VULNERABILITY & ADAPTATION ASSESSMENT TOOLKIT: INFRASTRUCTURE

User Manual

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Ministry of Social Security, National Solidarity, and Environment and Sustainable Development
(Environment and Sustainable Development Division)
Republic of Mauritius

Vulnerability & Adaptation Assessment (VAA) Toolkit (Mauritius): User Manual for Infrastructure

About this manual

This VAA-Infrastructure User Reference Toolkit manual forms part of a family of toolkits to assess vulnerability of climate change for the Infrastructure Sector. The user reference has been written from an application developer's perspective. A fundamental conceptual and operational knowledge of Excel is assumed.

Disclaimer

Data used has been obtained from reliable sources. The Ministry of Social Security, National Solidarity, and Environment and Sustainable Development (Environment and Sustainable Development Division) assumes no responsibility for errors and omissions in the data provided. Users are, however, kindly asked to report any errors or deficiencies in this product to the Ministry. The choices of calculation made in this tool are derived from TNC Report (2016).

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VAA-Infrastructure Toolkit

1. Introduction

This document refers to a user-friendly toolkit developed to assess vulnerability and adaptation in the Infrastructure sector – also known as VAA-Infrastructure Toolkit for the Republic of Mauritius. The VAA for the Infrastructure was assessed in the Third National Communications (TNC) Report (2016) for the various climate change-related impacts observed in the Infrastructure sector in Mauritius.

The VAA-Infrastructure Toolkit performs basic calculations taking the indicators of the Environmental Vulnerability Index (EVI) under different Infrastructure related issues. Applicable Infrastructure and related indicators were shortlisted, besides some common indicators about climate. Users of the VAA-Infrastructure Toolkit can adjust the indicators by choosing appropriate parameters/assumptions to suit their needs of the vulnerability assessment.

With the significant warming trend of about 1.2°C, a decreasing trend in rainfall amount of about 8% and a projected rise of sea-level ranging between 52 cm and 98 cm by the end of the century if no mitigating action is taken (IPCC, 2013), the risk from natural disasters arising from extreme events such as cyclones, flood and droughts are expected to increase. Already, according to the World Risk Report 2016, Mauritius is ranked as the 13th country with the highest disaster risk and 7th on the list of countries most exposed to natural hazards (UNU-EHS, 2015). The vulnerability of RoM is projected to increase with these phenomena impacting adversely on its socio-economic and environmental sectors. The assessment of the vulnerability made on the basis of climate trend projections of the regional climate model COSMO-CLM, developed under the Disaster Risk Reduction Strategic Framework and Action Plan 2013 (DRR, 2013), predicts temperature to increase, with a range (depending on the seasons and scenarios) between 1°C and 2˚C for the period 2061-2070, with respect to the period 1996-2005 (TNC, 2016).

The threatening impacts of climate change are increasingly being felt with an accelerated sea level rise, accentuated beach erosion, increase in frequency and intensity of extreme weather events, decreasing rainfall patterns as well as recurrent flash floods. The climate challenges ahead for Mauritius should not be underlooked, especially when considering the facts that water supply by 2030 may not be sufficient to satisfy projected demand, agricultural production may decline by as much as 30% and that several beaches, that are so important for our tourism industry may slowly disappear, thus severely undermining one of our major economic pillars and depriving the economic value of this sector, worth over USD 50 million by 2050.

2. Overview of the Infrastructure sector

Some 560 km² of Mauritius are built-up areas. These include roads and reservoirs and about 396 400 residential units, 6,600 industrial buildings, 41,000 commercial buildings and 600 unclassified buildings.

Concentrated within an area of 108 km2, are the main components that constitute Rodrigues's infrastructure sector, namely,

Land transport

The main road network of Rodrigues, extending either landside of Port Mathurin to Baie Malgache in the West, Anse aux Anglais in the East, and uphill to Mont Lubin to the Centre extending to Pointe Coton on one side and Plaine Corail and Port Sud-Est on the other, aggregate some 50 km. Other secondary roads, tarred and untarred amount to some 6 km. There had been major improvements on the road network over the last 10 years and this has been accompanied by a marked increase of 39% in the number of motor vehicles over the period 2010 to 2014.

Electricity supply

A total of 33 GWh of electricity was generated, out of which 9% was from renewable sources primarily wind farms (Figure 3.17). Non-renewable sources are mostly derived from diesel and heavy fuel oil (CEB, 2011)

Water resources

Rodrigues is characterised by highly rocky reliefs and steep slopes and it lacks dams and impounding reservoirs. The run-off from rivulets flows rapidly to the sea. River abstraction, boreholes and a few springs are the main sources of water supply, providing some 7 500 m³/day during periods of abundant rain, and as little as 3 000 m³/day during dry spells. Newly constructed desalination plants provide a maximum of 2 000 m³/day. The water requirement for a population of 42 000 (2014) is some 7 000 m³/day for domestic consumption only. The shortage of water poses severe restrictions on development, and the impacts of climate change may further aggravate this situation.

Building infrastructure

The building infrastructure comprise approximately 12 000 residential units, 340 institutions and public buildings, 50 industrial buildings, 375 commercial buildings and 85 unclassified buildings.

