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	2	3	4	5
Future Climate Scenarios	Risk Mapping	Identifying At-risk Infrastructure	Barriers to Climate Adaptation	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.

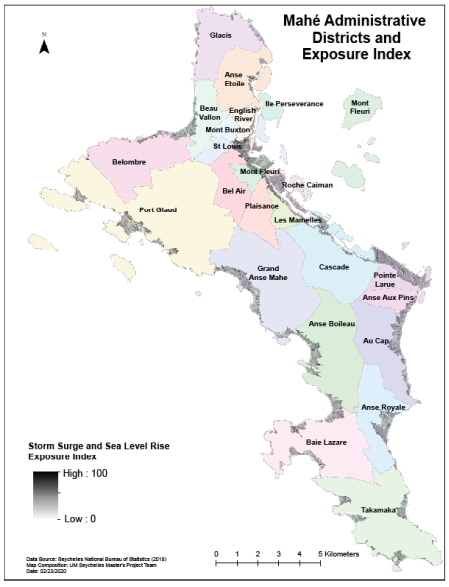
Infrastructure Exposure
Using infrastructure density and the Storm Surge and Sea Level Rise Exposure Index, an infrastructure exposure assessment was completed, giving individual pieces of infrastructure an exposure score.

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.

RISK

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.

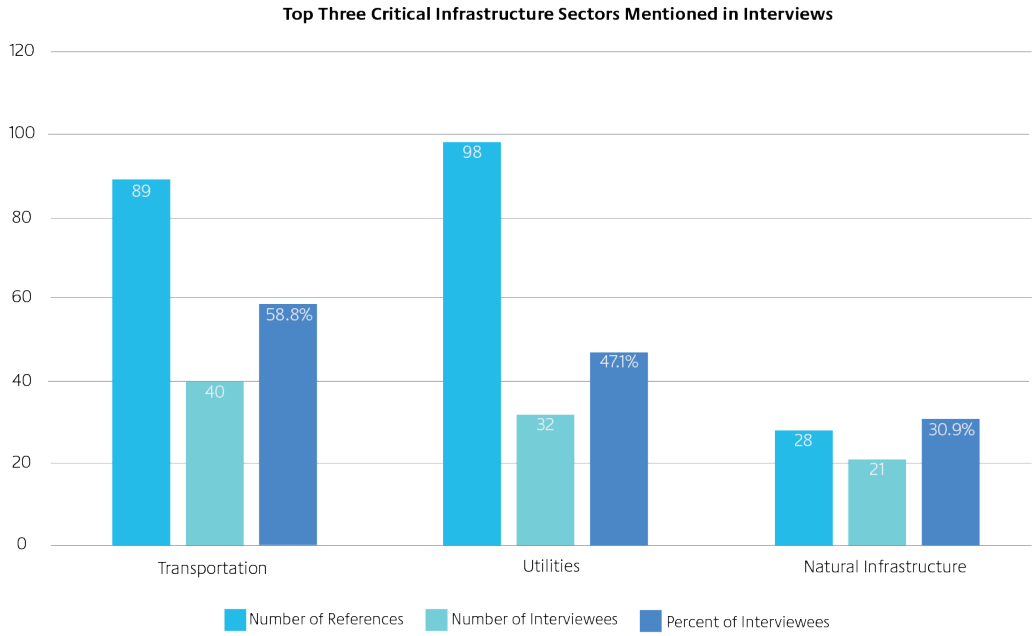


Administrative districts with Storm Surge and Sea Level Rise Exposure Index.

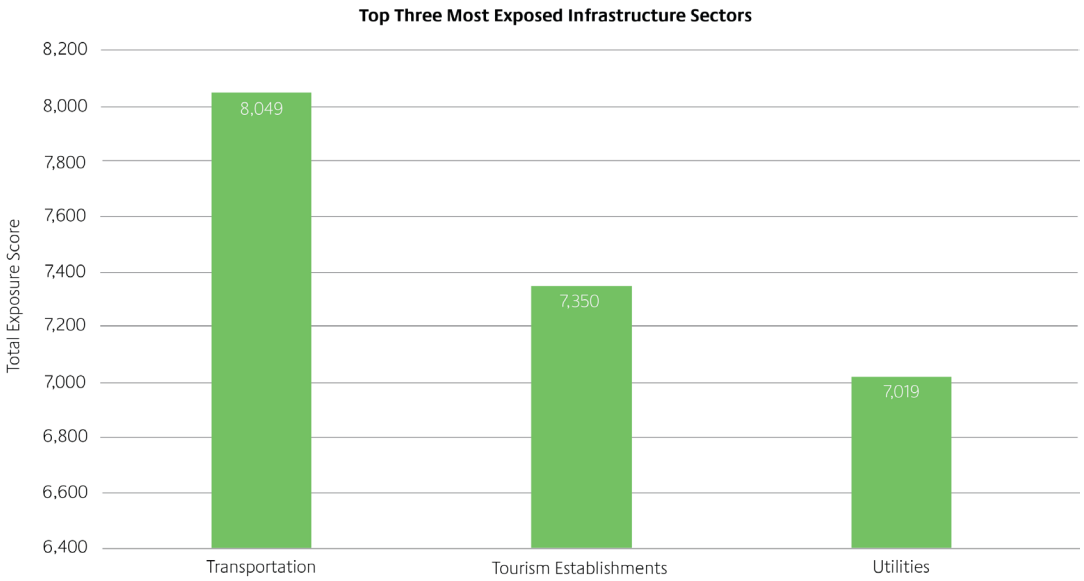
Data layers available online at:
https://bit.ly/2SqZD3I

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

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

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.

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