Technical Report

Climate Change – Identification of Risks and Impacts

&

Resource Efficiency – Greenhouse Gases

Contract Ref: C116/2019

Final Report – October 2020

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CONTRACT REF: C116/2019

Issue and Revision

Rev	Date	Description	Prepared by	Checked by	Approved by	SEZAD Review
R1	30.04.2020	First Draft	CTEC			
R2	17.07.2020	Final Draft	CTEC			
R3	18.10.2020	Final Report	CTEC			

ABBREVIATIONS

ADB	Asian Development Bank
API	American Petroleum Institute
AR	Assessment Report
BAT	Best Available Technology
CAPEX/OPEX	Capital Expense/Operating Expense
CCTV	Closed Circuit Television
CFC	Chloro-flouro Carbons
CMIP	Coupled Model Intercomparison Project
CO2	Carbon di Oxide
CRVA	Climate Risk Vulnerability Assessment
CSR	Corporate Social Responsibility
CTEC	Civil Technologies Engineering Consultancy
DEM	Digital Elevation Model
DGCC	Director General of Control and Compliance
DPP	Duqm Petrochemical Complex
DRPIC	Duqm Petrochemical Refinery Industrial Complex
E&S	Environment and Social
EIA	Environmental Impact Assessment
EIPCCB	European Integrated Pollution Prevention Control Bureau
ESAP	Environment and Social Action Plan
ESDD	Environment and Social Due Diligence
ESMS	Environment and Social Management Plan
EWS	Early Warning System
GCM	General Circulation Model
GEV	Generalised Extreme Value
GHG	Green House Gases

HDS	**Highway Design Standards**
IFC	**International Finance Corporation**
IPCC	**Inter-governmental Panel for Climate Change**
Km/Km2	**Kilometre/Kilometre Square**
LARS - WG	**Lars Ashton Research Station – Weather Generator**
LED	**Light Emitting Diode**
LNG	**Liquified Natural Gas**
m/mm	**Metre/millimetre**
MIGA	**Multi Lateral Guarantee Agency**
MW/KW	**Mega Watt/Kilo Watt**
NCR	**National Communication Report**
PACA	**Public Authority for Civil Aviation**
PET	**Potential Evapo-transpiration**
RCP	**Representative Concentration Pathway**
RD	**Royal Decree**
RO	**Rial Omani**
SEZ	**Special Economic Zone**
SEZAD	**Special Economic Zone Authority at Duqm**
SPEI	**Standard Precipitation Evapo-transpiration Index**
SQU	**Sultan Qaboos University**
TDS	**Total Dissolved Solids**
USD	**United States Dollar**
USEPA	**United States Environment Protection Agency**
USGBC	**United States Green Building Council**
WMO	**World Meteorological Organisation**

EXECUTIVE SUMMARY

The Special Economic Zone at Duqm (SEZD) is executing the construction of a Project consisting of seven Sub-Projects, which form enabling infrastructure to the Port, the Refinery and the wider Special Economic Zone (SEZ). As part of the Lender's requirements, SEZD had carried out environmental and social due diligence (ESDD) of this project and a detailed ESDD report and associated environmental and social action plan (ESAP) has been developed to be implemented by OPAZ/SEZD in relation to the seven Sub- Projects and the zone-wide environmental responsibilities of SEZD in accordance with the relevant IFC Performance Standards on Environment and Social Sustainability and Omani regulations.

As part of the ESAP, OPAZ/SEZD conducted a Climate Risk Vulnerability Assessment (CRVA) and Green House Gas (GHG) emission assessment as part of this study. Specific objectives include the following:

- Assess future change in likelihood of concurrence for material climate hazards;
- Consequence or impacts of climate hazards on built assets, human and environmental systems;
- Identify specific sensitivities of the existing systems which may exacerbate over time;
- Coping capacity of the existing system to absorb and limit the impacts of climate hazards;
- Climate risk and vulnerability pathways which express the connections between risk sources, risk receptors and risk mitigation options;
- A path to move towards enhanced climate resilience over the long term;
- Estimate GHG emissions for projects 6 and 7 during the operation phase; and
- Prepare a guidance on GHG footprint at SEZD to include accounting and reporting requirements.

According to the Intergovernmental Panel on Climate Change (IPCC), climate change is expected to place a greater pressure on economic, environmental and social assets. Consequently, this CRVA is to understand the climate and assess climate change threats to the Special Economic Zone at Duqm area, to determine to what extent the infrastructure and natural environment is vulnerable to climate change, and to recommend measures that will improve the climate resilience.

Variations in surface air temperature, rainfall, wind speed and sea level rise were identified as the key parameters to be considered. Due to the absence of long-term observations in SEZD area, meteorological records at Masirah observational station during 2004-2019 period were used to define the baseline climate. Future projections from five general circulation models

(GCMs) and two representative concentration pathways (RCP 4.5: stabilization scenario and RCP 8.5: business-as-usual) were downscaled using stochastic models to the local scale. These projections were incorporated in risk assessment in two future periods: 2040-2059 and 2060-2079. A summary of the findings is provided below:

Temperature:

- Number of very hot days (days with daily maximum temperature above 40 ˚C) projected for 2060-2079 period is higher than that in the 2040-2059 period.
- In the baseline, the averaged very hot days is about 3.5 days/year, which according to the RCP 8.5 scenario is likely to be double (7.5 days/year) in 2060-2079 period.
- Even though, heat waves did not happen more than once per year in the baseline period, all projections indicate that heat waves more than twice or thrice per year are also likely to occur in future climate.
- The annual occurrence probability of a heat wave in the baseline period is about 12.5%, which according to the RCP 8.5 scenario is likely to reach 41.5% in 2060-2079 period.

Extreme rainfall:

- There are some significant differences of one-day rainfall intensities estimated from baseline observational data and the documented values in Highway Design Standards (HDS, 2010).
- The 100-year 1-day rainfall intensity from baseline observations is about 288.5 mm/day (1% annual exceedance probability (AEP), which according to HDS (2010) is about 144 mm/day only.
- The estimated 1% annual exceedance probability in the baseline period (return level = 288.5 mm/day) will be likely increase to a 2.7% annual exceedance probability during 2040-2059 period as projected by the RCP 8.5 scenario.
- Even a moderate rainfall event can generate significant excessive floods if it occurs while the watershed has an elevated antecedent moisture level. The 100-year 5-days rainfall amount estimated from baseline observations is about 385.9 mm (1% AEP), which according to the RCP 4.5 scenario in 2040-2059 period is likely to increase up to 535.5 mm.

Droughts

- All four future scenarios projected that the overall proportion of time spent in drought would only change marginally compare to that in the baseline period.
- However, extreme droughts are likely possible even though such events have not occurred during the baseline period.
- The number of drought events estimated in baseline period in moderate, severe and extreme categories are 25, 5 and 0, accordingly. According to the RCP 4.5 scenario, they will likely change to 30, 5 and 3 in moderate, severe and extreme categories, respectively in the 2060-2079 period.

Wind speed

- A significant change of the days with strong winds (1-hr gust more than 15 m/s) was projected in all future periods compared to observations in baseline period.
- The RCP 4.5 scenario estimated 23 days of strong winds per year in 2040-2059 period compared to 1.6 days/year observed during baseline period.
- Results also showed that these strong winds will not likely be strengthened up to destructive levels in the Saffir-Simpson Hurricane Scale.
- The annual occurrence probability of a the Category 1 and Category 3 winds (Saffir-Simpson Hurricane Scale) in the baseline period is about 2.22% and 0.80%, respectively. According to the RCP 4.5 scenario, the annual occurrence probability of a Category 1 and Category 3 winds will likely increases to 2.86% and 0.95%, respectively in the 2040-2059 period.

Sea level rise and coastal flooding

- According to the RCP scenarios, between 0.26 and 0.98 meter of global sea-level rise are projected by 2100. Moreover, coastal flooding due to tropical cyclone can be a major concern in low-lying developing areas and natural settings such as coastal lagoons in Duqm.
- Total inundation land along a 90 km coastal line ranges from about 6 km^2 with sea level rise under 0.5 meters to over 50 km^2 under sea level rise of 5 meters that correspond to conditions of storm surge due to tropical cyclones

Climate vulnerability risk assessment

The impact of hazards were assessed in terms of economic, environmental, and social and public safety under the following categories.

- Machinery, equipment and construction materials (M/C), which are located outside.
- Damages to the assets and infrastructure.
- Tourism and service sector
- Health and productivity of construction workers and residents.
- Livestock and agricultural products.
- Groundwater quantity and quality.
- Coastal habitats and sabkha

Depend on the likelihood of the hazard and the consequence, climate risk was calculated and categorized as follows (to be read along with Annexure 6 for more information on aspects).

- **R1, Negligible risk**: Scenarios do not require further consideration
- **R2, Low risk**: Controls not likely required
- **R3, Moderate risk**: Some controls required to reduce risks to lower levels
- **R4, High risk**: High priority control measures required
- **R5, Extreme risk**: Immediate controls required

#	Climate Change Parameter	Risk: 2040 – 2059	Risk: 2060 – 2079
1	Max Temp Heat Wave: 4 types of impact: M/C, community health, livestock/agriculture & tourism	RCP 4.5: 1 x R1 & 3 x R2 RCP 8.5: Same	RCP 4.5: 1 x R2 + 3 x R3 RCP 8.5: 1 x R3 + 3 x R4
2	High Intensity Ext Rainfall: 4 types: Wadis, Roads, Port & Maintenance	RCP 4.5: 1 x R1 & 3 x R2 RCP 8.5: Same	RCP 4.5: 1 x R1 & 3 x R2 RCP 8.5: Same
3	Prolonged Rainfall Intensity >5 days: 3 types: Roads, Flooding & Structure	RCP 4.5: 2 x R2 & 1 x R3 RCP 8.5: 1 x R1 & 2 x R2	RCP 4.5: 1 x R1 & 2 x R2 RCP 8.5: 2 x R2 & 1 x R3
4	Droughts: 3 types: GW, Crops & Ecology	RCP 4.5: 1 x R2 & 2 x R3 RCP 8.5: Same	RCP 4.5: 1 x R3 & 2 x R4 RCP 8.5: Same
5	High Winds/Cyclones: 3 types: Port Ops/Coastal Topping, Bldgs/Infra, Dust Impacts on public health	RCP 4.5: 2 x R1 & 1 x R4 RCP 8.5: Same	RCP 4.5: 2 x R1 & 1 x R4 RCP 8.5: Same
6	Sea Level Rise: 3 types: Corrosion/damage, erosion/shoreline, loss of freshwater/agriculture	RCP 4.5: 3 x R2 RCP 8.5: 1 x R2 + 2 x R3	RCP 4.5: 1 x R2 & 2 x R3 RCP 8.5: Same

Climate change adaptations

In accordance with the findings of the risk analysis, several options were proposed to manage the climate risks. Most important once of those are mentioned below. Detail recommendations are provided in the main report.

- The PMP of 580 mm/day used for designing Jurf and Saay dams has a 285-years return period according to the observations in baseline period. The annual exceedance probability of such event is about 0.35% (R2 risk). According to the highest impact scenario (RCP 8.5 in 2040-2059 period), such rainfall event has an annual exceedance probability of 0.8%. Should SEZD wish to reduce the associated risk, NoC level of the dam can be increased as suggested in Jurf Detail Design Report (Renardet SA & Partners 2015).
- Similarly, 500-years 24-hour rainfall event in HDS (2010), which was used for Drainage network master plan, has approximately 100-years return period according to the observations in baseline period. The annual exceedance probability of such event is about 1% (R2 risk). According to the highest impact scenario (RCP 8.5 in 2040-2059 period), such rainfall event has an annual exceedance probability of 3.2%. Should SEZD wish to reduce the associated risk, embankment level can be increased in critical places after a detail study.
- Future designs in Duqm are required to consider the local rainfall records with full set of past data and potential changes in the future.
- Use flood-proof design and construction methods for industrial, commercial, and residential complexes and tourist hotels anticipating both surface flooding and underground flooding due to groundwater level rise. Construction/building permits issued to ensure design considerations for flood abatement.
- Implement groundwater-monitoring program to investigate the variation of groundwater level and quality.
- Implement aquifer reservoir recharge prior to only ‘storage’ at dam locations.
- Installing weather stations covering the entire catchment area and piloting Early Warning System (EWS) is highly recommended.

Future studies

Based on the risk assessment of the climate change, following future studies are recommended for SEZD area.

- An integrated flood inundation study considering future changes of rainfall, sea level rise and cyclone effects.
- Implement surveys after rainfall events to ground-truth inundation levels and maintain database for the same for future studies.
- Designing an Early Warning System (EWS) and groundwater monitoring program.
- Install climate change monitoring stations for land and sea.
- Modelling studies for inundation taking into considering 288 mm/day (baseline recorded 100 year 1 day rainfall) as opposed to the HDS value of 144 mm/day
- All plans to be ready for full implementation by 2060 including carbon banking and sequestration options.

In addition to the CRVA, a GHG assessment with reference to resource efficiency was conducted as part of the scope for sub-projects 6 and 7. Along with the estimation of GHG, a framework guideline for GHG reporting is to developed for integration into SEZD operations and/or for investors, tenants and contractors at SEZD. The requirement is part of the IFC performance standards 3: Resource Efficiency and Pollution Prevention. Based on the assessment, the total CO_2 emissions from direct and indirect emissions for the sub-projects are presented below:

- Sub-project 6 – Total emissions: 1,023.86 MT CO_2 per year; and
- Sub-project 7 – Total emissions: 739.87 MT CO_2 per year.

Finally, a GHG reporting framework has been proposed for SEZD and its tenants to monitor and report GHG emissions which ties-in to the ESMS framework of SEZD. The reporting mechanism would facilitate performance and resource efficiency of the SEZ whilst adhering to IFC PS and global reporting standards. The implementation of the same into SEZD operations has been discussed in Chapter 10 which recommends as staged roll-out of the implementation of the requirements of adaptation measures and ESMS requirements.

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1 INTRODUCTION

On August 18, 2020, the Government of Oman issued Royal Decree No. 105/2020 establishing the Public Authority for Special Economic Zones and Free Zones (OPAZ). This Royal Decree (RD) transferred the allocations, origins, rights, obligations, and assets of the Special Economic Zone Authority at Duqm (SEZAD)[1] to this new Authority. Accordingly, the Special Economic Zone at Duqm (SEZD) becomes part of the Public Authority for Special Economic Zones and Free Zones.

The SEZD manages, regulates, and develops all economic activities in Duqm. With a land area of 2,000 km2 and 90 km of coastline along the Arabian Sea, the Duqm SEZ is the largest in the Middle East and North Africa region and ranks amongst the largest in the world. OPAZ/SEZD is executing the construction of a Project consisting of seven Sub-Projects listed below, which form enabling infrastructure to the Port, the Refinery and the wider Special Economic Zone at Duqm. These Sub-Projects are at different stages of execution with an average 77% level of completion as of January 2019

OPAZ/SEZD is being supported by the Multilateral Investment Guarantee Agency ("MIGA"), to secure the financing of the seven (7) Sub-projects, through the Ministry of Finance. The list of seven sub-projects and their current stage of execution is summarized in Table 1-1.

Table 1-1: Seven MIGA Projects

Project No.	Contract No.	Project Description
1	IP3 - Contract C50/ 2015	Construction of roads, buildings and additional infrastructure at the commercial pre-gate, gates and inspection zone of Port of Duqm.
2	IP7 - Contract C78/2017	Design, procurement and construction of the marine structures and associated berths, dredging works and permanent reclamation areas of liquid bulk berths in the Port of Duqm.
3	Contract C81/2017	Construction of Road No. 1 and Road No. 5 to link the Liquid Berth Terminal at Duqm Port to the Heavy Industrial Zone and drainage systems along the two roads.
4	Contract C65/2016	Construction of Jurf and Saay flood protection channels in Duqm.
5	Contract C76/2016	Construction of Jurf and Saay flood protection dams in Duqm.

[1] SEZAD was established by the Government of the Sultanate of Oman through Royal Decree No. 19/2011 as an authority to manage, regulate and oversees the development of all economic activities in the Special Economic Zone at Duqm. This RD has been superseded by RD 105/2020 with the establishment of OPAZ which takes over the role of regulating and managing all the free zones in the Sultanate

Project No.	**Contract No.**	**Project Description**
6	Contract C80/2017	Engineering, procurement and construction of Duqm Refinery service corridor to liquid jetty.
7	Contract C73/2016	Construction of interface roadway projects in Duqm (Road Section 4).

Project Finance is a specialized type of finance and is used for high cost assets with long construction/ operation period, and generally it is for longer-term (typically 15+ years). The Lenders mainly rely on project contracts and not on physical assets as security. Project location is provided in Figure 1-1.

