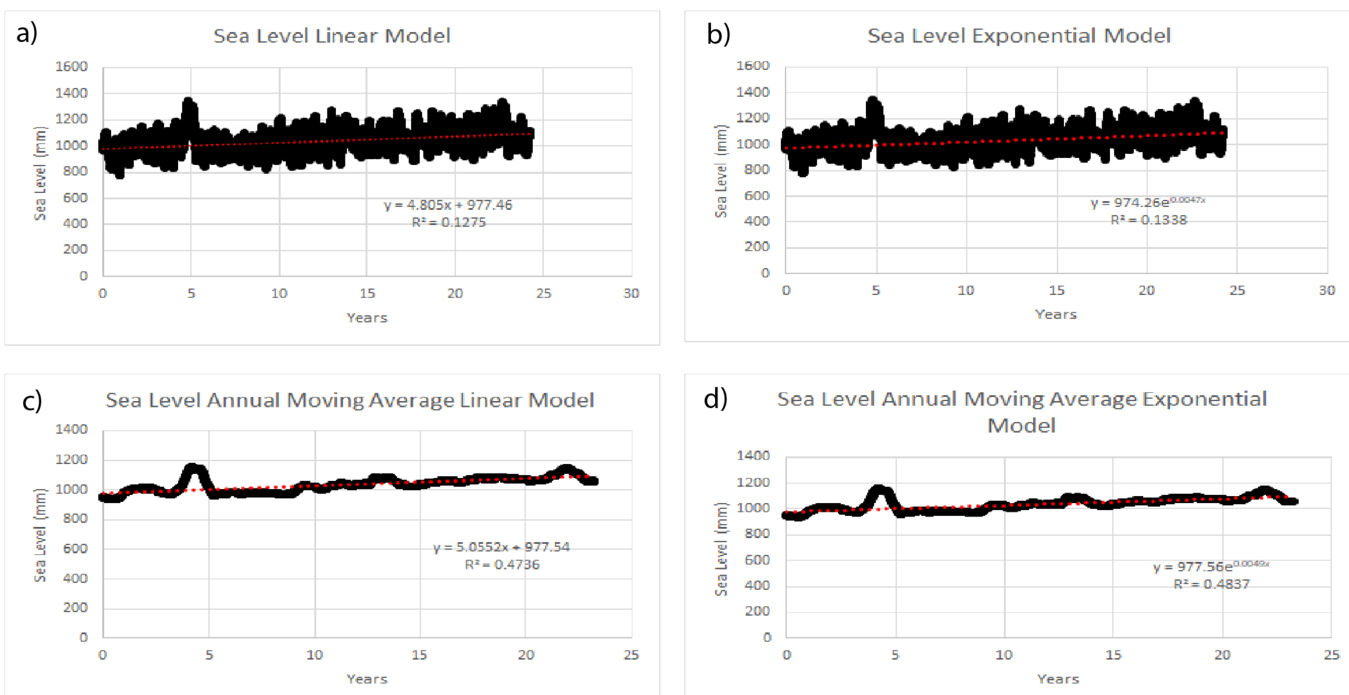

Figure 4.2: Graphical representations of all the different types of models produced using the daily sea level data. a). Linear model of the sea level data. b). Exponential model of the sea level data. c). Linear model of the moving average of sea level data. d). Exponential model of the moving average of sea level data

Though all four regressions returned a very low p-value, because of the higher R-squared values of the moving average models, only these were considered in the researchers' final mapping of sea level rise. Based on the above calculations, the moving average Linear Model predicts a 0.504 m rise by the year 2120, while the Exponential Model predicts a 0.566 m rise by 2120. Due to the similarity in the results of the two model types, the researchers decided to use a 0.5 m rise scenario for the sea level rise mapping and geospatial analysis. This 0.5 m scenario falls in line with the lower end of the range of global sea level rise predictions (Horton et al. 2014; Rosencranz et al. 2018) and similar to the sea level rise predictions of the Representative Concentration Pathway (RCP) 2.6 and RCP 4.5 greenhouse gas concentration scenarios listed in the IPCC's Fifth Assessment Report (Church 2013).

Though the global sea level rise scenarios mentioned earlier are less specific to the Seychelles, they are produced by process-based models which take into account the actual mechanics of global climate change and sea level rise (such as greenhouse gas emission scenarios, melting ice sheets, and thermal expansion). Because of this, they offer insight into future sea level rise that the researchers' data-driven statistical model cannot. As such, the researchers included them in their sea level rise exposure analysis, and mapped 1 m, 1.5 m, and 2 m sea level rise scenarios along with the researchers' 0.5 m scenario. High to low tides vary by about 2 m in the Seychelles (Figure 4.3), so in order to account for additional flooding exposure from high tides, an additional height of 1 m was added to each of these sea level rise scenarios.

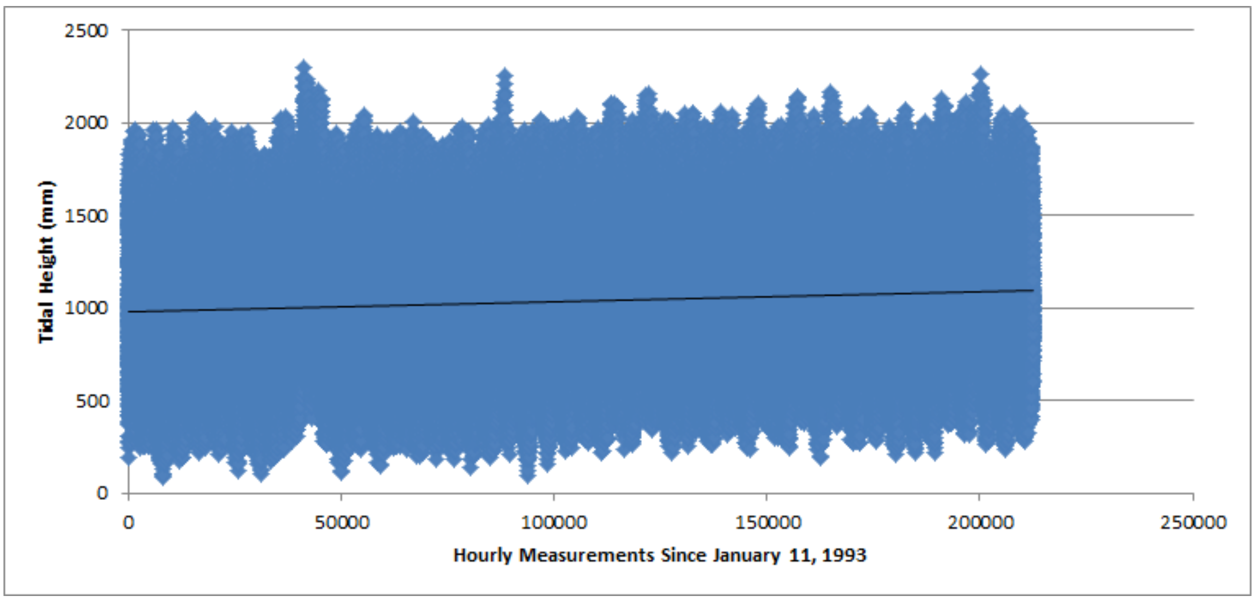

Figure 4.3: Hourly sea level measurements at Port La Rue monitoring station.

4.2.2 Sea Level Rise and Storm Surge Exposure Analysis

According the IPCC, exposure is defined as, *"the presence of…assets in places and settings that could be adversely affected"* (2014). An exposure assessment was performed using multiple scenarios of sea level rise and storm surge. Areas exposed to sea level rise are those with an elevation below the scenario of interest that are also connected to the coastline. Exposure to storm surge was calculated in a similar manner. Surge scenarios were broken up into mild, moderate, and severe. A mild surge was quantified at 0.5 m in height, moderate at 1.5 m, and severe at 3.0 m. These values were assigned based on previously conducted storm surge models for reasonable storm surge impacts in the Seychelles (Chang Seng & Guillande 2008). Exposed areas are those falling below the combined height of surge scenario and extent of sea level rise, and again, also connected to the coastline. As above, an additional height of 1 m was added to all scenarios to account for high tides (Figure 4.3). Infrastructure was laid on top of the exposed areas to determine the amount of specific infrastructure types that could be adversely impacted.

4.2.3 Storm Surge Vulnerability Analysis

As mentioned earlier, Seychelles has minimal record of taking damage due to a storm surge event, meaning there is little storm surge data to build a data-driven model with. Because there is no base data to make assumptions from, it is difficult to gauge how the effects of global climate change could increase the probability of a storm surge occurring. In addition, data on several parameters typically used in storm surge prediction models were not made available to the research team. As such, this study focuses not on how likely a storm surge is to occur and instead seeks to identify regions that would be vulnerable should a storm surge occur. This is in line with the IPCC definition of vulnerability as *"the propensity or predisposition to be adversely affected"* (IPCC 2014). With the existing data constraints, the storm surge vulnerability model also had to be a processed-based model, unlike the data-driven model that was used to predict sea level rise. Because this model is not calibrated by existing storm surge data, it is purely theoretical.

The research comprised storm surge vulnerability as topographical, geological, and hydrological conditions that make a region susceptible to flooding damage from a storm surge. The researchers' final storm surge vulnerability model is a Multi-Criteria Analysis model built using ArcGIS with Elevation, Slope, TWI, Cost Distance from River, Soil, and Vegetation Cover as the criteria of interest. All GIS analysis was done in the *WGS 84 UTM ZONE 40 S* projection. The full workflow of the methods used to produce the storm surge vulnerability index can be found in Figure 4.4.

The world record for highest storm surge is estimated to be around 13 to 14 m (Masters 2019). While it is highly improbable that Mahé will ever experience a storm surge near the height of the world record, this worst-case scenario of areas with an elevation of 15 m or lower was used for the researchers' storm surge vulnerability and risk analysis (Figure 4.5).

The researchers' analysis of topographic factors is based on 2 m resolution Digital Elevation Model (DEM) data provided by Seychelles' Ministry of Energy, Environment, and Climate Change. This elevation data itself is also utilized in the researchers' model as a predictor for storm surge risk. Areas of lower elevation are predicted to be more at risk from storm surges.

Slope is another topographic variable used in the researchers' model to predict storm surge vulnerability. Since water naturally flows downslope, a storm surge is less likely to scale steep slopes and flood waters are less likely to pool on slopes. As such, a high slope area can be considered a negative predictor for storm surge damage. Slope was derived from the DEM using the 'Slope' tool in ArcGIS and was output in units of percent slope.

