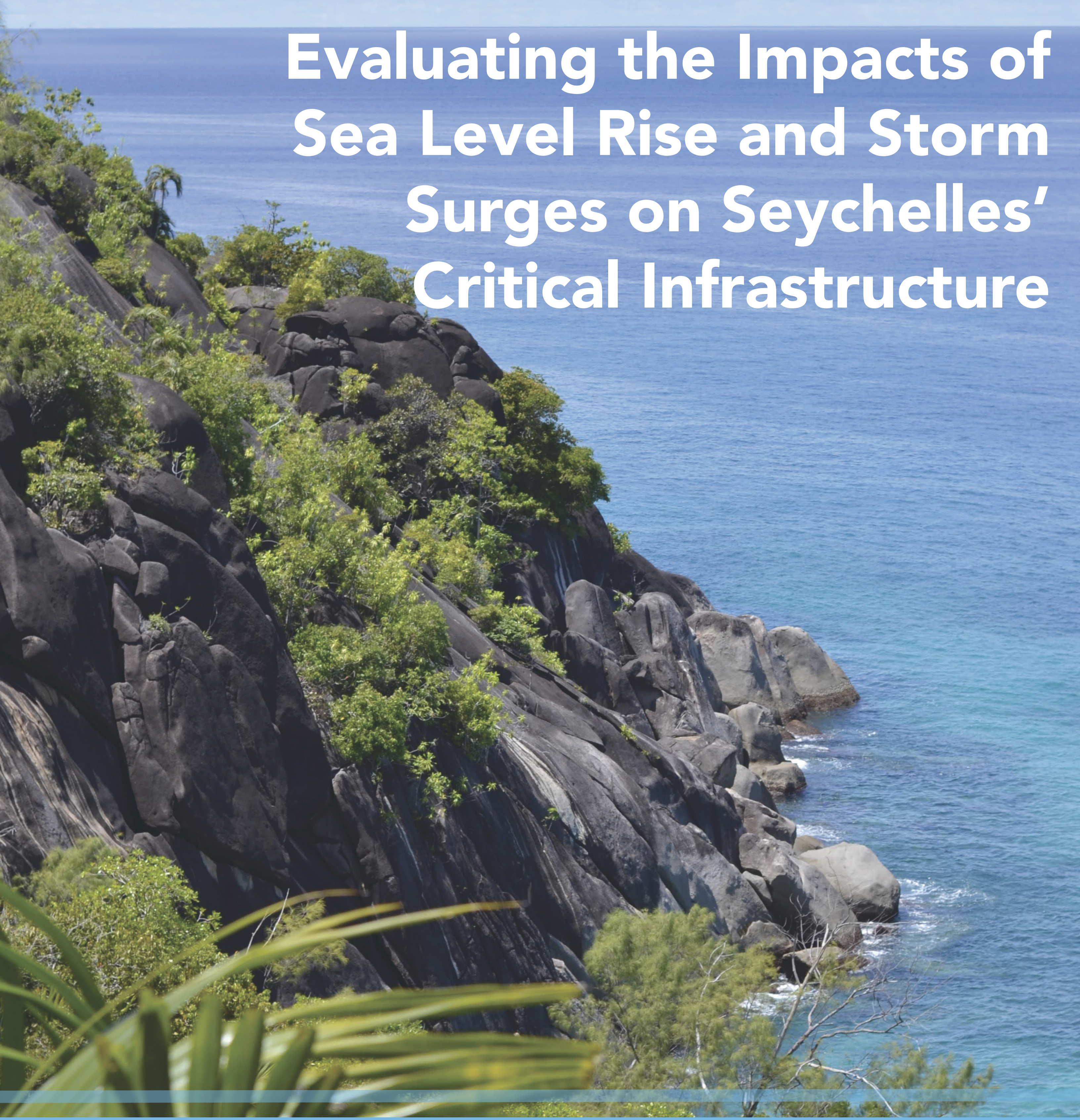
Evaluating the Impacts of Sea Level Rise and Storm Surges on Seychelles' Critical Infrastructure



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Lisa Maillard, Tonya Summerlin, Annalisa Wilder

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Acronym List

AHP	Analytic Hierarchy Process
AR5	Assessment Report 5 (5th Assessment Report)
CBA	Cost-Benefit Analysis
CMP	Coastal Management Plan
DEM	Digital Elevation Model
DRDM	Department of Risk and Disaster Management
EbA	Ecosystem-based Adaptation
EEZ	Exclusive Economic Zone
GCCA+	Global Climate Change Alliance+
GCM	Global Circulation Model
GMT	Global Mean Temperature
INDC	Intended Nationally Determined Contribution
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IRB	Institutional Review Board
ITCZ	Intertropical Convergence Zone
LAKI	Lima Adaptation Knowledge Initiative
MEECC	Ministry of Environment, Energy, and Climate Change
MHILT	Ministry of Habitat, Infrastructure, and Land Transport
MJO	Madden-Julian Oscillation
MO	Mode of Operation
PReP	Partnership for Resilience and Preparedness
PUC	Public Utilities Company
RGCM	Regional General Circulation Model
SCR	Seychellois rupees *(Exchange rate utilized in this report: US$1=SCR 13.75)*
SEAS	School for Environment and Sustainability
SEZ	Seychelles International Airport
SIDS	Small Island Developing States
STG	Subtropical Gyres
TEU	Twenty-foot Equivalent Units
TWI	Topographic Wetness Index
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute

Abstract

The Republic of Seychelles, like other island nations, is at risk from anthropogenic climate change. Adapting to future climate change requires making difficult decisions under conditions of uncertainty. While the uncertainty cannot be fully resolved, informed adaptation decisions can be made by broadly appraising the various dimensions of risk—climate hazards, exposure, and vulnerability—posed by sea level rise and storm surge to Seychelles' critical infrastructure. Global climate models, local climate feature projections, and local climate trends were synthesized to create five climate scenarios to guide Seychelles' adaptation decision-making. Vulnerability maps were created by combining local climate and socioeconomic data into a Geographic Information Systems (GIS) format. This report concludes with a list of recommendations aimed at better protecting Seychelles' critical infrastructure from sea level rise and storm surge and fostering climate-resilient development. In addition to this report, the project developed online risk maps and a Climate Scenario Planning Toolkit, all of which were designed to meet the needs of local stakeholders. This work is part of a larger effort by the United Nations Framework Convention on Climate Change (UNFCCC), known as the Lima Adaptation Knowledge Initiative (LAKI), which aims to close knowledge gaps regarding climate adaptation. In this capacity, it will serve not only to guide the Seychelles Government's approach to climate change adaptation but may also aid other island nations facing similar climate risks.

Evaluating the Impacts of Sea Level Rise and Storm Surge on Seychelles' Critical Infrastructure

Summary for Policymakers

OVERVIEW

The Republic of Seychelles, like other island nations, is at risk from anthropogenic climate change. Adapting to future climate change requires making difficult decisions under conditions of uncertainty. While the uncertainty cannot be fully resolved, informed adaptation decisions can be made by broadly appraising the various dimensions of risk and planning for a range of future climate scenarios. This research evaluated multiple dimensions of risk—climate hazards, exposure, and vulnerability—posed by sea level rise and storm surge to Seychelles' critical infrastructure:

Characterize Climate Hazards of Sea Level Rise and Storm Surge

Seychelles-specific climate models were used to project changes in frequency and intensity of climate hazards and to develop five future climate scenarios.

Geospatial analysis assessed the physical extent of sea level rise and storm surge on Mahé to generate a Storm Surge and Sea Level Rise Exposure Index.

Evaluate Exposure of Critical Infrastructure

Stakeholder interviews identified infrastructure that is frequently impacted by sea level rise and storm surge.

Georeferenced infrastructure was layered on the Storm Surge and Sea Level Rise Exposure Index to generate an Infrastructure Exposure Index.

Assess Social Vulnerability

Stakeholder interviews characterized Seychelles-specific vulnerabilities.

Geospatial maps illustrating social vulnerability issues—such as literacy rates, gender distribution—were layered on the Storm Surge Exposure and Sea Level Rise Index.

Integrate these Dimensions to Evaluate Climate Risk

Future climate scenarios provided insight on a range of climate risks facing Seychelles Geospatial analysis combined hazards, exposure, and vulnerability in order to assess climate risk.

Barriers to successful adaptation in Seychelles were identified by stakeholders.

This work is part of a larger effort by the United Nations Framework Convention on Climate Change (UNFCCC), known as the Lima Adaptation Knowledge Initiative (LAKI), which aims to close knowledge gaps regarding climate adaptation. This research fills a key gap identified by Seychelles and other small island nations in the Indian Ocean regarding the impacts of sea level rise and storm surges on critical infrastructure in coastal areas.[1] This summary for policymakers details five key outcomes of this research:

1 Future Climate Scenarios	2 Risk Mapping	3 Identifying At-risk Infrastructure	4 Barriers to Climate Adaptation	5 Recommendations
Five future climate scenarios were developed for Seychelles and used to build a toolkit to aid adaptation decision-making.	The impact of sea level rise and storm surge on Mahé was assessed using geospatial analysis.	Three key infrastructure sectors were identified.	Three categories of barriers emerged.	Three domains of recommendations are offered to aid climate adaption.

CLIMATE FEATURES

Five climate scenarios were developed to help Seychellois decision-makers better envision the country's climate future. These scenarios address not only sea level rise and storm surge, but other important climate impacts including coastal erosion, soil salinity, and disruption of marine ecosystems. The scenarios were based on several climate features specific to Seychelles' region:

General Climate Features

Ambient temperature, precipitation, sea surface temperatures, and sea levels are all projected to rise, according to the IPCC AR5 high-emissions scenario (RCP 8.5).[5]

Atmospheric-oceanic Features

The Somali Jet, Madden-Julian Oscillation, and Indian Ocean Dipole affect the directionality, seasonality, and intensity of precipitation in the region. All are projected to increase precipitation in the Seychelles region during the Southeast Monsoon and potentially decrease precipitation during the Northwest Monsoon.[2,3,4]

Topographic-oceanic Features

The Seychelles Dome is an area of shallow thermocline created by Seychelles' position on the Mascarene Plateau, an elevated ridge of land in an inverted "C" shape. The dynamic thermocline fluctuates between increased upwelling (cold water mixing with sea surface water) and decreased upwelling. The Seychelles Dome affects sea surface temperatures, which remain unusually high year-round.[6]

Geologic Features

Seychelles' inner islands have a granitic structure—the solubility of the granite makes them susceptible to rockfalls as a result of precipitation, as the rock is weakened by rainfall. This problem may be exacerbated by increased mountain construction on the islands.[5]

FUTURE CLIMATE SCENARIOS

Warm and Wet Scenarios

Extreme rain

- Increase in seasonal/monsoonal precipitation, with highest increase in extreme precipitation
- Increased occurrence of flooding in downtown Victoria and low-lying areas
- Shorter time intervals between flooding
- Increased occurrence of rockfalls, possibly impacting inland infrastructure and private property
- More extreme rain after seasonal rain, possibly increasing mudslides

Low sea level rise, extreme storm surge

- Slow but continuous coastal erosion
- Increase in extreme storm surge events, possibly impacting critical coastal infrastructure and fishing industry
- Shorter time intervals between extreme storm surge events
- Possibility of increased storm tides

Wind-related upwelling

- Increase in MJO-related westerly winds
- Related increase in cold-water upwelling in Seychelles Dome region leading to decreases in sea surface temperatures
- Reduced coral bleaching
- Reduced sea surface warming effect on marine ecosystems

High sea level rise, warmer sea surface

- Increased rates and occurrences of coral bleaching
- Disruption of marine ecosystems
- Accelerated coastal erosion, possibly impacting critical coastal infrastructure and private property
- Possibility of increased soil salinity, affecting agriculture yields and transformation of mangrove systems
- Possible overwhelming of drainage systems

Extended Warm and Dry Scenario

Drought

- Increase in likelihood of wildfires
- Increase in stagnation of water bodies, leading to increase in proliferation and spread of disease-carrying vectors
- Diminished supply of water for public consumption, industrial uses, and agricultural uses

MAPPING OF RISK

Geospatial analysis was used to assess the impact of sea level rise and storm surge on Mahé. Five major analyses were conducted to identify specific areas of concern for the island:

Mahé's Physical Exposure to Climate Hazards
Preliminary research yielded a Storm Surge and Sea Level Rise Exposure Index that calculated the physical exposure of the island to two meters of sea level rise and severe storm surge.

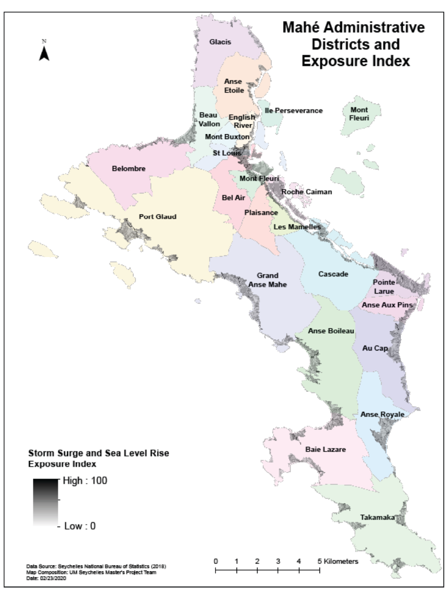
Infrastructure Exposure
Using infrastructure density and the Storm Surge and Sea Level Rise Exposure Index, an infrastructure exposure assessment was completed, giving individual pieces of infrastructure an exposure score.

Social Vulnerability
Adaptive capacity of the island, measured by financial resources and other social factors, was recognized as a critical part of assessing vulnerability. Researchers were able to use several socio-economic data sets to demonstrate ways in which to include social factors such as literacy, gender, and population density in adaptation decision-making.

Geologic Events
Increases in precipitation intensity and frequency may exacerbate geologic events such as landslides and rockfalls. To account for the risks they pose, geologic events from 1862 to 2011 were mapped.

Administrative Districts
Recognizing that some adaptation decision-making may be conducted at the subnational level, researchers layered exposure to storm surge and sea level rise with administrative districts.

RISK

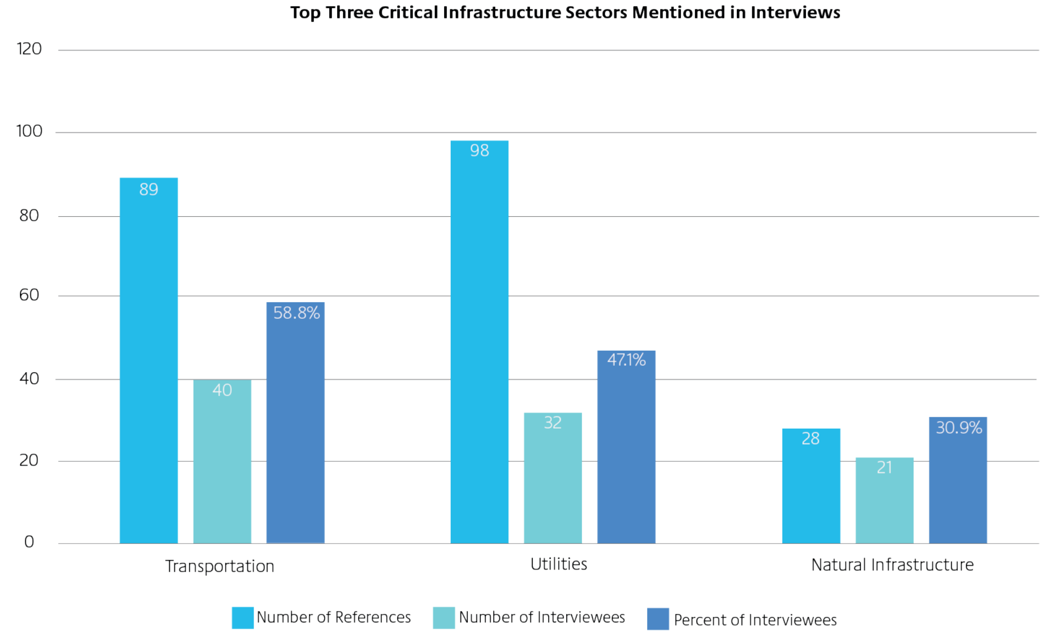


Administrative districts with Storm Surge and Sea Level Rise Exposure Index.

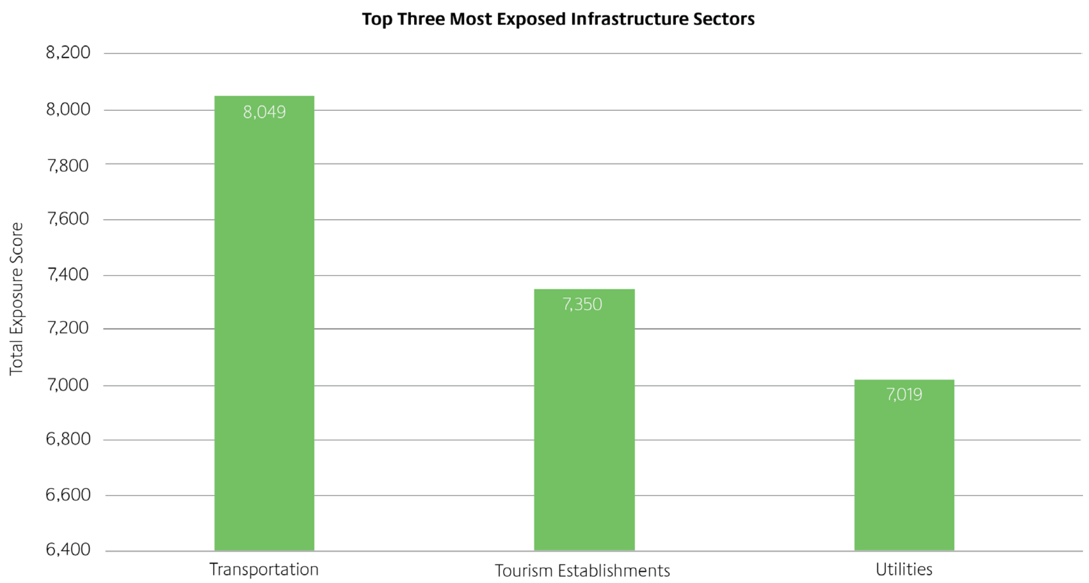
Data layers available online at:
https://bit.ly/2SqZD3I

IDENTIFYING AT-RISK INFRASTRUCTURE

Seychelles' at-risk critical infrastructure was identified using both interviews and geospatial mapping. These analyses identified three sectors as being the most exposed to climate hazards: transportation, tourism and fisheries, and utilities. Stakeholders described these sectors as the most critical because of their economic value, their necessity during a disaster or emergency, and the number of Seychellois they serve. Geospatial analysis revealed that these sectors also have high exposure to storm surge and sea level rise. An overview of each of these sectors, their functions, and their potential climate-related impacts are discussed on the following pages.



Top three critical infrastructure sectors mentioned by interviewees. Natural infrastructure encompasses the tourism and fisheries industries.



Top three infrastructure sectors most exposed to climate hazards. The fisheries industry was not included in this analysis because georeferenced data was not available.

AT-RISK INFRASTRUCTURE: TRANSPORTATION

This project's infrastructure exposure assessment identified the transportation sector (e.g., airports, seaports, bus systems, roads, culverts, retaining structures, and drainage) as having the highest exposure score across all sectors. Transportation was also the critical infrastructure sector most mentioned by Seychellois stakeholders.

A car driving along a coastal road in Bel Ombré.

The transportation sector has a diffuse authority structure, with several departments (e.g., The Department of Transportation, Land Transport Authority, Public Transport Corporation, Port Authority, and Civil Aviation Authority) managing distinct components. Each component of the transportation sector serves different needs. For example, the airport is necessary to support tourism which is one of the country's primary economic drivers. Fishing is another pillar of the economy and is supported by seaports. Bus routes cater to local inhabitants who support the local economy. Thus, the many components of the transportation sector are vital to the island of Mahé and the Seychelles archipelago.

Climate change is likely to impact transportation infrastructure. In the past, Mahé has been devastated by extreme weather events that have flooded the airfields, forced long-term road-closures, and damaged airport terminals, bridges, culverts, and retaining structures.[7] The functioning of the transportation sector is intrinsically linked to the functioning of drainage and sewerage systems, which have historically been overwhelmed by extreme precipitation events. Unfortunately, these events are anticipated to increase in both severity and intensity as a result of climate change. This may overwhelm the capacity of drainage and sewerage systems that were not designed to handle such intense storms.[8] Flooding effects may also be compounded by an increase in both storm surge and sea level rise.

The negative economic effects of consistent flooding on Mahé's transportation infrastructure could be considerable. Extended road closures could impede employee commutes to work, impair the provision of essential services (e.g., emergency response vehicles), and prevent the delivery of goods. In the long term, repeated exposure to extreme precipitation, storm surge, and rising sea levels may render some coastal roads unusable. At the airport, storms could disrupt flights and damage runways. Seaport damages could affect port shipping schedules.[9]

AT-RISK INFRASTRUCTURE: TOURISM AND FISHERIES

Though the fishing and tourism industries are independent of one another, they have been grouped together because of their shared dependence on the environment. These two Seychellois economic drivers are linked to the ecological health and preservation of coral reefs and coastal areas. Tourism establishments like hotels, bed and breakfasts, and self-catering facilities had the second highest exposure score of the sectors analyzed. Natural infrastructure (e.g., beaches, sand dunes, coral reefs, hotels, tourism, guest houses, tourism establishments, fisheries, the canning factory, fishing ports, fishing areas, processing plants, traditional fishing, and the ice plant) ranked third based on the percent of interviewees characterizing it as critical infrastructure. Unfortunately, the fishing industry was not included in the infrastructure exposure assessment because georeferenced data was not available for ice plants and fishing ports.

A group of local fishermen pull their boat ashore in Glacis.

Climate changes will impact the viability of Seychelles' exclusive economic zone (EEZ), a 1.3 million km^2 sea zone where Seychelles has exclusive rights to natural resources and economic activity.[10,11] Oceanic climate impacts in the EEZ (e.g., increased frequency and intensity of storm events, higher ocean temperatures, more ocean acidification, higher concentrations of oceanic carbon dioxide and lower concentration of oceanic oxygen) will increase stress on coral reefs, potentially resulting in disease outbreaks, bleaching, impaired reproduction, and reduced calcification.[11] Evidence shows that the deaths of fringing reefs will ultimately result in increased wave energy reaching the shorelines, erosion, and sand deposition behind beaches.[12] These conditions will also shift tropical tuna stocks poleward, decrease catch potential, and compress tuna habitats, ultimately reducing productivity of fisheries within Seychelles' EEZ.[13,14]

The fishing and tourism industries provide the majority of earnings and economic activities in Seychelles. Fisheries contribute about 80% of export revenues and employ about 11% of the population.[15] Eco-tourism employs 60% of the population.[10] The impact of oceanic and coastal hazards from climate change on these industries presents a serious risk to the national economy.

AT-RISK INFRASTRUCTURE: UTILITIES

Utility infrastructure (e.g., water system, electrical grid, oil storage facilities, telecommunication lines, sewerage system) had the third highest exposure score. It also had the second highest percentage of interviewees characterizing it as critical infrastructure.

Damages to water infrastructure (e.g., sewers) could lead to disruption of water services, increases in water prices, and a decline in agricultural production. Overwhelmed sewage systems could lead to wastewater overflow into land and freshwater systems.[16] Flooding could damage electrical infrastructure, leading to electrical energy shortages. Damage to telecommunications infrastructure could disrupt commerce.

Additionally, the high salinity of seawater can corrode metals and other building materials five times faster than freshwater, putting utility infrastructure at particular risk.[17] Saltwater intrusion can also contaminate freshwater resources, cause land subsidence, and change the flow patterns of rivers and lakes which can disrupt water pressure in pipes.[17]

A utility line runs along a coastal road in Bel Ombré.

Utility pipes along a hiking trail in Anse Major.

BARRIERS TO CLIMATE ADAPTATION

During interviews, many Seychellois working on climate adaptation relayed a common story: Climate documents are being produced, proclamations declared, and policies enacted, but nothing is being done to implement the projects. These stakeholders—government officials, NGO representatives and local business owners—identified three categories of barriers to the implementation of adaptation projects: lack of capital, scarce developable land, and limited human capacity.

Lack of Capital

While Seychelles has recently passed the World Bank threshold to being considered a developed country, the government does not have adequate capital to fund climate adaptation projects. Overall government budgets are limited and climate-related projects must compete with other government projects for annual funding. For example, the Ministry of Energy, Environment and Climate Change (MEECC) has to compete with educational programs and medical campaigns, which are more often prioritized. Meager funding for climate adaptation means that such projects must focus on keeping costs down instead of adequately preparing for climate risks.

Scarce Developable Land

Much of the developable land on Mahé is located on a narrow, low-lying coastal plain that is caught between the ocean and the mountains. This area is already prone to flooding and at further risk from sea level rise. A common adaptation approach involves moving critical infrastructure (e.g., public roads) to safer areas, but there is limited land for relocation. Some of that land is also privately owned which could cause conflicts if government projects need to utilize private property. The prospect of using land at higher altitudes is also limited because the slope into Mahé's mountain is extremely steep. Continuing to excavate the side of the mountain to, for instance, relocate roads decreases the stability of the mountain face and increases the likelihood of rockfalls. Currently, higher altitude development is not legal because the government has restricted development above a certain elevation in order to preserve the natural beauty of Mahé's mountains.

Limited Human Capacity

Because Seychelles' government has few climate experts, it relies on a limited supply of outside consultants. As a result, there is a lack of cohesive planning to address climate risk. Projects often start without a science-based foundation or approach, leading to an ineffective trial-and-error strategy. Poor coordination between government departments working on climate-related projects has led to redundant projects which not only waste limited capital, but also human capacity. Furthermore, because most government staff working on climate also have responsibilities in other areas, there is a higher turnover rate in climate departments. This hampers the development of local climate expertise and reduces the personnel crucial to implementing adaptation projects. For the general Seychellois population, climate change is a familiar but poorly understood concept. Most citizens expect the government to deal with the problem of climate change but do not appreciate the magnitude of the challenge. Government has not adequately communicated with the public about the climate risks facing the nation.

KEY TAKEAWAYS

FUTURE CLIMATE SCENARIOS

- Extreme rain
- Low sea level rise, extreme storm surge
- Wind-related upwelling
- High sea level rise, warmer sea surface
- Drought

AT-RISK INFRASTRUCTURE

TRANSPORTATION

Disruption of economic activity and provisioning of goods and services

Flight and shipping disruptions

Road flooding from overwhelmed sewerage/ stormwater infrastructure

TOURISM & FISHERIES

Bleaching, impaired reproduction, and reduced calcification of coral

Death of fringing reefs leads to stronger wave energy reaching shores, coastal erosion, and sand deposition behind beaches

Compression of tuna habitats and tuna stocks shifting poleward, resulting in decreased catch potential and productivity of fisheries

UTILITIES

Inundation of water infrastructure

Disruption of electrical and telecommunication services

Corrosion of infrastructure from saltwater

Increase in utility costs

BARRIERS TO CLIMATE ADAPTATION

- Scarce developable land
- Lack of capital
- Limited human capacity

RECOMMENDATIONS

These recommendations are discussed in greater detail in the conclusion chapter of the final report.

Research and Knowledge Sharing

1. Develop a policy and platform to share climate data across government agencies
2. Assess climate risk for all of Seychelles' islands
3. Construct a Social Vulnerability Index to improve climate risk assessment
4. Improve tracking and mapping of geologic events and restrict development in areas prone to damage
5. Invest in localized modeling for the West Indian Ocean to better understand Seychelles-specific climate change impacts
6. Integrate green and gray infrastructure adaptation projects and establish robust monitoring and evaluation plans

Stakeholder Engagement

7. Create a Seychelles Climate Commission to coordinate adaptation efforts
8. Engage the private sector and the citizenry in climate adaptation efforts

Funding Adaptation Projects

9. Employ staff to secure national and international funding for climate adaptation
10. Incentivize climate-resilient development
11. Encourage transitional financial support for recently designated high-income countries

Chapter 1
Introduction: Assessing Climate Risk in Seychelles

Small islands and low-lying coastal communities are particularly exposed to sea level rise and extreme weather events resulting from anthropogenic climate change.[18] The Republic of Seychelles, an East African archipelago made up of 115 islands in the Indian Ocean, is one of 58 Small Island Developing States (SIDS) around the world. Like many SIDS, Seychelles is currently facing unprecedented threats as a result of climate change.[19] Due to the geophysical nature of Seychelles—particularly its narrow coastal plain, which is susceptible to flooding from sea level rise, and central mountainous region, which causes extreme precipitation runoff toward the highly populated coastline during rain events—it is subject to recurrent flooding. These floods pose a risk to Seychelles' critical infrastructure, most of which is found on the eastern shoreline of Mahé, the island that contains 86% of the population, drives the entire country's economy, and is the seat of the national government (Photo 1.1).[20] Adapting Mahé's coastal zones requires integrating a risk assessment based on localized climate projections into community-based decision-making.

Photo 1.1. Victoria as seen from Copolia Trail.

To foster climate adaptation efforts, the United Nations Framework Convention on Climate Change (UNFCCC)-mandated Nairobi Work Programme established the Lima Adaptation Knowledge Initiative (LAKI) to fill knowledge gaps that inhibit the implementation and scaling of climate adaptation strategies.[1] By synthesizing existing adaptation research, LAKI improves information-sharing between scientists, policymakers, and stakeholders. Included in the methodology of LAKI are four key characteristics: 1) generating ownership and legitimacy of findings, 2) directing resources towards closing knowledge gaps, 3) streamlining the processes to enhance replicability, and 4) fostering collaborative opportunities. In a 2016 LAKI workshop, Seychelles and their small island counterparts in the Indian Ocean identified their primary knowledge gap as:

> *"insufficient information on the impacts of storm surges and other extreme events on coastal areas, including erosion and impacts on infrastructure, and drinking water supply."*[1]

Another knowledge gap identified was:

> *"insufficient information on the impacts of sea level rise on coastal areas, including erosion and impacts on infrastructure, and drinking water supply."*[1]

Filling these knowledge gaps can help Seychelles better adapt to their future climate. Doing so requires making decisions when the timing and severity of climate change impacts are uncertain. In order to improve such decision-making, this research assesses the risks that sea level rise and storm surge pose to Seychelles' critical infrastructure.

A climate risk assessment framework developed by the Intergovernmental Panel on Climate Change (IPCC) models the complex interactions between hazards, vulnerability, and exposure that determine climate risk (Figure 1.1).[5] Hazards are defined as the potential occurrence of a physical event or impact that may cause loss of life, injury, or damage and loss of property, infrastructure, livelihoods, service provision, ecosystems, or environmental resources. Exposure is the presence of people, livelihoods, ecosystems, services, resources, infrastructure, or assets in places that could be adversely affected.

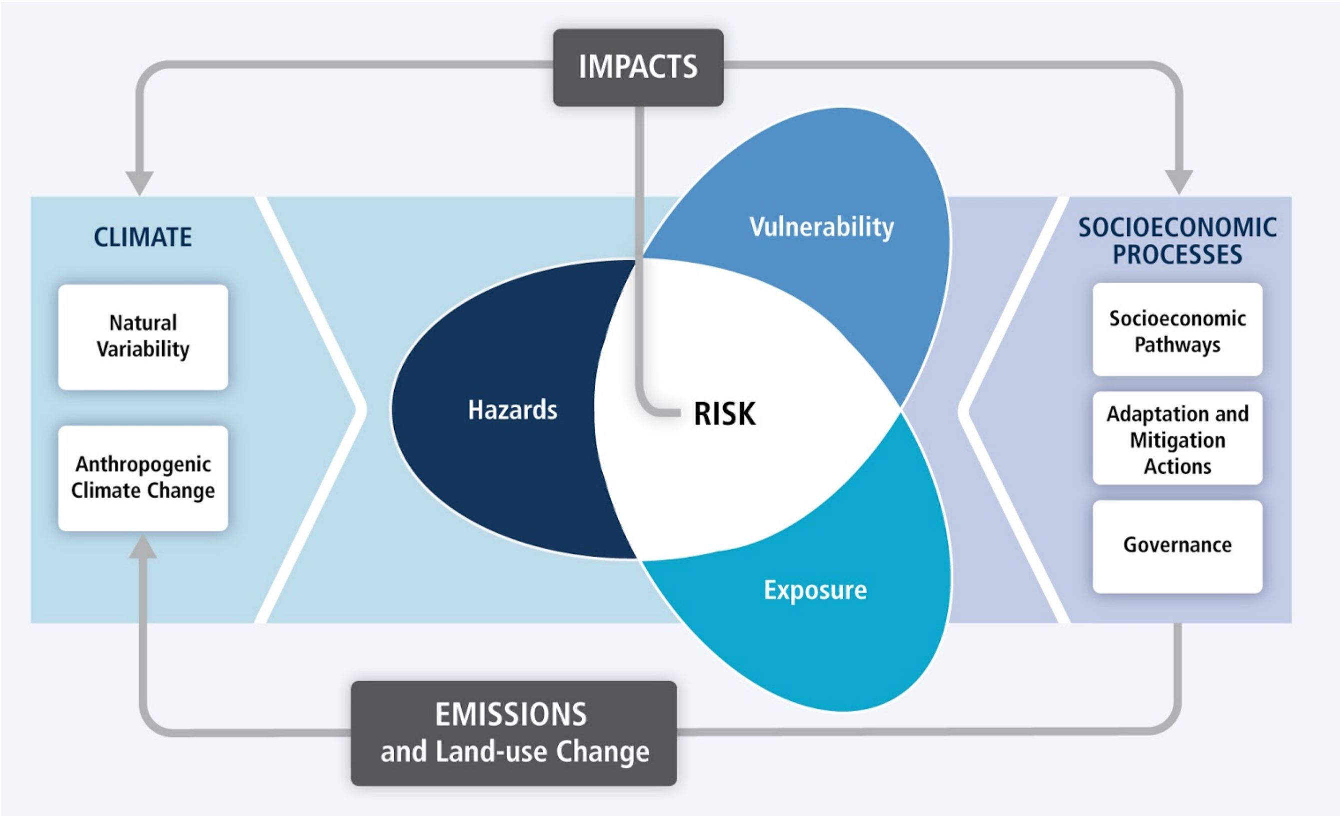


Figure 1.1. IPCC risk assessment framework. Reproduced from Climate Change 2014: Impacts, Adaptation, and Vulnerability: Part A: Global and Sectoral Aspects. (p. 3), by IPCC, 2014, Cambridge University Press.

Vulnerability is the propensity or predisposition to be adversely affected; it encompasses elements including susceptibility to harm and lack of capacity to cope and adapt. This research focuses on the hazards presented by sea level rise and storm surge in Seychelles, the exposure of critical infrastructure on the island of Mahé, the vulnerability of Seychellois residents, and the risks that arise from the interactions between them. The remainder of this first chapter describes each of these in detail and weaves in relative facts about Seychelles' climate, terrain, history, governance, economy, existing infrastructure, and current climate adaptation approaches.

1.1 Climate Hazards Facing Seychelles

> ***Hazard:*** *The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts.*[5]

As a low-lying island state in the Indian Ocean, Seychelles is threatened by several climate-related hazards, such as sea level rise and storm surge. This section describes the current climate system in Seychelles and the projected hazards from anthropogenic climate change.

1.1.1 Natural Climate Variability

Seychelles experiences a tropical climate with humidity of 80% to 82% year-round and temperatures ranging from 24°C to 33°C. Rainfall averages from around 2,500 to 4,000mm per year, with the most precipitation falling along the central mountain slopes in Mahé.[21] Seychelles weather is heavily influenced by the monsoonal seasons of the Indian Ocean region. From October to March, during the Northwest Monsoon, Seychelles experiences warm, wet, and humid weather accompanied with weaker winds, and the surrounding ocean is generally calm. Most of the rainfall comes in January and February. From May to September, during the Southeast Monsoon season, the weather is drier and cooler with stronger winds and rougher ocean conditions.[22]

Seychelles' climate is influenced by a number of regional features. The Somali Jet, which blows up and to the right along the East African Coast as a carrier of the Indian Summer monsoon, transports moisture away from and toward Seychelles seasonally.[23] The Madden-Julian Oscillation (MJO) is an area of enhanced and subsequently suppressed precipitation that travels across the Indian Ocean, playing a role in monsoonal intensity.[24] The Indian Ocean Dipole (IOD) is a phenomenon that takes place when the West Indian Ocean becomes comparably warmer (positive IOD phase) or colder (negative IOD phase) than the East Indian Ocean; a positive phase generally means more precipitation in the Seychelles region.[25] A positive IOD phase has been linked to El Niño, and a negative IOD phase linked to La Niña.[26] Finally, the Seychelles-Chagos Thermocline Ridge, or Seychelles Dome, is a region of abnormally high sea surface temperatures and a shallow thermocline (mixed ocean layer depth) that causes increased or decreased ocean upwelling on a periodic basis.[27] These features are expanded upon in Chapter 3.

Though the Seychelles archipelago lies outside the Intertropical Convergence Zone (ITCZ), where tropical cyclones are most prolific, some of the islands are impacted by cyclones from time to time. The outer islands closer to the ITCZ are sometimes directly hit by cyclones and the other islands often receive peripheral effects such as heavy rain and strong wind. Generally, most damage from tropical storms is concentrated on Seychelles' outer islands. Three notable cyclones have hit Seychelles in recent years. In 1990, Tropical Cyclone Ikonjo hit Desroches Island, an outer island, bringing strong winds and intense rainfall. In 2006, Tropical Cyclone Bondo made landfall over the Farquhar and Providence Atolls, also part of the outer islands, which bore the brunt of the damages from heavy winds, rain, and sea swells up to three meters high. Bondo also brought moderate rainfall and strong wind to the inner islands. In 2013, Tropical Cyclone Felleng made landfall in the inner islands, including Mahé, producing harsh winds and massive flooding, with the worst damages occurring in La Digue, the third largest island located north of Mahé.[22]

1.1.2 Anthropogenic Climate Change

Climate change is the result of anthropogenic emissions of greenhouse gases, such as carbon dioxide and methane, that are released into the atmosphere and trap the sun's radiative heat. This process, called radiative forcing, causes the Earth's atmosphere and ocean systems to warm, leading to the destabilization of other natural processes. This destabilization increases the length and intensity of weather events (i.e. drought, rainfall, and snow), melts land ice at the poles, subsequently causing global sea level rise, extends migration ranges of disease vectors, and leads to the extinction of many flora and fauna species. In addition to the effects felt on land, the ocean's ecosystems are also impacted through warming temperatures, ocean acidification, coral bleaching, and hypoxic zones. The IPCC has reported that anthropogenic greenhouse gas emissions have already raised global average temperatures by approximately 1°C above pre-industrial levels and a global average temperature increase of +1.5°C will have irreversible impacts.[28]

Localized climate change models for Seychelles, which can provide more granular projections than global models, are detailed in Chapter 3 of this report. In broad terms, Seychelles can expect a warmer and wetter climate in the coming decades. By 2100, the IPCC estimates that Indian Ocean islands can expect to see an increase in air temperature between 1.8 and 2.3°C, a change in the sea surface temperatures of subtropical gyres between –0.03°C and 0.90°C, and considerable increases in sea level rise and precipitation rates under a moderate warming scenario.[5] The rainy season is projected to be wetter.[29] These climatic shifts, and changes to the climate and ocean systems that dictate local weather patterns, are expected to impact Mahé and the other Seychellois islands in a variety of ways; an increase in local flooding, landslides, wildfires and coral die-off events are all possible.