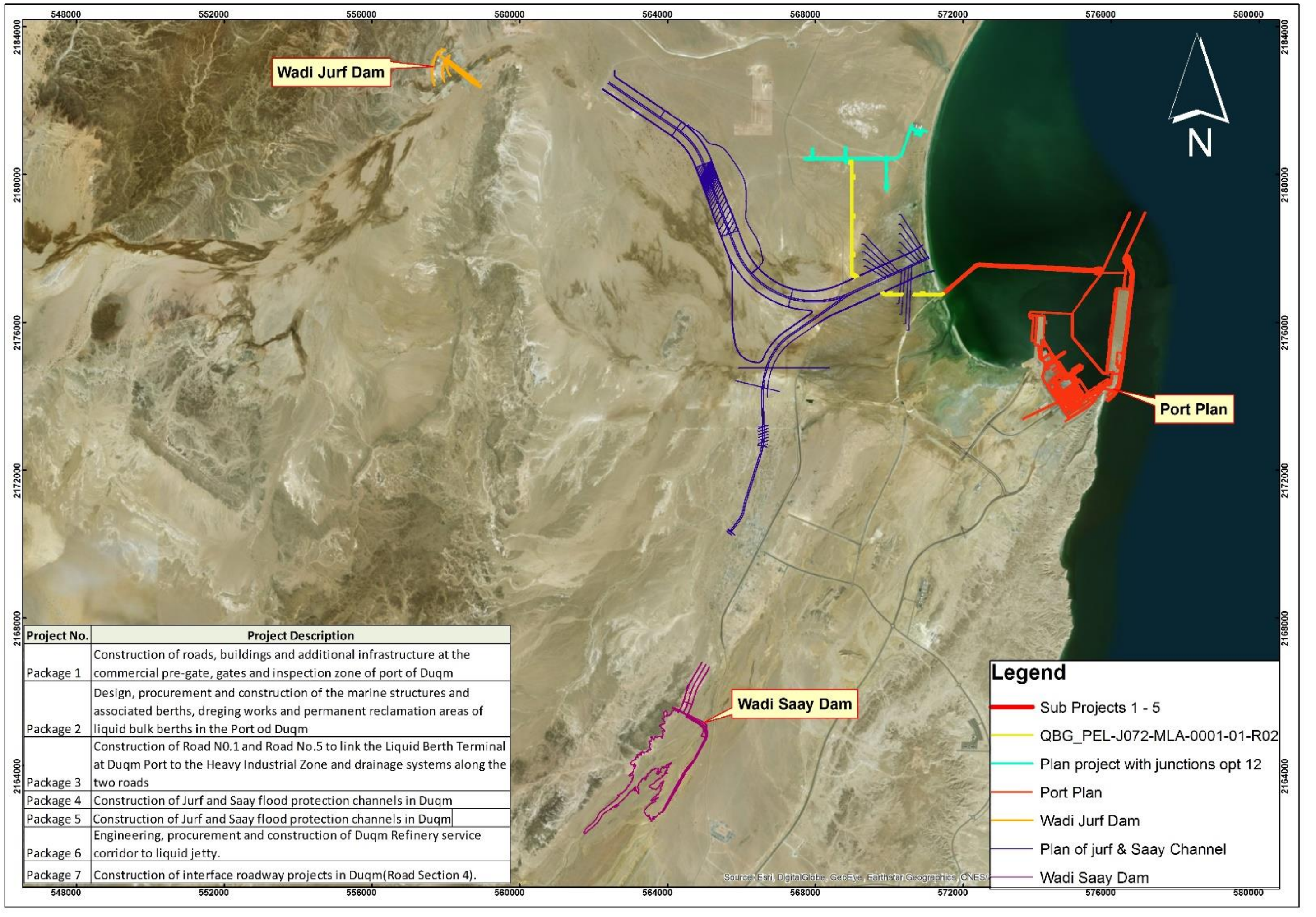


Figure 1-1: Projects Location within SEZD

As part of the Lender's requirements, OPAZ/SEZD had carried out environmental and social due diligence (ESDD) of this project and a detailed ESDD report and associated environmental and social action plan (ESAP) has been developed to be implemented by SEZD in relation to the seven Sub- Projects and the zone-wide environmental responsibilities of SEZD.

OPAZ/SEZD through tendering has appointed Civil Technology Engineering Consultancy (CTEC) vide contract no. C116/2019 to assist in fulfilling certain requirements under ESAP in accordance with the relevant IFC Performance Standards on Environment and Social Sustainability and Omani regulations, whichever is more stringent, and to the satisfaction of OPAZ/SEZD and the external auditor acting on behalf of MIGA and lending institutions. OPAZ/SEZD has shared relevant sections of the ESAP with CTEC for reference along with available ESIA reports for the SEZD area.

1.1 Objectives and Scoping Report

Based on the scope specified by SEZAD in the tender document (reference T-14/2019), the main objectives as part of the scope of work include preparation of the following:

- Identification of risks and impacts – climate risk vulnerability assessment (CRVA); and
- Resource efficiency – Green House Gases (GHG).

Specific objectives to be achieved in relation to the seven sub-projects and associated facilities include the following:

- Assess future change in likelihood of concurrence for material climate hazards;
- Consequence or impacts of climate hazards on built assets, human and environmental systems;
- Identify specific sensitivities of the existing systems which may exacerbate over time;
- Coping capacity of the existing system to absorb and limit the impacts of climate hazards;
- Climate risk and vulnerability pathways which express the connections between risk sources, risk receptors and risk mitigation options;
- A path to move towards enhanced climate resilience over the long term;
- Estimate GHG emissions for projects 6 and 7 during the operation phase; and
- Prepare a guidance on GHG footprint at SEZD to include accounting and reporting requirements.

A scoping report detailing the methodology and assumptions for executing the above scope was submitted to OPAZ/SEZD and MIGA on 27th January 2020. Subsequently, MIGA requested for clarifications on the proposed CTEC methodology in March 2020 followed by a conference call on 31st March 2020 wherein the scope and methodology for the current study was agreed. The clarifications and main discussion points are attached in Annexure – 1 of this report.

2 SCOPE OF WORK

The built environment in Oman, which includes some major investments, have been designed based on historical climate information with stationary assumption (properties of rainfall variation are constant with time) in their time series.

In order to avoid or to reduce the risks of changing climate and subsequent damages, more detailed assessment including the potential effects of climate change is required. CRVA can provide reliable information about damages and estimation of degree of vulnerability under the changing climate conditions. The objective of this work in SEZD area is to assess climate vulnerability and extremes as defined by IPCC.

2.1 References

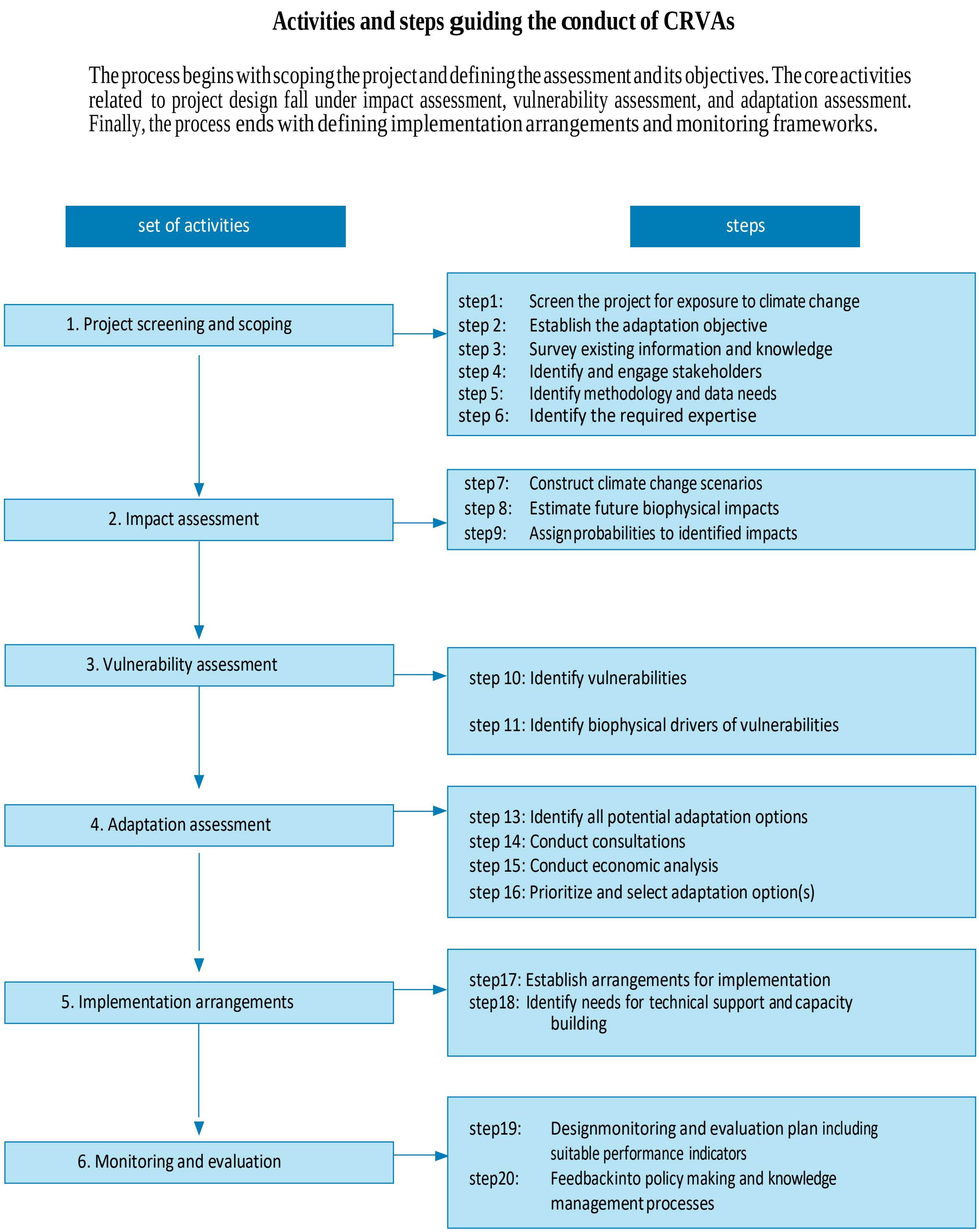
Assessments such as the CRVA require significant amount of specific data to arrive at an accurate output. These include met-ocean data (such as tides, waves, currents, etc.). meteorological data (wind speeds, precipitation, wind directions, temperature, etc.), extreme weather events (cyclones, storms, etc.) and engineering details of infrastructure in the area along with sensitive locations. It may be noted that not all of this information was available for the present study, therefore, suitable assumption and exclusions have been taken into consideration as discussed with SEZD and MIGA.

Some of the major data utilised for the present study include the following along with any assumptions or exclusions within parentheses:

- ESIA reports for sub-projects 6 and 7 (CTEC has received ESIA for sub-project 6. We note that there are no environmental records available for sub-project 7 at SEZD)
- Digital Elevation Model (DEM) with 5m resolution (Not available with SEZD, therefore, an older DEM of CY 1999 with 5m resolution was utilised for the presented study)
- CAD drawings for sub-projects (received from SEZD)
- Engineering reports/drawings for drainage channels and dam (received from SEZD)
- Flood risk reports for the area (not all available with SEZD)
- Meteorological data for Duqm and surrounding area (available with CTEC)
- 20-year sea level data at Duqm (not available with SEZD)
- Climate reports prepared for the Sultanate of Oman by SQU team through MECA (Information available on public domain sourced)

2.2 CRVA Guidelines

The CRVA assessment is based on the six-step process mentioned by ADB. The main activities are presented below:



Source: ADB. 2011. *Guidelines for Climate Proofing Investment in the Transport Sector.* Manila.

Figure 2-1: Typical Steps and Activities in CRVA

2.3 Background to the CRVA study

The purpose of this climate risk vulnerability assessment (CRVA) is to assess climate change threats to the SEZD area and to determine to what extent the infrastructure and natural environment is vulnerable to climate change, and to recommend measures that will improve the climate resilience.

This report has been prepared in accordance with the Scope of Work, and includes:

- An overview of the project background and context, including description of existing design reports;
- Details of the methodology adopted for the CRVA;
- A review of the exposure of OPAZ/SEZD to climate and other natural hazards;
- An assessment of the vulnerability and risk of the project to the identified hazards;
- Identification of measures to improve the climate resilience of the port; and
- Review of the key findings of the report and next steps.

2.4 Project Context

SEZAD area is expected to develop as a world-scale industrial economic center based on a seaport, ship repair yard and dry-dock complex, to international standards. The entire development area is about 123,000 ha (Royal Decree Boundary) as indicated in the land use Master Plan (Figure 2-2). Predominant land use area is allocated for industrial and residential zones. In addition, about 2,400 ha has been designated to develop as tourism projects.

The designated area is featured with five main wadis that channelize the water from the hilly area toward the sea (Figure 2-3). Among these, Wadi Jurf flows directly in the middle of the planned industrial area. Wadi Saay flows from south to the Arabian Sea through the area of the new port expansion. In order to lower the flood risk in the downstream and also to reduce significantly large artificial channel areas, Jurf and Saay dams were designed in the upstream sides of the catchments (Figure 3). When designing the channels, it was expected that two dams are able to reduce 1,000-year peak discharge to a 100-year peak discharge by routing floodwater through the reservoirs.

Figure 2-2: SEZD project area[2]

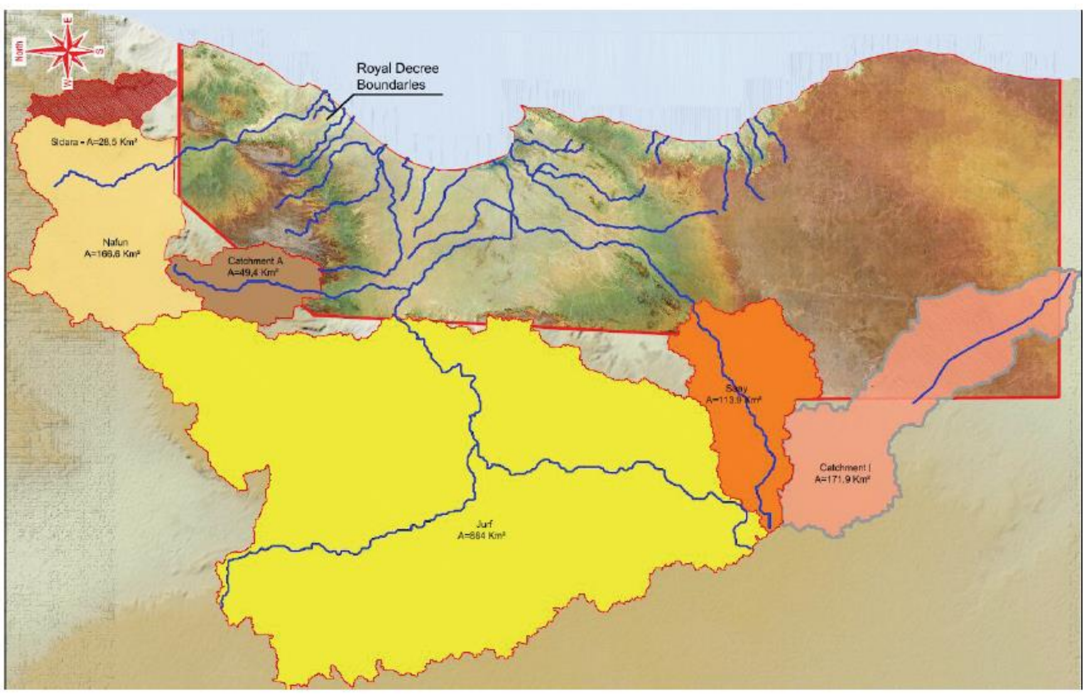


Figure 2-3: Distribution of Wadi Network and Catchment Areas[3]

[2] Source: SEZD – Duqm Free Zone Flood protection Scheme Report, Renardet SA & Partners for the Consultancy services, 2015
[3] Source: Drainage Model Final Results Executive Summary Report, Sering International , 2011

Figure 2-4: Two flood attenuation dams (Jurf and Sa'ay) and conveyance channels[4]

[4] Source: Duqm Free Zone Flood Protection Scheme, Jurf Detail Design Report, Renardet SA and Partners, 2015

According to the design reports provided by SEZD, hydrological and hydrodynamic designs cover three major components:

- Jurf and Saay dams;
- Jurf and Saay channels; and
- Drainage network master plan.

Design details of these studies are summarized in Table 2-1 below.

Table 2-1: Design details of the projects in Duqm area

Design Element	Consultant and Report	Details of Hydrological Inputs
Jurf and Saay dams	Renardet SA & Partners, Jurf Detail Design Report, 2015	• PMFs generated by PMP of 580 mm/day have been considered. • PMP has been calculated without considering tropical storm Ashobaa event in 2015.
Jurf and Saay channels	Renardet SA & Partners, Jurf and Saay Detail Design Report, 2015	• Flow rates for 1000-Yrs return period have been considered. • Rainfall intensity has been calculated without considering tropical storm Ashobaa event in 2015. • Water surface elevation at the outlet of the channels at the sea were considered to be 2.5 m a.m.s.l. This accounts 2.6 m for sea level rise and 1.56 m for surge due to cyclone.
Drainage network master plan	Sering International, Drainage Model Final Results Executive Summary Report, 2011	• Flow rates for 500-Yrs return period have been considered. • Rainfall intensity has been taken from Highway Design Standards (2010) in Oman.

2.5 Climate in Duqm area

The climate in Duqm is characterized by arid to hyper-arid. In general, there are two seasons, a long dry summer with high temperature between April and November and a relatively short winter period with mild to warm temperature. According to the available data in Masirah from 2004 to 2019[5], temperature varies from 47.2 ˚C maximum to 11.7 ˚C minimum with an average of 26.7 ˚C. Figure 2-5 shows the maximum, average and minimum monthly temperatures averaged over 2004-

[5] Maximum, minimum and average temperatures were calculated for each month based on daily data. These temperatures were then averaged over 2004-2019 period

2019 period. The maximum temperature of 41.4 ˚C and the minimum temperature of 15.7 ˚C were estimated in May and January, respectively.