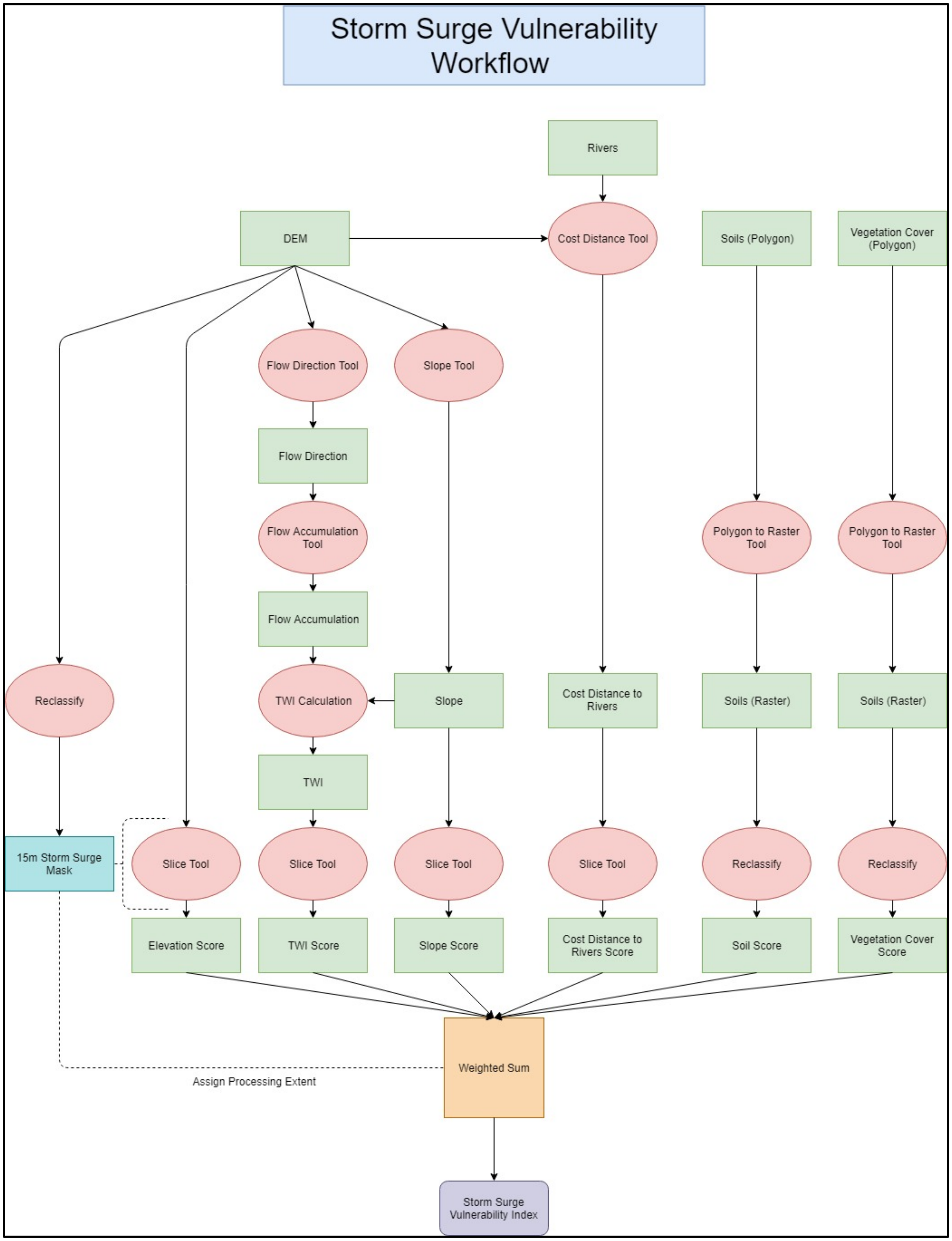

Figure 4.4: A workflow diagram depicting the basic steps taken to produce the storm surge vulnerability data.

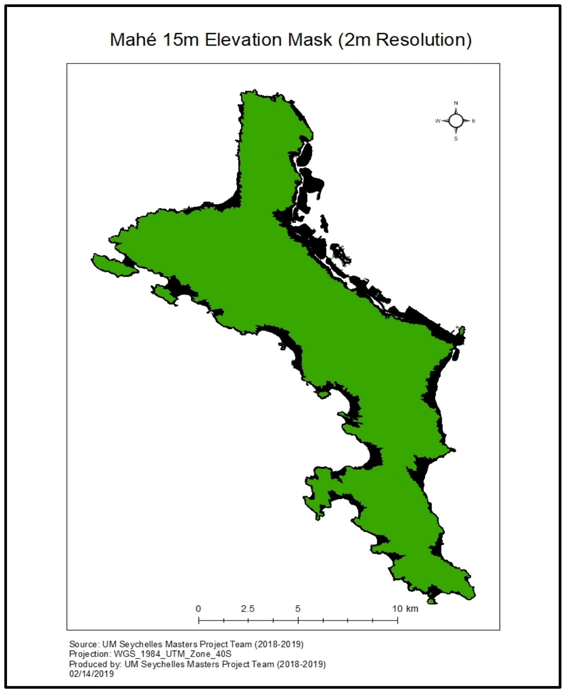

Figure 4.5: The mask of the processing extent that is used for storm surge analysis created from the 2 m resolution DEM.

Topographic Wetness Index (TWI) was also used as a measure of vulnerability to storm surge. The TWI was developed by Beven and Kirkby (1979) and is used to quantify interactions of topography in hydrologic processes (e.g. how water will flow or pool). In other words, areas with a high TWI value would be the final destinations of water in a given landscape, places that flow paths converge to. In addition to predicting hydrologic behavior of a landscape, TWI is also highly correlated to certain soil condition factors such as organic matter content and particle size/composition (Moore et al. 1993), factors that can also be used to help assess vulnerability to storm surge.

TWI is calculated with the formula: $TWI = ln(a/tan(b))$
Whereby (Sørensen & Seibert 2006):

- a = upslope area draining through a certain point per unit contour length
- tan(b) = slope in radians

In turn:

- $a = (x_{fa} + 0.01) * a / l$
    - x_{fa} = Flow Accumulation
    - a = Area of Cells
    - l = Contour Length of Cells
    - With the researchers' 2m x 2m cell resolution data, this means that a = 4 and l = 2.
- $tan(b) = (m + 0.01)/100$
    - m = Percent Slope

The flow accumulation raster used in this equation was created using the 'Flow Accumulation' tool in ArcGIS on the flow direction raster, which in turn was derived from the original DEM using the 'Flow Direction' tool. Note that 0.01 was added to the values of Flow Accumulation and Percent Slope to ensure 'NoData' values would not occupy any flat regions of the island.

Cost distance from rivers was another factor that was utilized in the researchers' storm surge vulnerability modeling. Backflow, a phenomenon that occurs when sea water from storm surges enter the mouths of tidal rivers and temporarily reverse the flow of the river, can increase river water levels well above their mean high-water level (MHW) and cause flood damage further inland than the storm surge would otherwise reach (Siefert 1978). As such, areas near riverbanks would be at greater risk of damage from a storm surge than those further away. Cost distance uses another factor (in this case elevation) to account for the difficulty of traversing the area, as opposed to standard Euclidean distance. So, for the purposes of the researchers' model, even if a given location is close to a riverbank, if it is at a much higher elevation than the riverbank, it would still have a high cost distance value to represent the difficulty water would have of moving upwards. The cost distance from rivers was derived from the DEM and a rivers shapefile by using the 'Cost Distance' tool.

Another factor necessary to consider in understanding flood vulnerability is the ability for soils to drain water. Infrastructure built on soils capable of effectively draining water are much less vulnerable than impervious surfaces or poorly-drained soils, such as clays (Massman & Butchart 2001). Polygon data of soils was converted to a 2 m resolution raster. Researchers then scored the different types of soils on a scale from 1 to 100 of increasing vulnerability. These scores were based on the soils' imperviousness, drainage capacity, and retention capacity.

Plants can be exceptional at holding soil in place as well as retaining and absorbing water, so vegetation cover is another important variable to consider when assessing storm surge vulnerability (Gyssels et al. 2005). Like the researchers' soils data, vegetation cover data is a 2 m raster produced from polygon data. Vegetation cover was also scored on a scale from 1 to 100 of increasing vulnerability. These scores were based on density of woody plants, with higher density assigned higher scores.

In order to ensure all input variables (Figure 4.6) were properly scaled to the masked extent, the researchers assigned them all scores of 1 (least vulnerable) to 100 (most vulnerable) using the 'Slice' tool in GIS with the processing extent being set to the 15 m elevation mask. The Slice tool reclassifies raster cell values to fit within the number of values assigned by the users (in this case 100 values). In other words, within the assigned extent, a cell with the maximum elevation of 15 m would be assigned a score of 100. In addition, elevation, slope, and cost distance to rivers all have a negative association with storm surge vulnerability, so their scores were reclassified to reflect that with the formula $y = -(x-101)$. Following the earlier example, this would reclassify that aforementioned 15 m maximum elevation cell to have a score of 1.

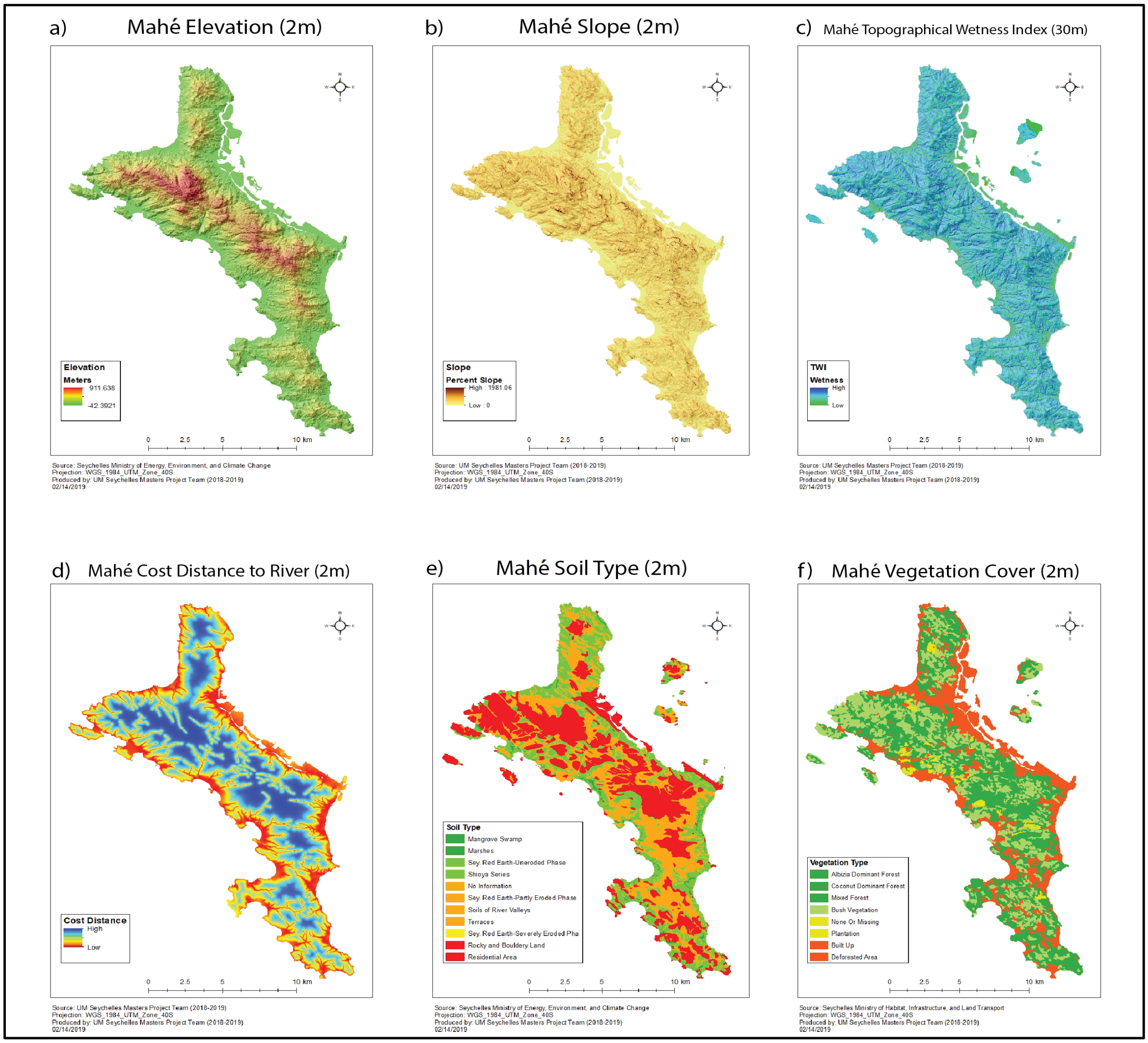

Figure 4.6: Visualizations of the researchers' six storm surge vulnerability variables. All maps besides TWI, which used 30 m data, were created with 2 m resolution data.

With all the variables sliced down to the same scale, weights were then assigned to each of them. The six variables were then arranged into a pairwise comparison matrix and assigned relative importance based on previous studies of flooding vulnerability (Pradhan 2009; Elsheikh et al. 2015). These relative importance values were then input into the AHP (Analytic Hierarchy Process) program created by Professor Eiichirou Takahagi of Senshu University (2005), which calculated appropriate weights for each variable (Table 4.1). The scored variables were then added together with their assigned weights using the 'Weighted Sum' tool to produce the Storm Surge Vulnerability Index raster.

Table 4.1: Table including the name of the variables used in this vulnerability analysis, whether the variable is negatively or positively associated with flooding, the reasoning behind the variables' inclusion in the model, and weight assigned to the variables in the model.

