

NIPPON KOEI

WORLD BANK

COASTAL WASTE MANAGEMENT
INFRASTRUCTURE IN A CHANGING
CLIMATE

- SEYCHELLES -

Risk Assessment Report

May 2019

Nippon Koei Co., Ltd.

COASTAL WASTE MANAGEMENT INFRASTRUCTURE IN A CHANGING CLIMATE
- SEYCHELLES -

Risk Assessment Report

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1. Introduction

1. 1. Objective of Risk Assessment

A risk assessment aims to identify current and future climate change-induced hazards to the Providence 1 (P-1) and Providence 2 (P-2) landfills, which are existing coastal waste management systems in Mahé island of the Republic of Seychelles. The assessment results provided valuable information that would be used to identify alternatives in the following technological, socioeconomic and financing assessment.

1. 2. Methodology

The consultant team conducted assessment of the system's vulnerability to climate change by analyzing existing data and documents. The assessment considered a range of potential climate scenarios and potential stressors, such as future land development and increase in waste production. The consultant closely cooperated with the Climate Change team from the World Bank, which is doing a parallel study on Coastal Risk Management, as well as the EU Team working for the development of Seychelles Solid Waste Master Plan.

Based on the results of the risk assessment, the consultant recommended potential adaptation measures to prevent human or environmental exposure to contaminants of concern.

Table 1.1 shows the list of documents of Seychelles reviewed for risk assessment.

Table 1.1 List of Documents

| Category | Name | Lead Agency | Year |
|-------------------------|---|---|------|
| Sustainable Development | Seychelles Sustainable Development Strategy, 2012-2020 | Government of Seychelles | 2012 |
| Climate Change | Intended Nationally Determined Contribution (INDC) Under the United Nations Framework Convention on Climate Change (UNFCCC) | Government of Seychelles | 2015 |
| | Second National Communication (SNC) under UNFCCC | Ministry of Home Affairs, Environment, Transport and Energy | 2011 |
| | National Climate Change Strategy | The Seychelles National Climate Change Committee | 2009 |
| | Seychelles Climate Change Scenarios for Vulnerability and Adaptation Assessments | Ministry of Environmental and Natural Resources | 2007 |
| | Climate Change Scenario Assessment for the Seychelles, Second National Communication (SNC) under the United Nations Framework Convention on Climate Change (UNFCCC) | Chang-Seng, S. D., National Climate Change Committee, Seychelles. | 2007 |

| | | | |
|-------------------------|--|--|------|
| Land Use | Seychelles Strategic and Land Use Plan 2040 | Government of Seychelles | 2015 |
| | Victoria Masterplan 2040 | Government of Seychelles | 2015 |
| Disaster Risk Reduction | UNISDR Working Papers on Public Investment Planning and Financing Strategy for Disaster Risk Reduction: Review of Seychelles | UNISDR | 2015 |
| | WB GFDRR Disaster Risk Profile | WB GFDRR | 2016 |
| | UNDP Disaster Risk Profile | UNDP | 2008 |
| Coastal Management | Coastal Management Plan 2019-2025 | WB | 2019 |
| | JICA Coastal Erosion and Flood Control Management | JICA | 2014 |
| | Preliminary Hazards analysis of sea level rise and coastal flooding | Ministry for Science, Technology and Environment, Environmental Agency, Hazard, Vulnerability and Risk Group | 2011 |

Source: Nippon Koei Co., Ltd.

2. Target of Risk Assessment

Targets of the risk assessment are the Providence 1 (P-1) and Providence 2 (P-2) landfills located in an artificial reclaimed land in Providence area of Mahé. Figure 2.1 shows the location of these landfills in the island. Another operational landfill is the Anse Royale landfill, which treats inert waste only. This landfill is located in an inland area and is therefore not been considered in the risk assessment.

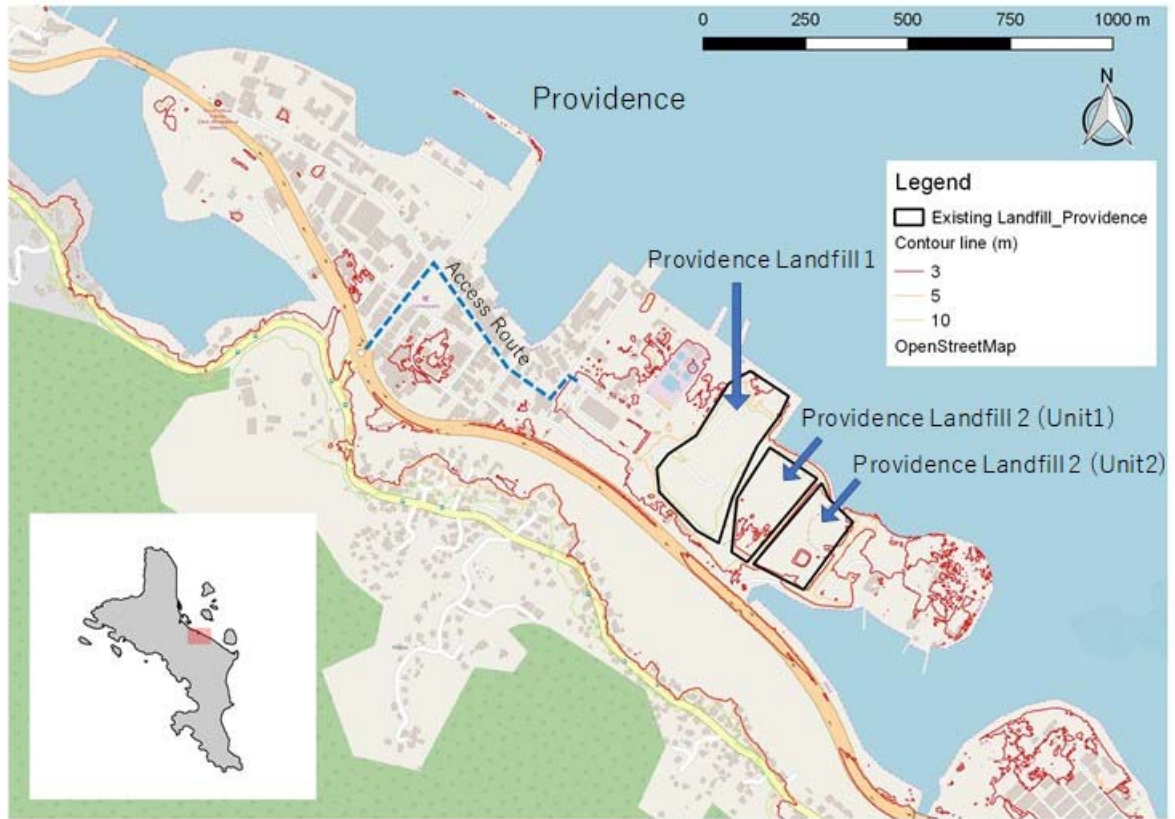


Source: Seychelles Strategic and Land Use Plan 2040 (2015), p.259

Figure 2.1 Location of Providence Landfill Sites in Mahé

2. 1. General Description of Providence 1 and Providence 2 landfills

Figure 2.2 shows a detailed location map of Providence landfill site.



Source: Nippon Koei Co., Ltd.

Figure 2.2 Detailed Location Map of Providence Landfill Site

(1) Providence 1 (P-1) landfill

The P-1 landfill started operation in 1996. In 2016, land filling was stopped at the site and was moved to P-2 sanitary landfill. However, the Ministry still allows the operator to dispose liquid waste, therefore the site is not fully closed.

Figure 2.3 shows current issues at P-1 landfill sites. The site has no bottom liner and leachate collection, therefore, leachate is seeping into the ocean on a daily basis. In addition, there is no collection of methane which in turn causes flaring of landfill gas with several fires over the years.

Figure 7: Issues with active landfills on Mahe⁵

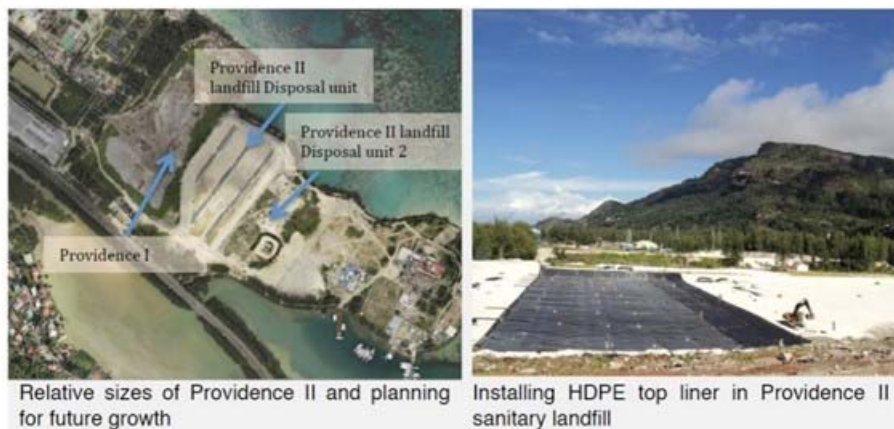


Source: Cliff J. J. Gonzalves 2017 Seychelles Solid Waste Assessment Report 2017(Consultation draft), p.23

Figure 2.3 Current Issues at Providence 1 Landfill Site

(2) Providence 2 (P-2) landfill

The P-2 landfill site started operation in 2016. The site is a sanitary landfill with a 7.9 ha land area and a void capacity of 710,000 m³, and is designed for lifetime of 21 years. In view of limited budget for leachate management, it was decided that construction phase be divided into two: disposal unit 1 (410,000 m³) and disposal unit 2 (300,000 m³). It was confirmed that the present operation plot of the P-2 landfill was designed and constructed as the disposal unit 1 of the entire landfill¹. Figure 2.4 shows the configuration of landfill plots and installed HDPE liner sheet installed in the P-2 landfill.



Source: Cliff J. J. Gonzalves 2017 Seychelles Solid Waste Assessment Report 2017(Consultation draft), p.24

Figure 2.4 Providence 2 Landfill Site

¹ Cliff J. J. Gonzalves 2017 Seychelles Solid Waste Assessment Report 2017(Consultation draft)

(3) Present Operation of P-2 landfill

The waste weight hauled to the P-2 landfill was about 70,000 ton/year in 2015, according to the record of weighing scale operated by the private contractor.

While the P-2 landfill was engineered and designed as sanitary landfill equipped with embankment, water proof liner, leachate collection system and leachate pre-treatment facility, it has not been operated as designed. Leachate treatment plant has never been operated due to mechanical failure in the facility. LWMA has been trying to fix the problem. The collected leachate through leachate collection system is pumped up and, without any treatment, introduced into P-1 area where no water proof facility exists. Figure 2.5 shows current situation of the P-2 landfill. Figure 2.5 shows the present situations of the P-2 landfill.

A part of leachate from P-2 must seep into the ground, same as leachate from dumped waste in P-1. It might then flow into the drainage leak and the surrounding sea because some wastes would exceed the boundary of the designated disposal area.

Table 2.1 gives the estimated amount of leachate generation from P-1 and P-2 based on assumptions, since real mechanism of seepage and leachate quality has not been surveyed in detail. Although the data of contaminants in leachate are not enough to evaluate the impact of leachate on the environment, it must contain Nutrients and even trace amount of heavy metals which may continuously affect the environment. Monitoring data to be taken at the leachate treatment facility of P-2 including generation amount and quality of leachate, would contribute to a more precise calculation of environmental load by leachate generation.



Source: Nippon Koei (2019)

Figure 2.5 Present Situation of Providence 2 Landfill Site

Table 2.1 Rough Estimation of Leachate Generation from Providence Landfill

| Landfill | Status | A. Area (m2) | I. Rainfall (mm/month) | E. Evaporation (mm/month) | Q. Leachate Generation (m3/month) |
|-------------|------------------|---------------------|------------------------|---------------------------|-----------------------------------|
| P-1 | Covered area | 64,400 | 193 | 157 | 1,395 |
| P-2 (Unit1) | Operational area | 35,100 | 193 | 157 | 1,267 |
| Source | - | Measured in the map | *1 | *1 | - |

Note: The following formula is applied for calculation of amount of leachate: (Source: (Operational area) $Q1=I \times A \times C1/1000$, Leaching factor $C1=1-E/I$, (Covered area) $Q2=I \times A \times C2/1000=I \times A \times 0.6 \times C1/1000$)

Source: Nippon Koei (2019),

*1: <https://www.mauritius-seychelles.com/seychelles-weather.php>

(4) Candidate Sites for Future Waste Facilities

The Government of Seychelles would start preparation of Unit2 of P-2 landfill which was previously designed together with Unit1, in the operation of the existing reclamation area. Apart from it, other sites are not specified for landfills and other SWM facilities in the Seychelles Strategic Land Use and Development Plan (2015).