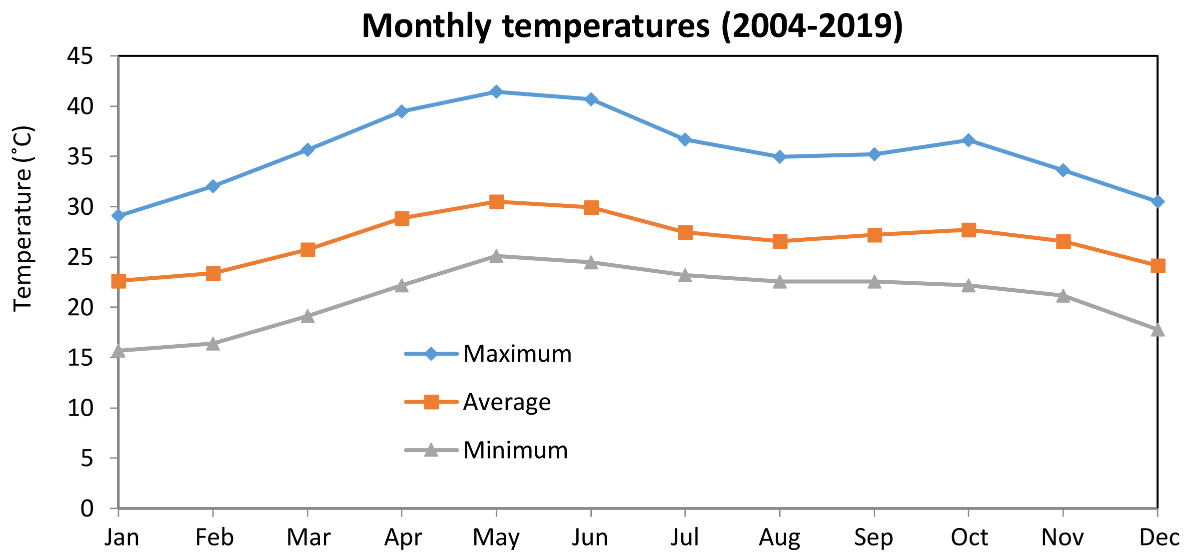


Figure 2-5: Monthly variation of maximum, minimum and average temperatures in Masirah calculated from data between 2004-2019.

Annual total rainfall averaged over the 2004-2019 period in Masirah is about 57 mm. In general, total rainfall amount and intensity is higher in June (Figure 2-6 and Figure 2-7). For example, tropical storm Ashobaa brought a 213 mm/day of rainfall intensity in Masirah in June 2015. This event was the highest in terms of the rainfall intensity in 2004-2019 period. In addition, the second highest rainfall event has also occurred in June 2010 with a daily intensity of 109 mm/day.

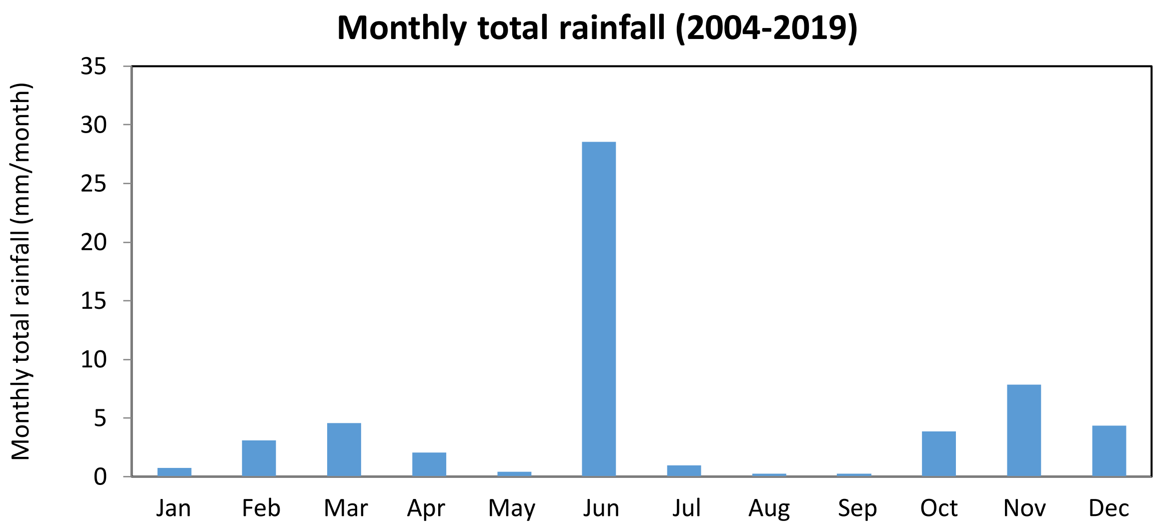


Figure 2-6: Monthly total rainfall averaged over 2004-2019 period.

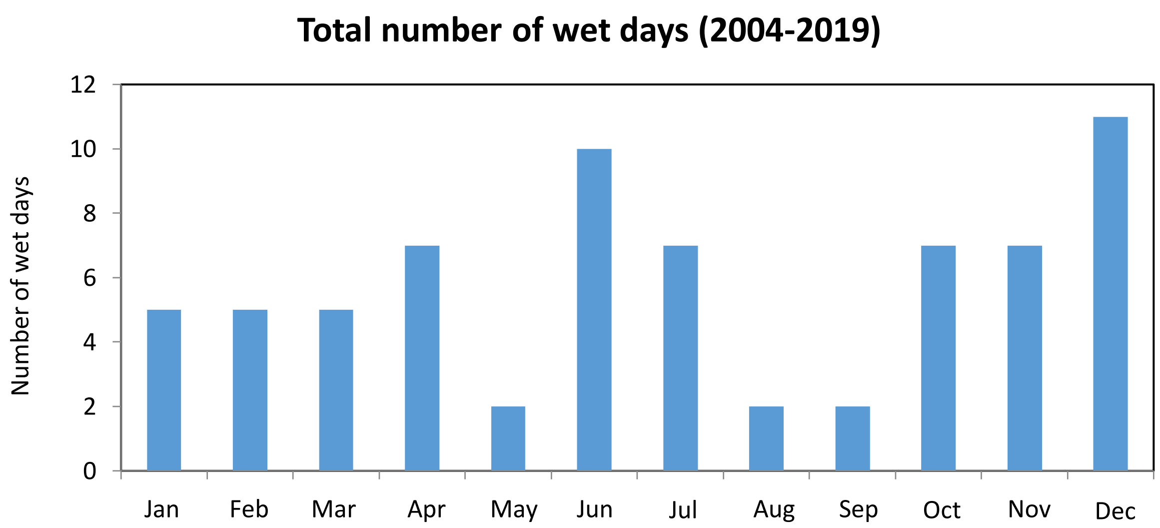


Figure 2-7: Total number of wet days[6] (days with daily rainfall more than 1 mm) cumulated over 2004-2019 period.

2.6 Groundwater quality

Two project reports provided data for groundwater quality in SEZD area. Environmental Impact Assessment Report (EIA) for Jurf dam (2015) includes information from 13 boreholes with the drilled depth ranges between 10 m to 19.5 m below the ground surface (Figure 2-8).

[6] This is the total number of wet days cumulated over 2004-2019 period

Groundwater level measurements and sampling have been obtained in the monitoring wells installed in boreholes BH-01, BH-03, BH-05, BH-07, and BH-13. The water levels in these wells ranged from about 1.47 m to 3.47 m below the ground surface. The chemical analyses of ground water samples indicated the highest total dissolved solids (TDS) of 101,180 mg/l (Brine water) in BH-03 and least TDS of 8,290 mg/l in BH-05 (Brackish water). It should be noted that the TDS level in freshwater should be less than 1,000 mg/l.

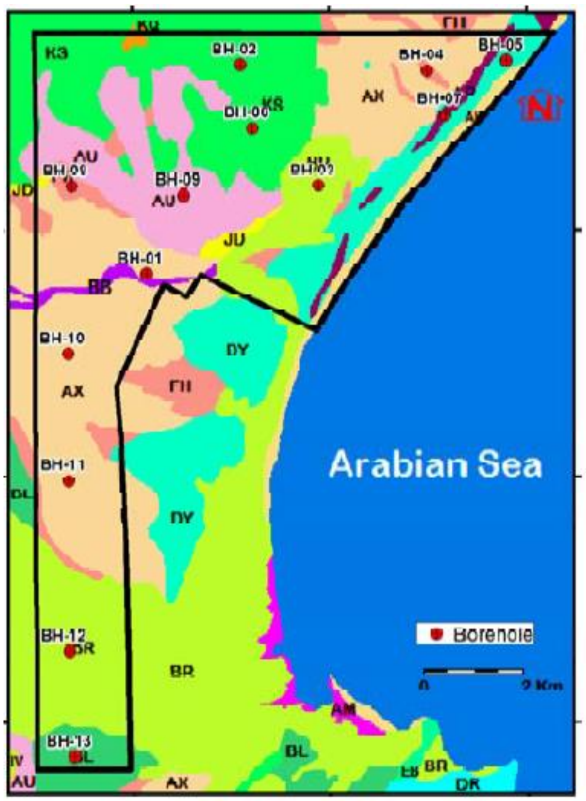


Figure 2-8: Location of boreholes in Duqm port area[7]

Similarly, Jurf Dam Detail Design Report (2015) documented higher level of TDS content in groundwater near to the Jurf Dam. Classification of these water samples are shown in Table 2-2.

[7] Source: EIA report for Jurf Dam, 2015

Table 2-2: Classification of water samples according to TDS content around Jurf dam[8]

Water Sample Location	TDS in mg/L	Classification	pH @ 25° C
Left Abutment	10,500	*Saline Water*	7.6
Left Abutment - Borehole with Gas Emission	39,990	*Brine*	6.7
Right Abutment	14,410	*Saline Water*	7.3
Downstream - 1.76 km from Jurf dam axis	56,320	*Brine*	7.3

[8] Source: Jurf Dam Detail Design Report, 2015

3 CRVA METHODOLOGY

When determining how climate change may influence a project, a standard approach is to determine current climate parameters, identify how they will change due to global climate change, assess how these climate hazards may affect the project design or impact the project assets, and then determine how to adapt the project specifications. This CRVA implements this standard approach to the extent possible.

3.1 Climate Statistics

With reference to the climate parameters and subsequent hazards, it was agreed with OPAZ/SEZD to use following climate statistics.

3.1.1 Rainfall

According to the Second National Communication Report (NCR-2, 2019) from Ministry of Environment and Climate Affairs submitted to United Nations Framework Convention on Climate Change, average annual rainfall will have changed substantially across Oman. Some portions of Dhofar Governorate will have annual rainfall either remained the same as mid-21st-century levels or slightly increase. When the changes of extreme rainfall are considered, Gunawardhana and Al-Rawas (2016) found that the contribution from extreme rainfall to the annual total rainfall has steadily increased in two major cities: Muscat and Salalah in the Sultanate of Oman during 1990-2009 period. Therefore, following set of rainfall indices that explore the potential changes of extreme rainfall in the future were considered.

- 100-year 1-day and 5-day maximum rainfall in the baseline and future periods;
- annual exceedance probability of the baseline 100-year return level of the maximum 1-day and 5-day precipitation amount (%);
- annual exceedance probability of a day with daily rainfall exceeding 25 mm (%);
- annual exceedance probability of a day with daily rainfall exceeding 50 mm (%);
- Annual exceedance probability of a 5-day event with total rainfall exceeding 50 mm;
- Annual exceedance probability of a 5-day event with total rainfall exceeding 100 mm; and
- Number of drought events in the baseline and future periods.

Although, rainfall is a major indicator of the availability of water, temperature is also an important factor that can influence the availability of water as it controls the rates of evapotranspiration. Under climate change, large increases in Potential Evapo-Transpiration (PET) in a warmer climate may cause an increase in widespread drying. Therefore, the Standardized Precipitation Evapotranspiration Index (12 month-SPEI) was used for assessing the temporal variation of droughts. The Hargreaves method was used for estimating PET. Data requirements include daily maximum and minimum temperatures. SPEI scale used for categorizing the severity of the drought is as follows (Tirivarombo et al., 2018).

a) Extreme droughts: SPEI ≤ -2;
b) Severe droughts: −2 < SPEI ≤ −1.5); and
c) Moderate droughts: −1.5 < SPEI ≤ −1.

Each drought severity category was assigned a specific weight from 0.5 to 1.5. The higher weight indicates the higher drought severity (Guo et al., 2019).

3.1.2 Maximum temperature

According to NCR-2 (2019), maximum temperatures in Oman are expected to rise by 2 ˚C-4 ˚C by the end of 21st century relative to the 1950-2000 baseline period. In Duqm area, following indices were used to estimate potential variations of maximum temperature in future periods relative to baseline period.

a) Monthly averaged daily maximum temperature of the warmest month;
b) Maximum daily temperature estimated for different percentiles from 90th to 99.9th;
c) Average number of days per year with daily maximum temperature above 40˚C;
d) Number of heat waves; and
e) Yearly probability of occurrence of heat waves, at least one time, at least two times, at least three times and more than three times.

The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5; 2013) stated that more frequent and intense extreme heat waves can be expected in the near future in response to recent climate change. According to the Task Team on the Definition of Extreme Weather and Climate Events commissioned by the World Meteorological Organization (WMO, 2018), a heat wave is defined as:

> *"A period of marked unusual hot weather (maximum, minimum and daily average temperature) over a region persisting at least three consecutive days during the warm period of the year based on local (station-based) climatological conditions, with thermal conditions recorded above given thresholds"*

Accordingly, a heat wave in Duqm area was defined as an event, which satisfied the following three conditions.

a) During a period of five consecutive days, the maximum daily temperature reached at least the 98th percentile of maximum temperature in baseline period (38.8 ˚C) in at least three days;
b) during these five days, mean maximum daily temperature was at least 38.8 ˚C; and
c) during which, the maximum daily temperature did not drop below the 90th percentile of maximum temperature in baseline period (36.0 ˚C).

3.1.3 Extreme wind

Because it was located parallel to the coastline, OPAZ/SEZD area is highly vulnerable to tropical storms originate from Arabian Sea. The wind climate is very important for the port as the wind-generated waves may limit operations at the port. NCR-2 (2019) pointed out that the infrastructure located along the coastline can be at high risk during future cyclonic events.

Accordingly, following indices were used for assessing changes in extreme wind:

a) The average number of days per year with maximum wind speed (1-hr gust) more than 15 m/s in the baseline and future periods;
b) annual exceedance probability of Category 1 and Category 3 winds (60-sec gust) based on Saffir-Simpson Hurricane Scale in the baseline and future periods; and
c) annual exceedance probability of 100-year return level estimated from baseline period in future periods.

The observed wind speeds are in hourly scale. Therefore, appropriate gust-factor must be used to match the estimations with the Saffir-Simpson Hurricane Scale. The gust-factor is a theoretical conversion between an estimate of the mean wind speed (1-hour observation) and the expected highest gust wind speed (60-sec gust) of a given duration within a stated observation period. In this CRVA study, guidelines from the WMO was applied and a gust-factor of 1.28 was used (Harper et al., 2008).

3.1.4 Sea level rise

Global sea levels are projected to continue to rise as the world warms, increasing mean sea level rise at the local level. The IPCC AR5 projected that the rate of global mean sea-level rise during the 21st century will exceed the historical rate observed during the 1971–2010 period for all RCPs. Between 0.26 and 0.55 m of sea-level rise are projected for RCP 2.6 by 2100, and between 0.52 and 0.98 m of sea-level rise are projected under RCP 8.5 by 2100.

Estimates of regional sea-level rise can differ from global estimates. NCR-2 (2019) used sea-level rise scenarios from 0.2 m up to 5 m added to mean high tide for estimating inundation areas in Oman. In this CRVA, sea level rise scenarios adapted in NCR-2 were considered with high resolution DEM data (5 m × 5 m) in Duqm area.

3.2 Climate Projections

3.2.1 Representative Concentration Pathways (RCPs)

The IPCC AR5 produced climate change projections for a range of RCPs based on different greenhouse gas (GHG) emissions scenarios developed to capture uncertainty of the scale of future economic activity and the global response to reducing emissions. In this study, following two RCPs were selected for developing plausible climate change scenarios for Duqm area.

a) RCP4.5 – Some GHG mitigation, stabilization scenario (538 ppm CO_2 by 2100); and
b) RCP8.5 – Very high GHG emissions scenario, little effort to reduce emissions (936 ppm CO_2 by 2100).

RCP8.5 is known as the “business as usual” scenario, whereas the RCP4.5 scenarios assume some reductions in GHG emissions.

3.2.2 General Circulation Models (GCMs)

Climate impact assessment in the future requires understanding plausible changes in local climate in the future. These climate projections however are subjected to a substantial level of variability due to uncertainties in the future emissions of greenhouse gases and the differences in representing the climate system in general circulation models (GCMs). The Coupled Model Inter-comparison Project Phase 5 (CMIP5) comprises a set of state-of-the-art GCMs that use RCPs to produce a wide range of climate scenarios. Even though, projections of temperature and rainfall are common, near surface wind speed is unavailable in some CMIP5 models. Therefore, 5 GCMs were selected, which includes the future changes of rainfall, maximum temperature, minimum temperature (required for drought analysis), and near surface wind speed. These GCMs are listed in Table 3-1.

Table 3-1: List of GCMs with their names and horizontal spatial resolutions

Modeling center	Model name	Grid size in degree (lon. × lat.)
Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia	ACCESS1.0	1.875 × 1.25
Canadian Centre for Climate Modelling and Analysis	CanESM2	2.8 × 2.8
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-ESM2M	2.5 × 2.0
Institute for Numerical Mathematics	INMCM4	2.0 × 1.5
Institute Pierre-Simon Laplace	IPSL-CM5A-LR	3.75 × 1.875

3.2.3 Downscaling coarse resolution GCMs to local Duqm area

Investigating the global warming effects on future climate conditions through the GCMs is a common practice worldwide. However, their ability to generate projections at finer spatial resolutions to be directly used in impact assessment is still limited. In this study, a stochastic weather generator (Long Ashton Research Station-Weather Generator; LARS-WG v5.5) was used to downscale the selected GCM's future projections at daily scale to local scale. LARS-WG produced semi-empirical probability distributions (discrete histograms with a fixed number of intervals with flexible lengths) based on observed climate variables (rainfall, and maximum and minimum temperatures) in baseline period.

When generating climate scenarios, the estimated cumulative probability function obtained from observations is adjusted by the relative change in magnitude of the corresponding parameter predicted by the future GCM scenario (detailed information can be found in Semenov and Stratonovitch 2010).

However, downscaling techniques that are effective for daily temperatures or precipitation may not be appropriate for extreme wind speed. Therefore, two-parameter Weibull distribution, which is long been established as a useful probability distribution for representing wind speeds, was used for downscaling wind speed (Tye et al., 2014). The Weibull distribution, with scale parameter $\alpha > 0$ and shape parameter $\beta > 0$, has a cumulative distribution function for $x > 0$ given by

$$\Pr(X \leq x) = F(x; \alpha, \beta) = 1 - \exp\left[-\left(\frac{x}{\alpha}\right)^{\beta}\right] \quad (1)$$

More details on the application of Weibull distribution on downscaling wind speed can be found in Annexure - 2.