Variable Name	Vulnerability Direction	Basic Rationale	Weights
Elevation (DEM)	Negative	Storm surge is less likely to reach areas of higher elevation	0.131004
Slope	Negative	Storm surges will be less likely to scale steep slopes and water is less likely to pool on slopes	0.131004
Topographic Wetness Index (TWI)	Positive	Areas that typically accumulate water are more likely to flood	0.363085
Cost Distance to River	Negative	Backflow of rivers can cause regions near those rivers to flood	0.227609
Soil Score	Positive	Soil attributes impact drainage and detention of flood waters	0.0736497
Vegetation Cover Score	Positive	Ecosystems have varying ability to absorb flood waters based on type of vegetation	0.0736497

4.2.4 Storm Surge Risk Analysis

After modeling what regions of Mahé would be vulnerable should a storm surge occur, infrastructure at risk was modeled by the researchers. The IPCC defines risk as *"the potential for consequences where something of value is at stake."* (2014). For the purposes of this report, storm surge risk can be defined as the likelihood that flooding damage will happen to infrastructure based on storm surge vulnerability and the density of infrastructure of the region. Where storm surge vulnerability broadly means conditions that exist which would make storm surge impacts more damaging to infrastructure, storm surge risk means conditions that exist which would make storm surge impacts more likely to do damage to infrastructure. Again, note that this does not predict the probability of a storm surge occurring but instead assesses what regions have a high density of infrastructure in locations that are vulnerable to storm surge damage. Similar to the storm surge vulnerability index, the researchers final storm surge risk model is a Multi-Criteria Analysis model with critical infrastructure density and the storm surge vulnerability index as criteria of interest. The full workflow of the methods used to produce the storm surge risk index can be found in Figure 4.7.

Based on the researchers' definition of critical infrastructure, this analysis includes data pertaining to distribution of energy, water, and sewage, as well as government facilities, ports, roads, and tourism establishments. Data were provided by the Centre for GIS and IT Support Services in Seychelles' Ministry of Habitat, Infrastructure, and Land Transport and the Seychelles Public Utilities Corporation. The infrastructure shapefile of point data provided contains: Tourism Establishments, District Administrations, Education Facilities, Medical Facilities, Police Stations, Fire Stations, Petrol Stations, Bus Terminals, Water Pressure Filter Houses, Water Pumping stations, Sewer Pumping Stations, Sewage Treatment Plants, Sewage Chambers, Electricity Transformer, and Energy Generation points. Desalination Plant point data were also used in the analysis and were created from a georectified image containing the desalination plants' locations. The infrastructure shapefile of line data provided contains: Water Pipes, Sewer Lines, Electricity Lines, and Roads. The infrastructure shapefile of polygon data provided contains the Seychelles International Airport. Polygon data of the Victoria Fishing Port, the Seychelles Port Authority, and the Seychelles Petroleum Company, Ltd. were also used in this analysis and were created by delineating their extent in Google Earth and importing those data into ArcGIS.

All density rasters were constrained to the 15 m mask created during the storm surge vulnerability modeling. A point density raster was created by the 'Point Density' tool using neighborhoods of 250 cells with the raster being 2 m resolution, then were sliced to a scale of 100. Due to the spatial overlap of some types of linear infrastructure features (e.g. water pipes being located under roads), multiple line density rasters were created with the 'Line Density' using a search radius of 600 square meters. These density rasters were combined and then also sliced to a scale of 100. The polygon file was converted into a raster and pixels that corresponded to the polygons were given a value of 100. The pixel values of these three rasters were then added together using 'Raster Calculator' and then sliced to 100 to create to total critical infrastructure density score raster. Maps of all density types can be seen in (Figure 4.8).

The vulnerability index was used and data were 'Sliced' to a scale of 100 for the purposes of this risk analysis. The total infrastructure density score raster and storm surge vulnerability score raster were combined with equal weights to create a storm surge risk raster.

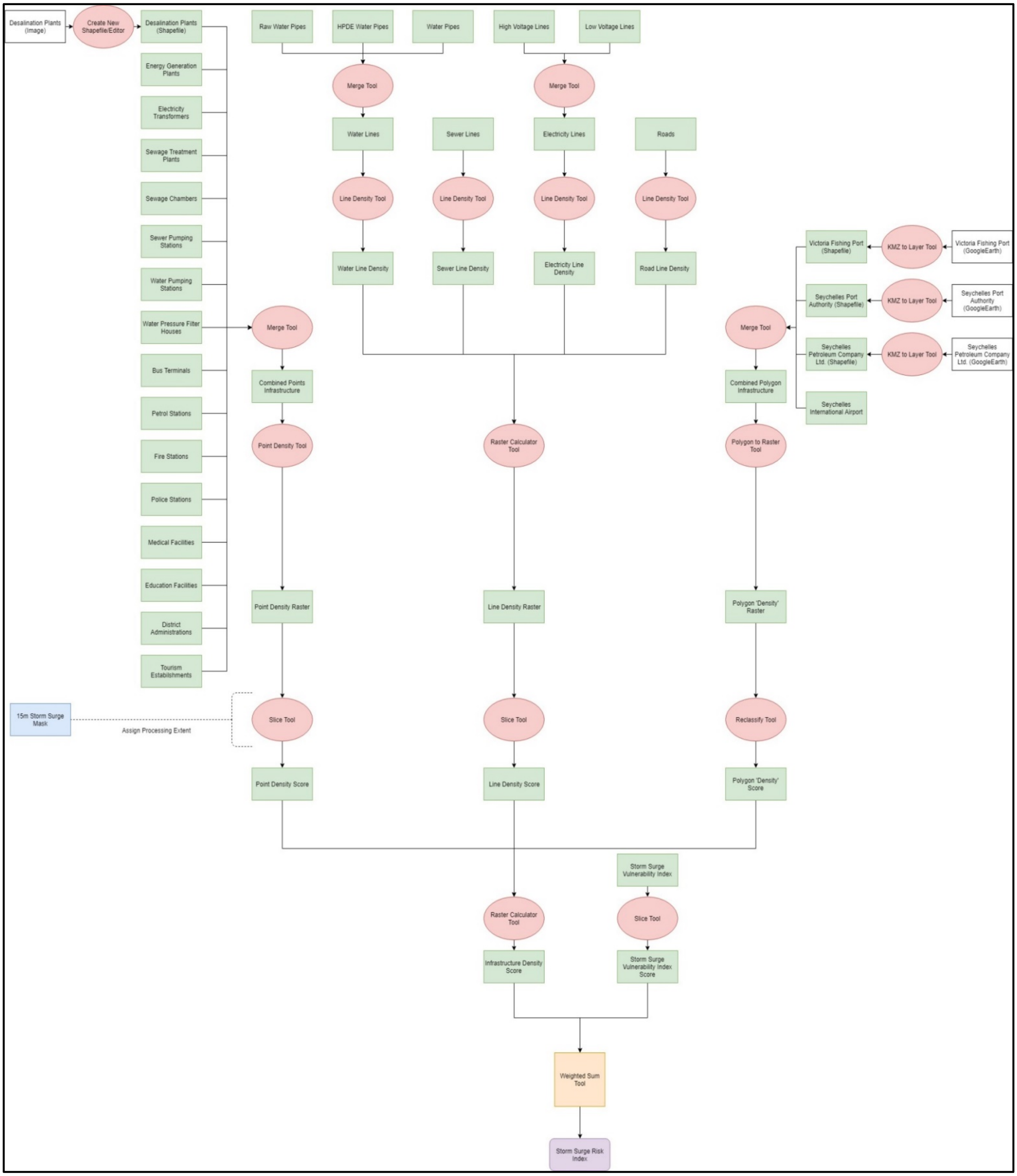

Figure 4.7: A workflow diagram depicting the steps taken to produce the storm surge risk data.

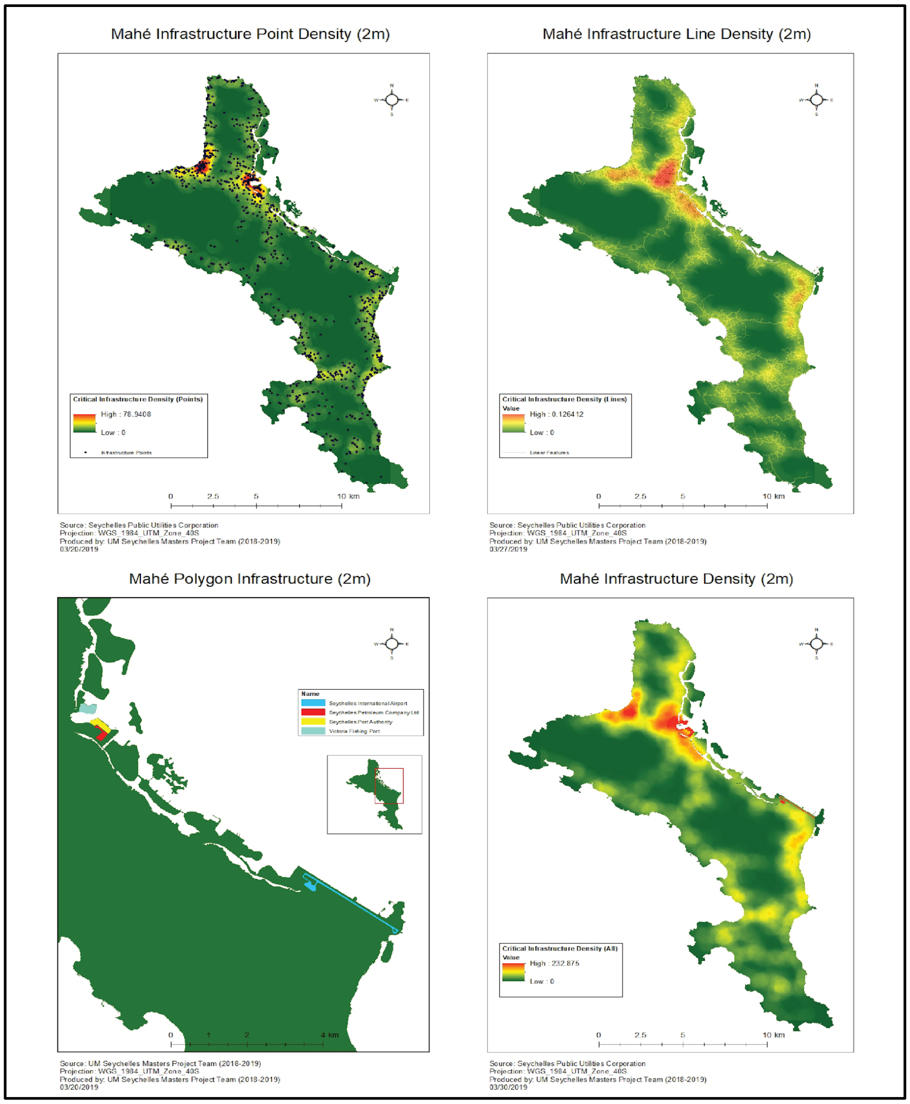

Figure 4.8: Maps of the different types of density raster and the total infrastructure density map. All maps are 2 m resolution data.

4.2.5 Precipitation Analysis

As a result of the prevalence that changing precipitation rates is cited in stakeholder interviews, the researchers decided to look beyond sea level rise and storm surges to determine what impacts climate change might be having on the precipitation Mahé receives. For this analysis, precipitation records from 1901 to 2015 provided by the World Bank Climate Portal were assessed (World Bank Group 2019a). A linear regression was conducted on the monthly precipitation values. In addition, the annual moving averages of the monthly precipitation data was also calculated and used in a linear regression by the researchers to reduce the high variance in data values due to seasonal precipitation differences, similar to the calculations for daily sea level data.

4.3 Results

4.3.1 Sea Level Rise and Storm Surge Exposure

Utilizing the produced sea level rise maps (Figure 4.9) and surge scenarios, the researcher's exposure analysis allowed them to see that a mild storm surge striking the country today would have minimal impact on its infrastructure (Table 4.2). A severe surge, on the other hand, exposes large amounts of the country's infrastructure. Even without any rise in sea level, 100% of Mahé's import/export infrastructure, fire stations, energy generation plants, sewerage district pumps, and sewer catchments are exposed to the impacts of a severe surge. Rising sea levels poses a threat to many types of infrastructure and exacerbates the future impacts of a storm surge. For example, a 0.5 m rise in sea level more than doubles the mild storm surge exposure of 18/26 of the types of infrastructure assessed. The most extreme sea level rise scenario of 2 m would devastate the country's infrastructure, inundating more than 20% of nearly all types of infrastructure analyzed. Overall, import/export infrastructure appears to be most exposed to the impacts of sea level rise and storm surge followed by the sewerage system, government buildings, and roads.

