Climate Proofing of West Container Terminal-1, Colombo for Adani Ports and Special Economic Zone Limited

Climate Vulnerability and Adaptation Planning Report for West Container Terminal-1 (WCT-1), Colombo, Sri Lanka

Submitted 23 March 2023

Submitted to:

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List of Abbreviations

APSEZ	Adani Ports and Special Economic Zone Limited
BAC	Building Adaptive Capacity
BEE	Bureau of Energy Efficiency
CCM	Cradle Communication Module
CDD	Continuous Dry Days
CEWL	Coastal Extreme Water level
CRZ	Coastal Regulation Zone
CWD	Consecutive Wet Days
DG	Diesel Generator
DRR	Disaster Risk Reduction
ECO	Ecosystem
EHV	Extra High Voltage
EMC	Environmental Management Centre
EM-DAT	Emergency Events Database
ENG	Engineering
ERC	Elastic Rail Clip
EWS	Early Warning Systems
FRP	Fibre Reinforced plastic
FWPH	Fire Water Pump
FY	Financial Year
GHG	Greenhouse Gas
GOV	Governance
GSB	Granular Subbase
HQ	Headquarter
HR	Human Resource
HVAC	Heating, Ventilation, and Air Conditioning
IMD	India Meteorological Department
IMS	Institute of Maritime Studies
IPCC	Intergovernmental Panel on Climate Change
IS	Indian Standard
ISM	International Safety Management
ISPS	International Ship and Port Facility Security
KL	Kilo Litre
LST	Land surface Temperature
LULC	Land use Land cover
MMT	Million Metric Tonne
MMTPA	Million Metric Tonne Per Annum
MT	Metric Tonnes
OP	Operational
PPE	Personal Protective Equipment
PPT	Precipitation
RCC	Reinforced Cement Concrete
RCP	Representative Concentration Pathway

RCM	Regional Circulation Models
SEZ	Special Economic Zone
SLR	Sea Level Rise
SOP	Standard Operating Procedure
SPM	Single Point Mooring
TEU	Twenty-foot Equivalent Unit
TSS	Total Suspended Solids
TXX	Maximum day-time temperature in °C
UPVC	Unplasticizized Polyvinyl Chloride
USFD	Ultrasonic Flaw Detection
VRV	Variable Refrigerant Volume
WCT	West Container Terminal

Executive Summary

Adani Ports and Special Economic Zone Limited (APSEZ) is the largest commercial ports operator in India. It has strategically located network of 13 ports in India (twelve ports) and Sri Lanka (one port). The ports and terminals are located in seven maritime states of Gujarat, Goa, Kerala, Maharashtra, Andhra Pradesh, Tamil Nadu and Odisha in India, and at Colombo in Sri Lanka.

Environmental Management Centre Pvt. Ltd. (EMC), formerly known as Environmental Management Centre LLP, was engaged to conduct a climate change vulnerability assessment and adaptation planning of their ports located across India and Sri Lanka. The objective of the study was to first assess impacts of climate variability and changes such as rise in temperature, variation in rainfall, sea level rise, extreme events, etc. on ports, its operations and associated facilities. This assessment was carried out based on modelling considering baseline and projected representative concentration pathway (RCP) scenarios (RCP 4.5) with timeframe 2021-2050 and 2041- 2070. Based on the outcomes of first study, a detailed risk identification and asset prioritization was carried out to draft an adaptation plan for assets at high and very high risks. This report describes the analysis of climate risk assessment and adaptation planning for a greenfield port at West Container Terminal 1 (WCT-1), Colombo, Sri Lanka.

The assessment was carried out in three phases.

Phase I involved the **Climate Vulnerability Assessment of the Port**. The climate change vulnerability assessment was conducted using the framework provided by Intergovernmental Panel on Climate Change (IPCC) for the WCT-1, Colombo (Sri Lanka). This included determining the climatic exposure and sensitivity of the port.

The exposure analysis included analysis of climate variables such as temperature (essential and climate extremes), precipitation- (essential and climate extremes), Sea Level Rise, Extreme Wind Speed, Extreme Events- Cyclone, Landslide, Floods and Heat Waves. The changes in essential and climatic extreme indices are compared with respect to the baseline period. As a greenfield port, sensitivity analysis is restricted to few indicators related to assets related information (Asset Cost, Cargo), workforce-based information (Age, Employment Type - Employed or contracted) and location details (Low lying area, Proximity to inland water bodies, Land use land cover change).

In **Phase II a Risk Identification & Prioritization was** carried out for the WCT-1, Colombo (Sri Lanka).

A one-on-one session was conducted with team of the port to identify the existing climate risks. A risk matrix was developed for the port to capture the *Likelihood and Consequence* of a risk component on an asset category against a climate stressor. This matrix thus captured the current perceived risk to climate change. Further, proposed adaptation measures and a factor based on the projected climate risks on these assets was used to arrive at the final risk. These risks were scored as Low, Moderate, High or Very High (prioritized).

For the **Phase III on Preparation of Adaptation Plan,** a library of adaptation measures for climate stressors were identified. A virtual workshop was conducted with experts who provided an overview and shared experiences on implementation of adaptation measures. Best fit adaptation measures were identified to strengthen existing measures and reduce the potential climate risks.

The adaptation measures were compiled and categorized based on the type as Building Adaptive Capacity, Ecosystem, Engineering, Operational and Governance based measures. The measures were further classified based on the timeline of implementation- whether it is an ongoing, immediate,

short- term, medium term or long-term measure. The measures were also grouped based on the estimated costs of implementation- low, moderate or high.

Recommendations were provided on the way forward on how to successfully implement the proposed adaptation plan and ensure its effectiveness. An institutional framework with a Climate cell at APSEZ corporate and climate cells at respective ports is proposed. The need for establishing a monitoring & evaluation framework is also described.

1 Introduction

1.1 Background

Adani Ports and Special Economic Zone Limited (APSEZ) is the largest commercial ports operator in India. In less than two decades, APSEZ has built and acquired an unparalleled portfolio of ports infrastructure across India, and recently at WCT-1, Colombo, Sri Lanka. It has strategically located network of 13 ports, which represents 24% of the country's port capacity of handling cargo. The ports are located in seven maritime states of Gujarat, Maharashtra, Goa, Kerala, Andhra Pradesh, Tamil Nadu and Odisha, and Colombo province in Sri Lanka.

APSEZ is concerned of the climate variability and change such as rise in temperature, variation in rainfall, sea level rise, extreme events, etc. that can have serious impacts on ports, its operations, and associated facilities. To better understand the impact of climate change and the associated physical risk on ports, APSEZ engaged Environmental Management Centre Pvt. Ltd. (formerly Environmental Management Centre LLP; EMC) to conduct a climate vulnerability assessment and adaption planning of their ports located across India and Sri Lanka.

This document presents Environmental Management Centre Pvt. Ltd. (EMC) findings on "Climate Vulnerability Assessment and Adaptation Plan for WCT-1, Colombo, Sri Lanka".

1.2 Approach & Methodology WCT-1, Colombo, Sri Lanka

The overall approach and methodology adopted for the climate change vulnerability assessment and preparation of the adaptation plans is given below:

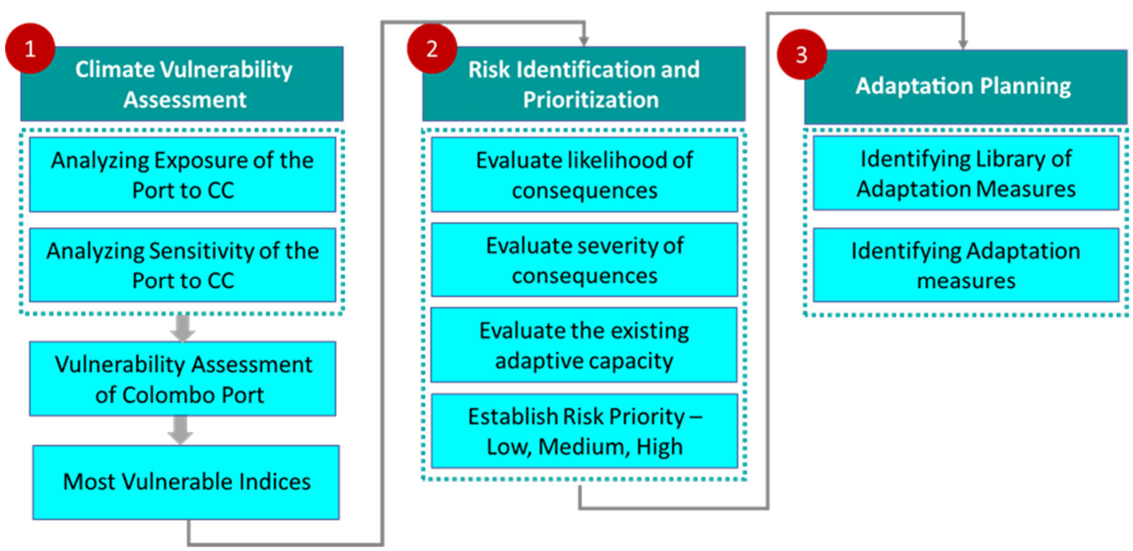

Figure 1 Overall Methodology for Climate Vulnerability Assessment and Adaptation Planning

1.2.1 Phase I: Relative Vulnerability Assessment of Port.

Relative climate change vulnerability assessment was conducted under two climate change scenarios - **RCP 4.5 with timeframe 2021-2050 and RCP 4.5 with timeframe 2041-2070 with respect to the baseline period (1981-2010).** The methodology was formulated using the framework provided by Intergovernmental Panel on Climate Change (IPCC).

Analysis for the WCT-1, Colombo (Sri Lanka) is performed separately from the relative climate change vulnerability assessment study for 12 Indian ports under APSEZ. WCT-1, Colombo is not included in the relative assessment for the following reasons:

1. The climatic exposure data source used for relative exposure assessment procured from GIZ portal is available only for ports on the Indian mainland.
2. Though the computation of climatic exposure indices is performed using same set of models, the observed data (for precipitation and temperature) which is required for bias-correction of model output is different. [Princeton university data portal is used as observed data source for bias-correction of model outputs as IMD do not provide datasets beyond Indian territories]
3. Quantile mapping bias-correction method (Li et al, 2014) is used for removing model bias in climatic data for Colombo city; however, no information about bias-correction of model outputs is provided in GIZ data portal documentation.
4. The calculation of extreme event index involves calculation of two indices: Hazard susceptibility index and frequency duration index. In case of Colombo port, computation of hazard susceptibility index is difficult as no complimentary maps are available for different hazards for Sri Lanka.
5. As a greenfield project, sensitivity indicator information for few indicators such as degree of automation (energy consumption) is not available due to no ongoing operations.

The methodology explained in GIZ portal documentation is used to compute the exposure indicators for temperature and precipitation using same set of regional climatic models. The median value for multi-model ensemble for each indicator is computed for both the time periods under RCP 4.5 scenario. Further, the changes in different climatic exposure indicators are analysed for future time periods with respect to baseline period.

1. Data Collection:

a. Data from various sources is obtained for port location.
b. Information on location, time frame and emission scenario (RCP 4.5) are boundaries set for obtaining the requisite projected data of climate variables.

Error! Reference source not found. highlights the data sources that were used for the computation of climate change vulnerability of WCT-1.

Table 1 Data Sources for the computation of relative climate vulnerability of WCT-1

Vulnerability Component	Variable Type	Source	Reason for Source Selection
Climate Exposure	Temperature- Essential and Climate Extremes	Climate Change Information Portal	• Predicted values are derived from 10 Regional Circulation Models (RCMs).[1] • High Data Accuracy of 0.5°× 0.5° (or 55 km × 55 km)
	Precipitation- Essential and Climate Extremes	Climate Change Information Portal	
	Sea Level Rise	CLIMsystems	• CLIMsystems is a consulting company based in Hamilton in New Zealand. • CLIMsystems focuses on climate change adaptation and risk assessment using modelling tools. It has team with a combined experience of over 200 years with projects completed over 50 countries.
	Extreme Wind Speed	CLIMsystems	
	Extreme Events- Cyclone, Landslide, Floods, Heat Waves, etc.	EM-DAT	Historical extreme events database- Emergency Events Database (EM-DAT) initiative aims to rationalise decision making for disaster preparedness, as well as provide an objective base for vulnerability assessment and priority setting
Sensitivity	**Asset based sensitivity**		
	Container Cargo volume	APSEZ	• Company reliable data
	Asset Value		
	Degree of Automation in terms of total energy consumed at the port		
	Damages incurred due to climatic events		
	Workforce based sensitivity		
	Age of workforce	APSEZ	• Company reliable data
	Employment Force		
	Location based sensitivity		
	Low Lying Areas	SRTM DEM	• Elevation Models derived from SRTM data at 90m resolution[2]
	Proximity to Inland Water Bodies	ArcGIS and Google Earth	• Most reliable software application for remote sensing and spatial data analysis.
	Land Use Land Cover Change	Terra MODIS	Night-time Land Surface Temperature at ~1 km × 1km

[1] http://cccr.tropmet.res.in/home/ftp_data.jsp

[2] https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm

2. Data Analysis

Different exposure variables are extracted using different RCM models which further are used to derive temperature and precipitation exposure variables. Sea Level Rise (SLR) and extreme wind speed data is procured for 50-year return period from ClimSystems for the port location.

Table 2 List of variables selected for assessing climatic exposure

Temperature	Precipitation	Sea Level Rise	Extreme Wind Speed	Extreme Events
Annual maximum temperature in °C (T_{max})	Annual precipitation in mm (PPT)	Annual average SLR in cm (SLR_{50p})	Median 50-year return period wind speed in kph (EWS_{50p})	Historical data of extreme weather events at a given location in or before 2010.
Annual minimum temperature in °C (T_{min})	Consecutive dry days in days (CDD)	Median 50-year return period coastal extreme water level in cm ($CEWL_{50p}$)	Extreme50-year return period wind speed in kmph (EWS_{95p})	Cyclone
Warm nights in % days (TN_{90p})	Consecutive wet days in days (CWD)	Annual extreme SLR in cm (SLR_{95p})		Riverine flood
Maximum night-time temperature in °C (TN_X)	Number of heavy precipitation days (R_{10})	Extreme 50-year return period coastal extreme water level in cm ($CEWL_{95p}$)		Coastal flood
Warm days in % days (TX_{90p})	Very wet day precipitation in mm (R_{95p})			Landslide
Maximum day-time temperature in °C (TX_X)	Extremely wet day precipitation in mm (R_{99p})			High winds
Warm spell duration indicator in days (WSDI)	Maximum 1-day precipitation in mm (RX_1)			
	Maximum5-day precipitation in mm (RX_5)			
Reference period of 1981-2010		***Reference period of 1995***	***Reference period of 2005***	***Before 2010***

Table 3 List of variables selected for assessing climatic sensitivity

Asset Information	Workforce	Location
• Container volume • Asset Value • Degree of automation	• Age • Employment Type (Employed or contracted)	• Low lying area • Proximity to inland water bodies • Land use land cover change • Damages incurred

1.2.2 Phase II: Risk Identification and Prioritization

The methodology applied in phase II of the study is a five-step process, as explained in Figure 2.

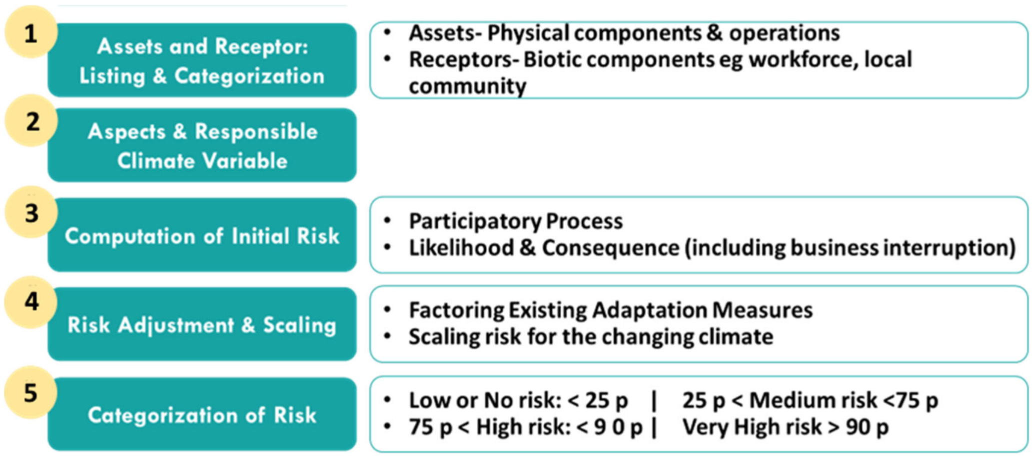

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Figure 2 Methodology for risk identification for assets and receptors at WCT-1, Colombo (Sri Lanka)

1.2.2.1 Assets and Receptors - Listing and Categorization:

- A request for the list of assets and receptors for WCT-1 was made to the APSEZ team.
- Based on the list obtained, assets & receptor categories were prepared in consultation with the APSEZ team
- The assets comprise of physical components and operations at the port (like buildings, roads, terminals, water pumping system, etc. Detailed categories are provided in Annexure 2: Asset Categories, Climate Risk & Climate Variables
- The receptors comprise of the biotic component at and near the port (e.g., local community, external stakeholders, farming community, workforce, etc. The detailed categories are given in Annexure 2: Asset Categories, Climate Risk & Climate Variables

1.2.2.2 Aspects and Responsible Climate Variable:

- For each of the assets and receptors categories, possible climate risk aspects and their responsible climate variable(s) were identified.
- The possible climate risks and their responsible climate variable were based on extensive literature review of port adaptation plans of various global ports.
- Experts on climate change and coastal infrastructure also provided their inputs on the identified climate risks and their responsible variable.

Table 4 illustrates the compilation of assets & receptors, their climate risk aspects, and the responsible climate variables. The detailed list is provided in Annexure 2: Asset Categories, Climate Risk & Climate Variables

Table 4 Illustrative list of assets, climate risk aspects and responsible climate variables

Assets/Receptor	Climate Risk Aspect/Component	Responsible Climate Variable
Office Buildings	Increase in Energy Needs	Temperature
	Decrease in Stability- Fracture/Fatigue	High Winds
	Inundation due to heavy rains	Precipitation
	Inundation due to sea water flooding	Sea Level Rise and Storm Surge
	Cracks due to high temperature	Temperature
Internal Roads at Port	Cracks	Temperature
	Inundation	Precipitation
	Inundation	Sea Level Rise and Storm Surge
	Dust generation	Temperature and High Wind
	Broken tarmac	Temperature
	Muddy	Precipitation
Cranes, Ship Unloaders, Stackers, Forklifts and Straddle Carriers	Operational delays in difficultly of handling the operations	Temperature
	Operational delays in difficultly of handling the operations	High Winds
	Operational delays in difficultly of handling the operations	Precipitation
	Muddy Conditions	Precipitation
	Physical damages- breakdown	High Winds
	Physical damages- breakdown	Temperature
Bridges	Stability- Sway	High Winds
	Expansion joints displacement	Temperature
	Physical damages- breakdown	High Winds
Railway Tracks (Internal & beyond Port)	Expansion joints displacement	Temperature
	Inundation	Sea Level Rise and Storm Surge
	Inundation	Precipitation
	Corrosion	Temperature + Salinity + Winds
Terminals	Submergence	Sea Level Rise and Storm Surge
	Operational delays in difficultly of handling the operations	Temperature
	Operational delays in difficultly of handling the operations	High Winds
	Operational delays in difficultly of handling the operations	Precipitation
	Operational delays in difficultly of handling the operations	Sea Level Rise and Storm Surge
Navigation & Berthing	Difficulties with berthing due to increased height of vessels berthed relative to quay and material handling equipment	Sea Level Rise
	Navigational safety	High Winds and Storm Surge
	Timetabling delays	High Winds
	Timetabling delays	Storm Surge
	Timetabling delays	Precipitation
Local Community	Increase in suspended particles due to cargo	Temperature, Precipitation & High Winds
	Effect on livelihood (fish catch) - decrease in quantity of fish and change in location	Sea Level Rise and Storm Surge
	Absenteeism due to bad weather	Temperature, Precipitation & High Winds

Assets/Receptor	Climate Risk Aspect/Component	Responsible Climate Variable
Workforce Management	Disaster Management Committee established	Extreme Events (cyclone/storm surges/High Winds)
	Established connect with External Agencies	Extreme Events (cyclone/storm surges/High Winds)
	Mock drills & Awareness	Extreme Events (cyclone/storm surges/High Winds)

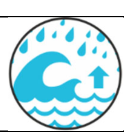
Responsible Climate Variables

The responsible climate variables linked to various climate risk aspects of the asset and receptor categories can be categorized into:

(1) Temperature
(2) Precipitation
(3) Sea level rise and storm surge
(4) High winds

The specific climate variables (or stressors) identified and their likely impacts on asset categories are listed below in Table 5.

Table 5 Indicative list of likely impacts of select climate stressors.

Climate Variable Category	Specific Climate Variable	Likely Impact
 **Temperature**	● Warm days in % days **(TX-90p)** ● Maximum day-time temperature in °C **(TXX)**	● Human heat stress ● Increase in water demand. ● Infrastructure damage- building, roads, rails, bridges, electric poles, etc. ● Decreased efficiency of power generation. ● Higher energy demand ● Operational delays and difficultly of handling the operations. ● Spoilage of container ● Dust generation
 **Precipitation**	● Consecutive dry days in days **(CDD)** ● Consecutive wet days in days **(CWD)** ● Maximum 1-day precipitation in mm **(R-X1)**	● Possibility of droughts ● Water borne diseases. ● Flood due to high intensity 1-day rain ● Infrastructure damage- Buildings, roads, rails, bridges, coastal equipment, electrical poles, security system, etc. ● Reservoir sedimentation ● Structural damage threat to Water Resources Infrastructure ● Operational delays and difficultly of handling the operations. ● Spoilage of container ● Damages to electrical equipment
	● Annual extreme SLR in cm **(SLR-95p)**	● Flooding ● Operational delays and difficulty on navigation and berthing

Storm surge and Sea level rise	• Extreme 50-year return period coastal extreme water level in cm **(CEWL-95p)**	• Infrastructure damage- Buildings, roads, rails, bridges, coastal equipment, electrical poles, security system, etc. • Sedimentation
High Winds	• Extreme 50-year return period wind speed in kmph **(EWS-95p)**	• Operational delays and difficulty on navigation and berthing • Infrastructure damage- Buildings, roads, rails, bridges, coastal equipment, electrical poles, security system, etc. • Dust generation • Damages to conveyor system • Disruption to hydrographic surveying regime and dredging regime. • Damage to marine navigational equipment (like Tide Gauge) and/or inaccessibility

1.2.2.3 Computation of Initial Risk

- A detailed questionnaire- A *Risk Assessment Questionnaire* was developed by EMC team to understand the various climate change risks and present adaptation capabilities within the terminal, covering all the critical assets, under various operations and departments.
- A virtual workshop was held with port to discuss the projected climate variables and the likely impact it will have on the port operations.
- The risk assessment questionnaire was also discussed during the workshop. The port team and representatives were asked to select the *Likelihood* and *Consequence* against the climate change aspect and corresponding climate stressor. It was assumed that the department representatives filling the questionnaire would use their past experiences at the port while filling the likelihood and consequence of a climate risk.
- Likelihood scoring is consistent for all assets and receptors and is given as-
    - **1**-Not Expected to Occur.
    - **2**- Very Rare Occurrence.
    - **3**- 30-50% Chance of Occurrence.
    - **4**- Occurs more than twice in the last decade.
    - **5**- Expect Occurrence annually.
- Consequence scoring is also from 1-5 but varies according to the climate risk aspect in consideration. The scoring for consequences captures business interruption, physical damages, health and safety, and operational delays. The following is the summary for consequence scoring:

Table 6 Consequence Scoring

Consequence Scoring	Climate Risk Aspect
1-No impact	**Refrigeration**
2-Slight increase in expenses	
3-Increase in expenses significantly > 50%	
4-Retrofits required	
5- Replacement/Installation of Infrastructure	
1-No impact or slight reduction in efficiency or operations	**Operational**
2-Slight interruptions in operations - less than half day	

3-Interuptions 1-2 days	
4-Interuptions 3-5 days	
5- >5 days or equipment/operations unable to proceed	
1-Minor complaints from community	**Community**
2- Minor actions required to resolve complaints	
3- Widespread local community opposition	
4- Interruptions in business due to community opposition	
5- Major interventions to be spent to appease community	
1- Suffer minor disruptions	**Stakeholder**
2- Suffer disruptions and minor losses	
3- Suffer major disruptions, delays and losses	
4- Consider using another port	
5- Use the services of another port	
1- No damages	**Environmental**
2- Minimal Damages with limited remediation/interventions	
3- Major damages requiring remediation & interventions for months	
4- Major damages requiring remediation & interventions for year	
5- Permanent Damages with irreversible effects	
1- Irritation/Local treatment- no absenteeism	**Health and Safety**
2- Medical treatment required results in absenteeism	
3- Injuries. Absenteeism > 1 week	
4-Estensive injuries/chronic health issues. Absenteeism > 1 month	
5- Fatalities or permanent disabilities	
1- No significant damage to the equipment/structure	**Equipment Thresholds**
2- Minimal damages with minor retrofits no interruption of work	
3- Significant damages with retrofit required & <1 day of interruption	
4- Significant damages > 5 days in interruption of work	
5- Permanent Damage needs to be replaced	

- The likelihood and consequence were selected from drop-down menus provided in the questionnaire. The values for likelihood and consequence varied between 1 and 5. An illustration of the drop-down list for likelihood and consequence is provided in **Table 7**.