Sea Level Rise

Sea level rise is a significant climate hazard facing Seychelles. Analysis of available, but inconsistent, sea level data in Seychelles shows an average sea level rise of 6.6mm per year from 1993 to 2010. A lack of consistent data collection has made it difficult to downscale regional models specifically to Seychelles, meaning that regional projections are currently the most complete information source. Regional models predict sea levels to rise anywhere from 0.4 to 0.6m by 2100, depending on the emission scenario.[22] This is likely to be an underestimation, as more recent iterations of coupled General Circulation Models (GCMs) tend to predict ever greater climate impacts, including sea level rise. The mean elevation of the coastal plateau of Seychelles' granitic islands is only two to ten meters above sea level and two to nine meters in the coral islands.[29] Additionally, the steep topography and lack of suitable land for infrastructure and development compounds the vulnerability to sea level rise as it has resulted in the concentration of economic activity and population on narrow coastal plains.[29] As a result, sea level rise could displace large portions of the population, low-lying coral islands and sand cays could disappear, and the tourism and fisheries industries are expected to be largely disrupted.[22] Sea level rise also poses a threat to property, infrastructure, and economic activity in Seychelles' coastal areas through increased flooding, erosion, and soil salination.[30] Higher sea levels also worsen the impact of storm surge and high tides.[22]

Storm Surge

A storm surge occurs when a cyclone or tropical depression makes landfall resulting in a sudden increase in sea level which moves inland.[22] Storm surges can cause extensive coastal damage, impair coastal infrastructure, accelerate beach erosion, and cause severe destruction when combined with high tidal events.[29] Because a storm surge only occurs when a cyclone makes landfall, and most of Seychelles lies outside the ITCZ, storm surges are uncommon in Seychelles. Due to their proximity to the equator, it is less likely that the island of Mahé and the inner islands will experience storm surges due to their proximity to the equator. However, the outer islands face a higher probability of storm surge events.[22] As previously mentioned, three notable cyclones have made landfall in Seychelles in recent years. While no storm surge has resulted from these cyclones nor have any others been recorded in Seychelles history, the IPCC expects an increase in intensity and magnitude of regional storm surges in the future.[18,22]

Climate hazards are explored further in:

- **Chapter 2:** Identifying a wider range of climate hazards through stakeholder interviews
- **Chapter 3:** Localized modeling of climate hazards to create several possible future scenarios
- **Chapter 4:** Assessing the physical extent of sea level rise and storm surge on Mahé using geospatial analysis

1.2 Exposure of Seychelles' Critical Infrastructure

Exposure: *The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.*[5]

Climate hazards will have different regional impacts in Seychelles, with coastal areas facing greater threats. In Mahé, dense population centers and most critical infrastructure sit on a narrow, low-lying coastal plain exposed to threats of sea level rise and storm surge. This section describes Seychelles' geophysical characteristics and critical infrastructure in order to evaluate potential exposure to climate hazards.

1.2.1 Geophysical Characteristics of Seychelles

The Seychelles archipelago has a total land area of about 445 km^2 and an exclusive economic zone (EEZ) of about 1.3 million km^2. Of the 115 islands that compose the archipelago, 41 are granitic and the remaining 74 are coralline.[10] Seychelles' EEZ is the bounded area of coastal water and seabed for which Seychelles has exclusive rights for fishing, drilling, and other economic activities.[31] All islands in Seychelles and the entirety of the country's EEZ can be found between zero and thirteen degrees south of the equator, although the four islands with the largest population concentration—Mahé, Praslin, Silhouette, and La Digue—are clustered within a 65 km region of the country.

Photo 1.2. Granitic rocks along the beach at Anse Major.

The main island of Mahé is largely developed within a small strip of coastal plateau that lies two meters above sea level.[29] Mahé is a granitic island which was formed by the peaks of a granitic microcontinent emerging from the underlying tectonic plates, reaching a peak at about 905 meters above sea level.[21] While the microcontinent is relatively stable within the greater African Tectonic Plate, and therefore unlikely to experience earthquakes, the granitic composition of the island makes it susceptible to landslides and rockfalls. Seychelles granites, as seen in Photo 1.2, are intrusive igneous rocks formed by the melting and pressurization of different minerals underground, followed by a period of cooling above the earth's surface.[21] Weaknesses along the fractures of the minerals within the granite are exacerbated by weathering, particularly physical weathering caused by rainfall or wave energy, which can lead to large pieces detaching from the rock mass and falling and erosion. These geological characteristics make Mahé and the other granitic Seychelles islands, paired with intensified rainfall patterns, storm surges, sea level rise, and increased wave energy, make the occurrence of landslides and rockfalls more likely. Land with high elevation, like the central peak on Mahé, is susceptible to orographic rain that is produced when air masses are lifted and move over areas of high elevation or mountain tops. This further exacerbates the weathering of the granitic islands.

1.2.2 Infrastructure in Seychelles

The core infrastructure in Seychelles includes the road system, seaport, airport, energy generation and distribution, water supply and distribution, sewerage system, agricultural land, and fisheries and tourism industries. Each piece of infrastructure has at least one agency that manages its operations. Table 1.1 outlines these agencies and their sectoral responsibilities as they relate the infrastructure of Seychelles.

Roads

The Department of Transportation supervises the transportation sector in Seychelles. Road operations, including maintenance of roads, bridges, culverts, retaining structures, drainage, and footpaths, are the Mahé—supports travel of both personal vehicles and public transportation.[32] Between 2010 and 2015, vehicle ownership grew by 8.4% while the population grew by 0.7%. Seychelles' public bus system makes over 600 bus trips per day, servicing as many as 60,000 residents. Buses are accessible to a majority of the island's population, with most responsibility of the Seychelles Land Transport Authority. The public transportation system is managed by the Seychelles Public Transport Corporation. The road network in Seychelles totals 508 kilometers—a bulk of which is found on residents living within ten to fifteen minutes of a bus stop. Existing traffic volumes within Victoria range from 300 to more than 900 vehicles per hour during peak driving periods.[32] Few roads cross through the middle of the island, given its mountainous terrain and steep elevation, but a perimeter road is located around almost the entire island, excluding a section on the northwestern side.

Table 1.1 Agencies and their respective sectoral responsibilities as they relate to infrastructure

Agency	Sector/Responsibility
Department of Transportation	Authority over transportation sector
Seychelles Land Transport Authority	Road operations, including maintenance of roads, bridges, culverts, retaining structures, drainage, and footpaths
Seychelles Public Transport Corporation	Manages public transportation system
Seychelles Port Authority	Manages Port of Victoria
Seychelles Civil Aviation Authority	Manages Seychelles International Airport
Public Utilities Corporation (PUC)	Oversees generation and distribution of electricity; storage, treatment, and distribution of potable water; and collection, treatment, and disposal of sewerage
Seychelles Energy Commission	Regulates electricity-related activities for adequate, reliable, cost-effective, and affordable electricity
Ministry of Fisheries and Agriculture	Oversees agricultural operations and the fisheries sector
Seychelles Fishing Authority	Manages development of industrial fishing, especially promoting, organizing, and developing industry resources
Tourism Department	Supervises the tourism industry
Seychelles Tourism Board	Maintains regulatory, functional, and promotional operations of the tourism industry

Sea Port

The Port of Victoria (Photo 1.3) is managed by the Seychelles Port Authority and operates 365 days per year, 24 hours per day, and is primarily used for fishing, imports, and exports. The port handles 80% of tuna from the nearby tuna processing plant with refrigerated units for export.[32] Port Victoria is the principal tuna transshipment port in the region with around 80% of tuna catch in the southwest Indian Ocean passing through the port.[33] Imported goods handled at the port include manufactured goods, fuels, minerals, food, chemicals, machinery, and transport equipment.[32] Tuna shipments comprise 66% of the exports from the port, with banknotes, ship stores in transit, tobacco cigarettes, and other dried or salted fish constituting the remaining 34%.[34] The port has an annual maximum container throughput capacity of 25,000 TEUs. In 2011, the port handled over six million tons of freight.[32]

Photo 1.3. A cargo ship docked at Port Victoria.

Airport

The Seychelles International Airport (SEZ) is located along the coastal plain on the southeast side of Mahé and is managed by the Seychelles Civil Aviation Authority (Photo 1.4
Photo 1.4). The runway can accommodate at least ten aircraft landings or take-offs per hour.[32] The average capacity of the terminal is estimated to be about one million passengers per year. 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 passengers that can be processed during peak traffic times.[32]

Photo 1.4. Employees at Seychelles International Airport prepare for an aircraft departure.

Energy Generation and Distribution

The Public Utilities Corporation of Seychelles (PUC) oversees the generation and distribution of electricity. The Seychelles Energy Commission regulates electricity-related activities for adequate, reliable, cost-effective, and affordable electricity. PUC operates a total of three power plants - two located on Mahé and one on Praslin. The plants on Mahé operate on heavy fuel oil, while Praslin's plant runs on light crude oil.[35] Oil to power these facilities is imported and stored in the Seychelles Petroleum Depot (Photo 1.5). The total power generation capacity in Victoria is 79.3MW, while the safe generation capacity is 53.4MW.[32] The transmission and distribution network cover a total of 395km and provides almost 100% of the population with access to electricity. This network includes 2,000km of distribution lines, 215km of overhead transmission lines, 70km underground transmission lines, and 279 substations. Domestic users make up 83% of electricity consumers in Seychelles, but only consume 33% of the electricity produced. Commercial use accounts for 14% of customers but consumes 55% of electricity produced. Government use accounts for 14% of customers and 12% of consumption.[35]

Photo 1.5. Silos storing oil at the Seychelles Petroleum Depot in Victoria.

Seychelles is dependent on imported fuel to meet its energy needs, but efforts have been made to expand the use of renewable energy sources. There are 290 solar PV systems connected to the electric grid in Seychelles, with a total installed capacity of 3,094kW. There is one wind farm in Seychelles (Photo 1.6), which has a capacity of 6MW. In 2018, renewable energy constituted 2.6% of total energy production in Seychelles.[35]

Photo 1.6. Off-shore wind turbine seen from East Coast Road in Victoria.

Water Supply and Distribution

PUC oversees the storage, treatment, and distribution of potable water, and the collection, treatment, and disposal of sewage. On Mahé, water is sourced primarily from rivers, reservoirs, and groundwater extraction, combined with four desalination plants as needed, depending on the intensity of the dry season. The country's water system includes 700km of pipes, three dams, four desalination plants, fifteen water treatment plants, and four sewerage treatment plants. Water supply coverage extends to more than 93% of the population in Seychelles. Domestic users constitute 90% of water customers, while commercial and government constitute 9% and 1%, respectively. 64% of water consumption is for domestic use, 27% for commercial, and 9% for government.[35]

Sewerage System

Photo 1.7. Sign detailing a wastewater treatment plant project in Victoria.

PUC also operates four sewerage treatment plants on Mahé, though there is an integral need to repair these plants in order to cope with current and future demands (Photo 1.7). The existing sewerage treatment and disposal system in Seychelles primarily consists of septic tanks and soak pits. Only 15% of the population is connected to the sewerage network, with a significant amount of homes located within the vicinity of the network, but not connected. 91% of sewerage customers are domestic users, who produce 51% of the volume processed by

PUC, commercial use makes up 8% of customers and 31% of the volume, and the government makes up 1% of customers and 18% of the volume.[35]

Agricultural Land

The Ministry of Fisheries and Agriculture oversees agricultural operations in Seychelles. Total arable land in Seychelles is estimated to be 500ha, of which 50% is exploited for agriculture. Agricultural land represents less than 1% of all land in Seychelles at a total of 3.75 km^2. The average farmland size is 0.5ha. Fruits, spices, vegetables, and root crops are the most common crops grown on agricultural land in Seychelles (Photo 1.8). Some meat—primarily beef and poultry—is produced in Seychelles, though it only accounts for 1% of total consumption in the country. Due to its limited agricultural production, Seychelles imports 70% of its food for consumption.[36]

Photo 1.8. Locally grown fruit being sold by a street vendor at the Sir Selwyn Selwyn-Clarke Market in Victoria.

Fisheries

Generally, the Ministry of Fisheries and Agriculture oversees the operations of the fisheries sector, but the Seychelles Fishing Authority manages the development of the industrial fishing, especially promoting, organizing, and developing the industry and resources in Seychelles. Fisheries contribute about 8% of national GDP in Seychelles and provide over 90% of export earnings. Fisheries export canned tuna, dried sea cucumber, sharks and rays, fish meal, and other consumable fish products such as smoked fish, fish oil, and artisanal fish (Photo 1.9). Canned tuna is the dominant output, followed by artisanal fish, and all other products. In 2014, the total inflow from the fisheries sector was US$508 million (SCR 6,986.5 million). Fish catch in Seychelles' EEZ consists primarily of yellowfin tuna, skipjack tuna, bigeye tuna, swordfish, marlins, sailfish, sharks, trevallies, jobfish, and mackerel, crabs, lobster, and sea cucumbers. There are six ice plants on Mahé with a daily production capacity of 40 tons, though ice shortages are a recurring problem for the fisheries. There are two processing plants and one canning factory on Mahé.[15]

Photo 1.9. Small fishing vessel enters Seychelles Fishing Port in Victoria.

Tourism Industry

The Tourism Department within the Ministry of Tourism, Civil Aviation, Ports, and Marine supervises the tourism industry, but the Seychelles Tourism Board, a public/ private body, maintains the regulatory, functional, and promotional operations of the tourism industry. Seychelles welcomed more than 361,800 visitors in 2018, a 3% increase from 2017. Most visitors (93%) visit Seychelles for a vacation trip and stay an average of ten nights. 66% of visitors come from Europe, 10% from Africa, 19% from Asia, and 4% from America. In 2018, foreign exchange earnings from the tourism industry amounted to US$569.5 million (SCR 7,832 million). Hotels account for 45% of all beds, self-catering establishments account for 36%, and guest houses constitute the remaining 19%.[37] Hotels typically offer a dining room with a menu of food prepared for guests, and sometimes offer room service. Self-catering establishments are apartments, hotel rooms, or hostels, where guests have facilities for cooking and preparing their own meals. Guest houses are private homes that are offered to visitors for exclusive lodging use.[37] There are 323 recorded tourism establishments throughout Mahé.[38]

Coral Reefs

Coral reefs in Seychelles cover an expanse of approximately 1,690 km^2 and provide habitat for fish and other organisms.[10] The reefs in Seychelles support both the country's tourism and fishing industries. Marketing of Seychelles as a vacation destination has traditionally focused on nature and "sea-sand-and-sun holidays." [39] Key tourism activities include boating, diving, and snorkeling. The current Tourism Master Plan includes strategic priorities such as focusing on eco- and marine-based marketing and development of a marine-based tourism strategy. However, there are no statistics collected on the number of tourists undertaking different marine activities, expenditure on marine activities, or the value of maritime tourism. The natural beauty of Seychelles—including its coral reef ecosystems—is the primary driver of tourism in Seychelles.[39]

The health of coral reefs is also linked to tuna stocks. Coral reefs directly support the distribution, reproduction, dispersal, recruitment, success, growth, and size of fish and other invertebrates associated with coastal habitats. Climate change impacts such as declining primary productivity and loss of corals affect these animals directly. The combination of these effects is expected to alter fish catch composition and reduce production. Tuna are pelagic fish, meaning they live in the water column (not near the bottom of the ocean or the shore), so they are not directly supported by coral reefs. However, tuna most commonly harvested in Seychelles prey on zooplankton, smaller fish, crustaceans, and small invertebrates - many of which are found in or around coral reefs. The decline of these prey species is directly related to the competitive interactions, and ultimate prosperity, of tuna stocks.[14]

Though coral reefs may not typically be considered infrastructure, Seychellois characterize them as such because they are critical to the local economy. Both tourism and fisheries rely on coral reefs for continued viability, making them a critical pillar of Seychelles' economy.

Government Buildings

There are a number of government buildings located across Mahé. These include food storage, public housing, educational institutions, medical facilities, police stations, district administration buildings, fire stations, and administrative offices.

The exposure of Seychelles' coastlines and critical infrastructure to climate hazards are explored further in:

- **Chapter 2:** Identifying at-risk critical infrastructure through stakeholder interviews
- **Chapter 3:** Localizing climate scenarios that address increase exposure for Seychelles
- **Chapter 4:** Identifying at-risk infrastructure through geospatial analysis

1.3 Vulnerability of Seychelles to Climate Hazards

> ***Vulnerability:*** *The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.*[5]

The propensity of Seychelles to be adversely impacted by future climate hazards depends not only on its financial resources, but also its political power, economic diversification, and the capability of its citizenry. For example, the distribution of governmental authority determines which agencies are responsible and capable of adapting to climate change. With respect to diversification, if the economy is based largely on climate-sensitive sectors, the country is more vulnerable to climate-induced economic shocks. Conversely, If the economy is more diverse and relies less on sensitive sectors, then the country is less vulnerable to such shocks. Regarding citizen capacity, a more educated population is typically going to be able to adapt more quickly and easily than a less educated population.

Adaptation measures can decrease vulnerability by reducing the impacts of climate hazards. Governance, including decision-making under uncertainty, coordination across scales, and monitoring adaptation actions, can enable effective implementation of adaptation action. This section describes the socioeconomic pathways, climate governance, and current adaptation approaches that influence Seychelles' vulnerability to climate change.

1.3.1 Socioeconomic Pathways

Population

Seychelles has a population of about 96,800 people.[40] 85.3% of the population lives on Mahé, 8.6% lives on Praslin, and 2.9% lives on La Digue and the Outer Islands. The male to female ratio is split evenly, but about 51% of households are female-headed as Seychellois culture is matriarchal. The average life expectancy is 72.6 years.[41] Literacy rates in Seychelles have been rising since 1987, reaching 95.8% in 2018.[42] This could be attributed to the free and compulsory schooling for all Seychellois. There is no indigenous population of the country, but immigrants of African, French, Indian, and Chinese ethnicity have shaped the ethnicity of most Seychellois today. The official languages of the country are English, French, and Seychellois Creole.[43]

Economy

Seychelles has a GDP of US$1.59 billion (SCR 21.87 billion).[40] Though Seychelles is one of the lowest ranked African countries for total GDP, it had the highest GDP per capita in Africa—US$15,410 (SCR 211,933)—qualifying it as a developed country by standards established by the World Bank.[40,44] The country has joined the ranks of high-income economies due to evidence of sustained economic growth fueled by rising productivity, due largely to its profitable tourism and fishing industries. While Seychelles is experiencing more economic stability and growth relative to many African countries, it has also accrued a large amount of debt to development institutions and other countries via foreign direct investment, business investments made by entities in foreign countries.[40] Additionally, its economic position is precarious in that it is not easy for Seychelles to diversify its economic portfolio. This is attributed to the country's heavy reliance on imports for many of its goods and services, lack of natural resources at its disposal, and vulnerability to natural disasters.[29] The amalgamation of these economic conditions makes the economy highly susceptible to external shocks.

Services, primarily the tourism industry, are key components of the national economy in terms of foreign exchange earnings, GDP, and employment generation. Direct earnings from the tourism sector constituted US$564 million (SCR 7,756.7 million) of the country's foreign exchange inflow in 2018.[45] The fishing industry is the second largest contributor to the economy, making up almost 90% of exports; fish (canned, processed, and fresh/frozen) made us US$295 million (SCR 4,057.1 million) of all domestic exports in 2018.[41] The prominence of tourism and fisheries—two economic sectors that are climate-sensitive—are a particular source of vulnerability for the country.

At the end of 2018, unemployment in Seychelles was at 3.5%, a decline of 0.6% from the previous year. The private sector accounted for 65% of employment, government accounted for 20%, and nongovernmental organizations with political authority accounted for the remaining 15%.[45] Absolute poverty levels are low in Seychelles, though there is still significant economic inequality.[40] In 2018, 22,011 beneficiaries received payments of social security, which amounted to a total of US$8.07 million (SCR 1,111 million) paid. The government expenditure in 2018 totaled US$537.3 million (SCR 7,389.5 million).[45] A breakdown of the 2018 expenditure is shown in Figure 1.2.

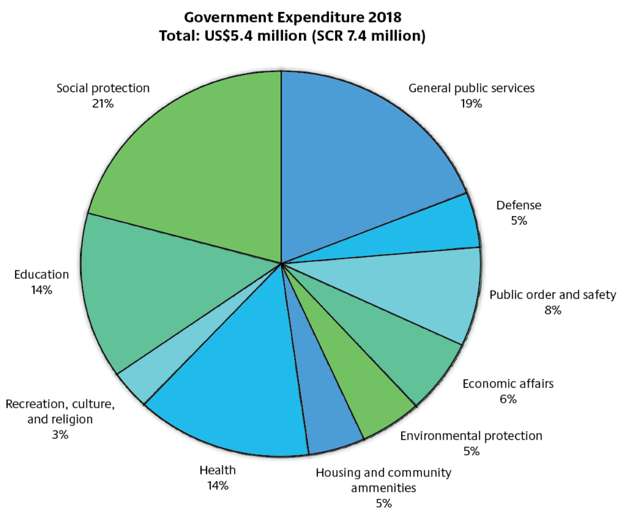


Figure 1.2. Total government expenditure for 2018, broken down by sector.

Political Structure

The islands that compose Seychelles today were first settled by French colonists in 1770. Battles between the French and British for control of the islands ended in 1814 when the archipelago was ceded to Great Britain. The British maintained control of the islands until they gained independence in 1976, when Seychelles became an autonomous country.[43] Following a coup to oust the first president in 1977, the country declared itself a socialist one-party state until 1993, when the current constitution was adopted. Today, Seychelles is a republic and holds free, democratic elections. The President of Seychelles is elected by popular vote for a five-year term. The President is the Head of State and Government and presides over a cabinet of Ministers appointed by the president and approved by a majority of the legislators. The National Assembly is the unicameral parliamentary body of Seychelles. The Assembly consists of 34 members, 25 of whom are elected directly by popular vote, while the remaining nine are appointed to parties on the proportional basis of election results. Members of the National Assembly serve five-year terms. The Supreme Court of Seychelles is the highest court in the Seychellois judicial system. Furthermore, the country is divided into 26 administrative districts. Eight districts make up the capitol region of Victoria, fourteen are found across the rest of Mahé, two in Praslin, one in La Digue, and one representing the Outer Islands.[46] The distribution of power between the federal and district levels plays an important role in climate adaptation in Seychelles. The decentralization provides the opportunity for local adaptation action, but could thwart information sharing across districts.

1.3.2 Climate Governance

Seychelles has three frequently referenced strategic documents for guiding climate change planning: Seychelles Sustainable Development Strategy, Seychelles Climate Change Strategy, and The Environmental Management Plan of Seychelles.[10,22,47] Each of these documents describe the current state of affairs regarding 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 surge 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, Seychelles has several policies in place to regulate coastal flood management. For example, the Environmental Protection Act allows the Ministry of Environment to designate a "coastal zone" which can then be regulated through preservation and conservation initiatives. Additionally, flooding in Seychelles is managed through the State Land & River Reserves Act, which makes provision for a ten-meter setback along both sides of rivers. Furthermore, the Town & Country Planning Act has recently been revised to incorporate a 25-meter setback from high tide, as well as increase standards for building codes and climate proofing. The Seychelles National Wetland Conservation and Management Policy aims 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. However, these policies often serve as guidelines, and are not enforceable laws.[22,48]

Seychelles' Intended Nationally Determined Contribution (INDC)—the communication the country provides as a party to the UNFCCC—gives explicit priority concern for adaptation to, rather than mitigation of, climate change. In order to adapt, there is a need for research to better understand the interplay between climate change and other climate phenomena. Particularly, the INDC lists changes in rainfall patterns leading to flooding, landslides, extended periods of drought, increases in sea temperature, changes in acidity and damage to marine ecosystems, increases in storm surges, and sea level rise as the primary threats in Seychelles. Critical infrastructure is first on the list of vulnerabilities to climate change, followed by tourism, food security, coastal and marine resources, water security, energy security, health, waste, and disaster preparedness.[49] The INDC highlights the establishment of the Climate Change Division within the Ministry of Environment, Energy, and Climate Change (MEECC), which serves as the focal point for adaptation planning and project implementation. An essential component of long-term adaptation and resilience efforts in Seychelles is recognizing and planning for critical infrastructure. This includes building capacity for managing critical infrastructure through clear linkages between government entities, a responsive education and awareness program targeting infrastructure users, appropriate research, and reflexive monitoring. To effectively adapt to climate change, Seychelles needs to mainstream climate change adaptation into planning processes for all new developments, make improvements to building codes and enforce the codes more rigorously. Tourism is the key economic sector related to adaptation as it requires nimble, adaptive responses because its success is predicated on proximity to the coast. Adaptive responses include expanding marine and mountain tourism and greater co-management between the Ministry of Tourism, Department of Risk and Disaster Management (DRDM), and MEECC. To support near-term adaptation and resilience efforts, the Seychelles National Disaster Risk Policy provides several adaptive actions: establishing integrated legal and institutional capacity for disaster risk management; improving risk identification, assessment, and monitoring mechanisms; reducing underlying risk and vulnerability factors; strengthening disaster preparedness for effective response and recovery; and enhancing information and knowledge management. The cost of implementing all adaptation actions laid forth in the INDC by 2030 is estimated to exceed US$295 million (SCR 4,057.1 million).[49]

The National Disaster Risk Policy (also referred to as the Disaster Risk Management Act) was adopted in 2014 to provide the country with a comprehensive legal framework for disaster risk management. The Act designates DRDM as the entity responsible for preparing the National Disaster Risk Management Plan and Strategy and implementing the integrated emergency management and coordination system. This gives DRDM a newfound legal authority to impose or restrict measures taken by other agencies in preparation for or response to a natural disaster. Under this policy, humanitarian organizations are granted legal facilities and required to cooperate and coordinate with national authorities during delays. These provisions are expected to mitigate delays and ensure adequate response is provided in the wake of a disaster. A Vulnerability Assessment Committee and National Platform for Disaster Risk Reduction were also formed as a result of this act to provide guidance and support for disaster risk reduction initiatives. A national risk communication warning system, as well as a management fund were also established under the policy. The National Disaster Risk Management Fund affords the Department a specific budget allocation for disaster risk management, which did not previously exist.[50]

The Seychelles Coastal Management Plan (CMP) 2019-2024 provides a framework for coastal management initiatives and provides guidance on long-term and nature-based interventions to address hazards in the coastal plain presented by climate change. The CMP describes existing coastal management practices, compiles available information on coastal flooding and erosion and other effects of climate change related to these processes, presents actions for coastal management, and a plan for implementation of these actions including timelines, financial implications, staffing requirements, and institutional capacity. The plan states that adaptive management should be integrated into every coastal management plan whenever possible. Adaptive management (Figure 1.3) is a structured, repetitive decision-making process used to reduce uncertainty over time through accountability and system monitoring.[51]

The MEECC has recently developed a National Climate Change Policy. President Danny Faure recommended such a policy be developed to encourage collaboration on climate issues in Seychelles. In June 2018, the MEECC decided to begin developing a national policy to facilitate a coordinated, coherent, and effective response to the challenges presented by climate change.[52] The physical vulnerabilities to sea level rise and storm surge, as determined in the first phase of this project, provided insights to the Ministry in establishing vulnerable locations in Mahé. Objectives of the policy include advancing understanding of climate change and its impacts on Seychelles, build capacity and social empowerment to adequately respond to climate change, and mainstream climate change considerations into development planning, budgeting, policies, strategies, plans, and implementation across all relevant sectors and all levels of government. To implement the institutional framework presented by the National Climate Change Policy, a National Climate Change Council is to be established as well.[52]

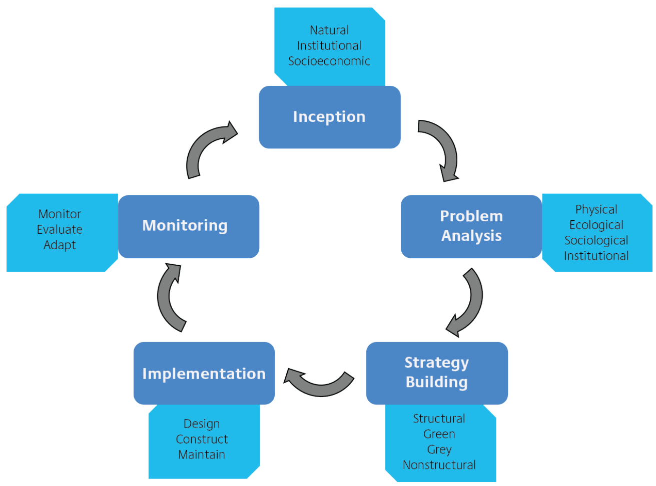


Figure 1.3. Adaptive coastal management process using general policy and planning cycles as integration points Adapted from Seychelles Coastal Management Plan.

1.3.3 Current Climate Adaptation in Seychelles

Seychelles has employed 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 (Photo 1.10), retaining walls, and groynes. Soft engineering approaches utilize ecological practices and principles to prevent negative impacts on the natural environment. Examples include timber piling and dune nourishment. Both approaches are utilized in Mahé with the intent of protecting the coast by buffering waves and providing structure to the coastline.

Photo 1.10. A man walks along a rock wall at Bel Ombré.

Sea walls, which also protect Seychelles' coast, have been made of stone, timber piling, and rock armoring. Sea walls made of stone are rarely used today in Seychelles as they were mostly constructed during the colonial era, are low in height, and currently compromised by wave action. Timber piling is a recent strategy often coupled with dune restoration and replanting of native coastal vegetation. The success rate for this type of strategy is inconsistent.

Most recent reclamation work on Mahé has been equipped with rock armor sea walls, a method that has proved useful at preventing coastal erosion, however it is frequently considered to be an eyesore.[53] Retaining walls are two to three meters in height and can be found throughout Au Cap, North East Point, and the coral reef along the east coast of Mahé.[54] Groynes—long structures that run perpendicular to the shoreline, extending into the ocean—have been used extensively in the past to slow the rate of coastal erosion. However, these structures have had negative consequences, such as beach degradation, as areas down-drift become exposed to greater erosion. Groynes are often used to protect ports in Seychelles and have proven effective when designed to consider currents and sand movement.[53]

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 Seychelles. Coral restoration often entails the propagation of corals that are more resistant to bleaching and is considered a promising technology by many stakeholders. There have also been wetland restoration efforts, which often entails general landscaping and replanting of mangroves, throughout the island. Dune restoration is another EbA strategy implemented on Mahé, which has been done through replanting natural vegetation and restricting vehicle access to the dunes.[53]

The researchers were given a guided tour of three wetland restoration sites. They were located at a beachside residential area in Grand Anse, a wetland near a river at the University of Seychelles campus in Anse Royale, and on reclaimed land in Roche Caiman near Victoria. At Grand Anse, the project was initiated after local residents contacted the Ministry of Environment, Energy, and Climate Change (MEECC) regarding problems of coastal flooding as a result of a failed rock wall. This project consisted of clearing invasive plants from the area and planting native mangroves in their place (Photo 1.11). The project at University of Seychelles was a result of the sea level rising past a rock wall barrier during cyclone Felleng in 2013. University students and staff volunteer to monitor and study the site. At Roche Caiman, mangroves were planted along a popular boardwalk area in a reclaimed wetland with the help of the local community (Photo 1.12).

Photo 1.11. Mangroves planted at a restored wetland in Grand Anse to mitigate the impacts of coastal flooding.

Photo 1.12. Mangrove saplings planted in a reclaimed wetland near Victoria in Roche Caiman.

Education and outreach efforts are usually intended to educate the Seychellois population about climate change more broadly, therefore indirectly protecting the country's infrastructure. 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.[55]

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 Seychelles and enhancing their knowledge of biodiversity and conservation, often times incorporating climate change impacts into their lessons.[56]

Nature Seychelles, the largest and oldest environmental NGO in Seychelles, is another organization leading the way on climate education and outreach in the country. Nature Seychelles maintains the Cousin Island Special Reserve, manages Seychelles' first and largest coral reef restoration project, and coordinates a number of different efforts to improve conservation of biodiversity in Seychelles. To facilitate learning, Nature Seychelles hosts training workshops and educational programs, runs the Community Climate Centre, and offers educational resources (academic papers, project reports, and casual reading) on biodiversity and climate change.[57] In addition, many television, radio, and newspaper pieces have been produced in recent decades to educate the population about adapting to the impacts of climate change like water shortage, flooding, and drainage issues.[47]

Vulnerability is explored further in:

- **Chapter 2:** Characterizing vulnerability through stakeholder interviews
- **Chapter 4:** Assessing social vulnerability (e.g., literacy rates and gender distribution) to climate hazards using geospatial analysis and developing a Storm Sturge and Sea Level Rise Exposure Index

1.4 Climate Change Risks Facing Seychelles

> ***Risk:*** *The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term risk is used primarily to refer to the risks of climate-change impacts.*[5]

The climate risks faced by Seychelles will depend in part on the hazards anticipated by climate models. These models continue to make more dire predictions each year. Risk will also depend on how much of Seychelles infrastructure remains exposed to climate hazards like sea level rise. Finally, risk will depend on the vulnerability of the Seychellois economy, people, and way of life which, despite Seychelles' adaptation efforts, remain threatened. This section considers the ways in which hazards, exposure, and vulnerability interact to put Seychelles at risk.

1.4.1 Climate Impacts on Infrastructure

Damaged infrastructure in Seychelles has numerous economic implications. The country has reached high-income status largely due to its reliance on the tourism and fishing industries. These industries stand to be severely damaged by the negative impacts of climate change because of their reliance on exposed critical infrastructure and natural environments. Adverse economic impacts could also arise from a limited capacity to import food and energy, most of which pass through the country's airport or seaport.[58] Furthermore, the costs of natural disasters to the Seychellois economy is about 1% of GDP, or roughly US$15 million (SCR 206.29 million), which is nearly double that of other Sub-Saharan African countries.[40,58]

Sea level rise is already having some degree of impact on Seychelles through flooding, coastal erosion, and increased salinization of soil and aquifers. The encroachment of ocean water has been gradual, but impacts have been notable. In May 2007, high tides combined with sea level rise caused flooding as far as fifty meters inland, resulting in damage to public infrastructure, including roads.[59] Storm surge causes extreme flooding and coastal erosion and poses considerable risk to the foundations and stability of coastal structures.[60] Though there are no recorded instances of storm surge events in Seychelles, there are some indications that the ITCZ may be shifting its range further north as a result of climate change. This could result in increased tropical storms over Seychelles in the future.[47]

Impacts from notable flooding events in 1997 and 2013 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 runway surface to crack. A total of 44 sites along the roads in Seychelles were damaged, requiring road closures and long periods of time to clear and repair the roads. Many of the country's water supply pipes were broken, and one reservoir had to be demolished and rebuilt. 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.[20]

Intense rainfall in 2013 overwhelmed Seychelles' drainage systems and retaining walls, resulting in flooding, rockfalls, and landslides. Impacts to infrastructure were so extensive that the Seychelles Damage, Loss, and Needs Assessment was developed as a result.[61] The road network was again impacted by flooding, affecting approximately eighteen km of roadways by stripping away asphalt, forming potholes, and damaging bridges, culverts, and retaining structures. Water treatment systems in Mahé were also impacted. Water 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. Moreover, seven of the country's schools sustained an estimated US$256,400 (SCR 3.5 million) in damage, primarily impacting science equipment, furniture, gutters, and building structures.[53] These events exemplify Seychelles' infrastructure susceptibility to flooding and erosion, which will advance as climate change increases the frequency and intensity of rainfall and storm events in Seychelles.[29]

Climate risks facing Seychelles are explored further in:

- **Chapter 2:** Exploring the interactions of exposure and vulnerability through stakeholder interviews
- **Chapter 3:** Developing climate scenarios—based on interactions between Seychelles' climate features and trends—to improve adaptation decision-making
- **Chapter 4:** Assessing risk by using geospatial analysis to layer climate hazards, infrastructure exposure, and social vulnerability

1.4.2 Assessing the Climate Risk to Seychelles' Critical Infrastructure

The following chapters work to fill knowledge gaps surrounding the impact of sea level rise and storm surge in Seychelles through a qualitative, quantitative, and visual approach. The goal of this research is to assess the multi-faceted risks from sea level rise and storm surge faced by Seychelles and its critical infrastructure by better understanding the complex elements—hazards, exposure, and vulnerability—that determine risk.

Chapter 2
Qualitative Analysis of Critical Infrastructure and Adaptation in Seycehelles

Stakeholder interviews offered a chance for end users of this research to provide direct feedback on proposed deliverables, as well as familiarizing the research team with climate challenges specific to Seychelles.

2.1 Methods

2.1.1 Questions

For the first round of stakeholder interviews, the researchers adapted a set of questions from a similar study done in Tanzania.[62] While there are large differences between Tanzania and Seychelles, including country size, livelihoods, and climatic challenges, the questions employed in that study are relevant to the Seychellois context as they seek to better understand the role of the individual in their respective organization, current strategies being employed by the organization, and relationship between climate-related challenges and local livelihoods. These questions were used when speaking with stakeholders in Seychelles to elucidate the relative importance and vulnerability of Seychelles' critical infrastructure, the current state of adaptation in Seychelles, the roles played by various institutions in adaptation, and what hinders the adaptation of critical infrastructure.

To develop interview questions for the second round of interviews, researchers reviewed the interview questions and findings of the first round. This allowed the team to determine what information gaps existed and which topics needed to be probed further. The team decided to revisit important infrastructure, but asked participants what they characterize as "critical infrastructure," rather than which infrastructure is socially and economically important, as was done in the first round. This allowed interviewees to characterize infrastructure they deemed critical based on their own perspective of importance, rather than just list infrastructure based on its social or economic importance. Similar to the first round of interviews, the team also asked participants what barriers to adapting critical infrastructure existed. Other than the overlap between the two aforementioned questions, the team developed a separate set of questions to reduce redundancy and explore new topics relevant to their research. The remaining interview questions were written to inquire about the prioritization of adapting critical infrastructure on Mahé, the current state of adaptation in Seychelles, weather and climate observations, and qualifications of the costs and benefits of adaptation in Seychelles.

2.1.2 Participants

To identify stakeholders to participate in the first round of interviews, the researchers consulted the UNFCCC's LAKI team and the University of Seychelles for relevant contacts, which allowed the team to establish contact with individuals at the MEECC and the Global Climate Change Alliance Plus initiative (GCCA+). The team 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 to the GCCA+. In the interviews, the 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.

In the first round of interviews, which took place in October and November 2018, a total of 25 semi-structured interviews were conducted with 31 stakeholders. Most of these were done face-to-face in Seychelles while the remainder were conducted via online video chat. Twenty of the 25 interviews were recorded and transcribed. For the five interviews not recorded, detailed notes were taken by interviewers and compared to ensure consistency.

In the second round of interviews, carried out in May 2019, the team conducted a total of 28 interviews with 37 stakeholders representing a variety of sectors and backgrounds. Unlike the first interview round that focused on government officials, the second round further explored the private sector. All participants in this round of interviews were interviewed in-person using semi-structured interview methods. Most interviews were conducted with just one individual, but five interviews were conducted with two or more representatives of the same organization. Thirty of the 37 interviews were recorded and transcribed, while the remaining were summarized.

Across both rounds of interviews, a total of 53 interviews were conducted with a total of 68 stakeholders for this project. Five of the 68 interviewees participated in both rounds of interviews. A list of all 63 interviewees can be found in Table 2.1.

2.1.3 Coding and Analysis

Themes across all the 68 interviews were analyzed by having two researchers independently code each of the transcriptions and interview notes. Analysis of the themes was done using NVivo software.

Identifying infrastructure that was critical to Seychelles' functioning was based on interview data. Each mention of a critical infrastructure type was counted and categorized into sectors. Critical infrastructure's exposure to sea level rise and storm surge was based on exposure scores developed with geospatial analysis (see Chapter 4). Infrastructure was grouped into industry sectors. Exposure scores were not calculated for all infrastructure mentioned by interviewees because georeferenced data was not available for some infrastructure. For instance, fisheries were mentioned by interviewees, but georeferenced data for fish processing plants or ice plants were not provided to the researchers preventing the calculation of their exposure scores.

Table 2.1. 63 interviewees across different sectors

Affiliation	Interviewees
Government	**28**
District Administration	1
Ministry of Health	1
Department of Risk and Disaster Management	3
Ministry of Energy, Environment, and Climate Change	8
Energy Commission	2
Meteorological Authority	1
Ministry of Fisheries and Agriculture	1
Seychelles Fishing Authority	2
National Bureau of Statistics	1
Seychelles Planning Authority	2
Ministry of Habitat, Infrastructure, and Land Transport	4
Ministry of Finance, Trade Investment, and Economic Planning	1
Seychelles Port Authority	1
Private Sector	**17**
Cable & Wireless	1
Sea Harvest	2
Fishermen	6
Independent Consultants	3
Public Utilities Corporation	2
Mason's Travel	1
Indian Ocean Tuna Ltd.	1
Seychelles Public Transport Corporation	1
NGOs	**12**
Nature Seychelles	1
Global Climate Change Alliance	2
Seychelles Climate Change Adaptation Trust	1
Seychelles Sustainable Tourism Foundation	2
Wildlife Club of Seychelles	1
Local Environmental NGO	1
Programme Coordination Unit	3
Friends of Mont Buxton	1
Education	**6**
University of Seychelles	6
Total	**63**

The researchers determined how many times reference was made to, how many interviewees mentioned, and the percentage of interviewees that mentioned each type of infrastructure. These numbers were then aggregated to determine a total for each sector. These data are summarized in Figure 2.1 and Figure 2.2 and detailed in Appendices A and B.

A variety of important infrastructure, insights into the current state of adaptation in Seychelles, barriers to adaptation, vulnerability of infrastructure, climate change effects, and preferences of the target audience were revealed across interviews. The findings were classified into the following categories:

- Characterization of critical infrastructure
- Barriers to adaptation
- Costs and benefits considerations
- Adaptation projects, strategies, and drivers
- Weather and climate
- Suggestions for improvements

2.1.4 Limitations

One limitation of this study is its relatively small sample size. Local communities, particularly those on the coasts where adaptation strategies have been employed, were notably underrepresented in this sample. Similarly, the petroleum industry and the private tourism industry could not be reached for interview. Another limitation is that participants available for interviews during the field visits did not always have the utmost expertise on climate change, adaptation, or infrastructure. Some of the interview questions were somewhat leading, which was done out of necessity to guide interviews, though could have been a limitation to some interviews. 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. Stakeholders indicated an interest in including the Seychelles islands of Praslin and La Digue, but that was outside the scope of this project.