4.3.2 Storm Surge Vulnerability and Risk

When considering the storm surge vulnerability index (Figure 4.10), the area surrounding Victoria and the Seychelles International Airport along the northwest and west coasts, respectively, returned high vulnerability scores. Similarly, the storm surge risk index (Figure 4.11) demonstrates that Victoria and the Seychelles International airport report high risk scores. In addition, the coastal region of Beau Vallon in the northeast returned a high risk despite relatively low vulnerability due to the high density of infrastructure (much of which are tourism establishments) in that region.

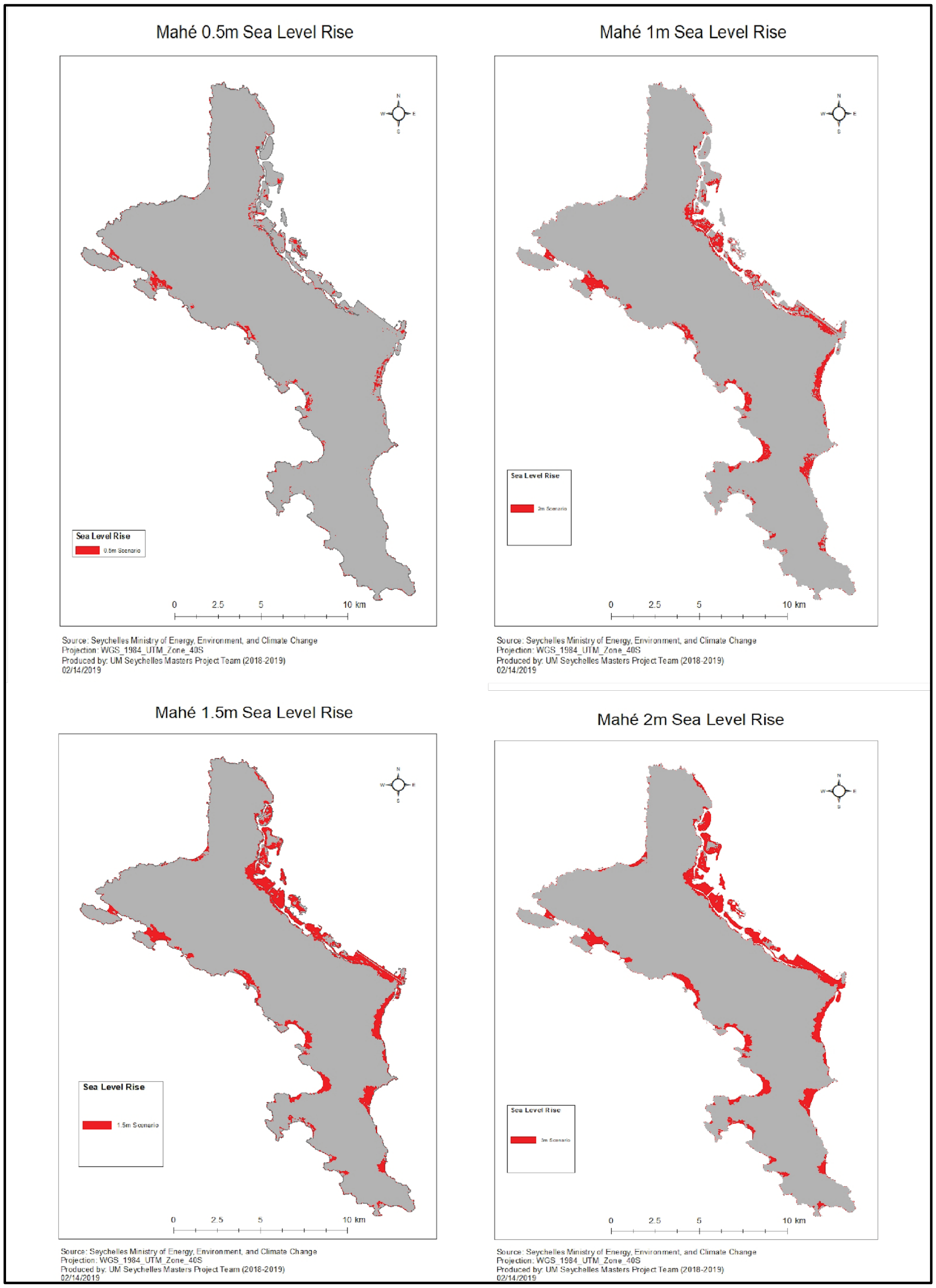

Figure 4.9: a). 0.5 Scenario produced by the researchers' linear regression model and described in Horton et al. 2014. b). 1m Scenario described in Mendez et al. 2013, Horton et al. 2014, Rosencranz et al. 2018. c). 1.5m Scenario described in Horton et al. 2014, Iwamura et al. 2013. d). 2m Scenario described in Horton et al. 2014, Iwamura et al. 2013. All scenarios assume a 1m high tide and all maps were produced using 2m resolution data

Table 4.2: Exposed infrastructure in Mahé at 0 m, 0.5 m, and 1.0 m sea level rise and different storm surge scenarios

Infrastructure Type	Examples	0m Sea Level Rise			0.5 m Sea Level Rise				1.0 m Sea Level Rise				Scenario
		Mild Surge	Moderate Surge	Severe Surge	No Surge	Mild Surge	Moderate Surge	Severe Surge	No Surge	Mild Surge	Moderate Surge	Severe Surge	
Road System	Roads	1.92	19.53	24.89	1.92	13.12	22.24	25.84	13.12	19.53	23.79	26.74	
	Bus Stop	6.12	23.62	32.94	6.12	16.33	27.99	33.53	16.33	23.62	31.20	35.57	
Imports/Exports	Shipping/Fishing Ports	100	100	100	100	100	100	100	100	100	100	100	
	Airport	0	100	100	0	100	100	100	100	100	100	100	
Government Buildings	Police Station	13.33	46.67	53.33	13.33	33.33	53.33	53.33	33.33	46.67	53.33	53.33	
	School	5.56	44.44	50.00	5.56	30.56	47.22	50.00	30.56	44.44	50.00	50.00	
	Bus Terminal	0	100	100	0	50.00	100	100	50.00	100	100	100	
	District Administration Building	4.00	36.00	48.00	4.00	36.00	40.00	48.00	36.00	36.00	48.00	48.00	
	Fire Station	0	50.00	100	0	0	100	100	0	50.00	100	100	
	Medical Facility	0	27.78	33.33	0	11.11	33.33	33.33	11.11	27.78	33.33	33.33	
Energy Generation and Distribution	Transformers	1.39	12.47	18.01	1.39	9.14	14.40	18.28	9.14	12.47	16.34	19.11	
	Energy Generation	0	100	100	0	0	100	100	0	100	100	100	
	Fuel Stations	0	50.00	50.00	0	20.00	50.00	50.00	20.00	50.00	50.00	50.00	% Exposed
	Electricity Lines	2.04	13.30	17.70	2.04	8.77	15.51	18.48	8.77	13.30	16.75	19.29	
Water Storage and Distribution	Distribution House	0	0	0	0	0	0	0	0	0	0	0	
	Pressure Filter House	0	7.14	7.14	0	0	7.14	7.14	0	7.14	7.14	7.14	
	Pumping Station	0	0.97	2.91	0	0	2.91	3.88	0	0.97	2.91	3.88	
	Dams	0	0	0	0	0	0	0	0	0	0	0	
	Water Pipes	1.92	18.08	23.81	1.92	11.88	21.21	24.74	11.88	18.08	22.69	25.59	
Sewerage System	District Pump	0	50.00	100	0	25.00	100	100	25.00	50.00	100	100	
	Chambers	7.04	87.32	98.59	7.04	73.24	90.14	98.59	73.24	87.32	91.55	100	
	Sewerage Pump Station	11.11	79.63	88.89	11.11	53.70	83.33	90.74	53.70	79.63	88.89	90.74	
	Sewer Catchment	0	100	100	0	100	100	100	100	100	100	100	
	Treatment Plants	0	33.33	66.67	0	33.33	33.33	66.67	33.33	33.33	66.67	66.67	
	Sewage Pipes	1.98	32.09	37.50	1.98	23.26	34.87	38.64	23.26	32.09	36.27	39.92	
Economically Vital	Tourism Establishments	0.93	19.20	27.24	0.93	10.84	24.77	28.48	10.84	19.20	26.01	31.58	
	Exposed Land (km^2)	**2.90**	**13.50**	**17.34**	**2.90**	**8.47**	**15.66**	**17.80**	**8.47**	**13.50**	**16.60**	**18.19**	

Table 4.3: Exposed infrastructure in Mahé at 1.5 m and 2.0 m sea level rise and different storm surge scenarios

Infrastructure Type	Examples	1.5 m Sea Level Rise				2.0m Sea Level Rise				Scenario
		No Surge	Mild Surge	Moderate Surge	Severe Surge	No Surge	Mild Surge	Moderate Surge	Severe Surge	
Road System	Roads	19.53	22.24	24.89	27.62	22.24	23.79	25.84	28.31	
	Bus Stop	23.62	27.99	32.94	37.90	27.99	31.20	33.53	39.07	
Imports/Exports	Shipping/Fishing Ports	100	100	100	100	100	100	100	100	
	Airport	100	100	100	100	100	100	100	100	
Government Buildings	Police Station	46.67	53.33	53.33	53.33	53.33	53.33	53.33	53.33	
	School	44.44	47.22	50.00	50.00	47.22	50.00	50.00	50.00	
	Bus Terminal	100	100	100	100	100	100	100	100	
	District Administration Building	36.00	40.00	48.00	52.00	40.00	48.00	48.00	56.00	
	Fire Station	50.00	100	100	100	100	100	100	100	
	Medical Facility	27.78	33.33	33.33	33.33	33.33	33.33	33.33	38.89	
Energy Generation and Distribution	Transformers	12.47	14.40	18.01	19.94	14.40	16.34	18.28	20.50	
	Energy Generation	100	100	100	100	100	100	100	100	
	Fuel Stations	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	% Exposed
	Electricity Lines	13.30	15.51	17.70	20.02	15.51	16.75	18.48	20.72	
Water Storage and Distribution	Distribution House	0	0	0	0	0	0	0	0	
	Pressure Filter House	7.14	7.14	7.14	7.14	7.14	7.14	7.14	7.14	
	Pumping Station	0.97	2.91	2.91	3.88	2.91	2.91	3.88	3.88	
	Dams	0	0	0	0	0	0	0	0	
	Water Pipes	18.08	21.21	23.81	26.36	21.21	22.69	24.74	27.04	
Sewerage System	District Pump	50.00	100	100	100	100	100	100	100	
	Chambers	87.32	90.14	98.59	100	90.14	91.55	98.59	100	
	Sewerage Pump Station	79.63	83.33	88.89	90.74	83.33	88.89	90.74	90.74	
	Sewer Catchment	100	100	100	100	100	100	100	100	
	Treatment Plants	33.33	33.33	66.67	66.67	33.33	66.67	66.67	66.67	
	Sewage Pipes	32.09	34.87	37.50	40.72	34.87	36.27	38.64	41.73	
Economically Vital	Tourism Establishments	19.20	24.77	27.24	33.13	24.77	26.01	28.48	34.06	
	Exposed Land (km^2)	**13.50**	**15.66**	**17.34**	**18.55**	**15.66**	**16.60**	**17.78**	**18.90**	