Table 7 Illustrative Likelihood, Consequence and Proposed Adaptive Capacity Scoring

Assets/Receptor	Climate Risk Aspect/Component	Responsible Climate Variable	Likelihood (1-5)	Consequence (1-5)	Existing/Proposed Adaptive Capacity (1-5)
Office Buildings	Increase in Energy Needs	Temperature	**1**-Not Expected to Occur. **2**- Very Rare Occurrence. **3**- 30-50% Chance of Occurrence. **4**- Occurs more than twice in the last decade. **5**- Expect Occurrence annually.	**1**-No impact. **2**-Slight increase in expenses. **3**-Increase in expenses significantly > 50%. **4**-Retrofits required. **5**- Replacement/Installation of Infrastructure.	**1**- Not Identified as a Risk or No Adaptation Yet. **3**- Proposed. **4**- Exists. Need Strengthening. **5**- Exists. Proven Effective.
	Decrease in Stability-Fracture/Fatigue	High Winds		**1**- No damages. **2**- Minimal Damages with limited remediation/interventions. **3**- Major damages requiring remediation & interventions for months. **4**- Major damages requiring remediation & interventions for year. **5**- Permanent Damages with irreversible effects.	
	Inundation due to heavy rains	Precipitation		**1**-No impact or slight reduction in efficiency or operations. **2**-Slight interruptions in operations - less than half day. **3**-Interuptions 1-2 days. **4**-Interuptions 3-5 days. **5**- >5 days or equipment/operations unable to proceed.	
	Inundation due to sea water flooding	Sea Level Rise and Storm Surge		**1**-No impact or slight reduction in efficiency or operations. **2**-Slight interruptions in operations - less than half day. **3**-Interuptions 1-2 days. **4**-Interuptions 3-5 days.	

Assets/Receptor	Climate Risk Aspect/Compone nt	Responsible Climate Variable	Likelihood (1-5)	Consequence (1-5)	Existing/Proposed Adaptive Capacity (1-5)
				5- >5 days or equipment/operations unable to proceed.	
	Cracks due to high temperature	Temperature		**1**- No damages. **2**- Minimal Damages with limited remediation/interventions. **3**- Major damages requiring remediation & interventions for months. **4**- Major damages requiring remediation & interventions for year. **5**- Permanent Damages with irreversible effects.	

- **Initial Risk** was computed by taking the product of Likelihood and Consequence scores (as shown in equation 1), as depicted in the figure given below. (Figure 4)

Equation 1

$$Initial\ Risk = Likelihood\ Value \times Consequence\ Value$$

Where, Likelihood and Consequence are scored between 1 to 5.

The snapshot of the detailed questionnaire- A *Risk Assessment Questionnaire* developed by EMC team to get the score for the likelihood and consequence value is given below (Figure 3).

S.No	Asset Category	Component	Due to Climate Variable	Likelihood (1-5)	Consequence (1-5)
1	*For Office Buildings- do you observe*	Increase in Energy Needs	Temperature		
		Decrease in Stability-Fracture/Fatigue	High Winc		
		Inundation due to heavy rains?	Precipitat		
		Inundation due to sea water flooding	Sea Level Rise and Storm Surge		
		Cracks due to high temperature	Temperature		
2	*Open Land*	Inundation	Precipitation		
		Inundation	Sea Level Rise and		

1-Not Expected to Occur
2- Very Rare Occurrence
3- 30-50% Chance of Occurrence
4- Occurs more than twice in the last decade
5- Expect Occurrence annually

Figure 3: Snapshot of Risk Assessment questionnaire

The risk for green field port is estimated for the worst-case scenario, that is maximum likelihood and consequence based on the responses from APSEZ team.

Box 1: Example for Initial risk calculation

Illustrative example of initial risk calculation for the asset

Office building

- The likelihood score for the event inundation due to climatic variable sea level rise and storm surge is given 5.
- Similarly, the Consequence score is also 5.

$$Initial\ Risk = 5 \times 5$$

- The likelihood score for the component increase in the energy need due to climatic variable rise in temperature is given 5.
- Similarly, the Consequence score is also 5, as mentioned above considering the worst-case scenario.

$$Initial\ Risk = 5 \times 5$$

Hence the initial risk of Office building for both the components, inundation and increase in energy need is **25**.

The detailed calculation for all the assets and receptors is given in the Annexure 3: Computation of Climate Risk for all the Assets

- Mathematically the initial risk can have values between 1 and 25, with higher value signifying higher risk.

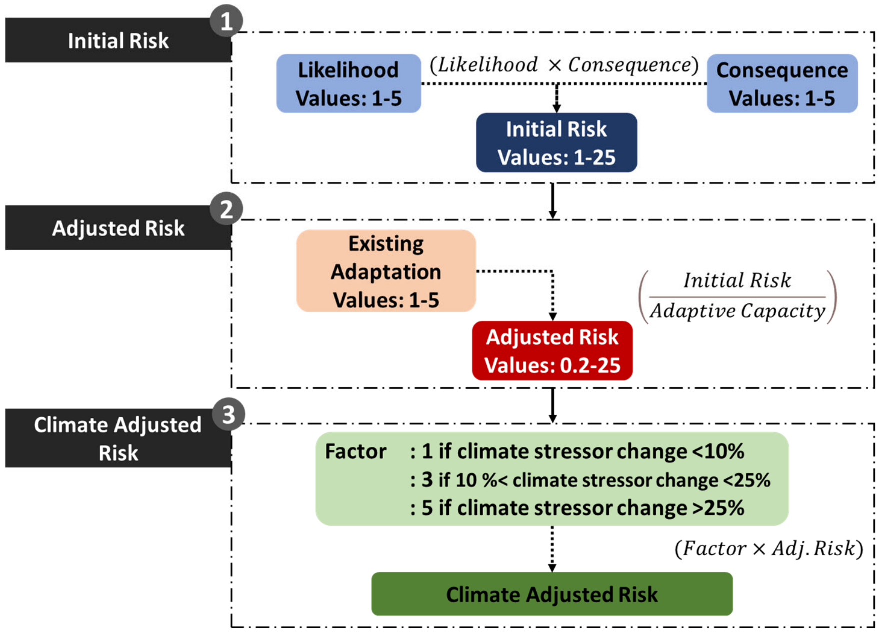


Figure 4 Methodology to compute climate adjusted risk for WCT-1, Colombo

1.2.2.4 Risk Adjustment and Scaling

- The initial risk computed in the above section does not incorporate the port's existing or proposed adaptation strategies that may be useful to combat climate change. Hence it was important to correct the initial risk for the port's existing adaptive capacity.
- The department representatives selected from the drop-down list, a score from 1-5 for proposed adaptive capacity, based on their judgement. They also described the proposed adaptation measures for the particular climate risk identified. Refer to Table 7 for illustrative scoring of adaptive capacity.
- Adaptive capacity scoring is consistent for all the climate risks and is given as-
  - **1**- Not Identified as a Risk or No Adaptation Yet.
  - **3**- Proposed.
  - **4**- Exists. Need Strengthening.
  - **5**- Exists. Proven Effective.

The snapshot of the questionnaire with the drop-down list for the adaptive capacity measures for the climate risk is shown below. (Figure 5)

S.No	Asset Category	Component	Due to Climate Variable	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptation Measure (Numeric)	Adjuste
1	*For Office Buildings- do you observe*	Increase in Energy Needs	Temperature				3- Proposed	
		Decrease in Stability- Fracture/Fatigue	High Winds				1- Not Identified as a Risk or No Ad 3- Proposed 4- Exists. Need Strengthening 5- Exists. Proven Effective	
		Inundation due to heavy rains?	Precipitation				3- Proposed	
		Inundation due to sea water flooding	Sea Level Rise and Storm Surge				1- Not Identified as a Risk or No	
		Cracks due to high temperature	Temperature				3- Proposed	
2	*Open Land*	Inundation	Precipitation				1- Not Identified as a Risk or No Adaptation Yet	
			Sea Level Rise and				1- Not Identified as	

Figure 5: Snapshot of Risk Assessment questionnaire

- The adjusted risk is calculated by dividing initial risk by proposed adaptation value as shown in equation 2.

Equation 2

$$Adjusted\ Risk = Intial\ risk\ \div Existing/Proposed\ adaptation\ value$$

Where, adaptive capacity is scored as 1,3,4 or 5

Box 2: Example for the calculation of adjusted risk

Example of adjusted risk calculation for the asset

Office building

- The computed initial risk for the event inundation due to climatic variable sea level rise and storm surge is given 25, considering worst case scenario.
- The score to adaptation measure for the event inundation due to climate variable sea level and storm surge is 1, which corresponds to no action taken.

$$Adjusted\ Risk = 25\ \div 1$$

Hence the adjusted risk of the office building due to inundation is **25**.

- The computed initial risk for the component increase in the energy need due to climatic variable rise in temperature is 25.
- The score to adaptation measure for the component increase in the energy need due to climatic variable rise in temperature is 3, which corresponds to proposed action.

$$Adjusted\ Risk = 25\ \div 3$$

Hence the adjusted risk of the office building due to increase in energy needs is **8.34**.

The detailed calculation for all the assets and receptors is given in the **Annexure 3: Computation of Climate Risk for all the Assets**

- The adjusted risk values can lie between 0.2 to 25, with higher values signifying greater risk.
- The **adjusted risk** computed above is based on the past and present experiences of the port operators. It does not incorporate the **risk** due to the increasing intensity and frequency of the climate stressors for the projected study period i.e., 2021-2050.
- A **climate scaling factor** was then computed corresponding to the change in climate stressor impacting a particular risk.
- The changes in each climatic indicator for different climatic stressors are given as:
    - change in climate stressor indicator is less than 50th percentile (50p) then factor = 1
    - change in climate stressor indicator is less than 75th percentile but greater than 50th percentile, then factor = 3
    - change in climate stressor indicator is greater than 75th percentile, then factor = 5
- The climate scaling factors for each climatic stressor are given as the sum of all factors representing different climatic indicators.

The below snapshot represents the climate scaling factor for each climatic stressor for the WCT-1 (Figure 6).

	A	B	C	D	E	F	G	H	I	J	K	L
1	Port	Ann.PPT_Delta (%)	Reverse_CDD_Delta (days)	CWD_Delta (days)	R10_Delta (days)	R20_Delta (days)	R95p_Delta (mm)	R99p_Delta (mm)	RX1_Delta (mm)	RX5_Delta (mm)	sum	Annual_Tmax_Delta (° C
2	Colombo	1	3	1	1	1	1	1	1	1	11	
3	Dahej	1	5	1	1	1	3	3	1	3	19	
4	Dharma	1	5	1	1	1	1	1	1	1	13	
5	Dighi	1	5	5	1	3	5	5	1	1	27	
6	Ennore	1	5	1	1	1	1	1	1	1	13	
7	Gangavai	1	5	1	1	1	1	1	1	1	13	
8	Hazira	3	5	1	1	1	5	5	5	5	31	

Figure 6: Snapshot for the climate scaling factor

- The **climate adjusted risk** is then computed by multiplying adjusted risk with the climate scaling factor as shown in equation 3. This product is the **final climate risk** for a given asset/receptor and climate aspect because of a given climate stressor.

Equation 3

$$Climate\ adjusted\ risk = Adjusted\ risk\ \times Climate\ scaling\ factor$$

Where, climate scaling factor for each climatic stressor are given as the sum of all factors representing different climatic indicators.

Box 3: Example for the computation of climate adjusted risk

Example of Climate adjusted risk calculation for the asset

Office building

- The computed adjusted risk for the event inundation due to climatic variable sea level rise and storm surge is given 25.
- The climate scaling factor for the event inundation due to climate variable sea level and storm surge is 12.

$$Climate\ adjusted\ risk = 25\ \times 12$$

Hence, climate adjusted risk of Office building due to inundation is **300**.

- The computed adjusted risk for the component increase in the energy need due to climatic variable rise in temperature is 8.34, considering the proposed actions.
- The climate scaling factor for the component increase in the energy need due to climatic variable rise in temperature is 11.

$$Climate\ adjusted\ risk = 8.34\ \times 11$$

Hence, climate adjusted risk of Office building due to increase in energy need is **91.67**.

The detailed calculation for all the assets and receptors is given in the **Annexure 3: Computation of Climate Risk for all the Assets**

1.2.2.5 Categorization of Risk

- After computing the climate adjusted risks for all assets/receptors categories at a port, the risks are classified into four categories - Low, Medium, High, and Very High (refer Table 8)
- The categorization is done as follows:
  - The climate adjusted risk values lower than 25^{th} percentile value (of the climate adjusted risks): Low Risk
  - The climate adjusted risk values between 25^{th} and 75^{th} percentile values (of the climate adjusted risks): Medium Risk
  - The climate adjusted risk values between 75^{th} and 90^{th} percentile values (of the climate adjusted risks): High Risk
  - The climate adjusted risk values greater than 90^{th} percentile value (of the climate adjusted risks): Very High Risk

Table 8: Risk Categorization

RISK LEVELS	DESCRIPTION OF RISK / ACTIONS REQUIRED
Very High	**Very high risks are unacceptable to APSEZ. Need to implement adaptation options to avoid, reduce or transfer risk.**
High	**Risks that pose operational constraints**
Medium	Medium risks can be tolerated if 'no regret' and 'low cost' adaptation options can turn them into residual risks.
Low or No Risks	Low risks are acceptable.

Box 4: Example of categorisation of final computation of climate adjusted risk for the asset

Categorisation of final computed Climate adjusted risk

- The computed climate adjusted risk values
  - lower than 25th percentile value, at low risk is < 55
  - between 25th and 75th percentile values, medium risk is between 55 and 275
  - between 75th and 90th percentile values, high risk is between 275 and 300
  - between 75th and 90th percentile values, very high risk is >300

Example of categorisation for asset

Office building

- The computed climate adjusted risk for the event inundation due to climatic variable sea level rise and storm surge is given 300.
- As per the above-mentioned criteria of categorisation, the computed climate adjusted risk value is greater than 90th percentile value of the climate adjusted risk of all the assets.

Hence the assets office building with component inundation falls under **very high-risk** category.

- The computed climate adjusted risk for the component increase in the energy need due to climatic variable rise in temperature is 91.67.
- And it value is between 25th and 75th percentile values of climate adjusted risk.

Hence the asset office building with component increase in energy need falls in **medium risk** category.

The detailed calculation for all the assets and receptors is given in the **Annexure 3: Computation of Climate Risk for all the Assets**

1.2.3 Finalization of Climate Vulnerability and Adaptation Plan Report

The inputs received during online consultations are incorporated in the **Final Climate Vulnerability and Adaptation Plan Report.** This report presents the key assets which highly vulnerable to climate-related risks. Finally, an adaptation plan is enclosed recommends strategies to overcome the risks/vulnerabilities identified in the detailed assessment for WCT-1.

1.3 Description of WCT-1

As part of a major initiative to boost economic growth, the WCT-1, Colombo, Sri Lanka is improving the import and export capabilities of seaports along the coast of the state. As part of this effort, the Sri Lanka Port Authority (SLPA) has formerly issued to Adani Port Adani Port & Special Economic Zone Limited (APSEZ) a Letter of Intent (LOI) to develop the West Container Terminal (WCT) at Colombo, Sri-Lanka on a Build, Operate and Transfer (BOT) basis. The proposed quay wall will extend from the NW corner of the SCT in the South Harbour of Colombo Port, within the current western jetty line. (Figure 7)

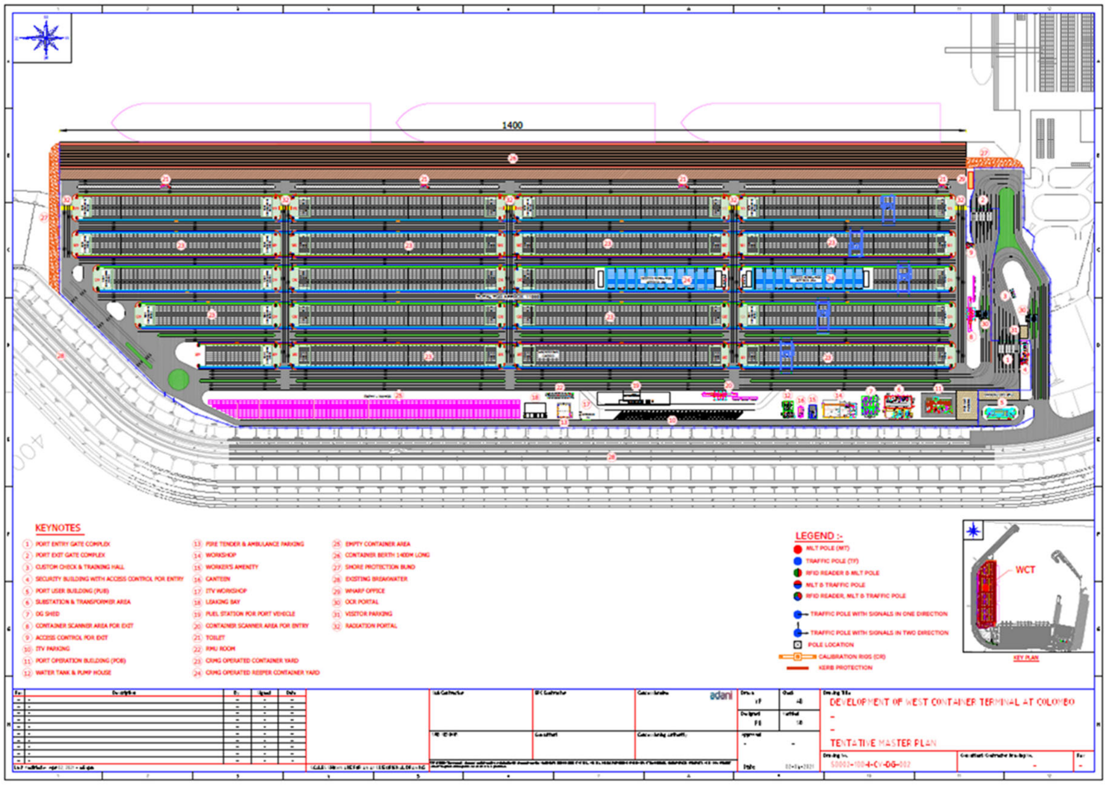


Figure 7: Layout of WCT-1

The WCT-1 is the most preferred regional hub for transhipment of Indian containers and mainline ship operators with 45% of Colombo's transhipment volumes originating from or destined to an APSEZ terminal in India.

1.3.1 Facilities in Requirement at WCT-1

1.3.1.1. Container Berth

- Development of total of 1400 m Container Berth. Level of the top of the Berth (+) 3.00m CD.
- Container Berth with block wall (supported on rock foundation at bed level) on the seaside with quarry run behind block wall along with steel pile underneath rear rail of RMQC and with pavement between two rail gauges.
- The berths shall cater to handling vessels with a maximum vessel size of 24000 TEU or 2,80,000 DWT to a Minimum vessel size of 500 TEU or 6500 DWT. The dredged bed level at the front of the berth shall be maintained at (-) 20.0m CD.
- RMQCs will have an outreach of 72m from the front rail centre the and front rail centre to the fender face is 5.55 m to handle 63 m beam vessels with extreme trim and a list of vessel conditions. Lifting height above wharf below spreader is 53 m. RMQC shall be a single trolley with a back reach of 20m. Under spreader, the load is 65T. RMQC rail gauge is 35 m, and the number of wheels is 8 no per corner.
- Design Dredge Level on waterfront shall be (-) 20.0m CD.
- Scour protection for avoiding the negative effect of the vessel's propeller on the Berth structure.

- Storm anchor and storm tie-down for RMQCs, as per requirement.
- Rubber moulded ladders for emergency pilot boarding.
- Design provision to accommodate the interface between the piled Berth and the
- Reclaimed Backup yard without affecting the terminal operations, for any differential settlement to occur between the 2 structures.
- Capital Dredging for West Container terminal operations and Backup area reclamation as per requirement shall vary from (-)24.0m CD to (-)26.2m CD, looking to firm strata for bearing of Gravity type, Block wall Structure.

1.3.1.2. Container Yard

Area Development

- Total Container stack Yard area is about 64.1 Hectares including building area, truck parking, gate complex, fuel station and other utilities.
- Construction of shore protection bunds on either side of the jetty to retain the reclamation.
- Development of container yard with paver block including pits for cables, electrical & conduits. Since reclamation of backup yard is proposed using dredging sand (hydraulic filing), all the container yard components / civil structures / stack yard / buildings will be designed with shallow / open foundations. In case of any poor / loose sub soil is encountered post reclamation, the necessary / suitable ground improvement will be carried out.
- Development of gate area with parking, and adequate driving lanes.

Features

- Stacking Yard shall have CRMG crane configuration parallel to the quay length. Each CRMG block will have approximately 500 TGS.
- CRMGs shall be of specification as per requirement, 12 rows across 36.54m span, 1 over 6 high.

Reefers Blocks

- Separate Reefer monitoring platforms for separate sectional blocks providing access up to 5 high stacked containers.
- Reefer plugs at various levels above ground as per proposed numbers.
- Reefer racks will be for 5 high container stacks.
- Adequate DG backup for reefers to be considered overall yard DG set.

1.3.1.3. Storm Water Drainage System

- The hydraulic design for stormwater drainage system shall be carried out with respect to design rainfall.
- The RCC drains to collect surface runoff from yard area. The drain section shall be of closed drain with perforated slab. The drain in the yard where traffic movement may occur shall be covered and designed for with heavy vehicular movement.
- Storm water drain collection and disposal system for terminal area.

- Open drain with non-vehicular design wherever applicable. The location of drain shall be separated from vehicular movement area with provision of kerb wall at regular interval.
- Final outfall shall be connected to the sea at two locations. RCC box drain or Hume pipe outfall o sea below Berth / rock with flap gate at each outfall.

1.3.2 Analysis of Historical Data at WCT-1

Trend in temporal variations in annual mean climatic conditions for temperature and precipitation, and monthly variations in sea level rise are assessed for the site location using observed data.[3] The objective is to understand the long terms changes in the trends in the historical period which are likely to influence future climatic conditions and its subsequent impacts.