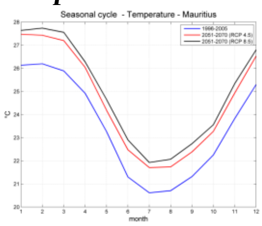
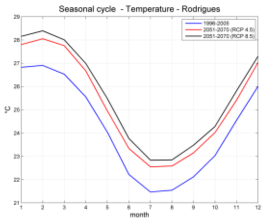
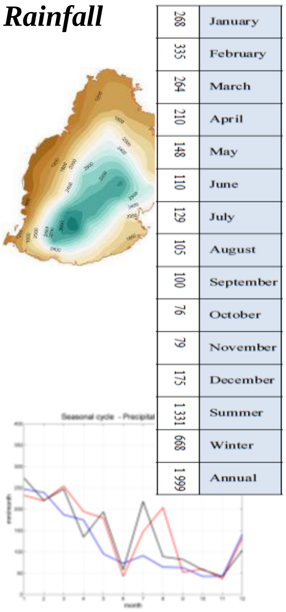
3. Climate, Climate variability and IPCC Forecasts

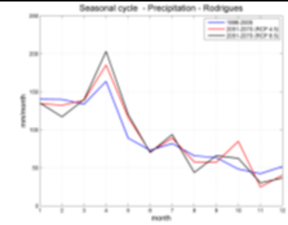
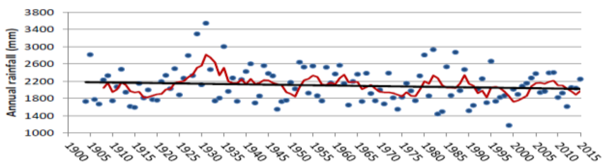
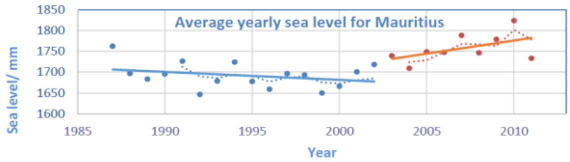
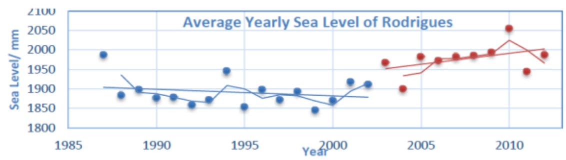
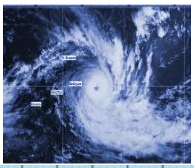
The various islands constituting the Republic of Mauritius (RoM) all enjoy a mild tropical maritime climate throughout the year. With the months of May and October described as transitional months, RoM observes two seasons:

- a warm humid summer extending from November to April and
- a relatively cool dry winter from June to September.

RoM, is located in the tropical cyclone belt of the South Western Indian Ocean (SWIO) where rapid formations of high intensity tropical cyclones and super cyclones have been observed. Table 3.1 shows the trend and projections (including future climate scenario for the region forecasted using IPCC regional models) of key weather parameters (for details see TNC, 2016). Table A1 (Appendix A) contains a list of climate change impact indicators for RoM.

Table 3.1: Trend and Projections of key weather indicators (TNC, 2016)

Indicator (TNC)	***Past and Present Trend (MMS)***	***Projections***
Temperature   	The mean temperature over Mauritius is 24.7°C during summer and 21.0°C during winter. The temperature difference between the two seasons is relatively small and it varies from place to place and is usually larger over coastal areas when compared to the Central Plateau. Records over the period 1951-2014 show a significant warming trend of about 1.2 °C in both Mauritius and Rodrigues. Analysis of temperature records indicate that the observed rate of temperature change is on average 0.020°C/yr and 0.023°C/yr for Mauritius for the period 1951-2014 and for Rodrigues for the period 1961-2014, respectively.	IPCC reckons an increase in mean annual temperature of up to 3.8°C by 2100; Projections made on the basis of RCP 4.5 and RCP 8.5 (the business as usual scenario and the worst case scenario, resp.) indicate an increase in temperature of up to 2 °C over Mauritius and Rodrigues for the period 2051-2070.
Rainfall  	From the mean monthly rainfall data for the period 1981-2010, February is the wettest month and October is the driest. Records over the period 1951-2014 show a decreasing trend in rainfall amount of about 8% for Mauritius and a change in precipitation pattern. For Rodrigues, which is a water scarce island, a downward trend has also been observed in the rainfall compared to the data of the 1960's. The trend and the 5-year moving average for the long-term variations in annual rainfall over Mauritius indicate a steady decreasing trend over the period 1904 to 2015.	A declining trend in total annual rainfall, but an increase in the frequency of intense rainfall episodes (Gastineau and Soden, 2009); Projections for RCP 4.5 and RCP 8.5 scenarios, does not show significant variation with respect to the present rainfall pattern. There will be a shift in rainfall distribution, over Mauritius (e.g., from March to October season). Further reduction in amount of water by 13% by 2050.