2. 2. Current Climate Risk

2.2.1. Natural condition of Mahé

(1) Geography

The land area of Mahé is 155km², consists of steep granite mountains surrounded by narrow plains. The plains are relatively small, covering only 5% of the total area. In Mahé, almost 75% of the land is forest and protected areas, with residential areas accounting for 20% and increasing with urban development (Figure 2.6).

Under such geographical conditions, Seychelles has a history of undertaking land reclamation to ensure that demand for land can be satisfied. However, reclamation has significant environmental implications. The Government of Seychelles will therefore only permit further reclamations wherein strategic needs can be demonstrated².

According to WB, new reclamations are most likely to be approved soon and the EIAs are currently being developed. The details of the new reclamations need to be confirmed for further investigation.

² Seychelles Strategic and Land Use Plan 2040 (2015)

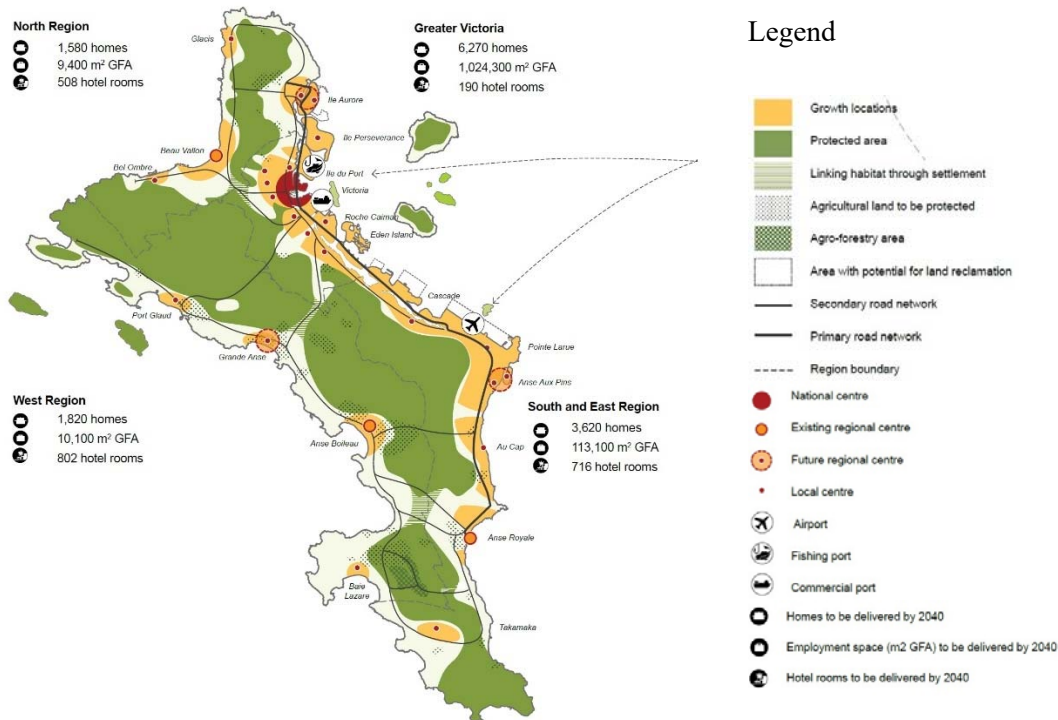


Figure 3.1 Spatial Strategy
 Note: The indicative growth distribution presented in this figure incorporates the existing development pipeline.
 Source: Seychelles Strategic and Land Use Plan 2040 (2015), p.36

Figure 2.6 Spatial Strategy of Mahé

(2) Climate

The Seychelles’ climate is always warm, without extreme weather conditions. The climate of Mahé is classified into two types: northwest monsoons from December to March, and southeast trade winds from May to October. Annual average temperature is at 27°C and annual rainfall measures 2372.8 mm. The island receives most rain during December to February.

Table 2.2 Climate Conditions at Seychelles International Airport

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|--------------------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|-------|-------|
| Rainfall (mm) | 402.6 | 283.2 | 194.9 | 186.7 | 151.6 | 105.1 | 76.6 | 119.3 | 154.0 | 189.7 | 206.3 | 302.8 |
| Temperature (°C) | 26.9 | 27.4 | 27.8 | 28.1 | 27.8 | 26.7 | 26.0 | 26.0 | 26.5 | 26.9 | 26.9 | 26.9 |
| Humidity (%) | 82 | 80 | 80 | 80 | 79 | 79 | 80 | 80 | 79 | 79 | 80 | 82 |
| Wind Direction | NW | NW | NW | SW-NW | SE | SE | SE | SE | SE | SE | SW-NW | NW |
| Wind Speed (knots) | 6.3 | 6.3 | 5.2 | 4.9 | 7.8 | 10.4 | 11.4 | 12.1 | 11.3 | 7.9 | 5.4 | 5.4 |

(http://www.seychelles.com/en/about_seychelles/climate.php)

Source: JICA Coastal Erosion and Flood Control Management, JICA, 2014, p.2-1

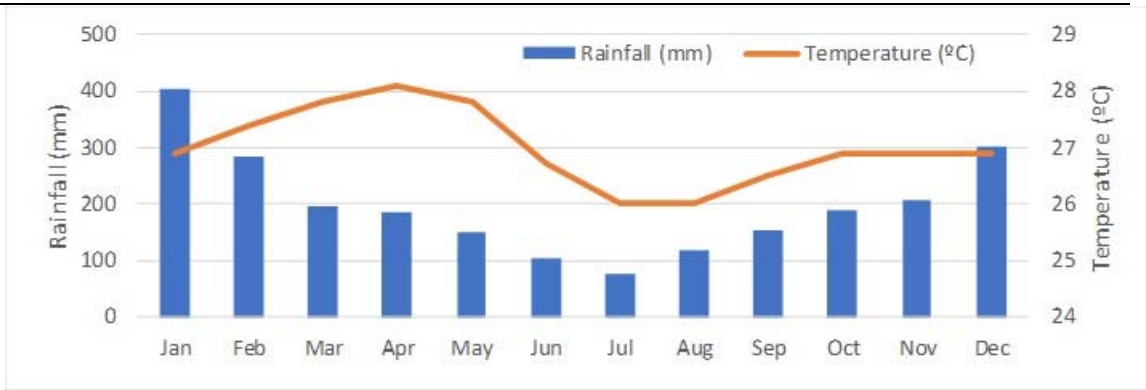
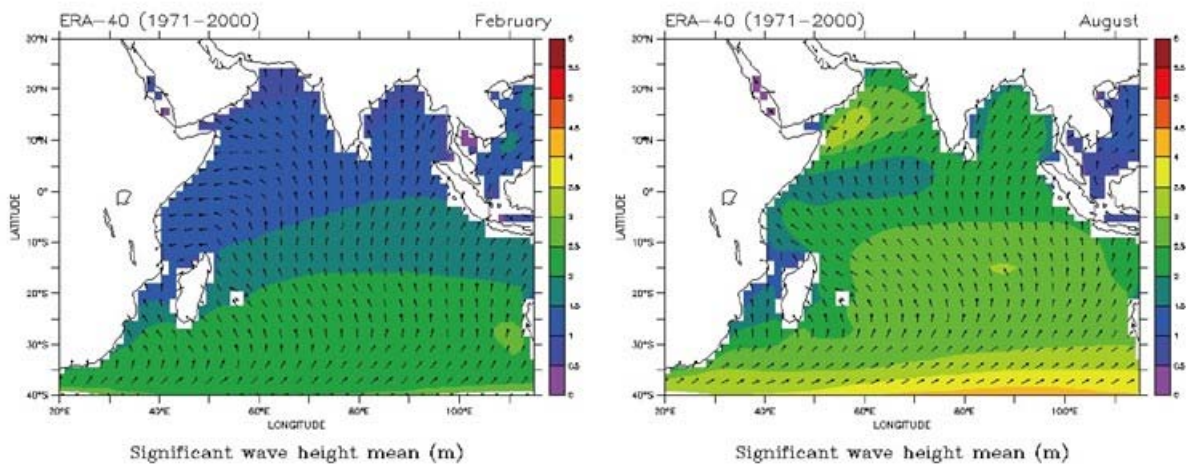


Figure 2.7 Seasonal Pattern of Temperature and Rainfall at Seychelles International Airport

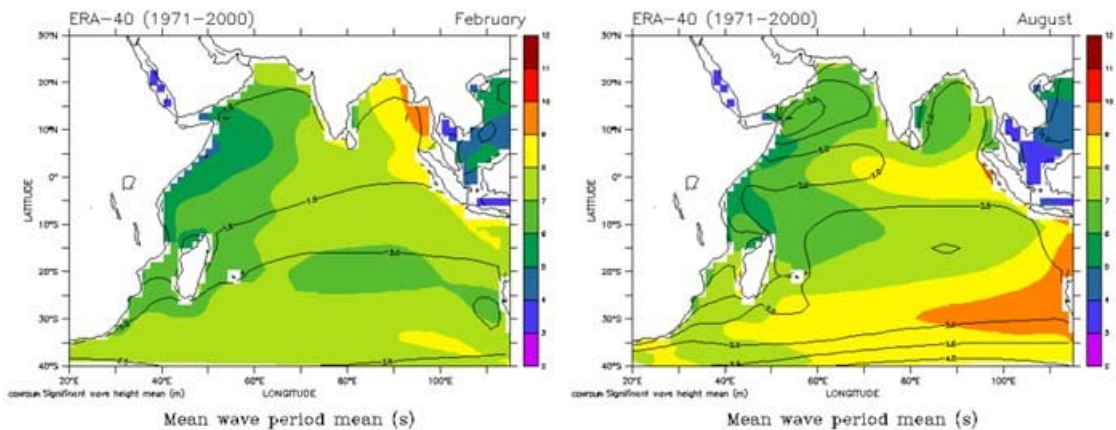
(3) Oceanic condition

Figure 2.8 and Figure 2.9 show monthly mean significant wave height and period, which is estimated as the average value from high wave data, in February and August. Most waves come from the southeast or south, and change direction depending on the season. The wave height ranges from 1.0m to 1.5m in January and February and from 2.0m to 2.5m in July and August.



Source: JICA Coastal Erosion and Flood Control Management, JICA, 2014, p.2-2

Figure 2.8 Monthly Mean Significant Wave Height (m): February and August



Source: JICA Coastal Erosion and Flood Control Management, JICA, 2014, p.2-2

Figure 2.9 Monthly Mean Significant Wave Period (s): February and August

2.2.2. Natural Disasters in Seychelles

(1) Disaster Database

1) EM-DAT

EM-DAT is a global disaster database maintained by the Centre for Research on the Epidemiology of Disasters (CRED). The database includes large scale disasters from 1900 until the present, conforming to at least one of the following criteria:

- 10 or more people dead;
- 100 or more people affected;
- The declaration of a state of emergency
- A call for international assistance

According to EM-DAT, five natural disaster events are registered to Seychelles as shown in Table 2.3. The worst damage was caused by Tsunami in 2004. Storms caused by tropical cyclone in 2002 and 2013 also affected significantly in terms of damage and number of affected people.