1.3.2.1 Temperature

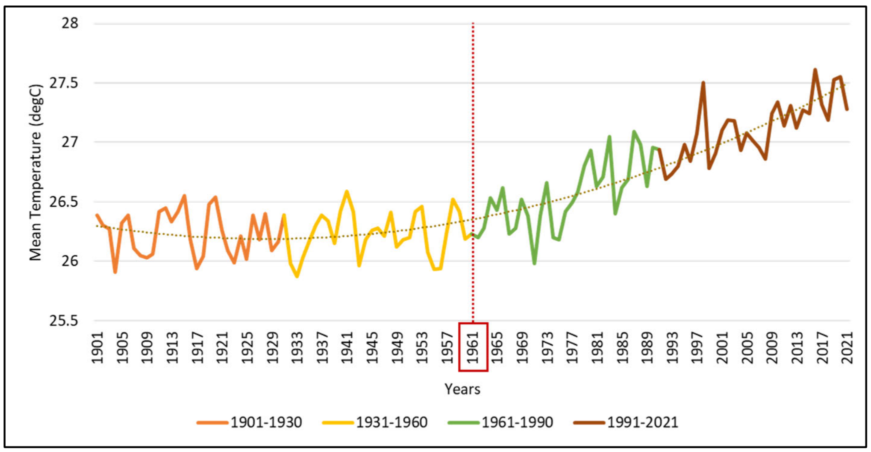


Figure 8: Trends in annual mean temperature(°C) at WCT-1

- Figure 8 shows the trend in annual mean temperature from 1901 to 2021 at WCT-1, Colombo. It is clearly observed that the fluctuations in temperature are quite stable and don't show any significant change in terms of their long-term annual mean temperature. However, a change point in year 1961 is observed post where the annual mean temperature shows a sudden increase which then continues to show an increasing trend till the present duration. This highlights the potential warming potential at same pace in future.

[3] https://crudata.uea.ac.uk/cru/data/hrg/; https://podaac.jpl.nasa.gov/dataset/ECCO_L4_GMSL_TIME_SERIES_MONTHLY_V4R4

1.3.2.2 Precipitation

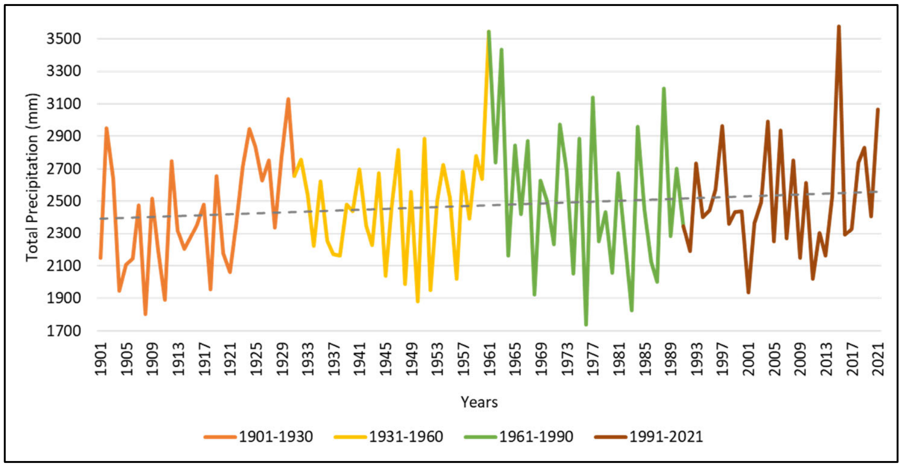


Figure 9: Trends in mean annual precipitation (mm) at WCT-1

- Figure 9 shows the trend in mean annual precipitation at WCT-1. The variability in precipitation is highly influenced by the temporal changes in temperature and other global phenomena and processes such as ENSO. Unlike temperature, changes in precipitation are more periodical. In case of Colombo, the variations in mean annual rainfall shows an increasing trend though the rate of change in precipitation is lower than the rate of change in temperature. Changes in annual precipitation can be attributed to either increase in total precipitation over the site or increase in number of heavy precipitation events.

1.3.2.3 Sea Level Rise

Figure 10 shows trend in monthly variations in sea surface height versus sea level anomaly from April 1992 to September 2022.

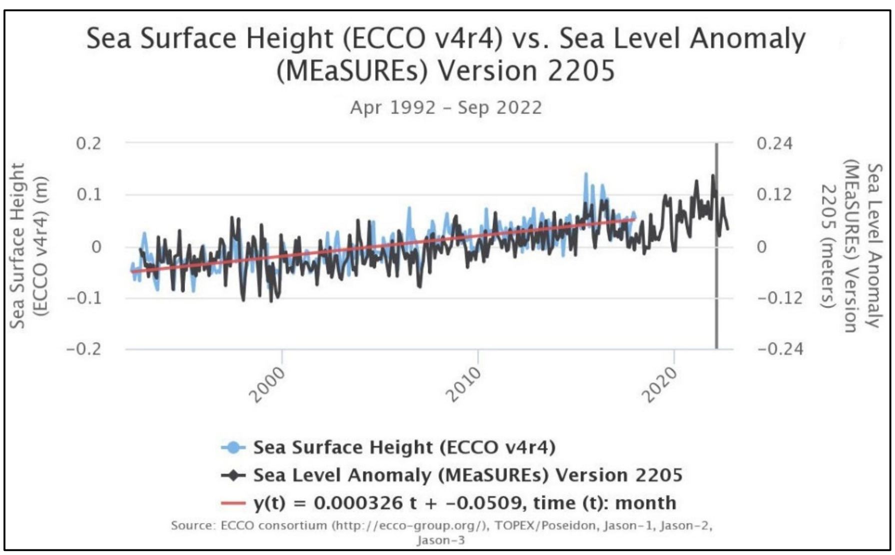


Figure 10: Trends in Sea Surface height (m) and Sea Level Anomaly (m)

- It is observed that sea level continues to rise at a rapid rate which is in tandem to the changes in mean temperature. Rise in global and regional temperature has resulted in higher rate of melting of polar ice which in turn is causing into rising sea levels. This increasing trend in sea level makes coastal regions susceptible to submergence due to sea water intrusion and greater likelihood of coastal flooding.

From the assessment in trends for key climatic variables, it is important to assess the changes in climatic stressors for future time period using climate models-based projections.

1.3.3 Organization of the Final Report

This report is organized as follows:

- The background, approach and methodology are presented in **Chapter 1**
- **Chapter 2** describes the climate vulnerability assessment study for WCT-1, Colombo (Sri Lanka).
- **Chapter 3** describes the structure of the Adaptation Plan.
- **Chapter 4** presents the analysis of climate risks, proposed adaptation plan and analysis of adaptation measures for WCT-1.
- **Chapter 5** highlights way forward on prioritization and evaluation of adaptation measures, along with a proposed institutional framework

2 Impacts of Climate Change on Ports

This section emphasizes on the likely impacts of the changing climate on ports. The climatic factors impacting ports are summarized below (Table 9).

Table 9 Climatic factors that impact ports.

					
Extreme Heat/ Heat Waves Extreme temperatures are location specific. Heatwaves are prolonged periods of excessively hot weather. Likely increases in extreme air temperature and heatwaves in most areas.	**Drought** A prolonged dry period in natural climate cycle which results in a shortage of water. Likely increase in drought conditions in some areas through a warming of air temperature and decrease in precipitation	**Extreme Precipitation/ Flooding** Extreme precipitation events are location specific and can cause flooding when downpours exceed the capacity of water sink such as river drainage systems. Uncertain climate projections are expected to intensify in some regions.	**Storm Surge** The difference between the actual water level under the influence of a meteorological disturbance (storm tide) and the level which would have been attained in the absence of the meteorological disturbance (i.e. astronomical tide). Sea level rise exacerbate storm surge height.	**Sea Level Rise** Anticipated sea level rise changes due to the greenhouse effect and associated global warming. Leads to changes in erosion and accretion, long term inundation, exacerbate storm surge and tsunami height.	**Storms** Severe weather systems involving high speed winds such as hurricanes, tropical cyclones or harsh winds

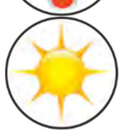
It is important while designing or rehabilitating infrastructure systems to follow **certain principles that will help create greater resilience by planning for the current climate as well as the climate scenarios projected for the entire design life of the port**.

These principles are as follows:

1. Impacts are a function of current and future climate variability, location, port design life, function, and conditions.
2. Climate change can cause direct damage to port and indirect impacts including loss of service.
3. Climate change may affect the availability of resources associated with the port.
4. Current infrastructure design is based on historical data and experience.

5. Climate variability or increased frequency of extreme events may mean that infrastructure is no longer optimally designed for even short-term purposes.
6. Uncertainty in climate projections should not prevent them from being considered in design.

Table 10 Illustrative climate change impacts and risks

Climate Factors		Impacts and Consequent Risk
Navigation and Berthing		
	**Sea Level Rise**	• Rising sea levels will decrease clearance under some bridges, reducing the number of low water level windows available for large vessels.
Materials Handling		
	**High Wind and Storms**	• High winds can restrict port operations and many port operations have critical thresholds relative to wind speeds. • Cranes cannot be moved when wind speeds are over certain threshold i.e. 22-27 knots
	**Extreme Precipitation/ Flooding**	• Heavy rain can affect a crane's electrical systems and the costs associated with these impacts can be as crippling and costly as the physical collapse of cranes. • Port operability is reduced during heavy downpours because of the risk of goods spoilage, for goods that are perishable or non-water resistant.
	**Extreme Heat/ Heat Waves**	• Increased temperatures would lead to higher energy costs, as more air conditioning is used in office buildings and refrigerated containers.
Vehicles Movement/Transport of goods		
 	**Extreme Heat/ Heat Waves**	• Longer periods of extreme heat, combined with traffic loading, speed and density can soften asphalt roads, leading to increased wear and tear. • Road surfaces are likely to require greater maintenance in higher temperatures. • Extreme heat can cause deformities such as buckling of rail tracks, at minimum resulting in speed restrictions and, at worst, causing derailments
	**Extreme Precipitation/ Flooding**	• Changes in precipitation can affect soil moisture levels, which can impact slope stability and result in more landslides affecting roads and railways embankments. • If soil moisture levels become too high or too low, the structural integrity of roads, bridges and tunnels can also be compromised.
Infrastructure, Building and Equipment		

	**Extreme Precipitation/ Flooding**	• Increased frequency of coastal and riverine flooding will severely impact the built infrastructure. • Electrical equipment is more vulnerable to flooding, which can lead to arcing and short-circuits. • Fast-moving waters can physically dislodge containers and other cargo from open storage areas, knock down buildings, destroy equipment, damage quay and pier structures.
	**High Wind and Storms**	• Extreme winds, storms or tropical cyclones can damage unreinforced terminal structures, such as metal warehouses which are lightweight & have large surface areas, and port equipment.
Workforce		
  	**Extreme Precipitation/ Flooding** **Extreme Heat/ Heat Waves** **High Wind and Storms**	• Changing climatic conditions (such as higher temperatures, heavier rainfall and increased wind speeds) can **create additional health and safety risks for port workers**, especially in relation to hazardous activities (e.g. flammable material storage and handling, use of machinery). • Climate change could **increase the risk of chemical or oil spills** at ports and from ships in harbours, in extreme rainfall, wind and/or wave conditions. • Climate change **effects on pollution risk** from port activities have the potential to **affect the health and livelihoods of surrounding communities.**

2.1 Vulnerability Assessment

This chapter delves into the concept of vulnerability assessment as given by the Intergovernmental Panel on Climate Change (IPCC), definitions of its components, scope of study, the broad methodology, assumptions, data sources for the study.

The chapter also discusses the scenario for which WCT-1 is assessed for its vulnerability to climate change.

2.1.1 Concept of Vulnerability Assessment

The IPCC Fourth Assessment Report (AR4)[4] describes vulnerability as

> "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity."

Vulnerability of a system is considered as **a function of exposure, sensitivity and its adaptive capacity** as depicted below (Figure 11).

[4] https://library.harvard.edu/collections/ipcc/docs/27_WGIITAR_FINAL.pdf

$$Vulnerability\ Index = f(exposure\ index, sensitivity\ index, adaptive\ capacity\ index)$$

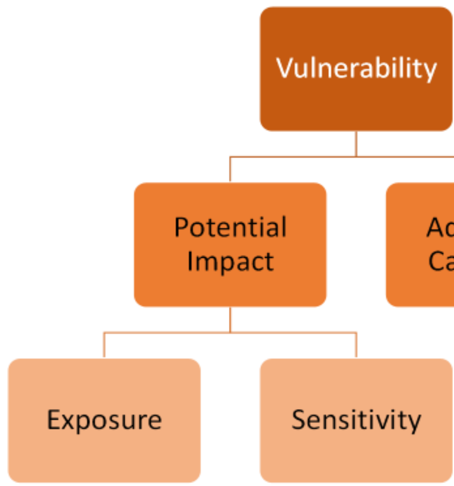


Figure 11 Conceptual framework of vulnerability

2.1.2 Definitions of Components of Vulnerability

The following definitions are most relevant to the APSEZ ports:

- **Exposure:** the extent to which a system comes in contact with the climate variables such as temperature, precipitation, sea level rise, etc. Section 2.2 elaborates on the exposure variables and their aggregation with respect to the scope of this study.

- **Sensitivity:** the degree to which a built, natural or human system is directly or indirectly affected by or responsive to changes in climate conditions or related impacts. Sensitivity can be ecological, economical, sectoral, location based, asset based, etc. Section 2.3 gives details of relevant sensitivity variables for this study.

- **Adaptive capacity:** relates to infrastructure and built assets, describes the degree to which the physical elements of a system can absorb, withstand, or respond to climate change impacts without incurring damage.

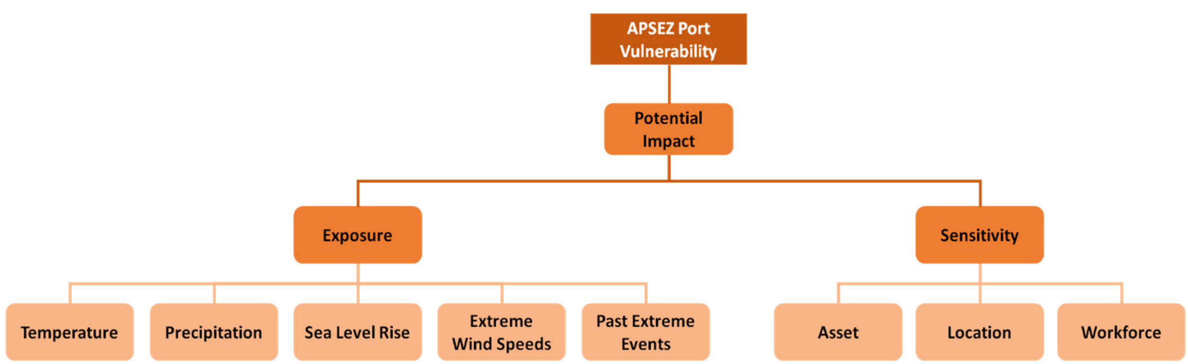


Figure 12: Different components of climate vulnerability assessment

2.1.3 Scenarios for Vulnerability Assessment

WCT-1 is assessed for climate change vulnerability corresponding to two scenarios.

- There are **two mutually exclusive temporal scales** i.e., short-term and long-term that correspond to 2021-2050 and 2041-2070 respectively.
- Intermediate GHG emission scenario is considered for the assessment. Description of the GHG emission scenarios is provided in Box 5.

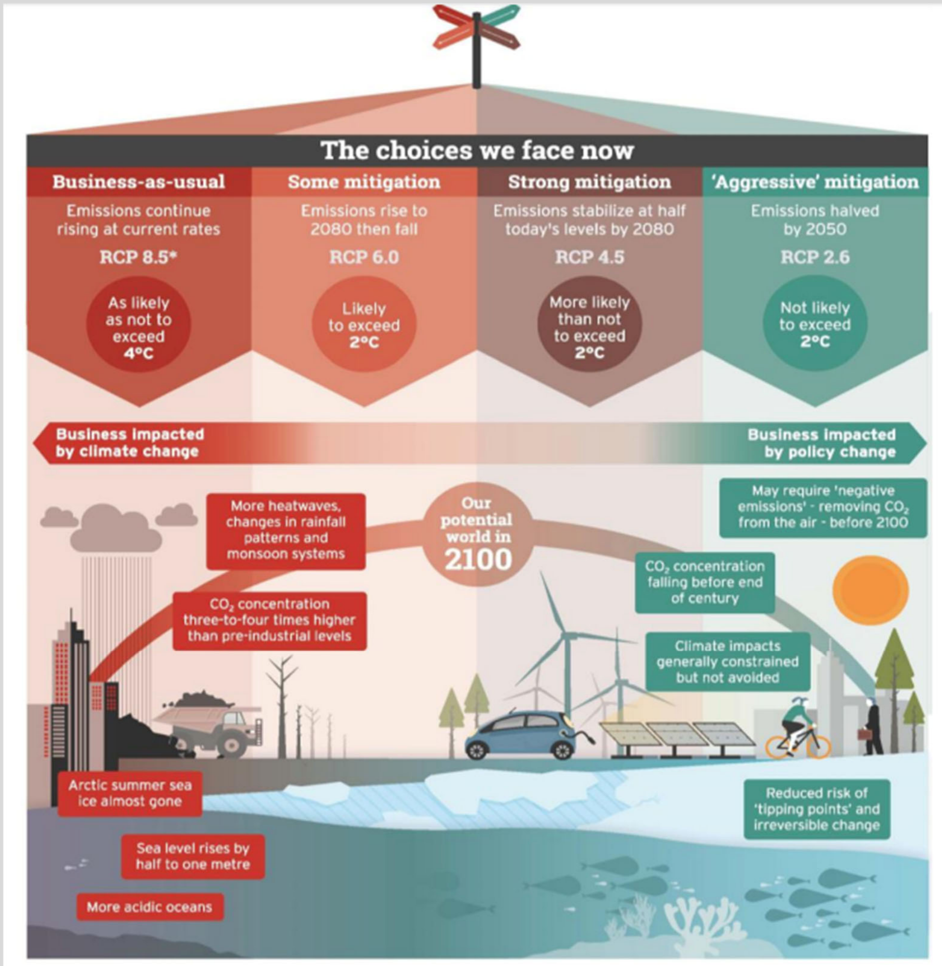
Summary of the scenarios considered in this study are given below (Figure 13).

Figure 13 Scenarios considered for climate change vulnerability assessment for the study.

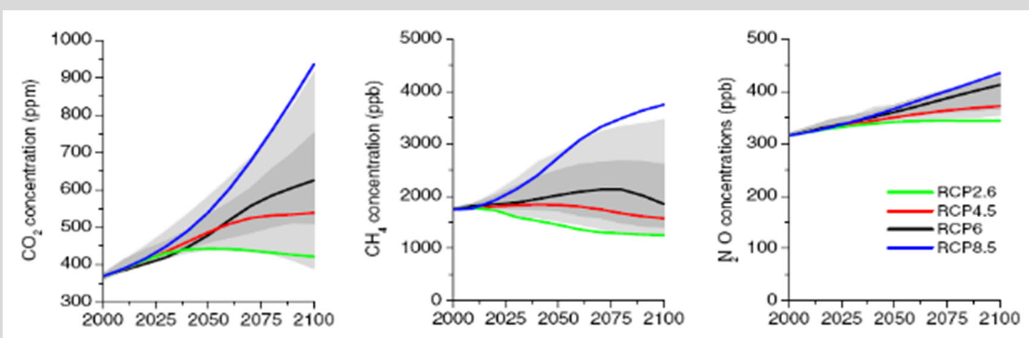
Box 5 Description of the GHG emission scenarios

The IPCC explores four potential future scenarios, also called Representative Concentration Pathway (RCP), depending on the policies governments adopt to curtail GHG emissions. These scenarios consider information on ***Land use & Land Cover, GHG Emissions, GHG Concentrations, Ozone & Aerosol Concentration Fields.*** A brief description of the four most widely cited and used scenarios is given below:

- **RCP 8.5**: It is the high-emissions scenario where no policy changes are made to reduce emissions and characterized by rising concentrations of the GHGs in atmosphere. It is aligned with current policies or Business-as-Usual scenario.
- **RCP 6.0:** represents a high-to-intermediate emission scenario where GHG emissions peak around 2060 and then decline through rest of the century.
- **RCP 4.5**: represents an intermediate-emissions scenario, representing ambitious emissions reductions with the peaking of GHG emissions circa 2040. Even with the ambitious targets set under this scenario, it fails to meet the target of 2°C limit/1.5°C aim agreed on in the Paris Agreement.
- **RCP 2.6**: It is the only IPCC scenario in line with the Paris Agreement. This RCP represents a situation where the peak GHG emissions occur around 2020 and then decrease linearly to become net negative by 2100. It is observed that RCP 2.6 is not possible to achieve.



RCP Scenarios **(Source: IPCC)**



Concentration of major GHGs under different Scenarios[5]

[5]https://skepticalscience.com/docs/RCP_Guide.pdf

2.2 Climate Exposure Analysis

This section explains the methodology adopted for computing climate exposure for a WCT-1 under selected scenarios. Individual components of the overall exposure are calculated. Finally, the results are discussed with inferences for decision-making.

The climate exposure observed at WCT-1 for a given scenario depends on the impacts of temperature, precipitation, sea-level rise, extreme wind speeds and past weather events (shown in Figure 14). The changes in each climatic exposure indicators and its impacts are compared for projected time period with respect to the baseline period.

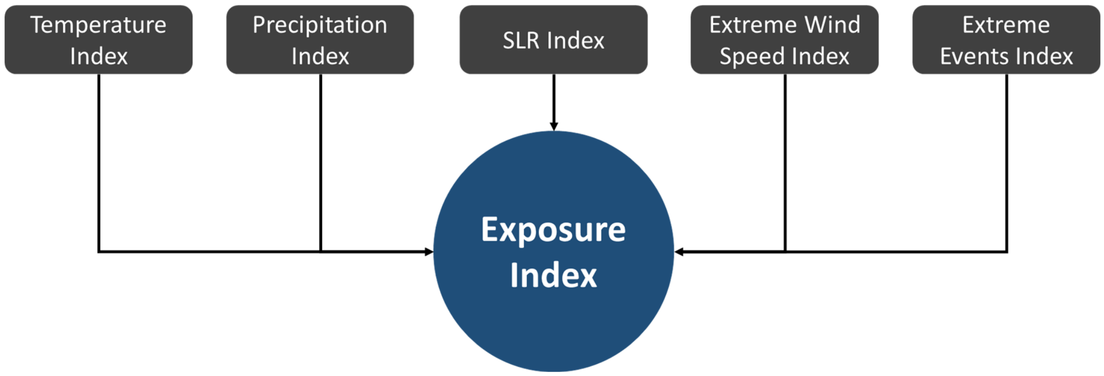


Figure 14 Components of climate exposure for a given location and scenario.

The outcomes of climate exposure analysis are explained in the following sections.

2.2.1 Temperature

This section elucidates the assessment of changes in temperature in the climate change vulnerability assessment for the two scenarios.

Projected essential and extreme temperature variables are determined for each scenario. These are listed below:

Table 11 List of essential and extreme temperature variables

Essential Temperature Variables	Extreme Temperature Variables
• Annual maximum temperature in °C (T_{max}) • Annual minimum temperature in °C (T_{min})	• Warm nights in % days (TN-90p) • Maximum night-time temperature in °C (TNx) • Warm days in % days (TX-90p) • Maximum day-time temperature in °C (TXx) • Warm spell duration indicator in days (WSDI)

*** It should be noted that the above parameters are expressed as (i) multi-model average value for the select emission scenario and time frame, and (ii) change with respect to the reference period of 1981-2010**

The changes in selected variables under projected scenario with respect to their baseline period are assessed for all variables. It is essential to understand these changes to identify possible impacts that the extreme temperature variables are likely to cause in port premise. Some of the likely impacts are listed below.

Table 12 Possible impacts due to extreme temperature

Parameter	Possible Impacts
TN-90p	Human Heat Stress
TNx	Human Heat Stress
TX-90p	Human Heat Stress
	Increase in water demand
	Infrastructure damage-Housing. Road
	Decreased efficiency of power generation
	Higher energy demand
	Forest Fires
TXx	Human Heat Stress
	Increase in water demand
	Infrastructure damage-Housing. Road
	Forest Fires
WSDI	Human Heat Stress
	Increase in water demand
	New Pests and Diseases
	Infrastructure damage-Housing. Road
	Forest Fires

Key Findings

- A warmer climate is observed at WCT-1 in future scenario for both time periods with warming of up to 1.4℃ in annual average temperature under long-term time period.
- Warmer nights and day are observed with rise of 1-1.4℃ increase in night-time (TNx) and 0.9-1.3℃ rise in maximum day time (TXx) temperature.
- Increasing temperature extremes tend to pose both local and global impacts. Higher temperature exposure causes greater damage to the port assets by reducing the longevity of the machinery. Further, warmer working environment is likely to reduce the efficiency or deployed workforce, thus increasing the energy demand of the port to overcome associated heat-stress.