3.3 Frequency analysis

The objective of this analysis is to examine whether the intensity of climate extremes is likely to increase in future. The yearly maxima of the daily precipitation, maximum temperature and wind speed were analysed using the Generalized Extreme Value (GEV) distribution function. The cumulative probability distribution function for the GEV is

$$F_{(x)} = \exp\left[-\left(1 + \xi\frac{x-\mu}{\sigma}\right)^{-1/\xi}\right] \quad (2)$$

where, $\{1 + \xi(x-\mu) / \sigma > 0\}$, $-\infty < \mu$, $\xi < \infty$ and $\sigma > 0$. The location (μ), scale (σ) and shape (ξ), parameters of this distribution were estimated by the maximum likelihood method. The goodness-of-fit of the fitted distribution was tested using the Kolmogorov-Smirnov test, which examines the null hypothesis that sample data follow the specified distribution. Given an annual exceedance probability of $P(X \leq x)$, the return period is calculated by the reciprocal of $P(X \leq x)$.

$$\text{Return period } (T) = \frac{1}{P(X \leq x)} = \frac{1}{1 - P(X > x)} = \frac{1}{1 - F_{(x)}} \tag{3}$$

A T-year return value is defined as the threshold that is exceeded by an annual extreme in any given year with the probability P = 1/T.

3.4 Baseline climate data in Duqm

There are five meteorological stations in Duqm area, which are maintained by the Public Authority for Civil Aviation (PACA) in Oman. Data availability and the percentage of missing data in these stations are shown in Table 3-2.

Downscaling climate variables to local scale requires long-term data (at least 15 years). This is important for capturing extreme events such as cyclone and heat waves. According to the available data in Duqm area, only the data from Masirah Island are long enough to use for climate projections. Therefore, it is not possible to assess the spatial variation of the climate variables in the study area. All the results presented in this study are therefore based on observations in Masirah Island in 2004-2019 period. The missing data were filled by considering the data from the nearest station that has the greatest correlation with the data from Masirah.

Table 3-2: Meteorological stations in Duqm and surrounding area

Station	Available longest data period	Missing data (%)
Yalooni	2010-2018	8.0
Duqm Airport	2009-2018	13.5
Haima	2012-2018	3.0
Zamaim	2012-2018	5.3
Masirah	**2004-2019**	2.7

3.5 Weight assignment for GCMs

Weighting individual GCM based on model performance has been used as a way to reduce the unwanted uncertainty in climate model projections. The rationale is that uncertainties can be reduced if the results from the better performing models are given a greater weight in the ensemble when used to produce probabilistic projections (Christensen et al., 2010). In this study, different weights were calculated based on the ability of the GCMs to represent climate in the baseline period. To compute the GCM weight, the bias B (%) was found first and then B was converted to a weight (W) using the following transformation.

$$B = 100\left[\frac{P_{GCM}}{P_{obs}} - 1\right]$$

$$W = 1 + B/100 \quad , \quad B < 0 \qquad (4)$$

$$W = \frac{1}{1 + B/100} \quad , \quad B > 0$$

Here P_{GCM} and P_{obs} are the interest climate variables from GCM and observations, respectively in baseline period. The application of Equation 4 for temperature, rainfall and wind speed is however different and depend on the extreme feature that we interest on capturing from GCM. Following section explains the application of the weighting method for each climate variable.

3.5.1 Weights for rainfall and wind speed extremes

Consideration of the far tails of rainfall distributions (99th, 99.9th and 99.99th percentiles) provides model performance of capturing extreme rainfall events. When a single time series from a particular RCP and a particular GCM is considered, weighting factors for the 99th, 99.9th and 99.99th percentiles were calculated, separately. These individual weights were then multiplied together to produce an overall weight for the interest GCM and RCP. Similar procedure was applied for the wind speed. The calculated weights are shown in Annexure - 2.

3.5.2 Weights for droughts

Because the SPEI includes precipitation, maximum temperature and minimum temperature, the weights calculated for extreme rainfall should not be used. Therefore, SPEI values were estimated for observations and all GCM scenarios in baseline period. Weighting factors for extreme, severe and moderate drought categories were then calculated separately based on Equation 4. These factors were then multiplied together to find final weight. The calculated weights are shown in Annexure - 3.

3.5.3 Weights for maximum temperature extremes

In case of the maximum temperature, the 99th, 99.9th and 99.99th percentiles of the distribution were computed from observations and model data to be used with Equation 4. This procedure was done for each season: winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug) and autumn (Sep-Nov). Then, for each season, weights belong to the different percentiles were multiplied together to form one factor. These seasonal factors were then multiplied together to yield final weight. The calculated weights are shown in Annexure - 3.

3.6 Vulnerability and Risk Matrix

Vulnerability to climate change is defined 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. Risk of the climate change can be assessed by considering both the consequence of an event occurring and likelihood that the same event occurs. Likelihood is used as a general description of probability or frequency, that is, how likely it is that climate event will occur. A consequence is the outcome or impact of an event. A risk assessment process such as the 'risk matrix' is a structured way of identifying impacts, adaptive responses and vulnerability to climate change (ISO 31000, 2009: Risk management-principles and guidelines).

In this CRVA study, likelihoods were assigned based on consideration of both the historical occurrence, and the level of confidence associated with the climate projections, for the key hazards as presented in Table 3-3 below:

Table 3-3: Likelihood categories[9]

S. No.	Likelihood	Description	Recurrent or event risks	Long term risks (under climate change scenario)
1	L5: Almost certain	Expected to occur in most circumstances.	Could occur several times per year.	Has a greater than 90% chance of occurring in the identified time period if the risk is not mitigated

[9] (**Source:** ISO 31000, 2009: Risk management-principles and guidelines)

S. No.	Likelihood	Description	Recurrent or event risks	Long term risks (under climate change scenario)
2	L4: Likely	Will probably occur in most circumstances.	May occur once every year.	Has a 60-90% chance of occurring in the identified time period if the risk is not mitigated.
3	L3: Possible	May occur at some time.	May arise once in 5 years	Has a 40-60% chance of occurring in the identified time period if the risk is not mitigated.
4	L2: Unlikely	May occur at some time, but is considered unlikely.	May arise once in 5 to 50 years.	Has a 10-30% chance of occurring in the future if the risk is not mitigated.
5	L1: Rare	Could occur in exceptional circumstances.	Unlikely during the next 50 years.	May occur in exceptional circumstances (i.e. less than 10% chance of occurring in the identified time period) if the risk is not mitigated.

Consequence of a climate change impact can be identified as either minor, moderate, major, severe or catastrophic. Details for this assessment are provided in Table 3-4.

Table 3-4: Consequence categories for assessing impact risk for economic, natural resources and social success criteria[10]

S. No.	Category	Profitability and growth	Natural resource sustainability and environment	Supply chain and market	Lifestyle and community	Public safety
1	**C5: Catastrophic**	Business would be unprofitable and contract markedly making it unviable. Business would have to be wound up.	Extreme, permanent and widespread loss of environmental amenity and progressive irrecoverable environmental damage	Loss of a key source of supply or market threatening the business	The region would be seen as very unattractive, moribund and unable to support its community	Large numbers of serious injuries or loss of lives
2	**C4: Severe**	Business would be unprofitable and contract markedly and would likely become unviable	Severe, semi-permanent and widespread loss	Severe disruption of a key source of	Severe and widespread decline in services and quality of life	Serious injuries or loss of lives

[10] (Source: Queensland Climate Change Centre of Excellence, 2011)

S. No.	Category	Profitability and growth	Natural resource sustainability and environment	Supply chain and market	Lifestyle and community	Public safety
		even with significant remedial action	of environmental amenity and likelihood of irrecoverable environmental damage	supply or market having a serious effect on the business	within the community	occurs routinely
3	**C3: Major**	The business would be unprofitable and contract and require significant remedial action to remain viable	Major, semi-permanent loss of environmental amenity and danger of continuing environmental damage	Major disruption of a key source of supply or market having a significant effect on the business	Major and widespread decline in services and quality of life within the community	Isolated instances of serious injuries or loss of lives
4	**C2: Moderate**	The business would only be marginally profitable with growth stagnant	Isolated but significant instances of environmental damage that might be reversed with intensive efforts	Components of the supply chain and market would require more than normal levels of management attention to protect the business	General appreciable decline in services	Small numbers of injuries
5	**C1: Minor**	The business is profitable and growth is achieved but they both fail to meet expectations	Minor instances of environmental damage that could be reversed	Isolated difficulties would arise in the supply chain and market but would be resolved	Isolated but noticeable examples of decline in services	Serious near misses or minor injuries

Depending on the likelihood of the hazard (Table 3-3) and the consequence (Table 3-4), a single value for the risk was calculated based on the guidelines in Figure 3-1.

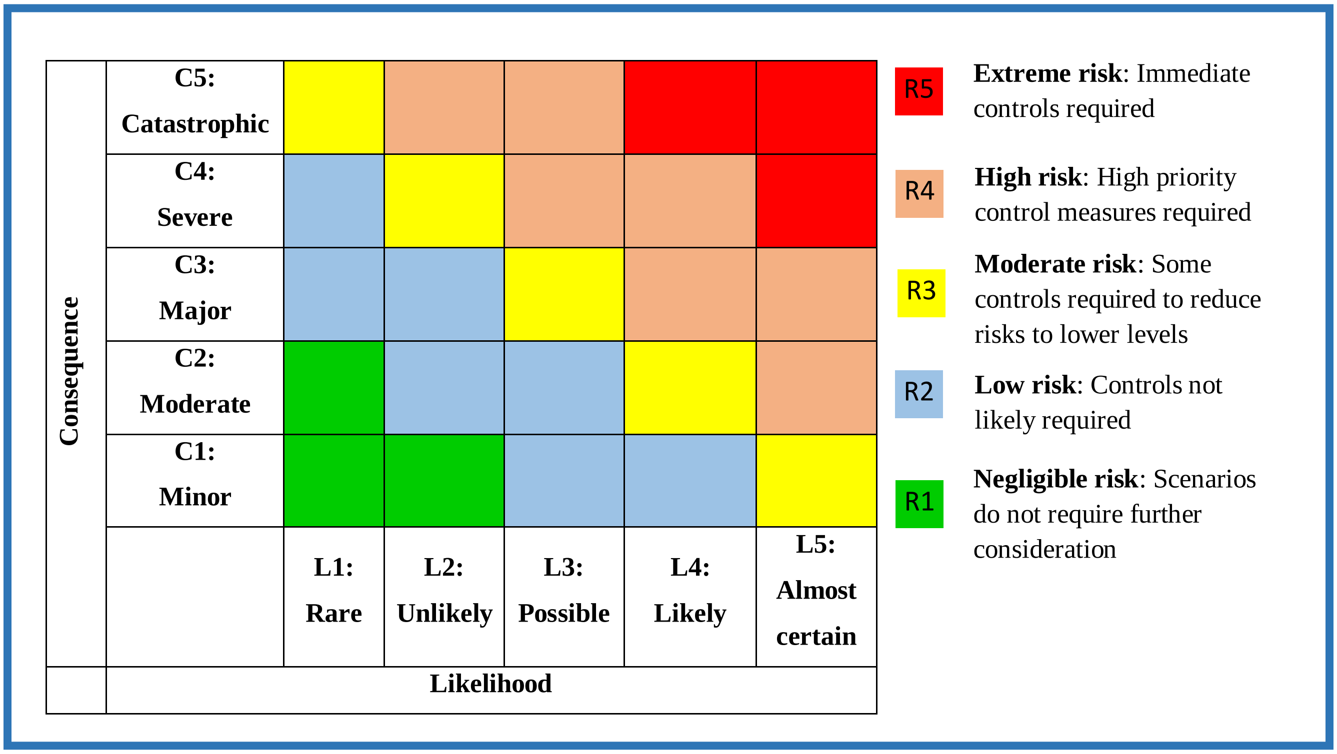


Figure 3-1 : Risk evaluation matrix (Source: Black et al. 2010).

4 FINDINGS OF THE CRVA

4.1 Impact analysis

The downscaled rainfall, temperature and wind speed values were compared with the observations at the local scale. Results are shown in Annexure 3. Attributed impacts of the climate change in Duqm area were analyzed in terms of maximum temperature, extreme rainfall, drought, wind speed and sea level rise. Following sections describe the potential changes of each climate variable as estimated using two RCPs in two future periods (2040-2059 and 2060-2079).

4.1.1 Maximum temperature

Projections for all emission scenarios indicate that the annual average daily maximum temperature increases in the future in Duqm area. When these changes are disaggregated in monthly scale (Figure 4-1), averaged daily maximum temperature of the warmest month increases for all months from November to June. Some minor reductions were estimated from July to September for the RCP 4.5 scenario. Under the high emission scenario (RCP 8.5), maximum temperature in the warmest month is projected to increase by 1.5 ˚C.

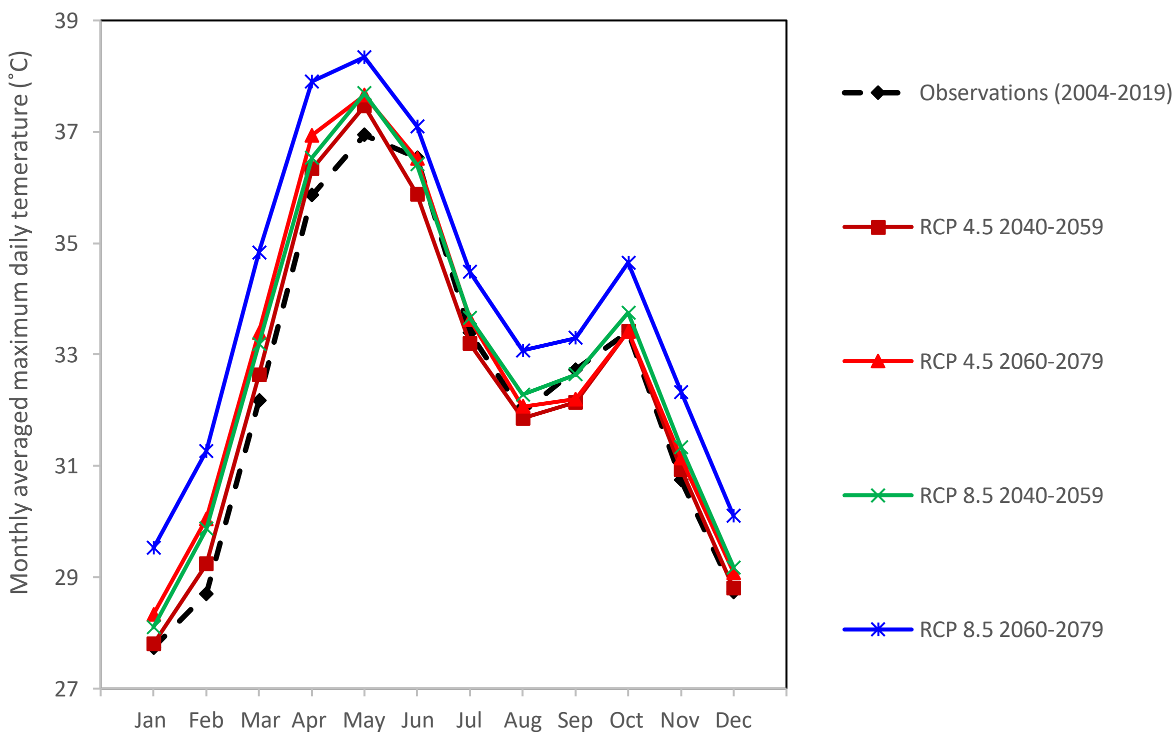


Figure 4-1: Monthly averaged daily maximum temperature of the warmest month.

Impact analysis of maximum temperature however requires impact estimations in finer time resolutions with different characteristics of the temperature regime. For example, high temperatures in a day negatively influence the workforce by reducing efficiency. Accordingly, the average number of days per year with daily maximum temperature is above 40˚C (a very hot day) were estimated for observations and future periods. Three of four scenarios presented in Figure 4-2 indicate that there will be more hot days in the future. RCP 4.5 scenario in 2040-2059 period shows that number of very hot days will be reduced by 1.2 days/year. Overall, RCP 8.5 scenario projects severe impact than the RCP 4.5 scenario. Also, number of hot days projected for 2060-2079 period is higher than that in the 2040-2059 period.

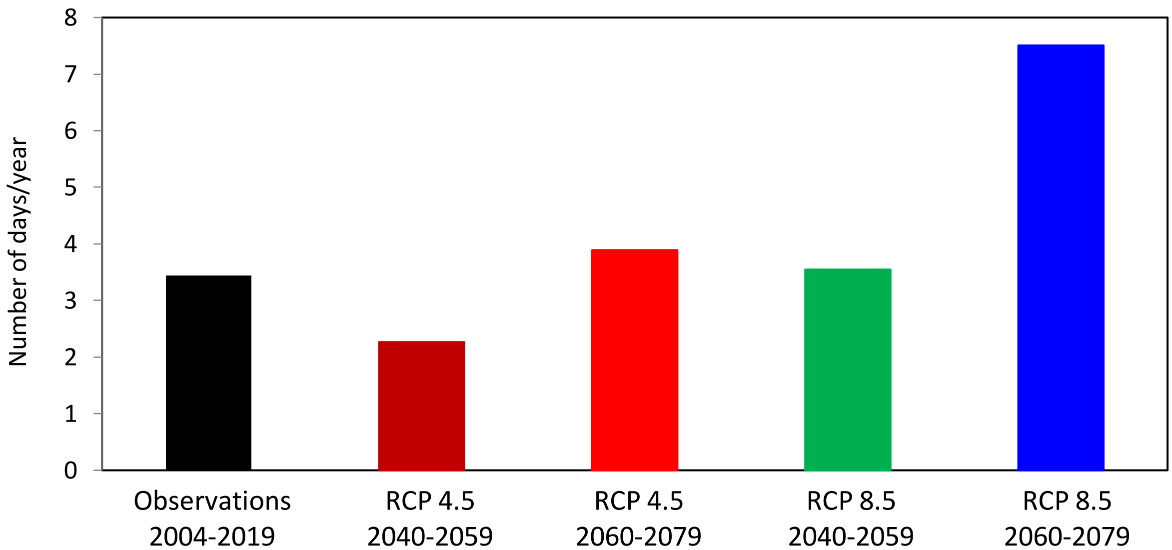


Figure 4-2: Average number of days/year with daily max temperature above 40˚C

The referenced temperature of 40˚C used to produce the results in Figure 4-2 is approximately equal to the 99th percentile of the daily maximum temperature in 2004-2019 period. However, some studies have shown that heat-related health conditions occur on isolated hot days that would not be classified as extreme temperatures or heat waves (Baccini et al., 2011). Therefore, potential changes of maximum temperature for different percentiles were also examined. According to Figure 4-3, all future scenarios, except the RCP 4.5 in 2040-2059 period, projected increases in extreme temperatures.