	The Central Plateau, the main recharge zone of  the island, has endured a decrease from a maximum of ~4000 m m/year (1951-1980) to ~3800 mm/year with more pronounced drying to the North and the West.	For Rodrigues, the interpretation of the model projections is quite complex as no clear long-term-trend could be identified. However, wide variations emerge across seasons, with a projected decrease in rainfall over the summer months and a likely increase over the transition months.
Sea level	Analysis of sea level data indicates an accelerated rise of 5.6 mm/yr and 5.1 mm/yr for, strikingly, for both Mauritius and Rodrigues, respectively since 2003, much higher than the global average of 3.2 mm/yr. The local mean sea level rose by 2.1 mm/year since mid-90's. The average yearly sea level for the period (1987 to 2011) along with the trend line and the 2-year moving average for Mauritius and those for Rodrigues clearly demarcates into a period when sea level was decreasing (blue) and a period when it is increasing (red). 	Sea level rise (SLR) of 18 – 59 cm by 2100; SLR of about 35 cm if the rate remains constant over the next 90 years;
Cyclones 	Cyclone season is normally from November to mid-May. For the cyclone seasons from 1975-76 to 2014-15, data show that: a) mean number of named tropical storms/cyclones in the SWIO has not changed; b) frequency of storms reaching at least tropical cyclone strength has increased; c) rate of intensification of tropical storms has increased, and a higher number of explosive intensification has been observed over the last 15 years; d) no change in latitudinal cyclogenesis has been observed. For cyclones which reach Category 5 intensity wind gusts can attain over 345 km/h. An increase in the intensity and the rate of intensification is also evident since 1975.	An increase in the intensity and rate of intensification of tropical (Lal et al, 2002);

4. Climate Change: Vulnerabilities, Impacts, and Projections on the Infrastructure sector

Table A1 (Appendix A) contains a list of climate change impact indicators for RoM.

Infrastructure such as properties, buildings and roads are affected or damaged due to flooding, erosion and landslide.

Mauritius

Mauritius has 560 km² (30%) of built-up areas that include roads and reservoirs; the main components are given in Table 4.1. The infrastructure sector in Mauritius is already affected by adverse impact of climate change with the recent occurrences of cracks on roads, collapse of bridges, flooding of culverts, and damages due to landslides. The Mauritius Container Terminal is particularly vulnerable to the impacts of severe weather systems such as heavy swells, strong winds, gusts and storm surges, which may result in stoppage of operations for several days. For instance, adverse weather conditions in 2013 led to a stoppage of port operations for 21 days resulting in a shortfall in revenue of about MUR 3.9 billion and in 2014, the suspension for 10 days represented a shortfall in revenue amounting to MUR 1.9 billion. The storm surges of 10 to 13 March 2015 led the Mauritius Ports Authority (MPA) to stop all its operations and closed the port for 79 hours so that the safety and integrity of Port infrastructures and ships in the harbour were maintained. It is projected that there will be accelerated softening and deterioration of bituminous pavement, surface and thermal cracks to concrete, increased corrosion of steel, scouring of foundations and embankment collapse and damage to buildings and power transmission masts in both Mauritius and Rodrigues.

Table 4.1: Main components of the infrastructure sector (TNC, 2016)

Component of infrastructure	Description
Land transport	Road transport relies on a road network aggregating 2 100 km out of which 49% are main roads, 29% are secondary roads, 4% are motorways and the remaining 18% are unclassified roads
Electricity supply	The total supply reached 3 000 GWh in 2014, out of which around 80% was generated from non-renewable sources (fossil fuel). Electricity is transmitted almost exclusively by overhead cables
Water resources	Water resources are harnessed through 11 reservoirs aggregating a storage capacity of 91 Mm³ and are used for power generation (275 Mm³/year); for domestic, industrial and tourism consumption (250 Mm³/year); and, for agriculture (375 Mm³/year)
Building infrastructure	The building infrastructure includes 396,400 residential units, 6,600 industrial buildings, 41,000 commercial buildings and 600 unclassified buildings

The various climate change-related impacts *observed* on these infrastructural assets are given in Table 4.2. The climate-related impacts observed so far are likely to persist, and worsen, when considering future temperature increase and rainfall variability.

Table 4.2: Observed impacts of climate change on infrastructure for Mauritius (TNC, 2016)

Effects of climate change	Observed impacts on infrastructure
Temperature rise at a rate of approximately 0.20ºC per decade	This may lead to accelerated softening and deterioration of bituminous pavement, formation of surface and thermal cracks in concrete, increased corrosion of steel, soil shrinkage, more evaporation from reservoirs and lakes and higher demand for domestic water and power, resulting from extended use of air conditioning
Increase in rainfall intensities coupled with a decline in total annual rainfall volume	This element often leads to soil erosion, landslides and flood. Soil erosion in turn leads to scouring of foundations and collapse of embankments, and landslides cause the destruction of buildings and road infrastructure. Floods inundate properties, buildings and water treatment plants, causing damage to infrastructure and fixtures, and the degradation of water quality, leading to serious health hazards. A decline in the total annual volume of rainfall may also leads to decreased water supply for domestic use, power generation, and irrigation
Storms or intense cyclones	Such storms cause damage to roads, buildings and power transmission masts
Sea level rise coupled with storm surges	These parameters often cause flooding of coastal roads and their temporary closure, erosion and washing away of coastal structures and salt water intrusion into the coastal water supply aquifer

Rodrigues

Climate change-related impacts similar to those in Mauritius have been observed on the infrastructural assets in Rodrigues, as follows:

(a) *Temperature rise* of 0.5 to 1.0ºC during the last ten years when compared to the 1961 – 90 long-term mean (Meteorological Services, 2016) has resulted in the deterioration of tarred surfaces, development of surface and thermal cracks, increased corrosion to steel and soil shrinkage, as is the case in Mauritius (Table 3.15).