Table 2.3 Natural Disasters in Seychelles

| Year | disaster type | disaster subtype | Total deaths | Total affected | Total damage ('000 US\$) |
|------|---------------|------------------|--------------|----------------|--------------------------|
| 1997 | Flood | - | 5 | 1237 | 1700 |
| 2002 | Storm | Tropical cyclone | - | 6800 | - |
| 2004 | Earthquake | Tsunami | 3 | 4830 | 30000 |
| 2013 | Storm | Tropical cyclone | - | 3000 | 9300 |
| 2014 | Flood | Riverine flood | - | 4435 | - |

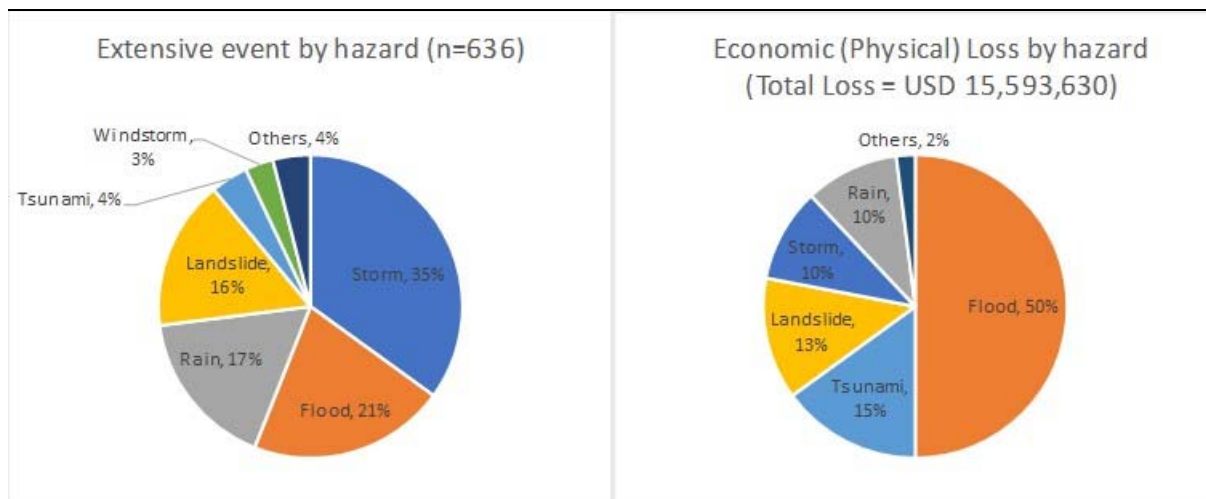
Created on: December 13, 2018

Source: EM-DAT: The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

2) Seychelles National Loss Database

Seychelles National Loss Database was developed by UNISDR. This database stores data of disasters occurred from 1980 to 2014 including not only large-scale disasters but also small-to-medium scale disasters. Figure 2.10 shows numbers of disaster events and economic loss recorded in the database. Among the registered 636 disaster events, storm is ranked the first (35%), followed by flood³ (21%), rain (17%), landslide (16%) and tsunami (4%). The largest share of economic loss is flood (50%), followed by tsunami (15%), landslide (13%), rain (10%) and storm (10%). According to the UNISDR report, local authorities have considered flood and landslides as major natural hazards because of their significant impacts, although the number of events are not ranked first.

³ A definition of flood in the database is not clearly described by the UNISDR report. Flood might mean fluvial, pluvial and coastal flooding.



Source: UNISDR Working Papers on Public Investment Planning and Financing Strategy for Disaster Risk Reduction: Review of Seychelles (2015), p.41-42

Figure 2.10 **Seychelles National Loss Database**

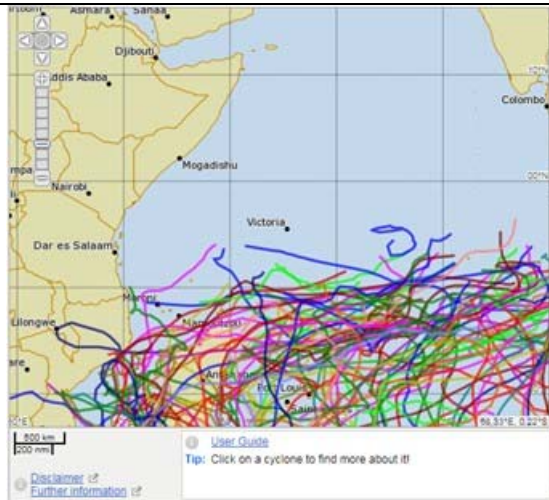
(2) Tropical Cyclone

The Indian Ocean is the most prolific of all oceans in terms of generating tropical cyclones. Nevertheless, tropical cyclone trajectories rarely come close to islands of the Seychelles located close to the equator. There have been no cyclones that have directly landed on Seychelles for the past 15 years (Figure 2.11).

However, it is important to note that extreme wave swells, storm surge and heavy rain resulting from Indian Ocean tropical cyclones do affect the Seychelles⁴. Although the Tropical Cyclone Felleng in January 2013 passed far south of Seychelles (Figure 2.12 and Figure 2.13), the total affected number of people was 3,000 as shown in Table 2.3.

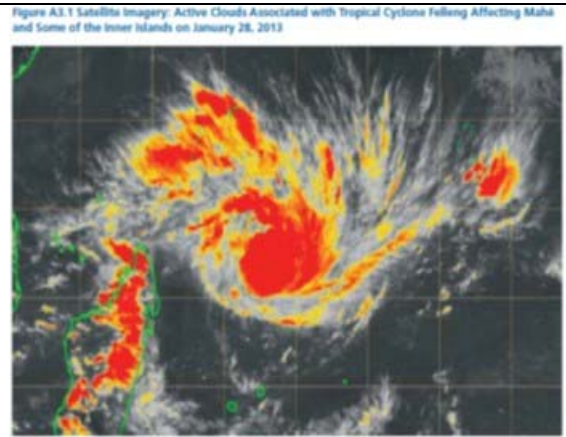
Tropical Cyclone Bondo (2006) and Gafilo (2004) are other tropical cyclones that made significant impact to several areas in Seychelles (Figure 2.13). In the case of Tropical Cyclone Bondo (2006), recorded wave height was at 12 m in the ocean, and arrived at the Seychelles coast in the order of 6 to 7 m. In the case of Tropical Cyclone Gafilo (2004), the maximum wind speed recorded was 20 m/s with a northwest direction.

⁴ The Seychelles National Climate Change Committee, 2009. Seychelles National Climate Change Strategy, p.96



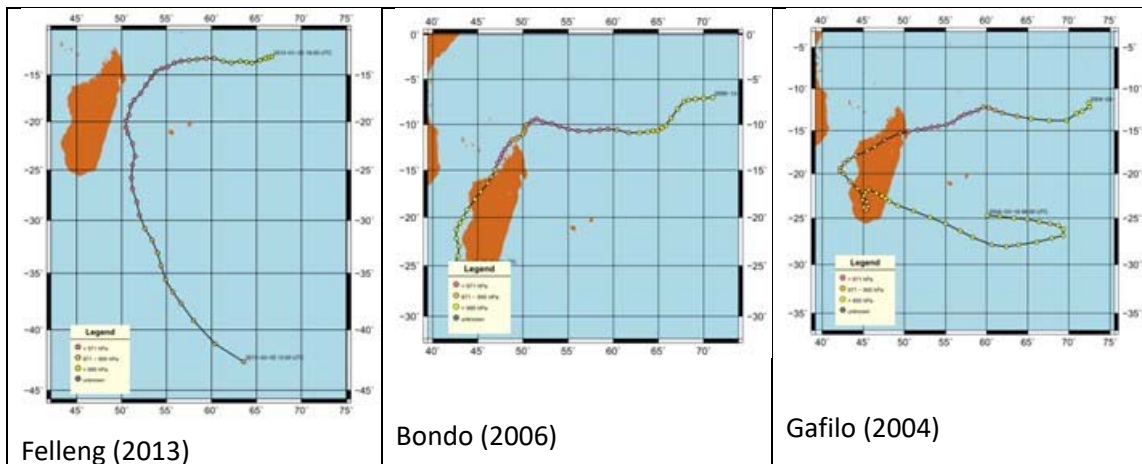
Source: Bureau of Meteorology, Australia, Southern Hemisphere Tropical Cyclone Data Portal

Figure 2.11 All cyclone tracks (2001-2015)



Source: Seychelles Damage, Loss, and Needs Assessment (DaLA) 2013 Floods A report by the Government of Seychelles June 2013, p.48

Figure 2.12 Tropical Cyclone Felling in January 2013



Source: Australiasevereweather.com

Figure 2.13 Historical cyclone tracks

(3) Tsunami

The Indian Ocean Tsunami in 2004 reached the Seychelles. The highest flood levels on Mahé ranged from 1.6 m to more than 4.4 m above mean sea level (Figure 2.14). However, no information on Tsunami damage at the Providence area is available.

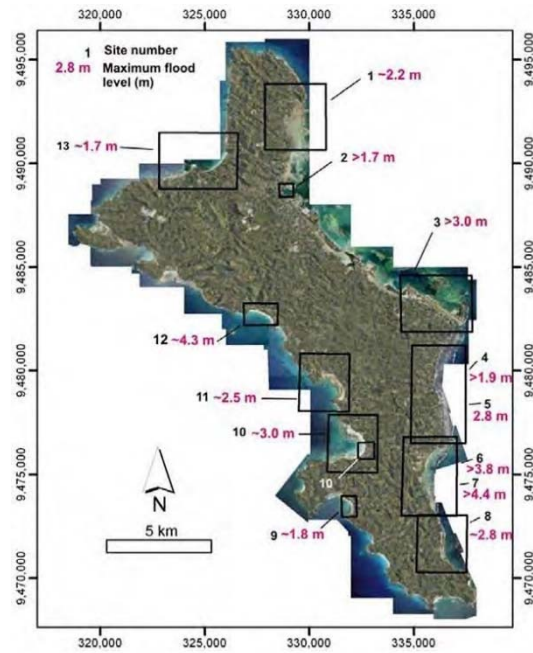


Figure 2-4-8: Tsunami Run-up Height on Mahé Island
 The red numbers refer to the maximum water level above mean sea level at each location (Jackson, L.E., Jr., Barrie, J.V., Forbes, D.L., Shaw, J., Manson, G.K., Schmidt, M.: Effects of the 26 December 2004 Indian Ocean tsunami in the Republic of Seychelles. Report of the Canada-UNESCO Indian Ocean Tsunami Expedition. Geological Survey of Canada, 2005.)

Source: JICA Coastal Erosion and Flood Control Management, JICA, 2014, p.2-19

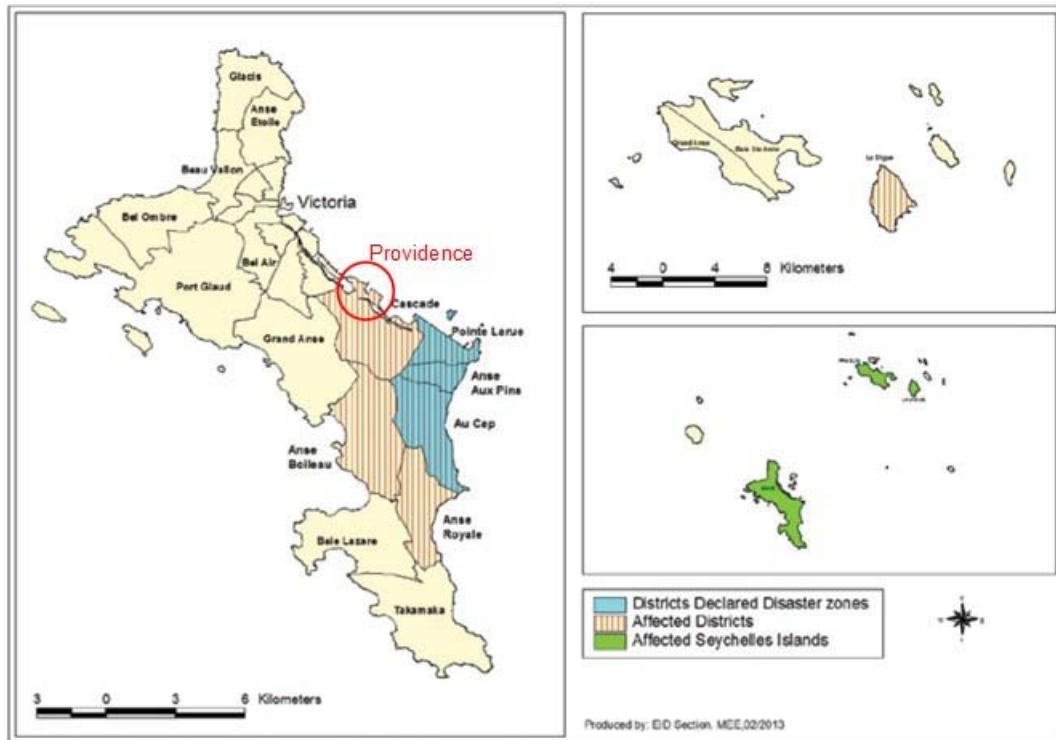
Figure 2.14 Tsunami Run-up Height on Mahé (The Indian Ocean Tsunami in 2004)

(4) Flood and Landslide

Heavy rainfall resulting from Tropical Cyclone Felling on January 27–28, 2013 caused severe flooding and landslides in Mahe. According to the Seychelles Damage, Loss, and Needs Assessment (DaLA) report, the island was within the coverage area of active clouds associated with the tropical cyclone and received a historical high rainfall, with a total amount of 871 mm, which is twice as much as the monthly average of 400 mm, the highest three consecutive days rainfall over 330 mm. In addition, the rains coincided with a high tide, which did not allow drainage canals to deposit floodwater from the plains into the sea.