Table 13: Multi model ensemble (MME) temperature values for the selected scenarios

Time frame	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
Baseline period	30.9	23.4	10.7	26.2	10.7	35.5	282.1
Short-term period	31.8	24.4	10.7	27.2	10.7	36.4	310
Long-term period	32.2	24.9	10.7	27.6	10.7	36.8	272.2

The inter-model variability for each temperature variable among all models is provided in the

Annexure 4a: Model wise Climatic exposure indicators for temperature, precipitation, SLR, CEWL and Wind speed

2.2.2 Precipitation

This section elucidates the assessment of changes in precipitation in the climate vulnerability assessment for the two scenarios at WCT-1.

Projected essential and extreme precipitation variables are determined for each scenario using outputs from 10 regional climate models. These are listed below:

Table 14 List of essential and extreme precipitation variables

Essential Precipitation Variables	Extreme Precipitation Variables
• Annual precipitation in mm (PPT)	• Consecutive dry days in days (CDD) • Consecutive wet days in days (CWD) • Number of heavy precipitation days (R10) • Very wet day precipitation in mm (R-95p) • Extremely wet day precipitation in mm (R-99p) • Maximum 1-day precipitation in mm (R-X1) • Maximum 5-day precipitation in mm (R-X5)

*** It should be noted that the above parameters are expressed as (i) average value for the select emission scenario and time frame, and (ii) change with respect to the reference period of 1981-2010**

The changes in selected variables under projected scenario with respect to their baseline period are assessed for all variables. It is essential to understand these changes to identify possible impacts that the changes in overall precipitation pattern and extreme precipitation events are likely to cause in port premise. Some of the likely impacts are listed below.

Table 15 Impacts due to extreme precipitation conditions

Parameter	Possible Impacts
CDD	Possibility of Drought
	Human Heat Stress
CWD	Water borne diseases
	Infrastructure damage-Housing. Road
	Threat to Water Resources Infrastructure
R10	Landslide due to high soil moisture content
	Water borne diseases
R-95p	Flood due to high intensity 1-day rain
R-99p	Flood due to high intensity 1-day rain
	Landslide due to high soil moisture content
	Infrastructure damage-Housing. Road
	Structural damage threat to Water Resources Infrastructure
R-X1	Flood due to high intensity 1-day rain
	Landslide due to high soil moisture content
	Infrastructure damage-Housing, Road
	Reservoir sedimentation
	Structural damage threat to Water Resources Infrastructure
R-X5	Flood due to high intensity 5-day rain
	Landslide due to high soil moisture content

Parameter	Possible Impacts
	Infrastructure damage-Housing. Road
	Structural damage threat to Water Resources Infrastructure

Key Findings

- Drier climatic conditions persist in future time periods due to decrease in mean frequency and amount of precipitation over Colombo region. This can be attributed to the decrease in average number of consecutive wet days (CWD) by 7-8 days in short-term and long-term future climatic conditions. This highlights the likelihood of water stress conditions over the surrounding areas, therefore increasing vulnerability to regular water availability throughout the year in future climatic conditions.
- A decrease in average number of extreme precipitation days (R10 and R20) and precipitation amount during extreme precipitation events (R95p, R99p) are observed with respect to baseline period, but the decrease is more prominent in short-term period in comparison to long-term period. This highlights fewer drier conditions over WCT-1 under long-term period (2041-2070) scenario.
- However, an increase in magnitude of 1-day extreme precipitation event is observed for both the time periods (up to 10% increase for long-term period). This observation reflects the possibility of high chances for flash flood kind of conditions due to high intensity (higher precipitation magnitude in terms of amount of rainfall received) short duration rainfall events. Such flash flood conditions may pose significant amount of damage to the ports experiencing even though the port is designed for extreme precipitation events based on historical data. It is highly likely for high return period events (such as 1 in 50 year or 1 in 100 year) to shift towards more frequent low return period events (1 in 2, 1 in 5 or 1 in 10 year). Therefore, it is important to incorporate the potential impacts of climate change while designing the port infrastructure at WCT-1.

Table 16: Multi model ensemble (MME) precipitation values for the different time frame

Time frame	Ann.PPT_ Mean (mm)	CDD_ Mean (days)	CWD_ Mean (days)	R10_ Mean (days)	R20_ Mean (days)	R95p_ Mean (mm)	R99p_ Mean (mm)	RX1_ Mean (mm)	RX5_ Mean (mm)
Baseline period	2414.3	20.3	42.09	76.84	26.3	643.5	264.4	124.4	270.9
Short term period	2139.3	26.1	34.2	70.6	24.3	568.2	239.9	125.9	254.6
Long term period	2236.9	24.4	33.7	73.0	26.4	609.7	259.8	135.8	274.3

The inter-model variability for each precipitation variable among all models is provided in the in the

Annexure 4a: Model wise Climatic exposure indicators for temperature, precipitation, SLR, CEWL and Wind speed

2.2.3 Sea level Rise

This section elucidates the assessment of changes in sea level at proposed site for WCT-1 in the climate change vulnerability assessment for the two scenarios.

Projected essential and extreme sea level rise parameters are determined for the ports**.** These are listed below.

Table 17 List of essential and extreme SLR variables

Essential SLR Variables	Extreme SLR Variables
• Annual average SLR in cm (SLR-50p) • Median 50-year return period coastal extreme water level in cm (CEWL-50p)	• Annual extreme SLR in cm (SLR-95p) • Extreme 50-year return period coastal extreme water level in cm (CEWL-95p)

*** It should be noted that the above parameters are expressed as (i) absolute value for the select emission scenario and time frame, and (ii) change with respect to the reference period of 1995**

The changes in selected variables under projected scenario with respect to their baseline period are assessed for all variables. It is essential to understand these changes to identify possible impacts that the changes in sea level and coastal extreme water level are likely to cause in port premise. Some of the likely impacts are listed below.

Key Findings

- Figure 15 shows the deviation is month-wise mean sea level for short-term and long-term scenarios with respect to the baseline period. On an average a rise of 18-33 cm is observed from short- to long-term climate scenario with maximum positive deviations during onset and retreat monsoon months for Colombo, Sri Lanka. The SLR is estimated to reach nearly 109 cm with respect to the baseline period for the region at which WCT-1 site is being developed.[6] This observation highlights the likelihood of exposing port assets to significant damage due to plausible intrusion of sea water into the port premise. The month wise values for sea level rise are mentioned in

[6] https://slr.climsystems.com/#6.93,79.85

- Annexure 4a: Model wise Climatic exposure indicators for temperature, precipitation, SLR, CEWL and Wind speed

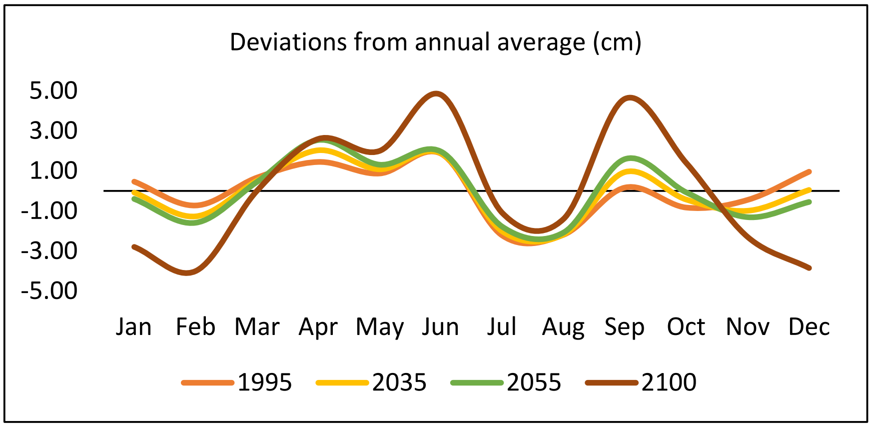


Figure 15: Monthly deviations in sea level from yearly mean in future climatic conditions (2035s and 2055s) in reference to baseline (1995s) for WCT-1

- Maximum deviation in sea level is observed during early monsoon period and decreases during July and August following the annual climatology of precipitation pattern over Colombo, which again start to peak during September and October. This thrusts upon the need to account for seasonal impacts of climatic exposure while devising adaptation strategies.
- The median values of SLR (SLR50p) increases from 18.5 cm to 32.9 cm from 2021-2050 to 2041-2070 showing high likelihood of seawater intrusion due to rising water level. Similarly, extreme SLR (i.e., SLR95p) increases by 23.37 cm from 2021-2050 to 2041-2070. (Table 18)
- Under short-term scenario (2021–2050), it is projected that the 1 in 50-year water levels will have increased 0.28 m on 50th percentile (CEWL-50p) for RCP4.5, and WCT-1 may experience increases of up to 0.42 m in long-term scenario. In terms of extreme conditions for coastal extreme water levels (CEWL-95p) at WCT-1, the 1 in 50-year water levels may increase by 30.4-0.54 m in future climatic conditions. The change in return levels is largely driven by SLR which increases the likelihood of higher coastal water levels during extreme conditions like storm surges.
- Rising sea levels and coastal extreme water levels near WCT-1 have high potential to cause damage to the port assets during extreme weather conditions.

Table 18: Annual average values for sea level rise (SLR; at 50th and 95th percentile) under baseline, and future climate scenarios.

Time period	SLR in cm (SLR-50p)	SLR in cm (SLR-95p)
Baseline period	0.00	0.00
Short term period	18.50	30.54
Long term period	32.90	53.91

Table 19: Annual average values for 1 in 50 year-return period estimates for coastal extreme water level (CEWL) at 50th and 95th percentile under baseline, and future climate scenarios.

Time period	coastal extreme water level in cm (CEWL-50p)	coastal extreme water level in cm (CEWL-95p)

Baseline period	0.55	0.57
Short term period	0.83	0.91
Long term period	0.97	1.11

2.2.4 Extreme Wind Speed

This section elucidates the assessment of changes in extreme wind conditions in the climate change vulnerability assessment for the two scenarios.

Projected essential and extreme wind speed parameters are determined which are listed below.

Table 20 List of essential and extreme wind speed parameters

Essential Wind Speed Variables	Extreme Wind Speed Variables
• Median 50-year return period wind speed in kmph (EWS-50p)	• Extreme 50-year return period wind speed in kmph (EWS-95p)

*** It should be noted that the above parameters are expressed as (i) absolute value for the select emission scenario and time frame, and (ii) change with respect to the reference period of 2005**

The changes in selected variables under projected scenario with respect to their baseline period are assessed for all variables. It is essential to understand these changes to identify possible impacts that the extreme wind speeds are likely to cause in port premise. Some of the likely impacts are listed below.

- Decrease in stability- Fracture/fatigue.
- Operational delays in difficultly of handling the operations.
- Physical damage if assets

Key Findings

- Higher extreme wind speeds (EWS50p and EWS95p) are observed in near and far-future (both time periods) with extreme wind speed events (1 in 50-year return period).
- For period 2021-2050, EWS50p and EWS95p increases by 8.2 (13.8% increase in magnitude) and 11.3 kmph (15.4% increase in magnitude), respectively while it increases by 8.94 (14.38% increase in magnitude) and 12.12 kmph (16.6% increase in magnitude), respectively under long-term scenario (Table 21).
- Colombo is subjected to extremely high winds during mainly during monsoon and cyclonic disturbances due to recent frequent occurrence in the Arabian Sea and Indian Ocean.
- Assets at WCT—1 are highly susceptible to be damaged to very high and extremely high winds under projected scenario for both the time periods.

Table 21: Values of essential and extreme Wind speed parameter at different time period

Time period	Wind speed in kmph (EWS-50p)	Wind speed in kmph (EWS-95p)
Baseline period	62.33	73.12
Short term period	70.53	84.40
Long term period	71.27	85.24

2.2.5 Past Extreme Events Exposure

Past frequency data and average duration of extreme events for floods, landslides, cyclones, extreme winds, and droughts is procured from EM-DAT disaster portal for the baseline duration. The data is processed for extreme events occurring over Colombo city, or Colombo state in western province for estimation. Details for the selected extreme events is provided in **Annexure 5: Extreme events data**.

Key Findings

- Colombo experiences frequent flooding due to extreme monsoonal rainfall and storms or cyclonic disturbance. During the considered duration devastating floods of 2004 Tsunami are also taken into consideration for understanding type of extreme weather condition near WCT-1.
- It is observed that WCT-1 is highly susceptible to frequent flooding (with 23 riverine and flash flooding between 1981-2020) caused as a result of extreme precipitation, sea water intrusion, storm surges, and cyclonic disturbances with an average duration of 4.2 days. The surrounding area to WCT-1 is highly susceptible to landslides which occurs as a compound extreme event along with extreme precipitation events.

Table 22: Past extreme events in areas surrounding to WCT-1

Hazard	Average duration (days)	Number of events
Floods	4.12	23
Landslide	-	9
Storm/Cyclonic disturbances /High Winds	5	4

2.3 Climate Change Sensitivity Analysis

This section explains the methodology adopted for computing climate change associated sensitivity for WCT-1. **The assessment performed is for the assets, workforce and location of ports and the derived sensitivity is assumed to be constant for both scenarios**. Individual components of the climate sensitivity are discussed with meaningful inferences for decision-making.

The **climate sensitivity** observed at any given scenario **is dependent on assets at the port, the workforce and location of the port** (shown in Figure 16)

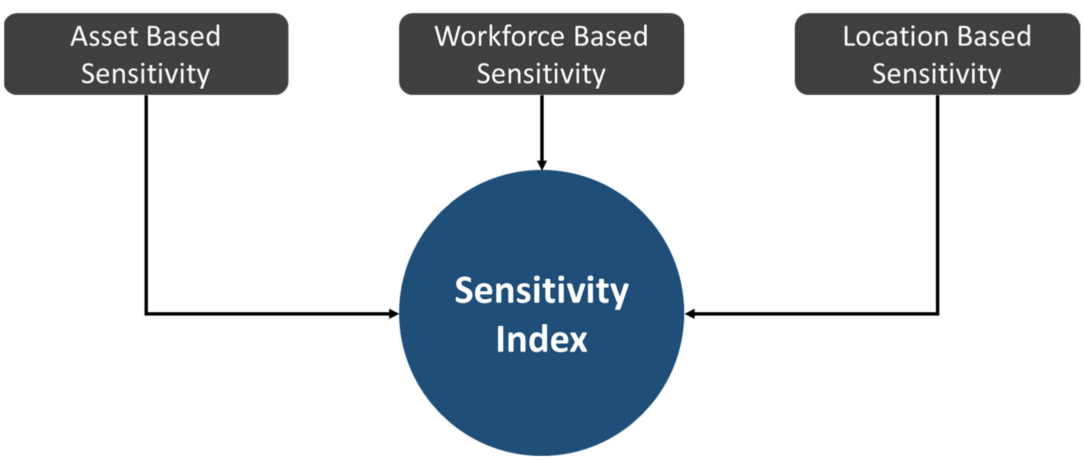


Figure 16: Components of sensitive index

2.3.1 Asset Based Sensitivity

Asset based sensitivity of any port is interpreted using data points on asset value and degree of automation (see Figure 17). However, only few data points are available for WCT-1, Colombo (Sri Lanka) as the port is yet in construction phase. The following sub-sections describe the step-by-step procedure adopted to ascertain the asset-based sensitivity.

Cargo-Type and Quantity

Container, dry and liquid cargo types have varying degree of risks due to storage and handling. Proportion of individual cargo types in the overall volume define the extent of port operations – and are factored in to determine the overall sensitivity index. At WCT-1, only container type cargos will be operated. Therefore, the climate-related risks associated with other cargo types which are susceptible to damages (delinquency, heat, corrosivity and handling) due to the changing climate, do not add additional sensitivity during their handling operations at WCT-1.

Asset Value

- Higher asset value signifies larger investments in ports' physical assets.
- Higher asset value implies greater sensitivity.
- The following steps are considered while computing the sensitivity score for the asset value.

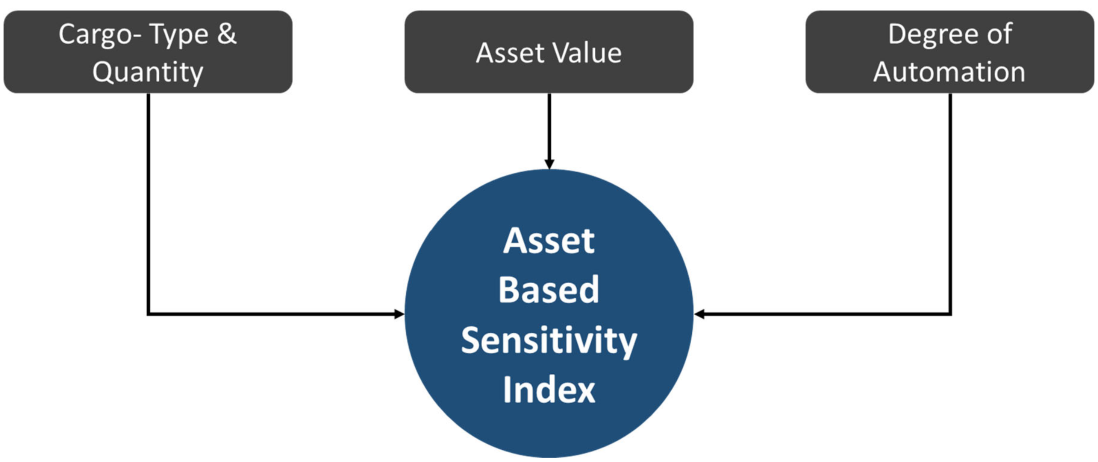


Figure 17: Components of Asset based sensitivity index.

Degree of Automation

- Higher degree of automation is prone to more work stoppages and instrument damages, during an event of extreme climate catastrophe.
- Higher degree of automation implies greater sensitivity.
- The following steps are considered while computing the degree of automation sensitivity score for each port. The WCT-1 is in construction phase; therefore, operation related indicators are not considered for the present study.

<u>Findings of Asset-based Sensitivity</u>

Post asset value for WCT-1 is approx. ₹ 4800 Cr that is susceptible to exposure by different climatic stressors such as extreme precipitation, temperature, and severely high winds. Apart from this, port assets are sensitive to damage caused by frequent inundation or seawater intrusion during storm surges and rising sea water level. Cargo handling operations are containers-based, thus reducing the climatic sensitivity caused by climate change in comparison to liquid or dry-based. The likelihood of damage to shipment is minimal under such circumstances. The projected cargo quantity at WCT-1 for FY25 is estimated to be 5.768 MMT, which is likely to rise to 14.084 MMT by FY26.

2.3.2 Workforce Based Sensitivity

Workforce based sensitivity is assessed using data points on age distribution of the employed workforce and the proportion of contracted labour (see Figure 18).

The location of housing for workforce was also envisaged in the analysis. As a greenfield project, the proposed workforce structure is assessed to understand the workforce-based sensitivity of WCT-1 to climate change.

The following sub-sections describe the details adopted to ascertain the workforce-based sensitivity.

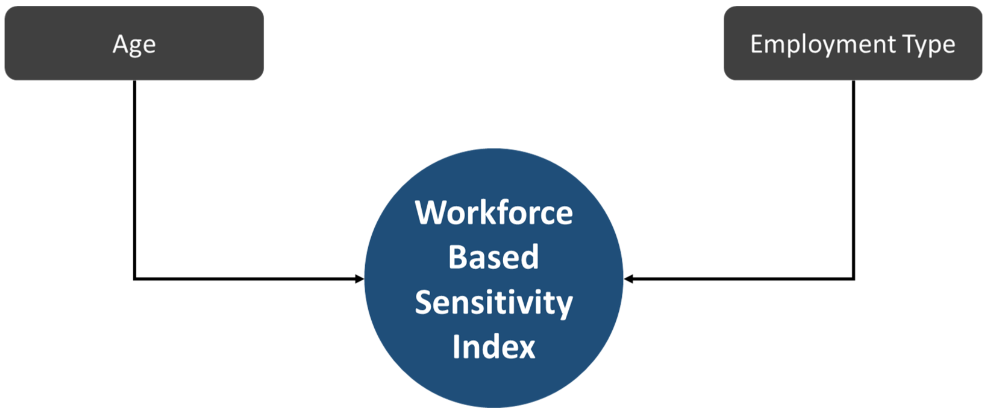


Figure 18: Components of workforce based sensitive index.

Workforce Age

- Certain age groups are more sensitive to the impacts of climate change than others.

Workforce Employment Type

- The assistance post disasters, including climate driven ones, are prioritized more towards employed workforce.
- Higher proportion of contracted labour implies greater sensitivity.

Findings

Workforce based sensitivity is driven by age distribution of employed workers and ratio of contractual workers. The port of Colombo has maintained a good ratio of more sensitive (<25 yrs. and >50 yrs.) to less sensitive, that is 5 per 100, employed population in comparison to Indian ports where as high as 37 per 100 employed population is observed with an average of nearly 1:5. Lesser sensitive population exposed to climatic stressors increases chances for relatively smoother execution of port operations due to less population experiencing health hazards due to climatic stress. However, greater percent of contractual workforce, that is ~68%, reflects the unnecessary burden that is likely to happen in cases of migration of contractual workers under climatic stresses like floods and heatwaves. Higher dependency on contractual workers thus increases the sensitivity of port operations to the impacts of climate change.

2.3.3 Location Based Sensitivity

Location based sensitivity is assessed using data points on low-lying areas at the port, changes in land use land cover (LULC) at and around the port, proximity to inland water bodies and damages incurred due to a climate catastrophe at the port site (see Figure 19). No damage-incurred data is available for WCT-1 as it is still under construction (that is, land reclamation phase).

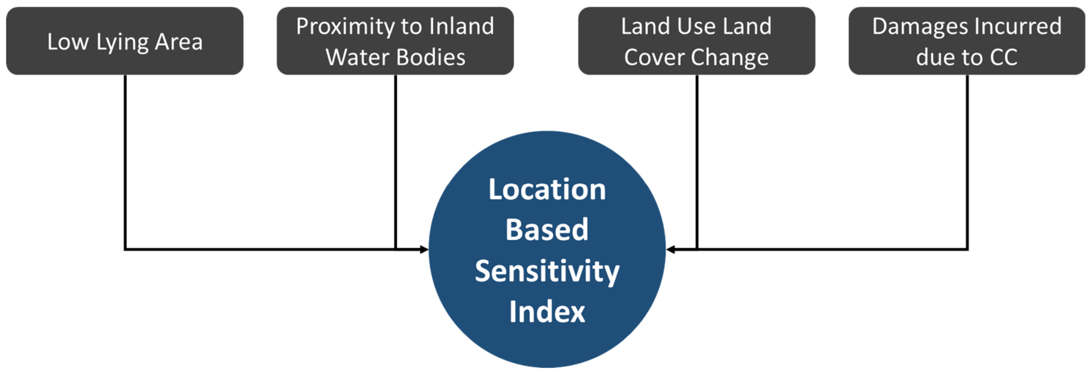


Figure 19 Components of Location based sensitivity index.

Low Lying Areas

- The severity of flooding (coastal or riverine) increases at ports with more low-lying areas. Thus, higher proportion of low-lying areas implies greater sensitivity of a port.

Proximity to Inland Water Bodies

Ports that are more proximal to inland water bodies are severely prone to riverine flooding during heavy rainfall seasons. Thus, higher proximity to inland water bodies implies greater sensitivity of a port. The method for estimation of sensitivity of WCT-1 due to proximity to an inland water body is provided in Annexure 1.

Land Use Land Cover (LULC) Change

- Anthropogenic activities at the port as well as surrounding areas result in Land Use / Land Cover (LULC) change is important so as to understand the changes in temperature conditions due to localised built-up area which creates additional heat stress conditions to the natural climate.
- Changes in LULC indicate pressure on the land resources – and hence is considered for location-based sensitivity. To understand the changes in LULC, Land Surface Temperature (LST) data from MODIS Terra is extracted and processed for May 2010 and May 2020.
- Night-time Land Surface Temperature (LST) is an indirect measure of surface emissivity. Hence, LST has been used as an indicator to represent changes in Land Use / Land Cover at areas located within 10 km radius of the proposed WCT-1 boundary.
- Changes in the landscape lead to change in the emissivity of the surface. Emissivity is the property of the surface to absorb solar radiation during the day and radiate it back to the atmosphere at night. For instance, surfaces made of concrete retain more heat during the day and radiate more heat at night, while barren land reflects most of the radiation that falls on it.