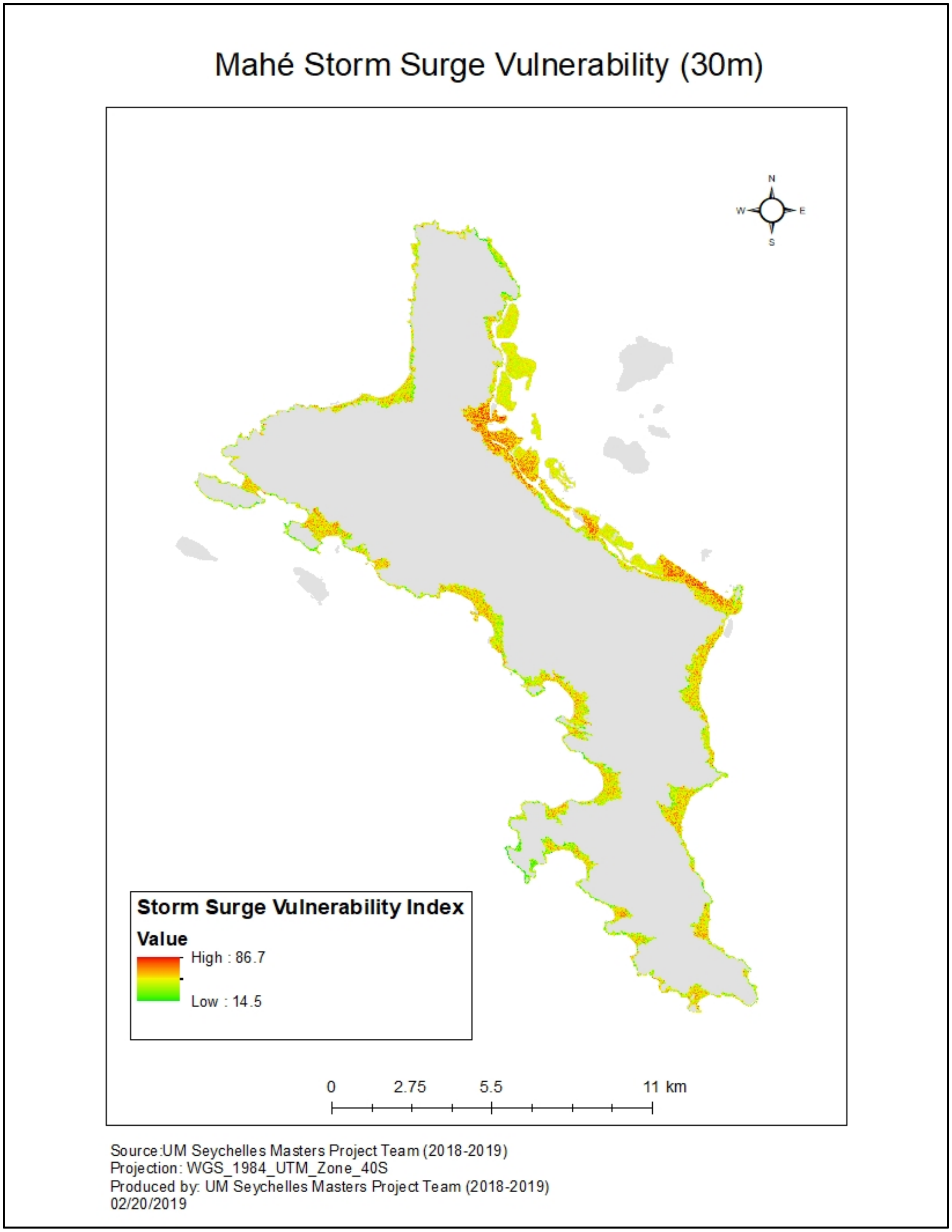

Figure 4.10: The completed storm surge vulnerability map. This map was created with 2m resolution data.

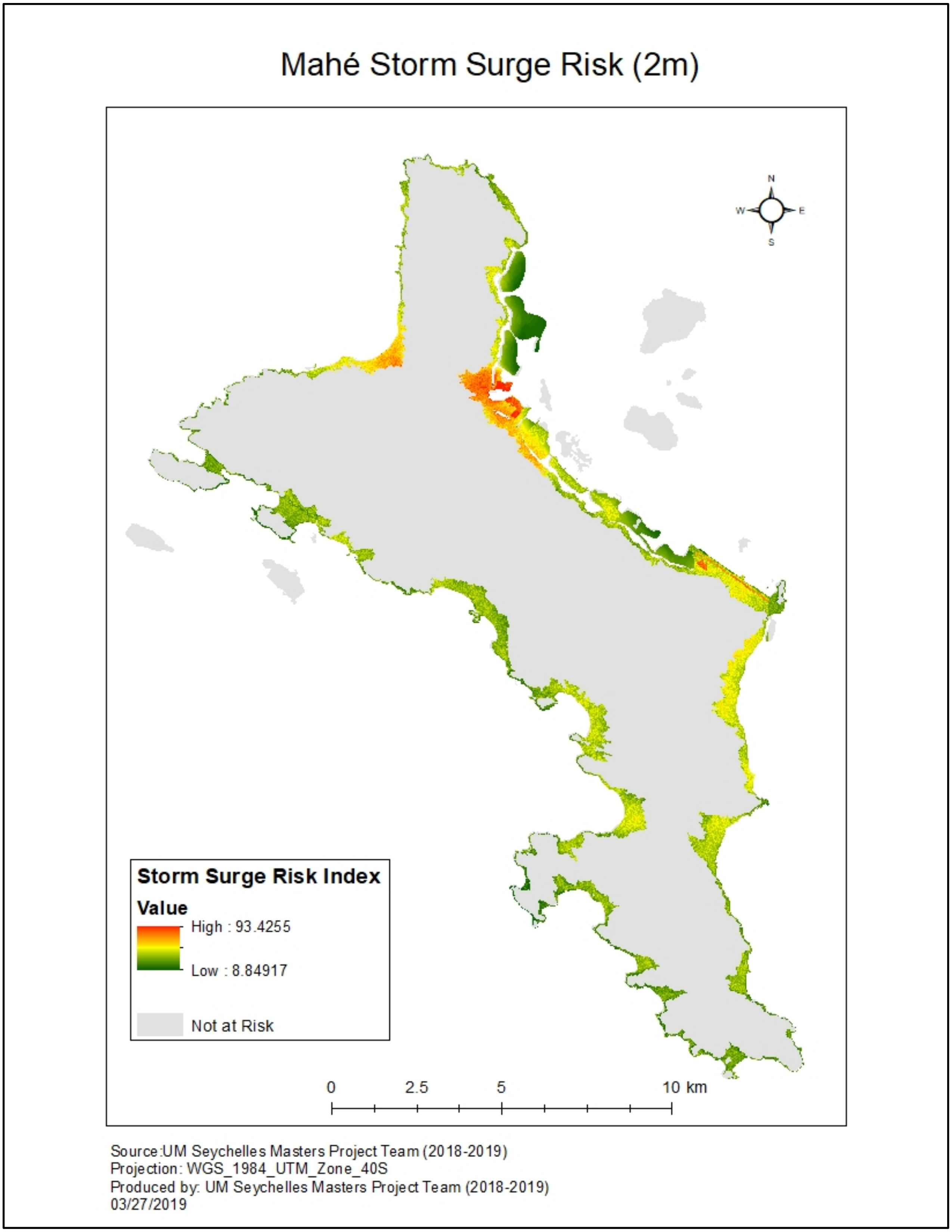

Figure 4.11: The completed storm surge risk map. This map was created using 2m resolution data.

4.3.3 Precipitation

The linear regression of monthly precipitation data and the linear regression of the annual moving average of precipitation data found no statistically significant change in precipitation values from the period 1901 to 2015 (p-value=0.7355 and p-value=0.1785, respectively) (Figure 4.12). The monthly precipitation model and the annual moving average of monthly precipitation model also both showed extremely low R-squared values (R-squared=0.00008 and R-squared =0.0013, respectively). These results suggest that there have not been any significant changes in the overall amount of monthly precipitation Mahé receives in the last 100 years. However, it is important to note that this analysis investigates overall rainfall quantity and not the number or intensity of rainfall events, meaning it is still possible that Mahé is experiencing fewer but more intense rainfall events.

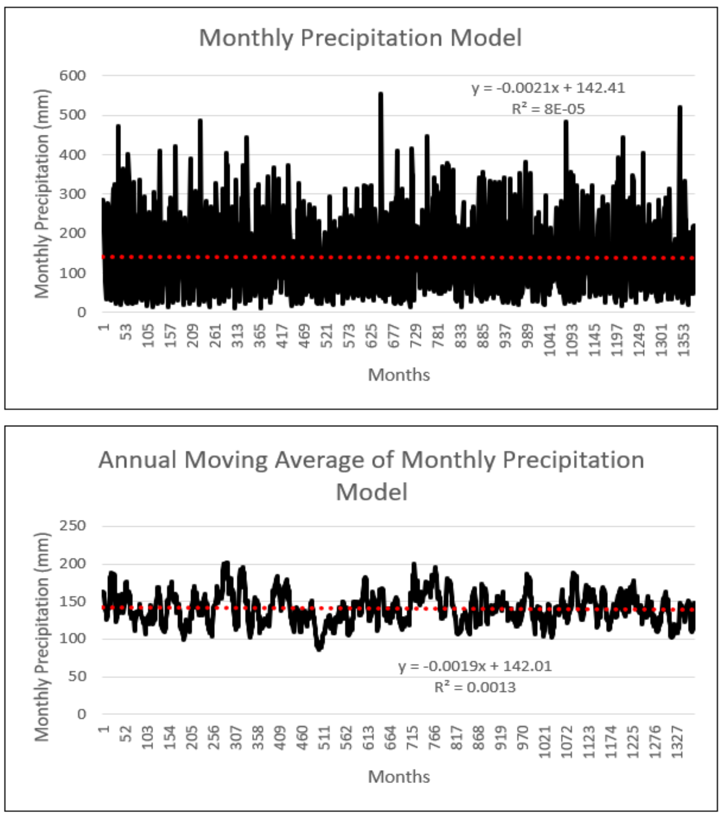

Figure 4.12: Graphical representations of the precipitation regressions.

4.3.4 Story Map

In recent years, the use of online interactive mapping has become more prevalent. An interactive map is a digital display of geographic data that provides users the ability to manipulate data displayed, seamlessly pan and zoom across geographies, and browse between areas of interest, among other features. Utilization of this tool has shown to be effective for communicating science to nontechnical audiences (Patterson & Bickel 2016) as well as engaging citizens with community issues (Santo et al. 2010). As such, the authors created a story map as a tool to help both experts and laymen understand the findings of this report.

The different domains in which interactive online mapping can be conducted include a self-hosted, cloud-service, and infographic format (Smith 2016). A self-hosted interactive map means that the data and structure is conducted over one's own institutional server. Creation of an interactive web map in this format requires extensive technical skills to create and maintain; however, it does provide the organization with extensive flexibility for content. The Seychelles currently has a basic self-hosted interactive map hosted by the Ministry of Habitat, Infrastructure, and Land Transport (Centre for GIS 2019). This map is useful for displaying GIS datasets under the authority of the MHILT, but is quite limited in the ability share, download, and input new GIS data, particularly for other ministries or users. On the other hand, a cloud-services framework allows users to create their own Interactive Online Map using a third-party service. Utilizing this format requires less technical expertise but also often requires purchasing the service. The third format is described as infographic. An infographic does not involve the same extent of holding and storing geographic data and is instead created with the goal of simplicity and story-led design. This research combines the latter two types of interactive mapping applications, as they have their own unique set of advantages and are not commonly used in the Seychelles.

In order to construct the aforementioned tool, data was compiled by an ArcGIS Online cloud-services framework (Figure 4.13). This framework was chosen based on its available features and free cost for those already subscribing to an ArcGIS Desktop account (ESRI 2019). GIS data collected from a variety of sources as well as the outputs of the researchers' models could all be stored in ArcGIS Online. This cloud-service framework allows multiple team members to access/manipulate the GIS data while also enabling the creation of online maps. This data is then fed to an ESRI infographic story map that could easily pull the maps created directly from ArcGIS Online. The story map allows the authors to guide users through the data visualization and explain results by incorporating additional text, pictures, and content along with the maps (Segel & Heer 2010). The easily shareable infographic result can be found here (https://arcg.is/1rW1uD) (Figure 4.14).