However, detailed information on flood damages at the Providence area is limited. Figure 2.15 shows flood affected areas by the heavy rain event. The Providence area was just indicated as affected districts and no information of flood damage at the Providence area is available in the DaLA report. Figure 2.16 shows satellite-detected analysis of standing water observed in February 2013. The analysis estimates 5,210 m² of water extent in the eastern part of the Providence area. However, causes of the water extent, whether from heavy rain and/or coastal flooding, are lacking.

Regarding damages caused by landslides, no specific information at the site and its surrounding areas is available.



Source: EID Section, MEE, February 2013.

Source: Seychelles Damage, Loss, and Needs Assessment (DaLA) 2013 Floods A report by the Government of Seychelles June 2013, p.3

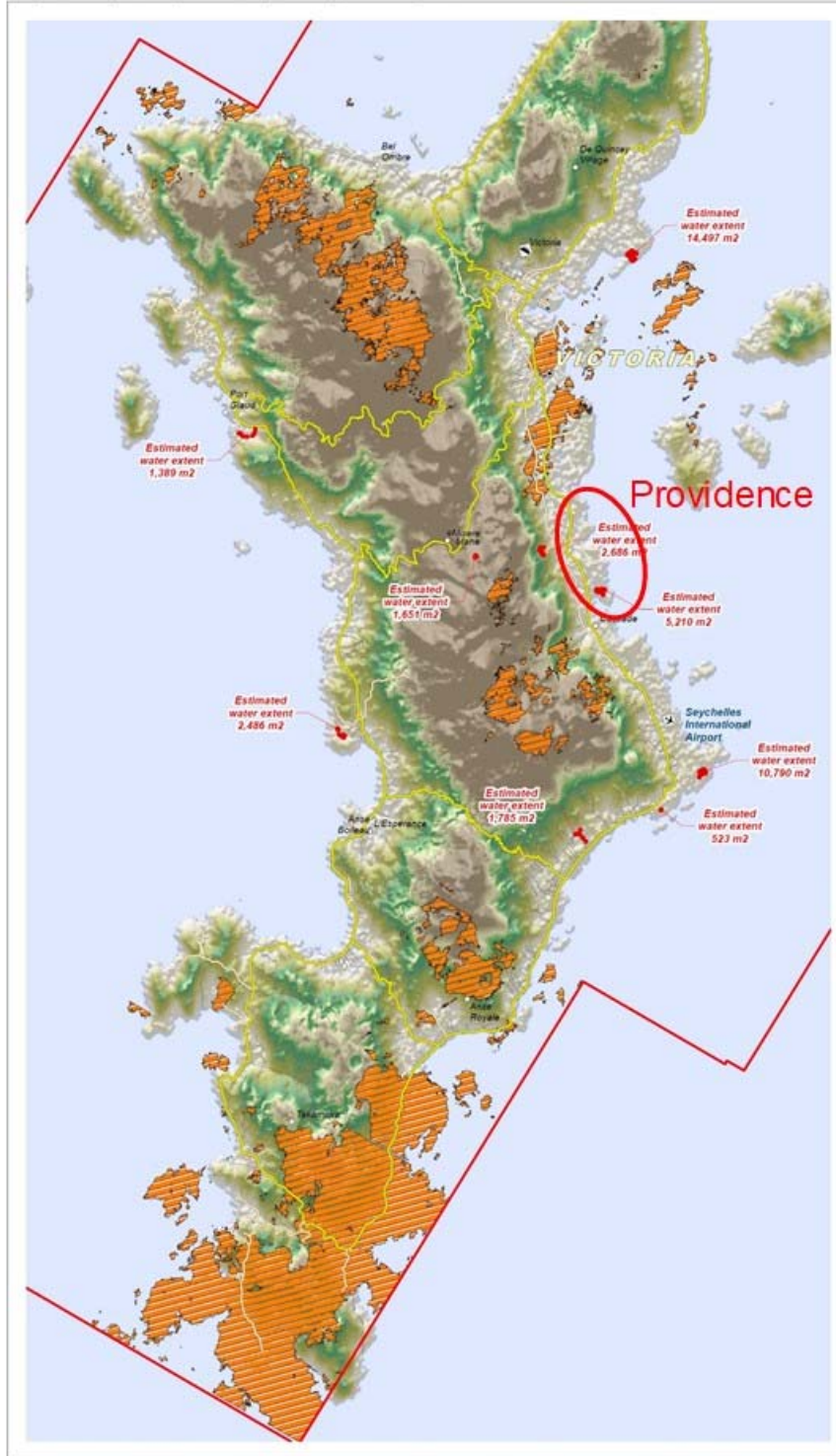
Figure 2.15 Flood-Affected Areas by Heavy Rainfall Resulting from Tropical Cyclone Felleng in January 2013

AREAS OF STANDING WATER, MAHÉ ISLAND, SEYCHELLES

Analysis with GeoEye-1 Data Acquired 5 February, 13 February, and 16 February 2013

Severe
Local Storm

Production Date:
07/03/2013
Version 1.0
Globe Number:
ST20130212SYC



This map illustrates satellite-detected areas of standing water observed on Mahé Island, Seychelles, in 12 separate GeoEye-1 images collected on 5 February, 13 February, and 16 February 2013. Though these images were very cloudy, UNITAR/UNOSAT reviewed them all for indications of standing water and also produced a cumulative cloud mask to indicate which portions of the island were completely cloud obscured. A total of 28 separate standing water bodies were identified, totaling 41,025 square meters and averaging 1,465 square meters in size. This is a preliminary analysis and has not yet been validated in the field. Please send ground feedback to UNITAR / UNOSAT.

LEGEND

- Main Airport
- Port
- Capital
- Populated Place
- Primary Rd.
- Secondary Rd.
- Urban Rd./Footpath
- Elevation (m)
- High: 4000
- Low: 0

STANDING WATER EXTENT ANALYSIS (Satellite-Based Analysis)

- Probable Standing Water
- Analysis Extent
- Cloud Obscured Area

Map Scale for A3: 1:71,000

Disaster coverage by the International Charter 'Space and Major Disasters'. For more information on the Charter, which is about assisting the disaster relief operations with multi-satellite data and information, visit www.disastercharter.org

Satellite Data (1): GeoEye-1
Imagery Date: 5 February 2013
Resolution: 50 cm
Copyright: DigitalGlobe
Source: US Geological Survey
Satellite Data (2): GeoEye-1
Imagery Date: 13 February 2013
Copyright: DigitalGlobe
Source: US Geological Survey
Satellite Data (3): GeoEye-1
Imagery Date: 16 February 2013
Copyright: DigitalGlobe
Source: US Geological Survey
Road Data: Google Map Maker / OSM / ESRI
Other Data: USGS, UNCC, NASA, NGA
Analysis: UNITAR / UNOSAT
Production: UNITAR / UNOSAT
Analysis conducted with ArcGIS v10.1

Coordinate System: World Robinson
Projection: Robinson
Datum: WGS 1984
Units: Meter

The depiction and use of boundaries, geographic names and related data shown here are not warranted to be error-free nor do they imply official endorsement or acceptance by the United Nations. UNOSAT is a program of the United Nations Institute for Training and Research (UNITAR), providing satellite imagery and related geographic information, research and analysis to UN humanitarian and development agencies and their implementing partners.

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www.unitar.org/unosat

Source: http://unosat-maps.web.cern.ch/unosat-maps/SC/SC-TC20130212-SYC/UNOSAT_SYC_TC20130212SYC_StandingWater_v1.pdf

Figure 2.16 Satellite-detected Areas of Standing Water Observed in February 2013

2.2.3. Current Climate Risk at Providence Landfill Sites

Considering historical records of natural disasters in Mahe, current climate risk at Providence landfill sites can be summarized as follows:

- Coastal flooding by high tide, storm surge, and tsunami might be the most significant current climate risks at the Providence landfill site.
- Also, heavy rain resulting from tropical cyclones might cause flooding at the site.
- These flooding might wash out pollutants and waste into the ocean or surrounding areas. In addition, there are risks that access routes might be block by flooding and/or landslides.

For further investigation for Viability Assessment in Task 1-3, following information are required, in particular from the viewpoints of vulnerability and exposure to flooding at the site:

- The design report of the Providence landfill site
- Coastal flood protection standards applied for the landfill reclaimed land
- Detailed information on historical damages at the Providence landfill site

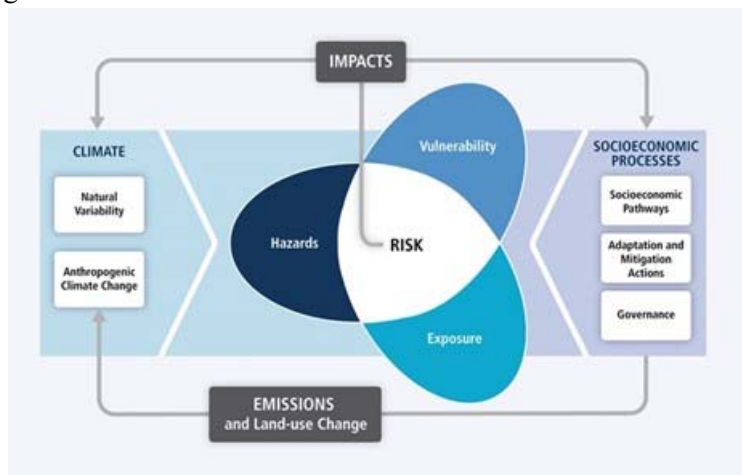
According to the interview conducted by Rapid Assessment, which was made at the Providence landfill site to the staff of the private contractor including manager, landfill staff and operators, the P-1 and P-2 landfills have not been significantly and physically affected by impacts of climate change such as sea level rise, storms, much or less rainfall, rise of ambient and sea water temperature, etc. This might be because these landfills are located and developed in a reclaimed land with facility elevation not as low as historical tidal level. However, it should be confirmed after collecting above additional information.

3. Risk Assessment

3. 1. Definition of Risk

Figure 3.1 shows an illustration of the core concept of risks⁵ and Table 3.1 shows the definition of terms in risk assessment. Risk of climate-related impact results from the interaction of climate-related hazards, with the vulnerability and exposure of human and natural systems. Changes in both the climate system and socioeconomic processes are drivers of hazards, exposure, and vulnerability.

Risk assessment of climate-related impacts to coastal waste infrastructure management involves a deliberate and systematic screening of hazards and consequences for people, infrastructure and environmental resources. The timescales for climate change and some of the consequences on waste management are similar because landfill sites can be operational for decades and still be active for decades following their closure.



Source: Field et al., p.37

Figure 3.1 Image of Core Concept of Risk

Table 3.1 Definition of Terms in Risk Assessment

| Term | Definition |
|----------|---|
| 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. |
| Hazard | The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life or health impacts, as well as damage and loss to infrastructure, environmental resources etc. |
| Exposure | The presence of people, infrastructure, environmental functions etc. in places and |

⁵ Field et al., 2014: Technical summary. In: ClimateChange 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of WorkingGroup II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 35-94.

| | |
|---------------|--|
| | settings that could be adversely affected. |
| Vulnerability | The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. |
| Impact | Effects of extreme weather and climate on natural and human systems. |

Source: Field et al., p.39-41

3. 2. Risk Identification

First step of risk assessment is the identification of risk that aims to recognize and describe risks of solid waste management system relying on the existing landfills in the coastal area. The identification was conducted by considering potential climate change hazard and potential stressors such as future land development and increase of waste production.