- The method for estimation of sensitivity of WCT-1 due to proximity to an inland water body is provided in Annexure 1: Detailed Location based Sensitivity Parameters Computation

Damages Incurred

- Damages incurred due to climatic events will be captured through data on the damages claimed by APSEZ in the past.
- Damages incurred signifies the sensitivity of the port to extreme climatic events.
- Higher value of damages claimed by APSEZ for a port implies greater sensitivity of that port.
- Since it is a greenfield project, no past damage incurred information is available for WCT-1.

Findings

Since WCT-1 is being developed over a reclaimed land over the sea, the estimation of location-based sensitivity provides observations about the areas surrounding to the port premise. It is important to understand the sensitivity of surrounding buffer area to estimate the indirect sensitivity of port operations due to disruption in connectivity with the mainland. Approximately 0.83 km^2 area fall under low-lying areas category within the port buffer area computed by considering 2 km^2 buffer around the layout location of WCT-1. Since it is a greenfield port, the port is under development and land reclamation phase. High area under low elevation in the mainland of Sri Lanka adjacent to proposed port location is likely to experience frequent water retention with higher disturbance to port operations during extreme precipitation climatic events and sea level rise. Higher frequency for short spell high magnitude events might cause flash flood kind of situation within the port premise. Proximity of port to inland water body (~5.2 km from river) is not that near thus reducing the likelihood of riverine flooding within the port premise. Based on LULC change assessment, a high urban/ concretised area (~20km^2) within 10 km buffer of port boundary is observed. The buffer area shows significant changes in land surface temperature over major fraction of its area with a change in night LST up to ±1.5 K (or ℃) (~19km^2) from 2010 to 2020. This shows high sensitivity of port (physical assets and workers) to changes in temperature extremes. High degree of such localised temperature change highlights the likelihood of greater difficulty in running port operations smoothly and maintenance of suitable conditions for good health of the working staff within the port premise.

3 Structure of Adaptation Plan

The Adaptation Plan has been developed to address the climate risks identified as Very High Risks and High Risks through adaptation measures for WCT-1. Each action plan for the port includes the following components:

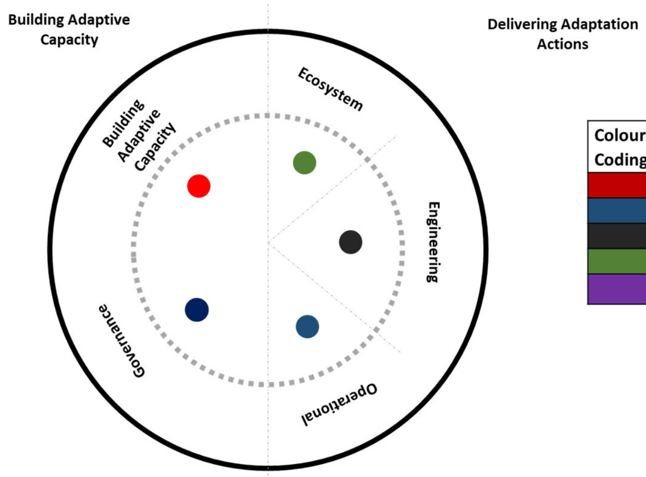
a) Asset Category
b) Component
c) Climate Variable (temperature, precipitation, high winds, etc.)
d) Risk Category (high and very high risk)
e) Existing Adaptation Measure
f) Proposed Adaptation Measures
g) Type of Adaptation Measure
h) Implementation Timeline (Short term, Medium Term, Long Term, Regular)
i) Cost (Low, Moderate and High)
j) Responsible department for implementing the action.

Description of components a) to e) have been covered in Section 1.2.2.1 to 1.2.2.5. The Proposed Adaptation measures as discussed during the workshop (Section 1.2.3.3) were listed across each climate risk identified. Each adaptation measure was further described by components g) to j) as illustrated in the sub-sections given below.

3.1 Type of Adaptation Measures

The adaptation measures proposed have been classified into:

a) **Building Adaptive Capacity (BAC)** measures such as conduct of detailed assessment studies, raising awareness, early warning systems, monitoring response, etc.
b) **Operational Measures (OP)** such as strengthen standard operating measures, periodic maintenance schedules, pre-post events monitoring check, etc.
c) **Engineering Measures (ENG)** such as civil work, establishment of physical interventions, etc.
d) **Eco-system Measures (ECO)** such as re-vegetation, afforestation, conservation, etc.
e) **Governance and Capacity Building (GOV)** measures



Colour Coding	Adaptation Strategy
	Measures that Build Adaptive Capacity
	Operational measures
	Engineered/hard structural solutions
	Ecosystem based adaptation measures
	Governance & Policy Related

Figure 20 Type of Adaptation Actions

3.2 Implementation Timeline

The adaptation measures have been classified into immediate, short, medium, long term and regular actions based on the nature of gap and its implement ability of actions in terms of human and financial resources required.

a) Immediate : 0-6 months
b) Short Term : 6 months – 1 year
c) Medium Term : 1-3 years
d) Long Term : 3-5 years
e) Regular : Ongoing

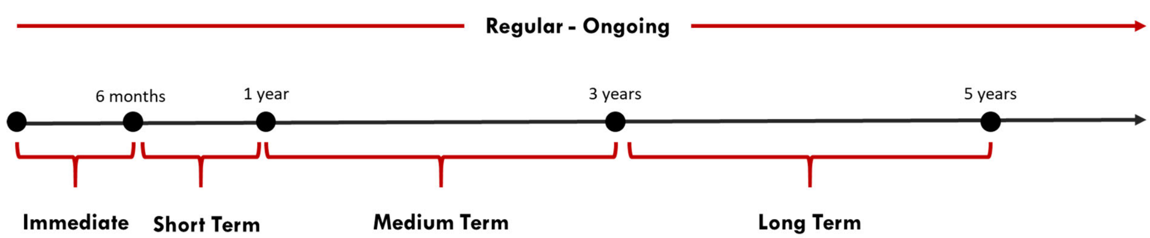


Figure 21 Timelines of Adaptation Measures

3.3 Cost

The cost for each of the adaptation measures have been given for the **WCT-1, Colombo (Sri Lanka)** on the basis of the following criteria:

a) **Low Cost:** Human resource time & low capital expenditure such as regular ongoing measures, capacity building & awareness generation, etc.

b) **Moderate Cost:** Minor capital expenditure or expenses towards engaging external technical services such as designing early Warning Systems, monitoring, retrofit & spares, etc.

c) **High Cost:** Major capital expenditure in implementing interventions such as engineering Interventions, remodelling/ rebuilding, eco-system services, etc.

4 Climate Change Risk and Adaptation Planning for WCT-1, Colombo

4.1 Climate Risks to WCT-1

The following subsections describe the climate risks identified for WCT-1 based on the methodology described in Section 1.2.2.5.

4.1.1 Risk Identification

Based on the climate risk assessment conducted for WCT-1, a total of 42 assets are categorised under **Very High and High risks** category (Refer to Figure 22). These risks are an indicator of where the adaptation strategies need to be focussed on.

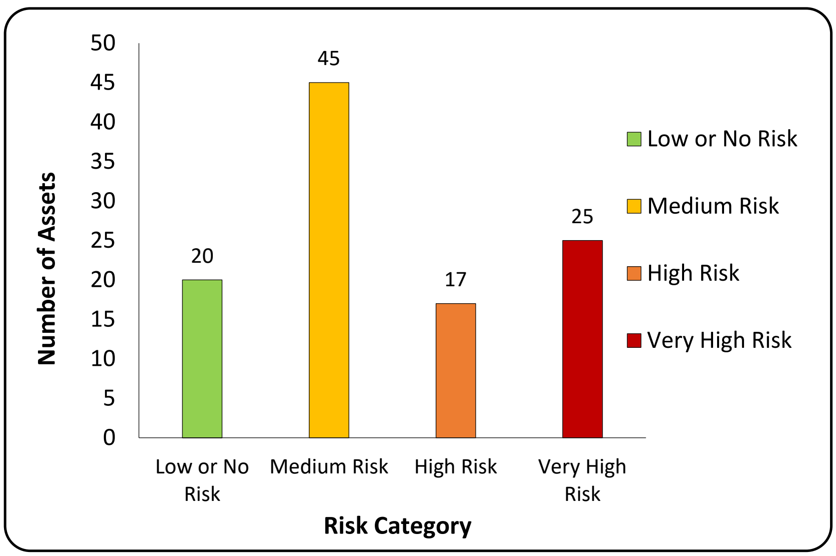


Figure 22: Number of assets under low, medium, high, and very high climate risk at WCT-1

4.1.2 Climate Stressors

Major climatic stressors causing impacts on assets under high and very high categories are categorised based on the outcomes of climate vulnerability assessment where different climatic variables are assessed and compared under the projected scenario with reference to the baseline period.

Table 23 below provides an example of the projected Climate Stressors that would cause a major impact to the operations and assets of the port.

Table 23 Future Climate Variables and their impacts to WCT-1

Climate Variables	Future Projected Scenario- RCP 4.5 Scenario (2021-2050)	Likely Impact to WCT-1 operations
Temperature 	Nearly **300 days** are warm in the projected scenario-which points towards very warm climatic conditions from the current baseline.	• Human Heat Stress • Increase in water demand • New Pests and Diseases • Infrastructure damage- Housing. Road
Sea Level Rise & Storm Surge 	The Extreme 50-year return period projected Sea Level rise is **18.5cm for SLR50p.** The magnitude of storm surges for 50-year return period median (**CEWL50p**) and 95th (**CEWL95p**) percentile values are 28 and 34 cm higher than the observed baseline. (1995)	• Inundation • Navigation & Berthing • Operational delays in difficulty in handling operations • Effect on Livelihood

Figure 23 shows the classification of number of assets under high and very high-risk category as per the type of climate stressors they are affected from under projected scenario. It is observed that assets under very high-risk category are likely to be predominantly affected by the impacts of sea level rise. Since it is a greenfield port, it becomes important to consider projected sea level information into account for elevating the port to a safer height.

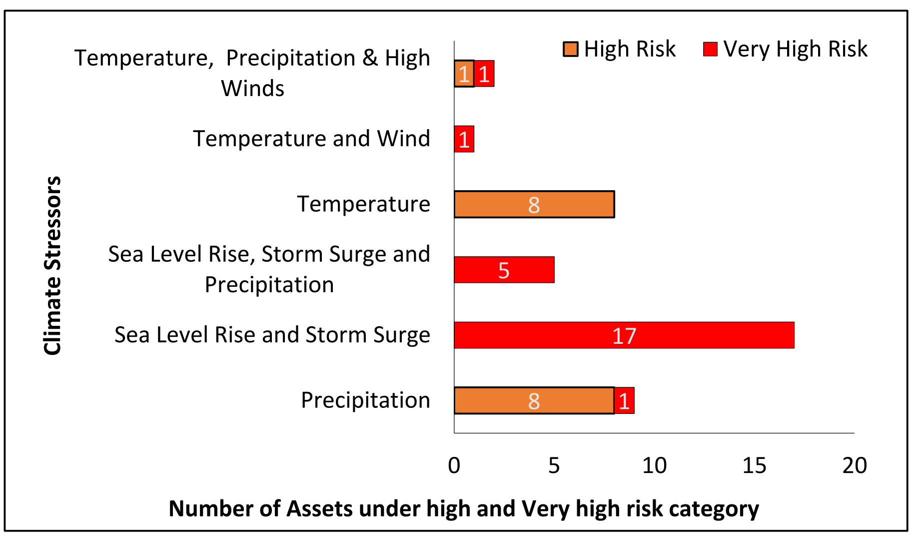


Figure 23: Number of assets (high and very high) under dominating (high and very high) climate stressors at WCT-1

4.1.3 Vulnerable Asset Categories

The assets under high and very high-risk categories are assessed to understand the plausible asset types which are likely to get affected by different climate stressor under projected scenario. The Vulnerable Asset & Receptor categories that demonstrate **very high** and **high risks** are described in Figure 24.

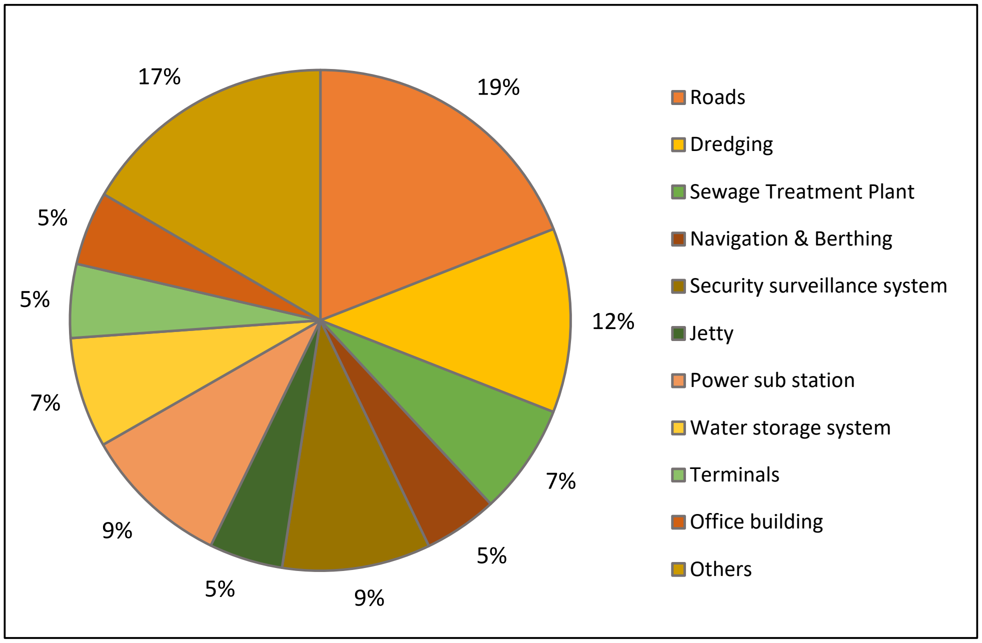


Figure 24: Percentage of asset classified under high and very high-risk categories at WCT-1

Out of the total assets under High and Very High Risks, 19% are associated with roads, followed by dredging, security surveillance system and power sub stations, which accounts for 12%, 9%, and 9% respectively.

Figure 25 shows the major consequences of potential climatic stress at WCT-1. It was observed that consequences which are likely to impact business at WCT-1 are primarily the delays due to Inundation (or flooding) of port premise or adjoining areas, followed by Fracture/Fatigue and Operational Delay/Stoppages.

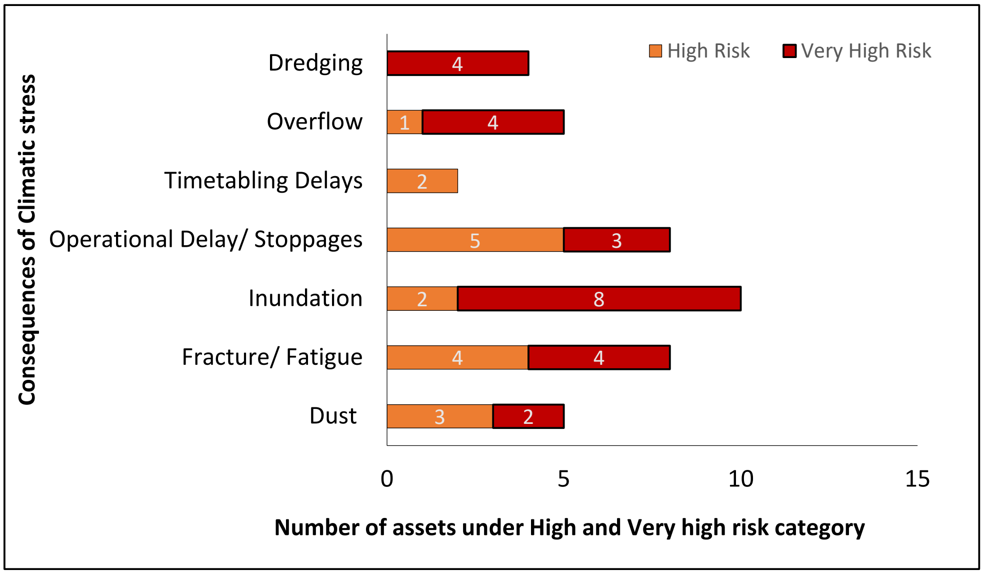


Figure 25: Number of assets under high and very high risk categories of consequences due to climate stressor

4.2 Adaptation Plan for WCT-1

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
Navigation & Berthing	Timetabling delays	Precipitation	**High Risk**	Early warning systems for extreme weather predictions for Precipitation, Sea waves and swells	BAC	Immediate	Low	Marine
			High Risk	Conduct site-specific climate risk studies	BAC	Short	Moderate	Marine
			High Risk	Use vessels with shallower /deeper drafts according to changing conditions.	OP	Long	High	Marine
Navigation & Berthing	Timetabling delays	Temperature	**High Risk**	Reduce manpower during heat waves and reschedule working hours	OP	Regular	Low	Marine
			High Risk	Having dedicated area for plantation to lower ambient temperature and provide shading	ECO	Medium	Moderate	Marine
			High Risk	Provide PPEs- creams, screen guards, cooling vests, cap, etc	OP	Immediate	Low	Marine
			High Risk	Medical insurance	GOV	Short	Moderate	Marine
Dredging	Adverse weather condition cause reduction in operational hours	Sea Level Rise, High wind speed, High current, High swells.	**Very High Risk**	Install Early Warning Systems (EWS)- helps in better planning and scheduling for dredging operations	ENG	Medium	Moderate	Dredging
			Very High Risk	Studies to determine the quantity of material to be dredged and availability of sufficient equipment at port	BAC	Regular	Moderate	Dredging

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
			Very High Risk	Implement sea level monitoring at key locations in the port.	OP	Regular	Low	Dredging
Cranes, Ship Unloaders, Stackers, Forklifts and Straddle Carriers Container	Operational delays in difficultly of handling the operations	Temperature	**High Risk**	Proper monitoring and supervision of workers esp. during peak temperatures of the day and providing accessible cool drinking water, sun protection gear (sunglasses, sunscreen etc)	OP	Regular	Low	Operation & Maintenance
			High Risk	Apply sun coating on roofs of heat radiating structures with using heat screens	ENG	Regular	Moderat e	Operation & Maintenance
Cranes, Ship Unloaders, Stackers, Forklifts and Straddle Carriers Container	Operational delays in difficultly of handling the operations	Precipitation	**Very High Risk**	Effective scheduling of heavy and strenuous work for cooler times of the day or year or distributing work to night shift staff	OP	Regular	Low	Operation & Maintenance
			Very High Risk	During summer (April, May, June) operations are suspended from 11 am - 3 pm under direct sun	OP	Regular	Low	Operation & Maintenance
Terminals	Operational delays in difficultly of handling the operations	Temperature	**Very High Risk**	Roof coating of control rooms and MCCs	ENG	Short	High	Operation & Maintenance
External Stakeholder	Difficulty in access port during floods	Precipitation	**High Risk**	Conduct flood risk studies to understand flooding related risks	BAC	Short	Low	Utilities

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
			High Risk	Prepare a regular de-silting plan before the onset of rains	OP	Regular	Low	Utilities
			High Risk	Increase diversity of clients from international regions less subject to storms	GOV	Medium	Moderate	Operation & Maintenance
			High Risk	Develop port facilities in response to changing customer demands and trade flows	ENG	Long	High	Operation & Maintenance
Internal Roads at Port	Inundation	Sea Level Rise and Storm Surge	**High Risk**	To develop the storm water drainage capacity to accommodate the future precipitation values.	ENG	Medium	High	Civil
			High Risk	Review the existing coastal barriers in construction phase for future sea level rise and extreme storm surges	BAC	Short	Low	Civil
Internal Roads at Port	Dust generation	Temperature and High Wind	**High Risk**	Adequate water sprinkling on unpaved area	OP	Regular	Low	Civil
			High Risk	Enough plantation on the sides of the road	ECO	Immediate	Low	Civil
Roads beyond Port	Inundation	Precipitation	**High Risk**	Provide the storm water drainage capacity across the roads as per the future precipitation values	BAC	Short	Moderate	Civil
			High Risk	Adequate storm water drainage capacity to accommodate the future precipitation values	ENG	Medium	High	Civil
Roads beyond Port	Inundation	Sea Level Rise and Storm Surge	**Very High Risk**	Conduct flood modelling study to find low lying areas	ENG	Short	Moderate	Civil

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
			Very High Risk	Provide Adequate storm water drainage capacity to accommodate the future precipitation values	ENG	Medium	High	Civil
			Very High Risk	Plantation on the sides of the road	ECO	Immediate	Low	Civil
Roads beyond Port	Muddy	Precipitation	**High Risk**	Regular cleaning of roads during rainy season	OP	Regular	Low	Civil
			High Risk	Regular maintenance of the road to repair depressions on the road surface	OP	Regular	Low	Civil
Galvalume sheets	Exposure of workforce to Noise	Precipitation	**High Risk**	Change to UPVC and FRP sheets	ENG	Medium	High	Civil
Drainage system, Culverts and sediment traps	Excessive Sedimentation	Sea Level Rise and Storm Surge	**Very High Risk**	Develop guide wall to stop running of silt into drains	OP	Medium	Moderate	Civil
			Very High Risk	Provision of deeper catch pits just before culverts. Regular cleaning of catch pits.	OP	Regular	Moderate	Civil

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
Water pumping system	Inundation	Sea Level Rise and Storm Surge	**Very High Risk**	A study to be conducted to assess the risk of inundation of water pumping system	BAC	Medium	Moderate	Civil
Power sub station	Damages to the fuel storage	Sea Level Rise and Storm Surge	**Very High Risk**	Adequate storm water drainage capacity around the power substation to accommodate the future precipitation values.	ENG	Medium	High	Civil
			Very High Risk	Auto tripping facilities to be installed	OP	Immediate	Moderate	Civil
			Very High Risk	Prepare a regular de-silting plan. Outlets to be checked, before heavy precipitation warnings, any blockages to be cleared instantly	OP	Regular	Low	Civil
Power sub station	Inundation	Sea Level Rise and Storm Surge	**Very High Risk**	Provide coastal barriers for future SLR and extreme storm surges	BAC	Medium	Moderate	Civil
			Very High Risk	Devote a dedicated area for the plantation on the shore to combat the sea level rise and storm surges	ECO	Medium	Low	Civil
Security surveillance system	Operational delays /stoppages	Temperature	**Very High Risk**	Regularly inspect flood lights and streetlights	OP	Regular	Low	Electrical & Security
			Very High Risk	Proper management guides for infrastructure development, considering design life and potential impact of future climate change.	BAC	Medium	Moderate	Admin
			High Risk	Early warning systems	BAC	Immediate	Moderate	Civil

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
Security surveillance system	Operational delays /stoppages	Sea Level Rise and Storm Surge	High Risk	Insulate electrical systems and make water resilient	OP	Short	Moderate	Electrical & Security
			High Risk	Initiate auto back-up prior to extreme weather event	OP	Immediate	Moderate	Electrical & Security
Electrical fittings (both inside buildings and outside)	Damages to the components	Sea Level Rise and Storm Surge	Very High Risk	Isolate electrical connections to reduce exposure to water and dust, reduced incidents of loss of power to reefers and consequent extra energy for re-cooling\refreezing	OP	Short	Moderate	Electrical & Security
			Very High Risk	Site safety and infrastructure checklists and plans for assessing damage following extreme events	BAC	Regular	Low	Electrical & Security
Office Buildings	Inundation due to sea water flooding	Sea Level Rise and Storm Surge	Very High Risk	During Construction phase long term measures under flood barriers or gates to all building	ENG	Short	High	Civil
			Very High Risk	To build a buoyant muti purpose building that would rest on pillars with buoyant tanks that raise it during floods.	ENG	Immediate	High	Civil
			Very High Risk	Design specifications to consider projected wind speeds & temperature. Quality of Building Material also needs to be recommended accordingly	OP	Short	Low	Environment
Open Land	Inundation	Precipitation	Very High Risk	Raise the elevation of the land to prevent inundation	ENG	Short	Moderate	Utlities
			Very High Risk	To build the high drainage capacity around the inundating land to prevent inundation	ENG	Medium	High	Utlities