An increasing number of studies have documented that temperature above a certain high level remains for few consecutive days is significantly associated with human mortality. Potential changes of climate in such context were analyzed by considering number of heat waves projected in observation time and future periods. Figure 4-3 shows that the number of heatwaves projected in 2060-2079 period by both RCP scenarios are considerably higher than that was calculated from observed temperatures or projected for 2040-2059 period. When compared with observations in 2004-2019 period, RCP 4.5 and RCP 8.5 scenarios projected 5.5 and 9.1 times higher number of heat waves in 2060-2079 period.

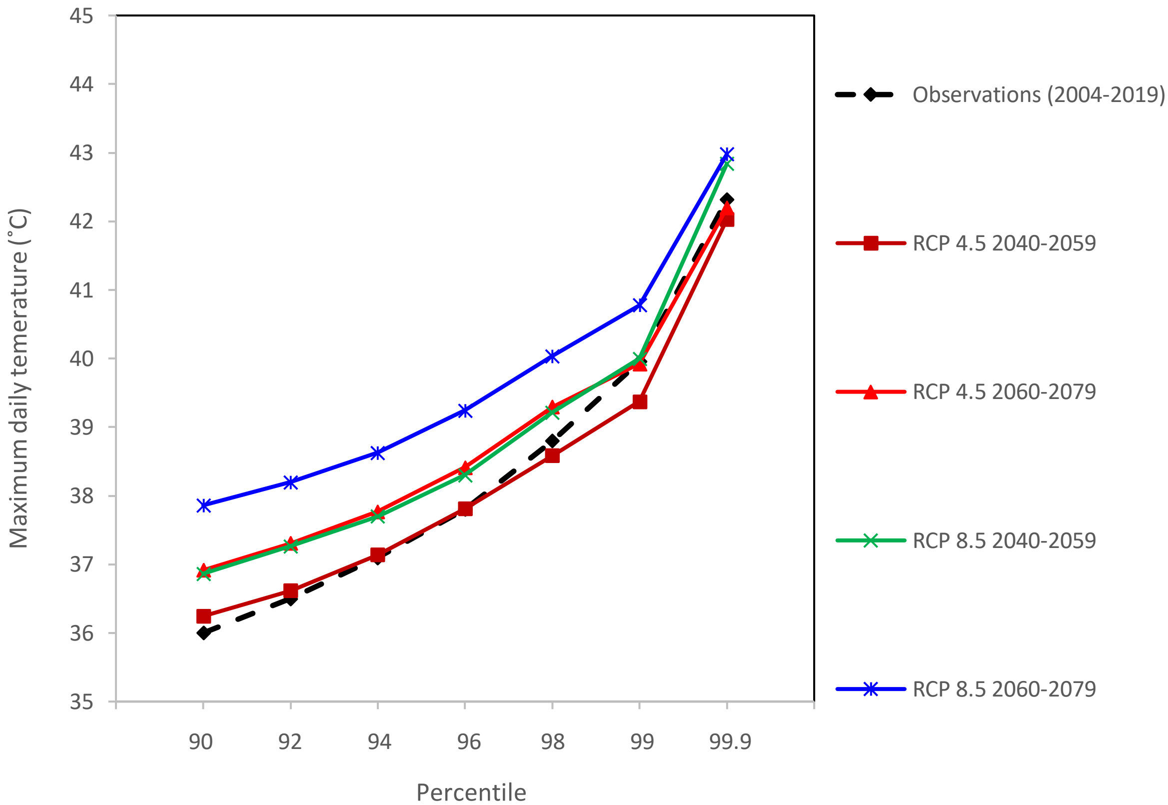


Figure 4-3: Maximum daily temperature estimated for different percentiles

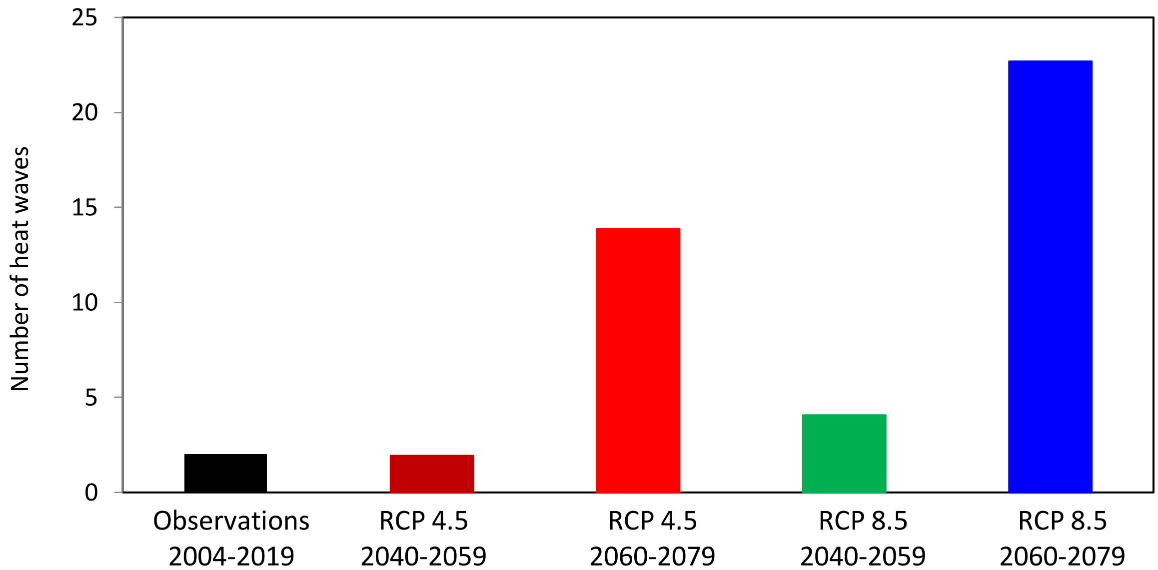


Figure 4-4: Number of heat waves in different periods

Table 4-1 shows the results from the frequency analysis of heat waves. Even though heat waves did not happen more than once per year during 2004-2019 period, all projections indicate that heat waves more than twice or thrice per year are also likely to occur in future climate. Overall, both RCP scenarios projected that the likelihood of having at least one heat wave per year decreases in 2040-2059 period. This is because, projected temperature of RCPs increases in this period by warming the winter months and slightly cooling the extremely hot summer days.

Table 4-1: Annual occurrence probability (%) of heat waves.

S. No.	Time period	At least one time	At least two times	At least 3 times	More than 3 times
1	Observations (2004-2019)	12.5	0.0	0.0	0.0
2	RCP 4.5 (2040-2059)	4.9	2.0	1.2	0.8
3	RCP 4.5 (2060-2079)	28.5	20.3	11.4	7.1
4	RCP 8.5 (2040-2059)	7.7	7.7	2.8	2.1
5	RCP 8.5 (2060-2079)	41.5	28.1	18.5	10.2

4.1.2 Extreme rainfall

Highway Design Standards (HDS, 2010) used in some designs in SEZD area greatly underestimates the rainfall intensity in local Duqm area. Figure 4-5 shows a comparison of intensity-frequency curves developed based on 1-day local rainfall observations in 2004-2019 period, HDS (2010) and future projections. The 100-year 1-day rainfall intensity from local observations is about 288.5 mm/day (1% annual exceedance probability), which according to HDS (2010) is about 144 mm/day only. Consequently, annual exceedance probability of such rainfall event with 288.5 mm/day according to HDS (2010) is smaller than 0.2% (Table 8). Any design, which is based on HDS (2010) in Duqm area (Table 2-1), must implement proper counter measures to reduce the climate change vulnerability.

Rainfall intensities projected by RCP 4.5 scenario for different return periods show only some minor changes (positive changes for return periods less than 50-years and negative changes for return periods more than 50-years) compared to the intensities estimated from observations. In contrast, RCP 8.5 projected consistently higher rainfall intensities in both future periods. In particular, RCP 8.5 in 2040-2059 period projected approximately 80% increases in rainfall intensity for 100-year5 return period. According to the guidelines on analysis of extremes in a changing climate prepared by WMO, a very heavy precipitation day is defined as a day with total rainfall is more than 20 mm (Tank et al., 2009).

Considering the extreme rainfall, two thresholds of rainfall: 25 mm and 50 mm were considered in this CRVA and there probability of occurrences were calculated. Table 4-2 shows that the annual exceedance probability of these two kinds of rainfall events are similar between observations and future projections by RCP 4.5 scenario in both periods. On the other hand, annual occurrence probabilities of those events projected by RCP 8.5 scenario were more than two times of those estimated by observations in 2004-2019 period.

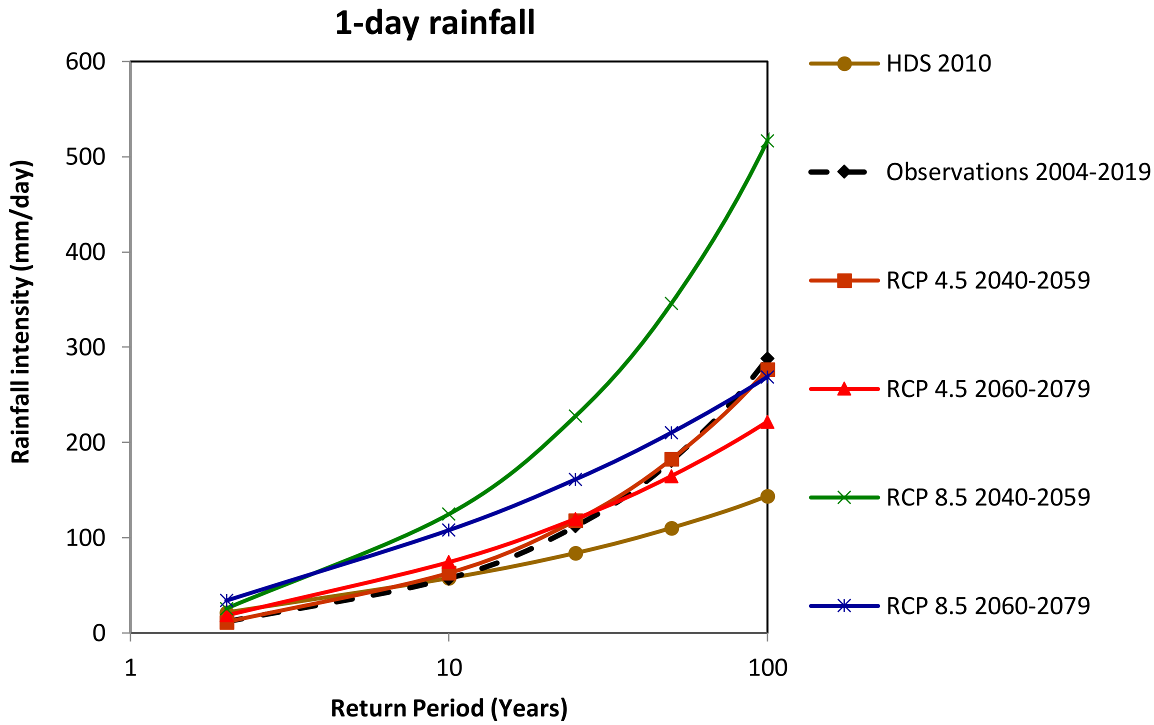


Figure 4-5: A comparison of 1-day rainfall intensity-frequency curves from HDS (2010) with those developed from local observations and future projections in Duqm area.

Table 4-2: Climate statistics based on 1-day rainfall.

Climate statistics	Baseline: Observations 2004-2019	HDS, 2010	RCP 4.5 2040-2059	RCP 4.5 2060-2079	RCP 8.5 2040-2059	RCP 8.5 2060-2079
100-year 1-day maximum rainfall	288.5	144	277.0	222.0	516.9	269
Annual exceedance probability of the **baseline** 100-year return level of the maximum 1-day precipitation amount (%)	1.0	0.2	0.9	0.5	2.7	0.8
Annual exceedance probability of a day with daily rainfall exceeding 25 mm (%)	30	40	30	36	50	67
Annual exceedance probability of a day with daily rainfall	12	14	12	18	31	33

Climate statistics	Baseline: Observations 2004-2019	HDS, 2010	RCP 4.5 2040-2059	RCP 4.5 2060-2079	RCP 8.5 2040-2059	RCP 8.5 2060-2079
exceeding 50 mm (%)						

Figure 4-5 and Table 4-2 depicted the potential changes of rainfall intensity in the future estimated from daily rainfall data. In Duqm, these intensities were generated by single rainfall events with duration generally less than 24 hours. However, even a moderate rainfall event can generate a disastrous flood if it occurs while the watershed has an elevated antecedent moisture level. In the Special Report of Working Groups I and II of the IPCC-AR5, Seneviratne et al. (2012) explained this as an effect of compound events, in which, combinations of events that are not themselves extremes but lead to an extreme event or impact when combined. Therefore, similar to 1-day rainfall analysis, intensity-frequency relationships and exceedance probabilities were calculated considering 5-days total rainfall.

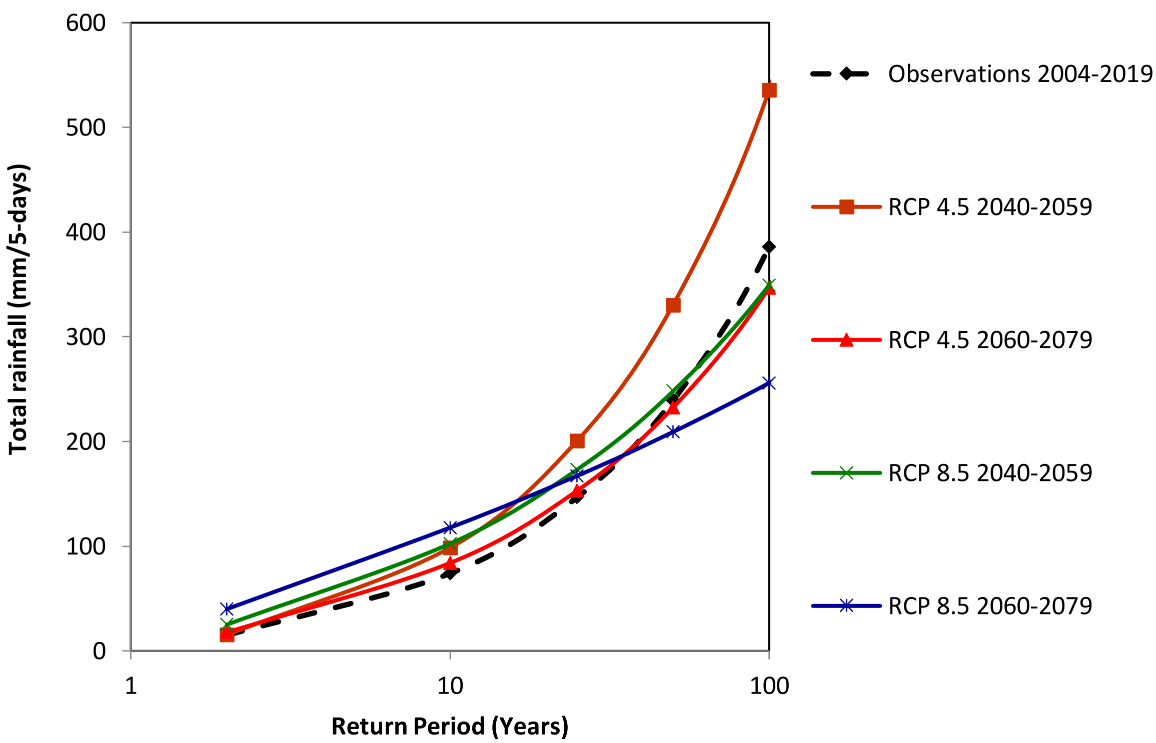


Figure 4-6: A comparison of 5-days rainfall intensity-frequency curves developed from local observations and future projections in Duqm area.

Figure 4-6 shows that rainfall projections generally have higher rainfall amounts than the observations for return periods less than 50-years. In contrast to 1-day rainfall intensities in Figure 4-5, 5-days rainfall amounts projected by RCP 8.5 scenario are smaller than the rainfall amounts calculated from observations for return periods greater than 50-years. Moreover, RCP 8.5 scenario projected smaller 5-day rainfall amount than the 1-day estimations. Inspection of individual time series revealed two reasons for this occurrence. Firstly, it was noted that the compound effect of RCP 8.5 rainfall events are dominant only for the events with smaller rainfall intensities. Rainfall events with higher intensities will occur mainly as single events within 5-day period. This behavior of the RCP 8.5 projections significantly change the shape of the probability distribution. Secondly, when assembling the multi-model results, different weighting factors (Table A-3.1) were considered for two time series based on the performances of the individual GCMs to project the 1-day and 5-day rainfalls during baseline period. These reasons have resulted smaller rainfall amount for 5-day events than that for the 1-day projections.