(b) *Annual rainfall* over Rodrigues indicates significant variation from year to year but long-term analysis shows a decreasing rainfall trend (Meteorological Services, 2016). This results in an acute water stress in Rodrigues which is estimated to have only three weeks of water shortage during dry periods. In addition, the increase in frequency of extreme weather events has led to soil erosion, landslides and floods with ensuing consequences for infrastructure, as is the case in Mauritius (Table 3.15).

(c) *Sea level* data in SWIO based on reconstructed tide gauge data and Topex/Poseidon altimeter for the period 1950 – 2001 show a rise of about 1.3 mm/year (Meteorological Services, 2016). Figure 1.5 gives more recent data on sea level rise for the period 1987 to 2012 which shows a more significant rise of 5.6 mm/year. Such rises in sea level together with surges during adverse weather conditions are adequate to inundate the low-lying areas constituting almost three quarters of the capital, Port Mathurin.

Hazards Assessment under DRR

According to the Disaster Risk Reduction (DRR) Strategic Framework and Action Plan (MoESDDBM, 2013), the elements that are at risk due to flooding (due to heavy rain during extreme weather events) and coastal inundation (due to storm surges and sea level rise) in Mauritius and Rodrigues are given in Table 4.3.

Table 4.3: Extent to which some elements are at risk from flood hazard in Mauritius and Rodrigues (DRR, 2013)

Flood hazard	Mauritius	Rodrigues
Agricultural land (km^2)	19-30	0.48-0.6
Built up land (km^2)	5-70	0.38-0.4
Motorway (km)	2.4-3	-
Main roads (km)	18-29	4.17-5.1
Secondary roads (km)	68-109	13.77-16.1

The cost of damages to building and infrastructures from flooding in 50 years (by the year 2070) has been estimated to be around USD 2 billion for Mauritius and USD 83 Million for Rodrigues (Table 4.4).

Table 4.4: Extent to which some elements are at risk from coastal inundation in Mauritius and Rodrigues (DRR, 2013)

Coastal Inundation	Mauritius	Rodrigues
Built-up land (km$^{2)}$	12.2	0.56
Expansion areas (km^2)	11.8	-
Primary roads (km)	60	22
Secondary roads (km)	80	23

Key infrastructures, namely, schools, health centres, hotels, fire stations, police stations, industrial sites are likely to be affected by the inland flooding, coastal inundation and landslide hazards (DRR Report, 2013). Details regarding the number of these infrastructures that may be adversely affected by flooding, inundation and landslides in Mauritius and Rodrigues are given in Table 4.5 and Table 4.6, respectively.

Table 4.5: Analysis of point elements at risk from flooding, inundation and landslides in Mauritius (DRR, 2013)

Typology of exposed elements (point)	N° of punctual elements at inundation risk	N° of punctual elements at landslide risk	N° of punctual elements at flood risk
Hotel	36	6	8
Industrial site	2	1	2
Medical facilities	9	11	12
Police station	1	5	3
School	11	19	16
Shopping mall	1	1	1

Table 4.6: Analysis of point elements at risk of flooding, inundation and in Rodrigues (DRR, 2013)

Typology of exposed elements (point)	N° of punctual elements at inundation risk	N° of punctual elements at landslide risk	N° of punctual elements at flood risk
Hotel	0	1	2
Industrial site	1	1	1
Medical facilities	1	8	1
School	0	4	1

5. Adaptation Strategies proposed under the TNC

Mauritius

In order to address the challenges posed by climate change impacts on the infrastructure sector, GoM, in collaboration with other stakeholders (investors, sponsors, private equities, funding agencies), may actively enforce adaptation policies with a view to incorporating successful, energy efficient and sustainable design parameters into the design of buildings and infrastructure (Table 5.1). Other structural measures may include sedimentation basins and filter drains to settle transported silt and exclude pollutants, on-site flood attenuation/retardation basins to depress the peak of flood, energy dissipators to reduce flow velocity on hilly terrain and prevent erosion, river training to enhance flow velocity on flat terrain, and prevent backflow of water into properties. Some non-structural measures envisaged are given in Table 5.2.