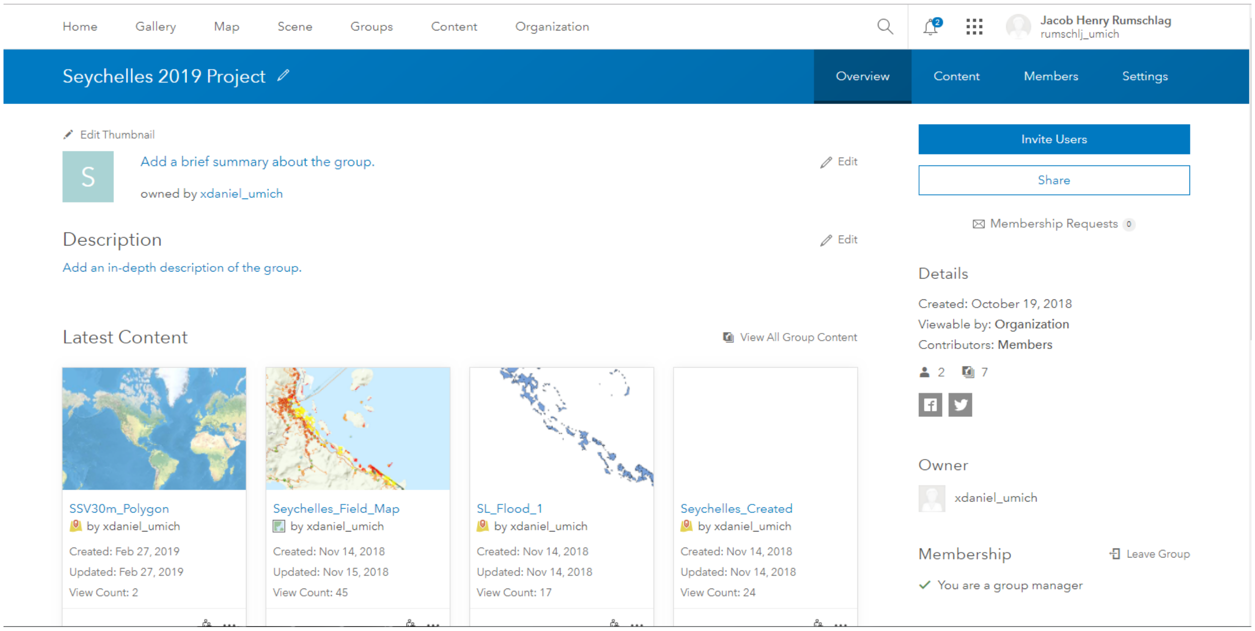

Figure 4.13: Screenshot of ArcGIS Online Interface. Using this cloud service allowed researchers to easily share datasets, create online maps, and export to an infographic Story Map.

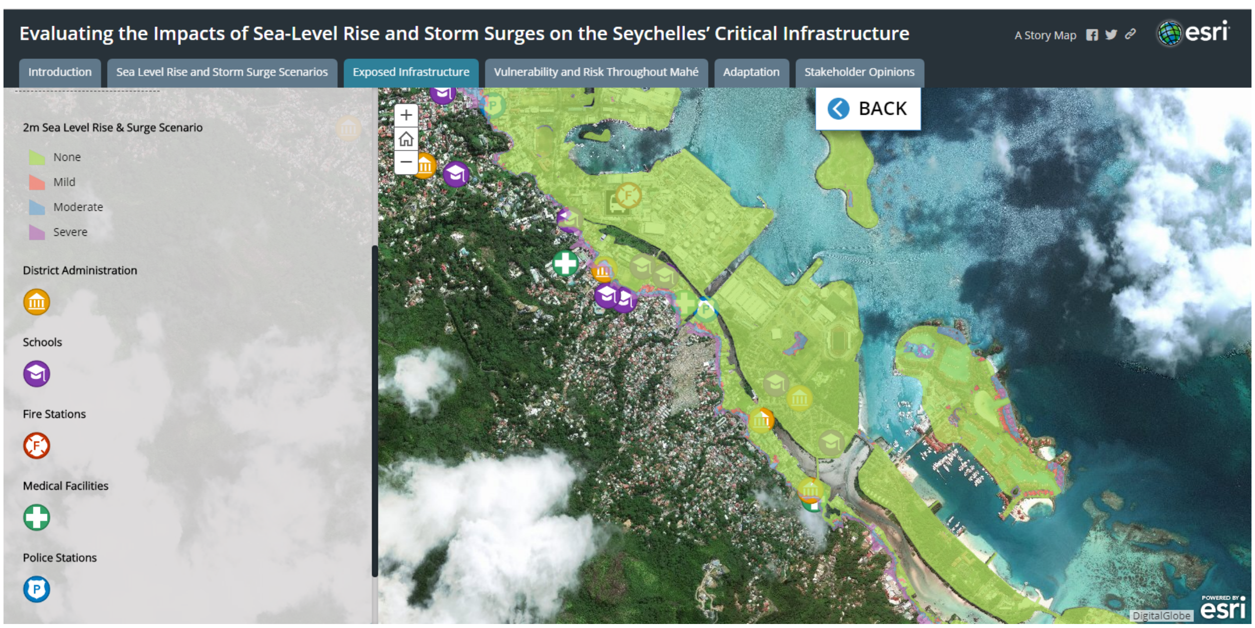

Figure 4.14: Screenshot from produced ESRI Story Map. This infographic allows users to learn at their own pace and explore different scenarios throughout Mahé.

Chapter 5

CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

Of the critical infrastructure assessed in this report, coastal roads and ports have been identified as the most vulnerable to the impacts of sea level rise and storm surges over the next century. Both of these forms of infrastructure are within the exposure ranges of even the lower sea level rise scenarios and score highly in the storm surge index. In fact, interviews have indicated that some coastal roads already experience coastal flooding even at the present sea level, as seen in Figure 5.1.

Figure 5.1: Water splashes onto the road during high tide on Bel Ombre Road.

In the context of Mahé as a whole, the vulnerability of these roads and ports does not just lie within the potential to incur physical damage but also the broader economic and social importance of these pieces of infrastructure. With the economic importance of the fishing industry to the Seychelles and the fact that most essential goods (e.g. food and petroleum) are imported, damage to the major ports on Mahé would cause considerable damage to the nation's economy and reduce the population's access to necessary resources. Similarly, because major roads are relatively scarce on Mahé and are mostly found along the coast, due to the island's steep slopes, damage to these key roads could halt the flow of goods around the island as well as impede access of key services such as bus terminals, hospitals, and fire stations. As testament to the importance of these pieces of critical infrastructure, roads and ports were the most commonly cited types of infrastructure in the researchers' interviews.

While various adaptation strategies exist for protecting critical infrastructure, at present, ecosystem-based adaptations are the most widely supported response to the threat of climate change in the Seychelles. Due to the nation's economic reliance on tourism and fishing, the nation acknowledges the need to preserve natural resources and thus prioritizes ecosystem-based adaptations. This is not only mentioned in interviews but also supported by a constitutional imperative stating, *"It shall be the duty of every citizen of Seychelles to protect, preserve, and improve the environment"* (Government of Seychelles 1993). Besides ecosystem-based strategies, relocation of critical infrastructure is another adaptation strategy that has been mentioned in interviews, particularly when discussing roads. However, this strategy has been met with particular resistance from community members who will not overturn their land use rights to the government for relocation. This is one of several barriers identified in this report to the adoption of climate change adaptation strategies to protect critical infrastructure that exist in Seychelles.

Various other barriers to adaptation currently exist, including funding, competing priorities, and timing. Indeed, financial constraints have been cited as the largest barrier to implementing adaptation measures in Seychelles. While ecosystem-based strategies are strongly supported by the government and the population, the national budget allocated for climate change adaptation has consistently declined in recent years, and there are challenges with the current reliance on international funding. One explanation for this lack of funding is that, while there is widespread acknowledgement of climate change as an issue among the people of Seychelles, there is a lack of urgency and understanding around the potential impacts of sea level rise and storm surge on critical infrastructure, as well as the harm it would have on the livelihoods of individuals in the country. This means adaptation actions are given low priority by the population and the government, thus, driving the reduced funding allocated to adaptation. In addition to limited funding, any current adaptations to protect critical infrastructure have largely centered around biodiversity benefits and ecosystem services. However, these EBA approaches are often long-term strategies that are unable to address more immediate threats to critical infrastructure, which is particularly challenging because of the current challenges in integrating future sea level rise and storm surge scenarios into planning and decision making.

A lack of serious consideration of the impacts of sea level rise and storm surges in the Seychelles has also resulted in insufficient accountability and enforcement for government regulations and recommendations pertaining to adaptation action. As a result, development of infrastructure occurs in areas that have been identified as exposed to sea level rise and vulnerable to storm surges, and new infrastructure is constructed without the necessary adaptation measures in place, which is often ascribed to high costs of equipping new developments with adaptive features. However, in the long term this ill-advised development will likely incur higher costs than if the overhead costs of adaptation were enacted at the outset.

Outside of limited enforcement mechanisms for adaptation policies, the Seychelles government also lacks coordination with both internal and external stakeholder groups. Lack of internal coordination has resulted in issues of data sharing and has regularly led to the repetition of projects by different agencies. Similarly, lack of coordination with external entities has led to redundancies in research on the impacts of climate change conducted by visiting research teams, NGOs, and international government partners, with very similar research repeated every few years by different groups. In addition, external experts have created plans for adaptation strategies that the Seychelles Government cannot enact because once the expert leaves, there is a lack of financing and technical expertise in the country to carry out the proposed projects. Similar issues arise when the data collected by the external entity is taken with them, which leaves government agencies without the necessary data for informed decision making. Therefore, there is a particular need for a more comprehensive procedure for working with researchers and other practitioners who come to the island so that the government can successfully complete, manage, and further develop projects that can protect their infrastructure from sea level rise and storm surges.

Though these issues hinder the adoption of climate change adaptation strategies to protect critical infrastructure, the researchers have identified numerous resources that the Seychelles can leverage to help overcome these barriers. The Seychelles has previously worked around a lack of funds by obtaining grants and debt restructuring/forgiveness from programs such as the Global Environment Facility (GEF), the World Bank, European Banks and The Adaptation Fund for undertaking biodiversity projects, which can include ecosystem-based adaptation actions (Global Environmental Facility 2016; Cole, S. & Brumme, C. 2019; Adaptation Fund 2018). However, this has led the government to rely on international funding mechanisms, some of which Seychelles may lose access to because they have recently risen into the World Bank Group's list of highly developed countries (World Bank Group 2019b). Thus, it is crucial that the Seychelles better collaborate with various groups in the country, a strategy they have begun to employ. Previously Sustainability 4 Seychelles, the Wildlife Clubs of Seychelles, and the University of Seychelles have helped to prioritize environmental issues for communities through education and outreach initiatives. By partnering with these groups, a similar effect could further action on climate change. Additionally, there are a host of policies that have recently or are currently being created which can be employed to strengthen climate policy enforcement mechanisms, namely a new National Climate Change Policy, an updated Set Back Policy, and the Victoria Masterplan. Finally, though unifying adaptation initiatives and data collection of the government's disparate agencies and external partners would be a difficult task, it would greatly reduce the amount of redundancy in projects completed, reduce unnecessary resource use, and make data more freely available to create useful tools such as this report's story map.

5.2 Recommendations

Utilizing interviews and hazard analysis, the researchers have identified the most vulnerable types of critical infrastructure, existing adaptation strategies, barriers to implementing adaptation action, and available resources which can be used to surmount the existing barriers. With all these in mind, the researchers have drafted five recommendations for future action.

5.2.1 Create a data sharing policy and platform to make data easily accessible across government agencies

To address the lack of data coordination among agencies and with external partners, the Seychelles should create a policy which requires the sharing of data collected by any in the country and a platform to host this data. This policy should require any individuals conducting research or other data collection in the country to sign an agreement that the country will be given the right to access and utilize all data collected from this work. This requirement may cause organizations who do not wish to share data to stop conducting research in the country; however, the continual repetition of projects leads to a reduction in the possible impacts of the technical expertise which the country has identified as a barrier to adaptation. Thus, the value of keeping this data for decision making purposes will increase the impacts it can have and reduce the repetition, in turn, allowing for a greater diversity of projects to be completed by external technical experts, but the researchers do recognize this policy and its data hosting platform do bring with them significant costs.