On the other hand, RCP 4.5 scenario projected consistently greater rainfall amounts during 2040-2059 period. For example, the 100-year 5-days rainfall amount from local observations is about 385.9 mm (1% annual exceedance probability), which according RCP 4.5 in 2040-2059 period is about 535.5 mm. Consequently, annual exceedance probability of such rainfall event with 385.9 mm /5-days increases from 1% in observational period to 1.6% in 2040-2059 period (Table 9).

Table 4-3: Climate statistics based on 5-day total rainfall.

Climate statistics	Baseline: Observations 2004-2019	HDS, 2010	RCP 4.5 2040-2059	RCP 4.5 2060-2079	RCP 8.5 2040-2059	RCP 8.5 2060-2079
100-year 5-day maximum rainfall	385.9	-	535.5	346.9	349.3	255.9
Annual exceedance probability of the **baseline** 100-year return level of the maximum 5-day precipitation amount (%)	1.0	-	1.6	0.8	0.8	0.2
Annual exceedance probability of a 5-day event with daily rainfall	20	-	25	22	29	40

Climate statistics	Baseline: Observations 2004-2019	HDS, 2010	RCP 4.5 2040-2059	RCP 4.5 2060-2079	RCP 8.5 2040-2059	RCP 8.5 2060-2079
exceeding 50 mm (%)						
Annual exceedance probability of a 5-day event with daily rainfall exceeding 100 mm (%)	7	-	10	7	10	14

4.1.3 Drought

The temporal variations of droughts projected in the future by different GCMs and RCPs for two future periods are shown in Annexure - 4. A summary of these projections is shown in Table 4-4 and Figure 4-7. All four future scenarios projected that the overall proportion of time spent in drought would only change marginally. These scenarios however indicate that extreme droughts are likely possible even though such events have not occurred during the baseline period (2004-2019) in Duqm. From all scenarios, RCP 4.5 projected the greatest changes in the 2060-2079 period compared to the experienced droughts in the past. When two future periods are compared, occurrence of droughts in all categories in the 2060-2079 period is expected to be higher than in the 2040-2059 period. In addition to the potential variations of monthly total rainfall, this difference can be attributed to the increases in evapotranspiration because of greater warming in the 2060-2079 period than in the 2040-2059 period.

Table 4-4: Number of drought events in different periods.

Category	Number of Drought Events			
	Extreme (W=1.5) (SPEI ≤ -2)	Severe (W=1.0) (−2 < SPEI ≤ −1.5)	Moderate (W=0.5) (−1.5 < SPEI ≤ −1)	Combined using weights
Observations 2004-2019	0	5	25	17.5
RCP 4.5 2040-2059	0.5	2.8	23.3	15.2
RCP 4.5 2060-2079	2.9	5.1	29.9	24.4
RCP 8.5 2040-2059	0.8	5.5	25.7	19.6
RCP 8.5 2060-2079	0.7	4.7	31.8	21.7

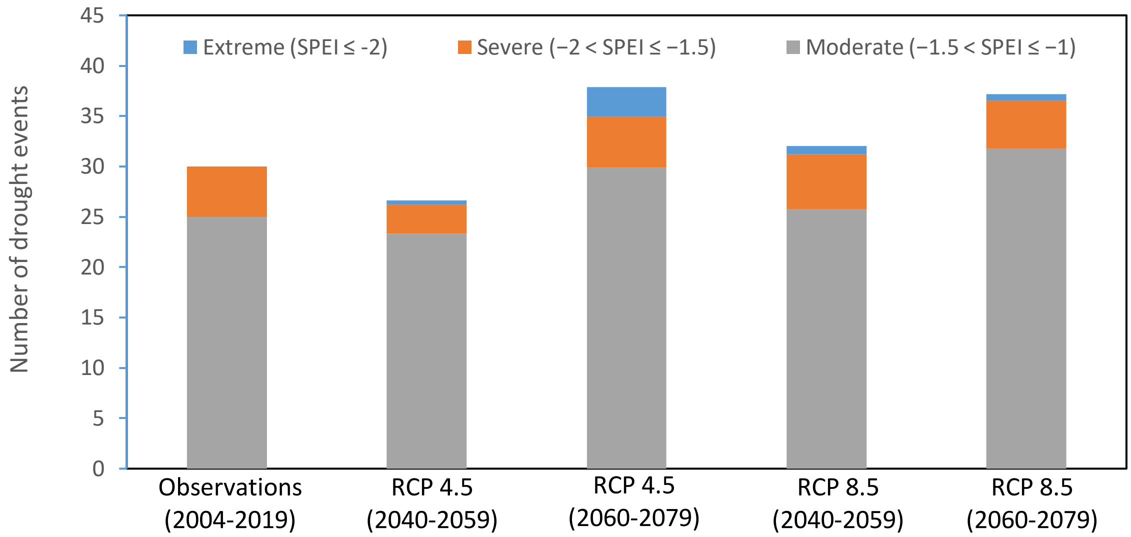


Figure 4-7: Distribution of extreme, severe and moderate droughts in different periods

4.1.4 Wind speed

The two-parameter Weibull distribution was used for downscaling wind data from GCMs. Estimated parameters of the Weibull distribution for different GCMs, RCPs and two future periods are shown in Annexure - 5. A significant change of the days with strong winds (1-hr gust more than 15 m/s) was projected in all future periods compared to observations in Duqm during 2004-2019 period. The greatest of which, RCP 4.5 scenario estimated 23 days of strong winds per year in 2040-2059 period compared to 1.6 days/year observed during baseline period in Duqm (Figure 4-8). Results also showed that these strong winds would not likely be strengthened up to destructive levels in the Saffir-Simpson Hurricane Scale.

According to the comparison of return-level and return period plots of 60-sec gust wind speed between observations and future projections, three out of four future scenarios indicated slightly smaller wind speeds than the estimated values from the observations in Duqm. The RCP 4.5 scenario alone showed increased wind speeds in the 2040-2059 period than the observations. Consequently, this scenario projected that the annual exceedance probability of the Category 1 and Category 3 winds will be increased by 0.64% and 0.15%, respectively (Table 4-5).

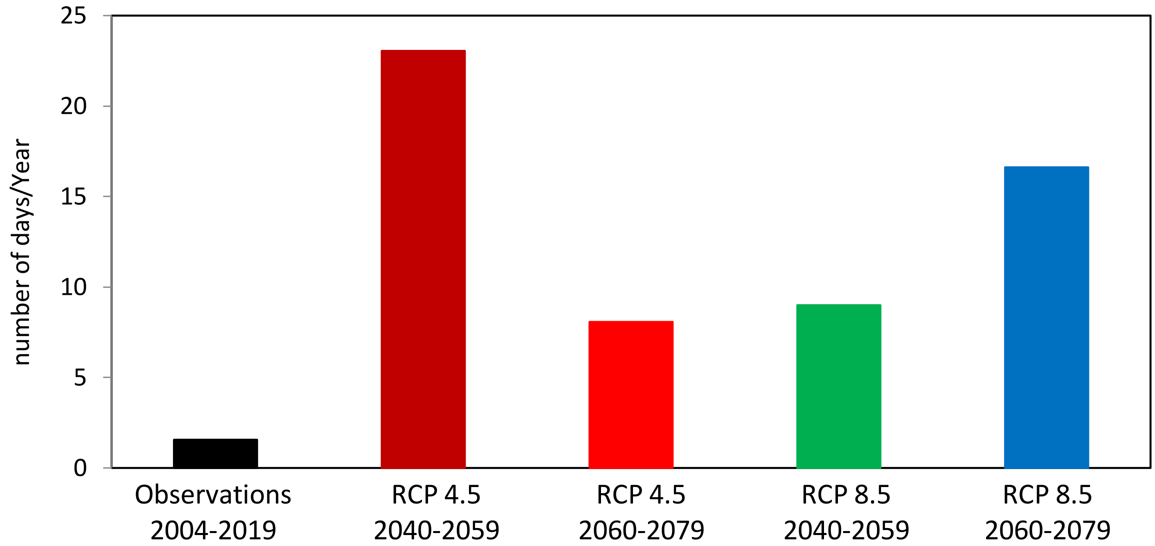


Figure 4-8: Average number of days per year with maximum wind speed (1-hr gust) more than 15 m/s.

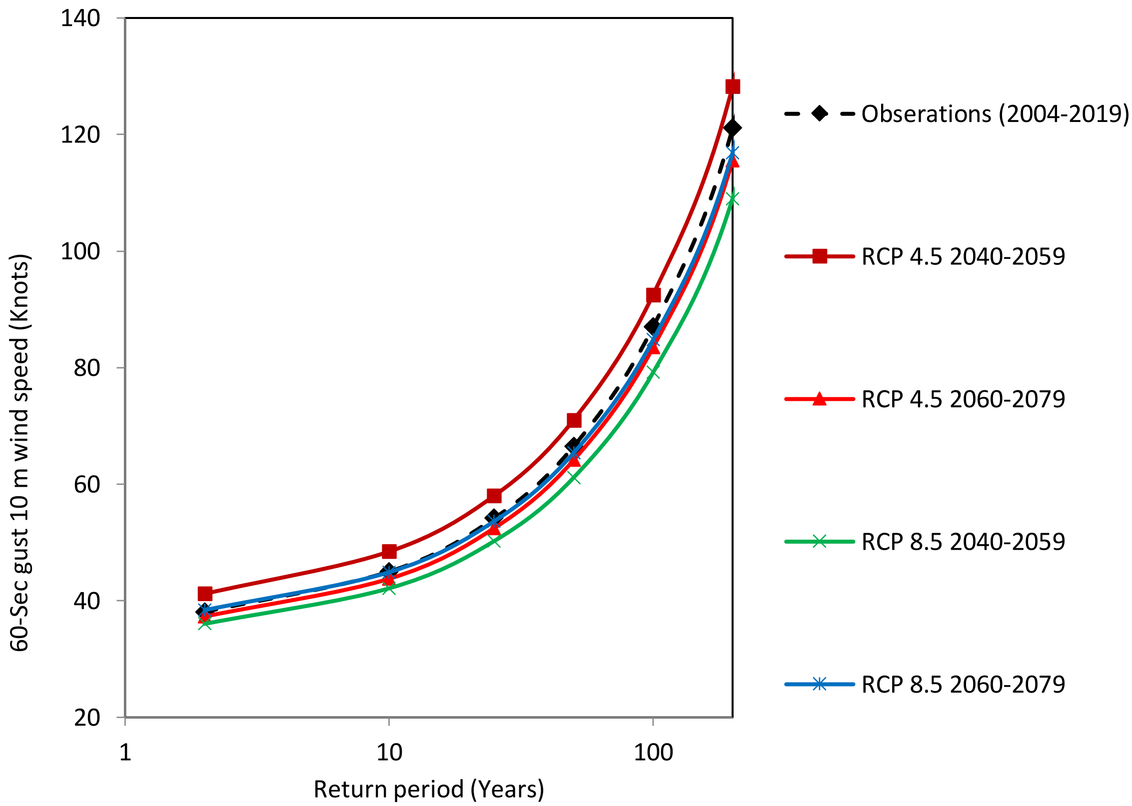


Figure 4-9: Relationship between 60-Sec gust 10 m wind speed and return period.

Table 4-5: Annual exceedance probability (%)

Time period	Category 1 winds based on Saffir-Simpson Hurricane Scale	Category 3 winds based on Saffir-Simpson Hurricane Scale	100-year return level estimated from observations
Observations (2004-2019)	2.22	0.80	1.00
RCP 4.5 (2040-2059)	2.86	0.95	1.18
RCP 4.5 (2060-2079)	2.00	0.74	0.95
RCP 8.5 (2040-2059)	1.82	0.65	0.83
RCP 8.5 (2060-2079)	2.22	0.77	0.95

4.1.5 Sea level rise

The IPCC AR5 (2013) reported an average rate of global sea level rise of 1.7 mm/yr over the period 1901 to 2010, corresponding to 0.19 m of relative MSL rise. It is noted, however, that the rate of sea level rise can vary over time, and for the period 1998-2010 the rate of rise was 3.2 mm/yr (IPCC, 2013), indicating an acceleration of the rate of rise over the two previous decades. According to the RCP scenarios, between 0.26 and 0.98 m of sea-level rise are projected by 2100. Moreover, coastal flooding due to tropical cyclone can be a major concern in low-lying developing areas and natural settings such as coastal lagoons in Duqm (NCR-2, 2019).

Long-term wave and surge reanalysis for the coastal inundation requires numerical wave models driven by re-analyzed wind data. In NCR-2 (2019), these effects were assessed by considering seven sea level rise scenarios for the year 2100 (0.2 m-5 m) added to mean high tide. In this CRVA study, same range of sea level rise was considered and potential inundation areas were calculated for a coastal belt of approximately 90 km long. Annexure 6 shows a set of figures generated by considering these scenarios. A summary of these figures are shown in Table 4-6. Total inundation land ranges from about 6 km^2 with sea level rise under 0.5 m to over 50 km^2 under sea level rise of 5 m that correspond to conditions of storm surge due to tropical cyclones (NCR-2, 2019).

Table 4-6: Inundation area attributed to different sea level rise scenarios.

S. No.	Sea level rise (m)	Inundation area (km^2)	Total Inundation area (km^2)
1	0.0-0.5	6.2	6.2
2	0.5-1.0	6.4	12.6
3	1.0-1.5	4.9	17.5
4	1.5-2.0	5.3	22.8
5	2.0-2.5	5.1	27.9
6	2.5-3.0	4.9	32.9
7	3.0-4.0	9.6	42.4
8	4.0-5.0	8.3	50.7

4.2 Assessment of Climate Risk

The risk assessment findings of the CRVA are documented in this section. Consequences of the hazards of maximum temperature, extreme rainfall, drought, extreme wind speed and sea level rise were evaluated in terms of potential impacts on economic, environmental, and social and public safety. They were related with the likelihood of the hazards to categorize the risk (Annexure 6). These finding indicated that the extreme wind effect on public health will have a high risk at R4 level during both of the future periods. Analysis of drought showed that the risk on the groundwater and coastal habitats will be high at R4 level during 2060-2079 period. According to RCP 8.5 scenario, the risk of the heat waves will be significant at R4 level during 2060-2079 period and affect on machinery, equipment, construction materials, public health and tourism sector. These highlighted cases will requires implementing appropriate control measures with a high priority to cope with potential impacts. The effects of sea level rise and the prolonged rainfall events are at R3 risk level during both of the future periods, which will require appropriate control measures to reduce the risk to lower levels. The next section of this report proposes some countermeasures and actions to cope with these climate risks.

Table 4-7: Climate change risk in different categories

#	Climate Change Parameter	Risk: 2040 – 2059	Risk: 2060 – 2079
1	Max Temp Heat Wave: 4 types of impact: M/C, community health, livestock/agriculture & tourism	RCP 4.5: 1 x R1 & 3 x R2 RCP 8.5: Same	RCP 4.5: 1 x R2 + 3 x R3 RCP 8.5: 1 x R3 + 3 x R4

#	**Climate Change Parameter**	**Risk: 2040 – 2059**	**Risk: 2060 – 2079**
2	High Intensity Ext Rainfall: 4 types: Wadis, Roads, Port & Maintenance	RCP 4.5: 1 x R1 & 3 x R2 RCP 8.5: Same	RCP 4.5: 1 x R1 & 3 x R2 RCP 8.5: Same
3	Prolonged Rainfall Intensity >5 days: 3 types: Roads, Flooding & Structure	RCP 4.5: 2 x R2 & 1 x R3 RCP 8.5: 1 x R1 & 2 x R2	RCP 4.5: 1 x R1 & 2 x R2 RCP 8.5: 2 x R2 & 1 x R3
4	Droughts: 3 types: GW, Crops & Ecology	RCP 4.5: 1 x R2 & 2 x R3 RCP 8.5: Same	RCP 4.5: 1 x R3 & 2 x R4 RCP 8.5: Same
5	High Winds/Cyclones: 3 types: Port Ops/Coastal Topping, Bldgs/Infra, Dust Impacts on public health	RCP 4.5: 2 x R1 & 1 x R4 RCP 8.5: Same	RCP 4.5: 2 x R1 & 1 x R4 RCP 8.5: Same
6	Sea Level Rise: 3 types: Corrosion/damage, erosion/shoreline, loss of freshwater/agriculture	RCP 4.5: 3 x R2 RCP 8.5: 1 x R2 + 2 x R3	RCP 4.5: 1 x R2 & 2 x R3 RCP 8.5: Same

5 CLIMATE CHANGE ADAPTATION

This section proposes options for managing the climate risks in accordance with the findings of the risk analysis in the previous section. Firstly, it is required to select which hazards, impacts and corresponding risks qualify for consideration. These actions were selected based on the risk matrix in Figure 3-1.

Table 5-1: Adaptation measures for key element of the OPAZ/SEZD project.