3.2.1. Potential Climate Hazard (Climate Drivers)

Potential climate hazard and impact to coastal waste management infrastructure under climate change are summarized based on the reference⁶ and shown in Table 3.2.

Table 3.2 Potential Climate Hazard and Impact to Coastal Waste Management Infrastructure under Climate Change

| Climate Hazards | Potential Impacts |
|--------------------------------|---|
| Sea level rise and storm surge | Lead to inundation at landfill sites by coastal flooding |
| | Lead to increase damage to the coastal waste infrastructure such as protective liner and leachate collection system |
| | Lead to increase disruption to transport infrastructure due to coastal flooding and hence delivery of waste |
| Higher temperature | Alter waste decomposition rate (increase with adequate moisture, decrease with less moisture) |
| | Increase strength of leachate due to reduction in dilution |
| | Increase health risk to workers from increased sunshine and exposure to UV radiation, increased pathogen and vermin activity, and increased methane and landfill fire |
| | Reduced worker comfort with negative impacts on productivity from higher temperature |
| | Increase site disamenity from odor, vermin, dust and litter |
| Increased rainfall | Increase on-site and off-site flooding |
| | Alter waste decomposition rate |
| | Increase leachate production |
| Reduced rainfall | Decrease waste decomposition rate due to less moisture |
| | Reduce water availability for site management (e.g. dust suppression) |
| | Increase strength of leachate due to reduction in dilution |
| | Shrinkage in clay lining and capping layers |
| Increased storminess | Increase incidences of windblown litter and debris |
| | Damage to buildings and site closure |

Source: Climate hazards and potential impacts from Bebb and Kersey, modified by the consultant team

⁶ Bebb and Kersey, 2003, Potential Impacts of Climate Change on Waste Management, Environmental Agency, UK

3.2.2. Potential Stressors (Non-climate Drivers)

(1) Future land development

The inland area is preferable for the landfill site in terms of avoiding the climate change impact, in particular, sea level rise. However, it is recognized that preferable inland flat areas are not available in Mahé. Inland areas are steep mountains with almost 75% of forest and protected areas. Flat areas are only available at narrow plains with risk of flood and landslides, as shown in Figure 3.2.

Development of reclaimed land is another possibility for the new landfill site although there is still risk of coastal flooding. As shown in Figure 3.3, the Providence area has potential for further land reclamation with 0.35 km². However, reclamation has significant environmental implications, thus detailed environmental assessment shall be conducted. In addition, because Providence is identified as strategic industrial location, it is not clear whether the potential reclamation areas are utilized as new landfill sites. It should be confirmed after collecting information on the planned reclamations and new developments in the area.

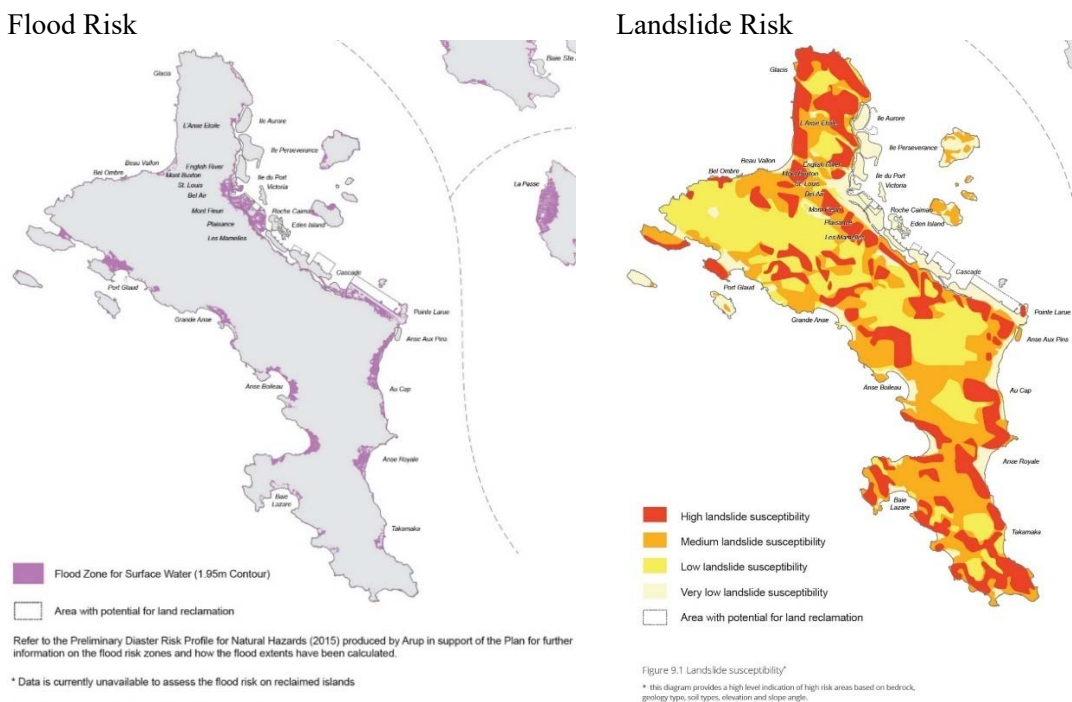
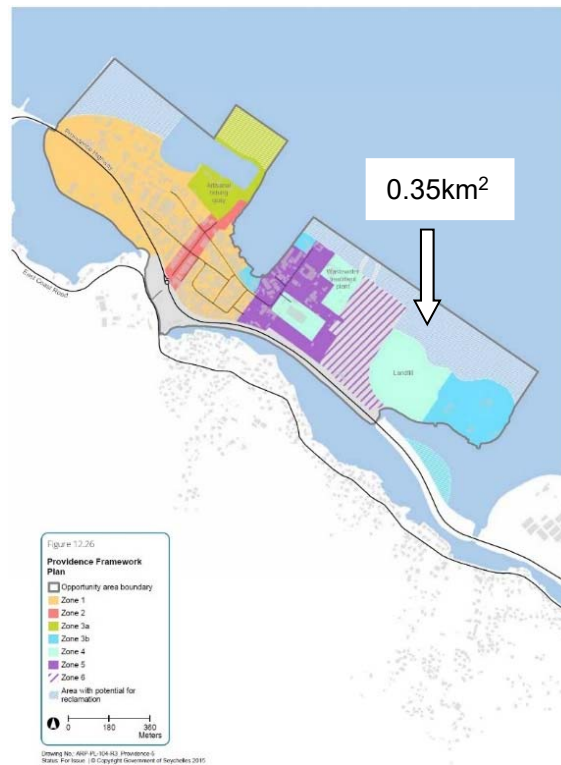


Figure 3.2 Flood and Landslide Hazard Map



Source: Seychelles Strategic and Land Use Plan 2040 (2015), p.279

Figure 3.3 Providence Framework Plan

(2) Increase in Waste Production

The amount of waste projection is a very basic factor in planning for solid waste management. The amount has been projected in various studies in the past, such as the Solid Waste Management Policy 2014-2018, a study by the University of Seychelles and ETH (2016), and the study for Seychelles Waste Policy & Strategy 2017-2023 (2017)⁷. The values of projections vary depending on assumed scenario as shown in Table 3.3.

All projections stated the increasing trend of solid waste in the future, in line with economic and population growth. The projection, which is recently conducted based on the analysis of studies in the past and available statistics, is retrieved from the Seychelles Solid Waste Assessment Report 2017. In this report, it is projected that the annual solid waste generation will reach 250,000 tons in 2040 as shown in Figure 3.4. However, detailed conditions as basis of this prediction are not described in the report. The long-term projection from year 2013 to 2040, with a span of more than twenty years, might have errors and might result to projecting too big or too small values. This projection will be further investigated considering another projection by an on-going solid waste master plan study.

Disaster waste would be produced by flood due to storm surge, sea level rise and increased heavy rain while it is difficult to estimate the increase of production quantitatively at this moment.

⁷ Cliff J. J. Gonzalves 2017 Seychelles Solid Waste Assessment Report 2017, contributing toward Seychelles Waste Policy & Strategy 2017-2023 (Consultation draft)

Another stressor would be the remaining lifetime of the existing final disposal site, which also depends on the projection of waste amount, as well as the remaining capacity of the present site. It is a challenge to get probable lifetime of the remaining site because of the following: 1) the volume of deposited waste is not clear because of decomposition waste; and 2) uncertain condition of soil cover and preparation of access road in the operation plot since the P-2 is not being operated as designed, as sanitary landfill.

Table 3.3 Projection of Waste Amount by the Studies in Past

| Study | Target Year | Approx. Waste Amount (ton/year) | Remarks |
|---|-------------|---------------------------------|--|
| Sustainability for Seychelles (2013) | 2016 | 135,000 | Assuming 40% of increase of waste in 10years by SDSS (2012-2020) |
| Solid Waste Management Policy (2014) | 2016 | 99,000 | Applied annual growth rate: 6% |
| Carl Bro Consultants (2005) | 2025 | 76,000 | |
| Waste Assessment Report (2017) | 2040 | 250,000 | |
| University of Seychelles and ETH (2016) | 2040 | 110,000 90,000 | Scenario "Business as usual" (no reduction) Scenario "Storyline 1" (slight reduction) |

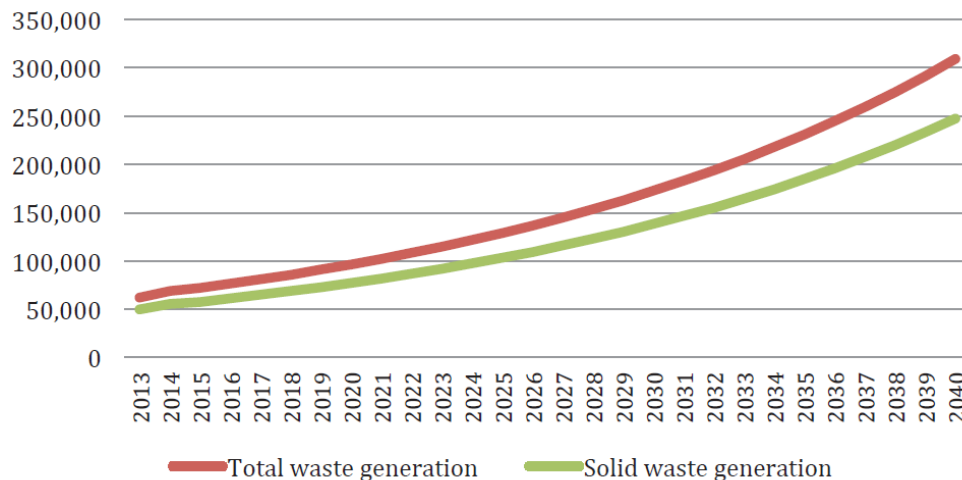
Note: The recorded amount of waste at the Providence landfill in 2015 is 70,000 ton/year.

Source: Cliff J. J. Gonzalves 2017 Seychelles Solid Waste Assessment Report 2017(Consultation draft)

Table 3.4 Lifetime of the Providence 2 Landfill

| Unit | | Designed | Estimated in 2017 ⁷⁾ |
|-------|-----------------|----------|--|
| Unit1 | Capacity (m3) | 410,000 | - |
| | Lifetime | - | Additional 5 years (until 2022) |
| Unit2 | Capacity (m3) | 300,000 | - |
| | Lifetime (year) | - | Additional 3 years + (until post 2025) |
| Total | Capacity (m3) | 710,000 | - |
| | Lifetime | 21 years | 8 years +(until post 2025) |

Source: Cliff J. J. Gonzalves 2017 Seychelles Solid Waste Assessment Report 2017(Consultation draft), p.17



Note: "Total waste generation" contains amount of liquid waste generation.

Source: Cliff J. J. Gonzalves 2017 Seychelles Solid Waste Assessment Report 2017(Consultation draft), p.17

Figure 3.4 Projection of Waste Amount up to 2040 (Solid Waste Assessment Report 2017)

3.3. Risk Analysis

The second step of risk assessment is risk analysis, that aims to understand characteristics of identified hazards and determine risk levels qualitatively. Based on available studies conducted in the country in addition to literature survey, risk levels for identified risks were determined by preparing a risk matrix on possibility and impact of risk occurrence.

3.3.1. Sea Level Rise and Storm Surge

A possible worst scenario assumed under climate change is sea level rise with an extreme high tide and waves caused by a tropical cyclone that passes close to the islands. The possible scenario was analysed by the review of available data and documents.