Table 5.1 Adaptation policies and strategies relating to structural measures (TNC, 2016)

Structures	Adaptation measures and strategies
Coastal infrastructure	The adaptation measures include wave breakers at sea and flood wall on the coastline to protect vulnerable on-land infrastructure, raising existing wharfs to lessen inundation by sea surges and building elevated roads or relocating coastal roads more inland (Box 5.1)
Transport infrastructure	The set of structural measures include increasing the carrying capacity of existing road-side drains to cope with more intense floods, re-dimensioning new drains, raising existing bridges and culverts to cope with higher flood level, increasing the drainage base layer under roadways to counter increased pore pressure due to rise in water table, reinforcing the wearing surface of roadways by the use of fabric reinforcement to cope with increased stress due to temperature rise, and re-designing of road furniture items such as direction and safety signage and road-marking
Buildings	The measures include protection of existing buildings by replacing cladding, flooring and linings with water resistant materials and constructing levees or floodwalls around them, incorporating energy efficient materials and components into the construction of new buildings, constructing ground floors at higher levels, encouraging natural ventilation and air conditioning optimisation through the use of reflective roofing paints or green roofs, and high performance glazing to reduce the rate of heat transfer into building structures

Box 5.1: Coastal Adaptation measures to protect vulnerable coastal infrastructure (TNC, 2016)

Soft and hard engineering measures to adapt to climate change White sandy beaches are the main assets for the tourism industry, one of the main economic pillars of RoM. Accelerated sea level rise and more intense tropical cyclones and sea swells are increasingly causing deterioration of beaches and damage to coastal roads and other infrastructures. A soft measure has been used to rehabilitate a degraded beach Figure 5.1 (left) and, a hard measure has been applied to protect a coastal road Figure 5.1 (right).

Figure 5.1:
(left) Beach nourishment at La Preneuse and
(right) Rock revetment for shoreline protection at Baie-du-Cap
(Source: MoESDDBM)

Table 5.2: Adaptation policies and strategies relating to non-structural measures (TNC, 2016)

Non-structural measures	Adaptation measures and policies
Management schemes on how to transport storm water	The storm water would be transported from residential areas as quickly and safely as possible, so flooding is controlled
A manual on procedures with hands-on advice on planning methods and management techniques for Government officials	Reduce the amount of runoff by increasing porous zones and reducing paved areas
	Develop integrated storm water and storm retardation management schemes such as treatment systems to remove suspended solids and phosphorus from storm water, prevent sedimentation of streams and establish an erosion control plan
	Increase public awareness on the need to maintain drains free of dumped waste and waterways free of unauthorised construction
	Restrict urbanisation to areas physically capable of a specific type of land development so as not to cause soil erosion or sedimentation or unjustified inconvenience, harm or health hazards to inhabitants
	Efficient operation and maintenance of energy systems
	Re-vegetation to increase ground cover and infiltration
Reviewing of design standards	Include higher factors of safety to account for climate change impacts such as wind loading, flood return periods and probable maximum floods
Research and development of innovative, eco-friendly and technically and economically sound building materials	Make better use of renewable energy, and promote energy efficiency

The implementation of VAA (Table 5.3) strategies is expected to reduce vulnerability to climate change by protecting existing infrastructures and incorporating more stringent materials and design criteria to new infrastructures, thereby protecting the population and the environment alike.

Table 5.3: VAA strategies for addressing current problems and transforming development challenges into new opportunities for achieving the development goals in the infrastructure sector (TNC, 2016)

Sector	Development challenges	Goals	VAA strategies	
			To address current problems	To create new opportunities
Infrastructure	(i) Frequency of floods and landslides ii)Increased expenditure for maintenance (iii) Economic competitiveness and social well-being	Increase infrastructure resilience	**IS1.** Upgrade drains, assure frequent maintenance	**ISN1.** Use of climate resilient materials and techniques (e.g. water-draining road pavement)
		Implement integrated landscape planning	**IS2.** Improve landscape management (slow water time of travel)	**ISN2.** Collection and use of topographic, hydrological and climate-related data in infrastructure planning (e.g. elevated roads and buildings)
		Improve awareness and capacity	**IS3.** Implement real time warning system for infrastructure failure	**ISN3.** Improvement of institutional capacity

Note[1]: IS1 etc. refer to proposed strategies to address current problems
Note[2]:ISN1 etc. refer to strategies for creating new opportunities while addressing the current problems

An integrated approach that identifies the intervention options, which turn challenges into opportunities, the corresponding required investments, and the resulting policy-induced avoided costs and added benefits in the infrastructure sector are given in Table 5.4 below.

Infrastructure - *Transforming challenges into opportunities* (Mauritius)
Strategies (IS1etc.) and corresponding actions (IS1.1 etc.) and investments from Households (*H*), Government (*G*) and Private sector (*P*) with resulting policy-induced avoided costs and added benefits