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
			Very High Risk	Prepare a regular de-silting plan which is currently on a need basis	OP	Regular	Low	Utlities
Open Land	Inundation	Sea Level Rise and Storm Surge	Very High Risk	Provide coastal barriers for future SLR and extreme storm surges	BAC	Medium	Moderate	Utlities
			Very High Risk	Devote a dedicated area for the plantation on the shore to combat the sea level rise and storm surges	ECO	Medium	Low	Admin/HR/Associated
Water storage system	Inundation	Sea Level Rise and Storm Surge	Very High Risk	Adequate drainage to incorporate projected rainfall	ENG	Short	High	Fire & Safety
			Very High Risk	Consider catchment level landscape planning and ecosystem-based adaptation options for reducing risk of drainage overflow	ECO	Long	High	Fire & Safety
			Very High Risk	Capacity building of workforce	BAC	Regular	Low	Fire & Safety
Water storage system	Contamination	Precipitation	Very High Risk	Apply pressure to the water provider to maintain service levels.	GOV	Short	Low	Fire & Safety
			Very High Risk	Avoid applying fertilizers in the vicinity before heavy rains	OP	Regular	Low	Fire & Safety
			Very High Risk	Regular water quality testing regime	OP	Regular	Moderate	Fire & Safety
			Very High Risk	Install back up RO/filtration unit	OP	Medium	High	Fire & Safety
Hospital	BMW storage flooding	Precipitation	High Risk	Collection of BMW waste in waster proof container	OP	Regular	low	Environment
			High Risk	Temporary flood panels that can be installed quickly by maintenance staff.	ENG	Short	Moderate	Civil
			High Risk	Construction of flood barriers or gates to new buildings.	ENG	Short	High	Civil

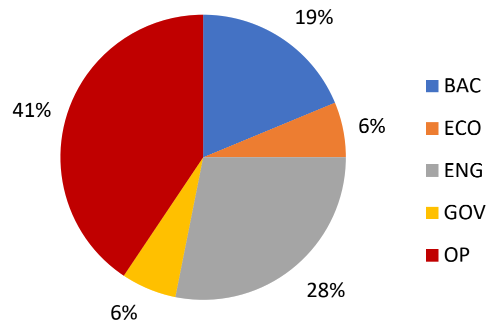
Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
Sewage Treatment Plant	Damages to the components	Precipitation	High Risk	Elevated electrical equipment and essential system.	ENG	Medium	High	Civil
			High Risk	constructing flood barriers or shields around individual pieces of equipment or areas containing essential equipment.	ENG	Regular	High	Civil
DG sets	Damages to the components	Precipitation	Very High Risk	Proper platform stack height and shed is provided to all DGs Regularly check if there is proper drainage around DG sets	OP	Long	High	Operation & Maintenance
			Very High Risk	Conduct a flood modelling study to identify low-lying areas. Ensure that the DG set is at an elevated ground and is not situated in the low-lying areas	OP	Regular	Low	Operation & Maintenance
			Very High Risk	Prepare electrical safety and DG related checklists and plans for assessing damage following extreme events.	ENG	Long	High	Operation & Maintenance
Local Community	Increase in suspended particles due to cargo	Temperature, Precipitation & High Winds	High Risk	Monitor dust problems and review dust mitigation measures to consider changing conditions.	OP	Regular	Low	Environment
			High Risk	Dust management protocols to be developed in discussion with the local community	OP	Short	Low	Admin/HR/Associated
Local Community	Increase in congestion	High Precipitation	Very High Risk	Security team handles traffic approaching the port. Awareness training program and drill to be conducted for security team to ease bottlenecks	BAC	Regular	Low	Security

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
			Very High Risk	Conduct regular traffic management studies capturing seasonal variation. Check whether the roads are designed as per the volume of the anticipated traffic	BAC	Short	Low	Environment
			Very High Risk	To Implement traffic management measures to minimize bottlenecks during extreme events	OP	Regular	Low	Security
Local Community	Effect on livelihood (fish catch) - decrease in quantity of fish and change in location	Sea Level Rise and Storm Surge	Very High Risk	Conduct awareness programs to inform fishermen of areas for better fish catch	BAC	Regular	Low	Environment
			Very High Risk	Conduct re-training & reskilling of fishermen + other sources of livelihood generation	BAC	Regular	Low	Environment
Workforce	Absenteeism due to bad weather	Temperature, Precipitation & High Winds	Very High Risk	Construct proper rest room & shelters within all facilities. Extend provisions to family as well.	ENG	Short	Moderat e	Admin
			Very High Risk	Implement flexible timings to incorporate seasonal fluctuations and bad weather	OP	Regular	Low	HR
			Very High Risk	Conduct regular check-ups and awareness sessions with doctors on how to improve immunity and recommended actions to reduce risks of heat stress	BAC	Regular	Low	HR
			Very High Risk	Monitor weather forecasts and issue bad weather-related health warnings when it exceeds human stress thresholds	BAC	Regular	Low	Admin

Asset Category	Component	Due to Climate Variable	Risk Category	Adaptation Measures	Type of Measure	Timeline	Cost	Department
			Very High Risk	Provide re-hydration fluids during extreme heat conditions	OP	Regular	Low	HR
Flora and Fauna	vegetation within the buffer area of 10 km from the port boundary	Sea Level Rise and Storm Surge	**Very High Risk**	Plant species & native species that can withstand climate stressors	ECO	Medium	Moderat e	Environment
		Temperature, Precipitation & High Winds	**Very High Risk**	Plantation design to include the following components of tall trees, maximising length, 2-3 rows of plantations, no gaps, diverse species, increase density with staggering	BAC	Medium	Low	Environment

4.2.1 WCT-1- Adaptation Measure Categories across Very High & High Risks

High Risk



Very High Risk

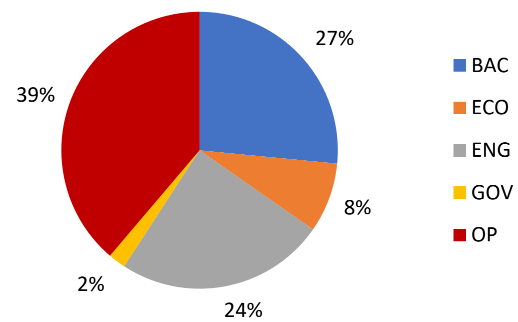
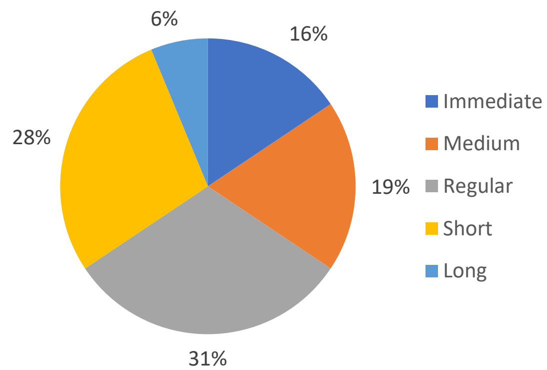


Figure 26 Percentage of Adaptation Measure categories across assets under Very High & High Risks- WCT-1

It is observed from Figure 26 that.

- For Very High Risks and High Risks, proposed adaptation measures are predominantly Operational Engineering (39% and 41% respectively) followed by Engineering and BAC measures.
    - Commonly proposed Operational measure include develop a guide wall to stop running of silt into drains. Also includes insolating electrical connections to reduce exposure to water and dust, reduced incidents of loss of power to reefers and consequent extra energy for re-cooling\refreezing.
    - Commonly proposed BAC measures include forming decision-making protocols from EWS, accounting for sea level rise in future procurement of assets and conducting port-specific flood risk assessment studies.
- Engineering measures 24 % and 28 % of the total proposed adaptation measures for Very High Risks and High Risks respectively. These measures constitute construction of flood barriers or gates or to raise the elevation of land to prevent from flooding and to increase the storm water drainage capacity to accommodate precipitation values. It also includes the sun coating on roofs of heat radiating structure to prevent from extreme condition.

4.2.1 WCT-1 Adaptation Measure Timelines across Very High & High Risks

<table>
<tr><td>High Risk</td><td>
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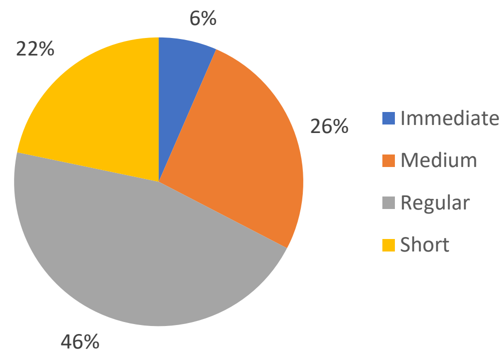
<tr><td>Very High Risk</td><td>
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Figure 27 Percentage of Adaptation Measure Timelines across Very High & High Risks- WCT-1

It is observed from Figure 27 that

- Majority of the proposed adaptation measures have a regular timeline for high (31%) and very High (46%) Risks and are needed to be addressed and revisited periodically to understand the effectiveness of adopted measure.
  - This can be attributed to both, Operational and Engineering adaptation measures proposed for WCT-1.
  - Most of the engineering and operational measures are generally ongoing as they need to be implemented periodically.
- The adaptation measures for medium timelines of Very High Risks (~26%) and High Risks (~19%) are attributed towards the implementation of engineering and BAC measures.

4.2.2 WCT-1 Adaptation Measure Costs across Very High & High Risks

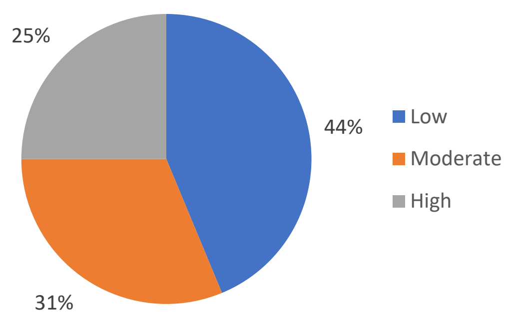
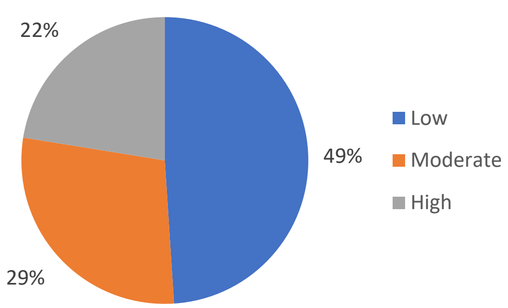
High Risk	
Very High Risk	

Figure 28 Percentage of Adaptation Measure Costs across Very High & High Risks- WCT-1

Figure 28 indicates the following:

- Majority of proposed measures are low cost (add some example) which accounts for 49% and 44% of adaptation measures proposed for WCT-1. This highlights that adaptation planning can be conducted by incorporating low-cost solutions with high impacts in reducing the damage or losses to the assets.
- Most of the proposed low-cost adaptation measures are operational in nature. These measures involve only human resource time cost, hence indicating a higher % of low-cost measures (49 % for Very High Risks and 44 % for High Risks).
- High costs (22% for Very High Risks and 25% for High Risk) involve engineering measures such as
  - Increasing drainage capacity to incorporate projected rainfall.
  - Higher deck-level elevation for jetties.
  - Paving roads with concrete.
  - Procurement of more tugs.

4.2.3 WCT-1 Adaptation Measures across Asset Categories

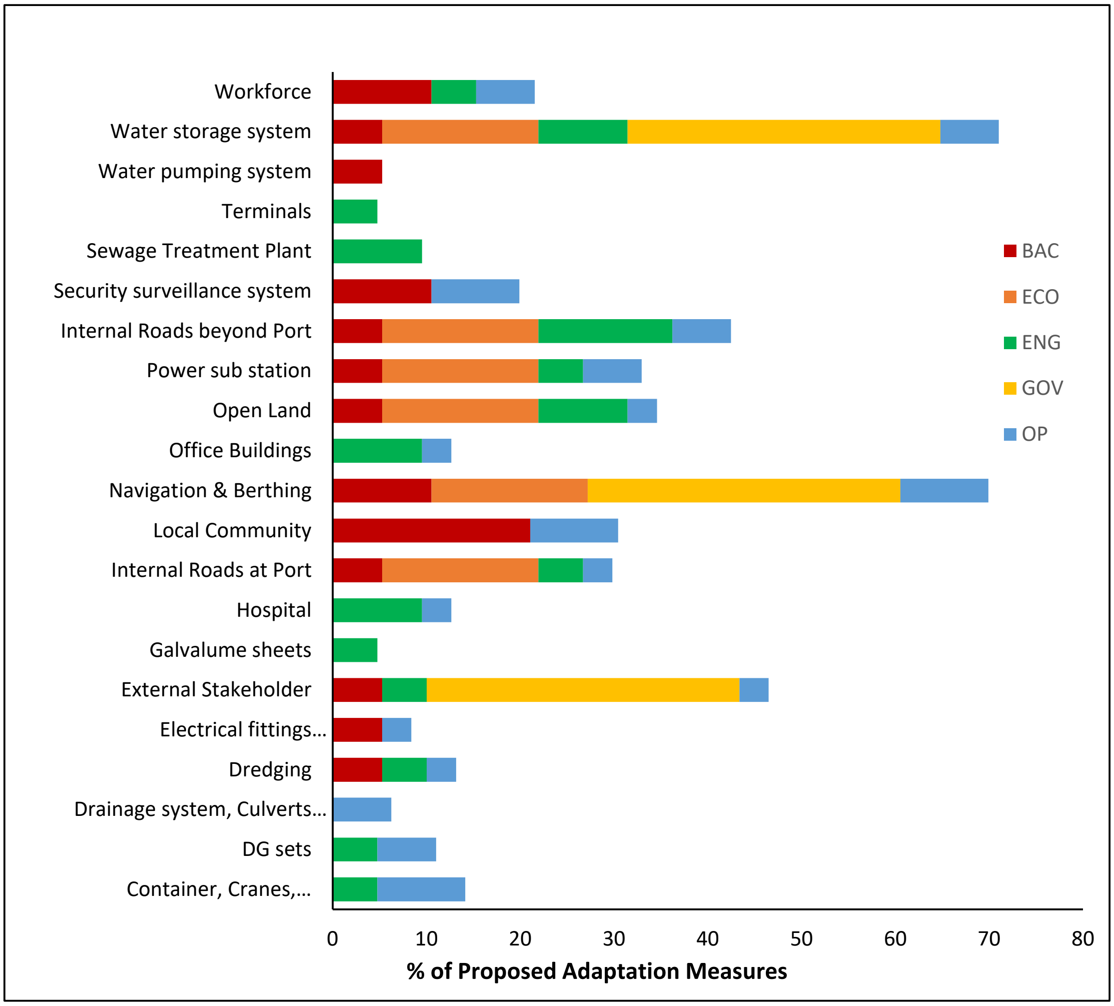


Figure 29: Adaptation Measures across Asset under high and very high-risk Categories at WCT-1

The Figure 29 illustrates that

- The maximum proposed measures are for water storage system followed by navigation and berthing and external stakeholder and are predominantly Engineering measures followed by Operational and BAC measures. Operational measures include-
    - Construction of flood barriers.
    - Robust drainage system.
    - Increase the drainage capacity.
    - Raising the quay height.
- Navigation and berthing have the next higher proposed measures. These measures are mostly BAC interventions followed by Governance and Capacity Building measures. Building Adaptive Capacity interventions include
    - Install and make decisions from early warning systems.
    - Carry operability assessments for berthing and manoeuvre to understand operational thresholds considering sea level rise and potential changes in storminess.

- Account for sea level rise when doing inventories for replacement and refurbishment of infrastructure.

4.2.4 WCT-1 Adaptation Measures across Cost Estimates

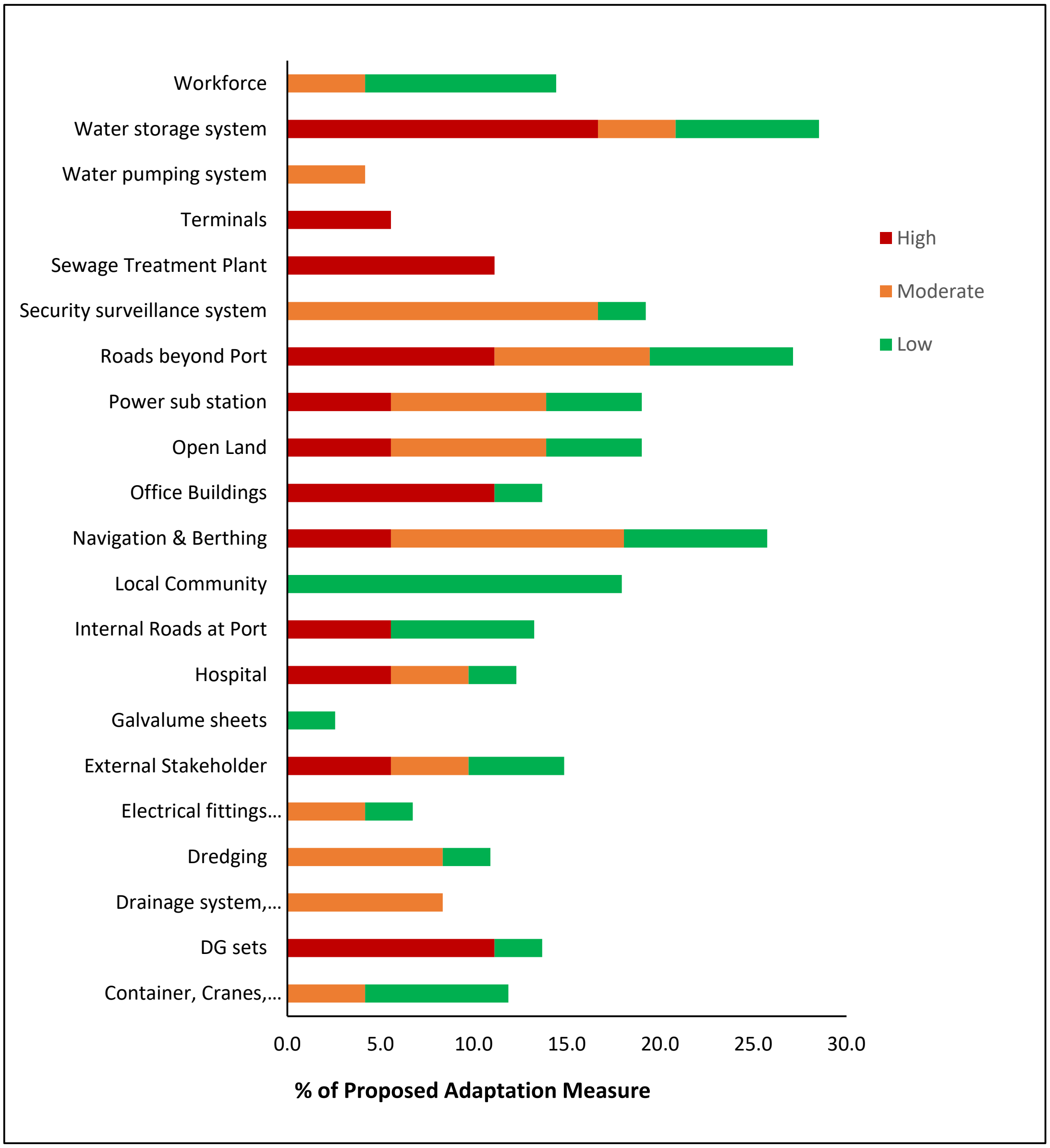


Figure 30: Percentage of proposed adaptation measures for assets under high and very high risk across as per the cost estimates at WCT-1

Figure 30 illustrates cost-wise proportion and distribution of adaptation measures proposed for different assets under high and very high-risk categories. It is observed that:

- Assets such as water storage system, terminals, STPs, office building, and DG sets have higher fraction of high-cost effective adaptation measures which mainly are engineering-based solutions.

- Water storage system asset category is highly dependent on cost intensive adaptation measures. The proposed measures mainly include physical and engineering measures such as
  - increasing storm water drainage capacity,
  - building flood barriers,
  - use vessels with shallower/deeper drafts according to changing conditions, and
  - raising elevation of assets.
- Most of the adaptation measures for human assets and receptors (workforce and local community) are moderate to low cost solutions as it involves more of capacity building, awareness and training programmes.
- List of adaptation measures proposed for navigation & berthing, office buildings and internal roads beyond port also have high percentage effective low-cost measures. These measures include application of remote sensing in decision-making, rescheduling work and providing appropriate PPEs to ensure minimum exposure of workforce to heatwaves, to engage with navigation authorities to ensure adequate management of risks, conducting annual energy audits, implementing BAC related awareness campaigns on energy conservation.

4.2.5 WCT-1 Adaptation Measures across Departments

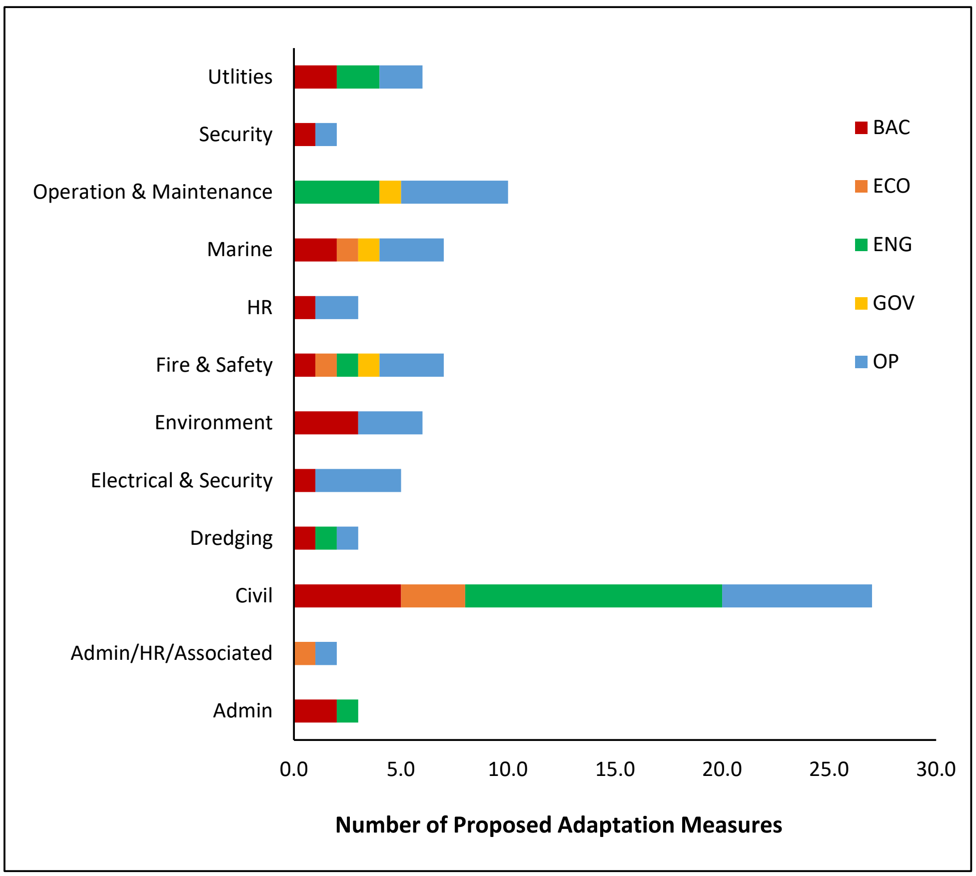


Figure 31: Number of proposed adaptation measure for assets under high and very high risk across department

From Figure 31 illustrates the responsible department for the different category of proposed adaptation measure under high and very high-risk categories. It is observed that:

- In WCT-1, the Civil department will be responsible for implementing the maximum proposed adaptation measures. Of which 12 measures are ENG measures followed by Operational measures (7).
- The second department/team proposed to be in-charge for the adaptation measures is the Operational & Maintenance Department. Maximum of these measures are related to Operations and BAC.