(1) Coastal Flood Hazard Mapping Data

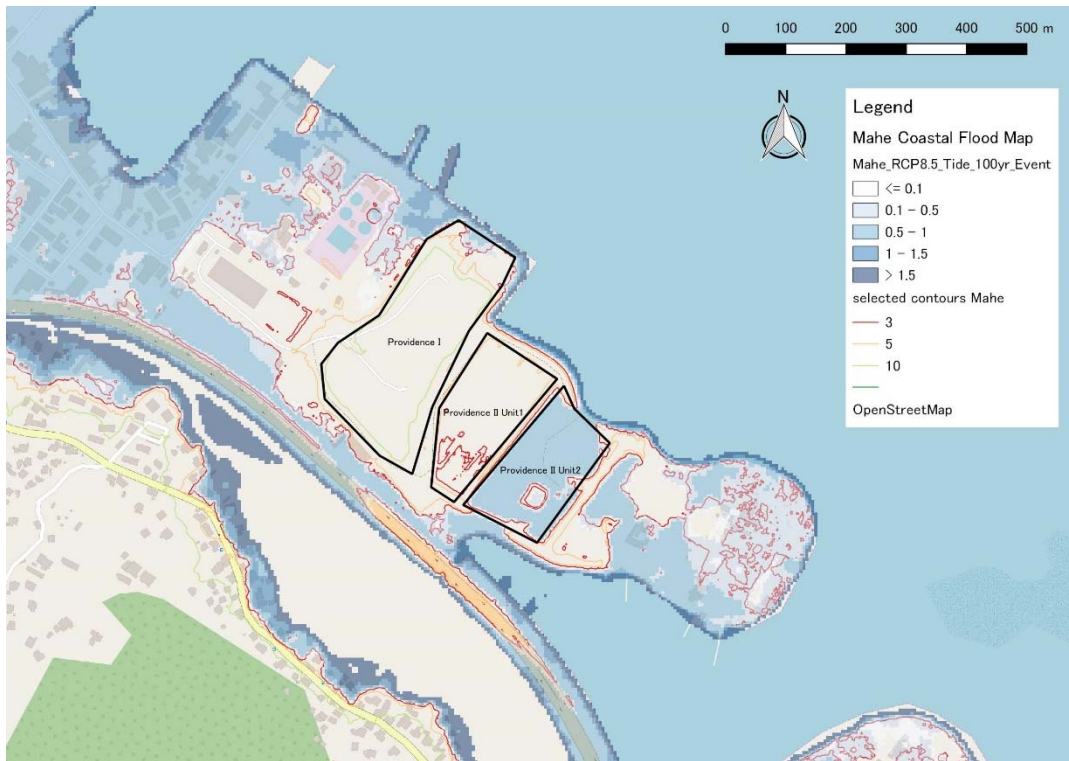
Climate Change Team from World Bank prepares coastal flood hazard mapping data under climate change⁸. The coastal flood inundation was simulated by 2-D flood model for four storm surge events of different severity, under current sea levels and also two future sea levels based on climate change scenarios RCP 4.5, and RCP 8.5 for the year 2100.

Figure 3.5 shows the coastal flood inundation depth under the worst climate change scenario, which is a 100-year return period flood under RCP 8.5 at year 2100. The result indicates that the areas of P-1 and the Unit 1 of P-2 might not be inundated, while the areas of the Unit 2 of P-2, which are not developed yet, might be inundated with a 0.7 m depth.

However, it should be noted that the model results potentially contain uncertainty because of following reasons:

- The simulation ignores the effect of wave overtopping. This is potentially the largest source of uncertainty and might underestimate inundation depth, particularly where large overtopping waves are frequent.
- The offset provided for the tide gauge to tie the data into an absolute zero of Digital Terrain Model (DTM) should be checked against actual observations and site visits.

⁸ Seychelles Coastal Flood Hazard Mapping Data – February 2019 Technical note V1 (Scott Ferguson)



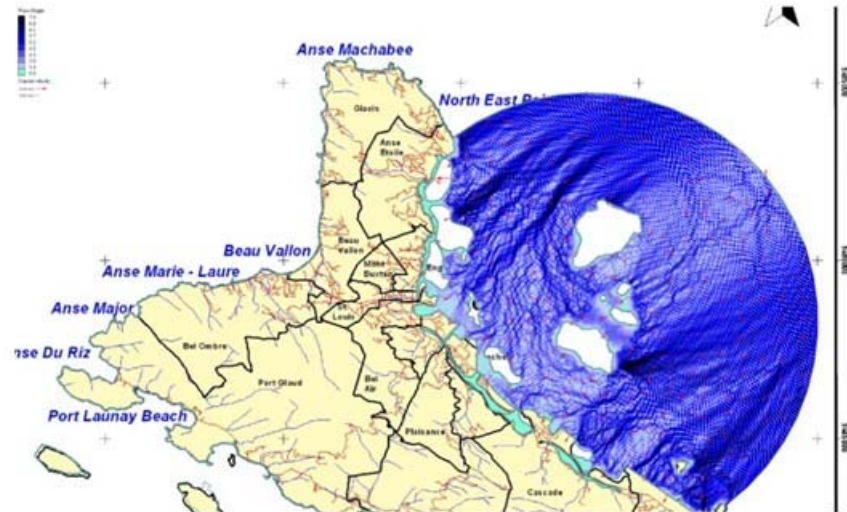
Source: Prepared by Nippon Koei Co., Ltd. using the data provided by Climate Change Team from World Bank

Figure 3.5 Coastal Flood Hazard Map (100-year return period at Year 2100 under RCP8.5)

(2) Wave Overtopping

Wave overtopping around the Providence landfills might be considered based on the wave height distribution simulated by Ministry for Science, Technology and Environment, Environmental Agency, Hazard, Vulnerability and Risk Group⁹. Figure 3.6 shows spatial wave distribution of wave height in coastal sector with the northeast direction. The estimated wave height is 3-4m around the site. Although wave overtopping cannot be estimated quantitatively because water depth data around the site is not available, wave overtopping might be an additional risk of inundation at the Providence landfills.

⁹ Ministry for Science, Technology and Environment, Environmental Agency, Hazard, Vulnerability and Risk Group, Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles. Climate Change for current and the projection for the years 2025, 2050 and 2100, (2011)



Source: Ministry for Science, Technology and Environment, Environmental Agency, Hazard, Vulnerability and Risk Group, Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles. Climate Change for current and the projection for the years 2025, 2050 and 2100, (2011), p.47

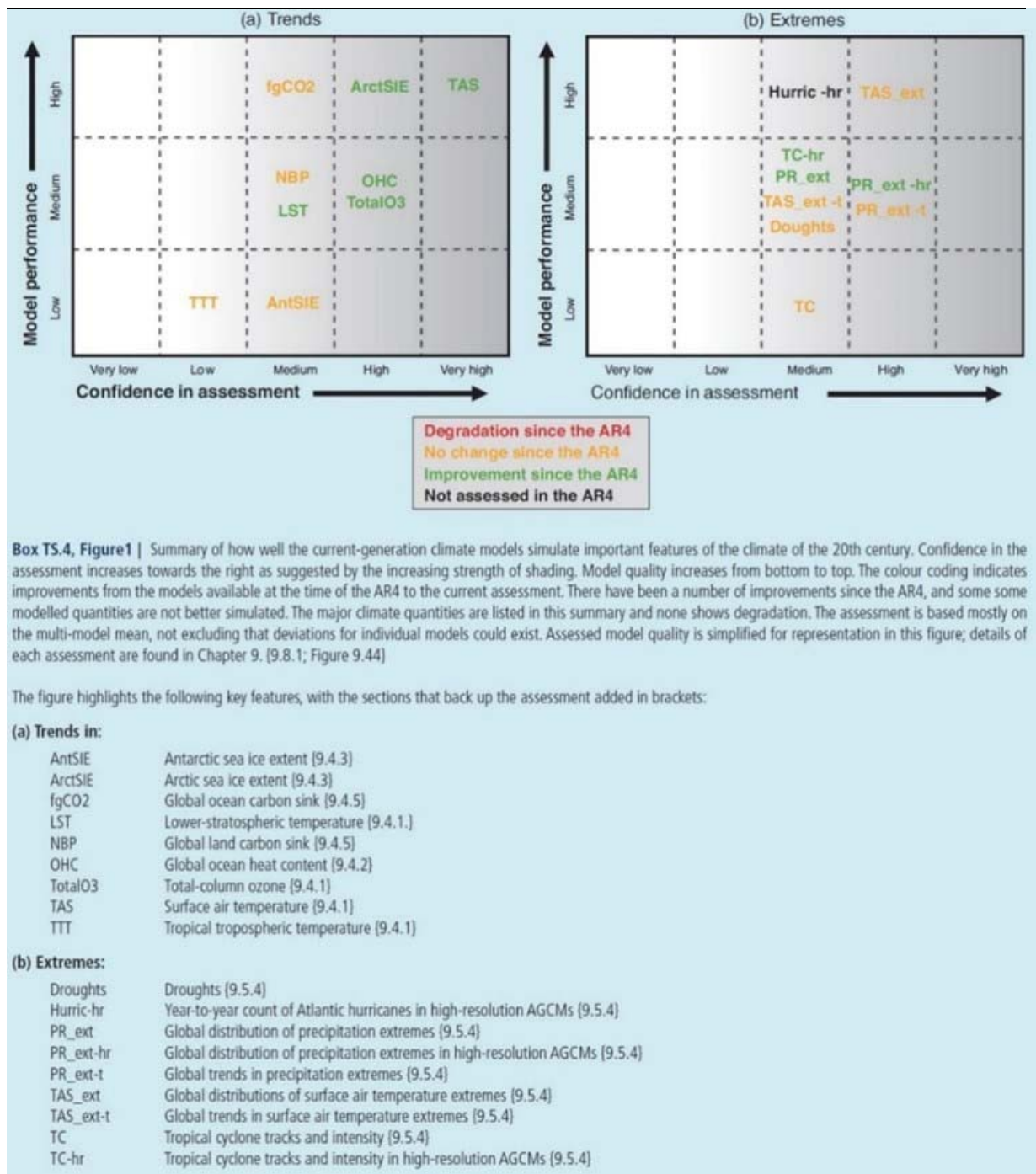
Figure 3.6 Wave height distribution with wave direction from northeast (50-year Return Period)

(3) Tropical Cyclone

The projection of tropical cyclone track and intensity by general circulation models (GCMs) is still a challenge¹⁰. Figure 3.7 shows overview of GCM's capabilities. The ability of GCMs to simulate surface temperature (TAS) has improved, thus resulting to a very high confidence as shown in Figure 3.7(a). However, GCMs perform less well for precipitation extremes (PR-ext-t) and tropical cyclones (TC) than for surface temperature, as shown in Figure 3.7(b). In the case of region-specific projections, there is low confidence in tropical cyclone frequency and intensity, storminess and associated storm surges (Figure 3.8).

Such low performances of GCMs are due to the issues of parameterization, cumulus model, spatial resolution, etc. Downscaling techniques, either dynamic or statistical, are useful for site-specific climate change assessments with high spatial resolution. However, such detailed studies at Seychelles have not been conducted.