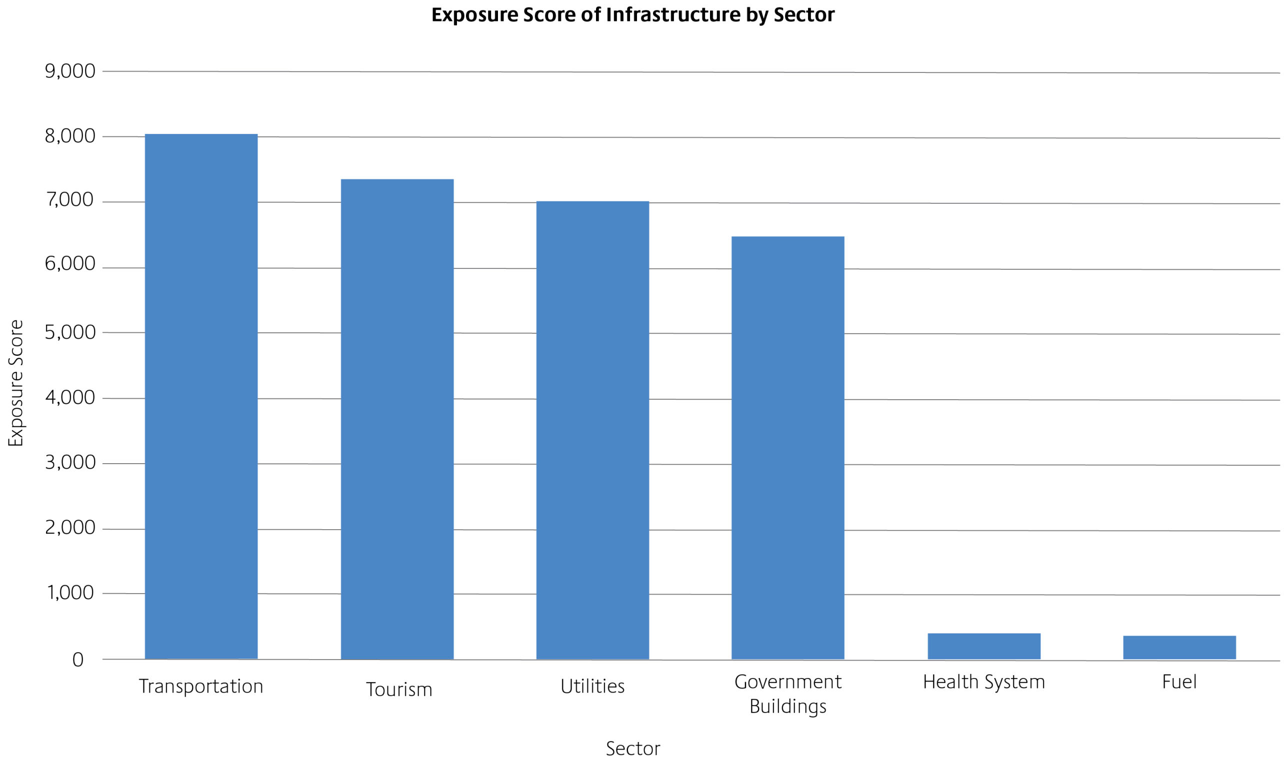


Figure 2.1. Exposure scores of each infrastructure sector. Note that the score for roads has been omitted to enhance readability.

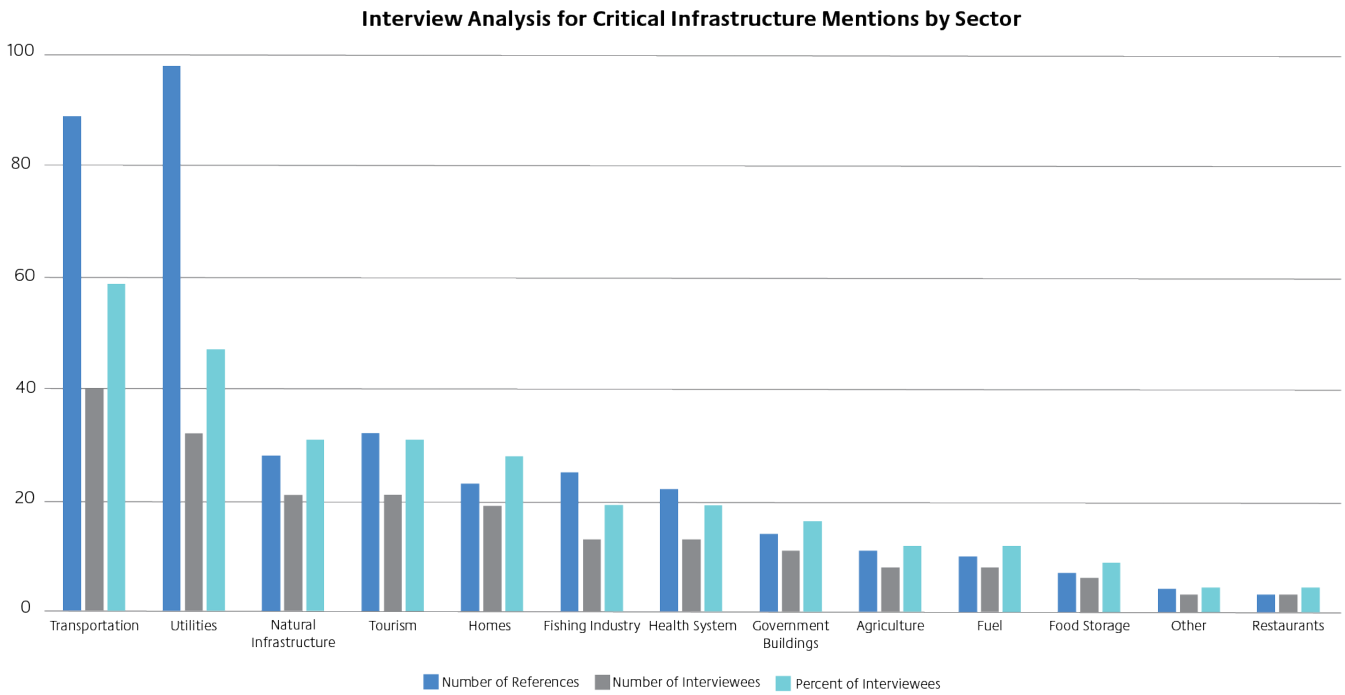


Figure 2.2. Number of mentions, number of interviewees who mentioned, and percentage of interviewees who mentioned infrastructure types, aggregated by sector.

2.2 Results

2.2.1 Characterization and Vulnerability of Critical Infrastructure

Infrastructure with high social, cultural, and economic value were characterized as critical. Interviewees also identified critical infrastructure based on its proximity to the shoreline, instances in which the infrastructure was impacted by extreme weather events, and the number of people it benefits. Many interviewees discussed vulnerability in similar frameworks; infrastructure's proximity to the shoreline, importance to social, cultural, and economic functions, and previous impacts were all considered.

Photo 2.1. Runway at Seychelles International Airport adjacent to the ocean.

Infrastructure related to the tourism and fishing industries hold great value to the Seychellois as the two industries compose a majority of the national economy. Particularly, the airport, hotels, shipping ports, fish processing sites, and the natural environment itself, including fish stocks, were viewed as crucial to interviewees. Hotels, the environment, and the airport all play significant roles in attracting and satisfying tourists and are pivotal for a healthy Seychelles economy; these pieces of infrastructure are also considered to be particularly vulnerable. Due to the airport's coastal location (Photo 2.1) interviewees highlighted its vulnerability and mentioned instances of the runway flooding

Photo 2.2. Seagrass accumulates on Beau Vallon beach, a popular tourist spot.

during high tide and storm events. Seychelles' natural beauty is a draw to tourists and makes it a financial asset to the country—in this way, the landscape itself is considered critical infrastructure. As coral reefs and mangrove forests provide recreation to tourists and natural protection from storm events, land reclamation and other coastal developments are unfavorable. Other threats to the natural environment mentioned in interviews include overfishing, destruction of engineered adaptation structures, algae, and seagrass (Photo 2.2), erosion of beaches (Photo 2.3), and pests and diseases that degrade or kill natural foliage. There was a common sentiment among interviewees that hotels are especially vulnerable to sea level rise and storm surge due to their attractive beachside location (Photo 2.4). Hotels are also largely impacted by the effects of coastal erosion.

Commercial fisheries rely heavily on the commercial and shipping ports, processing plants, the ice plant, and tuna stocks. These operations are all found along the coast in order to maintain close proximity to the fishing and shipping vessels. The financial value of the industry, and the exposure of its coastal infrastructure, make it both critical and vulnerable, respectively. Artisanal or longline fishing operations are dependent on the health and longevity of coral

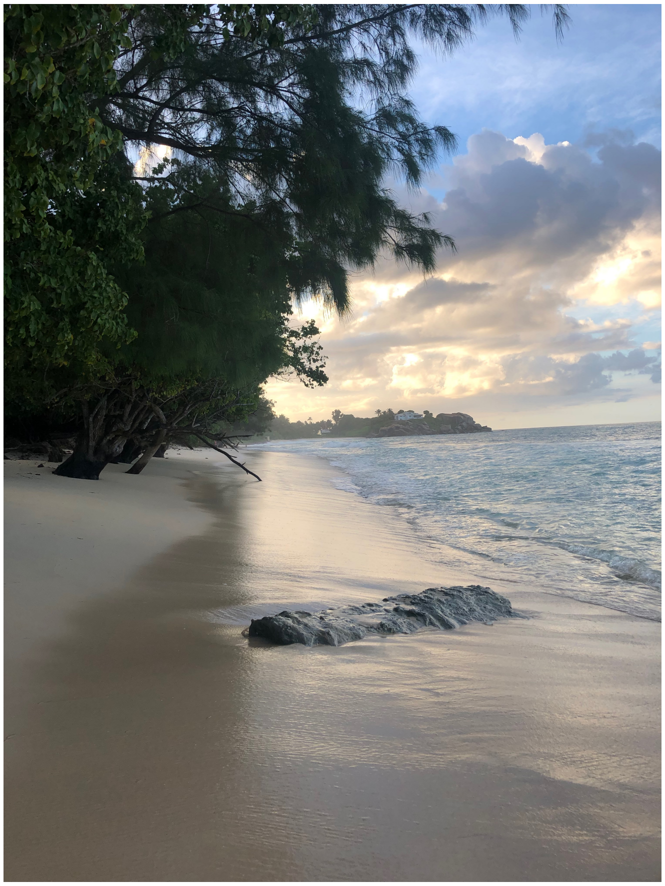


Photo 2.3. Beach erosion at Anse Nord D'est.

Photo 2.4. Eden Island, a collection of luxurious villas on an artificial island off the coast of Victoria.

reefs to sustain their affairs, emphasizing the value of Seychelles natural landscape as critical infrastructure.

Utility infrastructure such as fuel tanks, the petroleum network, power stations, power and telecommunication lines, pipelines, water treatment and distribution, and desalination plants were also deemed critical. In addition, roads were mentioned frequently, despite consisting of only one main stretch of highway and a few smaller roads. This is likely because of its importance to visitors and locals, and emergency response. Interviewees mentioned access to medical care, food, shelter, and emergency services in the event of a natural disaster is supported by the roads. Telecommunication, waterlines, and other utility lines can be found underneath or alongside roads on Mahé in increasing numbers. The drainage system integrated with the roads was also a prominent topic. Many interviewees spoke about their experiences with flooding on the roads and how a proper drainage system would alleviate that issue, but current systems are insufficient or inadequately maintained to control the flooding the country experiences.

Government buildings were also cited as critical infrastructure; these included administration buildings, government offices, schools, police stations, and healthcare facilities.

Another category of infrastructure characterized as critical was food storage and distribution sites. These included the commercial port, the airport, and food storage warehouses. The majority of food consumed in Seychelles is imported, so the ability to import and store food is crucial. Being a small island makes Seychelles vulnerable to changing food supplies and prices, but utilization of the airport for importing food was said to keep prices low. Given the need to keep food warehouses on flat and accessible land, relocation is not feasible.

Finally, private land and housing were characterized as critical infrastructure in Seychelles. Housing developed along the coast (Photo 2.5) was noted to be particularly vulnerable as increases in rockfall and flooding (both from sea level rise and storm events) are impacting homes. Social housing, rental housing owned and managed by the state and elderly homes were also mentioned. New state housing constructed along the coast could be particularly at risk to climate change impacts.

Photo 2.5. Private housing in Glacis.

2.2.2 Barriers

The interviewees identified barriers preventing Seychelles from undertaking adaptation successfully that were broken into three broad categories: lack of capital, limited human capacity, and scarce developable land. These barriers all contribute to a central theme: documents are being produced, policies made, and proclamations declared, but nothing is done once these actions have been taken.

> *"Well, the adaptation is taking place… but the thing is we're just concerned, but we're not acting…"*

Lack of Capital

Lack of financial capital was brought up often, in both a domestic and international context. In the last five years, Seychelles attained World Bank status as a "developed" or "high-income" country. As a result, Seychelles no longer qualifies for the external financial aid that previously sustained its adaptation endeavors. Interviewees expressed concerns over having to weigh running a functioning government and providing social services against addressing climate change. Interviewees suggested an interim period, or "weaning off" process, to lessen the financial blow upon the country's acceptance into high income status.

Interdepartmental dynamics further exacerbate the financial barrier to adaptation. According to many interviewees, there is a competition between sectors to secure an adequate budget. As a socialist government, Seychelles does not tax its people extensively, meaning the revenue for government departments and ministries is small. Other priority issues, such as healthcare or education, tend to win out over adaptation. For example, at the time of the interviews Seychelles was experiencing a heroin epidemic, which the Ministry of Health worked to combat with a strong national campaign. Furthermore, it is difficult to make a case for adaptation projects, whose outcomes aren't often guaranteed.

> *"It's a small economy and we cannot expect a country of 90,000 people to invest millions. Because they have priorities: health, education. That's a priority policy, you see? So, we are in competition with the other sectors."*

Finally, the intradepartmental financial barrier is no less difficult to overcome. With a tight environmental budget, departments may select the most frugal adaptation strategy over the more appropriate one. Furthermore, government personnel shortages limit monitoring and evaluation for adaptation projects. Limited monitoring and few measures of success can cause issues determining if projects should be scaled up in the future.

> *"So, if you plan for the future, there could have been a certain amount of money kept somewhere to develop the program, the project for the future. There are no plans, no money kept aside. Say in 3 years' time we say, 'Okay, now we have 5 million rupees to continue this project.' That is when they decide to implement a [new] project that they tried to seek funding for."*

Limited Human Capacity

A lack of human capacity was also frequently mentioned during interviews. Climate change is a slow-moving threat that is difficult to gain political momentum for something because voters do not generally notice on a day-to-day basis. Moreover, adaptation endeavors tend to be fragmented, uncoordinated, and in some cases redundant. Government departments do not communicate with each other effectively, partly out of a protectiveness over their own jurisdictions/ datasets, and therefore do not address any overlap between policies or regulations.

Seychelles suffers from a serious lack of in-house expertise on climate change issues and often must rely on outside consultants. In intradisciplinary work, lack of specialized understanding can limit project success. Meanwhile, without interdisciplinary ideas, such as EbA projects as opposed to standard hard engineering strategies, there is a re-enforcement of the status quo and a lack of cross-sectoral innovation. Department members cannot devote their time to any one cause for fear of neglecting their other responsibilities. The high staff turnover rate within departments hampers the building of experience and know-how, resulting in a shallow understanding of the bureaucratic process and effective decision-making. Additionally, it is difficult for government departments to find qualified applicants to fill vacancies, meaning some positions remain open for extended periods of time.

> *"I would have liked to base our decision-making process based on scientific data, on studies. Unfortunately, we don't have that capacity right now. So, it's purely reactive for the moment."*

The general Seychellois public also tends to be somewhat ambivalent in their view of climate change and their role in addressing it. In some cases, interviewees stated that the average Seychellois citizen was not aware of the problem of climate change, while other interviewees claimed that the average Seychellois citizen blamed a majority of their problems on climate change. This was attributed to a lack of stakeholder communication and coordination, which prevents stakeholders from fully educating themselves on the issue. Meanwhile, the lack of public action on climate change was due to the lack of perceived action channels: most Seychellois citizens expect the government to "handle" the problem of climate change.

> *"[The barrier to adaption is] two-tiered. It's the element of—do people even know? Have they been making the connection between that flood and climate change? And then the second [tier] is how does that inform their decision-making in a multitude of things, whether it is buying housing, whether it is consumer choices, whether it is when they go to the ballot box."*

Scarce Developable Land

The most frequently discussed physical barrier to climate change adaptation is the limited amount of usable land on the island of Mahé. The main strip of usable land around the island coast is quite narrow, caught between the ocean and the mountains, leading to fierce competition between new development projects, the relocation of existing structures, and government adaptation projects. To preserve the natural beauty of the landscape and address development that makes the granite more prone to rockfalls, the government has imposed a "limiting contour line" that prevents development above a certain elevation in the mountains of Mahé (Photo 2.6).

2.2.3 Costs and Benefits

Seychellois stakeholders offered conflicting views on the importance of cost-benefit analysis in adaptation decision-making. Some government officials indicated they preferred to know the costs and benefits of a decision prior to allocating funding to reduce the risk of making mistakes. However, others believe the fast-moving nature of climate change does not offer enough time to do cost-benefit analyses.

Photo 2.6. Structures built into the steep incline of the central mountainous peak on Mahé.

Interviewees identified four primary categories by which costs and benefits should be measured in adaptation decision-making: social, environmental, economic, and political.

Co-benefits

A number of interviewees discussed the importance of considering the co-benefits of adaptation work. For example, if a project would help communities as well as improve environmental conditions or spur economic growth, then interviewees claimed the project would likely to be very popular with the public and government officials. In addition, important external funding sources, such as the World Bank, make their funding for adaptation contingent on strategies being both environmentally and socially focused. The importance of co-benefits for funding is critical because nearly all stakeholders confirmed that Seychelles will be unable to fully fund all adaptation needed and will continue to need bilateral or multilateral funding for projects.

Social Benefits

There were a number of social costs and benefits frequently mentioned by Seychellois stakeholders, the most common of which was protecting vulnerable populations on the coast. In Seychelles, the most vulnerable populations are considered to be groups of lower socioeconomic status that are directly in the projected floodplains for rising sea levels. Thinking of how a community might benefit from implementing a strategy, such as improved livelihood, protected assets, raising awareness, or protecting public health is often the strongest argument that will garner funding from Seychelles' government. In addition to considering direct social costs and benefits for how to allocate funding, projects being done for research, education, and public awareness are considered indirect social benefits and also important for decision-making. If a project has both direct and indirect benefits for a population, its popularity among funders should, and often does, increase significantly.

Environmental Benefits

Seychellois stakeholders attribute the importance of environmental benefits to the country's long history of dedication to conservation and sustainability. Stakeholders indicated that a crucial part of Seychellois culture is to be environmentally conscious; therefore, it makes sense that environmental benefits of a strategy are highly important. In addition, conservation efforts that improve resilience, such as mangrove and coral reef restoration projects, are of interest to Seychelles because they mesh well with their sustainable culture and, conservation is preferred over the restoration of damaged habitats. Some environmental benefits of adaptation are also considered as benefits towards Seychelles' mitigation goals. Improving mangrove habitats, expanding protected areas, and conserving natural carbon sinks both help with preventing beach erosion and mitigating carbon emissions in Seychelles.

> *"The costs of restoration of a coral reef is very high, but, if you compare it to the cost of a sea wall in the long run, then we have to start to think, 'Is a real coral reef, the cost of preserving it, restoring it and all that, the equivalent to rock armoring where it may work, it may not work, it's going to lead to more?' So, the value of nature is very important for us to understand versus manmade structures because people don't understand that."*

Economic Benefits and Financing

As discussed in Section 2.2.1, many interviewees identified beaches and hotels as important to the economy, in addition to natural areas, marine protected areas, and islands with ecotourism. According to the stakeholders interviewed, economic benefits derived from adaptation strategies should be measured by avoided damages or avoided economic losses to important economic sectors. For example, if a strategy will protect large parts of the economy like tourism, then it will improve the chances of that adaptation being funded by the government or international funders. Economic benefits were not considered the most important way to measure costs and benefits and some interviewees attributed this to Seychelles' unique culture of putting society, culture, and the environment (Photo 2.7) over economic or private gain.

Political Benefits

Many stakeholders also mentioned the impact that politics play in selecting adaptation strategies, though this was the least commonly mentioned benefit or cost considered. For Seychelles, the primary role that politics play in adaptation is through the National Assembly that requires departments, agencies, and ministries to justify their budgets before funds will be allocated. Interviewees discussed the importance of getting support from a political party or individual politicians and how that will increase your chances of funding. In addition, if a strategy is going to have large impacts on society or the environment, particularly on minority voters or vulnerable groups, then politicians will likely support the strategies more because it will secure more votes.

Photo 2.7. Rocky shoreline at Bel Ombré beach.

Unlike the US, most did not consider climate change or discussions of adaptation as being inherently political—the vast majority of Seychelles' population and government officials consider climate change a fact. In Seychelles' politics, it is less a question of if they need adaptation work and more of a question of how to decide what to prioritize.

2.2.4 Adaptation Projects, Strategies, and Drivers

Adaptation topics covered in the second round of interviews included:

- Past adaptation projects
- Stories of successes and failures
- Project lifecycle and mode of operation
- Phasing and scaling
- Financing projects
- Drivers of adaptation
- Ideas for future adaptation

Interviewees reported that most adaptation projects were reactive in nature, rather than proactive. Typically, the only proactive projects were EbA projects funded by foreign aid. Interviewees expressed that EbA strategies were preferred, but not always feasible as they typically require large amounts of time, funding, knowledge, resources, and capacity to implement. Current procedures prioritize adaptation in terms of urgency, typically performing short-term fixes in the form of hard engineering structures. Lack of capacity, experience, and information sharing has shaped the system of trial and error that dominates adaptation in Seychelles today. Interviewees also stated that most projects happen in phases or are scaled up after proving success. This is due to limitations of the adaptation strategies themselves, prioritization, timing, and/or finance.

The most popular coastal adaptation strategies among interviewees were:

- The raising and rebuilding of the seaport and bridges
- Moving transformers and telecommunication lines beneath roads
- Coral and mangrove restoration
- Policies & regulations (i.e. the coastal management plan, setback policy, and construction restrictions)
- Hard engineering (rock armoring, jetties, and groins)
- Improved disaster preparedness systems

When asked for examples of successful adaptation projects, interviewees often brought up the large-scale coral restoration project implemented by Nature Seychelles. This project integrated mangrove and water catchment restoration with rock armoring covered with sand and vegetation in Anse Royale. When asked about failures, there were a few recurring characteristics of "failed" projects. Hard engineering projects that do not integrate EbA, like some rock armoring (Photo 2.8), were said to have collapsed and broken by the impact of storm events or because people removed rocks from the structures. Engineering structures built on beaches have led to coastal erosion. Even opinions on the coral reef restoration projects were mixed, as some have ceased or been forced to restart when storm or bleaching events killed the coral. Beyond these instances, overall lack of research, follow-up, monitoring, or evaluation has led to the failure of adaptation projects. Additionally, the failure of EbA projects resulted from improper siting, as the implementing agency wasn't familiar with the current state of the land, the livelihoods of the local people, or other site-specific ecological knowledge that could have prevented shortcomings. Lastly, policy-based solutions were considered to be failures as proper enforcement mechanisms are not enforced.

Photo 2.8. Rock armoring in Bel Ombré.

> *"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 that ecosystem-based adaptation is getting the priority. If you can adapt through ecosystem-based adaptation, I think it's better for all."*

Financial mechanisms were also said to play a large role in the implementation and outcome of adaptation projects. The cost of construction in Seychelles is high, which means that when building new structures, people choose the cheapest option. This leads to structures being built in unsafe locations (i.e. in a coastal area susceptible to flooding or on the side of the mountain susceptible to rock falls) using cheap materials that will not withstand storm events or severe flooding. Having better construction siting processes and more durable materials would prevent these buildings from needing to be adapted in the first place.

> *"The cost of construction is very high in Seychelles and based on that, people will take the easiest options. If we can organize the construction sector in a better way, we can have more durable development, development that can resist certain changes in the climatic system."*

In terms of financial resources for adaptation, it was stated that international funding typically goes towards EbA projects, while national funding goes towards reactive, hard engineering projects. However, as previously mentioned in Section 2.2.2, there is not enough funding to undertake all the desired adaptation projects. To remedy this lack of funding, interviewees expressed interest in acquiring additional funds from civil society organizations and the private sector. Some expressed that the Seychellois government should encourage the private sector, particularly businesses in the tourism industry, to fund adaptation as they greatly benefit from and rely upon the aesthetics of the clean, healthy natural environment in Seychelles.

The MEEC was often mentioned as the driver of Seychelles adaptation. Interviewees from MEECC acknowledged their important role of being an impetus for adaptation but stressed that the agency cannot take on adaptation alone. There is a need for more partnerships with other institutions, capacity building, and additional. Other entities noted to have the power to drive adaptation in Seychelles included the Planning Authority, NGOs, the Ministry of Finance, Trade Investment, and Economic Planning, the Ministry of Land Use and Housing, DRDM, and the organizations that operate critical infrastructure (i.e. Seychelles Civil Aviation Authority, PUC, and Seychelles Trading Company).

2.2.5 Weather and Climate

Generally, the most commonly mentioned nuisance weather event was extreme rain, which often results in flooding in Seychelles. This was also mentioned as a long-term change that had been noticed by many interviewees: the extreme rain events seem, at least based on anecdotal testimony, to be increasing in intensity but decreasing in duration. Other long-term changes included rising sea surface temperatures and sea level rise.

Changes in seasonal/regional variability generally focused on the lessened predictability of the seasons, with the start and end of the Northwest and Southeast Monsoons reportedly being more variable than they were in the past, and the rainy and drought periods getting longer. Additionally, patterns anticipated in one season are being seen in the other, such as extreme precipitation events typical of the rainy season being observed during the dry season, or vice versa. Interviewees listed numerous impacts that result from these changes in nuisance weather and long-term climate patterns. Some of the most frequently mentioned responses were the result of extreme rain events. These included the widespread flooding of downtown Victoria, the airport, and residential neighborhoods; landslides leading to the collapse of retaining walls, road damage, blockage, or collapse, and demolished houses; the spread of zoonotic or waterborne illnesses; fallen trees; and utilities disruptions. Other impacts unrelated to extreme rain events included coral reef bleaching, change in fish catch (less diversity in catch and fewer deep-sea fish), harmful algal blooms, the occurrence of forest fires (predominantly on Praslin), change in agricultural crop yields, lack of water supply as a result of drought, and sand erosion and saltwater intrusion from sea level rise.

Chapter 3
Localizing Climate Models and Preparing for Future Scenarios

A climate scenario is a description of future climate conditions. Climate scenarios may be qualitative and/or quantitative in nature, and they vary in the amount of detail that is included based on the needs of the user. Typically, greater amounts of detail (i.e., descriptions beyond how annual temperatures and precipitation might change) make the scenarios more tangible for users and policymakers to incorporate into their planning, but those details do not necessarily need to be quantitative. For the purposes of this project, five distinct climate scenarios were constructed of possible climate futures in Seychelles. These scenarios were incorporated into a planning toolkit that walks decision-makers through their management goals in a scenario-specific context, by considering how different climate conditions will manifest locally and disrupt business-as-usual activity.

This approach was used to develop a toolkit for Seychelles to offer them a more holistic picture of the possible futures they might face as a result of climate change, as well as to provide information on the local weather and climate features which will determine climate change effects. This toolkit is the result of the amalgamation and synthesis of a variety of academic and NGO-produced sources of climate change-related information, along with the consultations of experts in the field.

The full Climate Scenario Planning Toolkit can be found in Appendix G.

3.1 Why a Climate Scenario Planning Toolkit?

IPCC Rationale: IPCC AR5 includes the following statement on the need for scenario research in the context of small islands specifically:

> *"Uncertainty in the projections is not a sufficiently valid reason to postpone adaptation planning in small islands. In several small islands, adaptation is being progressed without a full understanding of past or potential impacts and vulnerability. Although assessment of future impacts is hampered because of uncertainty in climate projections at the local island level, alternative scenarios based on a general understanding of broad trends could be used in vulnerability and sensitivity studies to guide adaptation strategies."*[5]

Co-production. With an urgent need for policymakers to use climate science in an actionable, solutions-based way, the onus falls upon climate researchers to produce materials that can be easily understood and used by non-expert decision-makers. The concept of co-production brings researchers and non-scientific users together to create research, data, and tools that speak directly to the needs of real-world application. The University of Michigan School for Environment and Sustainability (SEAS) is fortunate enough to house one of these co-production labs, the NOAA-funded Great Lakes Integrated Sciences and Assessment (GLISA) group. Taking advantage of this resource and the many leading experts at SEAS, the researchers aim to create a Seychelles-specific deliverable based on co-production design.

Holistic Appeal. More often than not, climate tools paint a rather narrow picture of regional climate change, preferring to focus on what is "probable" rather than what is "possible." Unfortunately, this may be unhelpful, as climate change is incredibly dynamic and difficult to project; each new improvement in modeling only serves to demonstrate how lacking the previous models were. The interviews conducted with Seychellois end users emphasized the need for a comprehensive depiction of their climatic future: as they are operating on an extremely limited budget with a small staff, it does not make sense to plan for a specific future that may or may not actualize. By offering a range of possible future scenarios, none of which is labeled more likely than the others, the toolkit aims to ensure that Seychellois investments in infrastructure adaptation are flexible and complete enough to accommodate whatever lies ahead.

Feature-based Understanding. The final aim of this toolkit is not only to give Seychellois decision-makers a range of futures to familiarize themselves with, but also to give them an understanding of the features that help shape those futures. They are provided with an in-depth description of the climatic, oceanic, and topographic features that play a role in Seychelles' climate and weather, how those features interact with each other, and what the literature suggests about the ways these features will change in the future. This is done in an attempt to contextualize the scenarios that have been developed, and to encourage local climate researchers to keep an eye on these particular processes and the way they evolve as climate change manifests more strongly.

3.2 Methodology

The team worked closely with Dr. Richard Rood of the University of Michigan Climate and Space Sciences and Engineering Department, who is a Core Faculty Member of GLISA, to create the scenario planning toolkit. The steps used to create the toolkit are outlined below:

February-April 2019. The GLISA Fort Custer Climate Scenario Workbook is chosen as a template for the Climate Scenario Planning Toolkit. It is included in the variety of possible deliverables offered to the Seychellois interviewees during the field visit in late April-early May of 2019.

April-May 2019. An exemplar of the Fort Custer Climate Scenario Workbook is shown to Seychellois interviewees. The proposed Climate Scenario Planning Toolkit is ranked as the second most desirable deliverable by interviewees. Data gathered during field interviews inform team members of the local climate and weather patterns in Seychelles.

September-November 2019. Team members begin compiling and synthesizing information on general climate change effects on SIDS and Indian Ocean Island States, mainly from the IPCC AR5. These effects include general warming, sea surface temperature warming, coral bleaching, and extreme weather events.

December 2019-January 2020. Team members compile and synthesize information from sources on Seychelles-specific climate, ocean, and topographic features, from a variety of academic articles. These features include the Somali Jet, Madden-Julian Oscillation, Indian Ocean Dipole, Mascarene Shelf, and Seychelles Dome. The rudimentary interaction effects between these features is modeled.

February-March 2020. Team members incorporate information on climate effects on Seychelles-specific features and create corresponding scenarios. Climate scientist Dr. Ángel F. Adames-Corraliza is consulted in conjunction with Dr. Richard B. Rood to fine-tune climate change projections on Seychelles' region created by team members

March-April 2020. Team members incorporate existing climate projections provided by the World Bank, NOAA, NASA, and the World Resources Institute (WRI) to include quantitative analysis in the Climate Scenario Planning Toolkit. The Scenario Planning Toolkit is reviewed by Dr. Rood and research advisor, Dr. Avik Basu.

3.3 Seychelles-specific Climate Features

Seychelles' climate is broken into two monsoonal seasons. From May to October, the Southeast

Monsoon brings a relatively dry period which reaches its peak from July to August.[63] During this time, there is very little precipitation and temperatures average at 27°C. By November, the winds start to change, bringing lighter, warmer winds and the start of the Northwest Monsoon, the main rainy season.[63] From December to March, Seychelles experiences consistent precipitation, reaching its peak in December and January.[63]

The climate in Seychelles is strongly related to the following atmospheric-oceanic, topographic, and topographic-oceanic features.

3.3.1 Atmospheric-oceanic features

Somali Jet. The Somali Jet is a low-level jet that penetrates East Africa in May before heading east over the Arabian Sea and reaching India in June.[23] Due to coastal upwelling at 9ºN, it is a major source of moisture in the South Asian summer monsoon.[64] It reverses its trajectory in boreal winter, bringing moisture from the Northern to the Southern Hemisphere.[65] The trajectory of this jet, and its moisture transfer from the Northern to Southern Hemisphere in summer and vice versa in winter, is thought to play a role in the strength and direction of Seychellois monsoons: As the Somali Jet carries moisture away from the equatorial zone and toward India in boreal summer, Seychelles experiences a dry monsoon season. Conversely, as the jet reverses its trajectory and brings the moisture back down to the equatorial zone in boreal winter, Seychelles experiences a wet monsoon season. The angle at which the Somali Jet approaches dictates the directionality of Seychellois monsoons; since the jet is shaped like a "C" around the equatorial region, as seen in Figure 3.1, the dry monsoon hits Seychelles from the Southeast, and the wet monsoon hits it from the Northwest (a reverse of the jet's Southwest summer and Northeast winter monsoons).

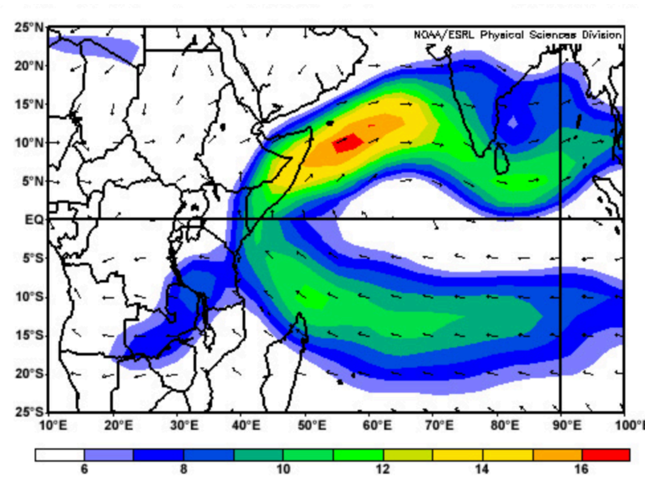


Figure 3.1. Path of Somali Jet in Western Indian Ocean. Reproduced from University Corporation for Atmospheric Research. Jet Streams. 2012.

Madden-Julian Oscillation. The Madden–Julian oscillation is the largest element of intra-seasonal variability in the tropical atmosphere.[66] It is characterized by an eastward progression of large regions of both enhanced and suppressed tropical rainfall, usually first observed over the Western Indian Ocean—a depiction of this precipitation anomaly is shown in Figure 3.2.[24] Seychelles sits on the MJO's trajectory across the Indian Ocean, and is therefore directly affected by its movement from east to west.[67] Typically, strong MJO winds cause dry winds from the coast of East Africa to travel across the Indian Ocean, which may pause precipitation in Seychelles during boreal summer. Meanwhile, the winter MJO moves in a sort of see-saw motion after forming in the east and brings the moisture back over Seychelles as a result. This contributes to the Northwest Monsoon by increasing humidity during the boreal winter months, thereby increasing precipitation. The winter MJO has a direct effect on the Northwest monsoon in Seychelles.

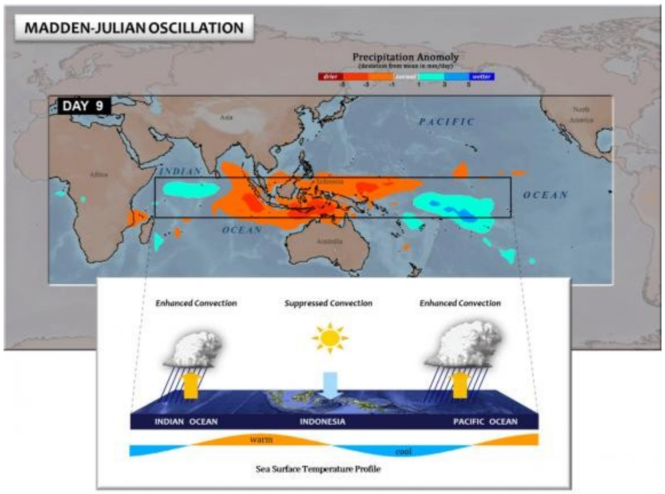


Figure 3.2. Enhanced precipitation over Seychelles, Day 9 of MJO. Reproduced from NCAR & UCAR Science. Tropical weather maker in motion – The Madden-Julian Oscillation [video]. 2011.

Indian Ocean Dipole. The Indian Ocean Dipole (IOD) is an irregular oscillation of sea surface temperatures in which the western Indian Ocean, off the coast of East Africa, becomes alternately warmer (positive phase; Figure 3.3) and then colder (negative phase) than the eastern part of the ocean, close to Australia and Southeast Asia.[68] This causes increased rainfall over the western Indian Ocean region (encompassing Seychelles) during a positive phase and decreased rainfall during a negative phase, as warmer sea surface temperatures increase the rate of convection and subsequently affect the rate of precipitation. The IOD acts as a contributing factor to the strength of the wet monsoon season.[25]

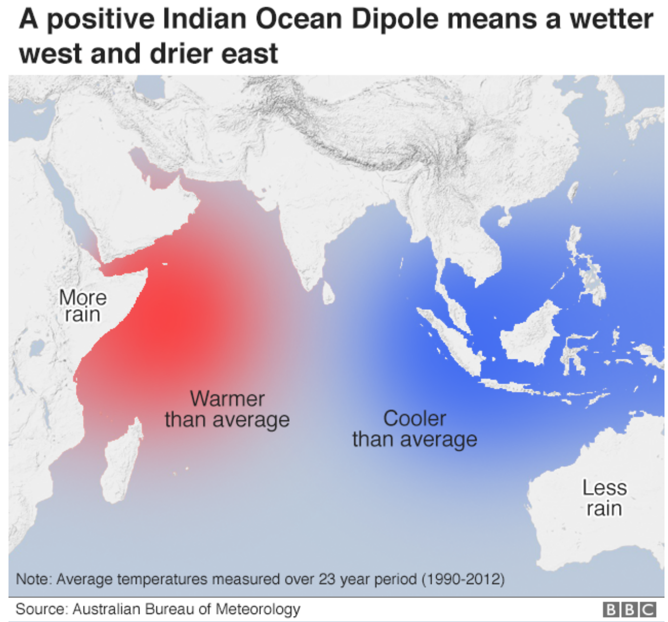


Figure 3.3. IOD in its positive phase, indicating a wetter west and drier east. Reproduced from Australian Bureau of Meteorology. Madden-Julian Oscillation (MJO).

3.3.2 Topographic feature

Seychelles' climate is also affected by extreme topography and its location on the Mascarene Plateau.

Topography. Many of the inner islands are granitic and have extreme topography—Mahé rises to a height of roughly 905m quite precipitously.[69] Because Mahé is such a mountainous island, it is susceptible to topographic precipitation, which occurs as mountains push winds up and over their slopes, causing the air to cool as it rises and forcing it to condense, depositing rain on windward slopes.[70]

Mascarene Plateau. The chain of Seychelles islands sits atop the Mascarene Plateau (Figure 3.4), a submarine plateau that curves around Madagascar in an inverted "C" shape and encompasses Seychelles, Mauritius, and Réunion.[71] The plateau covers an area of over 115,000m² of shallow water before plunging 4,000 meters at the edge of the abyssal plane.[71] This vast area of shallow water allows for unique climatological and oceanic features that are specific to the southwest Indian Ocean.

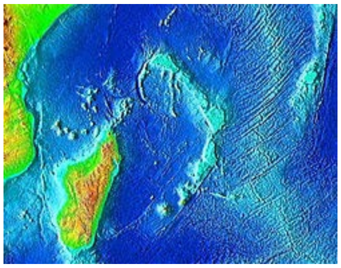


Figure 3.4. Topography of the Mascarene Plateau, encompassing Seychelles, Mauritius, and Réunion

3.3.3 Topographic-oceanic feature

Seychelles' topography influences the Seychelles Dome, or Seychelles-Chagos Thermocline Ridge, surrounding the country's island chain.