No.	Likely impact of climate change	Activity description	Time frame for implementation
1.	Effect of the heat waves on machinery, equipment and construction materials.	• Performance of assets during heatwave conditions depends on a range of factors, including: materials used, condition, maintenance, etc. • Install reliable instrument/machinery (of suitable specification) that conforms to operating conditions at SEZ considering at least 30 days of heatwave days. • SEZD to issue permits based on these considerations. • Instrument/machinery to be housed in an enclosure with a regular maintenance schedule.	Roll-out mechanism to be developed by 2025 and fully implemented by 2060
2.	Effect of the heat waves on the health and productivity of construction workers	• Follow building standards & design guidelines to reduce the impacts of heat wave on personnel. • Provision of shade, insulation and ceiling fans as appropriate for workers. • Recommendations on working during extreme heat conditions per H&S procedures.	Recommend implementation by Q4 of 2021
3.	Effect of the heat waves on elderly, very young people and persons with existing chronic health conditions	• Awareness of public on heat wave and its consequences. • Ensure buildings ability to maintain stable internal temperatures.	Roll-out mechanism to be developed by CY 2023 along with CSR initiatives
4.	Effect of the heat waves and droughts on livestock and crops.	• Heatwaves that occur during a drought year are more devastating because a drought year limits heatwave management options. • Educate farmers about the impacts of heatwaves and consequences and adopt smart farming techniques as necessary.	Roll-out mechanism to be developed by CY 2030 based on priority as there are no major

No.	Likely impact of climate change	Activity description	Time frame for implementation
			farming activity in the SEZ area.
5.	Effect of the heat waves or flood on the tourism.	• Electricity services can be disrupted during heat wave periods or flood times. • Promotion of more renewable energy sources such as solar energy to control spikes in electricity demand.	Roll-out mechanism to be developed by 2025 and fully implemented by 2060
6.	Impact of extreme rainfall on infrastructures.	• The PMP of 580 mm/day used for designing Jurf and Saay dams has a 285-years return period according to the estimations from 2004-2019 observations in Masirah. The annual exceedance probability of such event is about 0.35% (R2 risk). According to the highest impact scenario (RCP 8.5 in 2040-2059 period), Such rainfall event has an annual exceedance probability of 0.8%. Should OPAZ/SEZD wish to reduce the associated risk, NoC level of the dam can be increased as recommended. • 500-years 24-hour rainfall event in HDS (2010), which was used for Drainage network master plan, has approximately 100-years return period according to the 2004-2019 observations in Masirah. The annual exceedance probability of such event is about 1% (R2 risk). According to the highest impact scenario (RCP 8.5 in 2040-2059 period), Such rainfall event has an annual exceedance probability of 3.2%. Should OPAZ/SEZD wish to reduce the associated risk, embankment level can be increased in critical places based on a detail study.	Associated risk is at R2 level. Time to implement adaptation measures will depend on the OPAZ/SEZD decision to lower the probability of the Hazard. Recommend modelling studies to be conducted with 288 mm/day (recorded baseline of 100 year 1 day rainfall) as opposed to 144 mm/day suggested by HDS by CY 2023

No.	Likely impact of climate change	Activity description	Time frame for implementation
		• Erosion of the embankment: External sides of the channel embankments are protected from rainfall erosion with 200 mm thick of gravel layer. All other relevant designs are required to take necessary measures to prevent erosion from heavy rainfall and weakening of the basements due to groundwater level rise attributed to prolonged rainfall events.	As appropriate.
		• Flood-proof design and construction methods for industrial, commercial, and residential complexes and tourist hotels anticipating both surface flooding and underground flooding due to groundwater level rise.	To be considered in the planning stages of projects and issuance of permits
		• Implement groundwater-monitoring program to investigate the variation of groundwater level and quality.	To be implemented by CY 2025
		• Installing weather stations (land and sea) covering the entire catchment area and piloting Early Warning System (EWS) is highly recommended. • Creating a database: Monitoring/surveying and recording occurrence of climate events and the impacts of climate events on assets and performance, including the details of damages, costs and the repairs required.	To be implemented by CY 2030
7.	Impact of extreme rainfall on workforce	• Develop a policy that includes measures to reduce the health risks during floods.	Recommend implementation by Q4 of 2021
8.	Impact of droughts on groundwater and associated ecosystems	• The dams are designed for the protection from floods and consequently, they are not intended for permanent storage of floodwater to recharge the groundwater aquifers. It is proposed to use the dams and reservoirs for both flood management and groundwater recharge except in cases where the flood event is severe and a threat for the safety of the dam.	Plan for aquifer recharge to be developed by CY 2030. Baseline update to be considered (water levels, diversity) every 10 years along

No.	Likely impact of climate change	Activity description	Time frame for implementation
		• Releasing water through the wadi in a regulated manner also can enhance the groundwater recharge. • Maintain ecological corridors, which improves biodiversity with positive consequences.	with biodiversity baseline studies.
9.	Extreme wind effects on infrastructure	• Estimated risk of extreme wind on infrastructure remains at R1 level in the future. However, up-to-date, wind projections in GCMs are considered less reliable. Therefore, adherence to a standard code of practice (e.g., gusts of over 15 m/s for extended time periods) and consideration of potential changes of wind effect in future designs are recommended to reduce the risk.	Roll-out mechanism to be developed by 2025 and fully implemented by 2060
10.	Extreme wind effects on public health	• Awareness of public on dust storms and its consequences. • Provide recommendations to workforce about working during extreme wind conditions.	Roll-out mechanism to be developed by CY 2022 along with CSR initiatives
11.	Effects of sea level rise on coastal flooding	• According to Jurf and Saay Detail Design Report (Renardet SA & Partners 2015), water surface elevation at the outlet of the channels at the sea were considered to be 2.5 m a.m.s.l. This accounts 2.6 m for sea level rise and 1.56 m for surge due to cyclone. Therefore, sea level rise effect on coastal flooding will not be likely an issue in near future. However, compound effects of sea level rise and cyclone may course severe storm surge. In such incidence, consequences can be exacerbated if it coincides with an extreme flood event. Therefore, integration of a EWS with dam operation is recommended. • Implement long-term sea level monitoring program to investigate sea level rise in Duqm port area.	Roll-out mechanism to be developed by 2030 and fully implemented by 2060
12.	Effects of sea level rise on coastal erosion, shoreline	• Beach/shore nourishment, i.e. the replacement of eroded sand (or sand that is expected to be eroded), can be considered as an adaptation option	Roll-out mechanism to be developed by 2030 and fully

No.	Likely impact of climate change	Activity description	Time frame for implementation
	retreat and port operations.	(Hinkel et al., 2010). Because sand nourishment is expensive, such activity must be carried out in local scale considering viability of all other options. • Design and build of foreshore structures considering both the design wave criteria and sea level rise.	implemented by 2060.
13.	Effects of sea level rise on saltwater intrusion	• Regulate the groundwater pumping in proposed industrial and tourist areas by monitoring groundwater level and quality. • Use Jurf and Saay dams for recharging groundwater aquifers during regular rainfall events.	Extraction of groundwater to be regulated and supervised by OPAZ/SEZD based on data collected and modelled as appropriate. Roll-out mechanism to be developed by 2030 and fully implemented by 2060

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6 RESOURCE EFFICIENCY - GHG

In addition to the CRVA study, the scope of work as part of the contract C119/2019 entails estimation of Green House Gas (GHG) emissions for Sub-projects 6 and 7 for the operation phase of the projects. Along with the estimation of GHG, a framework guideline for GHG reporting is to developed for integration into OPAZ/SEZD operations and/or for investors, tenants and contractors at SEZD. The requirement is part of the IFC performance standards 3: Resource Efficiency and Pollution Prevention.

6.1 Background

The work packages which require greenhouse gas estimation include the following for the operation phase:

a) Sub-Project 6 (Duqm refinery service corridor): Establishment of a Service Corridor for the transportation of the Refinery Petroleum Derivatives and its peripherals such as cables, roads and the required protection fences. The service corridor stretches from the location of Duqm Refinery till the Export Jetty at Duqm Port with a length of 6.5 km and width of 37.2 metres and other checkpoints.
b) Sub-Project 7 (Road section 4): The project covers the construction of 2.2 km dual carriageway, 3 km single roads, 2 dual entrances to Duqm Refinery with a total length of 574 m long. The project will also include traffic signals, 2 roundabouts, concrete channel for rainwater drainage of 3830 m long, concrete box culverts, street lightening and protection of existing services.

The above corridor is mainly for the transport of vehicles and also transport of various hydrocarbons in the pipelines located in the corridor. The greenhouse gases from the construction of these corridors are provided in the respective Environment Impact Assessment / Statement. The main greenhouse gas emissions during operations of this corridor are the following:

a) Vehicle movement (trucks, buses, cars, other multipurpose vehicles)
b) Road maintenance vehicles & equipment such as re-surfacing, trucks, rollers, etc.
c) Fugitive emissions from the hydrocarbon pipelines
d) Offices and other related facilities involved in the operation and maintenance of this road
e) Indirect GHG from the lighting provided to the road lights, traffic lights, etc.

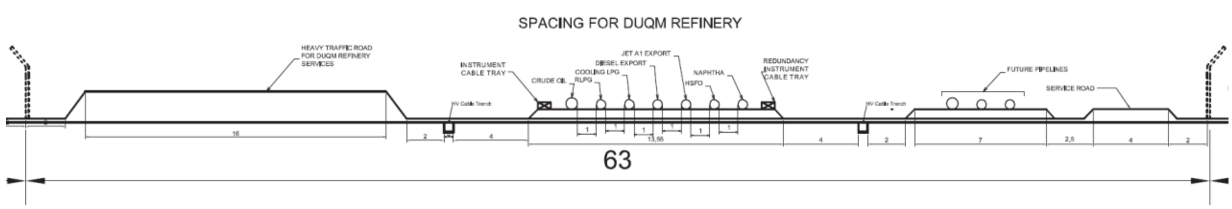
The following sections present the Greenhouse gases estimations and workings along with assumptions for the two sub-projects.

6.2 GHG Emissions for Sub-project 6

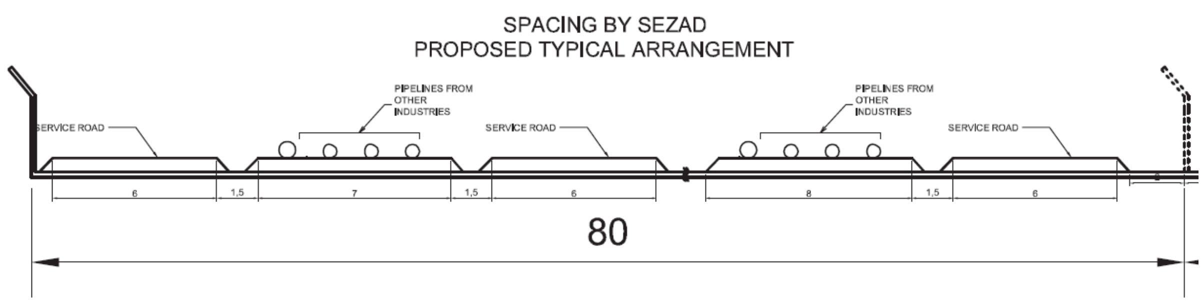
This section provides the estimation of the Greenhouse gas from the Sub-Project 6 (Duqm refinery service corridor): Establishment of a Service Corridor for the transportation of the Refinery Petroleum Derivatives and its peripherals such as cables, roads and the required protection fences. The service corridor stretches from the location of Duqm Refinery till the Export Jetty at Duqm Port with a length of 6.5 km.

The utility corridor is developed in phases with the refinery utility corridor is the initial phase. Two subsequent phases may be developed in future and hence included in the GHG estimation. The corridor cross section is provided in Figure 6-1.

Refinery Corridor



Potential expansion 1 (left of refinery corridor)



Potential expansion 2 (right of refinery corridor)

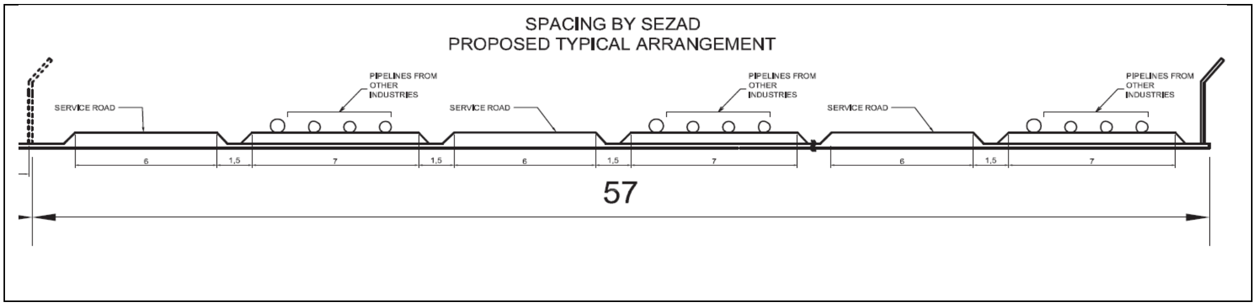


Figure 6-1: Cross-section of Utility Corridor

The calculation of GHG is based on the following parts in sub-sections:

a) Vehicle movement (trucks, buses, cars, other multipurpose vehicles) – Sub-section 6.2.1;
b) Road maintenance vehicles and equipment such as re-surfacing equipment, trucks, rollers, etc. – Sub-section 6.2.1;
c) Fugitive emissions from the hydrocarbon pipelines – Sub-section **Error! Reference source not found.**;
d) Offices and other related facilities involved in the operation and maintenance of this road – Sub-section **Error! Reference source not found.**; and
e) Indirect GHG from the lighting provided to the road lights, traffic lights, etc. – Sub-section **Error! Reference source not found.**.

6.2.1 Vehicle Movement and Road Maintenance

The vehicle movement is determined based on the type of roads and vehicle types. The various roads are listed below:

a) Refinery corridor: Heavy Haul Road;
b) Refinery corridor: service road;
c) Expansion phase 1: 3 service / construction roads; and
d) Expansion phase 2: 3 service / construction roads.

Road maintenance such as relaying of surface etc., are minimum compared to regular traffic. As the regular traffic is estimated on a conservative level, the road maintenance is not estimated separately. The roads are also designed for 20-25 years and hence will need minimum road maintenance.

The attached excel sheet provides the vehicle estimation methods which are used to determine the kilometers driven, vehicle type and at different sections of the road.

Part 5 Calculation of
Vehicle movement.xlsx

The kilometers estimated along with vehicle type is input into the ghgprotocol.org calculation sheet for vehicle movements. The sheet uses UK Defra emission factors for the calculation of the GHG emissions.

Part 5
Transport_Tool_v2_6.x

The GHG emissions from the vehicle movement is summarized below:

Table 6-1: GHG Emissions from Vehicle Movement

S. No.	Scenario	CO_2 emissions / Year
1	Refinery utility corridor	902.41 MT
2	Expansion corridor – phase 1	49.36 MT
3	Expansion corridor – phase 2	49.36 MT
4	Total from overall corridor	1,001.13 MT

6.2.2 Fugitive Emissions from Pipelines

The list of pipelines and the products to be transported are illustrated in the following figure.

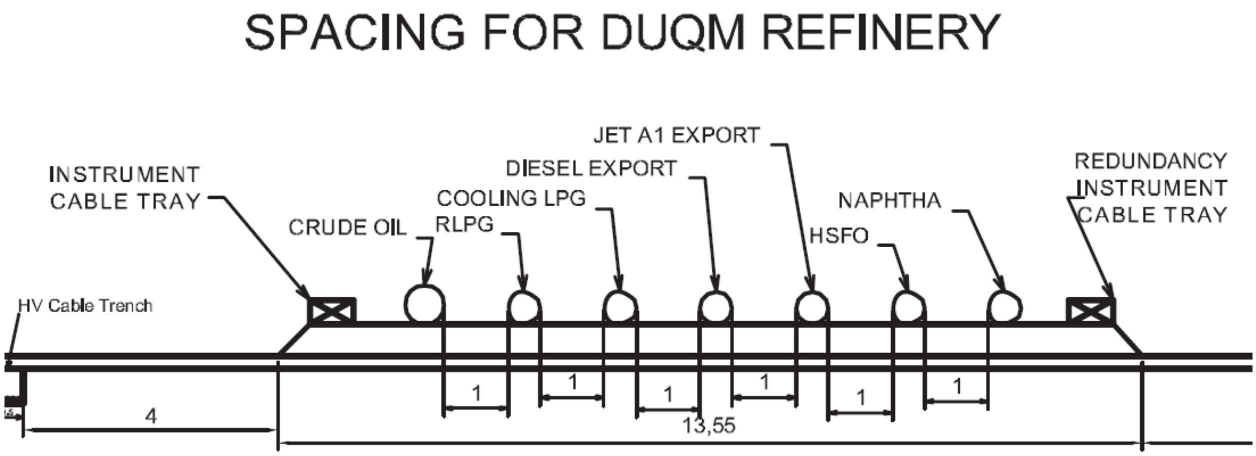


Figure 6-2: Pipelines and Products in Corridor

None of the hydrocarbons are expected to have CH_4 (Methane) in the composition. Hence there will be no GHG fugitive emissions from the pipelines during operation.

6.2.3 Offices and Other Buildings

There are no offices related to this road. All facilities will be within the refinery or the port which will considered under the respective facilities.

6.2.4 Indirect GHG Emissions

Indirect GHG emissions are from the power consumption along the corridor. The corridor is not expected to be lit during night. Hence the power consumption is minimum only for lights at few vantage points and other requirements such as CCTV, guard house, etc. There are no details available on the power requirement. Hence a conservative value of 5 kW (0.005 MW) is assumed for the whole road section.

The Oman electric grid emission factor as per API compendium 2009 is provided in the table below:

Table 6-2: Total Direct and Indirect Emissions

GHG Category	Emission Factor (tons/MW-h)	Power Consumption (MW)	Emissions (tons)
Direct Emissions	-	-	1001.13
Indirect Emissions	0.519	0.005	22.73

GHG Category	Emission Factor (tons/MW-h)	Power Consumption (MW)	Emissions (tons)
Total Emissions for Sub-Project 6			1,023.86

6.3 GHG Emissions for Sub-project 7

This section provides the estimation of the greenhouse gas from the Sub-Project 7 (Road corridor): The project covers the construction of 2.2 km dual carriageway, 3 km single roads, 2 dual entrances to Duqm Refinery with a total length of 574 m long. The project will also include traffic signals, 2 roundabouts, concrete channel for rainwater drainage of 3,830 m long, concrete box culverts, street lightening and protection of existing services. The road locations are shows in the Figure 6-3.