¹⁰ Stocker et al. 2013: Technical Summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA



Source: Stocker et al. 2013, p.76

Figure 3.7 Overview of GCM's Capabilities

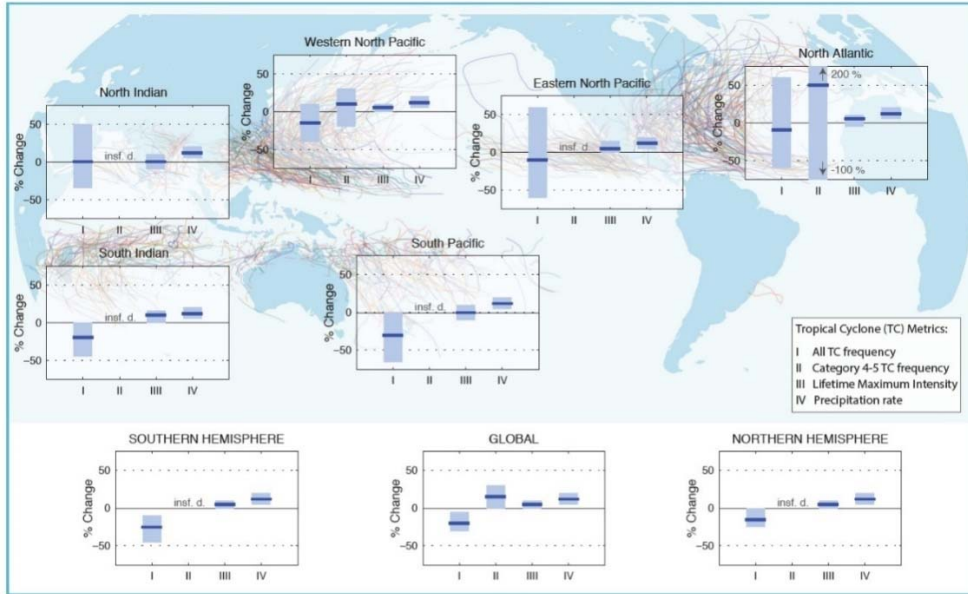


Figure TS.26 | Projected changes in tropical cyclone statistics. All values represent expected percent change in the average over period 2081–2100 relative to 2000–2019, under an A1B-like scenario, based on expert judgement after subjective normalization of the model projections. Four metrics were considered: the percent change in I) the total annual frequency of tropical storms, II) the annual frequency of Category 4 and 5 storms, III) the mean Lifetime Maximum Intensity (LMI; the maximum intensity achieved during a storm's lifetime) and IV) the precipitation rate within 200 km of storm center at the time of LMI. For each metric plotted, the solid blue line is the best guess of the expected percent change, and the coloured bar provides the 67% (*likely*) confidence interval for this value (note that this interval ranges across –100% to +200% for the annual frequency of Category 4 and 5 storms in the North Atlantic). Where a metric is not plotted, there are insufficient data (denoted X) available to complete an assessment. A randomly drawn (and coloured) selection of historical storm tracks are overlaid to identify regions of tropical cyclone activity. See Section 14.6.1 for details. [14.6.1]

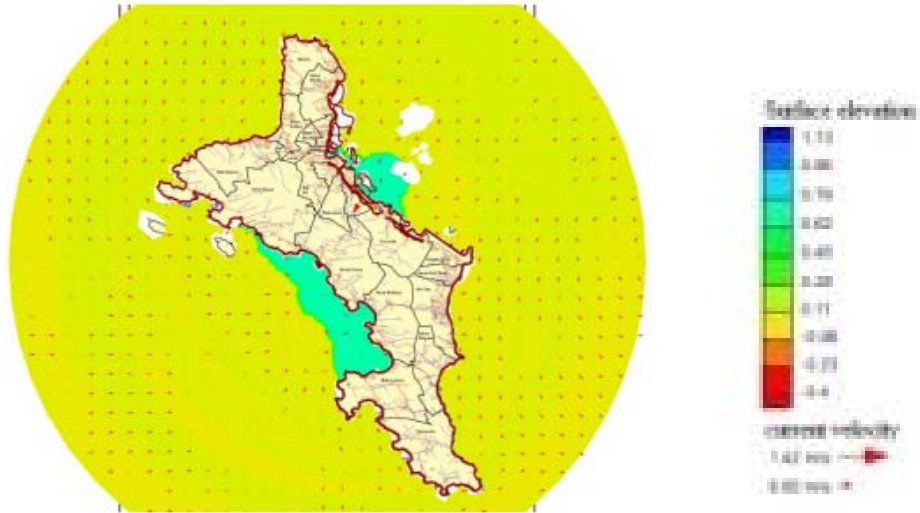
Source: Stocker et al. 2013, p.108

Figure 3.8 Projected Changes in Tropical Cyclone Statistics

(4) Storm surge

The impact of storm surges caused by tropical cyclone under climate change cannot be quantitatively assessed because of low confidence on the projections of occurrence and frequency as shown in Figure 3.7(b). However, it is important to note that storm surges might affect the Seychelles when a cyclone passes nearby.

From the limited references about the storm surge simulation, the result of Tropical Cyclone Bondo (2006) is shown in Figure 3.9 as an example. During the historical event, the maximum storm surge at Mahe is simulated as 0.84 m (Figure 3.9). In case the same tropical cyclone event occurs in the future, the risk of coastal flooding due to tide deviation of 0.84 m might be high, particularly during occurrence of high tide and sea level rise.



Source: Ministry for Science, Technology and Environment, Environmental Agency, Hazard, Vulnerability and Risk Group, Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles. Climate Change for current and the projection for the years 2025, 2050 and 2100, (2011), p.45

Figure 3.9 Storm surge by tropical cyclone Bondo (2006)

3.3.2. Higher Temperature

According to Seychelle's Second National Communication¹¹, key future climate trends of temperature include:

- Air temperature at Mahé is, more likely than not, to warm by +3.0°C;
- The relative warming will occur mainly during the cooler southeast monsoon;
- The warming ranges are from +0.4° to 0.7°, 0.9° to 1.4° and 1.8° to 2.9° C respectively, for the years 2025, 2050 and 2100.

These results are obtained by Chang-Seng (2007)¹², which assesses seasonal future change of temperature at Mahé based on seven GCMs outputs from the Coupled Model Intercomparison Project (CMIP) data set under A1 and B2 Special Report on Climate Change Scenarios (SRES) scenarios. The SRES scenarios are not utilized in the latest Fifth Assessment Report of IPCC. However, since recent studies under the future scenario of RCP, which are utilized in the Fifth Assessment Report, about local projections of temperature change in Seychelles are not available, the projection results under SRES scenarios were referred here.

Figure 3.10 shows projected temperature changes by a composite analysis, which is simply an average of the seven GCMs outputs. The results indicate warming trend throughout a year with high confidence.

¹¹ Second National Communication (SNC) under UNFCCC, Ministry of Home Affairs, Environment, Transport and Energy, 2011

¹² Chang-Seng, S. D. 2007 Climate Change Scenario Assessment for the Seychelles, Second National Communication (SNC) under the United Nations Framework Convention on Climate Change (UNFCCC), National Climate Change Committee, Seychelles.

A1 high-range emission

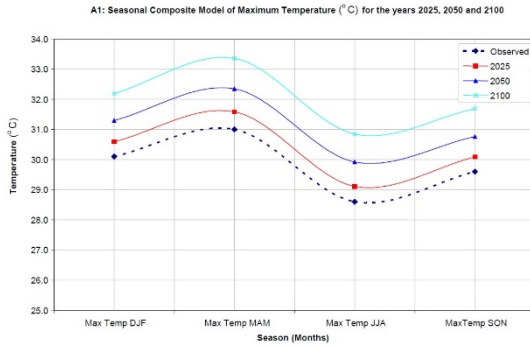


Fig 4.3.7: Observed (1972-90) and GCMs composite seasonal maximum temperature values (°C) for the International Airport, Mahe, Seychelles for the A1 high-range emission with a high-range climate sensitivity for the years 2025, 2050 and 2100

Source: Chang-Seng, S. D. 2007, p.37 and 55

B2 mid-range emission

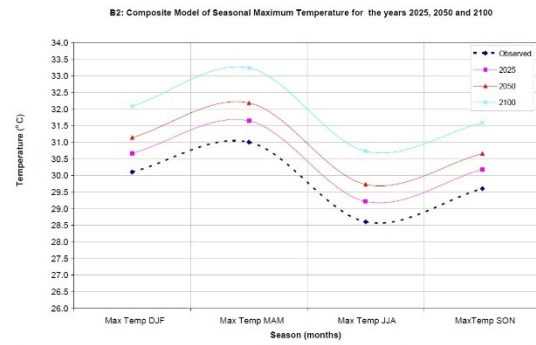


Fig 3.4.7: Observed (1972-90) and composite model scenarios for average maximum temperature values (°C) for the years 2025, 2050 and 2100 at the International Airport, Mahe, Seychelles for the B2 mid-range emission with a mid-range climate sensitivity

Figure 3.10 Projected Temperature Changes by the End of 21st Century

3.3.3. Changes in Rainfall

Same as the projection of temperature change above, since recent studies under the future scenario of RCP about local projections of rainfall change in Seychelles are not available, the projection results under SRES scenarios were referred here.

Key future climate trends of rainfall described in Seychelle's Second National Communication include:

- Likely extremes of low rainfall in the dry season with a deficit of -12.7 % (-9.9 mm) in rainfall for the year 2025, and a decrease of -36.3 % (-31.1 mm) in the year 2100;
- In contrast, the likely extremes of wet conditions are likely to be characterized by an increase of +5.9 % (+19 mm) for the year 2025, +9.3 % (+25.4 mm) for the year 2050 and +12.4% (+38.6 mm) for the year 2100.

Table 3.5 and Figure 3.11 show projected rainfall changes by the composite analysis. The composite change in rainfall for the Dec-Feb (DJF), Mar-May (MAM), Jun-Aug (JJA) and the Sep-Nov (SON) seasons for the year 2025 is +3.7 %, +2.0 %, -3.3% and +3.8 % respectively. The year 2050 composite change in rainfall for the same respective months is +5.3%, + 4.3%,+7.3 % and +2.4 %. The year 2100 composite rainfall changes are +4.9%, +10.5%, -10.8 %, and +11.8 % for the DJF, MAM, JJA and SON seasons respectively. However, projection ranges by GCMs vary in positive and negative trends. It indicates less confidence in the future projection of seasonal rainfall pattern change than that of temperature change.

Table 3.5 Projected Rainfall Changes by the End of 21st Century

| SRES Scenario | Year | Season | Rainfall Change (mm) | | Percentage Change (%) | |
|---------------|------|--------------------|----------------------|------------------|-----------------------|------------------|
| | | | Composite Model | Projection Range | Composite Model | Projection Range |
| B2 | 2050 | Annual | +58 | -105 ~ +184 | +2.7 | -4.8 ~ +8.5 |
| | | Rainy season (DJF) | +17 | -11 ~ +25 | +5.3 | -0.3 ~ +9.3 |
| | | Dry season (JJA) | +6 | -6 ~ +18 | +7.3 | -7.7 ~ +22.7 |
| | 2100 | Annual | +119 | -188 ~ +355 | +5.4 | -8.6 ~ +16.3 |
| | | Rainy season (DJF) | +15 | -18 ~ +39 | +4.9 | -5.6 ~ +12.4 |
| | | Dry season (JJA) | -9 | -31 ~ +13 | -10.8 | -36.3 ~ +14.9 |
| A1 | 2050 | Annual | +99 | +50 ~ +212 | +4.6 | +2.3 ~ +9.7 |
| | | Rainy season (DJF) | +11 | -11 ~ +25 | +3.4 | -3.4 ~ +8.2 |
| | | Dry season (JJA) | +0 | -20 ~ +6 | -8.7 | -25.0 ~ +7.8 |
| | 2100 | Annual | +125 | -199 ~ +375 | +5.8 | -9.1 ~ +17.2 |
| | | Rainy season (DJF) | +16 | -19 ~ +41 | +5.2 | -6.0 ~ +13.1 |
| | | Dry season (JJA) | -9 | -31 ~ +13 | -11.4 | -38.3 ~ +15.8 |

Note: DJF (December, January and February), JJA (June, July and August)

(Source: Chang-Seng, S. D., 2007. *Seychelles Climate Change Scenarios for Vulnerability and Adaptation Assessments*, Report for Ministry of Environment and Natural Resources, Republic of Seychelles)

A1 high-range emission

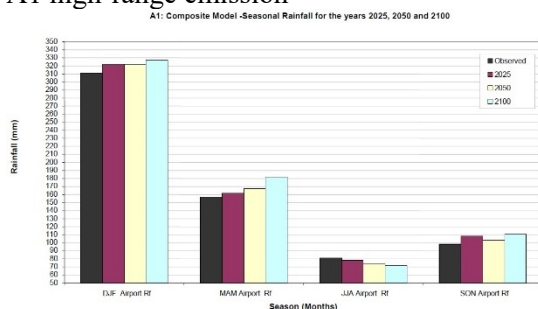


Fig 4.2.4: Observed (1972-1990-Grey color) and composite model scenarios of seasonal precipitation values (mm) for the International Airport for the years 2025, 2050 and 2100 for A1 high-range emission with a high-range climate sensitivity.