Seychelles Dome. The Seychelles Dome is the combination of a shallow oceanic thermocline (layer of water through which water temperature changes rapidly, dividing upper mixed layer with deep calm water below; Figure 3.5) and high sea surface temperatures sitting atop the western half of the Mascarene Plateau.[27] This combination of shallow underwater topography and shallow thermocline yields abnormally high sea surface temperatures year-round, with temperatures above 27°C for almost all seasons and above 28.5°C during the summer (Figure 3.6).[72]

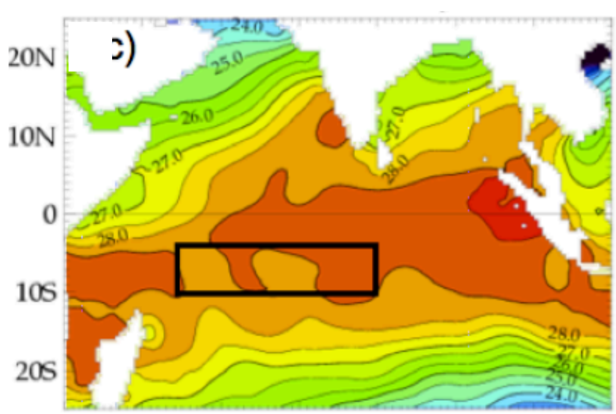


Figure 3.5. Sea surface temperature of Seychelles Dome in boreal winter (Jan-Feb-Mar)

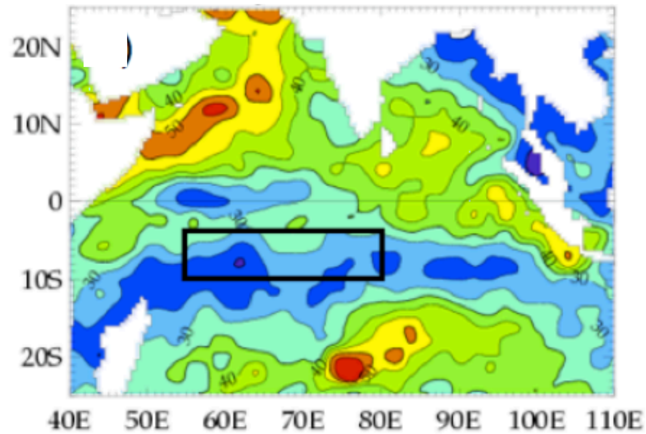


Figure 3.6. Thermocline depth of Seychelles Dome in boreal winter (Jan-Feb-Mar)

The deeper the thermocline is, the higher the sea surface temperature, and the more tropical cyclone days are felt in the Southwest Indian Ocean, where Seychelles resides. The Seychelles Dome is not constant, and fluctuates between a strong phase (shallow thermocline) that causes more upwelling of cold water and a weak phase (deeper thermocline) that causes less upwelling of cold water.[73] Upwelling is focused in the west during austral spring and summer and forms a zonally elongated ridge during austral autumn and winter.[72] In addition to playing a role in convection rates and precipitation, the Seychelles Dome may play a role in coral rehabilitation, as it may or may not allow for cooler water brought to the surface by upwelling to mediate the effects of sea surface temperature warming.

3.3.4 Geologic feature

Seychelles' geology plays a role in climate events, as when you cut into granitic rock, which is necessary for infrastructure development on Mahé and the other main islands, it becomes less stable and is more likely to experience rock falls. This is a primary concern of local Seychellois policymakers and a common nuisance on Mahé. The dynamics between local weather events (precipitation) and local geology (granitic island composition) play a role in climate event as well—rainwater is naturally slightly acidic, and as a result will "chemically weather", or dissolve, the silica in granite over time, increasing its susceptibility to fractures and subsequent rocks falls and slides.[74] Extreme precipitation can trigger landslides and tree falls by transporting debris down the side of the mountain. Wind can also play a role in the erosion of the rock, exacerbating the risk of rock fractures.

3.3.5 Interactions Between Climate Features

It is also important to recognize these features do not operate independently from each other, and often influence the strength and speed of several other features at once. A broad understanding of the dynamics between these features is useful in grasping the possible feedback loops that will shape Seychelles' climate in the future.

Somali Jet. The Somali Jet is affected by both the MJO and the Seychelles Dome. As it is a strong driver of precipitation across the Indian Ocean, the MJO affects the amount of moisture content of air masses advected by Somali Jet during its Southwest summer trajectory—as the MJO moves moisture away from the coast of East Africa eastward across the Indian Ocean, it may lessen the amount available for transport toward India in boreal summer.[75] Meanwhile, higher sea surface temperatures in the Seychelles Dome region south of the equator cause reductions in upwelling, which are related to anomalously weak south-westerlies in late spring, lessening the intensity of the Jet.[76]

Madden-Julian Oscillation. The MJO is affected by both the Somali Jet and the IOD. The Somali Jet plays a role in the movement of the MJO, causing the latter to advect toward India. Additionally, a particularly strong Somali Jet may move moisture away from the MJO northeastward toward India. The IOD in its positive phase causes comparative changes in sea surface temperature between the Western Indian Ocean and the Eastern Indian Ocean whereby the former is warmer than the latter, which can then cause positive humidity anomalies over the Western Indian Ocean and negative humidity anomalies over the Eastern Indian Ocean.[77] A positive IOD, therefore, may increase the amount of precipitation carried eastward by the MJO.

Seychelles Dome. The MJO and the IOD can both impact the Seychelles Dome—more specifically, each can play a role in the depth of the thermocline, changing the rate of upwelling as a result.[78] The MJO causes Rossby waves, huge, undulating movements of the ocean that stretch horizontally across the planet and affect the earth's climate because of their size.[76] These Rossby waves deepen the Seychelles Dome thermocline seasonally, toward the end of boreal winter (February-March).[79] Similarly, a positive IOD will cause a reversal of wind direction, transforming westerly winds into easterly winds. This, combined with the subsequent Ekman pumping (downwelling as a result of wind dynamics) also generates Rossby waves, which in turn deepens the thermocline.[6]

Indian Ocean Dipole. The IOD is impacted by both the MJO and the Seychelles Dome. In the suppressed convection phase of the MJO, anomalous upwelling can result from oceanic Kelvin waves leading to a shoaling of the thermocline (the thermocline becomes shallower) in the Eastern Indian Ocean, which can then help onset a positive IOD.[26] The Seychelles Dome, because of the role its thermocline plays in dictating sea surface temperatures, can cause warming in the Western Indian Ocean, which feeds into a positive IOD.[72]

3.4 Projected Climate Changes

The following section gives an overview of how the atmospheric and oceanic processes mentioned above will change, and the degree of certainty associated with the models predicting these changes.

3.4.1 Changes in Atmospheric Climate

According to IPCC AR5, medium emissions scenario suggests about a 1.8°C to 2.3°C median annual increase in surface temperature in the Indian Ocean small islands by 2100 compared to a 1980–1999 baseline, with an overall annual decrease in precipitation of about a 3 to 5% increase in the Indian Ocean small islands.[5] Comparative projections for the RCP4.5 scenario suggest about a 1.2°C to 2.3°C increase in surface temperature by 2100 compared to a 1986–2005 baseline and a 1 to 9% increase in the Indian and Pacific Ocean small islands regions.

The IPCC acknowledges the lack of climate change data and scenarios, lack of information on historical climate events and attribution of those events to climate change, and lack of adequate projections for climate impacts beyond sea level rise and temperature, although regional temperature data has been found to be satisfactory.[5]

3.4.2 Changes in Oceanic Climate

Sea Surface Temperature Warming. According to the IPCC's AR5, under a moderate warming scenario, the temperatures of the subtropical gyres (STG), including the Indian Ocean STG, are projected to increase by 0.17°C to 0.56°C in the near term (over 2010–2039) and between –0.03°C to 0.90°C in the long term (over 2010–2099).[5] Under an extreme warming scenario, however, surface temperatures of the world's STG are projected to be 0.45°C to 0.91°C warmer in the near term and 1.90°C to 3.44°C warmer in the long term. These changes in temperature are very likely to increase water column stability and reduce the depth of the thermocline—as models seem to be projecting more extreme futures as their accuracy increases, the extreme warming scenario may be the most useful for creating scenarios. Additionally, coral reef waters were found to show strong increases in average monthly temperature (0.07°C to 0.14°C per decade)).[5]

Currently, the multi-model ensemble-mean SST biases over the western equatorial Indian Ocean are warmer than the observations during the summer monsoon season.[80] However, about half the models show positive SST biases, and the other half show negative SST biases. The formation of SST biases is related to surface current biases induced by the weaker biases of southwesterly monsoon winds and SST biases over the southwestern equatorial Indian Ocean, which are advected by the East African Coastal Currents.

Sea Level Rise. While current scientific projections show a global sea level rise rate estimated at between 2 and 3 millimeters per year, rates of sea level rise are not uniform across the globe and large regional differences have been detected including in the Indian Ocean and tropical Pacific, where in some parts rates have been significantly higher than the global average.[81] Generally, regions at the lower-to-mid latitudes are projected to experience a more severe change in sea level than regions in the upper latitudes; this means Seychelles may be strongly impacted.[5]

Although current models (CMIP5 for instance, which is the amalgamation of 16 global climate models used by the IPCC) do an adequate job of modeling ocean heat content and have added the effect of volcanic eruptions on thermal expansion contributing to sea level rise, the modeling of large ice sheet has only recently been incorporated into models, and add a considerable amount of uncertainty to sea level rise projections.[5]

3.4.3 Changes in Atmospheric-oceanic Features

Somali Jet. A relatively under-researched phenomenon, the work available on the projected changes in Somali Jet trajectory and behavior indicate that the Somali Jet will weaken in the early 21st century, regain some strength toward the middle of the century and reach its weakest point at the end of the 21st century.[82] This in turn is projected to weaken the South Indian Monsoon during boreal summer as increasing the likelihood of drought in East Africa, potentially negatively impacting the moisture content of the Seychellois summer monsoon in the process.[2]

The models used to project Somali Jet changes tend to simulate a weaker Somali Jet than those recorded for a given time period.[82] More worryingly, multi-model analysis reveals a large standard deviation in projections, meaning significant differences in projections and making it difficult to pinpoint exactly what the inaccuracy stems from.[83] One possible cause is Arabian Sea cold sea surface temperature biases, but this may not be the only contributing factor.[84]

Madden-Julian Oscillation. Climate change is projected to strengthen the MJO, as well as causing it to move faster than it has in the past.[85] The timescale between changes in oscillation will be shorter, and this will result in an increase in variable heat and humidity in the Seychelles region. Because the MJO plays a role in the formation of the Northwest Monsoon, its increased variability may cause rain events to weaken, or not occur at all. However, in combination with the increase of the IOD positive phase and warming sea surface temperatures, it is more likely that a strengthened MJO will cause wetter conditions in Seychelles.[3]

According to the latest IPCC report, simulation of the MJO in contemporary coupled and uncoupled climate models remains unsatisfactory, and tends to underrepresent MJO variability, making it difficult to distinguish from background variability, as well as failing to adequately simulate vital parts of the MJO such as monsoonal rainfall variability, failing to accurately model the MJO's spatial structure, and difficulties with ocean-atmosphere coupling.[5] However, the researchers consulted with a leading expert on the MJO and its modeling process to provide the most accurate predictions available.

Indian Ocean Dipole. The frequency of positive IOD events is projected to increase linearly as the warming proceeds, and double at 1.5 °C warming.[4] However, the extreme IOD frequency peaks as the global mean temperature stabilizes. Under a business-as-usual scenario in which the global mean temperature (GMT) increases by over 4°C by year 2100, the frequency of climate extremes, including extreme positive IOD events and extreme El Niño events, is projected to increase substantially.[4] This may lead to increased moisture convection and precipitation in the Seychelles region.

In most models, IOD peak-season amplitudes are systematically larger than that of the observed, a bias that deterministically affects climate projections in affected regions.[86] This is a result of improper modeling of the thermocline-sea surface temperature feedback, a mean easterly wind model bias, and an overly strong west-minus-east sea surface temperature (SST) gradient.[86] Because of these issues, IOD projections may overemphasize the role that IOD will play in regional climate change.

3.4.4 Changes in Topographic-oceanic Feature

Seychelles Dome. Very little research has been done specifically on the changes in Seychelles Dome thermocline depth, temporal variability, and location as a result of climate change, although research has been conducted to understand current Seychelles Dome dynamics. This lack of climate projections may be due to the fact that changes in the Seychelles Dome will be secondary effects to changes in wind patterns and other climate features. However, when considering the impact of a positive IOD on the Seychelles Dome—IOD causes a wind anomaly and associated Ekman pumping to generate off-equatorial Rossby waves, which deepen the thermocline and warm the SST in the western part of the Indian Ocean—it can be extrapolated that an increase in positive IOD occurrence will deepen the Seychelles Dome thermocline and increase SST warming in the region.

Based on a study of Seychelles Dome model accuracy, among the 35 general circulation models studied, fourteen models erroneously produce an upwelling dome in the eastern half of the basin, whereas the observed Seychelles Dome is located in the southwestern tropical Indian Ocean—improper location/placement simulation of the Seychelles Dome was the most significant problem discussed.[87] Unfortunately, compared to the earlier and arguably less accurate CMIP3 models, the CMIP5 models are even worse in simulating the dome longitudes.[87]

3.5 Future Climate Scenarios

Based on the anticipated changes in the climate and ocean systems above, it is possible to create scenarios of ways the climate in Seychelles might be affected. These scenarios are developed by looking at anticipated changes in local climate trends and features, doing a qualitative analysis on how the changes might interact with one another and produce different overall climate environments in the future, and packaging these into distinct scenarios that give a more real-world view of what the future climate may look like. Multiple scenarios have been prepared in an attempt to help Seychellois policymakers plan for a future with many moving parts. No scenario is considered more accurate or likely than the others; decision-makers should do their best to incorporate strategies for all of the scenarios outlined below.

3.5.1 Warm and Wet Scenarios

Four scenarios were created to account for these conditions:

Scenario 1: Extreme rain

→ Increase in seasonal/monsoonal precipitation, with highest increase in extreme precipitation events
→ Increased occurrence of flooding in downtown Victoria and other low-lying areas on Mahé
→ Shorter time intervals between flooding events
→ Increased occurrence of rockfalls and landfalls, with possibility of impacting inland infrastructure and private property
→ Individual events will have more rain in shorter period of time than previous events
→ More extreme rain after seasonal rain can increase mudslides than instances in the past

Scenario 2. High sea level rise, warmer sea surface

→ Increase in rates and occurrences of coral bleaching
→ Disruption of marine ecosystems
→ Accelerated coastal erosion, with possibility of impacting critical coastal infrastructure and private property
→ Possibility of soil salinification, affecting agriculture
→ Higher sea level rise will slow down drainage

Scenario 3. Low sea level rise, extreme storm surge

→ Slow but continuous coastal erosion
→ Increase in events of extreme storm surge, with possibility of affecting critical coastal infrastructure and fishing industry
→ Shorter time intervals between extreme storm surge events
→ Possibility of increased storm tide due to combination of large seasonal tidal fluctuations in region and sea level rise

Scenario 4. Wind-related upwelling

- → Increase in MJO-related westerly winds
- → Related increase in cold-water upwelling in Seychelles Dome region leading to a decrease in sea surface temperatures
- → Reduced coral bleaching
- → Reduced sea surface warming effect on marine ecosystems

3.5.2 Extended Warm and Dry Scenario

One scenario was created to account for the possibility of a warm, dry summer, leading to potential drought complications:

Scenario 5. Drought

- → Increase in likelihood of wildfires
- → Increase in stagnation of water bodies, leading to increase in proliferation and spread of disease-carrying vectors
- → Diminished supply of water for public consumption, industrial uses, and agricultural uses

3.6 Next Steps

This toolkit can help inform policies for adapting critical infrastructure to climate impacts. In the past, similar tools have encouraged cities to evaluate several key pieces of infrastructure.

The scenarios presented may be enough to stimulate critical infrastructure management discussions on their own, but the team believes essential components must be included by the end-users themselves, as they are most familiar with local context and priorities. With this in mind, the following steps are recommended for the completion of the toolkit:

Pick scenario-specific critical infrastructure management goals to focus on. These goals should be suited to addressing each scenario's most pressing adaptation priorities individually. For instance, a potential management goal for the "Extreme rain" scenario might be improving Seychelles stormwater system capacity. Using this approach, each scenario should have its own management goal(s).

Incorporate specifics into each management goal. The more detail included in the plans to achieve each goal, the better. Breaking everything down on a step-by-step basis will facilitate goal visualization and execution. Incorporating deadlines/benchmarks, budget estimates, etc., will improve the usefulness of the toolkit.

Consider potential obstacles to goal achievement posed by scenario conditions. This means applying the effects of each scenario onto its respective management goal(s) specifically. Considering the most pressing obstacles posed by each scenario to its management goal(s) will help with action prioritization: What needs to get done first based on the challenges that might manifest?

Chapter 4
Geospatial Modelling of Sea Level Rise and Storm Surge Risk

Geospatial analysis was used to assess the impact of sea level rise and storm surge on Mahé. First, a Storm Sturge and Sea Level Rise Exposure Index was developed. Once exposed areas of the island were identified, an infrastructural risk assessment was conducted to identify the level of risk posed by storm surge and sea level rise to specific types of critical infrastructure. Adaptive capacity of the island, ideally measured by financial resources and other social factors, was also recognized as a critical part of assessing vulnerability. With limited data from the 2010 Seychelles Population and Housing Census, the researchers were able to use several socioeconomic data sets from Seychelles' National Bureau of Statistics to demonstrate how to include social factors such as literacy, gender, and population density in adaptation decision-making. Given the importance of increased precipitation intensity and frequency in the Climate Change Scenario Toolkit, geologic events such as landslides and rockfalls were mapped and included in the series of maps produced as they can be exacerbated or triggered by precipitation. Finally, recognizing the potential for adaptation decisions being made at a sub-national level, researchers layered the exposure to sea level rise and storm surge with administrative districts.

To facilitate information sharing, some georeferenced data sets have been made publicly available on the Partnership for Resilience & Preparedness (PReP Data; prepdata.org), detailed in section 4.6 of this chapter.

Full PDF versions of all maps generated by the research team can be found in Appendix D.

4.1 Storm Sturge and Sea Level Rise Exposure Index

In order to estimate the physical impact of two meters of sea level rise and severe storm surge on Mahé, the research team developed a Storm Sturge and Sea Level Rise Exposure Index. For the development of this index, exposure to sea level rise and storm surge is composed of the topographical, geological, and hydrological conditions that make a region susceptible to flooding damage from a storm surge. The final storm surge exposure 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 exposure index can be found in Figure 4.1.

The world record for highest storm surge is estimated to be around 13 to 14.[88] While it is highly improbable that Mahé will experience a world-record level storm surge, a worst-case scenario of a 15 meter storm surge was used in this exposure analysis. The researchers analyzed the island's exposure to two meters of sea level rise by accounting for elevations fifteen meters or lower.

The researchers' analysis of topographic factors is based on 2m resolution Digital Elevation Model (DEM) data provided by the MEECC (Figure 4.2). This elevation data itself is also utilized in the researchers' model as a predictor for storm surge exposure. Areas of lower elevation are predicted to be more exposed to storm surge.

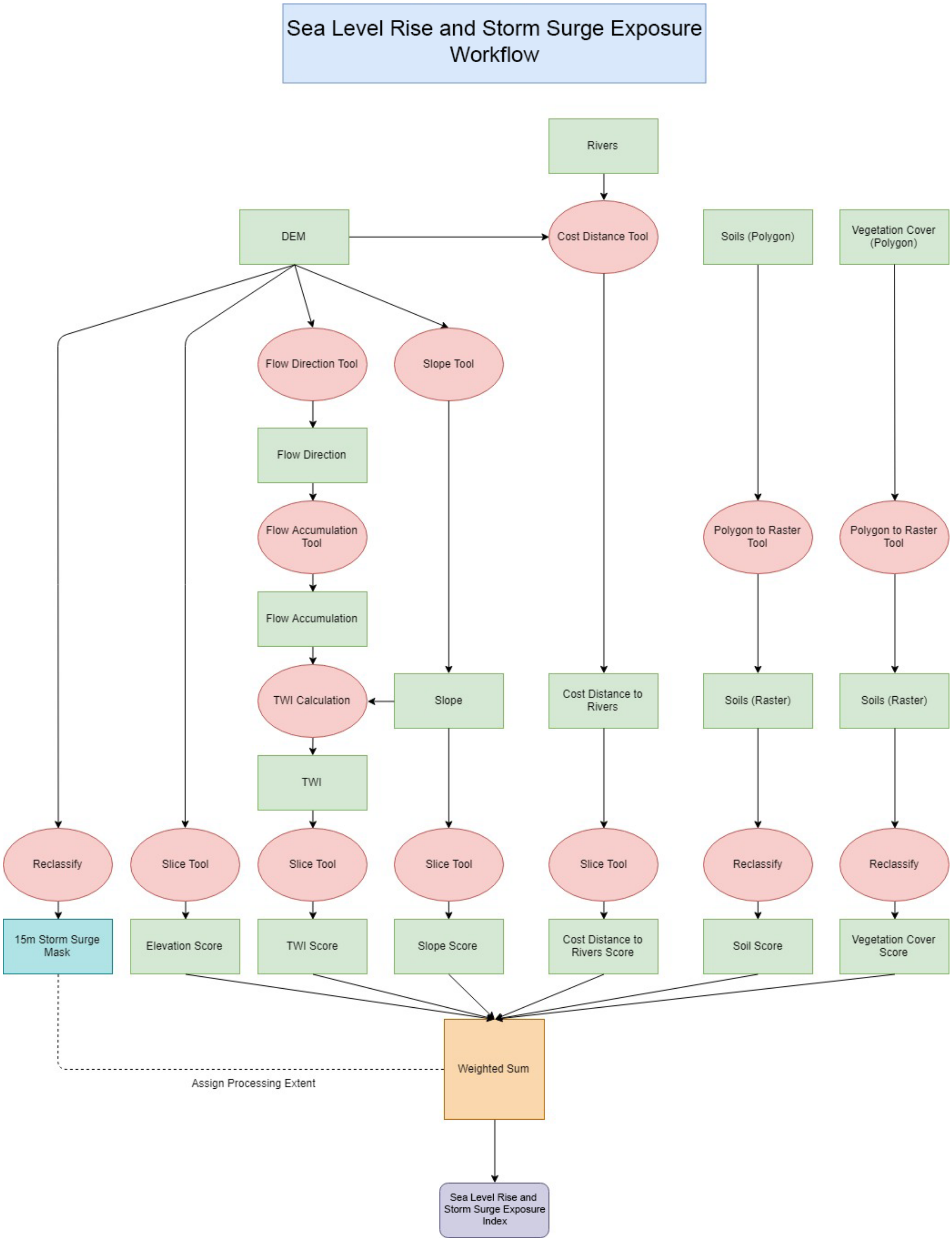


Figure 4.1. Full workflow of the methods used to produce the storm surge exposure index in ArcGIS.

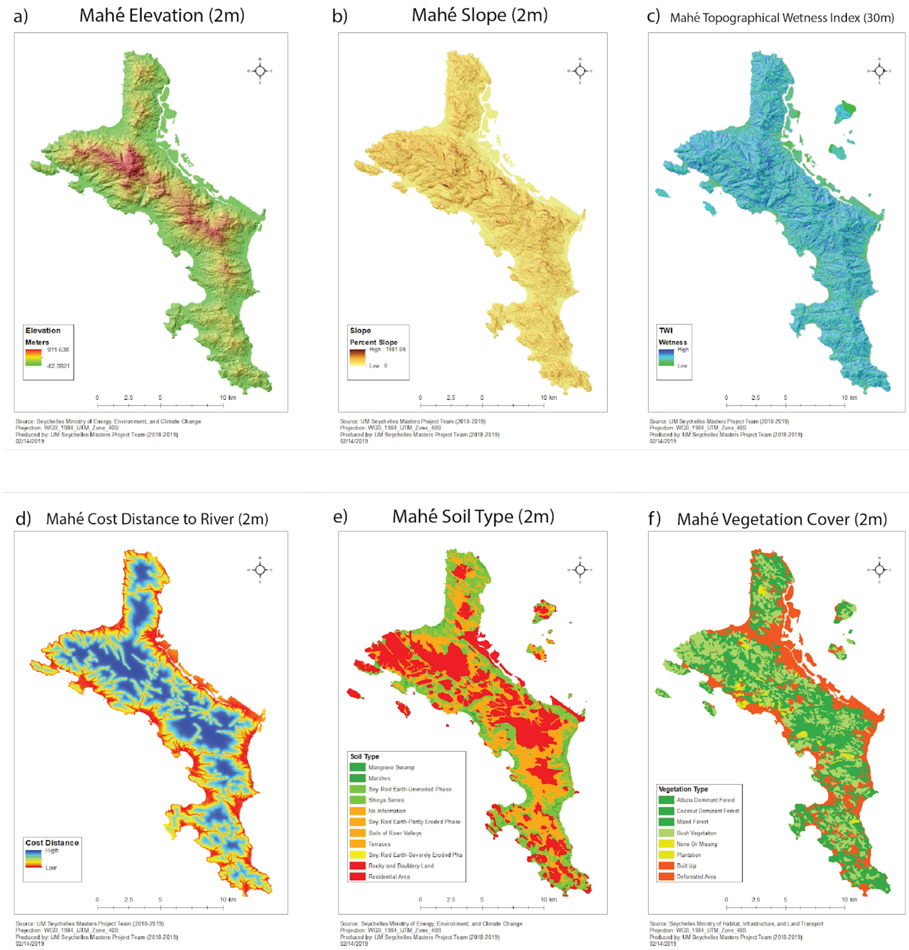


Figure 4.2. The topographical, geological, and hydrological inputs used in the Storm Sturge and Sea Level Rise Exposure Index.

Variable Name	Exposure Direction	Basic Rationale	Weight
Elevation (DEM)	Negative	Storm surge is less likely to reach areas of higher elevation	0.131004
Slope	Negative	Storm surge is 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

Table 4.1. Including the name of the variables used in this exposure analysis, its association with flooding, the reasoning behind the variables' inclusion in the model, and weight assigned to the variables in the model.

Slope is another topographic variable used in the researchers' model to predict storm surge exposure. 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.

Topographic Wetness Index (TWI) was also used as a measure of exposure to storm surge. The TWI was developed by Beven and Kirkby[89] 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, factors that can also be used to help assess exposure to storm surge.[89]

Photo 4.1. A steep slope of the central mountain in Mahé.

The flow accumulation (calculated in Figure 4.3) 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.

TWI is calculated with the formula:

$$\text{TWI} = \ln\left(\frac{a}{\tan(b)}\right)$$

where:

a = upslope area draining through a certain point per unit contour length

tan(b) = slope in radians

To calculate a:

$$a = \frac{\text{cell area} \times (x_{fa} + 0.01)}{\text{cell contour length}}$$

where, with a 2x2m cell resolution:

x_{fa} = flow accumulation

cell area = 4

cell contour length = 2

To calculate tan(b):

$$\tan(b) = \frac{(\text{percent slope} + 0.01)}{100}$$

Figure 4.3. Calculation of Topographic Wetness Index[90]

Cost distance from rivers was another factor that was utilized in the storm surge exposure 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.[91] 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 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 provided by the Seychelles Centre for GIS by using the 'Cost Distance' tool in ArcGIS.

Another factor necessary to consider in understanding flood exposure is the ability for soils to infiltrate water. Infrastructure built on soils capable of effectively draining water are much less exposed than impervious surfaces or poorly-drained soils, such as clays.[92] Polygon data of soils provided by the MEECC was converted to a 2m resolution raster. Researchers then scored the different types of soils on a scale from 1 to 100 of increasing exposure. These scores were based on the soils' imperviousness, drainage capacity, retention capacity, and level of existing erosion damage.

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 exposure.[93] Like the soils data, the vegetation cover data is a 2m raster produced from polygon data provided by the MEECC. Vegetation cover was also scored on a scale from one to 100 of increasing exposure. These scores were based on the density of woody plants, with higher density assigned higher scores.

In order to ensure all input variables were properly scaled to the masked extent, the researchers assigned scores of 1 (least exposed) to 100 (most exposed) using the 'Slice' tool in GIS with the processing extent being set to the 15m 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 15m would be assigned a score of 100. In addition, elevation, slope, and cost distance to rivers all have a negative association with storm surge exposure, so their scores were reclassified to reflect that with the formula $y = -(x - 101)$. Following the earlier example, this would reclassify that aforementioned 15m maximum elevation cell to have a score of 1.

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 exposure.[94,95] These relative importance values were then input into the AHP (Analytic Hierarchy Process) program created by Professor Eiichirou Takahagi of Senshu University, which calculated appropriate weights for each variable (Table 4.1).[96] The scored variables were then added together with their assigned weights using the 'Weighted Sum' tool to produce the Storm Surge exposure Index raster in Figure 4.4.

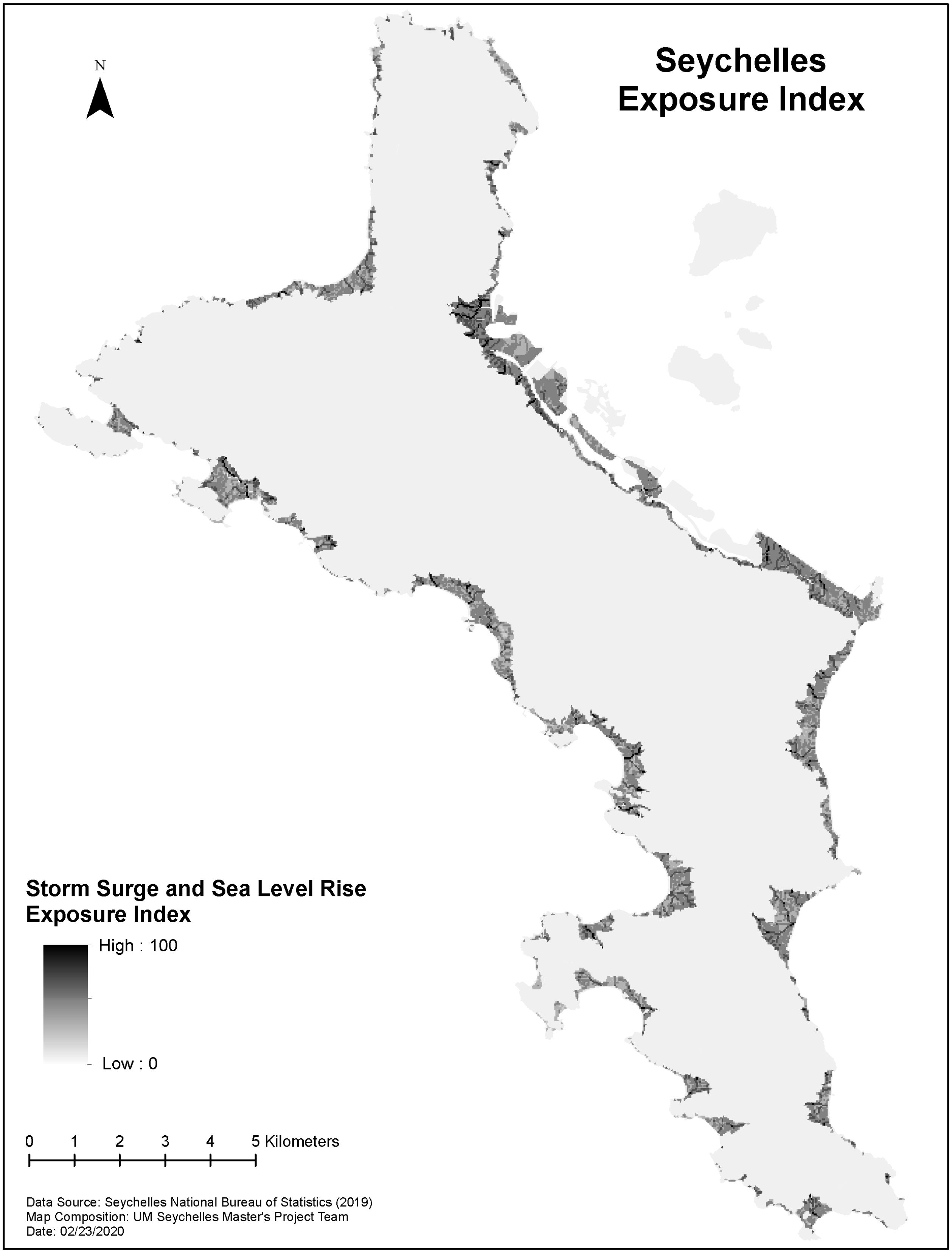


Figure 4.4. The Storm Surge and Sea Level Rise Exposure Index generated by the researchers.

4.2 Infrastructure Exposure Index

After modeling what regions of Mahé would be impacted by storm surge and sea level rise, infrastructure exposure was modeled by the researchers. Appendix F has detailed exposure index scores for infrastructure at 0m, 0.5m, 1m, 1.5m, and 2m of sea level rise and storm surge scenarios. For the purposes of this analysis, infrastructure exposure can be defined as the likelihood that infrastructure will be damaged by flooding based on storm surge and sea level rise exposure and the density of infrastructure of the region. Where storm surge and sea level rise exposure broadly means conditions that exist which would make storm surge impacts more damaging to infrastructure, storm surge and sea level rise means "conditions that exist which would make storm surge and sea level rise impacts more likely to do damage to infrastructure." Again, note that this does not predict the probability of a storm surge and sea level rise occurring but instead assesses what regions have a high density of infrastructure in locations that are exposed to storm surge or sea level rise damage.

The researchers' final infrastructure exposure model is a Multi-Criteria Analysis model with critical infrastructure density and the Storm Sturge and Sea Level Rise Exposure Index as criteria of interest. The full workflow of the methods used to produce the Infrastructure Exposure Index can be found in Figure 4.5.

Based on the characterization of critical infrastructure by stakeholders, the researchers included data pertaining to distribution of energy, water, and sewage, as well as government facilities, ports, roads, and tourism establishments in the analysis. Data sets were provided by the Centre for GIS in Seychelles' Ministry of Habitat, Infrastructure, and Land Transport (MHILT) and PUC. 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 (Septic Tanks), Electricity Transformers, 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: Raw Water Pipes, HDPE Water Pipes, 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, Seychelles Port Authority, and 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 15m mask created during the storm surge exposure modeling. Point density rasters were created by the 'Point Density' tool using neighborhoods of 250 cells with the raster being 2m 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' tool 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 a total critical infrastructure density score raster. Maps of all density types can be seen in Figure 4.6.

The Storm Sturge and Sea Level Rise Exposure Index was used, and data were 'Sliced' to a scale of 100 for the purposes of this infrastructure exposure analysis. The total infrastructure density score raster and Storm Sturge and Sea Level Rise Exposure Index were combined with equal weights to create a storm surge and sea level rise infrastructure exposure raster. This was the final step in creating the scores that can be used to understand the risk sea level rise and storm surge pose on individual pieces of infrastructure.

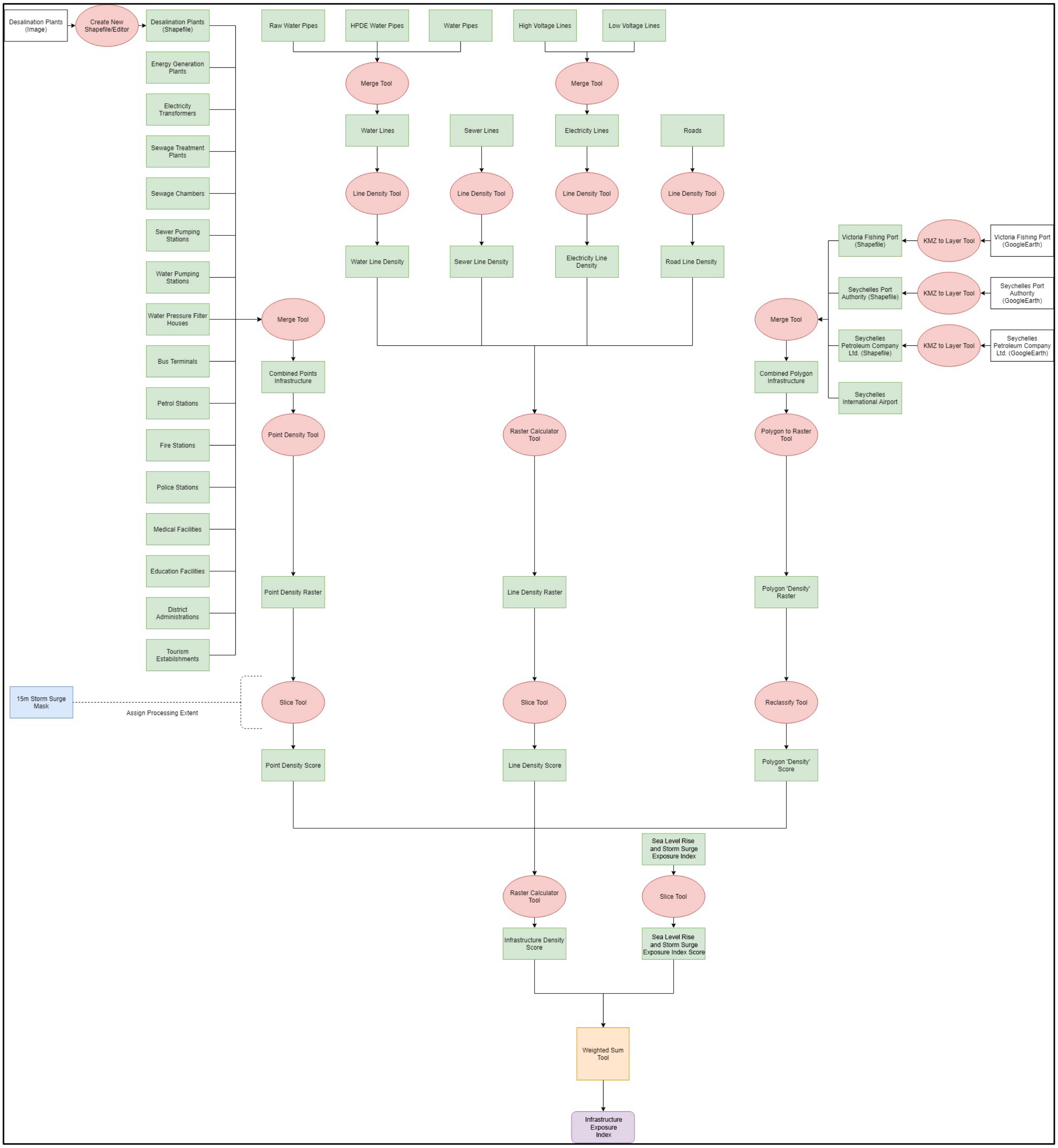


Figure 4.5. A workflow diagram depicting the basic steps taken to produce the infrastructure exposure data

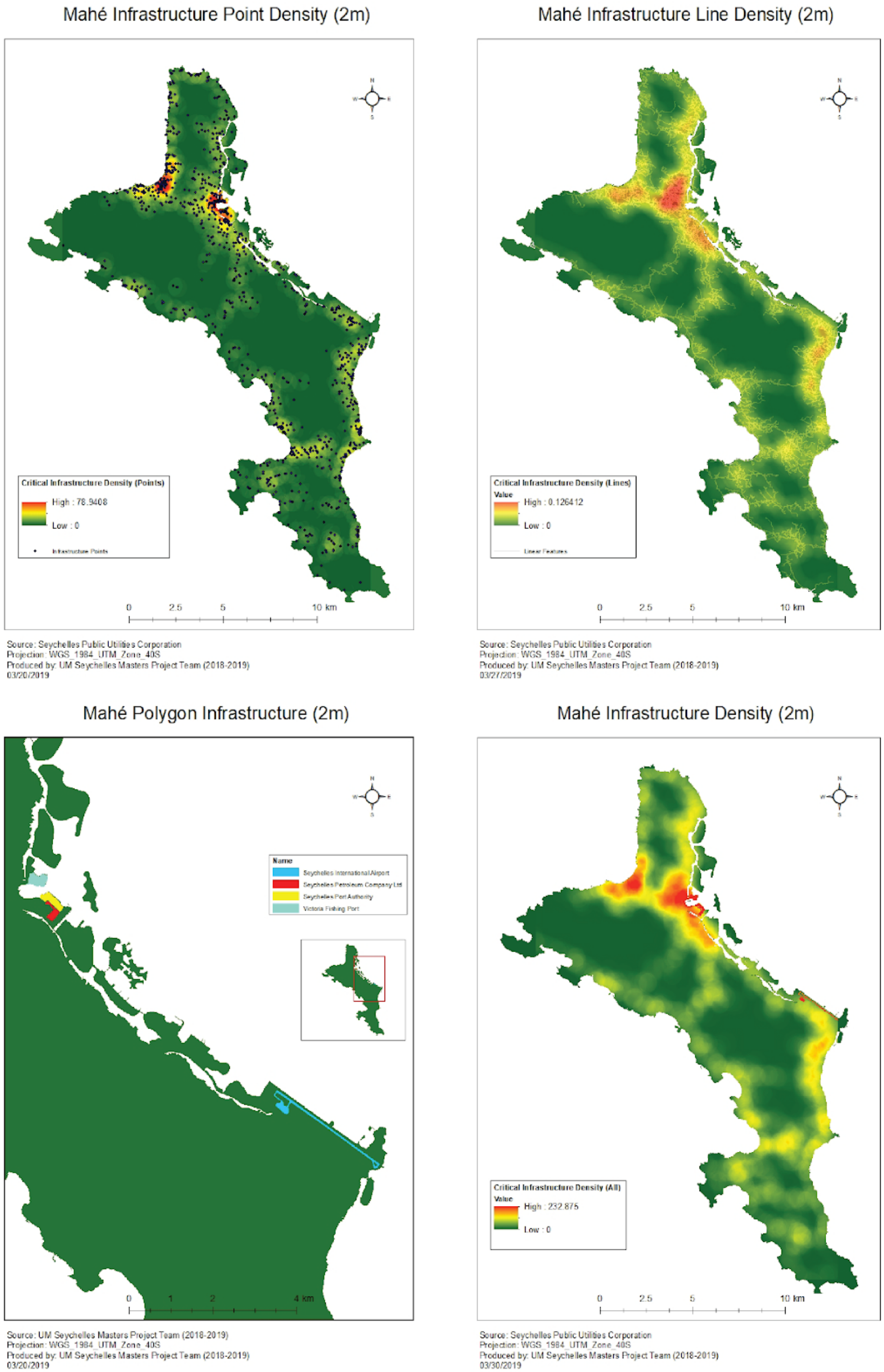


Figure 4.6. Maps depicting point, line, and polygon infrastructure density layers on Mahé.