5 Way Forward

This report presents climate vulnerability assessment and various adaptation measures for each WCT-1, Colombo (Sri Lanka).

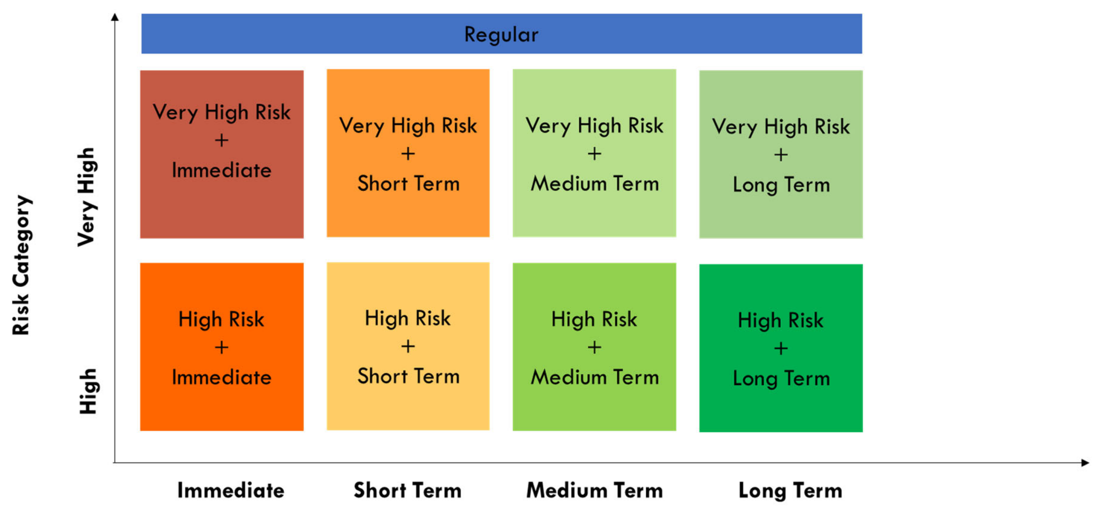
In this chapter of way forward, suggestions have been made on how to successfully implement the proposed adaptation plan and ensure its effectiveness outlining the next steps.

5.1 Prioritization of Adaptation Measures

Selecting and prioritizing appropriate adaptation measures for implementation will involve a multi criteria analysis (MCA). This would involve ranking and selecting preferred measures with a multi-stakeholder audience ranging from senior management at the port and the APSEZ corporate, climate change experts and operations team.

The Multi-criteria analysis would involve ranking options across aspects such as

- Current baseline condition
- Climate Risk Severity
- Effectiveness of the measure to counter the climate risks.
- Benefit to workforce and communities
- Timeline for implementation
- Scalability with incremental implementation
- Feasibility of implementation



- Synergy with other environmental initiatives

Figure 32 Prioritization of Adaptation Measures

The proposed adaptation plan would take some time to crystallize for taking on Implementation using the MCA approach. Till such time, Figure 32 illustrates prioritization of adaptation measures of Very High Risks that can be implemented over a shorter timeline.

It is observed that the regular measures cover **35-40%** of adaptation measures of which **40-45%** are Low Cost. These measures include building adaptive capacity and operational measures, which can begin with the existing teams within WCT-1.

5.2 Evaluate Options

Once the adaptation measures have been prioritized, each measure needs to be further assessed on the following aspects

- The extent to which the measure will help to counter the projected climate risks
- Feasibility of the adaptation measure within the port
- Identifying barriers for implementation.
- Cost of implementation
    - Cost Benefit Analysis including comparison **with cost of No Action**
- Legal Compliances required
- Social considerations and impacts on the workforce and community
- Other Environmental impacts including their contribution to increasing or reducing GHG emissions, water quality, soil quality and biodiversity.

5.2.1 Determining Cost of No Action

Estimation of cost of no action focuses on comparing a do-nothing ("business as usual") scenario with a proactive adaptation scenario.

The Cost of No Action situation compares cost of damages to assets and business interruption costs due to extreme climate events across different climate scenarios to the cost of implementation of adaptation measures.

5.3 Institutional Framework

It is recommended to set up a **Climate Cell** at the Corporate Level to over-see implementation of adaptation measures. Figure 33 represents the recommended institutional set up for the implementation of adaptation measures across all port. The Climate cell could consider the following initiatives:

- Take up Building adaptive capacity activities **common across** all the ports to improve workforce's awareness towards projected climate events
- Propose a guidelines and procedures in preparing Standard Operating procedures for each port– in terms of design specifications for climate stressors
- Constitute an expert panel of climate change, biodiversity, flood management, cyclones, early warning systems expert panel. This panel can oversee the progress of the implementation of the adaptation plan and provide handholding if necessary.
- Forums for sharing of experiences of ports should be established.
- Monitor & evaluate the effectiveness of the implemented adaptation plan across all ports

It is also recommended to set up a Climate Cell at port level at WCT-1 to implement adaptation measures. The Climate Cell at the port will be aligned to the initiatives taken up by the APSEZ corporate Climate cell as well as the senior management team within each port. The Port Climate Cell will co-ordinate with different project teams within the port to implement adaptation measures.

The Port climate cell will

- Constitute Cross functional teams.
- Implement adaptation measures according to priority matrix & evaluation of options.
- Adhere to the targets committed by the Senior Management Team and the APSEZ climate cell.
- Monitor the progress and impact of the adaptation measures being implemented at the port.

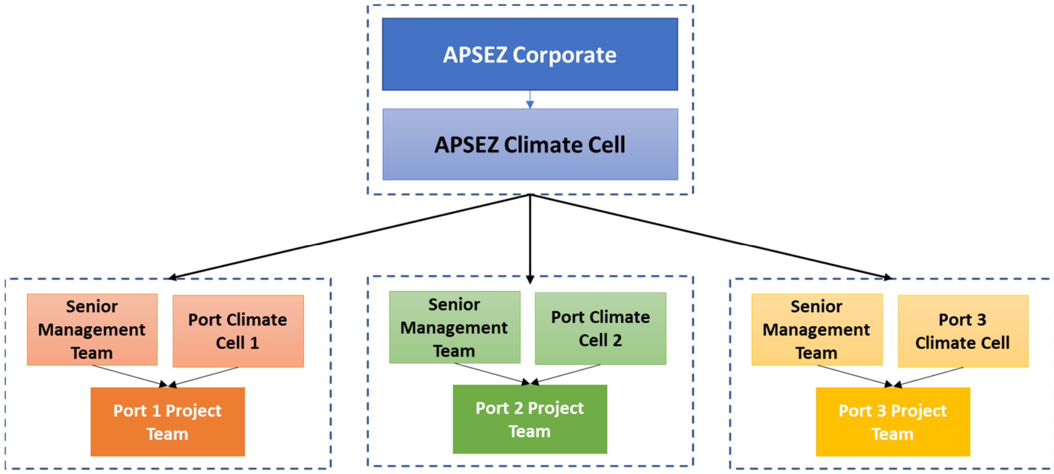


Figure 33 Institutional Set up for implementation of the Adaptation Plans at WCT-1

5.4 Monitoring & Evaluation

To ensure the effectiveness and sustainability of the adaptation plan, it is important to monitor and evaluate the progress periodically. A Monitoring and Evaluation framework needs to be formulated to assess whether:

- the proposed adaptation measures have been implemented
- the implemented measures have had the expected results
- objectives in countering the climate stressors have been achieved by the measures.

5.4.1 Design Adaptation Indicators

Monitoring needs to be undertaken using indicators. An adaptation indicator describes an existing situation and helps to track changes or trends over a period of time. The indicators should consider all aspects that meet the adaptation objectives.

The indicators are to be designed for qualitative and quantitative information. The indicators could be classified into three categories

- Indicators that measure building of the adaptive capacity- Number of workforce trained, early warning systems installed, preliminary studies conducted.
- Indicators that determine whether the vulnerability has reduced
- Indicators that measure the progress of the implementation against the timelines set in the adaptation plan
- Indicators that measure the impact of the adaptation measures on other environmental components such as water quality, GHG emissions, soil quality and biodiversity

The indicators need to be developed using a combination of process and outcome indicators, recognising that in some cases adaptation outcomes cannot be determined for many years.

5.4.2 Monitoring & Evaluation Framework

Based on the indicators formulated, means of verification and frequency of measurement will also be determined. Data sources have to be identified for measuring baselines, defining benchmarks and measuring indicators. Part of the monitoring will also involve documenting climate events that have occurred, and the effectiveness of measures implemented till date.

The monitoring framework should also include how to take up the monitoring results. Review of the monitoring results should be taken up bi-annually at the port level and annually with the APSEZ Climate Cell. Recommendations will be made for improving the effectiveness of the implementation of the adaptation plan.

Annexure 1: Detailed Location based Sensitivity Parameters Computation

Proximity to Inland Water Bodies.

The following steps were undertaken to arrive at a proximity to inland water bodies score of the port:

1. The AutoCAD/kml layouts Port was made provided by APSEZ.
2. These layouts were standardized in a shape file(.shp) format to perform a GIS analysis.
3. The buffer with distance 1km, 3km, 5km and 7 km were created from the port boundaries.
4. The shape files of the inland water bodies within the study area were downloaded from DivaGIS in both area based and line based vector formats.
5. The seasonal changes in the water bodies were also traced from Google Earth to capture the highest level of water surge during the peak seasons.
6. The shapefiles of the water bodies were then overlaid on the all the respective port buffer files.
7. Proximity to inland water bodies from the port buffers was estimated and scoring for WCT-1 was done.
8. This score was then normalized and ranked to arrive at the proximity to inland water body sensitivity score.

Table 24: Scoring for Proximity sensitivity score

Proximity to the Port (km)	Score
< 1	5
1-3	4
3-5	3
5-7	2
> 7	1

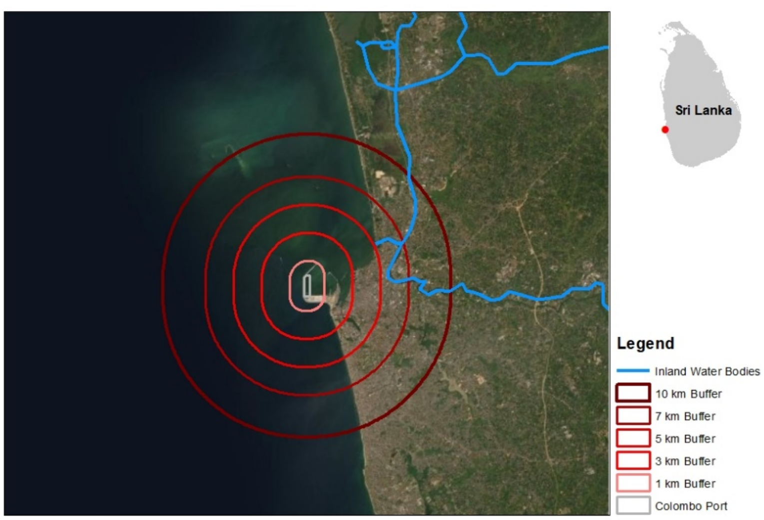


Figure 34:Map showing Proximity to inland water bodies in WCT-1

Land Use Land Cover Change

The following steps were considered while computing the LULC sensitivity score for port -

1. Land Surface Temperature (LST) is measured across the globe on a daily basis by MODIS sensor, mounted on NASA's Terra satellite.
2. The LST data from MODIS Terra is available for download at NASA Earthdata Portal and the data code is MOD11A2.
3. The spatial resolution of the data is 1 km and the temporal frequency is twice within a day.
4. Since the month of May receives maximum solar influx across India, daily LST data for May month for years 2010 and 2020 was chosen for analysis.
5. The MOD11A2 file has several datasets. Dataset of interest (Night-time LST at 1 km) was extracted and monthly averaged maps were prepared for May 2010 (baseline) and May 2020 (current) scenarios in ArcGIS.
6. Raster calculator function in ArcGIS was used to plot a change detection map of India. The LST raster for May 2010 was subtracted from LST raster for May 2020 to compute the changes in LST (and hence, changes in Land Use Land Cover).
7. Port Layouts in shapefile (.shp) format were provided by APSEZ. A buffer of 10 km was defined around each of the ports in ArcGIS.
8. The LST raster (from Step 6) was clipped for each of the port layouts and 10 km buffer (from Step 7) around them.
9. The clipped raster files was reclassified into custom ranges and changes in LST values were assigned scores as shown in the table below –

LST Change (Kelvin)	Score
-0.5 to 0.5	1
-1 to -0.5 and 0.5 to 1	2
-1.5 to -1 and 1 to 1.5	3
-2 to -1.5 and 1.5 to 2	4
-2.5 to -2 and 2 to 2.5	5
-3 to -2.5 and 2.5 to 3	6
-3.5 to -3 and 3 to 3.5	7

10. The relative frequency of each of the temperature ranges (from Step 9) were computed.
11. The relative frequencies (from Step 10) were multiplied with scores (from Step 9) and aggregated by summation for each port.
12. To calculate the final sensitivity scores, the aggregated indices (from Step 11) were divided by 7 (maximum scoring for LST change).

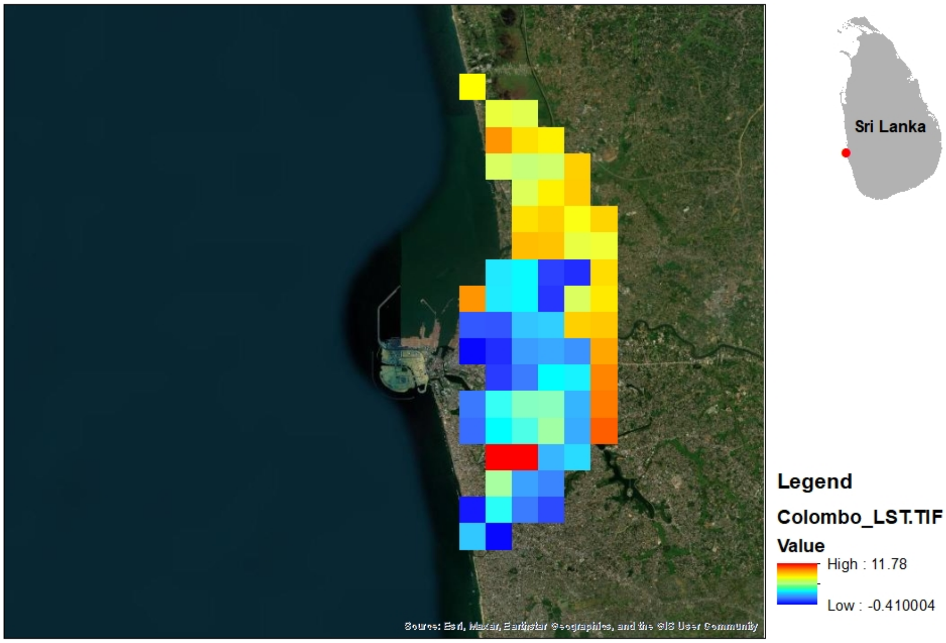


Figure 35: Map showing Changes in Night-time LST values (2010-2020) for WCT-1

Annexure 2: Asset Categories, Climate Risk & Climate Variables

S.No	Asset/Receptor Category	Component	Due to Climate Variable
1	*For Office Buildings- do you observe*	Increase in Energy Needs	Temperature
		Decrease in Stability- Fracture/Fatigue	High Winds
		Inundation due to heavy rains	Precipitation
		Inundation due to sea water flooding	Sea Level Rise and Storm Surge
		Cracks due to high temperature	Temperature
2	*Open Land*	Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
3	*Internal Roads at Port*	Cracks	Temperature
		Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
		Dust generation	Temperature and High Wind
		Broken tarmac	Temperature
		Muddy	Precipitation
4	*Roads beyond Port*	Cracks	Temperature
		Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
		Dust generation	Temperature and Wind
		Broken tarmac	Temperature
		Muddy	Precipitation
5	*Steel structures immersed in sea water*	Corrosion	Temperature+Salinity+Winds
6	*Galvalume sheets*	Stability- Fracture/Fracture	High Winds
		Exposure of workforce to Noise	Precipitation
		Corrosion	Temperature + Precipitation
7	*Drainage system, Culverts and sediment traps*	Excessive Sedimentation	Sea Level Rise and Storm Surge
		Overflow	Precipitation
		Overflow	Sea Level Rise and Storm Surge
8	*Cranes, Ship Unloaders, Stackers, Forklifts and Straddle Carriers*	Operational delays in difficultly of handling the operations	Temperature
		Operational delays in difficultly of handling the operations	High Winds
		Operational delays in difficultly of handling the operations	Precipitation

S.No	Asset/Receptor Category	Component	Due to Climate Variable
		Operational delays in difficultly of handling the operations	Temperature + Precipitation
		Muddy Conditions	Precipitation
		Physical damages- breakdown	High Winds
		Physical damages- breakdown	Temperature
9	*Terminals*	Submergence	Sea Level Rise and Storm Surge
		Operational delays in difficultly of handling the operations	Temperature
		Operational delays in difficultly of handling the operations	High Winds
		Operational delays in difficultly of handling the operations	Precipitation
		Operational delays in difficultly of handling the operations	Sea Level Rise and Storm Surge
10	*Water storage system*	Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
		Contamination	Precipitation
		Contamination	Sea Level Rise and Storm Surge
11	*Water pumping system*	Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
		Accumulation of dust	Temperature and High Wind
12	*Façade work*	Physical damages- breakdown	High Winds
		Stability- Sway	High Winds
13	*Vehicle parking area*	Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
14	*Hospital*	BMW storage flooding	Precipitation
		BMW storage flooding	Sea Level Rise and Storm Surge
15	*Power sub station*	Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
		Damages to the fuel storage	Temperature
		Damages to the fuel storage	High Winds
		Damages to the fuel storage	Precipitation
		Damages to the fuel storage	Sea Level Rise and Storm Surge
16	*Sewage Treatment Plant*	Inundation	Precipitation
		Inundation	Sea Level Rise and Storm Surge
		Damages to the components	Temperature
		Damages to the components	High Winds

S.No	Asset/Receptor Category	Component	Due to Climate Variable
		Damages to the components	Precipitation
		Damages to the components	Sea Level Rise and Storm Surge
17	*Jetty*	Submergence	Sea Level Rise and Storm Surge
		Operational delays in difficultly of handling the operations	Temperature
		Operational delays in difficultly of handling the operations	High Winds
		Operational delays in difficultly of handling the operations	Precipitation
		Operational delays in difficultly of handling the operations	Sea Level Rise and Storm Surge
18	*Security surveillance system*	Operational delays /stoppages	Temperature
		Operational delays /stoppages	High Winds
		Operational delays /stoppages	Precipitation
		Operational delays /stoppages	Sea Level Rise and Storm Surge
19	*Centralized HVAC systems*	Reduced efficiency	Temperature
		Reduced efficiency	High Winds
20	*Electrical fittings (both inside buildings and outside)*	Damages to the components	High Winds
		Damages to the components	Precipitation
		Damages to the components	Sea Level Rise and Storm Surge
21	*DG sets*	Inundation	Sea Level Rise and Storm Surge
		Inundation	Precipitation
		Damages to the components	Temperature
		Damages to the components	High Winds
		Damages to the components	Precipitation
		Damages to the components	Sea Level Rise and Storm Surge
22	*Navigation & Berthing*	Difficulties with berthing due to increased height of vessels berthed relative to quay and material handling equipment	Sea Level Rise

S.No	Asset/Receptor Category	Component	Due to Climate Variable
		Navigational safety	High Winds and Storm Surge
		Timetabling delays	High Winds
		Timetabling delays	Storm Surge
		Timetabling delays	Precipitation
		Timetabling delays	Temperature
		Damage to marine navigational equipment (like Tide Gauge) and/or inaccessibility	High Winds
23	*Dredging*	Reduction in time of unloading of cargo due to dredging operations	Sea Level Rise, Storm Surge and PPT
		Increased maintenance dredging resulting in higher operational downtime	Sea Level Rise, Storm Surge and PPT
		Increased disposal of maintenance dredging material affecting benthic habitat	Sea Level Rise, Storm Surge and PPT
		Increased loss of water quality and benthic habitat due to increased runoff, maintenance dredging and disposal of dredge material	Sea Level Rise, Storm Surge and PPT
		Loss of draft clearance	Sea Level Rise, Storm Surge and PPT
		Disruption to hydrographic surveying regime and dredging regime	High Winds
24	*Local Community*	Increase in suspended particles due to cargo	Temperature, Precipitation & High Winds
		Increase in congestion	
		Effect on livelihood (fish catch) - decrease in quantity of fish and change in location	Sea Level Rise and Storm Surge
25	*External Stakeholder*	Damage to customer property	High Winds
		Difficulty in access port during floods	High Precipitation
		Increase in insurance terms	Extreme Events (cyclone/storm surges/High Winds)
		Change in trade route	Extreme Events (cyclone/storm surges/High Winds)
26	*Workforce Management*	Absenteeism due to bad weather	Temperature, Precipitation & High Winds
		Disaster Management Committee established	Extreme Events (cyclone/storm surges/High Winds)

S.No	Asset/Receptor Category	Component	Due to Climate Variable
		Established connect with External Agencies	Extreme Events (cyclone/storm surges/High Winds)
		Mock drills & Awareness	Extreme Events (cyclone/storm surges/High Winds)
27	*Flora and Fauna*	Vegetation within the buffer area of 10 km from the port boundary	Sea Level Rise and Storm Surge
			Temperature, Precipitation & High Winds

Annexure 3: Computation of Climate Risk for all the Assets

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
1	*For Office Buildings- do you observe*	Increase in Energy Needs	Temperature	OP	5	5	25	3	8.33	11	91.66	2
		Decrease in Stability-Fracture/Fatigue	High Winds	REP	5	5	25	3	8.33	2	16.66	1
		Inundation due to heavy rains?	Precipitation	OP	5	5	25	3	8.33	11	91.66	2
		Inundation due to sea water flooding	Sea Level Rise and Storm Surge	OP	5	5	25	1	25	12	300	4
		Cracks due to high temperature	Temperature	REP	5	5	25	3	8.33	11	91.66	2
2	*Open Land*	Inundation	Precipitation	REP	5	5	25	1	25	11	275	3

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
		Inundation	Sea Level Rise and Storm Surge	REP	5	5	25	1	25	12	300	4
3	*Internal Roads at Port*	Cracks	Temperature		5	5	25	3	8.33	11	91.66	2
		Inundation	Precipitation		5	5	25	3	8.33	11	91.66	2
		Inundation	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
		Dust generation	Temperature and High Wind		5	5	25	4	6.25	13	81.25	2
		Broken tarmac	Temperature		5	5	25	3	8.33	11	91.66	2
		Muddy	Precipitation		5	5	25	1	25	11	275	3
4	*Roads beyond Port*	Cracks	Temperature		5	5	25	1	25	11	275	3
		Inundation	Precipitation		5	5	25	1	25	11	275	3
		Inundation	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
		Dust generation	Temperature and Wind		5	5	25	1	25	13	325	4
		Broken tarmac	Temperature		5	5	25	1	25	11	275	3
		Muddy	Precipitation		5	5	25	1	25	11	275	3
5	*Steel structures immersed in sea water*	Corrosion	Temperature+Salinity+Winds		5	5	25	3	8.33	13	108.33	2
6	*Galvalume sheets*	Stability-Fracture/Fracture	High Winds		5	5	25	4	6.25	2	12.5	1
		Exposure of workforce to Noise	Precipitation		5	5	25	1	25	11	275	3
		Corrosion	Temperature + Precipitation		5	5	25	3	8.33	22	183.33	2
7	*Drainage system, Culverts and*	Excessive Sedimentation	Sea Level Rise and Storm Surge		5	5	25	3	8.33	12	100	2