More specifically regarding the platform for hosting this data, there should exist a document that characterizes all projects done in the country, the dates in which they were completed, any data collected for them, the hosting ministry, and a place where the data can be accessed. This document should be held in a location where it can be accessed by all members of the Seychelles government, and the researchers also recommend that it be extended to any other parties in the country. This serves to reduce the amount of overlap in projects conducted in the island nation, standardize data used, and increase the employment of data for decision making. Moreover, it hopes to enable greater coordination amongst agencies when managing the impacts of sea level rise and storm surge to the country's infrastructure.

In particular, this recommendation seeks to address the large challenges the researchers faced in attempting to collect relevant and timely infrastructure data. The files and previously completed work were often spoken about and projects recognized, but few were aware of where this data was held. Moreover, it would be useful to the country to host this data in a central location because the researchers' analysis was inhibited by the inability to access information about agricultural lands and certain government buildings, pieces of infrastructure defined as critical by various stakeholder groups. However, infrastructure data is simply one area in which coordination could help, the researchers believe this recommendation should be scaled to include all data collected in the country.

5.2.2 Increase enforcement of policies requiring considerations of sea level rise and storm surges in developing new infrastructure

Due to the current procedure for decision-making on new developments and managing previously created ones, there is a lack of climate proofing that goes into the construction of many structures, including some of the country's critical infrastructure (e.g. government buildings). This ultimately results in infrastructure being built on land that is vulnerable to sea level rise and storm surges. Thus, the researchers recommend the MEECC be given a stronger mandate to ensure that any new construction be climate proofed. This is of particular importance at this moment as the country is in the process of finishing the new National Climate Change Strategy and Coastal Setback Policy. It is crucial that these policies provide the relevant ministries with the necessary power to ensure that resources are not utilized to create infrastructure in locations which are set to be inundated in the next 100 years. Moreover, it is necessary that climate change impacts be a central aspect of the creation and implementation of various plans for the future of the country (i.e. Victoria Masterplan 2040), particularly those having to do with land-use planning.

5.2.3 Strengthen collaboration among stakeholders from various sectors to highlight the impacts of sea level rise and storm surges on critical infrastructure and foster more adaptation to protect it

The private sector, particularly fisheries and tourism (Figure 5.2), are set to be greatly impacted by the impacts of sea level rise and storm surges on critical infrastructure, but the common theme is to look to the government to take action on climate adaptation. In order to reduce the burdens on both entities, partnerships between the two sectors should be developed and further strengthened to implement adaptation strategies to protect critical infrastructure. For example, with private sector funds, the government could provide direction and expertise on protecting the coastal roads which lead to the various tourism establishments. In addition, there should be a more comprehensive approach to incorporate the perspectives of citizen groups (e.g. Friends of Mont Buxton and Seychelles National Youth Assembly) and local Seychellois—possibly through the Ministry of Local Government—into the decision-making process. This will help the government to better understand the needs of communities, while also helping to deter the currently pervasive community pushback hindering adaptation in the country.

In addition, local NGOs and educational groups in the country should be included in conversations to help in educating the public and brokering a greater impact in the community. The researchers recommend tapping into already existing networks of education and communication professionals in the country to construct and implement a comprehensive educational program that focuses on how climate change will impact individual Seychellois and the importance and ability to adapt their homes, farmland, and various other areas of critical infrastructure in which they have some control over. This strategy serves to address the need to bring this challenge to the forefront of the minds of those in the country and to establish it as a priority among diverse groups. This strategy must not only focus on school aged children but also older individuals. In particular, there is a distinct need to educate policy and decision-makers on these matters to ensure climate impacts are considered in decision-making and actions to combat them are both understood and implemented effectively and efficiently. Particularly, there is a strong need to discuss the nuances of sea level rise and storm surges with ministries outside of the MEECC. The researchers recommend utilizing the ESRI-hosted story map created in this report to characterize these challenges. This recommendation is strengthened by the mention of similar strategies by both the GCCA+ and JICA projects recently completed.

Figure 5.2: Fishing and tourism vessels sit outside Port Victoria

To gather relevant parties together, the researchers recommend putting together, or increasing the influence of an already existing, climate change committee that hosts individuals from each of the aforementioned sectors. This group, which could be a continuation of the Seychelles National Climate Change Committee, should be utilized in understanding how to better assess the challenges with and solutions to addressing climate change for all in the country, and therefore, should include members from all sectors in the country.

5.2.4 Identify and secure more funding for adaptation of critical infrastructure in the country and the international community

As a small-island developing state, financial barriers are an immense challenge for most policy areas. However, the Seychelles' continual reduction in government allocations to climate change adaptation have largely inhibited the country's ability to protect critical infrastructure. Therefore, the researchers recommend that the government return to previous levels of budget allocation to protect critical infrastructure, particularly as this infrastructure is crucial to country's economic and social well-being. This strategy serves to protect the country's economy by adapting critical infrastructure to impending sea level rise and storm surges, as costs of fixing it after an event will be much larger than proactively protecting it. In addition, the movement into the most developed country category may result in a reduction in the amount of international funding the country is able to secure; thus, internal funding will be a crucial part of adaptation going forward. However, there must still be approaches to securing international funding.

While a greater proportion of funding from the country's budget would provide more resources for adaptation, the costs of the necessary projects far exceeds the country's financial capacities. In addition, the Seychelles has a history of finding innovative international funding from the "debt for dolphins" agreement with the Nature Conservancy to the various partnerships with Asian and European countries (Thande 2018). The researchers recommend that the Seychelles increase the usage of such mechanisms for funding and dedicate resources to the creation of at least one position to identify and apply for international funding. This could entail funding from GEF, the Adaptation Fund, or other similar sources. Additionally, they should continue to utilize the country's unique biodiversity and environment to bolster investments from international governments and organizations.

5.2.5 Conduct future research on climate change, vulnerability of critical infrastructure, and adaptation measures to protect it

One clear opportunity for further investigation is to take the work performed in this report and apply it to the remaining islands in the Seychelles. Although at the beginning of this project the researchers deemed that the focus should be kept on Mahé due to prevalence of infrastructure present and time and resource constraints, this research seems incomplete without evaluation of the country in its entirety. It is also possible that focusing on the remaining islands in the Seychelles would have unique or differing results.

The hazard analysis produced in this research should be used as a springboard for further analyses. One area of work is to include infrastructure types that were identified as critical but were not synthesized in this study. These include agricultural lands, Mahé's ice plants, food storage, and public housing. Infrastructure characteristics could also be incorporated. The type, age, and building materials of infrastructure in an area are all factors to consider when assessing an area's predisposition to be affected by a storm surge. Assessing the economic, environmental, and social value of infrastructure would permit a better assessment of risk. Finally, precipitation patterns should be analyzed on a month-to-month, rather than long term, basis because it would show changes in drought and extreme rainfall occurrence.

Identifying and evaluating specific adaptation strategies for vulnerable infrastructure is another useful next step. Using the cost benefit analysis framework that has been developed in Appendix C, the researchers recommend assessing adaptation approaches in order to prioritize them.

Among the most supported adaptation strategies in the Seychelles is ecosystem-based adaptation (EBA). However, EBA approaches are known to take longer, thus cannot often be used as quick fixes. Therefore, the researchers suggest the Seychelles be proactive and incorporate EBA strategies to protect any infrastructure characterized as vulnerable in this report and any others which have been identified in previous studies, in turn, protecting and enabling the usage of the country's natural resources for the economic pillars of tourism and fisheries. Moreover, the researchers suggest monitoring and evaluating the current and future EBA approaches utilized to ensure the resources employed to protect these pieces are most efficiently and effectively used. This should entail research on how long these strategies take to reach their full adaptive potential, how long they are able to withstand the pressures of sea level rise and storm surges, and what climate-based changes affect their adaptive capacity, among others. Lastly, there is a need to prioritize these pieces in terms of both most vulnerable and most critical to the country. This research suggests starting with the roads between the University of Seychelles and the capital city, Victoria.

This research highlights the vulnerability of the Seychelles' critical infrastructure to sea level rise and storm surges, adaptations to protect it, and barriers to doing so. In performing this analysis and creating informative and interactive tools for disseminating the information, the researchers wish to characterize how other small island developing states and members of the LAKI, particularly those in the Indian Ocean subregion, can assess the impacts and knowledge gaps which currently exist in terms of the impacts of sea level rise and storm surges on critical infrastructure. Moreover, the tools and recommendations from this analysis may serve as a starting point for other, similar nations to adapt to the impending effects of climate change.

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APPENDICES

Appendix A - Literature Review Documents

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Appendix B - Semi-Structured Interview Questions

1. What is your name and position?
    a. Can you tell us about what you do in this role?

Infrastructure

2. What pieces of infrastructure do you believe are socially and economically important to your country/community? Why?
3. For the pieces of infrastructure, you just listed, which pieces are particularly vulnerable to sea level rise and storm surges? Why?

Adaptation

4. What adaptation strategies are currently being implemented to protect those pieces?
    a. Governance options, engineering solutions, planning documents, etc.
5. What adaptation strategies for adaptation are currently being planned for the country?
6. Who usually drives these adaptation measures?
7. What strategies do you believe would be effective in protecting these pieces of infrastructure?
8. Are there currently any partnerships to create adaptation?
    a. In particular, any focus on community and government collaboration? Private and public sectors?

Barriers

9. What are some of the barriers to creating adaptation measures for infrastructure?
    a. Any knowledge gaps? Lack of technical capacity? Financial considerations?
10. Do you believe the government could be doing more to assist the country in adapting to climate change?
    a. What could they be doing?
    b. What are some of the barriers they face in doing so?
    c. Whose responsibility is it to fund and implement these strategies?

Follow-Up

11. What questions did we not ask that we should have?
12. Are there other experts you suggest we interview for this project? (Ensure we get names and contact information)
13. Are there any documents from your ministry or organization which would help in our understanding of this infrastructure, adaptation strategies, or the country more generally?

Appendix C - Preliminary approach for a Cost Benefit Analysis

A simplified formula for cost benefit analysis is detailed below,

$$B\text{-}C = Net\ Benefits$$

The net present value of benefits and costs are assessed,

$$\sum = NPV(Benefits) - NPV\ (Cost)$$

To account for the present values of both benefits and costs, a discount rate (r) is used in the formula for all future cash flows that occur for the duration of the investment timeframe (n),

$$NPV = \frac{Value_1}{(1+r)^1} + \frac{Value_2}{(1+r)^2} \ldots + \frac{Value_n}{(1+r)^n}$$

n = the number of years accounted for in the assessment decision-making
$Value_{1,2\ldots n}$ = the net cash flow at the given period (month, year, etc.)
r = discount rate

Once this is done, different projects can be compared by dividing the net present value of benefits by the net present value of costs to reveal a Benefit-Cost Ratio (BCR), or,

$$BCR = B/C$$

By calculating a BCR for a given project, and showing the relative extent of benefits in comparison to costs, alternative projects can be discussed to inform more prudent decision making with limited resources.

Infrastructure in the Seychelles

In the Seychelles, public infrastructure, including the road network, is funded by government budget allocations and has significant resource gaps, as modeled. Using the CATSIM model, the government realized a financing gap of 102 to 329 years to address all risks (Government of Seychelles 2015). Of the $66 million cost to address the road infrastructure, there is a $40 million funding gap (African Development Bank 2015).

Despite the fact that the roads and transport sector were most affected by the 2013 flood (35.1% of total, direct disaster effects), no CBA of adaptation efforts pertaining to the island's roads network, to date, were found. Of the island's 586 km of roads, approximately 18 km (5 km of primary roads, 10 km of secondary roads, and 3 km of feeder roads) were damaged in a previous flooding event; primary roads incurred a cost of $746,373 (Government of Seychelles 2013). The costs to road infrastructure totaled $2,869,389 in damages and $170,007 in losses, with a macroeconomic impact of $331,721 or .03% of GDP and .08% of the government's recurrent budget (Government of Seychelles 2013). This is distinct from recovery and reconstruction needs, which stand higher. To better address the gap, a framework, which incorporates lessons from interviews and hazard mapping, may be used to inform and support outreach within a wider participatory community.