	Strategies	Action List	Investment	Avoided costs	Added benefits
IS1	Upgrade drains, frequent maintenance	IS1.1. Site investigation IS1.2. Topographical assessment IS1.3. Construction work	H: N/A G: consultancy, contractors (equipment and labour), compensation (during work) P: N/A	H: injuries, property value G: compensation (extreme events), public spending P: productivity, property value	H: mobility, well-being, employment G: health (reduced vector-borne diseases) P: mobility, revenue
IS2	Use of climate resilient materials and techniques (e.g. water-draining road pavement)	IS2.1. Suitability assessment IS2.2. Site investigation IS2.3. Construction work	H: N/A G: consultancy, contractors (equipment and labour), training, awareness raising P: training, marketing	H: injuries (roads) G: public spending (maintenance and health) P: N/A	H: mobility, well-being, property value G: tax revenue P: property value, productivity (roads)
IS3	Improve landscape management (e.g. slow water time of travel)	IS3.1. Restore landscape integrity (native plant species) IS3.2. Enforce river/creek buffer requirements IS3.3. Public awareness and voluntary reporting (empowering force vive)	H: weeding and planting trees G: weeding and planting trees, public outreach, labour (enforcement) P: weeding and planting trees	H: injuries, property value G: compensation (extreme events), public spending P: productivity, property value	H: well-being, employment G: carbon sequestration, branding P: tourism, revenue
IS4	Collection and use of topographic, hydrology and climate-related data in infrastructure planning (e.g. elevated roads and buildings)	IS4.1. Collection of data IS4.2. Capacity building for the use of data IS4.3. Topography/hydrology-based zoning/planning	H: construction G: consultancy (data and site investigation), contractors (equipment and labour), training P: training	H: injuries, property value G: compensation (extreme events), public spending P: productivity, property value	H: mobility, well-being, employment G: tax revenue P: mobility, revenue
IS5	Real time warning system for infrastructure failure	IS5.1. Technology deployment IS5.2. Identification of hotspots and "escape routes" IS5.3. Awareness raising	H: N/A G: consultancy, contractors (equipment and labour), training, awareness raising P: training	H: injuries (possibly congestion, energy cost), insurance G: public spending (health cost) P: insurance, (possibly congestion, energy cost, productivity)	H: well-being G: public safety, labour productivity P: profits
IS6	Improvement of institutional capacity	IS6.1. Capacity building planning and implementation IS6.2. Quality control unit (monitoring and evaluation) IS6.3. Law enforcement	H: N/A G: training, labour P: training	H: N/A G: public spending (avoided malpractice) P: N/A	H: employment and income, human capital G: skilled workforce, tax revenue P: revenue

Rodrigues

In order to address the challenges posed by climate change impacts on the infrastructure sector, RoM in collaboration with the Rodrigues Regional Assembly (RRA) and other stakeholders, could undertake to enforce adaptation policies, as is the case in Mauritius (Table 5.1).

(a) Structural measures

As for Mauritius, the structural measures include improvement of coastal, transport and building infrastructure and others. Additional sectoral measures may comprise:

a) Water infrastructure

- i) de-siltation of existing reservoirs to maintain their retention capacities;
- ii) rehabilitation and improvement of the distribution system of potable water;
- iii) construction of desalination plants powered by wind energy;
- iv) identification of potential small dam sites to cater for medium and long-term water needs of the population;
- v) construction of small dams across valleys and using high density polyethylene (HDPE) liner to arrest infiltration;.
- vi) better design and planning of rain water harvesting techniques (vii)grey water recycling for irrigation.

b) Agriculture:

Increasing the number, resilience and height of retaining walls to terraces for crop plantation

(b) Non-structural

In addition to those mentioned for Mauritius and applicable to Rodrigues as given in Table 5.2, non-structural measures will also include:

- i) Training and capacity building on efficient use of water in all sectors, proper monitoring of quantity and quality of water, and improving cooperation and collaboration with end-users;
- ii) More sustainable, cost-effective and eco-friendly buildings and infrastructure to protect workers, occupants and the environment.

The implementation of the VAA strategies in Rodrigues as in the case of Mauritius (Table 5.3) is expected to reduce vulnerability to climate change by protecting existing infrastructures and incorporating more stringent material and design criteria into new infrastructures, thereby protecting the population and the environment alike. The implementation of green technologies would continue to be subsidised to a large extent by the Government in order to encourage sustainable results in the long-run.

An integrated approach that identifies the intervention options, which turn challenges into opportunities, the corresponding required investments, and the resulting policy-induced avoided costs and added benefits in the infrastructure sector are given in Table 5.5 below.

Infrastructure- ***Transforming challenges into opportunities*** **(Rodrigues)**
Strategies (A1etc.) and corresponding actions (A1.1 etc.) and investments from Households (*H*), Government (*G*) and Private sector (*P*) with resulting policy-induced avoided costs and added benefits