Source: Chang-Seng, S. D. 2007 p.26 & p.44

B2 mid-range emission

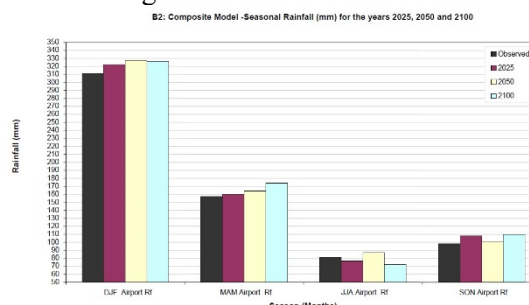


Fig 3.2.4: Observed (1972-1990-Grey color) and composite model scenarios of seasonal precipitation values (mm) for the International Airport for the years 2025, 2050 and 2100 for B2 mid-range emission with a mid-range climate sensitivity.

Figure 3.11 Projected Rainfall Changes by the End of 21st Century

A climate change scenario conducted by the local Meteorological Services in 2009 had predicted that in the next 20 years, rainfall will continue to be short and heavy. The research had also shown that the dry season will be longer and drier. However, the Meteorological Services have noticed that in the past five years, the dry season has actually gotten wetter¹³. These gaps between actual observation and projections indicate that the projection of rainfall change is less confident and contains uncertainty compared with the projection of temperature change.

3.3.4. Increase storminess

The probabilistic risk analysis by UNISDR¹⁴ mentions that loss by tropical cyclonic wind were estimated to be zero because Seychelles is located quite close to the Equator, enough to be sufficiently away from the path of tropical cyclones. Given the location of the country, strong winds

¹³ Seychelles Meteorological Authority website, <https://www.meteo.gov.sc/#/newsDetails>

¹⁴ Working Papers on Public Investment Planning and Financing Strategy for Disaster Risk Reduction: Review of Seychelles (2015)

are not expected to reach any of the islands, and in consequence, there is no risk resulting from these events.

However, the projection of tropical cyclone track and intensity by GCMs, particularly the region-specific projections of storminess (Figure 3.7), is still a challenge. Therefore, occurrence of increased storminess cannot be negligible and should be considered as one of the future climate risks for the waste management infrastructure although the GCM projections still include uncertainty.

3.3.5. Result of Risk Analysis

Based on the risk analysis of potential climate hazards and stressors, risk levels for the identified risks were determined by relative comparison in a form of a risk matrix, with occurrence and consequences being qualified as high, medium or low.

Figure 3.12 shows the result of risk analysis based on the following reasons:

(1) Sea level rise and storm surge

- The result of coastal flood inundation depth under the worst climate change scenario, which is a 100-year return period flood under RCP 8.5 at year 2100, prepared by Climate Change Team from World Bank indicates that the existing Providence landfill sites might not be inundated, while the areas of the Unit 2 of P-2, which are not developed yet, might be inundated. However, the results potentially contain uncertainty because of the ignorance of the effect of wave overtopping and the unreliable offset applied to adjust elevation.
- Wave overtopping cannot be estimated quantitatively because of lack of water depth data around the site. However, wave overtopping might be an additional risk of inundation at the Providence landfills with sea level rise.
- Simulation of tropical cyclones by GCMs is still challenging and there is low confidence in tropical cyclone frequency, intensity and associated storm surges. However, it is important to note that storm surges might affect the Seychelles when a cyclone passes nearby. Assuming that the same event of historical tropical cyclone occurs in the future, the risk of coastal flooding due to tide deviation caused by storm surge might be high, particularly during occurrence of high tide and sea level rise.
- Although there is low confidence in GCM projections of tropical cyclones, a level of consequence might be high once coastal flooding occurs at the landfills and causes outflow of waste contaminant into the ocean as well as damages to the existing facilities.

(2) Higher temperature

- GCM projections show a warming trend throughout a year with high confidence. Higher temperature might cause several impacts to the site environment.
 - However, consequence of higher temperature might be less than that of coastal flooding in terms of physical impacts.
-

(3) Increased rainfall

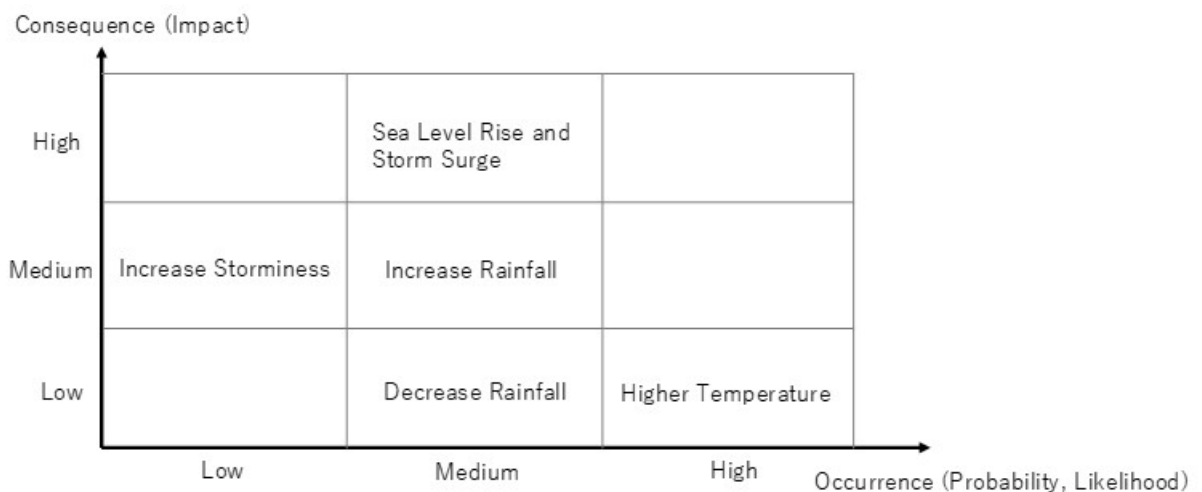
- GCM projections of rainfall changes vary in positive and negative trends. It indicates less confidence in the future projection than temperature changes. It should be noted that these do not necessarily mean higher variation throughout the year. Simulation of rainfall by climate models is challenging due to the issues of parameterization, cumulus model, spatial resolution, etc.
- Increased rainfall might cause more significant physical impacts to the landfill facilities than the impacts by decreased rainfall, because flooding caused by heavy rainfall might wash out pollutants and waste into the ocean or surrounding areas and also block access routes to the landfill site.

(4) Decreased rainfall

- Same as the results of increased rainfall, a level of confidence in the projection of rainfall changes is less than temperature changes.
- In the case of decreased rainfall, the physical impacts might be less than the impacts by increased rainfall.

(5) Increased storminess

- There is low confidence in region-specific projections in the 21st century of storminess.
- The physical impacts caused by increased storminess might be less than that by sea level rise, but more than that by higher temperature.



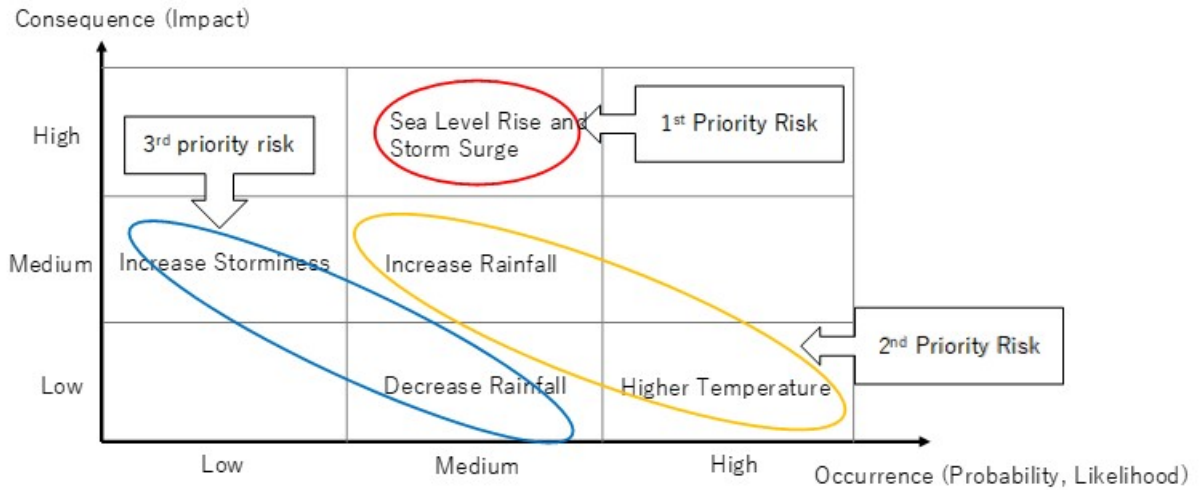
Source: Nippon Koei Co., Ltd.

Figure 3.12 Result of Risk Analysis

Current vulnerability and exposure at the Providence landfill site cannot be analyzed due to the lack of detailed information on the site, such as design of the site and protection standards applied for the landfill reclaimed land, as discussed in 2.2.3. Further investigation will be done after collecting above additional information.

3. 4. Risk Evaluation

The final step of risk assessment is risk evaluation that aims to determine priority to correspond to risks. Priority of correspondence to risks was determined by relative comparison based on the qualified occurrence and consequences in the risk matrix and the result is shown in Figure 3.13.



Source: Nippon Koei Co., Ltd.

Figure 3.13 Result of Risk Evaluation

3. 5. Potential Adaptation Measures

Based on the results of the risk assessment, potential climate change adaptation measures of coastal waste infrastructure are identified, as shown in Table 3.6. These adaptation measures are categorized from the viewpoint of risk types as follows:

- Risk Reduction (reduce vulnerability)
- Risk Avoidance (reduce exposure)
- Risk Transfer (secure finance for recovery)

These outputs will be utilized in Sub-task 1.3 (Technical, Socioeconomic and Financing Assessment) that aims to recommend the most appropriate climate resilient waste infrastructure and green technology to reduce the ecological and health risks associated with inadequate waste management in view of climate change.

Table 3.6 Potential Climate Change Adaptation of Coastal Waste Infrastructure

| Priority | Climate Hazards | Potential Impacts | Potential Adaptation |
|-----------------|--------------------------------|---|--|
| 1 st | Sea level rise and storm surge | Lead to inundation at landfill sites by coastal flooding | [Reduction] Construct a flood wall at a coastal landfill site |
| | | Lead to increase damage to the coastal waste infrastructure such as protective liner and leachate collection system | [Reduction] Heighten the elevation of landfill |
| | | Lead to increase disruption to transport infrastructure due to coastal flooding and hence delivery of waste | [Avoidance] Construct new landfill site in inland areas without disaster risk [Transfer] Secure budget for recovery |
| 2 nd | Higher temperature | Alter waste decomposition rate (increase with adequate moisture, decrease with less moisture) | [Reduction] Regular soil cover on the compacted and leveled waste |
| | | Increase strength of leachate due to reduction in dilution | [Reduction] Increase capacity of leachate treatment plant |
| | | Increase health risk to workers from increased sunshine and exposure to UV radiation, increased pathogen and vermin activity, and increased methane and landfill fire | [Reduction] Installation of landfill gas ventilation pipes to the closed area |
| | | Reduced worker comfort with negative impacts on productivity from higher temperature | |
| | | Increase site disamenity from odor, vermin, dust and litter | |
| 2 nd | Increased rainfall | Increase on-site and off-site flooding | [Reduction] Increase capacity of leachate treatment plant |
| | | Alter waste decomposition rate | [Reduction] Installation of rainwater drainage to reduce leachate amount |
| | | Increase leachate production | [Reduction] Compaction of waste, formation of slope to prevent collapsing of waste pile |
| 3 rd | Increased storminess | Increase incidences of windblown litter and debris | [Reduction] Regular soil cover on the compacted and leveled waste |
| | | Damage to buildings and site closure | [Transfer] Secure budget for recovery |
| 3 rd | Reduced rainfall | Decrease waste decomposition rate due to less moisture | [Reduction] Installation of landfill gas ventilation pipes to the closed area |
| | | Reduce water availability for site management (e.g. dust suppression) | [Reduction] Regular monitoring and maintenance on facilities such as capping layers, leachate treatment plant |
| | | Increase strength of leachate due to reduction in dilution | |
| | | Shrinkage in clay lining and capping layers | |

Source: Nippon Koei Co., Ltd.