4.3 Socioeconomic Factors and Vulnerability

Seychelles National Bureau of Statistics data from the 2010 Population and Housing Census, and its nearly completed 2020 iteration, were used to demonstrate how to include social factors, such as literacy and gender, in adaptation decision-making. The following maps and figures include the Exposure Index developed above as a measure of physical risk to the island overlaid with various social factors. Some important socioeconomic data sets (e.g., household income) were unavailable, thus preventing the development of a comprehensive social vulnerability index. Therefore, instead of a weighted scale normally used to develop and index, the following maps layer georeferenced social indicators on the Storm Sturge and Sea Level Rise Exposure Index.

4.3.1 Population Density

Based on interviews with key Seychellois stakeholders, population density was identified as one of the most important considerations for adaptation policy. Mapping population density allows decision-makers to understand population exposure to sea level rise and storm surge. Identifying highly populated areas exposed to sea level rise and storm surge offers a method for prioritizing specific areas and making adaptation decisions.

Seychelles has a population of approximately 96,800 people, and over 85% reside on the island of Mahé.[40] Population was measured by the National Bureau of Statistics in 2019, as part of the Population and Housing Census to be published in 2020. Census data is collected by enumeration areas. There are over 600 enumeration areas on the three main islands of Seychelles; this data set focuses on the enumeration areas on Mahé. Enumeration areas are composed of approximately fifty to seventy dwelling units each. The boundaries were drawn to make the workload for each field worker manageable, outline each area distinctly, ensure complete coverage, and avoid double-counting households.

Population density for the analysis was calculated by dividing the total number of individuals in an enumeration area by the area in square kilometers of the respective enumeration area, shown in Figure 4.7. Researchers used the WGS 84 UTM ZONE 40 S projection, matching the Storm Sturge and Sea Level Rise Exposure Index calculation.

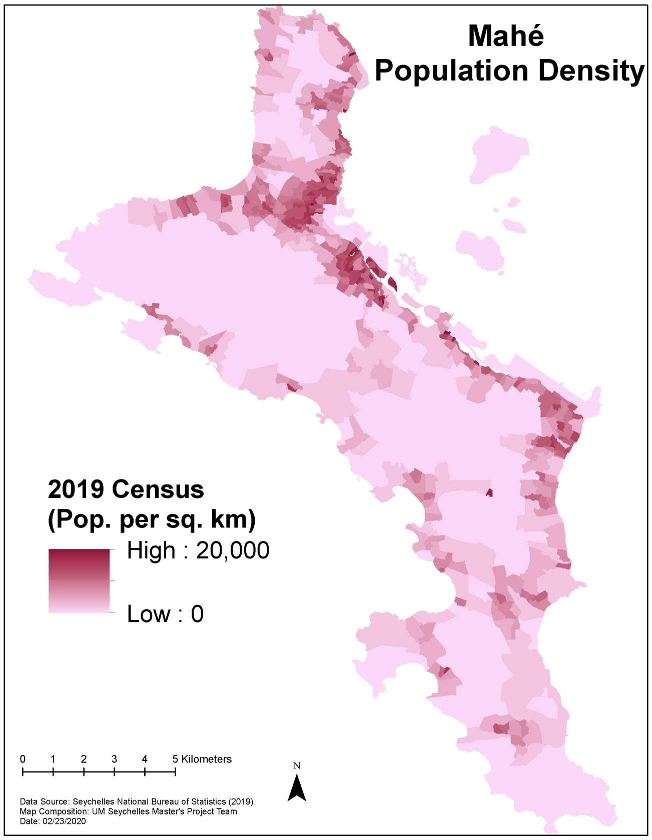


Figure 4.7. Mahé population density calculated from Population and Housing Census data collected in 2019.

To identify highly populated areas that are vulnerable to sea level rise and storm surge on Mahé, population density was layered with the Storm Sturge and Sea Level Rise Exposure Index. The population density layer was placed over the exposure index and displayed at a transparency of 60% as shown in Figure 4.8.

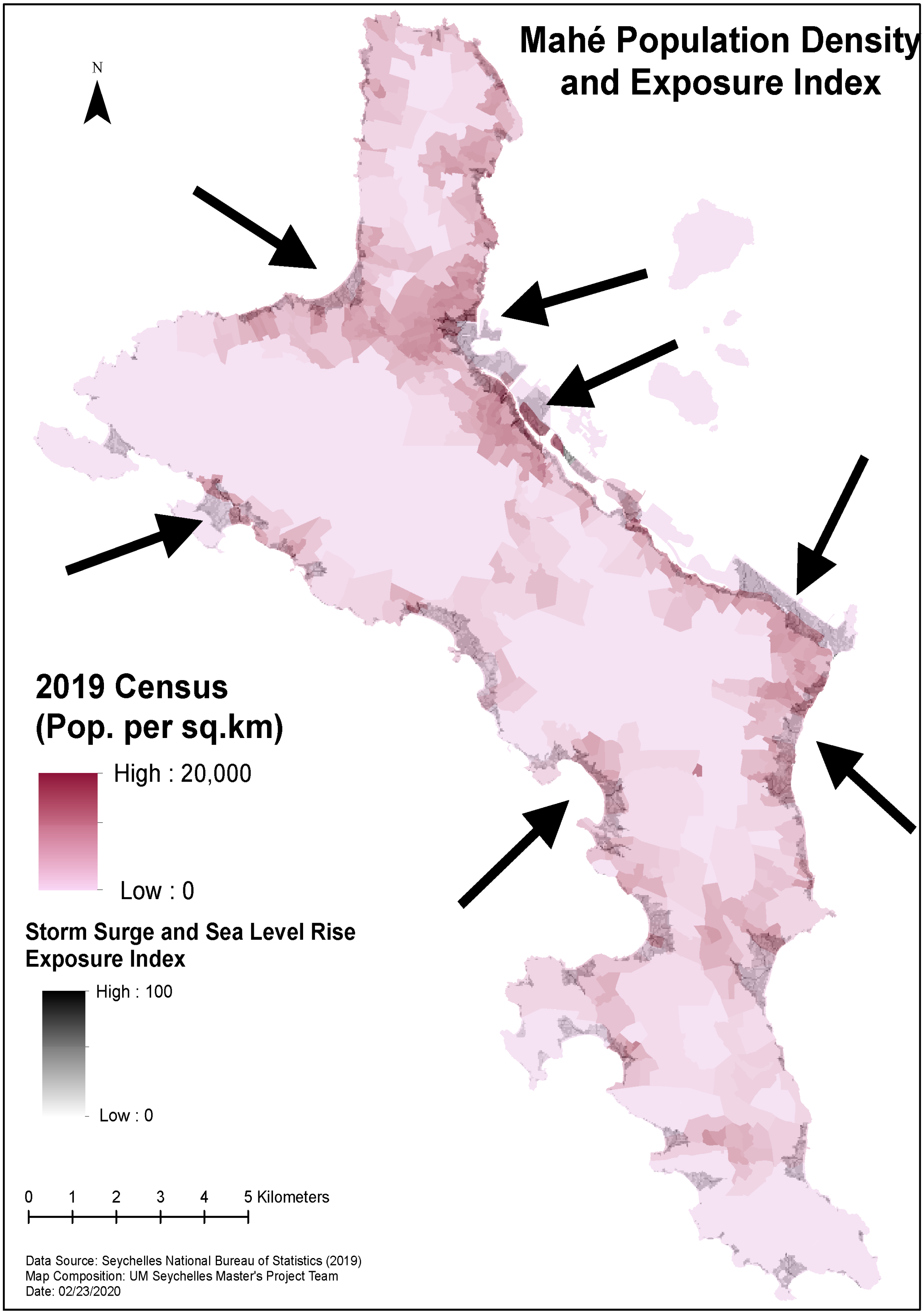


Figure 4.8. Full scale map of Mahé depicting usage of black arrows to indicate where population density and Storm Surge and Sea Level Rise Exposure Index intersect.

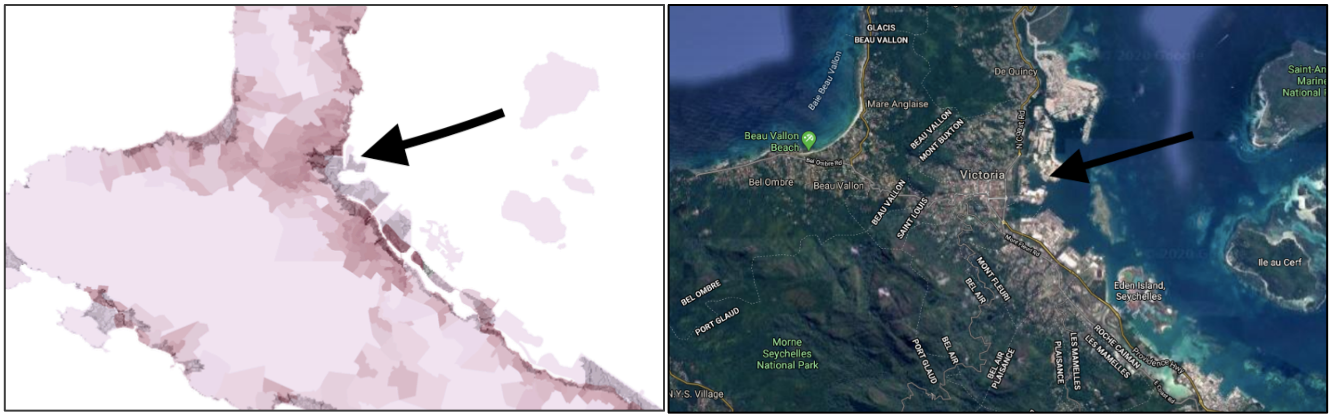


Figure 4.9. Zoomed-in maps with arrows highlighting Victoria, where high population density overlaps with areas exposed to storm surge and sea level rise.

The black arrows indicate clusters of enumeration areas on the island that have both high population density and have high exposure to climate hazards.

With this analysis, areas can be identified as priorities for adaptation based on their exposure and population density. For example, the most highly populated region of Mahé, the capital city of Victoria, can be identified (Figure 4.9). The visual analysis of areas where population density and exposure intersect can be conducted for the entire island of Mahé in an effort to enhance decision-making under conditions of uncertainty.

Implications of Population Analysis

This analysis implies that the focus of adaptation policies could be on areas that have the highest population density. Knowledge of where physical exposure to sea level rise and storm surge will have the largest human impact could be helpful for choosing where to focus resources for adaptation projects and encourage planning for these regions first. This could also signal that continued development in these regions, without adaptive planning is ill-advised.

4.3.2 Literacy Rates

Literacy refers to the ability to read, write, and use numeracy in at least one language. In 2018, Seychelles' literacy rate was 95.9%. Literacy rates have been rising since 1987 and education has been free and compulsory until sixteen years old since 1981.[42] Literacy is a critical component of adaptive capacity because improved communication of climate knowledge enhances the community's ability to respond to hazards such as sea level rise and storm surge. Therefore, areas with low literacy rates are likely to be more vulnerable and less able to adapt to the impacts of climate change. The areas of low literacy on the island are important to note as they may require different forms of disaster communication, have lower understanding of the impacts of climate change, and be less prepared to respond in the event of storm surge or sea level rise.

In this analysis, researchers used the rates of literacy per enumeration area from the Seychelles National Bureau of Statistics' 2010 Population and Housing Census Report. This report has been published six times: in 1977, 1987, 1994, 1997, 2002 and 2010. The next census is scheduled to be published in 2020. There are over 600 enumeration areas on the three main islands of Seychelles; this data set focuses on the enumeration areas on Mahé. Enumeration areas are composed of approximately fifty to seventy dwelling units each. The boundaries were drawn to make the workload for each field worker manageable, outline each area distinctly, ensure complete coverage, and avoid double-counting households.

The literacy rates were calculated by dividing the number of literate individuals in an enumeration area by the population of the respective enumeration area and converted to a percentage. This data represents the percentage of the population in each enumeration area that is classified as literate. The data is displayed in Figure 4.10.

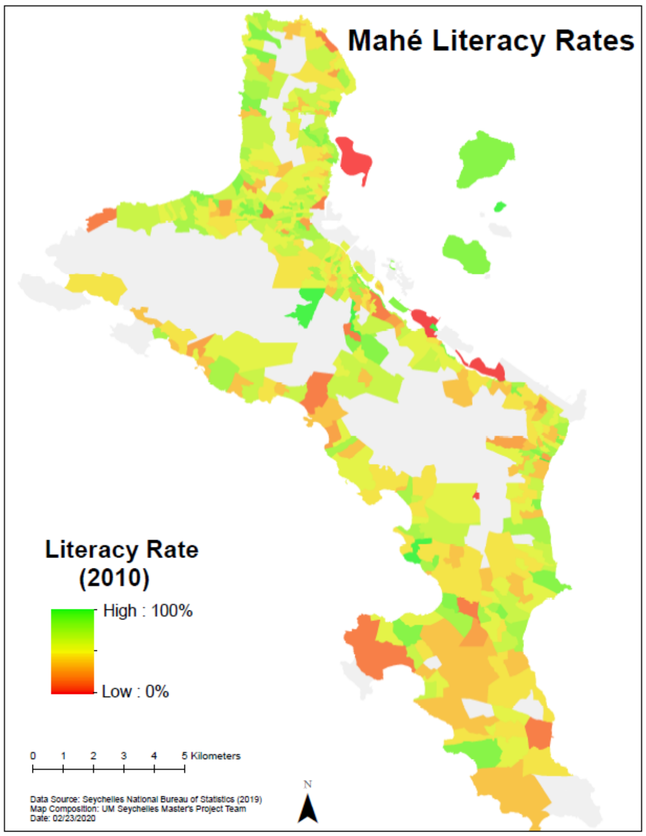


Figure 4.10. Map of Mahé literacy rates per enumeration area.

As with the population density analysis, literacy rates alone do not indicate a form of social vulnerability to sea level rise and storm surge. In order to identify areas that may have increased social vulnerability to sea level rise and storm surge because of low literacy, literacy rates were layered on top of exposure scores and displayed at a transparency of 60%. Areas of concern were identified where low literacy intersected with high exposure to sea level rise and storm surge. These areas are depicted with black arrows in Figure 4.11.

Implications of Literacy Analysis

This analysis suggests that policies could be put in place that address the education gap between different regions of the island as a means for addressing climate change. Increased literacy may lead to increased adaptive capacity for Mahé as well as an enhanced ability for the government to share disaster risk knowledge to citizens. Information sharing on the island with regards to climate change could reduce difficult-to-measure overall vulnerability and help individuals with decision-making. This analysis also implies that adaptation policies could best serve the public by targeting efforts in the areas where social vulnerability may be higher.

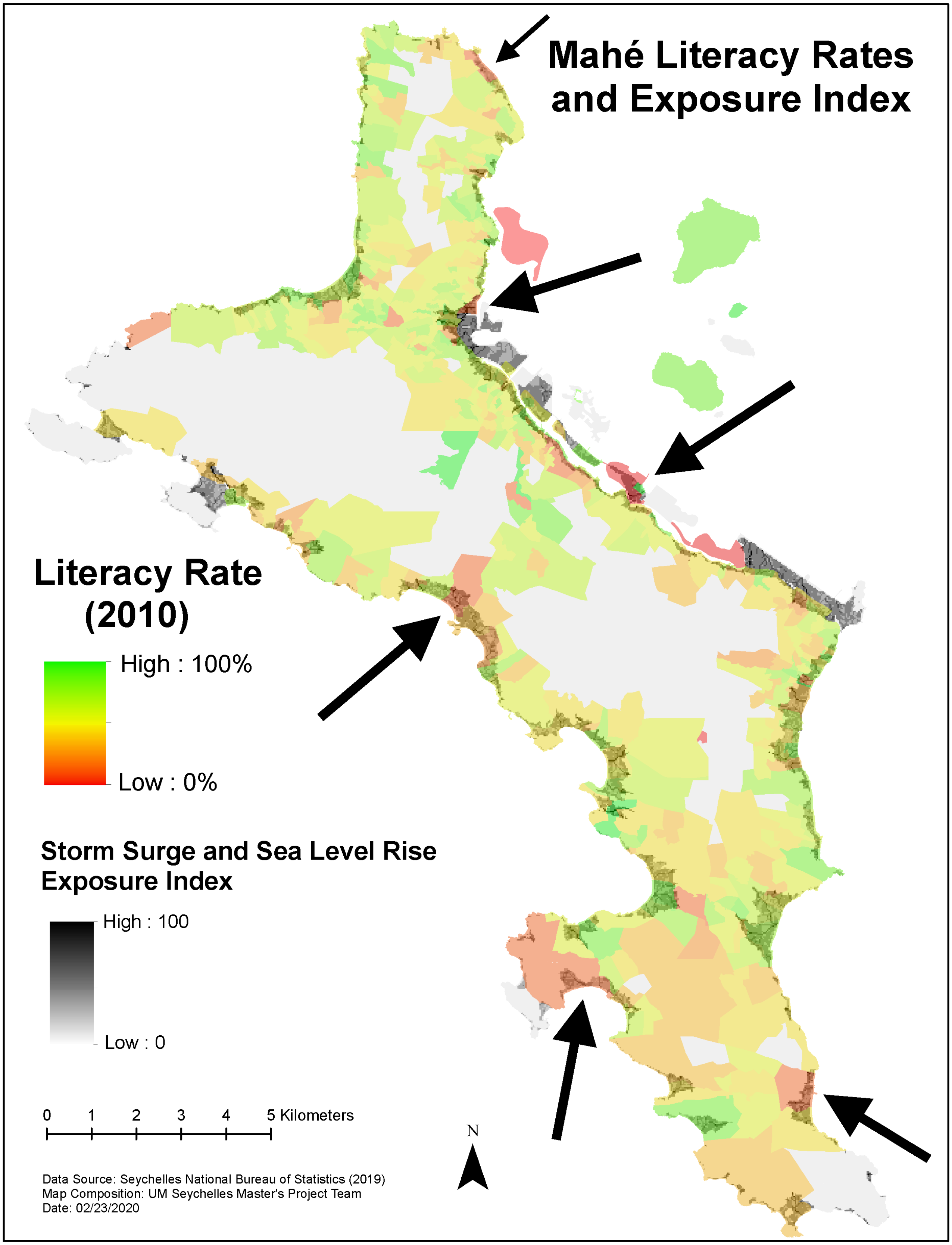


Figure 4.11. Mahé literacy rates layered with Storm Surge and Sea Level Rise Exposure Index. The black arrows depict areas where low literacy and high exposure index scores overlap.

4.3.3 Gender

In 2018, over 80% of individuals displaced by climate change were women. International actors, such as the UN have conducted studies that show women are more likely to be affected by climate change than men. This is of particular concern when the woman's role is primary caregiver and provider of food and fuel under flooding and droughts conditions.[97] In Seychelles, the impact of interest for this study is sea level rise and storm surge, indicating female share of the population should be considered as a social vulnerability factor, as flooding is projected. As of 2019, Seychelles' gender ratio between men and women is nearly equally distributed with 1.06 males per one female.

Figure 4.12 displays the female share of the population per enumeration area from the Seychelles National Bureau of Statistics 2010 Population and Housing Census Report. This report has been published six times: in 1977, 1987, 1994, 1997, 2002 and 2010. The next census is scheduled to be published in 2020. There are over 600 enumeration areas on the three main islands of Seychelles; this data set focuses on the enumeration areas on Mahé. Enumeration areas are composed of approximately fifty to seventy dwelling units each. The boundaries were drawn to make the workload for each field worker manageable, outline each area distinctly, ensure complete coverage, and avoid double-counting households.

The female share of the population was calculated by dividing the number of females in an enumeration area by the population of the respective enumeration area and converted into a percentage. This data represents the percentage of the population in each enumeration area that identifies as female.

From Figure 4.12, it is evident that the population is largely evenly balanced between male and female. There are, however, several areas that have a particularly large female share of population. These areas are displayed as dark purple regions. Light purple regions have a low female share of population. One area of interest is the southernmost part of Mahé, which has a very high female share of population.

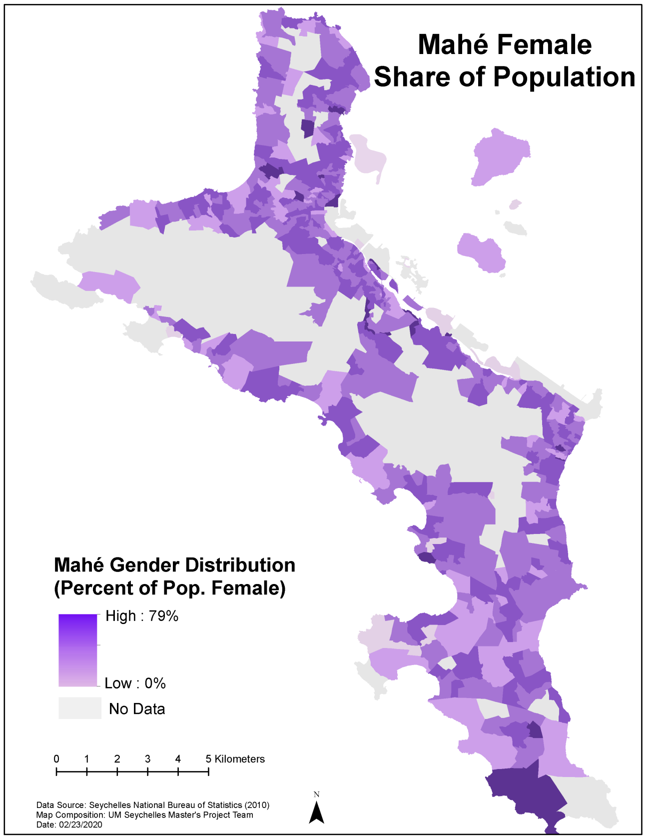


Figure 4.12. Female Share of population on Mahé.

Similar to the population density and literacy rate analysis, female share of population alone does not indicate a form of social vulnerability to sea level rise and storm surge. In order to identify areas that may have increased social vulnerability to sea level rise and storm surge because of a largely female population, female share of population data was layered on top of exposure scores and displayed at a transparency of 60%. Areas of concern were identified where high female share of population intersected with high vulnerability to sea level rise and storm surge. These areas are depicted with black arrows in Figure 4.13.

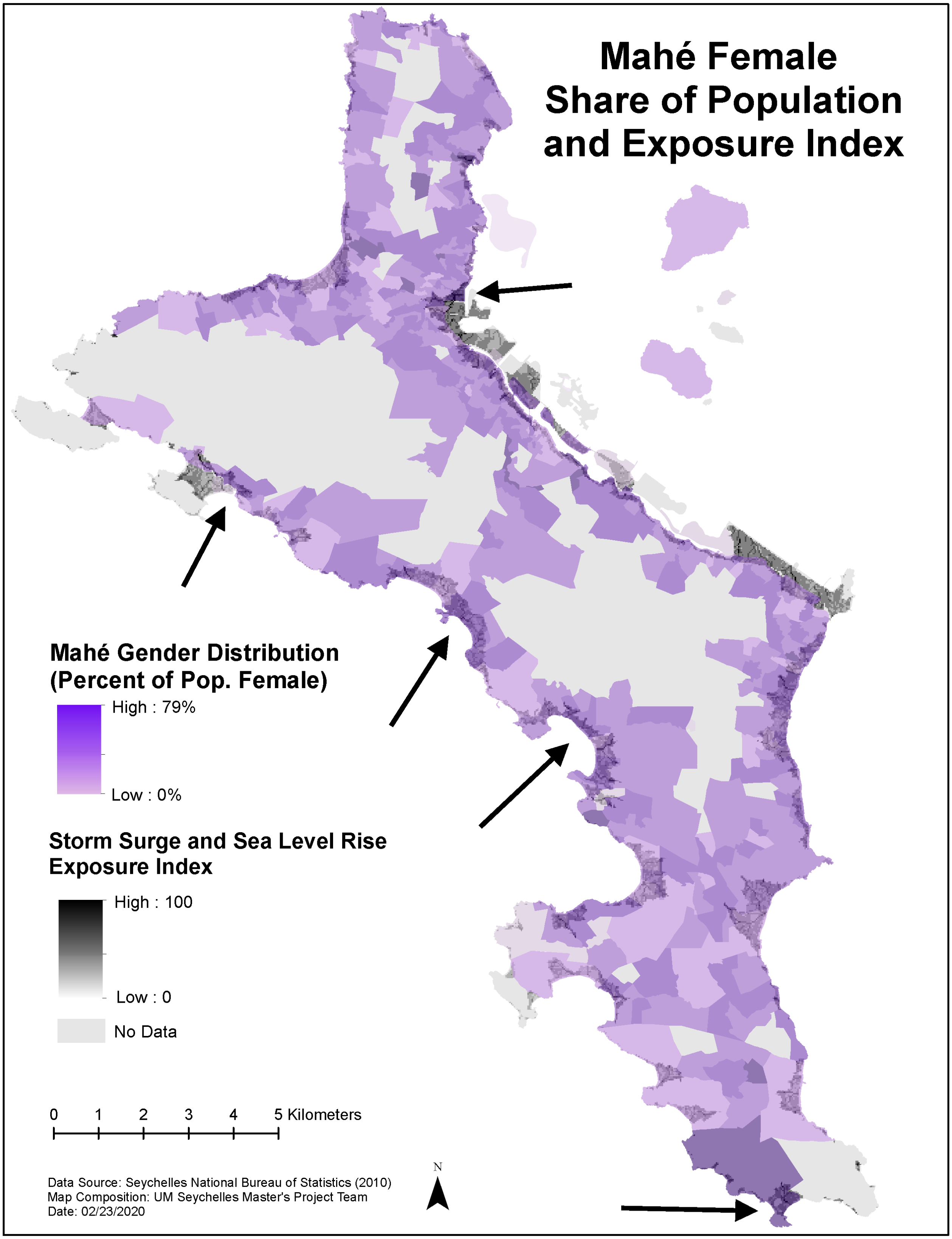


Figure 4.13. Female share of population layered with black arrows that indicate where the Storm Surge and Sea Level Rise Exposure Index overlaps with areas that are majority female.

Implications of Gender Analysis

This analysis suggests that policies could be put in place that consider the different regions of the island that are heavily populated by women as a means for addressing climate change impacts. Increased attention and adaptive projects in these female-dominated areas could best serve the public by targeting efforts in the areas where social vulnerability may be higher. Identifying where women may be more impacted on the island may allow Seychelles to recognize that women are disproportionately impacted by climate change in their coastal management policies.[97]

4.4 Geologic Events

The data for the geologic events layer (Figure 4.14) was adapted from a document shared with the researchers by DRDM. The document was originally created as a part of a Sustainable Land Management project to develop a geological and contour risk map to assess areas at particular risk for landslides, flooding, and rockfalls. The source document represents the only concerted effort to compile information on geological disasters in Seychelles in such detail. The authors of the source document assembled data from the National Archives—primarily archived newspaper reports and TV reports from the Seychelles Broadcasting Corporation—and studies on geologic risks commissioned by government departments.[98]

The document included geologic events that occurred from 1862 through 2011 on the islands of Mahé, Praslin, and La Digue, though this map only contains events that occurred on Mahé. Events were classified as landslides, slope failures, rockfalls, debris falls, or debris flows. Causes were classified as rain events, tsunamis, or drainage issues.

Events

As defined in the source document, landslides are the downslope movement of soil, rock, and organic materials under the effects of gravity. Landslides depicted in this layer represent mass movements in which the material on a zone of weakness is separated from the more stable underlying material. There are distinct classifications of landslides associated with varying mechanics of movement and types of material. The specific landslide classifications exhibited here are rockfall, debris fall, and debris flow.

Rockfalls are sudden and rapid processes by which a rock detaches from a slope and descends by falling, bouncing, or rolling. They typically occur along cliffs or steep slopes and result in the displacement of large rocks, sometimes landing on roads or built structures. Rockfalls are strongly influenced by gravity, mechanical weathering, and interstitial weather such as regular intervals of rain.

Debris falls are the processes by which a combination of soil, rock, mud, and organic material detaches from a steep slope and descends by falling, bouncing, or rolling as a conglomerate. They typically occur suddenly along cliffs or steep slopes, resulting in displaced materials that can land on roads or built structures. Debris falls are strongly influenced by gravity, mechanical weathering, and interstitial weather such as regular intervals of rain.

Debris flow (commonly called a mudslide) is the process by which masses of loose soil, fragmented rocks, mud, organic matter, and water move down a slope under the influence of gravity. While a debris flow mobilizes as a conglomerate, the components move independently. Source areas of debris flows are typically adorned with steep gullies. Debris flows deposit materials in fan-like shapes at the foot of the slope or accumulate where an obstruction—like a built structure—is encountered. Debris flows are commonly caused by intense surface water flow due to heavy rain that erodes material on a slope.

Slope failures are abrupt processes in which a very steep slope collapses due to weakened self-retainability, or the ability to uphold materials. Slope failures typically occur along slopes that are steeper than landslides and are characterized by smaller-scale movement than landslides. Materials displaced as a result of slope failure accumulate at the bottom of the slope. Slope failures are commonly triggered by heavy rain or earthquakes.

Causes

The causes of the events displayed in this data layer were derived from the source document. Most events were attributed to rain events - torrential rain, rainstorms, or rainfall. Events attributed to tsunamis refer to the tsunami that made landfall in Seychelles in December 2004 as a result of an earthquake in Sumatra. Events attributed to drainage issues were characterized as such in the source document.[98] Though many drainage issues were coupled with rain events, the researchers chose to keep them separate as these events may not have occurred during the associated rain event if not for the poor drainage. Events attributed to El Niño refer to the El Niño event of August 1997. During this event, a tropical depression became stationary over the main Seychelles islands in the middle of the dry season, dumping more than 600mm of rain on Mahé over a period of five days.[98]

Mapping

The geologic events detailed in the source document were given an alphanumeric name representing the district where it occurred, the date of occurrence, an event number, and source of the information. When extracting data from the report, the researchers recorded the name, event type, cause, and location information of relevant geologic events. Latitude and longitude coordinates were provided for some events in degrees minutes seconds format while other events had no associated geographic location. Events that included degrees minutes seconds coordinates were converted into XY coordinates using an online conversion tool. Events with no exact location information were, however, accompanied by additional details, such as photos and descriptions of surrounding areas, that allowed the researchers to determine the relative location of the event using Google Maps.

To illustrate the data, a table (Appendix E) containing event names, X and Y coordinates (in degrees of latitude and longitude), event type, and event cause was uploaded to ArcMap and points were displayed using the Display XY Data tool. The data points were then projected to match WGS 84 UTM ZONE 40 S projection of the existing maps. Display of the points was subsequently adjusted to distinguish between event types by color.

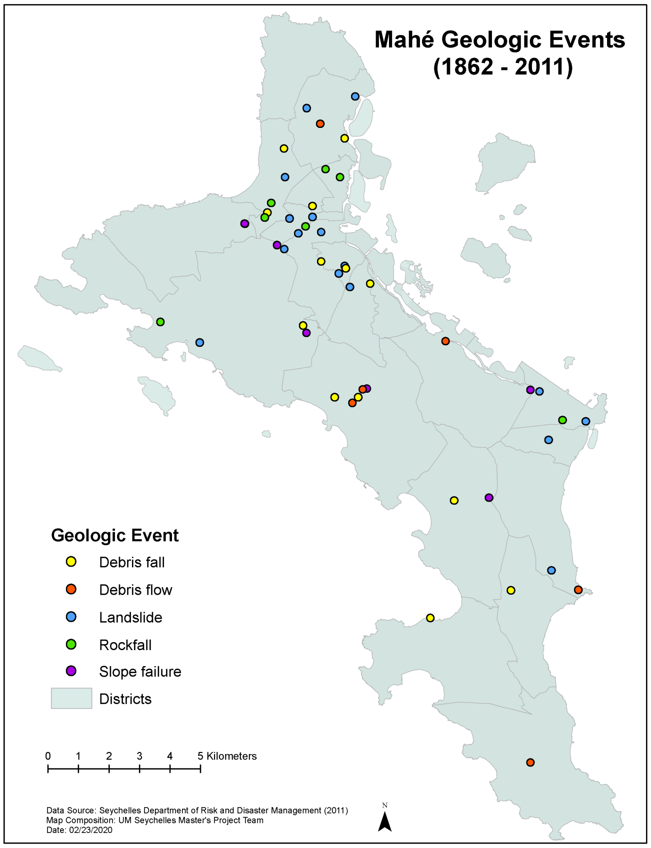


Figure 4.14. Map of geologic events on Mahé from 1862 to 2011.

Overall, most geologic events shown in Figure 4.14 occur along the coastal plain that lines the island. A major cluster of events can be seen in the area surrounding Victoria. The low elevation of most of these events is not surprising as their recorded locations were representative of the place of impact or the material's final resting site. So, it would make sense that the recorded locations are often downslope from where the anticipated outset of the event might be. The consistency with which the events occur along roads (Figure 4.15) and populated areas is unsurprising for a similar reason; These types of events are more likely to be reported when they cause damage to homes, roads, or other built structures. The movement of soil and other organic materials in an uninhabited area is less likely to be noticed and subsequently recorded. It is likely that additional geologic events have happened in more remote parts of the island but were unreported.

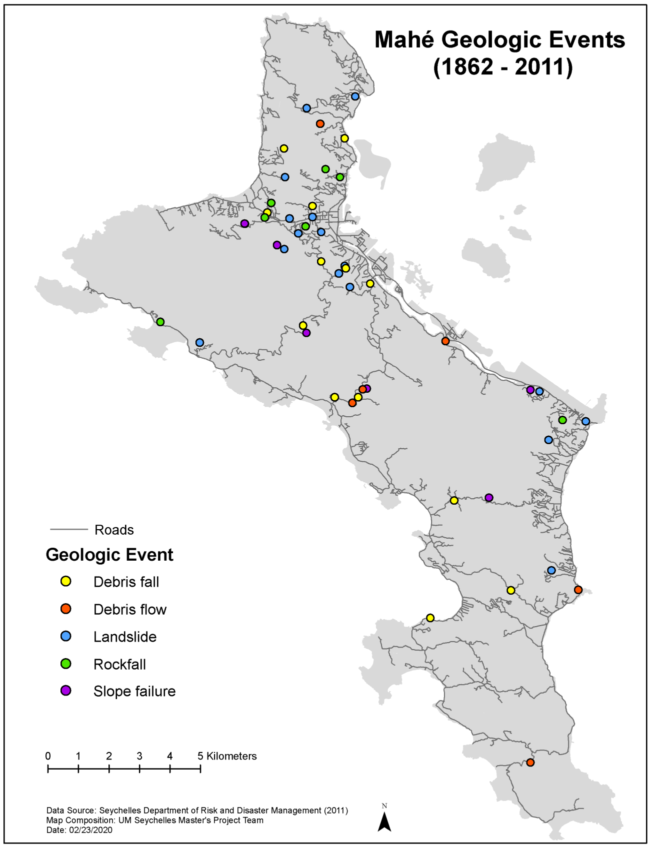


Figure 4.15. Geologic events that occurred on Mahé from 1862 to 2011 superimposed over a layer showing the road system on Mahé.

In total: thirteen debris fall events, seven debris flow events, sixteen landslide events, seven rockfall events, and six slope failure events accounted for in this data set. Three events were caused by drainage issues, fourteen events were caused by the El Niño event, 23 events were caused by rain events, and nine events were caused by the tsunami. The high frequency of debris falls and rain events is valid as debris falls are heavily influenced by interstitial weather, which is exhibited in Seychelles by regular patterns of rainfall.

The determining factors of susceptibility to landslides and other geologic hazards can be grouped into two categories: preparatory and dynamic triggering factors. Preparatory variables are conditions that make land surface susceptible to failure, such as topography, geologic history, and land use. Dynamic triggering factors are events that have the potential to activate such an event, like rainfall or seismic activity.[99] The relevant preparatory variables - soil type, elevation, slope angle, and proximity to human settlement - are thoroughly examined in the source document.

Extreme rainfall, in the form of high intensity and/or long duration, is among the most common dynamic triggering mechanisms for landslides, along with earthquakes.[99] Because the Seychelles islands are situated in a tectonically stable location within the African tectonic plate and has an intra-plate configuration (meaning it is located on the interior of a tectonic plate, not along a fault line), there is a very low likelihood of large earthquakes occurring in Seychelles.[98] This leaves rainfall as the primary triggering factor driving geologic risk in Seychelles. There is some discussion in the source document regarding areas prone to flooding, but no analysis of anticipated climate or weather changes and how they might exacerbate the geologic risk in Seychelles.

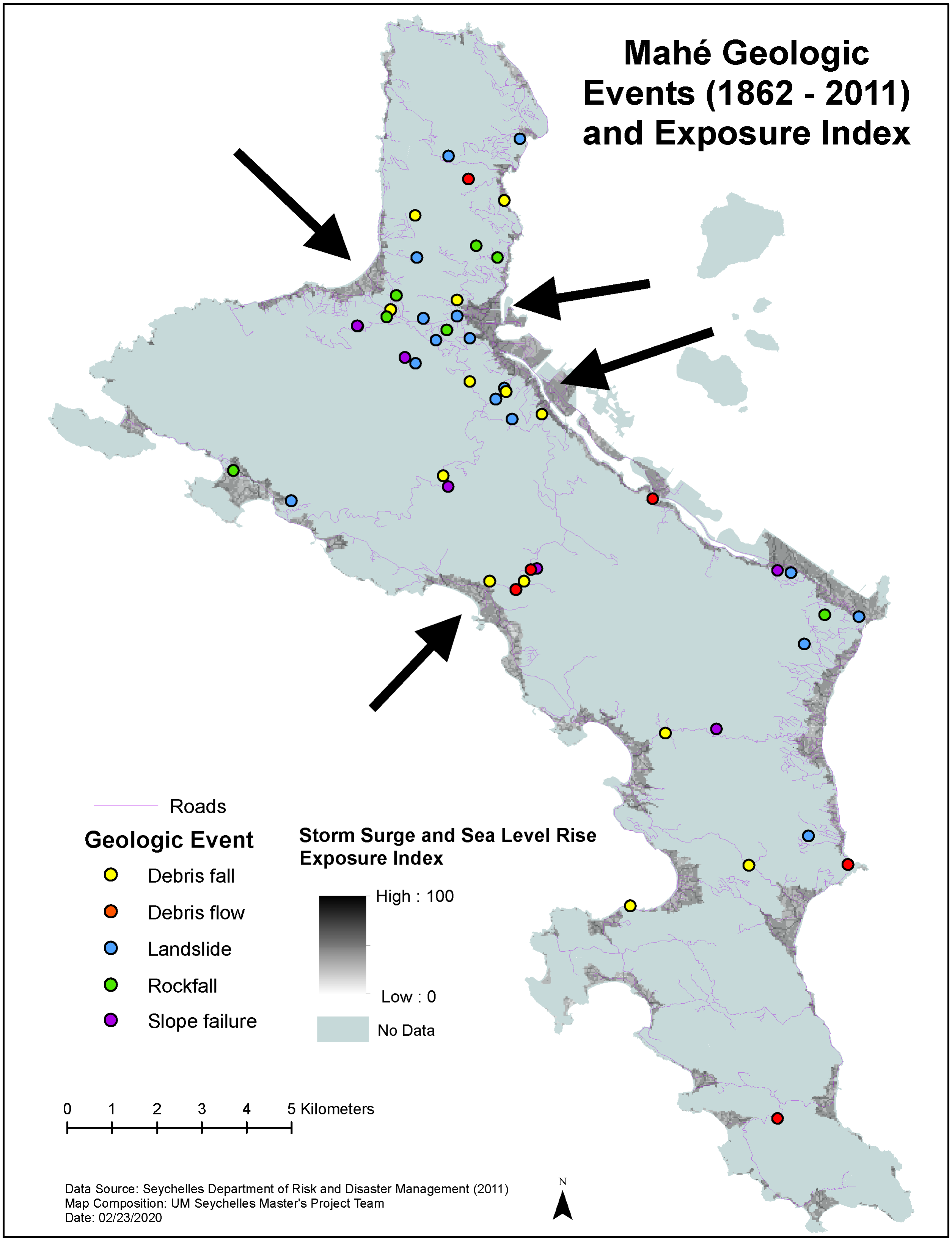


Figure 4.16. Map of geologic events layered over Seychelles' road network and the Storm Surge and Sea Level Rise Exposure Index. The black arrows indicate areas on Mahé that are exposed to both geologic events and sea level rise and storm surge.