	Strategies	Action List	Investment	Avoided costs	Added benefits
I1	Upgrade drains, frequent maintenance	**I1.1.** Site investigation **I1.2.** Topographical assessment **I1.3.** Construction work	*H:* N/A *G:* consultancy, contractors (equipment and labour), compensation (during work) *P:* N/A	*H:* injuries, property value *G:* compensation (extreme events), public spending *P:* productivity, property value	*H:* mobility, well-being, employment *G:* health (reduced vector borne diseases) *P:* mobility, revenue
I2	Use of climate resilient materials and techniques (e.g. water-draining road pavement)	**I2.1.** Suitability assessment **I2.2.** Site investigation **I2.3.** Construction work	*H:* N/A *G:* consultancy, contractors (equipment and labour), training, awareness raising *P:* training, marketing	*H:* injuries (roads) *G:* public spending (maintenance and health) *P:* N/A	*H:* mobility, well-being, property value *G:* tax revenue *P:* property value, productivity (roads)
I3	Improve landscape management (e.g. reduce water accumulation and slow water time of travel)	**I3.1.** Restore landscape integrity (native plant species) **I3.2.** Enforce river/creek buffer requirements **I3.3.** Plan for emergency response for pumping operations	*H:* weeding and planting trees *G:* weeding and planting trees, public outreach, labour (enforcement) *P:* weeding and planting trees	*H:* injuries, property value *G:* compensation (extreme events), public spending *P:* productivity, property value	*H:* well-being, employment *G:* carbon sequestration, branding *P:* tourism, revenue
I4	Collection and use of topographic, hydrology and climate-related data in infrastructure planning (e.g. elevated roads and buildings)	**I4.1.** Raising or relocating machineries/buildings in flood prone areas **I4.2.** Capacity building for the use of data **I4.3.** Topography/hydrology-based zoning/planning	*H:* construction *G:* consultancy (data and site investigation), contractors (equipment and labour), training *P:* training	*H:* injuries, property value *G:* compensation (extreme events), public spending *P:* productivity, property value	*H:* mobility, well-being, employment *G:* tax revenue *P:* mobility, revenue
I5	Real time warning system for infrastructure failure	**I5.1.** Technology deployment **I5.2.** Identification of hotspots and "escape routes" **I5.3.** Awareness raising	*H:* N/A *G:* consultancy, contractors (equipment and labour), training, awareness raising *P:* training	*H:* injuries (possibly congestion, energy cost), insurance *G:* public spending (health cost) *P:* insurance, (possibly congestion, energy cost, productivity)	*H:* well-being *G:* public safety, labour productivity *P:* profits
I6	Improvement of institutional capacity	**I6.1.** Capacity building planning and implementation **I6.2.** Quality control unit (monitoring and evaluation) **I6.3.** Law enforcement	*H:* N/A *G:* training, labour *P:* training	*H:* N/A *G:* public spending (avoided malpractice) *P:* N/A	*H:* employment and income, human capital *G:* skilled workforce, tax revenue *P:* revenue

Cross-sectoral considerations

Cross-sectoral considerations (Table 5.6) are now taken into account to identify and highlight entry points for interventions that will lead to increase efficiency of budget allocation and policy implementation. The strategies that more markedly contribute to the overall development include capacity building and awareness-raising, along with improved data collection and analysis. In addition, ecosystem restoration (terrestrial and marine) was identified as an ideal intervention in six of the seven sectors analysed. The main benefits identified when considering cross-sectoral dynamics include a reduction in public spending (with several instances in which avoided costs emerge) along with an increase of public revenues (e.g. tax revenues, through increased economic activity); employment creation (across all sectors and interventions); improved well-being (with better health and a reduction of injuries and diseases); and an amelioration of leisure opportunities (both for the local population and for tourists).

Table 5.6: Policy interventions and their inclusion in sectoral strategies (TNC, 2016)

	Sustainable land use planning	Ecosystem restoration	Resource efficiency	Integrated water management	Climate resilient infrastructure	Eco-tourism	Institutional capacity and support	Awareness raising	R&D and data analysis
Agriculture	√	√		√			√	√	√
Coastal areas and tourism	√	√	√	√	√	√		√	√
Water		√	√	√				√	√
Biodiversity	√	√				√		√	√
Fisheries	√	√					√	√	√
Health					√		√	√	√
Infrastructure		√		√	√	√	√	√	√

Table 5.7 highlights some of the more outstanding opportunities emerging from cross-sectoral linkages for the Infrastructure sector.

The use of climate-resilient materials and techniques can decrease the health risks associated with natural hazards. The restoration of landscape integrity can benefit biodiversity; and, the upgrade of drains can improve water quality.

A better management of water (e.g. restoration of water catchment areas) can reduce flood and damage to infrastructure, and the restoration of marine habitat can reduce coastal vulnerability.

Table 5.7: Strategies and opportunities emerging from cross sectoral linkage for the Infrastructure sector (TNC, 2016)

Mauritius	Rodrigues
Strategies 1 Use climate resilient materials and techniques ***Direct Cross cutting issues/ benefits*** Decrease the health risks associated with natural hazards ***Strategies 2*** Restore landscape integrity ***Direct Cross cutting issues/ benefits*** Can benefit biodiversity ***Strategies 3*** Upgrade drains ***Direct Cross cutting issues/ benefits*** Improvement of water quality ***Strategies 4*** Better manage water (e.g. restoration of water catchment areas) ***Direct Cross cutting issues/ benefits*** Reduction in floods and damage to infrastructure as well as the restoration of marine habitat ***Strategies 5*** Restore marine habitat ***Direct Cross cutting issues/ benefits*** Reduction in coastal vulnerability ***Other benefits and remarks*** –	***Strategies*** Build new interceptor and road-side drains to channel surface run-off to the sea, rehabilitate / upgrade existing drains, reinforce the wearing surface of roadways by the use of fabric reinforcement, replace cladding, flooring and linings with water resistant materials and construct levees or floodwalls around them, and encourage air conditioning optimisation.

6. VAA-Infrastructure Toolkit

The structure, methodology, and components/modules of the VAA-Infrastructure Toolkit has been described in the main User Manual.