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
	sediment traps	Overflow	Precipitation		5	5	25	3	8.33	11	91.66	2
		Overflow	Sea Level Rise and Storm Surge		5	5	25	3	8.33	12	100	2
8	*Cranes, Ship Unloaders, Stackers, Forklifts and Straddle Carriers*	Operational delays in difficultly of handling the operations	Temperature		5	5	25	1	25	11	275	3
		Operational delays in difficultly of handling the operations	High Winds		5	5	25	5	5	2	10	1
		Operational delays in difficultly of handling the operations	Precipitation		5	5	25	5	5	11	55	2
		Operational delays in difficultly of handling the operations	Temperature + Precipitation		5	5	25	5	5	22	110	2
		Muddy Conditions	Precipitation		5	5	25	5	5	11	55	2
		Physical damages-breakdown	High Winds		5	5	25	5	5	2	10	1
		Physical damages-breakdown	Temperature		5	5	25	1	25	11	275	3
9	*Terminals*	Submergence	Sea Level Rise and Storm Surge		5	5	25	3	8.33	12	100	2

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
		Operational delays in difficultly of handling the operations	Temperature		5	5	25	1	25	11	275	3
		Operational delays in difficultly of handling the operations	High Winds		5	5	25	3	8.33	2	16.66	1
		Operational delays in difficultly of handling the operations	Precipitation		5	5	25	1	25	11	275	3
		Operational delays in difficultly of handling the operations	Sea Level Rise and Storm Surge		5	5	25	3	8.33	12	100	2
10	*Water storage system*	Inundation	Precipitation		5	5	25	3	8.33	11	91.66	2
		Inundation	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
		Contamination	Precipitation		5	5	25	4	6.25	11	68.75	2
		Contamination	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
11	*Water pumping system*	Inundation	Precipitation		5	5	25	3	8.33	11	91.66	2
		Inundation	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
		Accumulation of dust	Temperature and High Wind		5	5	25	3	8.33	13	108.33	2
12	*Façade work*	Physical damages-breakdown	High Winds		5	5	25	3	8.33	2	16.66	1
		Stability- Sway	High Winds		5	5	25	3	8.33	2	16.66	1

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
13	*Vehicle parking area*	Inundation	Precipitation		5	5	25	5	5	11	55	2
		Inundation	Sea Level Rise and Storm Surge		5	5	25	5	5	12	60	2
14	*Hospital*	BMW storage flooding	Precipitation		5	5	25	1	25	11	275	3
		BMW storage flooding	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
15	*Power sub station*	Inundation	Precipitation		5	5	25	5	5	11	55	2
		Inundation	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
		Damages to the fuel storage	Temperature		5	5	25	4	6.25	11	68.75	2
		Damages to the fuel storage	High Winds		5	5	25	5	5	2	10	1
		Damages to the fuel storage	Precipitation		5	5	25	5	5	11	55	2
		Damages to the fuel storage	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
16	*Sewage Treatment Plant*	Inundation	Precipitation		5	5	25	5	5	11	55	2
		Inundation	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
		Damages to the components	Temperature		5	5	25	1	25	11	275	3
		Damages to the components	High Winds		5	5	25	1	25	2	50	1
		Damages to the components	Precipitation		5	5	25	5	5	11	55	2
		Damages to the components	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
17	*Jetty*	Submergence	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
		Operational delays in difficultly of	Temperature		5	5	25	3	8.33	11	91.66	2

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
		handling the operations										
		Operational delays in difficultly of handling the operations	High Winds		5	5	25	3	8.33	2	16.66	1
		Operational delays in difficultly of handling the operations	Precipitation		5	5	25	3	8.33	11	91.66	2
		Operational delays in difficultly of handling the operations	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
18	*Security surveillance system*	Operational delays /stoppages	Temperature		5	5	25	1	25	11	275	3
		Operational delays /stoppages	High Winds		5	5	25	5	5	2	10	1
		Operational delays /stoppages	Precipitation		5	5	25	4	6.25	11	68.75	2
		Operational delays /stoppages	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
19	*Centralized HVAC systems*	Reduced efficiency	Temperature		5	5	25	5	5	11	55	2
		Reduced efficiency	High Winds		5	5	25	1	25	2	50	1

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
20	*Electrical fittings (both inside buildings and outside)*	Damages to the components	High Winds		5	5	25	1	25	2	50	1
		Damages to the components	Precipitation		5	5	25	5	5	11	55	2
		Damages to the components	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
21	*DG sets*	Inundation	Sea Level Rise and Storm Surge		5	5	25	3	8.33	12	100	2
		Inundation	Precipitation		5	5	25	4	6.25	11	68.75	2
		Damages to the components	Temperature		5	5	25	4	6.25	11	68.75	2
		Damages to the components	High Winds		5	5	25	4	6.25	2	12.5	1
		Damages to the components	Precipitation		5	5	25	5	5	11	55	2
		Damages to the components	Sea Level Rise and Storm Surge		5	5	25	1	25	12	300	4
22	*Navigation & Berthing*	Difficulties with berthing due to increased height of vessels berthed relative to quay and material handling equipment	Sea Level Rise		5	5	25	4	6.25	6	37.5	1
		Navigational safety	High Winds and Storm Surge		5	5	25	4	6.25	8	50	1
		Timetabling delays	High Winds		5	5	25	4	6.25	2	12.5	1
		Timetabling delays	Storm Surge		5	5	25	1	25	6	150	2
		Timetabling delays	Precipitation		5	5	25	1	25	11	275	3

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
		Timetabling delays	Temperature		5	5	25	1	25	11	275	3
		Damage to marine navigational equipment (like Tide Gauge) and/or inaccessibility	High Winds		5	5	25	5	5	2	10	1
23	*Dredging*	Reduction in time of unloading of cargo due to dredging operations	Sea Level Rise, Storm Surge and PPT		5	5	25	1	25	23	575	4
		Increased maintenance dredging resulting in higher operational downtime	Sea Level Rise, Storm Surge and PPT		5	5	25	1	25	23	575	4
		Increased disposal of maintenance dredging material affecting benthic habitat	Sea Level Rise, Storm Surge and PPT		5	5	25	1	25	23	575	4
		Increased loss of water quality and benthic habitat due to increased runoff, maintenance dredging and disposal of dredge material	Sea Level Rise, Storm Surge and PPT		5	5	25	1	25	23	575	4

S.No	Asset Category	Component	Due to Climate Variable	Risk Category	Likelihood (1-5)	Consequence (1-5)	Initial Risk (1-25)	Existing Adaptive capacity	Adjusted Risk	Climatic variable	Final Risk	Risk Category
		Loss of draft clearance	Sea Level Rise, Storm Surge and PPT		5	5	25	1	25	23	575	4
		Disruption to hydrographic surveying regime and dredging regime	High Winds		5	5	25	5	5	2	10	1
24	*Local Community*	Increase in suspended particles due to cargo	Temperature, Precipitation & High Winds		5	5	25	5	5	24	120	2
		Increase in congestion	Temperature, Precipitation & High Winds		5	5	25	0	0	24	0	2
		Effect on livelihood (fish catch) - decrease in quantity of fish and change in location	Sea Level Rise and Storm Surge		5	5	25	3	8.33	12	100	2
25	*External Stakeholder*	Damage to customer property	High Winds		5	5	25	1	25	2	50	2
		Difficulty in access port during floods	High Precipitation		5	5	25	1	25	11	275	3
		Increase in insurance terms	Extreme Events (cyclone/storm surges/High Winds)		5	5	25	1	25	0	0	2
		Change in trade route	Extreme Events (cyclone/storm surges/High Winds)		5	5	25	1	25	0	0	2
26	*Workforce Management*	Absenteeism due to bad weather	Temperature, Precipitation & High Winds		5	5	25	4	6.25	24	150	3
		Disaster Management Committee established	Extreme Events (cyclone/storm surges/High Winds)		5	5	25	3	8.33	0	0	2

		Established connect with External Agencies	Extreme Events (cyclone/storm surges/High Winds)	5	5	25	3	8.33	0	0	2
		Mock drills & Awareness	Extreme Events (cyclone/storm surges/High Winds)	5	5	25	4	6.25	0	0	2
27	*Flora and Fauna*	Vegetation within the buffer area of 10 km from the port boundary	Sea Level Rise and Storm Surge	5	5	25	1	25	12	300	4
		Vegetation within the buffer area of 10 km from the port boundary	Temperature, Precipitation & High Winds	5	5	25	1	25	24	600	4

Annexure 4a: Model wise Climatic exposure indicators for temperature, precipitation, SLR, CEWL and Wind speed

Definitions of the climatic variables:

Sr. No	Climate Variable	Definition
	CDD	Maximum length of dry spell: maximum number of consecutive days with RR < 1mm
	CWD	Maximum length of wet spell: maximum number of consecutive days with RR ≥ 1mm
	R10mm	Annual count of days when PRCP ≥ 10mm
	R20mm	Annual count of days when PRCP ≥ 20mm
	R95p	Annual total PRCP when RR > 95th percentile
	R99p	Annual total PRCP when RR > 99th percentile
	Rx1day	Maximum 1-day precipitation
	Rx5day	Maximum consecutive 5-day precipitation
	TN90p	Percentage of days when TN > 90th percentile
	TNx	Maximum value of daily minimum temperature
	TX90p	Percentage of days when TX > 90th percentile
	TXx	Maximum value of daily maximum temperature
	WSDI	Warm spell duration index: annual count of days with at least 6 consecutive days when TX > 90th percentile

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
Baseline period																
ACCESS1-0-CSIRO-CCAM	2641.6503	19.0666667	72.7	73.4	18.8	815.0642	398.5849	175.5	304.8	30.8	23.4	10.7	25.7	10.47407	36.40603	142
CNRM-CERFACS-CNRM-CM5-SMHI-RCA4	2249.58578	20.6666667	24.76667	79.23333	33.16667	489.2121	154.9413	81.25733	227.8683	30.86874	23.43851	10.52534	26.51467	10.73303	35.48567	315
CNRM-CM5-CSIRO-CCAM	2749.43635	21.4666667	72.3	87.53333	19.26667	826.4372	402.6777	175.541	297.9594	30.86804	23.43766	10.82069	25.66657	10.52884	36.26487	122
ICHEC-EC-EARTH-SMHI-RCA4	2293.22179	17.8	34.56667	73.2	26.26667	590.6849	219.7729	97.8109	246.8085	30.86858	23.438	10.556	26.36103	10.8094	35.29563	337
IPSL-IPSL-	2348.46591	17.6666667	25.06667	80.83333	31.5	510.3123	182.3521	101.675	258.566	30.86882	23.43855	10.69984	26.64687	10.82041	35.22987	248

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
CM5A-MR-SMHI-RCA4																
MIROC-MIROC5-SMHI-RCA4	2355.25419	21.1333333	34.8	83.43333	29.23333	530.8638	193.7563	83.0156	243.2934	30.86901	23.43825	10.85757	26.2603	10.92813	34.87413	533
MPI-ESM-LR-CSIRO-CCAM	2604.98612	18.1	67.93333	62.43333	20.1	950.4218	475.4208	215.0558	358.6688	30.86817	23.43827	10.715	25.8019	10.54071	36.17877	114
MPI-M-MPI-ESM-LR-REMO2009	2196.17786	26.7333333	23.8	62.73333	30.46667	645.085	217.159	118.541	283.9831	30.86832	23.43814	10.52224	25.71727	10.62901	35.05843	278
MPI-M-MPI-ESM-LR-SMHI-RCA4	2386.7087	20	29.13333	83.6	27.1	541.4699	201.9759	98.14563	240.8239	30.86851	23.43815	10.81641	26.49203	10.69711	35.02167	320

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
NOAA-GFDL-GFDL-ESM2M-SMHI-RCA4	2317.52388	20.7333333	35.83333	82	27.13333	535.5259	196.9336	97.20023	246.4836	30.86854	23.43793	10.77158	26.40427	10.76582	34.7778	412
Multi-model ensemble (MME)	2414.30109	20.3366667	42.09	76.84	26.30333	643.5077	264.3574	124.3772	270.9335	30.86853	23.43816	10.70292	26.15902	10.69265	35.45929	282.1
Short Term period (2021-2050)																
ACCESS1-0-CSIRO-CCAM	2180.673	27.5	50.7	60	20.16667	735.6706	359.7963	188.7899	290.4599	31.88324	24.32408	10.70266	26.60543	10.58013	36.95617	112
CNRM-CERFACS-CNRM-CM5-SMHI-RCA4	2072.56974	23.1	26.6	78.76667	26.13333	404.0674	142.4177	81.13337	194.675	31.65454	24.26165	10.67209	27.52177	10.82069	36.3905	447
CNRM	2192.68817	26.0333333	49.83333	60.8	14.43333	791.6401	456.3081	212.4281	334.1253	31.55845	23.97445	10.74141	26.16233	10.51389	37.1674	133

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
-CM5-CSIRO-CCAM																
ICHEC-EC-EARTH-SMHI-RCA4	2235.28873	21.0333333	31.13333	77.6	28.26667	494.6549	171.0634	89.6252	239.2383	31.62477	24.43646	10.55702	27.29697	10.82061	36.09543	346
IPSL-IPSL-CM5A-MR-SMHI-RCA4	1934.59693	32.6666667	23.33333	72.03333	26.76667	413.0169	143.4074	87.85783	209.4842	32.26891	24.90744	10.47676	28.2294	10.64978	36.73933	217
MIROC-MIROC5-SMHI-RCA4	2100.39452	31.2	29.66667	79.76667	24.86667	445.9783	180.723	97.91967	230.4797	32.01087	24.65391	10.8975	27.566	10.97693	36.3483	535
MPI-ESM-LR-CSIRO-CCAM	2327.27379	24.4666667	50.33333	54.5	18.93333	927.9184	447.9763	222.5503	377.0874	31.76673	24.2176	10.73577	26.56277	10.57026	36.97447	164
MPI-M-	2287.27694	26	23.8	67.06667	33.26667	652.442	212.0586	115.623	290.8328	31.79088	24.5186	10.68004	26.7079	10.71764	36.02537	408

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
MPI-ESM-LR-REMO2009																
MPI-M-MPI-ESM-LR-SMHI-RCA4	2024.7947	21.5	26.3	77.23333	24.5	399.565	138.9494	82.84333	194.1208	31.87404	24.5452	10.73221	27.43603	10.70844	36.08183	339
NOAA-GFDL-GFDL-ESM2M-SMHI-RCA4	2036.98411	27.6666667	29.96667	78.5	25.46667	416.6276	146.5544	81.22577	185.8736	31.66715	24.28405	10.75181	27.41907	10.66306	35.67297	399
Multi-model ensemble (MME)	2139.25406	26.1166667	34.16667	70.62667	24.28	568.1581	239.9255	125.9997	254.6377	31.80996	24.41234	10.69473	27.15077	10.70214	36.44518	310
Long Term period (2041-2070)																
ACCESS1-0-CSIRO	2431.92116	23.2	52.86667	62.16667	24.9	875.4564	415.0593	227.6867	359.8117	32.23342	24.81949	10.7341	27.06007	10.45669	37.12037	122

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
-CCAM																
CNRM-CERFACS-CNRM-CM5-SMHI-RCA4	2139.24662	22.7333333	23.3	81.1	28.56667	425.3228	154.4135	90.682	207.3446	32.10855	24.74754	10.56004	28.06197	10.95885	36.87033	321
CNRM-CM5-CSIRO-CCAM	2440.53206	22.5666667	51.2	62.3	19.2	964.147	542.065	250.9687	432.624	31.96471	24.36178	10.82905	26.5178	10.46729	38.0605	148
ICHEC-EC-EARTH-SMHI-RCA4	2334.1726	20.3	30.9	83.06667	29.7	515.8673	179.8847	82.24453	239.3873	32.09202	24.96858	10.7602	27.8168	10.62458	36.38333	413
IPSL-IPSL-CM5A-MR-SMHI-RCA4	2052.05587	29.7666667	22.7	75.36667	28.16667	459.9183	173.4609	101.4879	253.5903	32.62448	25.40123	10.65601	28.6611	10.72786	37.00437	236
MIRO	2071.21951	29.6333333	28.96667	80.7	26.76667	410.2913	146.5626	80.11707	197.4795	32.40098	25.05396	10.97174	27.97607	11.0066	36.57057	455

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
C-MIROC5-SMHI-RCA4																
MPI-ESM-LR-CSIRO-CCAM	2485.09468	19.4	51.16667	59.46667	23.26667	976.7732	485.5073	248.7519	394.1817	32.12763	24.6815	10.60189	26.9388	10.3905	36.99717	108
MPI-M-MPI-ESM-LR-REMO2009	2270.90408	25.4333333	24.46667	66.4	33.46667	623.5314	197.8912	105.9187	253.5044	32.24627	24.97937	10.61016	27.09793	10.55031	36.33983	290
MPI-M-MPI-ESM-LR-SMHI-RCA4	2083.36563	20.9	24.23333	81.3	24.56667	408.1786	145.1858	80.03203	189.0862	32.40225	25.04851	10.77493	27.82407	10.54091	36.58227	320
NOAA-GFDL-GFDL-ESM2M-	2060.74811	30.1333333	27.63333	78.4	25.73333	437.0835	158.1916	90.34713	216.2168	32.07019	24.6881	10.65473	27.75023	10.79256	35.96167	309

Models	Ann.PPT_Mean (mm)	CDD_Mean (days)	CWD_Mean (days)	R10_Mean (days)	R20_Mean (days)	R95p_Mean (mm)	R99p_Mean (mm)	RX1_Mean (mm)	RX5_Mean (mm)	Annual_Tmax_Mean (° C)	Annual_Tmin_Mean (° C)	TN90p_Mean (% days)	TNX_Mean (° C)	TX90p_Mean (% days)	TXX_Mean (° C)	WSDI_Mean (days)
SMHI-RCA4																
Multi-model ensemble (MME)	2236.92603	24.4066667	33.74333	73.02667	26.43333	609.657	259.8222	135.8237	274.3226	32.22705	24.87501	10.71529	27.57048	10.65162	36.78904	272.2

Annexure 4b: Addressing Uncertainty in Climate Risk Assessment

Climate vulnerability assessment is subjected to high level of uncertainties due to the intermodal variability, use of multiple scenarios, and low confidence in long-term projections. In this study, climate vulnerability assessment and detailed asset-based climate risk assessment is conducted for a greenfield port (WCT-1) located in Colombo (Sri Lanka).

The study is conducted in three phases (1) assessing changes in climatic stressors for the proposed port location using outputs of 10 dynamically downscaled model data (2) calculation of asset-based climate risk assessment, and (3) adaptation planning for WCT-1.

To ensure uncertainty posed by different climate model outputs is addressed, a multi-model ensemble (MME) is developed for all climatic variables considered in the study. The climatic variables are computed for each model which are then aggregated to an MME with median value as the representative value. The rationale for selection of median is to ensure that the errors introduced due to outliers in the selected models are minimized by avoiding the skewness of the inter-model variability. MME thus able to capture the inter-model variability better and address the issues of uncertainties caused by different climate models. Annexure 4a in the report provide model-wise values computed for all selected climatic variables along with their MME showing the maximum and minimum values of the uncertainty band for the baseline, near-term and long-term scenarios.

The second phase uses the MME outputs for assessing asset-based climatic risk to minimize propagation of uncertainty to climate risk assessment for each asset. MME provides a representative set of climatic stressors incorporating and aggregating information from different models in a single value for each variable. This climatic stressor information for baseline and future climatic conditions (projected scenarios) is used to compute changes in future climatic conditions. The final climate risk computed based on port operators judgement, are then corrected or adjusted using this climatic factor derived from phase 1 of the study by computing changes in future period with respect to the baseline. This ensures incorporating influence of climate change as a risk adjustment factor to incorporate influence of climate change under projected scenario.

Use of multiple models for performing climatic adjustment will propagate the same inter-model uncertainty to the adjusted climatic risk, which may increase further. To prevent this chain of uncertainty, MME provides a representative and effective solution to address uncertainty for calculating asset-specific risk under projected scenario. The details for calculation of climate adjustment factor is provided in section 1.2.2.4.

Finally, the adjusted climate risk derived from MME is used to devise asset-wise specific adaptation plans for WCT-1. Thus, the climatic factor for each climate stressor (derived from MME) used in this study ensure addressing the uncertainty, which will ultimately be propagated and incorporated within the adaptation plans by virtue of climate scaling factor adjustment.

Annexure 5: Extreme events data

Year	Disaster Subgroup	Disaster Type	Disaster Subtype	Location	Associated Dis	Duration	Total Affected
1984	Hydrological	Flood	Riverine flood	Ratnapura, Kegalce, Gampaka, Colombo		1	70000
1989	Hydrological	Flood	Riverine flood	Colombo, Gampaha, Kegalle, Ratnapura, Kalutara, Galle, Matara, Nuwera Eliya, Aranayake districts		1	501000
1991	Hydrological	Flood	Riverine flood	Galle, Kalatura, Colombo, Gampaha districts		5	297151
1992	Hydrological	Flood	Riverine flood	Galle, gampaha, kalutara districts (Colombo)		4	250000
1993	Hydrological	Flood	Riverine flood	Colombo, Southern Kalutara, Galle, Matara, Ratnapura areas	Rain	11	180000
1994	Hydrological	Flood	Riverine flood	Colombo			150000
1998	Hydrological	Flood	Flash flood	Colombo Galle Kalutara Gampaha		4	135000
1999	Hydrological	Flood	Riverine flood	Ratnapura, Colombo, Gampaha, Kalutara, Galle, Matara, Kandy, Kegalle, Level 1 = Central, Sabaragamuwa, Southern, Western		6	375000

Year	Disaster Subgroup	Disaster Type	Disaster Subtype	Location	Associated Dis	Duration	Total Affected
2004	Geophysical	Earthquake	Tsunami	Jaffna, Kilinochchi, Mullativu, Trincomalee, Batticaloa, Ampara, Hambantota, Matara, Galle, Kalutara, Colombo, Gampaha, Puttalam, Vavuniya districts			1019306
2005	Hydrological	Flood	Riverine flood	Colombo, Gampaha districts (Western province), Trincomalee district (Eastern province), Jaffna, Kilinochchi, Mullattivu districts (Northern province)	Slide (land, mud, snow, rock)	4	145000
2008	Meteorological	Storm	Tropical cyclone	Colombo, Kalutara, Gampaha districts (Western province), Ratnapura, Kegalle districts (Sabaragamuwa province), Puttalam district (North Western province), Nuwara Eliya district (Central province), Galle district (Southern province)	Flood	7	50000

Year	Disaster Subgroup	Disaster Type	Disaster Subtype	Location	Associated Dis	Duration	Total Affected
2008	Meteorological	Storm	Tropical cyclone	Colombo, Kalutara, Gampaha districts (Western province), Ratnapura, Kegalle districts (Sabaragamuwa province), Puttalam district (North Western province), Nuwara Eliya district (Central province), Galle district (Southern province)	Flood	7	50000
2009	Hydrological	Flood	Flash flood	Colombo district (Western province)		2	60000
2011	Hydrological	Flood	Riverine flood	Kegalle district (Sabaragamuwa province), Galle district (Southern province), Gampaha, Colombo, Kalutara districts (Western province)		1	8600
2016	Hydrological	Flood	Flash flood	Kilinochchi district (Northern province), Colombo district (Western province), Kegalle district (Sabaragamuwa province)	Slide (land, mud, snow, rock)	2	301602

Year	Disaster Subgroup	Disaster Type	Disaster Subtype	Location	Associated Dis	Duration	Total Affected
2017	Meteorological	Storm	Tropical cyclone	Galle, Matara (Southern), Colombo, Badulla (Uva), Gampaha, Kalutara (Western), Nuwara Eliya (Central)	Flood	3	160077
2017	Hydrological	Flood	Flash flood	Ratnapura, Matara, Kalutara, Galle, Gampaha, Colombo, Sabaragamuwa, Hambantota	Slide (land, mud, snow, rock)	6	879932
2017	Meteorological	Storm	Tropical cyclone	Galle, Matara (Southern), Colombo, Badulla (Uva), Gampaha, Kalutara (Western), Nuwara Eliya (Central)	Flood	3	160077
2018	Hydrological	Flood	Flash flood	Puttalam,Gampaha, Ratnapura, Colombo, Kurunegala, Kalutara,Kegalle districts	Slide (land, mud, snow, rock)	7	153712
2019	Hydrological	Flood	Flash flood	Galle, Kalutara, Gampaha, Ratnapura, Kegalle, Matara, Colombo	Slide (land, mud, snow, rock)	5	136607