Throughout the 750 million years of its existence, natural fractures have fissured the Seychelles microcontinent and exposure has induced fracturing along the weakest point of the rock's atomic structure.[98] This fracturing is exacerbated by weathering mechanisms—namely wind and rain—which can cause pieces of rock to detach from the larger rock mass, resulting in these geologic events.[74] Rain, in particular, has a weathering effect on granite because it is mildly acidic due to the absorption of trace gases in the atmosphere; this is a process called chemical weathering. Over time, this slight acidity slowly dissolves the minerals that compose granite rocks. Humid tropical zones are the sites of the most intense chemical weathering on the planet.[74] Coupled with increased rain events is the threat of sea level rise. The inundation of the Seychelles islands with sea water is also a potential source of weathering that could cause geologic events. As oceans become more acidic, chemical weathering of the underlying geology of the granitic islands will only be further exacerbated. However, there is no information on these impacts at a scale comparable to that exhibited in Seychelles, as these are the only mid-oceanic granitic islands on the planet.

In an effort to display the compounding effect of geologic events, sea level rise, and storm surge, the researchers produced a map detailing these three factors. Figure 4.16 depicts Mahé's history of geologic events, road infrastructure, and the Storm Sturge and Sea Level Rise Exposure Index. Areas highlighted with arrows face the compound risk of geologic events, storm surge, and sea level rise such as the cities of Victoria, Beau Vallon, Grand Anse Village, and the Mont Fleuri District.

Implications of Geologic Event Analysis

An increase in rain and storm events, sea level rise, and ocean acidification in and around Seychelles will exacerbate the risk of geologic disasters. When developing disaster preparedness plans, land use plans, and climate adaptation mechanisms, Seychellois decision-makers should continue to account for such risks.

4.5 Administrative Districts

Seychelles is divided into 26 administrative districts. 22 are located on Mahé, each with government-appointed administrators. The eight districts in the capitol region of Victoria and the other fourteen found across the rest of Mahé were included in this analysis.

Stakeholder interviews indicated that some adaptation decisions occur at the district level. As an additional decision-making support tool, the researchers prepared a district-focused map that depicts the twenty-two districts on Mahé with the exposure index layered over it. From this analysis, areas of specific districts that fall within the 2m Sea Level Rise and Severe Storm Surge Exposure Index, shown in (Figure 4.17)

Implications of District Analysis

The district-level analysis implies that some districts have higher levels of exposure to sea level rise and storm surge than others. For example, some districts on the northern part of the island have smaller areas that have high exposure scores, whereas districts near Victoria and the eastern side of the island have large, densely populated areas that are within the sea level rise and storm surge projection region. These maps allow individual district administrators to prioritize areas along the coast and to focus adaptation efforts where exposure scores are highest.

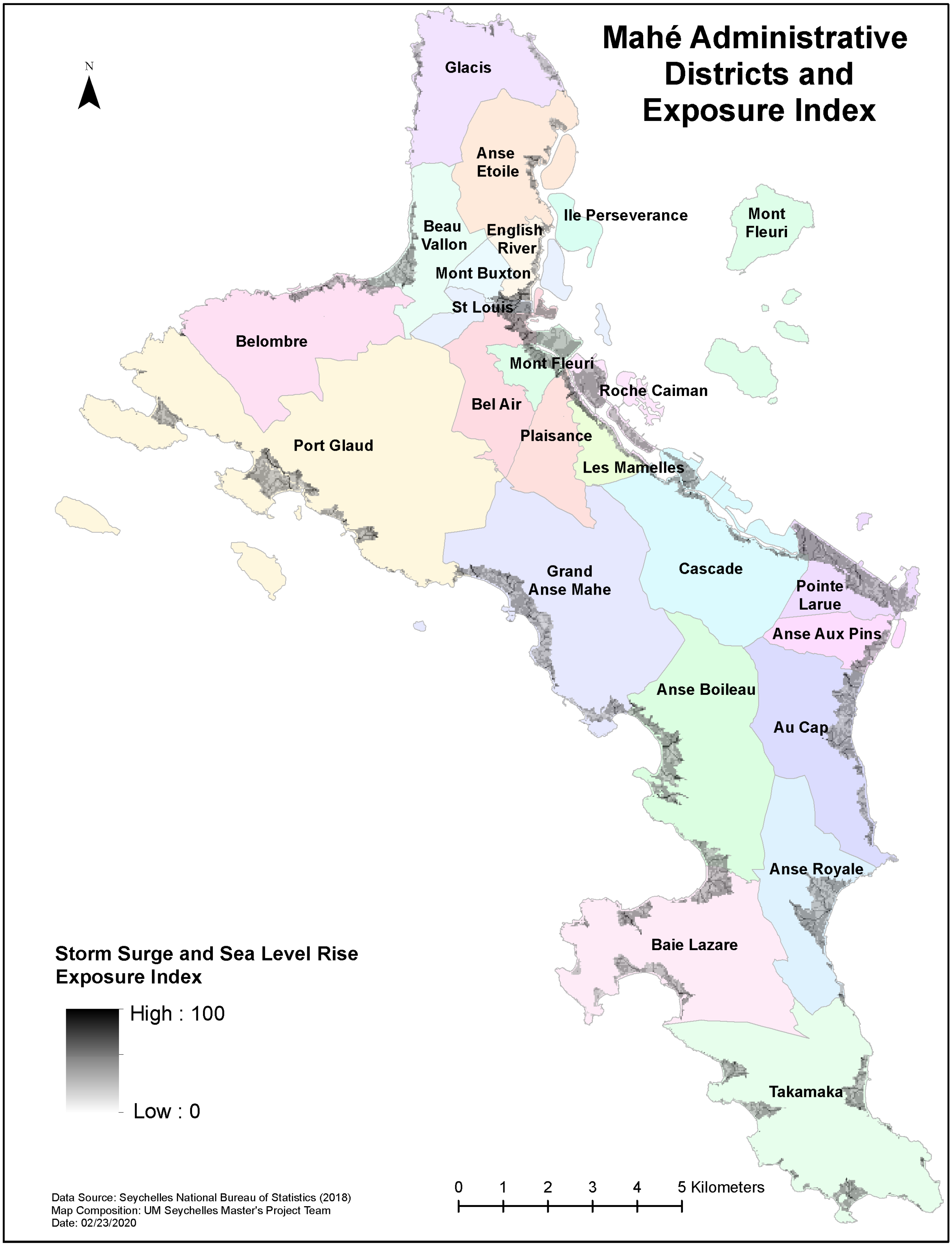


Figure 4.17. Map of Mahé administrative districts layered below the Storm Surge and Sea Level Rise Exposure Index.

4.6 Data Sharing

To facilitate information sharing surrounding climate adaptation, the researchers partnered with PReP, a data sharing partnership and platform managed by Resource Watch, a subsidiary of the World Resource Institute. PReP was developed to address challenges related to access to useful, timely, and credible data by opening a line of communication between data providers and users. The website, prepdata.org, is a map-based open data online platform that allows users to access and visualize spatial data that reflects past and future climate, as well as physical and socioeconomic settings.

PReP is an accessible and interactive platform tool that can be utilized for adaptation planning. Data sets curated and published by PReP are able to be accessed and downloaded by any user with access to the internet. Users can create and share custom visualizations, including maps, tables, and charts, of georeferenced data. Users can also create accounts on the PReP website which allow them to create dashboards. A dashboard is a feature that allows users to collect relevant data, maps, tools, and stories in one place. Users can amalgamate dynamic resources specific to geographic or topical interests and share their findings with this feature. This could be a useful resource for decision-makers in Seychelles to gather relevant climate data that can be used to support adaptation decision-making processes.

Seychelles-specific data sets available on PReP include infrastructure (bus stops, bus terminals, car parks, dams, district administration buildings, educational facilities, fire stations, jetties, petrol stations, police stations, roads, and tourism establishments), reclamation areas, wetlands, storm surge exposure index, sea level rise, administrative district boundaries, population density, gender, literacy rates, and geologic events.

The direct link to these Seychelles-specific data sets is: https://bit.ly/2SqZD3I.

Using the interactive features of PReP, users are able to combine these data layers to visualize physical characteristics, climate exposure, and social data, allowing them to identify vulnerable locations based on a custom combination of parameters. For instance, users could layer population density, geologic events, and district boundaries in order to determine which districts are most at risk (Figure 4.18). Along with these data sets, global data related to climate, exposure, vulnerability, and physical features are also available on PReP. Though they are less granular, these data sets can provide additional relevant information for decision-makers.

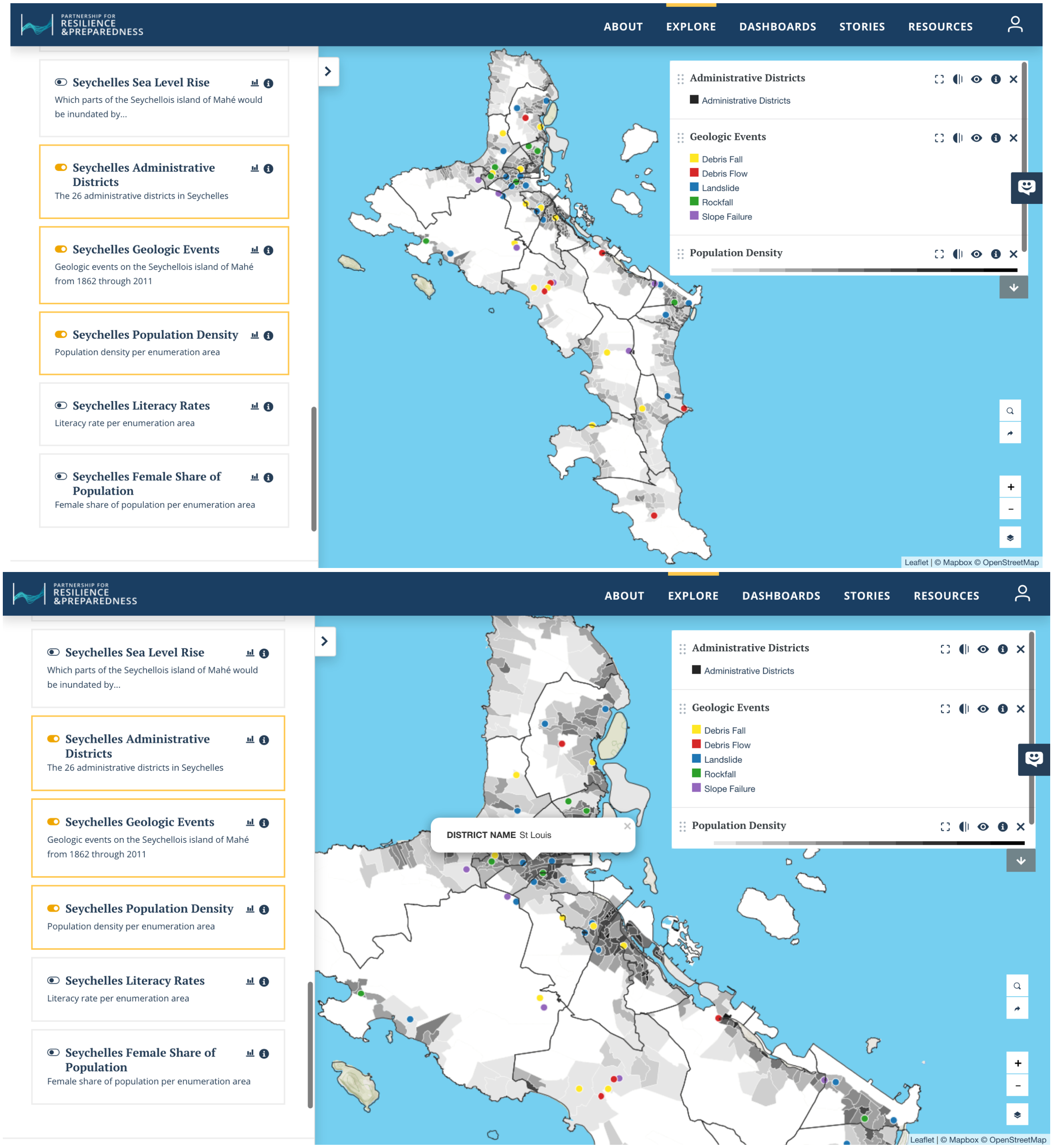


Figure 4.18. Two images of the PReP website displaying administrative districts, geologic events, and population density data layers for Seychelles. The bottom image provides an up-close look at the St. Louis district in Victoria area, which has high population density and high exposure to sea level rise and storm surge.

Chapter 5
Conclusions and Recommendations for Adaptation

5.1 Conclusions

Due to the complex climatic, oceanic and weather systems in the Western Indian Ocean region, the future of Seychelles climate is uncertain. This research made an effort to approach adaptation and climate risk from several distinct directions to help decision-makers be efficient in their adaptation plans and related budgeting. The multi-pronged analysis in this report began by considering stakeholder perspectives and characterizations of hazards, exposure, vulnerability, and risk. Next, climate change projections and climate scenarios were developed using qualitative and quantitative information about sea surface temperature, precipitation, sea level rise, storm surge, wind-related upwelling and drought. Finally, several geospatial analyses were conducted that assessed sea level rise and storm surge hazards, infrastructure exposure, and social vulnerabilities that help to determine risk.

5.1.1 Climate Risks to Vulnerable Sectors

Transportation

Climate change is anticipated to cause structural damage to the transportation sector, resulting in the disruption of economic activities and the functioning of goods and services. Damage to the airport and seaport could result in flight delays and cancellations and disruption of shipping routes. The relocation or retrofitting of coastal infrastructure (e.g., the coastal highway) may be needed, though it would be an expensive undertaking.

Natural Infrastructure

The fishing and tourism industries were characterized as critical infrastructure because they drive the Seychellois economy. Both depend on the ecological health of coral reefs. Climate change impacts, specifically increases in SST, threaten the viability of coral reefs and tuna stocks in Seychelles' EEZ. This will result in coral bleaching, impaired coral reproduction, and reduced coral calcification. The absence of fringing reefs increases wave energy reaching the shoreline, exacerbating coastal erosion and sand deposition behind beaches. Higher SST will also compress tuna habitats and shift tuna stocks poleward, ultimately decreasing catch potential and lowering fishery productivity. Options for rehabilitating reefs and enhancing coral resilience to climate change include coral transplants, utilization of coral nurseries, and genetic manipulation. Coral transplanting is the physical relocation of corals from one environment to another in order to increase the chance of survival. Coral nurseries are designated sites, typically found in the ocean, used for growing coral stock collected from nearby reefs that are later transplanted to a new substrate to facilitate regrowth and regeneration. Genetic manipulation—also referred to as assisted evolution—is the process of genetically engineering corals in sites, usually a laboratory, to modify and strengthen genes that enhance corals' ability to withstand bleaching stress, ultimately accelerating the rate of natural evolution and adaptation. Enhancing adaptation and resilience to climate change in the fisheries sector relies upon fishery diversification. Increasing catch diversity of the fisheries sector to target new species reduces sensitivity to external shocks.

Utilities

Sea level rise and storm surge will have varying impacts on utility infrastructure in Seychelles. All utilities could face corrosion by sea water, which corrodes materials five times faster than freshwater. Inundation of sea water could also damage freshwater resources and cause land subsidence. Overall, as a result of these impacts, Seychelles' utility services could be disrupted which could limit their service capacity and increase operational costs.

5.1.2 Barriers to Climate Adaptation

Three domains of barriers were identified by Seychellois stakeholders as significant barriers to climate adaptation. These barriers—lack of capital, scarce developable land, and limited human capacity—could be addressed in policy and budgeting decisions. The recommendations in the following section provide some guidance with regards to these barriers.

5.2 Recommendations

On the basis of this research, the study team has developed a series of recommendations which could help Seychelles close remaining knowledge gaps and increase their capacity to adapt to sea level rise and storm surge. These recommendations are divided into three categories. The first covers suggestions to improve future climate research and knowledge sharing. The second category is about engaging a wide range of stakeholders in climate adaptation. The third category of recommendations covers issues funding for climate adaptation.

5.2.1 Research and Knowledge Sharing

1. Develop a policy and platform to share climate data across government agencies

Climate data is generated in different projects across multiple government agencies. However, these data are often unnecessarily reproduced because one agency lacks knowledge of, or access to, data already produced by another agency. For example, this project faced challenges in collecting current data about Seychelles' infrastructure, in particular information about agricultural lands and government buildings. While employees of one agency were aware of infrastructure-related projects carried out in a different agency, few knew how to access this data.

To address this lack of coordination, Seychelles could develop a policy requiring that any government climate project must share the data it produces. The outputs of diverse climate projects could populate an online repository, with an index describing each data product's completion date, hosting ministry, and other useful metadata. The repository would be accessible by all members of the Seychellois government and could be shared with non-government entities as needed. This could reduce redundancy in data collection efforts, inform future climate research, and improve the adaptation decision-making process.

2. Assess climate risk for all of Seychelles' islands

While all of Seychelles' 115 islands are facing climate risks, this research was only able to focus on Mahé. A future study could apply this project's research methods to the remaining islands in Seychelles. It is possible that a comprehensive risk analysis of all the islands could help prioritize adaptation projects more efficiently than by considering Mahé alone.

The risk analysis carried out in this project could also be made more comprehensive. First, the exposure analysis could account for infrastructure not included in the present project, such as agricultural land, food storage buildings, public housing, and Mahé's six ice plants. It could also incorporate additional characteristics of the infrastructure, such as type, age, building materials, and economic value. The outcome of this effort would allow more detailed comparisons of existing infrastructure exposure that could feed into future risk and cost-benefit analyses.

3. Construct a Social Vulnerability Index to improve climate risk assessment

When trying to analyze social vulnerability in Seychelles, some key components to constructing a social vulnerability index were missing from the available 2010 data. After speaking with stakeholders involved in the 2020 census, it was apparent that enough data would be made available to construct an SVI. In practice, SVIs use census data to determine social vulnerability of a given area or population and, in Seychelles, census enumeration areas would likely be a good option. In an SVI analysis, enumeration areas are ranked on social factors with high ranks meaning high social vulnerability and low ranks meaning low social vulnerability. In order to construct a social vulnerability index, more detailed and georeferenced data would allow four thematic areas to be better understood. The four thematic areas commonly used in a social vulnerability index are: socioeconomic status, household composition, race/ethnicity/language, and housing/transportation. Specifically, it would be helpful to collect data on household income, car ownership, access to transportation, household crowding, disability status, minority group membership, and mobile phone access. SVI maps could then be used to:

- Estimate the amount of needed supplies like food, water, medicine, and bedding.
- Help decide how many emergency personnel are required to assist people.
- Identify areas in need of emergency shelters.
- Plan the best way to evacuate people, accounting for those who have special needs, such as people without vehicles, or the elderly.
- Identify communities that will need continued support to recover following an emergency or natural disaster.[100]

4. Improve tracking and mapping of geologic events and restrict development in areas prone to damage

Geologic events triggered by rainfall cause a great deal of damage in Seychelles. Due to the geophysical nature of Mahé, continued development of the island, and anticipated increases in frequency and intensity of rain events, these destructive geologic events are expected to be exacerbated. Tracking and mapping the locations of these events will be useful for informing future development policies. A georeferenced map of all these events, including details such as event type, causes, and inflicted damage could be created and shared with agencies involved in construction and development. This would allow relevant parties to understand where and why these destructive events are happening.

In addition, mapping the geomorphologic risks on Mahé could help develop a more detailed hazard assessment. Using historical, topographical geomorphological data, and weather data, a hazard map could be created to identify areas on the island more prone to these geologic events. Though the events may not be predicted with a high degree of certainty, understanding the interactions of the local geomorphology, rain events, and human-caused disturbances could be useful in assessing risks from geological hazards.

5. Invest in localized modeling for the West Indian Ocean to better understand Seychelles-specific climate change impacts

Developing a Regional General Circulation Model (RGCM) for the West Indian Ocean region could reduce reliance on global data and mathematical downscaling, which produces less accurate results. A coupled model—one that addresses both the atmospheric and oceanic components impacting regional climate—would be ideal. If this is too expensive for Seychelles to undertake alone, partnership could be formed with other countries in the region to pool resources and make a joint investment.

The research done on the interaction of different local climate features (e.g., Somali Jet, MJO, IOD, and Seychelles Dome) is significantly lacking. It is critical to understand both the feature's individual dynamics under changing climate conditions and how each feature may augment or suppress another in the future. It is equally important to understand the interactions of general weather and climate trends such as precipitation, ambient temperature, sea surface temperature, coral reef temperature, and sea level rise.

6. Integrate green and gray infrastructure adaptation projects and establish robust monitoring and evaluation plans

Ecosystem-based adaptation was identified by stakeholders as a preferred method of adaptation to sea level rise and storm surge risk. The approach has been recognized by the government and mandated in the constitution. Although EbA could protect the biodiversity that supports the country's tourism and fisheries industries, EbA approaches are not quick fixes. Researchers recommend an integrated approach to adaptation that strategically combines EbA solutions (green infrastructure) with man-made structures and mechanical equipment (gray infrastructure) to both provide ecosystem services and achieve other development goals for Seychelles. Evidence from case studies in other Small Island Developing States indicates that the integration of green and gray infrastructure can provide timely responses to urgent climate impacts while allowing for EbA to produce resilient and lower-cost services.[101,102]

Stakeholders also identified the need for more robust monitoring and evaluation of adaptation projects on Mahé. A robust monitoring and evaluation plan could be established for future adaptation projects. Additionally, future research efforts could assess how long EbA strategies take to reach their full adaptive potential and how well they mitigate climate hazards.

5.2.2 Stakeholder Engagement

7. Create a Seychelles Climate Commission to coordinate adaptation efforts

A large structural barrier to adaptation in Seychelles is a lack of departmental coordination on climate adaptation efforts. Due to the largely decentralized nature of Seychelles' government, cohesive adaptation is difficult to achieve. An interdepartmental commission that includes representatives from all branches of local government could tackle these issues collaboratively. Having everyone in the room could keep all departments on the same page, reduce project overlap, and overcome bureaucratic obstacles.

8. Engage the private sector and the citizenry in climate adaptation efforts

Industries, particularly fisheries and tourism, will be greatly impacted by climate change. The government needs the private sector to develop with climate change in mind and the private sector benefits when the government takes action on climate adaptation. Thus, a partnership between government and industry may be mutually beneficial for sharing information and implementing adaptation strategies to protect the national economy.

Existing networks of education organizations could implement a comprehensive educational program that focuses on the impact climate change will have on the lives of everyday Seychelles citizens. The programs could also help Seychellois learn approaches to adapt their own homes, farmland, and other infrastructure.

Local citizens can aid climate adaptation efforts if given an adequate opportunity. By incorporating the perspectives of individual stakeholders and citizen groups in the decision-making process, the government may better understand the needs of communities, while also helping to raise public understanding of impending climate hazards. The Ministry of Local Government could help facilitate such a process. Fostering collaboration with the general public may deter the currently pervasive community pushback hindering national climate projects (see Chapter 2).

These types of collaborations can help prioritize climate change across diverse groups. To foster collaboration, the government could create a climate change committee, or empower an existing one, to connect individuals from industry, tourism, academia, government, and the nonprofits sector. This group would be charged with collaboratively assessing future challenges and developing climate adaptation strategies for Seychelles.

5.2.3 Funding Adaptation Projects

9. Employ staff to secure national and international funding for climate adaptation

While recognizing that financial barriers are a persistent challenge for small island developing states, the Seychellois government's constant reductions in funding for climate change adaptation put critical infrastructure at greater risk. Repairing and replacing infrastructure after it has been damaged by sea level rise or storm surge will incur higher costs than proactively protecting it. Because Seychelles' recent categorization as a developed country may reduce the international funding it can acquire for climate projects, making adequate allocations in the national budget for climate adaptation is even more crucial. The country's infrastructure and, in turn, its economic and social well-being, depend on it.

Unfortunately, the cost of necessary climate projects far exceeds the country's financial capacity. While it may be more difficult now to obtain international funding, it is still important to seek it and to do so creatively. Seychelles has long been innovating in finding international funding (e.g., Seychelles "Debt for Dolphins" agreement with The Nature Conservancy). Further innovations could be aided by the creation of dedicated staff positions to identify and apply for international funding from various sources including the Green Climate Fund, Global Environment Facility, and Adaptation Fund. These staff members could continue to promote the country's unique biodiversity and environment to bolster investment in adaptation and conservation from international governments and organizations. Finally, the staff members could advocate for climate funding from the national government.

10. Incentivize climate-resilient development

Designing, building, and retrofitting infrastructure to withstand future climate hazards is a key component of adaptation. The current building permitting process does not incentivize climate-resilient development. As a result, infrastructure continues to be built in areas that are exposed to future sea level rise and storm surge.

As the country begins to implement their National Climate Change Strategy and Coastal Setback Policy, it is crucial that the government incentivize development that accounts for future climate hazards. For example, development could be prohibited, or at least limited, in locations likely to be inundated in the next 50 years. To address this issue, the MEECC could be given a stronger mandate to ensure that any new public or private sector construction be climate proofed. Climate change impacts could also be incorporated into master plans and other land-use planning for communities across the country (e.g., Victoria Master Plan 2040).

Deterring further development in areas prone to geologic hazards, regulations could also be enacted to restrict development on geologically unstable or exposed land. For instance, rock falls are more likely to happen when it cuts into steep slopes of granite. Restricting developers from cutting into slopes above a certain slope angle could prevent future rockfalls and subsequent damage. The DRDM could be given the authority to develop such a regulation and be in charge of approving all new developments. A required consultation with the Department would allow for a risk assessment of the particular location to be done before construction commences. On the basis of the assessment, the Department could deny the construction request or require an adjustment to the construction plan to minimize risks from geologic hazards. Such an approval process would require the training and cooperation of geologists, engineers, and architects. DRDM personnel involved in the approval process may benefit from training to identify and mitigate geologic hazards.

11. Encourage transitional financial support for recently designated high-income countries.

This final recommendation is not directed towards Seychellois decision-makers, but rather towards international organization funding climate adaptation.

Seychelles has recently been categorized as a high-income country by the World Bank. While this is a sign of economic progress, it has had unfortunate consequences for Seychelle's climate adaptation efforts. Funding that was previously available to Seychelles as a developing country is either no longer available or greatly diminished. Yet, funding remains crucial to Seychelles climate adaptation efforts. Thus, large funding organizations (e.g., World Bank, UNDP, Green Climate Fund, Global Environment Facility) should recognize countries that have recently transitioned to high-income status and account for that in making funding decisions, particularly with climate projects that are essential for development.

Seychelles is already feeling the impacts of climate change. Persistent flooding, erosion, and other impacts will only exacerbate in the coming decades. As the country prepares to adapt to a future that looks different from its past, it is the researchers' hope that this report, the accompanying Climate Scenario Planning Toolkit, and the online risk maps (https://bit.ly/2SqZD3I) aid in the country's efforts to craft a climate-resilient future for Seychelles.

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Appendices

Appendix A. Interview data analysis to identify critical infrastructure sectors

Infrastructure sectors sorted by the number of times they were mentioned by interviewees

Infrastructure sector	Number of times mentioned	Number of interviewees mentioning	Specific words mentioned by interviewees
Transportation	**89**	**40 (59%)**	
Roads	43	33 (49%)	Cars, bridges, roads, and transportation routes
Ports	23	17 (25%)	Ports, shipping, and harbor
Airport	20	16 (24%)	Airport
Bus system	3	3 (4%)	Bus depot, public buses, bus system, and bus terminal
Utilities	**98**	**32 (47%)**	
Water	31	15 (22%)	Desalination plant, water treatment, water treatment, water catchment, pump station, pipelines, water system, reservoirs, and dams
Drainage system	13	13 (19%)	Drains, culverts, and drainage system
Electricity	29	11 (16%)	National grid, underground cable, power stations, submarine cables, electricity, substation, generator, power lines, wind farm, poles for lines, and solar farm
Utilities	6	6 (9%)	Utility system and lines
Sewerage	8	5 (7%)	Sewage system and sewage treatment plant
Telecommunication	6	5 (7%)	Fiber cables, telecommunication, fiber optic, and communication
Waste	5	4 (6%)	Waste management, landfill, garbage, dump sites, and waste disposal
Natural Infrastructure	**28**	**21 (31%)**	
Coral reefs	16	16 (24%)	Coral reefs
Beaches	12	12 (18%)	Sand dunes and beaches
Tourism industry	**32**	**21 (31%)**	
Tourism industry	18	16 (24%)	Tourism industry, guest houses, and tourism establishments
Hotels	14	12 (18%)	Hotels

Note: Table continues on following page.

Infrastructure sectors sorted by the number of times they were mentioned by interviewees (continued)

Infrastructure Sector (continued)	Number of times mentioned	Number of interviewees	Specific words mentioned by interviewees
Homes	**23**	**19 (28%)**	Houses, homes, residential land, social housing, guest houses, and low-cost housing
Fishing industry	**25**	**13 (19%)**	
Fishing	21	12 (18%)	Fishing industry, fisheries, canning factory, fishing ports, fishing areas, processing plants, and traditional fishing
Ice plant	4	4 (6%)	Ice plant
Health System	**22**	**13 (19%)**	
Hospital	13	11 (165)	Hospital
Health institutions	9	6 (9%)	Clinics, health centers, health sector, specialist hospitals, and health system
Government Buildings	**14**	**11 (16%)**	
Schools	11	9 (13%)	Schools and education
Government buildings	3	3 (9%)	Government administration, offices, and buildings
Agriculture	**11**	**8 (12%)**	Agriculture, agricultural land, farms, and irrigation
Fuel	**10**	**8 (12%)**	Petroleum storage, distribution, stations, tanks, and depot
Food Storage	**7**	**6 (9%)**	Food storage facilities and warehouses
Other	**4**	**3 (4%)**	Command center for police, army, manufacturing structures, and emergency services
Restaurants	**3**	**3 (4%)**	Restaurants

Appendix B. Infrastructure Exposure Index analysis to identify at-risk critical infrastructure sectors

Infrastructure sectors sorted by Infrastructure Exposure Index scores (higher scores indicate greater exposure)

Infrastructure sector	Exposure Score	Notes
Transportation	**61,425**	
Roads	53,376	
Bus stops	7,637	
Bus terminal	263	
Ports	100	
Runway	49	
Tourism industry	**7,350**	
Tourism establishments	7,350	Includes hotels, guesthouses, and self-catering lodging
Utilities	**7,019**	
Transformers	4,477	
Sewerage pumps	2,020	
District pumps	173	
Sewer catchments	104	
Distribution houses	69	
Pressure filter houses	64	
Treatment plants	58	
Energy generation	54	
Government Buildings	**6,483**	
Chambers	3,571	
Educational facilities	1,453	
District administration	842	
Police stations	490	
Fire stations	127	
Health Systems	**415**	
Medical Facilities	415	Includes clinics, medical offices, and the hospital
Fuel	**375**	
Fuel stations	326	
Petroleum	49	

Appendix C. Interview themes with examples

Interview themes and subthemes with illustrative examples

Theme	Subtheme	Example
Importance of Critical Infrastructure	*Roads*	*"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	*"[Fisherman] leave their boats by the sea, by the beach, and whenever [storm surges] happen, it impacts their livelihoods."*
	Seaports	*"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	*"It's the electricity because desalination will not work without electricity. Sewage treatment plants will not work without electricity."*
	Homes	*"And many people live right along the coastal strip."*
	Airport	*"[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	*"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	*"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	*"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	*"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	*"[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	*"Well, we have schools, community centers, I mean all of those places, those gathering places."*
	Bus Terminal	*"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	*"The government administration is located in low-lying areas as well."*

Note: Table continues on following page.

Interview themes and subthemes with illustrative examples (continued)

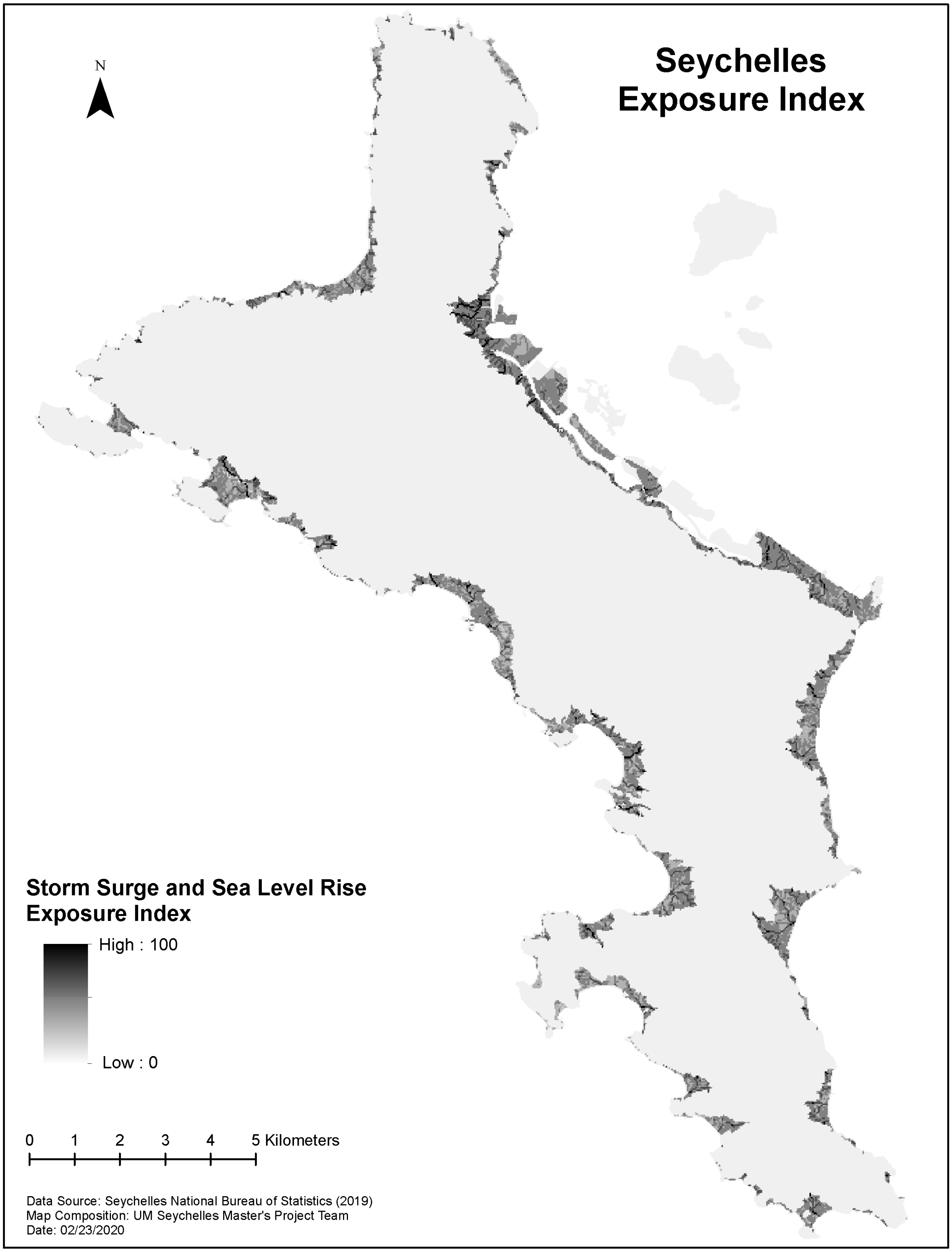
Theme	Subtheme	Example
Barriers to Adaptation	*Lack of Action / Political Challenges*	*"None of us thought about sea-level rise, or your issue of storm surges or anything related to climate change. It didn't necessarily exist when we were planning for these infrastructures."*
	Information Capacity	*"But 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	*"But the government doesn't have money to build [another runway]. They're looking for funding from elsewhere."*
	Space Constraints	*"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	*"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	*"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	*"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	*"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	*"[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	*"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."*

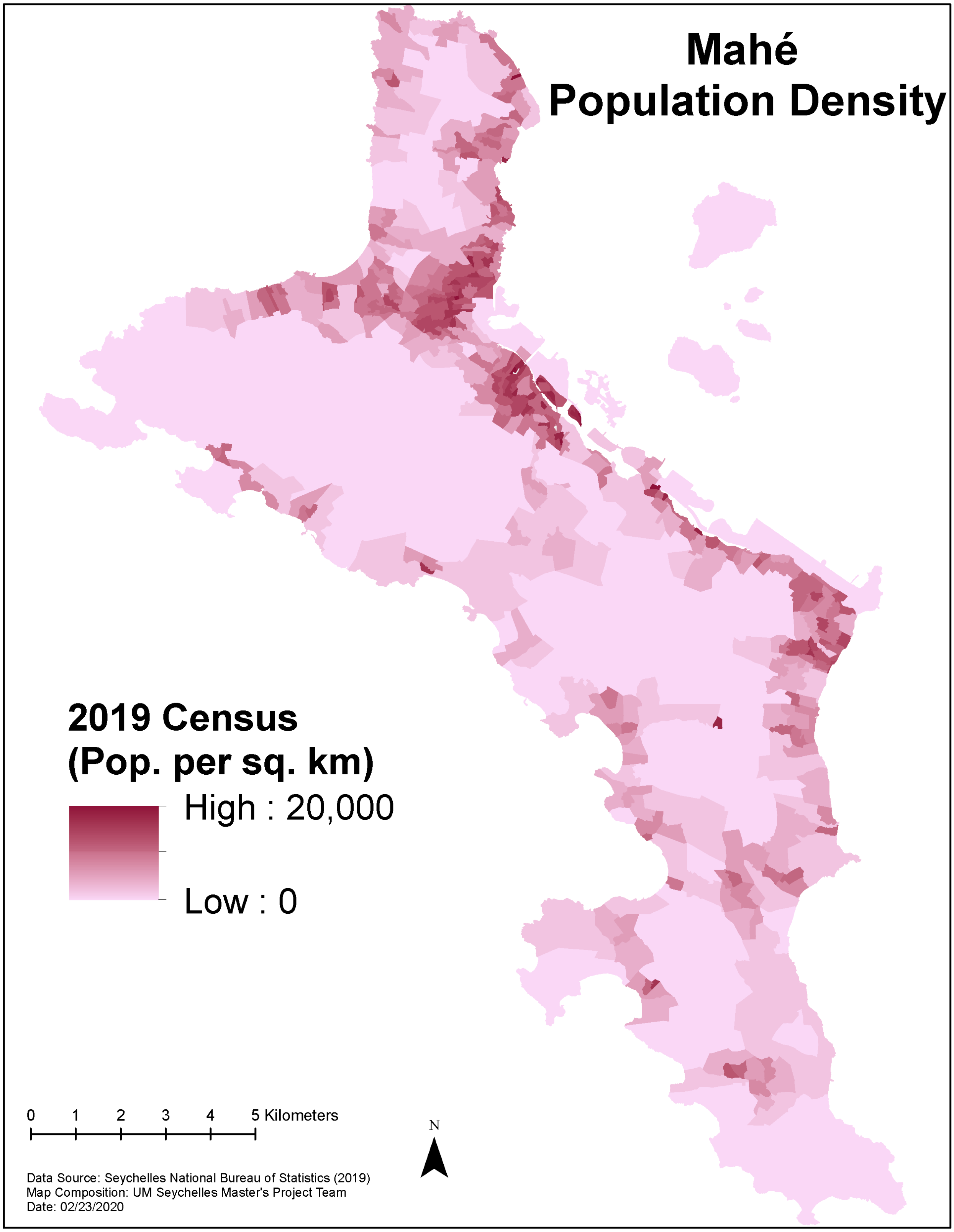
Note: Table continues on following page.