7. References

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8. Appendices

Appendix A

Key Climate Change Impact indicators for RoM

Table A1: Key CC Impact indicators for RoM (source: DRR Report, 2016)

Indicator	*Trend (DRR Report)*	*Cases*
Beach Erosion	17% of the beaches are suffering from long term erosion and that 23% are being accreted, the remaining 59% are considered as being stable. A loss of **10 meters** of beaches over the last 8 years has been observed.	At Pointe aux Cannoniers, in the north of the island the shoreline has retreated by 10m and up to 18m within 45 years from 1967, with the volume of sediment loss amounting to 10,000 m^3. Mon Choisy, the shoreline has retreated by 12m on average and 18m at the maximum within the same period of time with a sediment loss of 20,000m^3 loss. Coral condition at Mon Choisy has been noticed to be relatively worse comparing to other coral reefs in Mauritius.
Flash Floods	Some 19-30 km2 of agricultural land, 5-70 km2 of built up land, 2.4-3 km of motorway, 18-29 km of main roads and 68-109 km of secondary roads are at risk of flooding. The damages to building and infrastructures have been estimated to be around USD 2 Billion in 50 years (2070 horizon).	Increase in the frequency of extreme weather events more frequent torrential rains resulting in flash floods, causing 11 deaths in March 2013. During recent heavy rainfall in January 2015, over 250 sites were flooded in Mauritius. During the first five days of May 2017, Mauritius recorded a mean rainfall of 275mm which represents 186% of the long term mean rainfall for the month; the Eastern part recording almost 300% of its normal rainfall. The flash flood of May 2017 affected around 74 households in the Flacq region namely, Central Flacq and Poste de Flacq (Cite Hibiscus, Camp Poorun and Cite Débarcadére).
Landslides	As heavy precipitation events increase, so does the risk of landslide. In Mauritius, 3 mountainous/hilly zones (enclosing 38 localities) are highly prone to landslide. The estimated values of built up areas and roads exposed to landslide are in the order of 7233 Million USD and 196 Million USD respectively.	These are 3 zones are notably regions around Vallee des Pretres-Chitrakoot, Quatre Soeurs-Louis de Rochecouste and Grande Riviere Noire-Chamouny. Regions such as Chitrakoot and Quatre Soeurs have recurrently been affected by landslide events such that in situ infrastructures are prone to damages. More recently the Terre Rouge-Verdun road was damaged due to landslide after a heavy downpour.
Coastal Inundation and Storm Surges	According to the DRR report, 12.2 km2 of built-up land, 11.8 km2 of expansion areas and 60 km of primary and 80 km of secondary roads are identified at risk to inundation as a result of sea surges. The damages to building and infrastructures has been estimated to be around 1.4 Billion USD for inundation in 50 years (2070 horizon).	According to scenarios established in the DRR, the north area of Mauritius is highly exposed to coastal risk, especially the zone between Pointe aux Cannoniers and Cap Malheureux. Analogously, the entire shoreline between Mon Choisy and Baie de l'Arsenal seem to be subject to significant inundation. Besides, high coastal risk appears in correspondence of Port Louis area from Baie du Tombeau to Baie de la Grande Riviere. The same type of problem is found in the south of Flic en Flac, through Baie de Tamarin up to Baie de la Grande and Petite Riviere Noire. Along the southern border, localized issued are in Pointe aux Roches, Pomponette, Riambel and in Mahebourg. Along the eastern coast, high local

		risk has been identified at Trou d'Eau Douce, Poste de Flacq and Roche Noires.
Sea water intrusion	Problem of salinity due to sea water intrusion in the water ponds on farms in the south eastern and south coastal belts.	Areas such as Belle Mare, Palmar, Quatre Soeurs and Deux Frères, Bambous Virieux and Pomponette has been observed.
Forest/Bush Fire	Climate change is projected to increase the extent, intensity and frequency of forest fires in certain regions of Mauritius. Warmer summer temperatures, coupled with decreases in water availability, dry out woody/dry grasses materials in forests/grassland increases the risk of wildfire.	Regions that are regularly plagued by wildfires in Mauritius include: Signal Mountain, La Ferme, Ile D'Ambre, Petit Sable and Ile aux Benitiers.
Coral Bleaching	El Niño Southern Oscillation (ENSO) generated massive bleaching and coral mortality during 1982-1983, 1997-1998, 2002-2003, 2005, and 2010, and contributed to the likely extinction of a coral species. In 1998, the NOAA reported an episode of extremely high ocean temperatures migrated from south to north throughout the Indian Ocean during the first six months of 1998 causing considerable coral reef bleaching in its wake. It was estimated that 16% of the world's coral was lost.	Bleaching has been reported in the Indian Ocean reefs of Mauritius as well as in Seychelles, Reunion, Madagascar and Maldives, amongst others. The coral reefs of Rodrigues which escaped the mass coral-bleaching event of 1997-1998, was affected by the 2016 El-Nino event. Surveys showed occurrences of severe bleaching leading to the mortality of up to 75% of corals at some sites, particularly in the North and West of Rodrigues.
Acidification	Since the beginning of the industrial era, oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 pH units (high confidence), corresponding to a 26% increase in acidity. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. According to the Fifth Assessment Report of the IPCC, Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century. The decrease in surface ocean pH is in the range of 0.06 to 0.07 (15 to 17% increase in acidity) for RCP 2.6.	