Applying a CBA framework, planners and practitioners can benefit in the consideration of alternative options for pieces of critical infrastructure by assessing the costs and benefits of those that incorporate adaptation and those that do not. This distinction can help within the context of the national adaptation planning under scarce resource settings to prioritize project investments. The following framework, which includes an example of a set of different adaptation options, is considered. As stated, this is, perhaps best demonstrated in a scenario where a comparison of a project that does, in fact, consider adaptation is considered, compared to a project that does not. The below is not all inclusive and adaptation options can be employed where best suited.

With Adaptation:

Expected Cost = direct cost of hard engineering adaptation measure$_{1,2,3,4,5}$ + direct cost of ecosystem-based adaptation measure$_{1,2,3,4,5,6}$ + direct cost from policy measure$_{1,2}$+direct cost of education campaign$_{1}$

Where 'Direct cost of hard engineering adaptation measure' = material, labor, transport, maintenance, monitoring for design recommendations, for example:

Hard Engineering Adaptation Measure (1) = constructing a viaduct
Hard Engineering Adaptation Measure (2) = raising a road
Hard Engineering Adaptation Measure (3) = moving a road
Hard Engineering Adaptation Measure (4) = installing dykes/seawalls
Hard Engineering Adaptation Measure (5) = rock armoring

Ecosystem based adaptation cost (1) = species identification
Ecosystem based adaptation cost (2) = species removal
Ecosystem based adaptation cost (3) = site preparation/engineering
Ecosystem based adaptation cost (4) = sediment deposition
Ecosystem based adaptation cost (5) = species plantings
Ecosystem based adaptation cost (6) = monitoring and maintenance

Policy Measure (1) = increased set back implications
Policy Measure (2) = demand/congestion pricing for infrastructure

Education Campaign (1) = costs for media purposes towards carrying out educational outreach

And where, 'costs' may include,

- *Site Visits/Charrette*
- *Design Phases/Drafting Documents*
- *Material Acquisition*
- *Labor*
- *Transport to Site*
- *Maintenance*
- *Monitoring*

Expected Benefit* = *Avoided Damages* {exceedance probability*Loss (a) + Loss (b)}

Where exceedance probability = a percentage that denotes the capacity of the adaptation measure to absorb the sea level rise of a given height (0 m, .5 m, 1 m, 1.5 m, 2 m) or storm surges of a given height (0 m, .5 m, 1 m, 1.5 m, 2 m), occurring from historic record of a similar intensity and frequency, and incorporating the weighted sum factor that is based on elevation, slope, soils, distance to rivers, TWI and vegetation cover.

Loss {a} = the most up to date damage assessment from historical record of the same intensity and frequency event that impacted the specific piece of critical infrastructure, $2,970,565 in the case of 'transport - roads' (Government of Seychelles 2013)

Loss {b} = economic damages to consumer and producer industries

Without Adaptation:
Expected Cost = exceedance probability*Loss {a} + Loss {b}

Where exceedance probability = the frequency and intensity of sea level rise of a given height (0 m, .5 m, 1 m, 1.5 m, 2 m) and/or storm surging with an intensity of a given height (0 m, .5 m, 1 m, 1.5 m, 2 m)

'Loss {a}' = the most up to date damage assessment from historical record of the same intensity and frequency on a specific infrastructure piece of critical infrastructure, $2,970,565 in the case of 'transport - roads' (Government of Seychelles 2013)

'Loss {b}' = economic damages to consumer and producer industries

$$\text{Expected Benefit* = direct cost of hard engineering adaptation measure}_{1,2,3,4,5} + \text{direct cost of ecosystem-based adaptation measure}_{1,2,3,4,5,6} + \text{direct cost from policy measure}_{1,2} + \text{direct cost of education campaign}_{1}$$

*The expected benefits are the avoided damages based on a probabilistic return profile of a natural disaster based on historic damage records. In the 'without adaptation' scenario, funds are available to be spent elsewhere in the economy and represent realized, short-term benefits.

Indirect Costs and Damages to Private Sectors (Tourism, Fisheries)

This can be applied for different road infrastructure users for a particular segment, where data is available. It can be recommended to start with vital sectors to the economy. By surveying location of facilities and interviews with establishments, around a) utilization of the road b) daily production and c) transportation costs, the *benefit* from increased supply can be assessed. Similarly, this may apply when moving a road so that new costs or benefits occur based on the newly proposed route.

Cost Benefit Analysis in the Seychelles

Avoided Damages

The East Coast Road is a primary road between the University of Seychelles and the Airport (10 km). This then continues to the capital of Victoria (9.9 km). The cumulative damage incurred for 5 km of primary road in the 2013 flood ($746,373) can be extrapolated to arrive at a cost for 19.9 km ($2,970,565) based on the costs per km of road, realized by the post disaster needs report (Government of Seychelles 2013). In accordance to the predictions for sea level rise and storm surge, the roads should be adapted to absorb the sea level rise of a given height (0 m, .5 m, 1 m, 1.5 m, 2 m) and storm surges of a given height (0 m, .5 m, 1 m, 1.5 m, 2 m).

Time Frame

It is recommended these projects be modeled over periods that mirror the life of the asset. For example, roads are commonly modeled over 10-20 years; although, this may be expanded in scope if maintenance and replacement are not being conducted at this time interval. Any replacement periods the country currently uses can be applied and subtracted from the investment in adaptation or by reducing the life of the particular adaptation investment up to the replacement period that would otherwise, normally, occur. A further consideration is that the time frame is set large enough to address the time or frequency, of the related risk. However, because, these are long incidences occurring over 100 years, with limited budget the government should consider incremental periods over the 100-year frame to strategically plan across sequential budget and investment cycles. A sensitivity analysis is recommended that varies the time frame between 10, 15, 20, 25 and even 40 or 60 years (to include maintenance) without any explicit replacement period provided by the Ministry of Habitat, Infrastructure, and Land Transport. While doing this, all other assumptions are held constant and the calculations adjusted to the different time periods to better understand the implications of different investment levels and to compare across the immediate opportunity cost of limited funds at that point in time.

Discount Rate

This is different from the social time preference, which states how an economy (or culture), at constant growth and productivity, adjusted for population growth, is willing to exchange consumption patterns across time; how it views current consumption relative to future consumption. A discount rate of r=.05 and r=.074 was used in previous national documentation regarding the water sector and airport (Government of Seychelles 2017a; UNISDR 2015). A sensitivity analysis is recommended that varies the discount rate value to provide a comprehensive overview of the project cash flows overtime (0, 1.5, 3, 5, 7). Ultimately, this should be confirmed with the Ministry of Finance.

Increasing Exposure

Previous studies calculated an increase in exposure rate of 1.5% per year. This is due to the fact that development on low lying areas continues to occur and the exposed asset based may be likely to increase over time if this continues. This is something to consider depending on the infrastructure analyzed.

CBA Projects to Date

To arrive at the above, the researchers surveyed existing documentation and conducted interviews to determine the state of CBA assessments in the Seychelles. Table 9.1 provides the findings and a starting point for understanding the modeling parameters, economic results, as well as ecological, societal and governance implications.

Table 9.1: Existing Literature on Cost Benefit Analysis in the Seychelles

Adaptation		*Flood Alleviation*	*Coastal Armouring/Land Reclamation*	*Ecosystem Based Adapatation*		*Ecosystem Based Adpatation& Water Security*	*Industry Development & Water Security*	*Conservation & Adaptation*
Sector		*Infrastructure/ Airport (Commercial)*	*Economically Vital Infrastructure*	*Water Supply and Distribution, Agrigultural Land*		*Infrastructure/ Industrial/Water Supply and Distribution*	*Water Supply and Distribution (Residential)*	*Economically Vital Infrastructure*
NAME		*Case Study: Flood Alleviation Project in Point La Rue (UNSIDR 2015)*	*Anse La Mouche Coastal Rehabilitation Works (MEECC 2017)*	*Ecosystem based Adaptation to Climate Change in Seychelles (Government of Seychelles 2012)*		*Dam Raisin, Environmental and Social Management Plan (Mutasa, C. & Shoji, H 2014)*	*Rooftop Rainwater Harvesting Study (Government of Seychelles, 2017)*	*Seychelles Conservation and Climate Adaptation Trust (Cole, S. & Brumme, C. 2019)*
Primary Organization (s)		*UNISDR*	*MEECC - CAMP*	*UNDP*		*African Development Bank*	*P.U.C.*	*The Nature Conservancy*
				GEF, GCCA+			*UNISDR*	
Secondary Organization(s)		*Ministry of Environment and Energy, Environmental Engineering and Wetland*	*World Bank*	*MEECC*	*P.U.C.*	*Department of the Environment*	*Industry*	*Government of Seychelles*
		Seychelles Aviation Authority		*National Parks Authority*	*Seychelles Agricultural Agency*	*Maldives Contractor, Various Consultants*	*Aquaglass, Souris, City Enterprise, Bodgo, Bestway, Watermaster*	*Programme Coordination Unit*
Status		*Proposed*	*On-Going*	*Completed*		*Unconfirmed*	*Proposed*	*On-Going*
Year 1		*2013*	*2011*	*2014*		*2014*	*N/A*	*2017*
Years Modeled		*30*	*N/A*	*5.5*		*2.3+*	*10*	
District Administration		*Pointe La Rue*	*Baie Lazare*	*Mare aux Couchons*	*Baie Lazare*	*Anse Etoile*	*TBD*	*Protected Marine Resources*
			Anse La Mouche	*Mont Plaisir*	*Caiman River*	*Anse Glacis*		
Total Cost SCR (UsD)		*23,867,920*	*4,154,015*	*79,774,067*		*2,213,500*	*5,896,280*	
		$ 2,105,307	*$ 315,456*	*$5,966,000*		*$ 173,648*	*$ 436,325*	*$ 6,400,000*
Up Front Cost SCR (UsD)		*23,574,700*	*3,772,328*	*12,976,467*		*2,213,500*	*884,000*	
		$ 1,955,057	*$ 286,799*	*$1,017,999*		*$ 173,648*	*$ 65,416*	*$ 430,000*
Operating Costs SCR (UsD)		*293,220*	*381,687*	*66,797,600*		*0*	*5,012,280*	
		$ 150,250	*$ 28,657*	*$4,948,001*		*$ -*	*$ 370,909*	*$ 8,170,000*
Benefits (Categorical)	***Environmental***	*Flood Alleviation*	*Land Reclamation*	*Watershed & Coastal Rehabilition*		*Soil Erosion, Water Resources, Water Quality, Species and Habitat Impact*	*None Reported*	*Land/Biodiversity Preservation*
	Social	*Address public and private good*	*Address public goods*	*Addresses Vulnerable Communities depedent on river water sources*		*Water Security, Emergency Prepardeness-with staff at Anse Etoile School*	*Local Business Development*	*None-Reported*
	Governance	*Disaster Risk Reduction, Disaster Risk Management and Risk Sharing Demonstration*	*Collaboration between National and Disitrict Administrators*	*Developing a National Watershed Monitoring System*		*Regulatory/Permitting Compliance*	*Public-Private Parnternship Demonstration, Tax Incentive*	*Enhanced International Collaboration and Operational Capacity*
	Economic	*Risk-Reduction, Loss Assessment*	*None Provided*	*None Reported*		*Producer and Consumer Savings*	*Impact Assessment (Job Creation & Household Income Savings), Tax Incentive*	*National Debt Restructuring, Grant Funding, Impact Capital*
Benefits (Quantified)	***Environmental***	*None Reported*	*N/A*	*2,800 (hectares of watershed and forest land) +- 20% (water flow rates)*		*% of 77 (species) and km (unspecified secondary forests and shrubs) Water Measurements (unspecificied monitoring of water quality)*	*None Reported*	*400,000 km (protected lands)*
	Social	*None Reported*	*None Reported*	*21,415 (estimated individual water users impacted)*		*Worker Code of Conduct to all applicable laws and standards*	*25,000 (households)*	*None Reported*
	Governance	*None Reported*	*None Reported*	*Not Reported (# of small-scale water storage/detention facilities)*		*Wastewater and Ambient Water Quality, Air Emissions and Ambient Air Quality*	*None Reported*	*None Reported*
	Economic	*SCR 25383170 $2,538,016*	*None Reported*	*None Reported*		*None Reported*	*SCR 362,779,866 $26,845,710*	*$5,600,000 & $3,000,000*