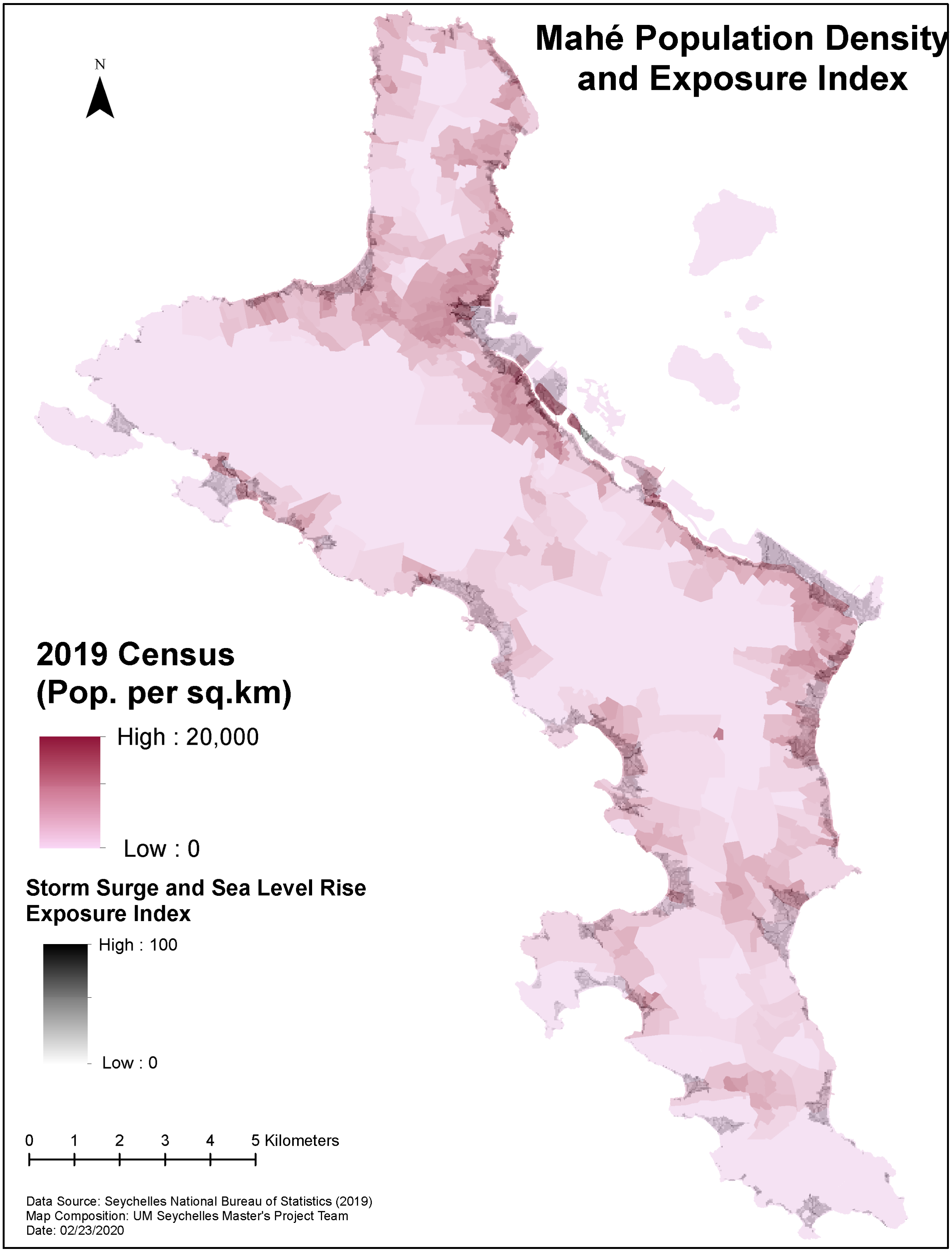
Interview themes and subthemes with illustrative examples (continued)

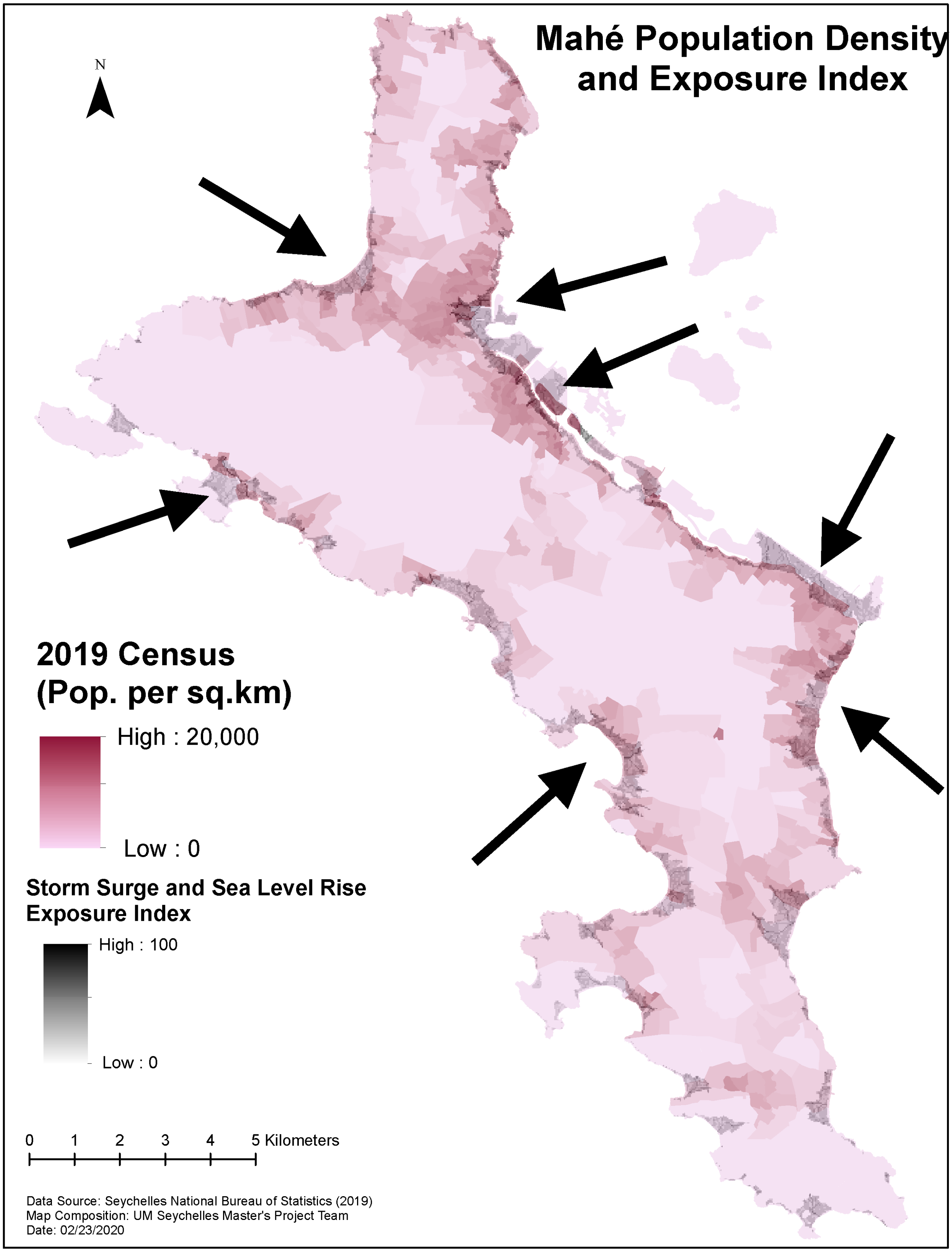
Theme	Subtheme	Example
Adaptation Strategies	*Identifying and Securing Financing*	*"It is on everybody on the island. Government should give direction, steer, possibly put in some money and also try to motivate the private sector to participate and to contribute."*
	Education & Outreach	*"It's a little 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	*"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	*"[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	*"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	*"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	*"Well with housing, it's raising of the plane, so if you do have flooding, the buildings will not be flooded."*
	Relocation	*"We may do some proposal as well to whereby we can shift certain essential buildings [and] avoid big impact when calamity comes."*
	Altering Landscapes	*"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	*"Okay I'll give an example. Instead of planting crops, which they did, they go for chicken farming."*
Who Drives Adaptation?	*N/A*	*"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*	*"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."*

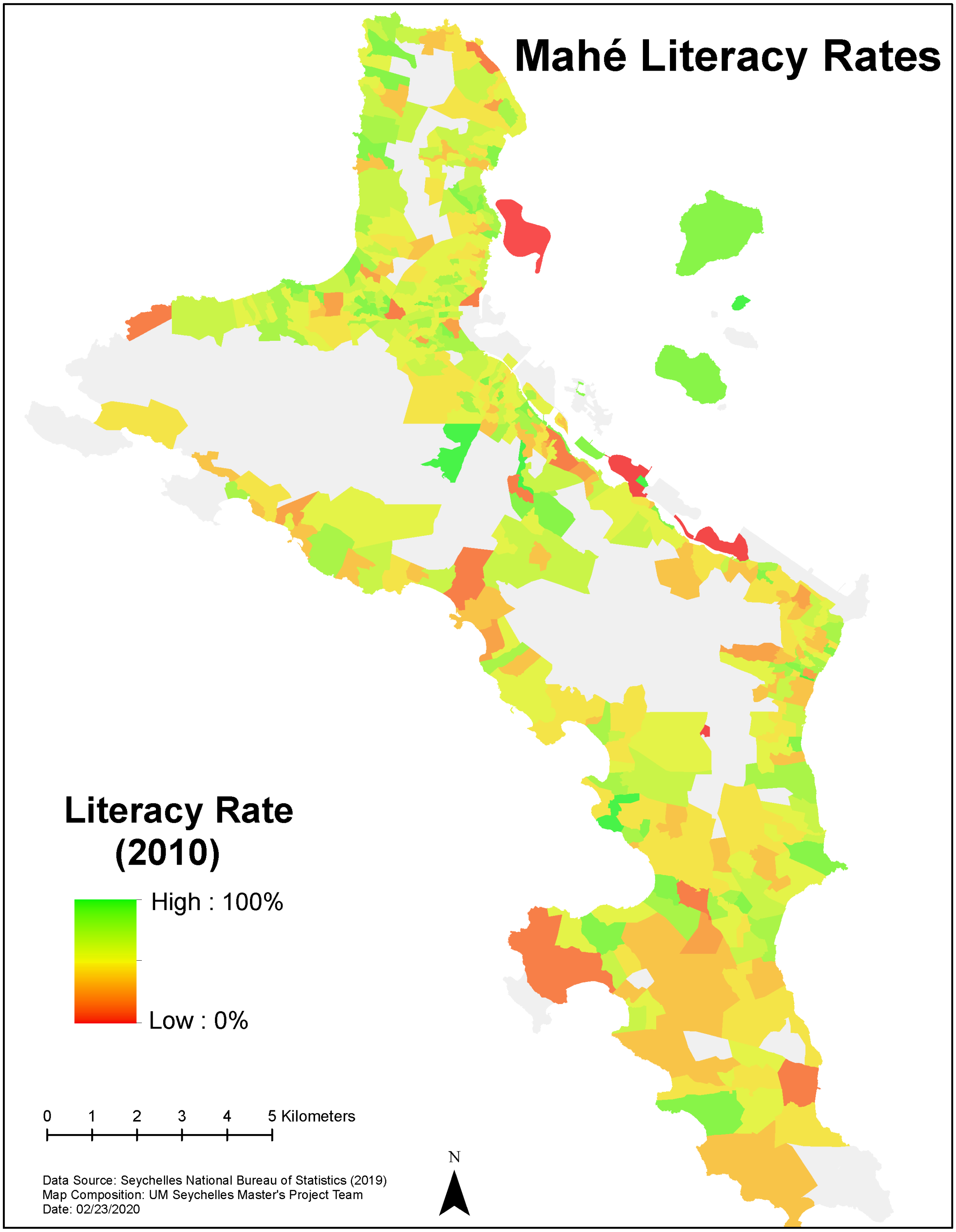
Appendix D. Maps from geospatial risk analysis




Mahé
Population Density
2019 Census
(Pop. per sq. km)
High : 20,000
Low : 0
0 1 2 3 4 5 Kilometers
N
Data Source: Seychelles National Bureau of Statistics (2019)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Population Density
and Exposure Index
N
2019 Census
(Pop. per sq.km)
High : 20,000
Low : 0
Storm Surge and Sea Level Rise
Exposure Index
High : 100
Low : 0
0 1 2 3 4 5 Kilometers
Data Source: Seychelles National Bureau of Statistics (2019)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Population Density and Exposure Index
N
2019 Census
(Pop. per sq.km)
High : 20,000
Low : 0
Storm Surge and Sea Level Rise Exposure Index
High : 100
Low : 0
0 1 2 3 4 5 Kilometers
Data Source: Seychelles National Bureau of Statistics (2019)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020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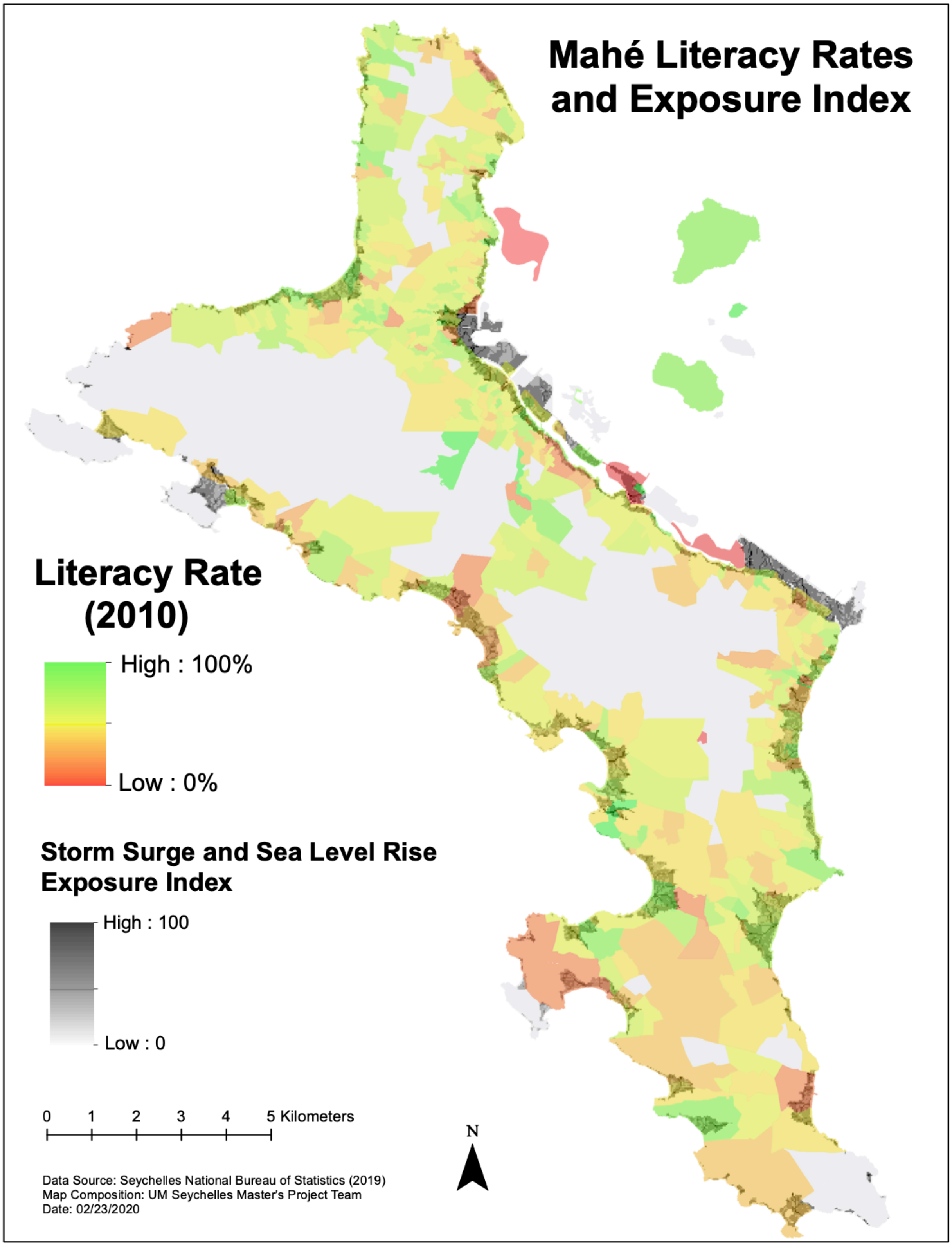
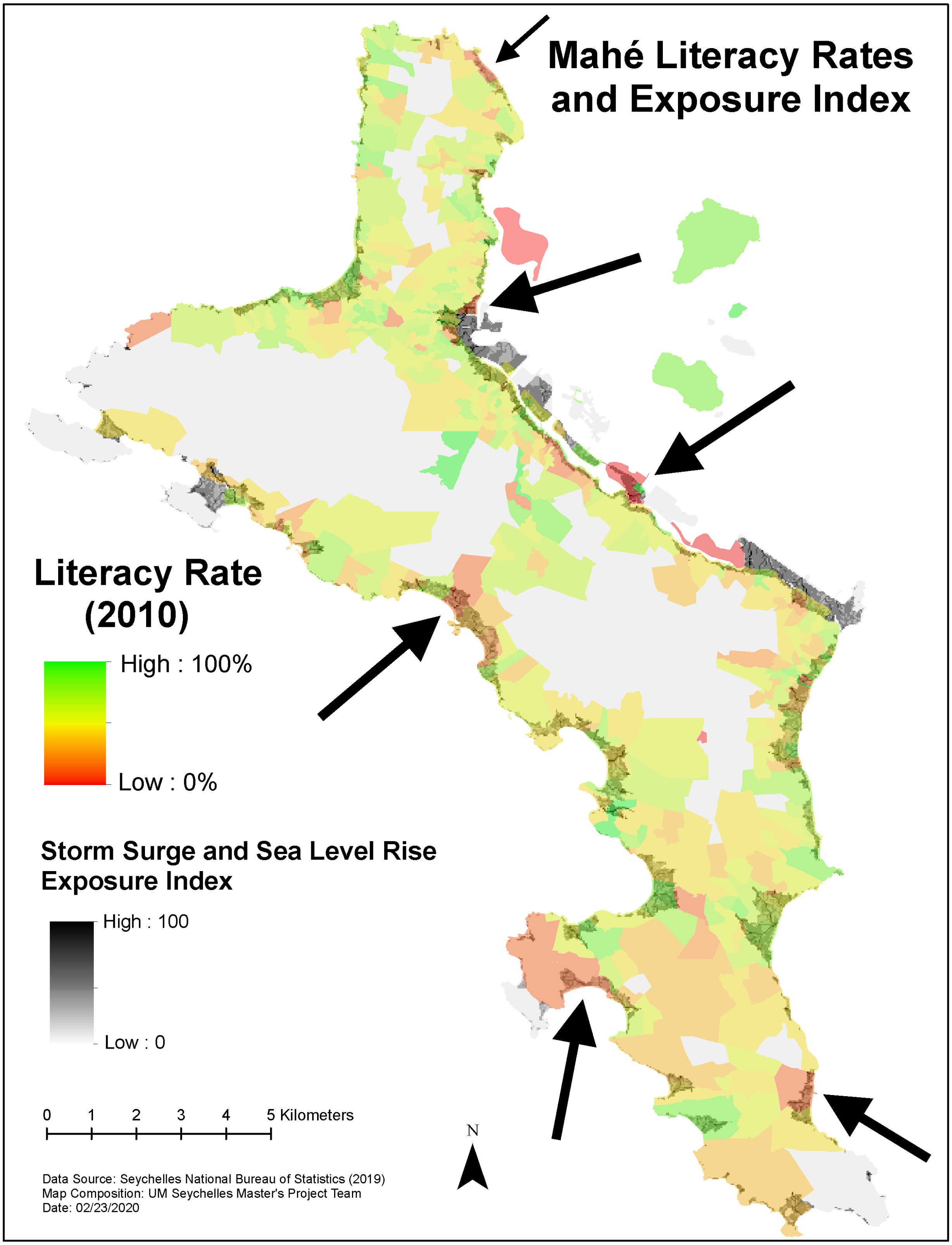
Literacy Rate (2010)
High : 100%
Low : 0%
0 1 2 3 4 5 Kilometers
N
Data Source: Seychelles National Bureau of Statistics (2019)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Literacy Rates
and Exposure Index
Literacy Rate
(2010)
High : 100%
Low : 0%
Storm Surge and Sea Level Rise
Exposure Index
High : 100
Low : 0
0 1 2 3 4 5 Kilometers
N
Data Source: Seychelles National Bureau of Statistics (2019)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020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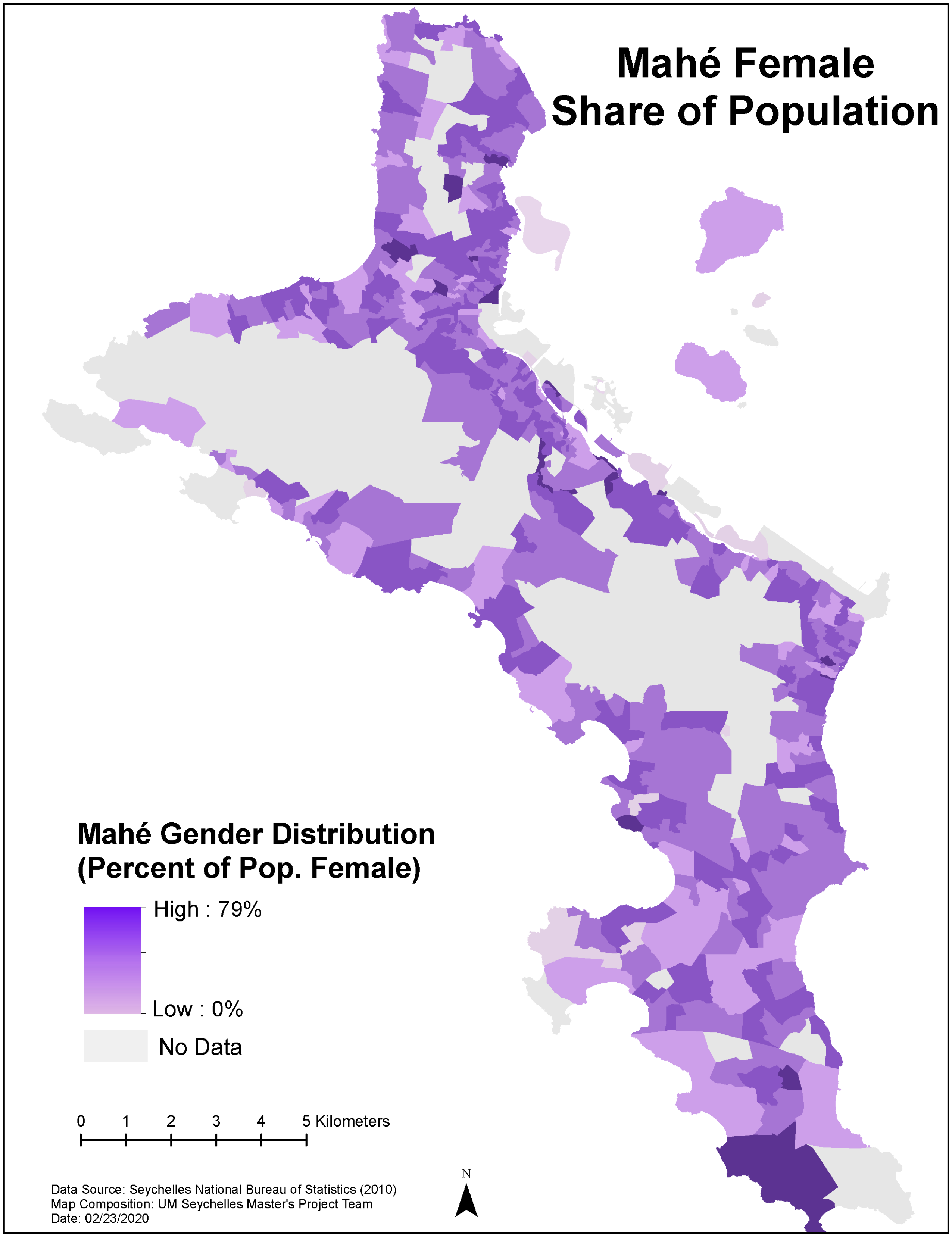
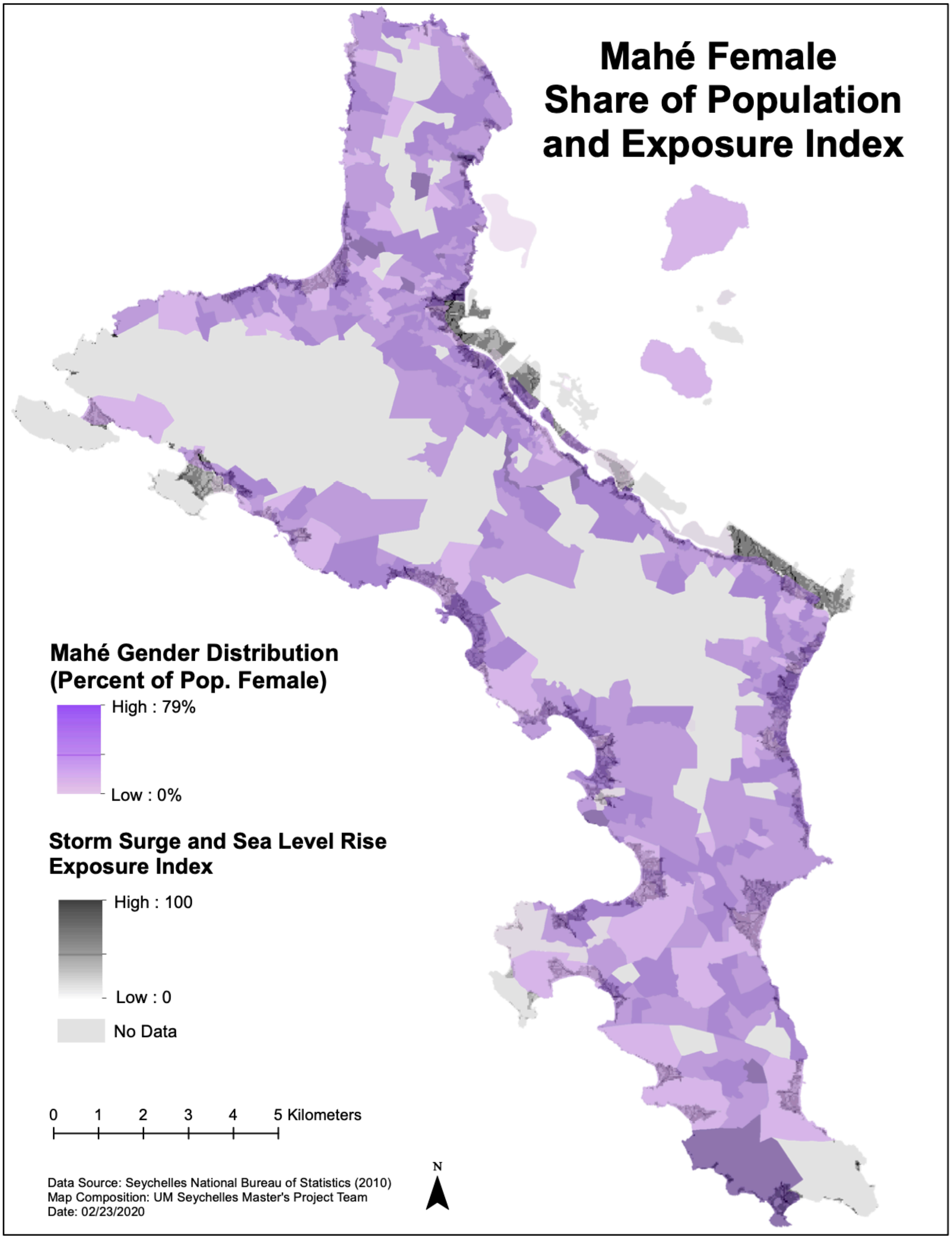
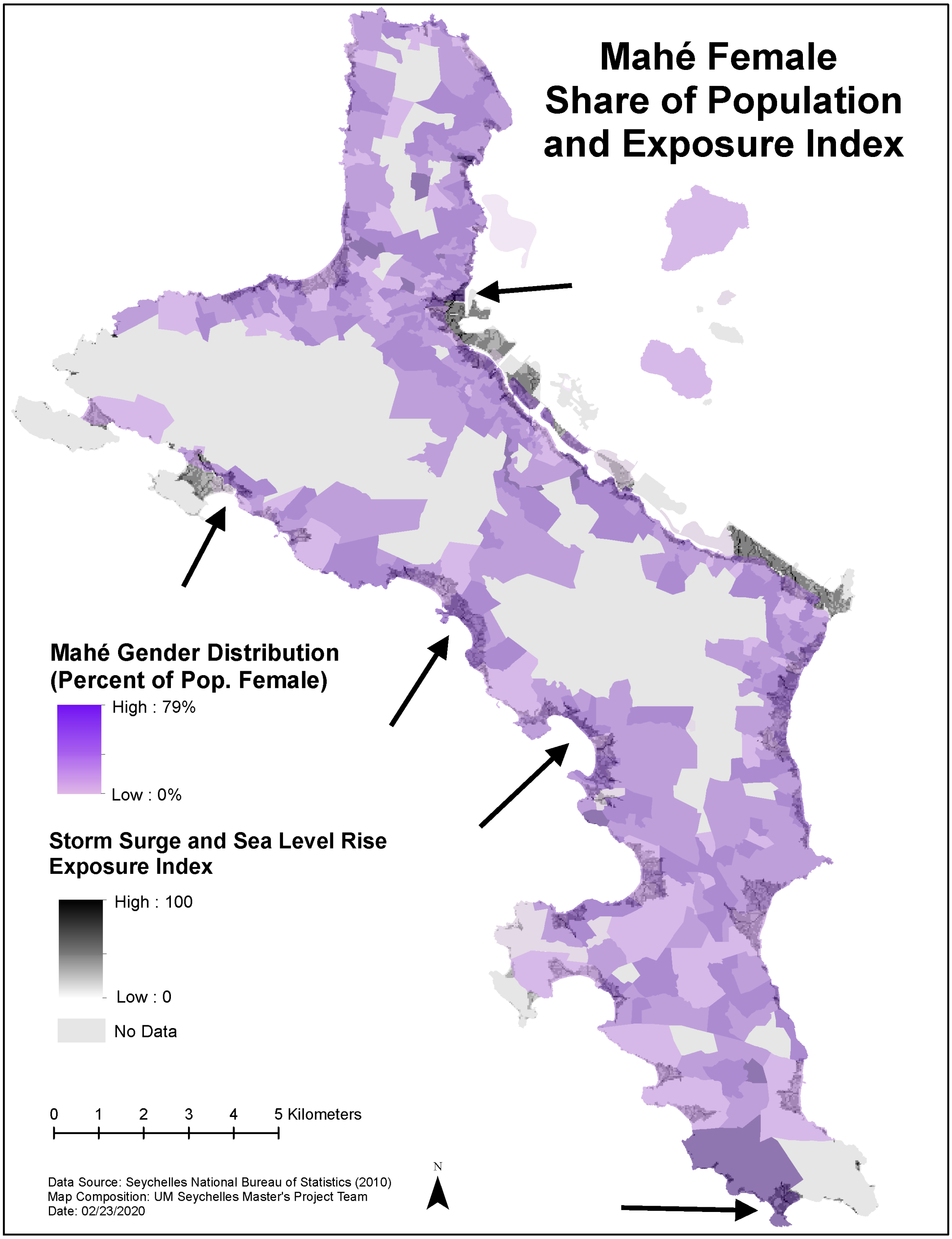
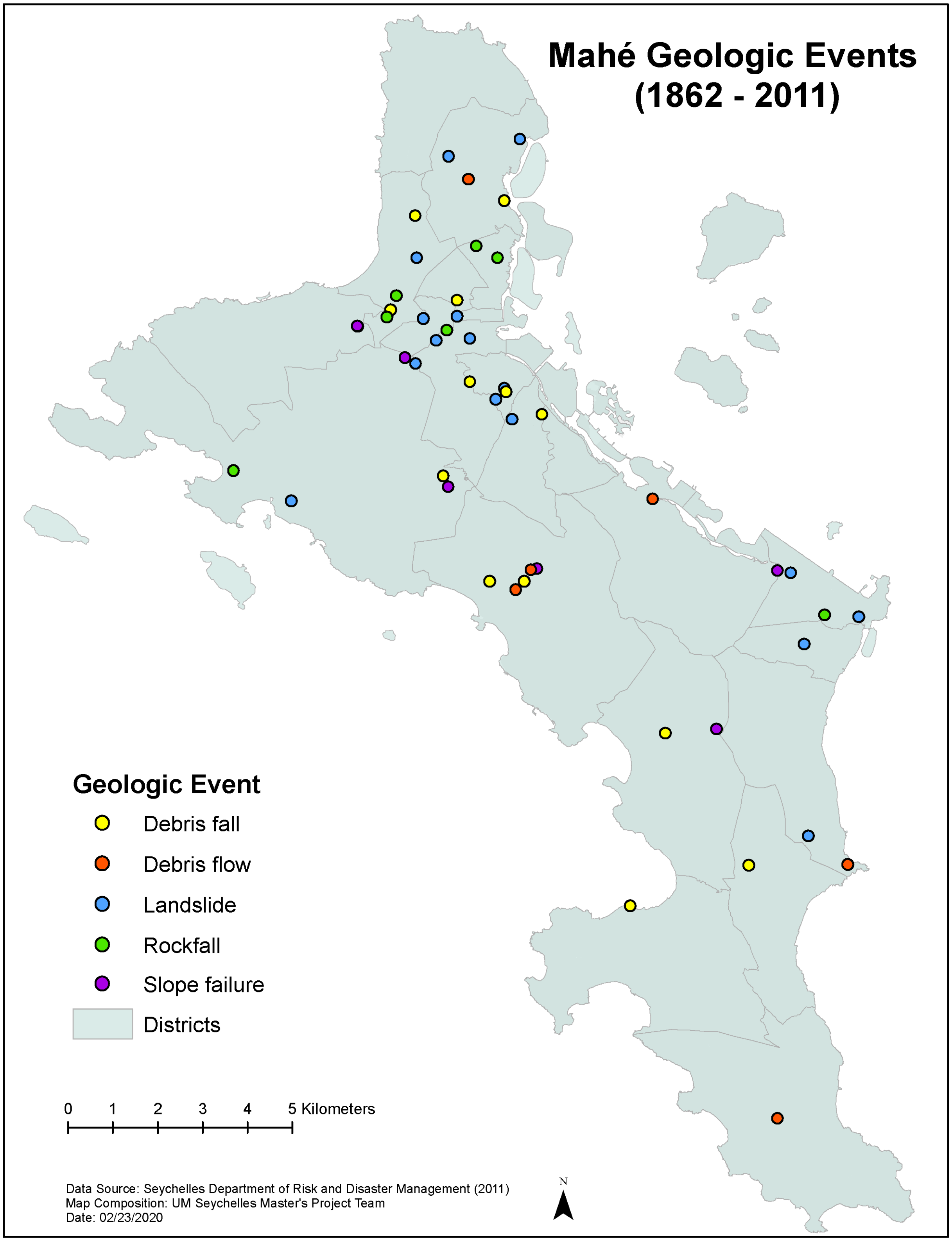
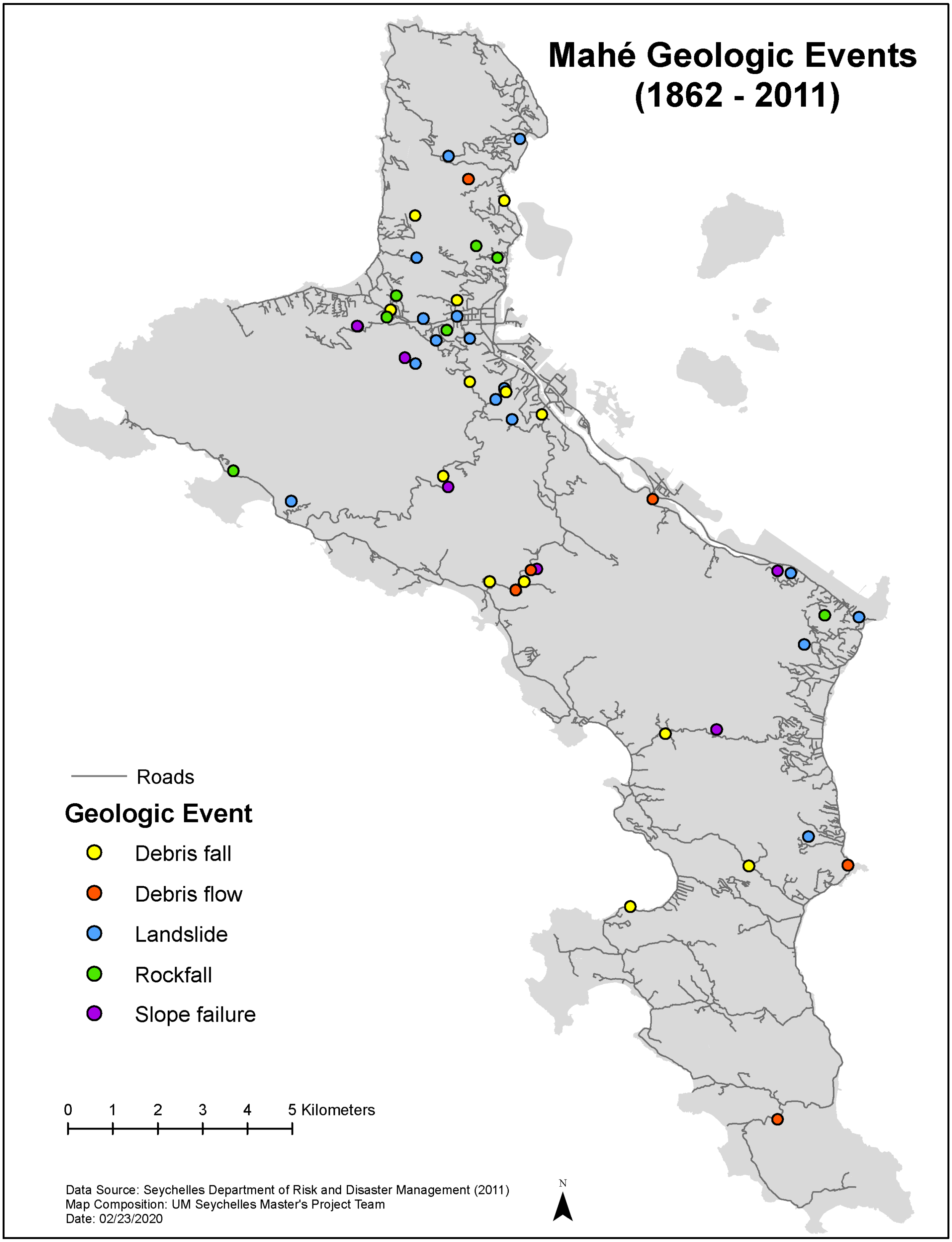
Literacy Rate (2010)
High : 100%
Low : 0%
Storm Surge and Sea Level Rise Exposure Index
High : 100
Low : 0
0 1 2 3 4 5 Kilometers
N
Data Source: Seychelles National Bureau of Statistics (2019)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Female
Share of Population
Mahé Gender Distribution
(Percent of Pop. Female)
High : 79%
Low : 0%
No Data
0 1 2 3 4 5 Kilometers
N
Data Source: Seychelles National Bureau of Statistics (2010)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Female
Share of Population
and Exposure Index
Mahé Gender Distribution
(Percent of Pop. Female)
High : 79%
Low : 0%
Storm Surge and Sea Level Rise
Exposure Index
High : 100
Low : 0
No Data
0 1 2 3 4 5 Kilometers
N
Data Source: Seychelles National Bureau of Statistics (2010)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Female
Share of Population
and Exposure Index
Mahé Gender Distribution
(Percent of Pop. Female)
High : 79%
Low : 0%
Storm Surge and Sea Level Rise
Exposure Index
High : 100
Low : 0
No Data
0 1 2 3 4 5 Kilometers
N
Data Source: Seychelles National Bureau of Statistics (2010)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Geologic Events
(1862 - 2011)
Geologic Event
Debris fall
Debris flow
Landslide
Rockfall
Slope failure
Districts
0 1 2 3 4 5 Kilometers
Data Source: Seychelles Department of Risk and Disaster Management (2011)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020
N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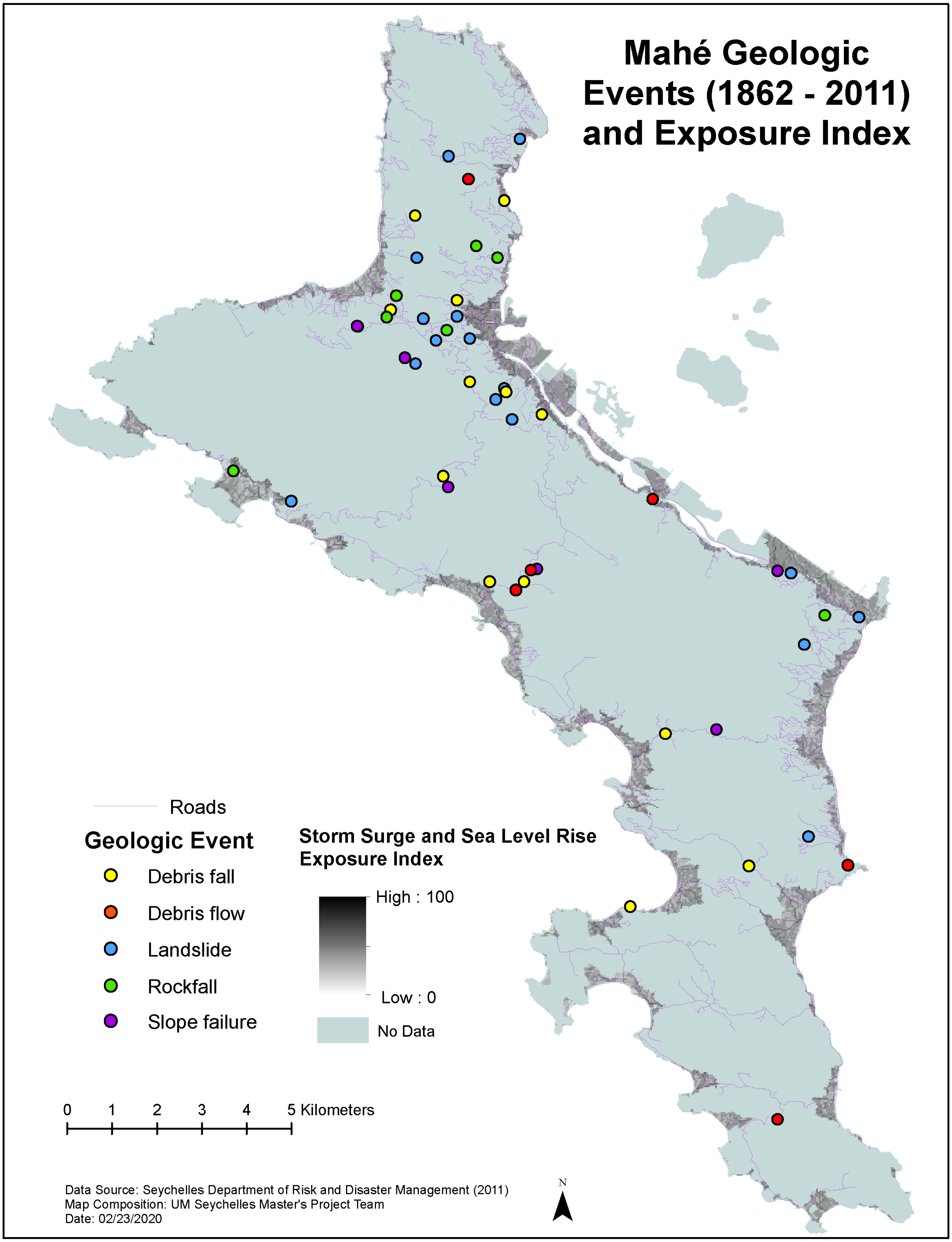
(1862 - 2011)
Roads
Geologic Event
Debris fall
Debris flow
Landslide
Rockfall
Slope failure
0 1 2 3 4 5 Kilometers
Data Source: Seychelles Department of Risk and Disaster Management (2011)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020
N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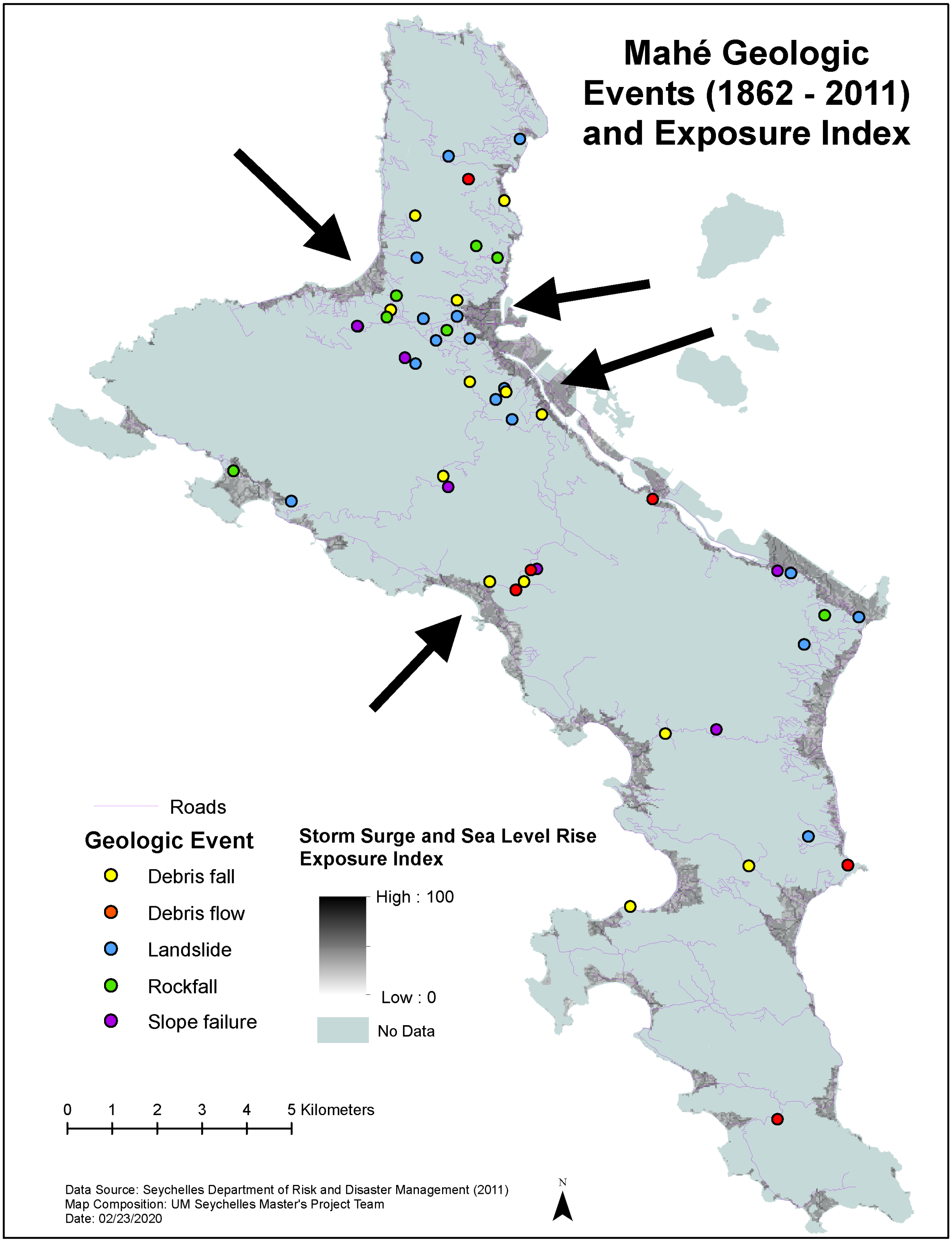
Events (1862 - 2011)
and Exposure Index
Roads
Geologic Event
Debris fall
Debris flow
Landslide
Rockfall
Slope failure
Storm Surge and Sea Level Rise
Exposure Index
High : 100
Low : 0
No Data
0
1
2
3
4
5 Kilometers
Data Source: Seychelles Department of Risk and Disaster Management (2011)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020
N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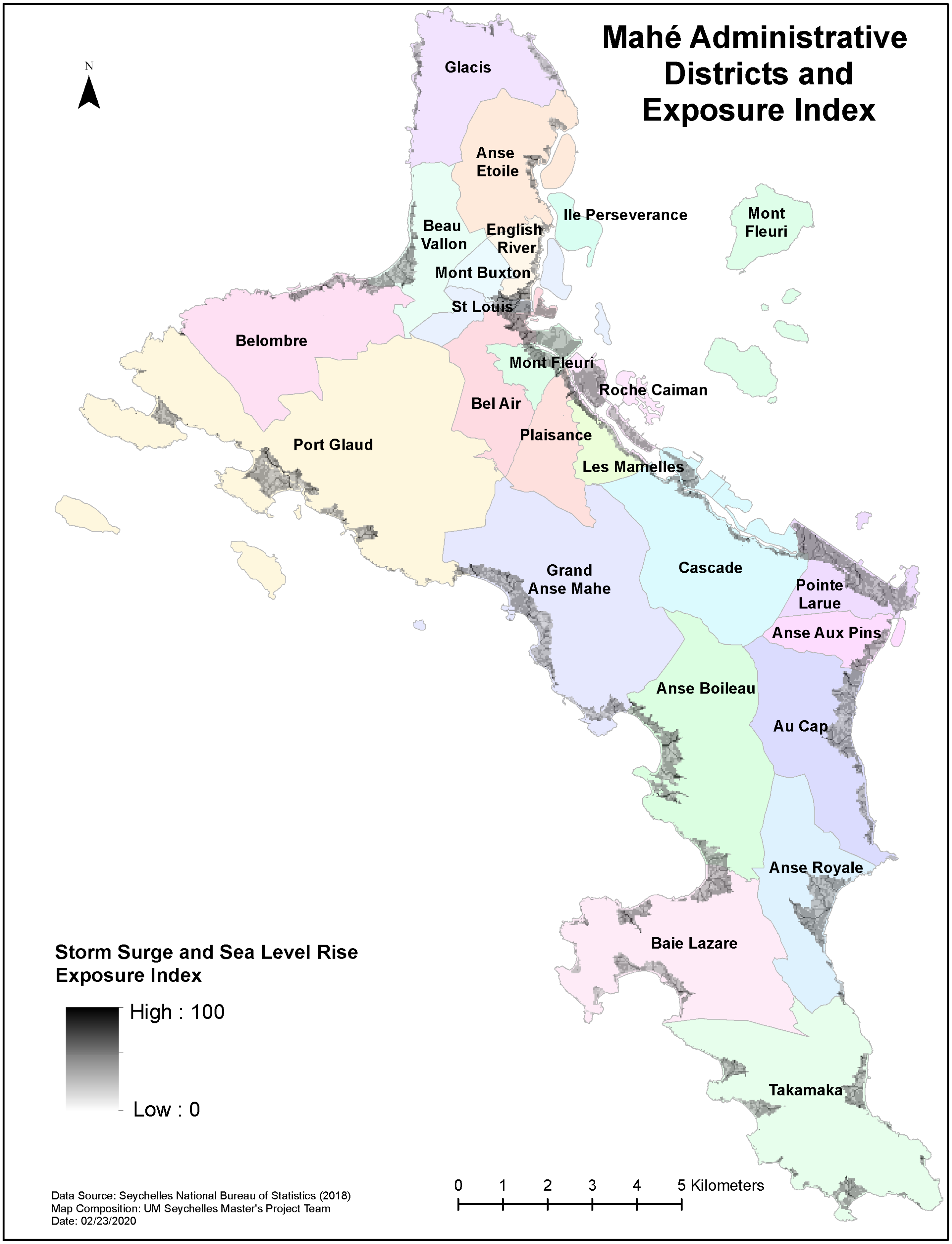
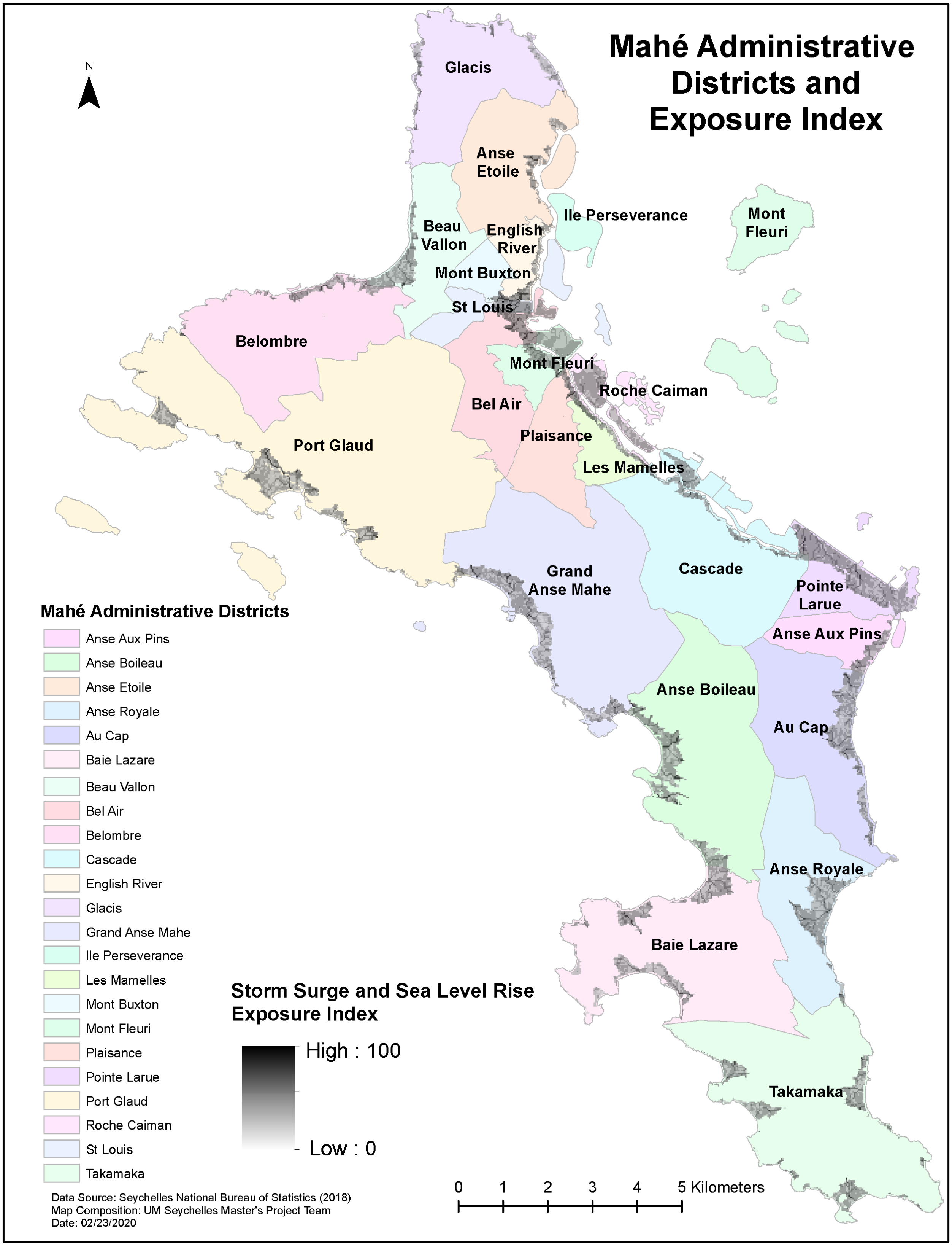
Roads
Geologic Event
Debris fall
Debris flow
Landslide
Rockfall
Slope failure
Storm Surge and Sea Level Rise Exposure Index
High : 100
Low : 0
No Data
0 1 2 3 4 5 Kilometers
Data Source: Seychelles Department of Risk and Disaster Management (2011)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020
N


Administrative Districts
N
Glacis
Anse Etoile
Beau Vallon
English River
Ile Perseverance
Mont Fleuri
Mont Buxton
St Louis
Belombre
Mont Fleuri
Roche Caiman
Bel Air
Plaisance
Port Glaud
Les Mamelles
Grand Anse Mahe
Cascade
Pointe Larue
Anse Aux Pins
Anse Boileau
Au Cap
Anse Royale
Baie Lazare
Takamaka
0 1 2 3 4 5 Kilometers
Data Source: Seychelles National Bureau of Statistics (2018)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Administrative Districts and Exposure Index
N
Glacis
Anse Etoile
Beau Vallon
English River
Ile Perseverance
Mont Fleuri
Mont Buxton
St Louis
Belombre
Mont Fleuri
Roche Caiman
Bel Air
Plaisance
Port Glaud
Les Mamelles
Grand Anse Mahe
Cascade
Pointe Larue
Anse Aux Pins
Anse Boileau
Au Cap
Anse Royale
Baie Lazare
Takamaka
Storm Surge and Sea Level Rise Exposure Index
High : 100
Low : 0
0 1 2 3 4 5 Kilometers
Data Source: Seychelles National Bureau of Statistics (2018)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020


Mahé Administrative Districts and Exposure Index
N
Glacis
Anse Etoile
Beau Vallon
English River
Ile Perseverance
Mont Fleuri
Mont Buxton
St Louis
Belombre
Mont Fleuri
Roche Caiman
Bel Air
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Cascade
Pointe Larue
Anse Aux Pins
Anse Boileau
Au Cap
Anse Royale
Baie Lazare
Takamaka
Mahé Administrative Districts
Anse Aux Pins
Anse Boileau
Anse Etoile
Anse Royale
Au Cap
Baie Lazare
Beau Vallon
Bel Air
Belombre
Cascade
English River
Glacis
Grand Anse Mahe
Ile Perseverance
Les Mamelles
Mont Buxton
Mont Fleuri
Plaisance
Pointe Larue
Port Glaud
Roche Caiman
St Louis
Takamaka
Storm Surge and Sea Level Rise Exposure Index
High : 100
Low : 0
0 1 2 3 4 5 Kilometers
Data Source: Seychelles National Bureau of Statistics (2018)
Map Composition: UM Seychelles Master's Project Team
Date: 02/23/2020

Appendix E. Geologic event data

Geologic Event Data from 1862-2011

Event Name	Year	X Coordinate	Y Coordinate	Event Type	Cause
SL-10/1862-01-ARC	1862	-4.631221	55.43921	Landslide	Rain event
SL-08/1985-01-ARC	1985	-4.630022	55.43710	Slope failure	Rain event
SL-12/1987-01-ARC	1987	-4.621718	55.44755	Landslide	Rain event
SL-12/1987-01-ARC	1987	-4.617527	55.43537	Rockfall	Rain event
SL-12/1987-01-ARC	1987	-4.609874	55.45571	Rockfall	Rain event
BV-01/1991-01-ARC	1991	-4.609866	55.43947	Landslide	Rain event
SL-02/1994-01-SBC	1994	-4.624500	55.44546	Rockfall	Drainage issue
CC-02/1994-01-SBC	1994	-4.658679	55.48687	Debris flow	Drainage issue
AB-11/1994-01-SBC	1994	-4.706034	55.48923	Debris fall	Rain event
MF-01/1997-01-ARC	1997	-4.636264	55.45702	Landslide	Rain event
PL-08/1997-01-ARC	1997	-4.682183	55.52138	Rockfall	Rain event
BV-08/1997-01-ARC	1997	-4.622115	55.44077	Landslide	Rain event
AAP-09/1997-01-ARC	1997	-4.688095	55.51720	Landslide	Rain event
BA-01/1997-01-SBC	1997	-4.626207	55.45012	Landslide	Rain event
BA-08/1997-01-FW	1997	-4.634947	55.45009	Debris fall	El Niño
PG-08/1997-01-FW	1997	-4.653924	55.44475	Debris fall	El Niño
PG-08/1997-02-FW	1997	-4.656156	55.44570	Slope failure	El Niño
GAM-08/1997-01-FW	1997	-4.672751	55.46356	Slope failure	El Niño
GAM-08/1997-02-FW	1997	-4.672946	55.46229	Debris flow	El Niño
GAM-08/1997-03-FW	1997	-4.675218	55.46095	Debris fall	El Niño
GAM-08/1997-04-FW	1997	-4.676934	55.45923	Debris flow	El Niño
GAM-08/1997-05-FW	1997	-4.675193	55.45396	Debris fall	El Niño
BL-08/1997-01-FW	1997	-4.740862	55.48217	Debris fall	El Niño
TMK-08/1997-01-FW	1997	-4.783901	55.51167	Debris flow	El Niño
AR-08/1997-01-FW	1997	-4.732626	55.52595	Debris flow	El Niño
PL-08/1997-01-FW	1997	-4.673639	55.51459	Landslide	El Niño
CC-08/1997-01-FW	1997	-4.673195	55.51193	Slope failure	El Niño
BV-08/1997-01-FW	1997	-4.620374	55.43417	Debris fall	El Niño
MB-03/1998-01-SBC	1998	-4.618465	55.44752	Debris fall	Rain event
AR-07/1998-01-SBC	1998	-4.732678	55.50596	Debris fall	Drainage issue
AE-01/1999-01-SBC	1999	-4.589390	55.44592	Landslide	Rain event

Note: Table continues on following page.

Geologic Event Data from 1862-2011 (continued)

Event Name	Year	X Coordinate	Y Coordinate	Event Type	Cause
PL-02/2001-01-SBC	2001	-4.682572	55.52820	Landslide	Rain event
LM-02/2001-01-SBC	2001	-4.641531	55.46458	Debris fall	Rain event
MF-12/2003-02-SBC	2003	-4.636918	55.45735	Debris fall	Rain event
AE-12/2004-01-ARC	2004	-4.607531	55.45144	Rockfall	Tsunami
AR-12/2004-01-ARC	2004	-4.726810	55.51801	Landslide	Tsunami
AE-12/2004-01-FW	2004	-4.585931	55.46031	Landslide	Tsunami
AE-12/2004-02-FW	2004	-4.598353	55.45713	Debris fall	Tsunami
BV-12/2004-01-FW	2004	-4.623743	55.42752	Debris flow	Tsunami
BV-12/2004-02-FW	2004	-4.601383	55.43921	Debris fall	Tsunami
BV-12/2004-03-FW	2004	-4.621814	55.43340	Rockfall	Tsunami
BO-12/2004-01-FW	2004	-4.623639	55.42748	Slope failure	Tsunami
AE-12/2004-02-FW	2004	-4.594056	55.44992	Debris flow	Tsunami
PG-06/2005-01-SBC	2005	-4.658909	55.41409	Landslide	Rain event
PG-06/2005-02-SBC	2005	-4.652782	55.40254	Rockfall	Rain event
BA-02/2010-01-SBC	2010	-4.626563	55.44332	Landslide	Rain event
AB-01/2011-01-ARC	2011	-4.705182	55.49960	Slope failure	Rain event
PLS-01/2011-01-FW	2011	-4.642505	55.45859	Landslide	Rain event
BA-01/2011-01-FW	2011	-4.638478	55.45530	Landslide	Rain event

Appendix F. Exposed infrastructure scores for Mahé

Exposed infrastructure scores for Mahé with 0 m, 0.5 m, and 1.0 m sea level rise under 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	% Exposed
	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	
	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**	

Exposed infrastructure scores in Mahé with 1.5 m and 2.0m sea level rise under 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	% Exposed
	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	
	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**	

Seychelles Climate Scenario Planning Toolkit

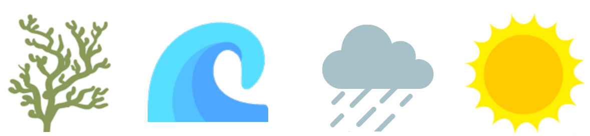
Preparing for a future different than the past

Why use a Climate Scenario Toolkit?

The purpose of this toolkit is to help local planners and decision-makers envision different climate scenarios to better plan for a future that will likely look very different from the past in terms of weather and climate. The approach, developed by U.S.-based Great Lakes Integrated Sciences and Assessments (GLISA), has helped local communities prepare for changing climatic conditions. The information in this toolkit has been developed specifically for the Seychelles context and can be applied to guide many climate-related policy documents such as the Seychelles National Setback Policy, National Climate Change Strategy, or Coastal Management Plan.

The aims of this toolkit are to:

- Familiarize users with local climate trends, features, and future scenarios
- Provide a set of climate scenarios tailored to the policymaking needs of the Seychelles
- Help users better understand scenario planning
- Allow users to more clearly be able to picture how Seychelles natural resource management activities are impacted by weather/climate



What are Climate Scenarios?

A climate scenario is a description of future climate conditions. Climate scenarios may be both qualitative and quantitative and they vary in the amount of detail that is included, based on the needs of the end user. Typically, greater amounts of detail (i.e., descriptions beyond how annual temperatures and precipitation might change) make the scenarios more tangible for users and policymakers to incorporate into their planning, but those details do not necessarily need to be quantitative.

Ultimately, most users are interested in climate scenarios as a means to explore potential future impacts on people, resources, and the environment. The climate scenario framework presented here looks at possible future outcomes without assigning them specific probabilities. This supports an equal exploration of both high risk/low probability events and low risk/high probability events, fostering broad adaptation discussions covering many possible futures.

How were the Climate Scenarios developed?

The five climate scenarios presented here were developed using several climate models downscaled to make better local projections for the Western Indian Ocean/Seychelles region. The climate scenarios will address four primary management concerns identified by Seychellois stakeholders in field interviews, as well as a few others:

- Flooding in Victoria and other low-lying areas
- Damage to coastal infrastructure
- Coastal/beach erosion
- Coral bleaching

The management concerns and the five climate scenarios developed around them are provided in the climate scenarios section on page 4.

A man walks along a rock wall at Bel Ombré in Mahé, Seychelles

The remainder of this toolkit guides the user through Seychelles' current seasonal climate, future climate trends, and local climate system feature, which then feed into the five climate scenarios tailored for Seychelles.

This toolkit is meant to aid decision-making by Seychelles' climate and natural resource policymakers. The toolkit is designed for use by any group (government department, NGO, business) seeking to undertake climate adaptation. The toolkit works best when multiple decision-makers collaboratively engage with it and address management goals from multiple perspectives.

The following steps are involved:

Step 1: Familiarize yourself with Seychelles climate trends, features, and future scenarios

Step 2: Compare the impact of local climate events on adaptation management goals

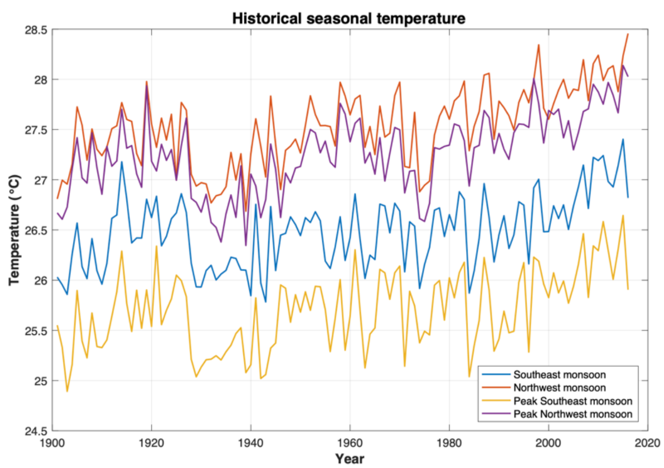
Step 3: Develop climate adaptation goals, make plans to achieve them, and explore future challenges

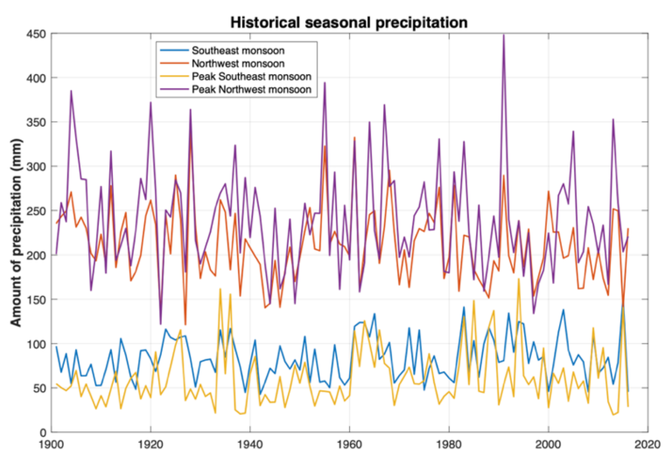
Step 1: Familiarize yourself with Seychelles climate features, trends, and future scenarios

Current Climate in Seychelles

Seychelles' annual climate can be broken down into two monsoonal seasons: From May to October, the Southeast Monsoon brings a relatively dry period which reaches its peak from July to August. During this time, there is very little precipitation and the average high temperature is 27°C. By November, the winds start to change, bringing lighter, warmer winds and the start of the Northwest Monsoon, the main rainy season. From December to March, Seychelles experiences consistent precipitation, reaching its peak in December and January. The average high temperature during Northwest Monsoon is 30°C.

Below are two figures depicting the historical trends for temperature and precipitation in Seychelles. These figures show the stability of the monsoonal effect over the last 118 years, with significant differences between general monsoonal conditions and peak conditions. These trends may affect the seasonality of management plans.

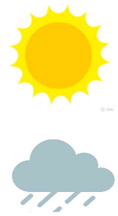




Open-source temperature and precipation data charted from 1900-2018 showing stability of monsoonal trends

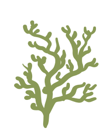
Future Climate Trends for the Seychelles

The following are projected to be the key effects of climate change in Seychelles:



General Warming and Precipitation: According to downscaled CMIP5 projections for the Seychelles region, mean annual temperature will rise by 1.5°C in 2050 and mean annual precipitation will rise by 70.1mm in 2050. Both monsoonal trends are expected to amplify—this means a wetter Northwest Monsoon (December-March) and a drier Southeast Monsoon (May-October) by the end of the century. Projected monthly temperatures also reflect amplified monsoonal trends, with the Northwest Monsoon months experiencing a greater temperature increase than the Southeast Monsoon months.

Sea Level Rise: While current scientific projections show a global sea level rise rate estimated at between 2 and 3 millimeters per year, rates of sea level rise are not uniform across the globe. Large regional differences have been detected in the Indian Ocean and tropical Pacific, where some regions have significantly higher sea levels than the global average. Generally, regions at the lower-to-mid latitudes are projected to experience a more severe change in sea level than regions in the upper latitudes; this means Seychelles may face higher sea level rise than the global predictions. The IPCC's 2019 *Special Report on the Ocean and Cryosphere in a Changing Climate* predicts a .84m increase by 2100, under its high emissions scenario (RCP 8.5).



Sea Surface Temperature and Coral Reef Temperature: Under a high emissions scenario (RCP 8.5), sea surface temperatures of the world's sub-tropical gyres, which includes the Indian Ocean sub-tropical gyre and Seychelles, are projected to be 0.45°C to 0.91°C warmer in the near term (by 2039) and 1.90°C to 3.44°C warmer in the long term (by 2100). These changes in temperature are very likely to increase water column stability, reduce the depth of the thermocline, and influence key parameters like nutrient availability. Year-round sea surface and deeper coral reef water temperatures are projected to increase from 0.07°C to 0.14°C per decade.

Climate Features of the Seychelles

In order to properly create climate scenarios specific to the Seychelles, it is helpful to understand the climate and ocean processes that affect local climate trends and weather events. These are briefly described below, as are their expected changes resulting from climate change:

Atmospheric-Oceanic Features

Somali Jet: The Somali Jet is a low-level jet that transfers moisture north toward India from the equatorial latitude in boreal summer and reverses its moisture transfer in winter. As the Somali Jet carries moisture away from the equatorial zone in summer, Seychelles experiences its dry monsoon season. Conversely, as the jet reverses its trajectory and brings the moisture back down to the equatorial zone in winter, Seychelles experiences its wet monsoon season. The Somali Jet is generally expected to weaken with climate change, possibly negatively impacting the moisture content of Seychelles' winter monsoon.

Madden-Julian Oscillation (MJO): The MJO is characterized by the eastward progression of large regions of both enhanced and suppressed tropical rainfall, usually first observed over the Western Indian Ocean. Typically, strong MJO winds cause dry winds from the coast of East Africa to travel across the Indian Ocean, which may pause precipitation in the Seychelles during boreal summer. Meanwhile, the winter MJO moves in a sort of see-saw motion after forming in the east, bringing moisture back over the Seychelles. Climate change is projected to strengthen and accelerate the MJO. The timescale between changes in oscillation will be shorter, and this will increase the variable heat and humidity in the Seychelles region.

Indian Ocean Dipole (IOD): The Indian Ocean Dipole is an irregular oscillation of sea surface temperatures in which the western Indian Ocean, off the coast of East Africa, becomes alternately warmer (positive phase) and then colder (negative phase) than the eastern part of the ocean, close to Australia and Southeast Asia. This causes increased rainfall over the western Indian Ocean region (encompassing Seychelles) during a positive phase and decreased rainfall during a negative phase. The frequency of positive IOD events is projected to increase linearly as the warming proceeds. This may lead to increased moisture convection and precipitation in the Seychelles region.

Topographic Feature

Mascarene Plateau: The chain of Seychelles islands sits atop the Mascarene Plateau, a submarine Plateau that curves around Madagascar in an inverted "C" shape and encompasses Seychelles, Mauritius, and Réunion. The plateau covers an area of over 115,000 m^2 of shallow water before plunging 4,000 meters at the edge of the abyssal plane. This vast area of shallow water allows for unique climatological and oceanic features that are specific to the southwest Indian Ocean.

Topographic-Oceanic Feature

Seychelles Dome: The Seychelles Dome is the combination of a shallow oceanic thermocline (layer of water dividing upper mixed layer with deep calm water below), and high sea surface temperatures sitting atop the western half of the Mascarene Plateau. This combination of shallow underwater topography and shallow thermocline yields abnormally high sea surface temperatures year-round. The Seychelles Dome is not constant, fluctuating between a strong phase that causes more upwelling of cold water (shallow thermocline) and a weak phase that causes less upwelling of cold water (deeper thermocline). Regarding climate change effects, when considering the impact of a positive IOD on the Seychelles Dome—IOD, deepens the thermocline and warms the sea surface temperature in the western part of the Indian Ocean—it can be extrapolated that an increase in positive IOD occurrence will deepen the Seychelles Dome thermocline and increase sea surface temperature warming in the region. It is also possible that strong MJO winds prompt a deeper thermocline and more upwelling, which will slow the rate of coral reef die-off.

Geologic Feature

Granitic Island Chain Structure: Seychelles geology plays a role in climate events, as when you cut into granitic rock, which is necessary for infrastructure development on Mahé and the other main islands, it becomes less stable and is more likely to experience rock falls. The dynamics between local weather events and local geology play a role in climate event as well—rainwater is naturally slightly acidic, and as a result will "chemically erode", or dissolve, the silica in granite over time, increasing its susceptibility to rock slides. Extreme precipitation can trigger landslides and tree falls by transporting the rockslides down the side of the mountain.

Five Climate Scenarios for the Seychelles

Although there are several common themes among the projections for Seychelles, the changing climate, oceanic, and oceanic-topographic features offer differences to explore. Five distinct climate scenario frameworks were developed by accounting for climate stressors unique to each management area. The scenarios, four wet and one dry, represent *possible* outcomes of climate change without assigning them specific probabilities. They are meant to be compared with one another qualitatively as opposed to probabilistically. The development of an adaptation plan addressing these scenarios is discussed in Step 3 (page 6).

Some caveats: Uncertainty and Feedback Loops

The development of these scenarios relied on IPCC climate models. However, like any model, climate models cannot perfectly predict future conditions. Most of the figures obtained for the General Climate Trends section of this toolkit were created by CMIP5, the 5th iteration of the IPCC's amalgamation of 16 global climate models. The latest version, CMIP6, may be more accurate in its predictions, which have more dire climate outcomes than CMIP5. The scenarios presented here use the most extreme CMIP5 projections (RCP 8.5, High Emission) on the basis that the most severe projections in CMIP5 are more similar to moderate projections in CMIP6. Ideally, this toolkit could be routinely updated to include the latest climate projections.

While this toolkit presented climate features and trends separately (page 2 and 3, respectively), these elements do not operate independently of each other. Well-documented relationships and feedback loops have been studied between each component. While these interactions are not covered in detail here, it is important to keep in mind that a change in one climate feature could exacerbate or, conversely, moderate a change in another. Future climate models will better account for these interactions and, in turn, generate better predictions. The interactive relationships between some of Seychelles' climate features are explored more thoroughly in the LAKI report (https://bit.ly/2yjDNs9) that accompanies this toolkit.

Warm and Wet Scenarios

1. Extreme rain

→ Increase in seasonal/monsoonal precipitation, with highest increase in extreme precipitation
→ Increased occurrence of flooding in downtown Victoria and other low-lying areas
→ Shorter time intervals between flooding
→ Increased occurrence of rock debris falls, possibly impacting inland infrastructure and private property
→ More extreme rain after seasonal rain, possibly increasing mudslides

2. Low sea level rise, extreme storm surge

→ Slow but continuous coastal erosion
→ Increase in extreme storm surge events, possibly impacting critical coastal infrastructure and fishing industry
→ Shorter time intervals between extreme storm surge events
→ Possibility of increased storm tides

3. High sea level rise, warmer sea surface

→ Increased rates and occurrences of coral bleaching
→ Disruption of marine ecosystems
→ Accelerated coastal erosion, possibly impacting critical coastal infrastructure and private property
→ Possibility of increased soil salinity, affecting agriculture yields and transformation of mangrove systems
→ Possible overwhelming of drainage systems

4. Wind-related upwelling

→ Increase in MJO-related westerly winds
→ Related increase in cold-water upwelling in Seychelles Dome region→ decrease in sea surface temperatures
→ Reduced coral bleaching
→ Reduced sea surface warming effect on marine ecosystems

Extended Warm and Dry Scenario

5. Drought

→ Increase in likelihood of wildfires
→ Increase in stagnation of water bodies, leading to increase in proliferation and spread of disease-carrying vectors
→ Diminished supply of water for public consumption, industrial uses, and agricultural uses

Step 2: Compare the impact of weather events and climate trends

Now that you have familiarized yourselves with Seychelles' climate trends, features, and the five climate scenarios, it is time to look at how local climate and weather events impact your management goals. The aim of this exercise is to understand the relative impacts of projected climate trends in order to prioritize your adaptation efforts.

In the table below, please rate the impact of the listed weather events and climate trends on your management goals **by putting a check mark on either Low Impact, Medium Impact, or High Impact**. If the seasonality of the event matters, please take note of that in the column along with your rating. You may also list and rate additional climate events by adding them to the last two rows in each table (labeled *other*).

Weather Events	Low Impact	Medium Impact	High Impact
Very hot days			
Heavy precipitation/storm events			
High windstorms			
Multiple consecutive days with rain			
Multiple consecutive days without rain			
Other:			
Other:			

Climate Trends	Low Impact	Medium Impact	High Impact
Warmer annual and seasonal temperatures			
Increased annual precipitation			
Altered timing of seasonal precipitation			
Prolonged periods of drought			
Prolonged periods of moist conditions			
Increased coastal flooding			
Increased beach erosion			
Other:			
Other:			

Combined Weather Events & Climate Trends	Low Impact	Medium Impact	High Impact
Extreme precipitation event during an extended dry period (any time of the year)			
Several consecutive dry summers interrupted by a particularly wet summer			
Several consecutive wet summers interrupted by one or multiple dry summers			
Other:			
Other:			

Step 3: Develop climate adaptation goals, make plans, and explore future challenges

For each of the five climate scenarios, what goals should be set in your group to help the community adapt to the projected climate changes? What steps must be taken to achieve each of the goals? What challenges will need to be overcome in each scenario to achieve the adaptation goal? Are there contingency plans to counteract these potential climate- and weather-related challenges?

The table below provides a matrix for you to consider these questions for each of the scenarios. It likely provides too little space for your input so feel free to use a separate document. For group efforts, a whiteboard or blackboard can be helpful.

Climate Scenarios	*Scenario 1.* *Extreme rain*	*Scenario 2.* *Low sea level rise, extreme storm surge*	*Scenario 3.* *High sea level rise, warmer sea surface*	*Scenario 4.* *Wind-related upwelling*	*Scenario 5.* *Drought*
Set a goal: How can your group adapt to each climate scenario?					
Examples of adaptation goals	Improve stormwater system capacity	Storm-proof downtown infrastructure	Prevent saltwater intrusion	Help coral systems benefit from increased upwelling	Prepare for increased likelihood of wildfires
Make a plan: What steps do you need to take to achieve your adaptation goals? When should these steps be completed?					
Examples of one step in a plan	Increase catch basin retention + detention	Reinforce + weatherproof building fronts	Increase natural saltwater filtration systems	Prioritize areas of strong upwelling for coral transplants	Increase frequency of prescribed burns (esp. in residential areas)
Explore challenges: What challenges do you foresee arising in each climate scenario?					
Examples of challenges	Flooding may delay construction projects	Increased storm surge may damage infrastructure	Saltwater intrusion threatens local brackish ecosystems	Will be difficult to determine hardiest coral species for transplant	Decreased water supply with which to fight wildfires