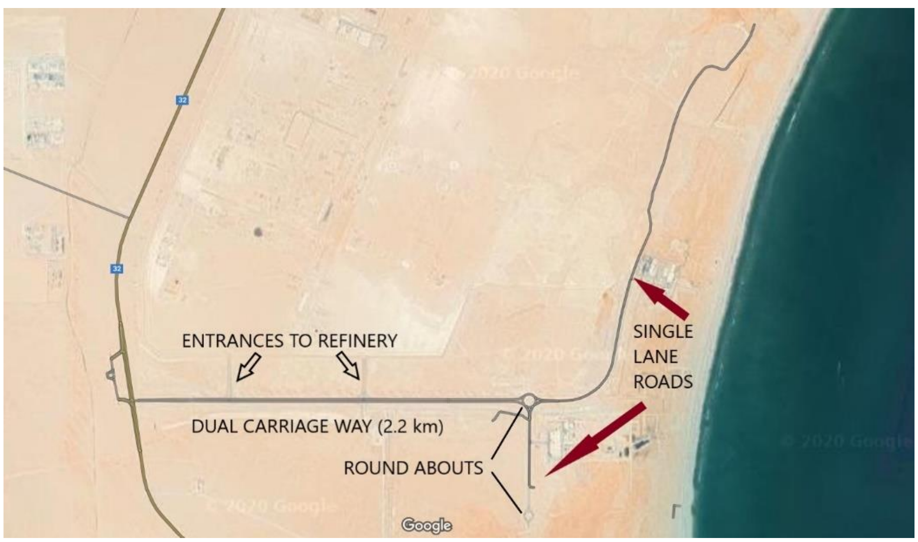


Figure 6-3: Locations of Roads

The calculation is based on the following parts

a) Vehicle movement (trucks, buses, cars, other multipurpose vehicles) – Sub-section 6.3.1
b) Road maintenance vehicles and equipment such as re-surfacing equipment, trucks, rollers, etc. – Sub-section 6.3.1
c) Offices and other related facilities involved in the operation and maintenance of this road – Sub-section **Error! Reference source not found.**
d) Indirect GHG from the lighting provided to the road lights, traffic lights, etc. – Sub-section **Error! Reference source not found.**

6.3.1 Vehicle Movement and Road Maintenance

The vehicle movement is estimated based on the total operation phase workers of 900 (obtained from the EIA of Duqm refinery). The split of the vehicle type is given below:

a) 250 personnel drive individually in car – 250 cars

b) 250 personnel travel in light vehicle (2 people in each vehicle) – 125 vehicles

c) 400 personnel travel in bus (20 people in each bus) – 20 buses

In addition, 500 contractors and other vendors are expected to visit the facility every day. The split of the vehicle is given below:

a) 100 personnel drive individually in car – 100 cars

b) 100 personnel travel in light vehicle (2 people in each vehicle) – 50 vehicles

c) 300 personnel travel in bus (30 people in each bus) – 10 buses

The total truck movements into and out of the refinery is not available. However, it is assumed 100 trucks will use this road on a daily basis. Road maintenance such as relaying of surface etc., are minimum compared to regular traffic. As the regular traffic is estimated on a conservative level, the road maintenance is not estimated separately. The roads are also designed for 20-25 years and hence will need minimum road maintenance.

Most of the vehicles listed above will travel about 5 km in the dual carriage way and refinery entrances. In addition, 20% of the vehicles is assumed to travel an additional 6 km in the other single roads. The total kilometers driven is calculated in the Table 6-3 below:

Table 6-3: Estimation of Distance Driven in Kms

Vehicle Type	Total vehicles	Distance driven (km)	Total kilometers in year	Km / vehicle class
Cars (80%)	280	5	511,000	792,050
Cars (20%)	70	11	281,050	
Light vehicle (80%)	140	5	255,500	396,025
Light vehicle (20%)	35	11	140,525	
Bus (80%)	24	5	43,800	67,890
Bus (20%)	6	11	24,090	
Trucks (80%)	80	5	146,000	226,300
Trucks (20%)	20	11	80,300	

The kilometers estimated along with vehicle type is input into the ghgprotocol.org calculation sheet for vehicle movements. The sheet uses UK Defra emission factors for the calculation of the GHG emissions.

Part 5
Transport_Tool_v2_6.x

The GHG emissions from the vehicle movement from the above movement is **620 metric ton / year**.

6.3.2 Office and Other Buildings

There are no offices related to this road. All facilities will be within the refinery or the port which will considered under the respective facilities.

6.3.3 Indirect GHG Emissions

Indirect GHG emissions are from the power consumption along the corridor. The corridor is expected to be lit during night. The power consumption is for lighting, traffic lights at few vantage points and requirements such as CCTV. High energy efficient LED will be used for all lighting.

Lighting poles are assumed to be installed every 50 m along the roads. A total of 116 light poles (total km of 5.8 km = 2.2 km + 0.6 km + 3 km) will be available in this road package. Each pole is assumed to consume a conservative estimate of 500 watt of power.

Power for others (traffic lights and CCTV) are estimated to be 1 kW. A total of 60 kW (0.06 MW) is assumed for the whole road section with an operational period of 10 hours / day.

The Oman electric grid emission factor as per API compendium 2009 is provided in the Table 6-4 below:

Table 6-4: Total Direct and Indirect Emissions

GHG Category	Emission Factor (tons/MW-h)	Power Consumption (MW)	Emissions (tons)
Direct Emissions	-	-	620.00

GHG Category	Emission Factor (tons/MW-h)	Power Consumption (MW)	Emissions (tons)
Indirect Emissions	0.519	0.06	119.87
Total Emissions for Sub-Project 7			739.87

7 GHG REPORTING FRAMEWORK

7.1 Introduction

OPAZ/SEZD manages, regulates, and develops all economic activities in Duqm. It plans, designs, and implements long-term strategies for infrastructural development and attracts investments to promote a wide spectrum of economic activities. It also oversees the urban expansion of the modern Duqm city while protecting the environment, thereby ensuring Duqm its rightful place as the best location to visit, live, work and invest in at the Middle East.

7.1.1 Masterplan

OPAZ/SEZD has been developing the Duqm city according to the master plan established for the area (refer Figure 7-1). The master plan includes the following facilities:

Table 7-1: Major Activities at SEZ at Duqm

Landfill	Light industry
Sewage treatment plant	Residential areas
Cement products area	Hotels
Heavy industry	Port storage areas
Refinery	Dry docks
Power and desalination plant	Liquid jetty
Railway yard	Commercial areas
Medium industry	Liquid and equipment storage
Parks	Tourism areas
Fishery port	Fishery industry complex
City center	Renewable energy area
Government organisation buildings	Airport and Port

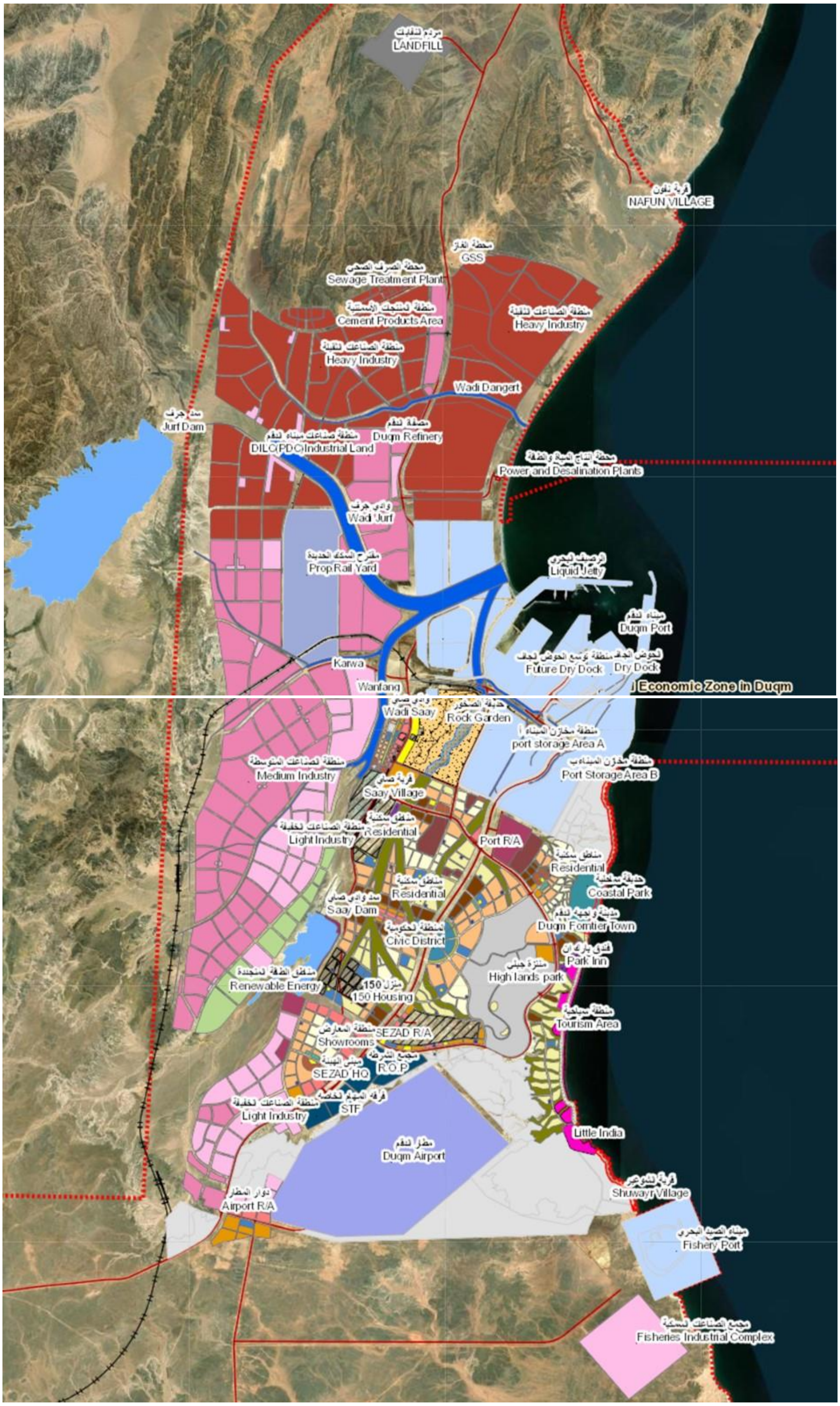


Figure 7-1: General Masterplan for Duqm SEZ

7.2 Green House Gases (GHG)

A greenhouse gas is a gas that absorbs and emits radiant energy within the thermal infrared range. Greenhouse gases cause the greenhouse effect on planets which can lead to climate change. The primary greenhouse gases in Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

The gases such as CO_2, methane, nitrous oxide are emitted from various natural and man-made sources. Man-made sources include several power plants, oil and gas developments, heavy, medium and light industry, transportation, waste treatment plants, etc.

7.2.1 SEZD and GHG

SEZD is a special economic zone which allows several operators to install and operate several industries including port operations. SEZD also includes other associated facilities such as residential areas, commercial and governmental buildings, leisure activities, airport, railway and road infrastructure. All these activities lead to GHG from construction and operation of the facilities.

OPAZ/SEZD has obtained loans from financial institutions for the development of infrastructure and other facilities. As part of the requirement of financial institutions and more important, the requirements of Ministry of Climate and Environment Affairs (MECA)[11] in Oman, a greenhouse gas reporting framework is required which will be used by all industries and other establishment to report their emissions to OPAZ/SEZD.

7.2.2 GHG Framework

OPAZ/SEZD has developed this GHG framework to provide a guideline for the establishment in the economic zone to calculate the GHG emissions and to report the emissions to OPAZ/SEZD. OPAZ/SEZD will follow this methodology illustrated below for the reporting of GHG.

[11] Pursuant to the recent reshuffle of the ministries in the Sultanate of Oman (August 2020), the functions of MECA has been transferred to the newly established Environment Authority as per RD 106/2020

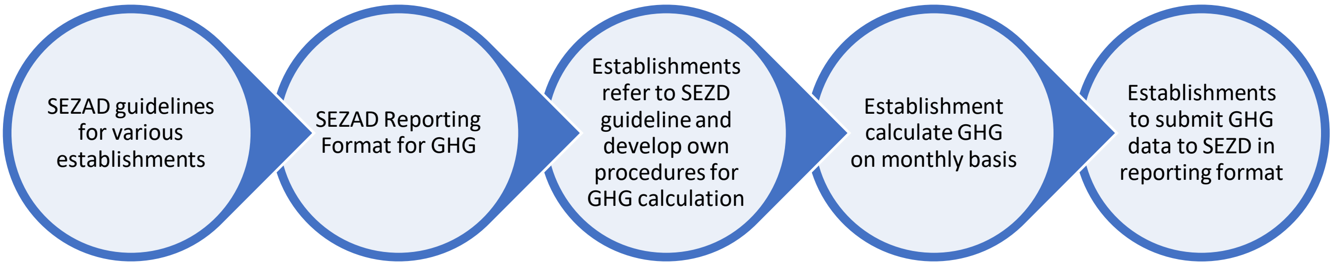


Figure 7-2: Illustration – GHG Reporting

7.2.3 SEZAD Reporting Format

SEZD will require all establishments to calculate their emissions monthly, with reports filed to SEZD quarterly. Data shall be submitted to OPAZ/SEZD in the below format within 30 days of completion of the Quarter. For example: Q1 2020 shall be submitted by the 30 April 2020. Reporting Template of GHG emissions to OPAZ/SEZD

GHG template
SEZAD.xlsx

SEZD will work on an e-page which will substitute the above form subsequently. All data shall be input into the webpage on a quarterly basis. Any change in the data can be requested with OPAZ/SEZD after the closure period.

The following sections provide guidelines for specific industry or other establishments. Flexibility is provided to all establishments to ensure they adopt their own method of calculations but provide the required GHG data to OPAZ/SEZD. Establishments in SEZD may use one of more sector guidelines based on the type of activities. For example: refinery operations may use energy sector guidelines for internal power generation, transportation sector for transport, oil and gas sector for all other emissions from the refinery. The emission factors related to IPCC is provided as a separate electronic application to this document.

This document will provide a framework for managing the GHG emissions from the facility. The following continuous improvements shall be adopted by the respective organisation to ensure importance is provided for GHG emissions.

Quality control: Quality control is important to ensure the GHG numbers are verified at various levels. This can be achieved by setting up procedures for internal auditing of data and collection methodology, improvement of data gaps and verification by cross departments.

Data Management: Data management includes managing data associated with GHG emission such as flow rate of gas, production capacity, etc. through documented procedures which also provides the responsible person for each stage. This shall also include the data approvers and the competency related to GHG emissions.

Identification of improvements: Improvements in the organisation for reduction of GHG emissions shall be conducted on a periodic basis. This can be energy saving audits, adoption of low GHG technologies, etc. These improvements shall be assessed for techno economic feasibility and implemented based on the outcome of feasibility.

GHG Plan: The plan should include the timeline for the GHG emission estimation, calculation, finalization as required. In addition, the plan for implementation of improvements identified in the organisation shall be included, tracked and appropriate budgets shall be made available as part of the organisation financial planning.

GHG Baseline: GHG baseline is very important step after which the organization shall continuously look for GHG improvement methodologies. Baseline can be determined after one or two years of stable operations.

7.3 Sector: Transportation

7.3.1 Scope and background

Transportation is the backbone for all establishments and facilities in SEZD region. This includes movement of road transport (trucks, bus, cars, other vehicles), railways (when established) and air traffic. All these will lead to GHG emissions due to burning of fossil fuels. In case, electric vehicles are used, there will be no direct emissions.

Establishment can track their vehicles used in the commercial purpose. However, cars and other passenger vehicles within SEZD may be random and will be difficult to track. SEZD will determine these based on the traffic design assisted with random traffic surveys once a year. All traffic within the airport shall be monitored by the airport authorities. The emissions from airline operations shall not be included. This shall be monitored by the airline and not by airport. Maritime operations are covered under port sector.

7.3.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Mode of transport;
b) Vehicle type and fuel used for road traffic;
c) Kilometers driven in a month / year for road traffic; and
d) Fuel used in rail traffic.

7.3.3 Calculation Guidelines

7.3.3.1 Guideline A:

Calculation of the GHG can be calculated by using the GHGprotocol.org calculation sheet provided below. These sheets have emission factor based on the 5th assessment report of Intergovernmental Panel on Climate Change. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.

Transport_Tool_v2_6.
xlsx

7.3.3.2 Guideline B:

A secondary source of calculation methodology can be accessed from US Environment Protection Agency (US EPA) at https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation

7.4 Sector: Power and desalination

7.4.1 Scope and background

A power and desalination plant is under construction in SEZD which has a capacity of 326 MW and 1,500 m3/hr. The plant is based on natural gas fired combined power plant integrated with desalination and will be in operation by 2022. There are potentially other power generation within the heavy, medium and light industry which are also included in this scope.

Diesel may be used in the emergency power generation in several establishment. It is expected that these scenarios are extremely rare and hence excluded. Diesel used as back up fuel in power plants will be included for GHG emissions as these may be used for few days which will lead to significant quantities of diesel usage and CO_2 emissions.

7.4.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Quantity of natural gas / diesel used for power generation (by flow meters);
b) Heating value of the natural gas;
c) Type of equipment; and
d) Hours of operation,

7.4.3 Calculation Guidelines

The combustion sources calculations can be conducted via several methodology and each method provides different levels of accuracy in the estimation.

7.4.3.1 Guideline A:

US EPA AP 42 Chapter 3 Section 1

https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s01.pdf

7.4.3.2 Guideline B:

The spreadsheet from ghgprotocol.org – Use energy as sector

Stationary_combustion_tool_(Version4-1).xls

7.4.3.3 Guideline C:

API Compendium 2009 – a new version is in development which can be used at https://www.api.org/~/media/files/ehs/climate-change/2009_ghg_compendium.ashx

7.5 Sector: Port and Maritime Operations

7.5.1 Scope and background

Port operations involves vessel movement, dry dock operations, loading & unloading of containers, bulk materials, jetty operations of liquid hydrocarbons including crude and its products. These activities will lead to direct emissions from the vessels and temporary diesel generators.

The fugitive emissions from the transport, loading and unloading of hydrocarbons are negligible as these hydrocarbons do not have methane. Indirect CO2 emissions from use of power shall be recorded separately. The power for operations are likely to be obtained from power plant in Duqm. Double counting of emissions should not be included in the GHG emissions of overall SEZD.

7.5.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Quantity of fuel oil used for maritime vessels (only within SEZD boundaries);
b) Vessel type, fuel type (marine fuel, LNG, etc.);
c) Quantity of diesel oil used for diesel generators; and
d) Power consumption records.

7.5.3 Calculation Guidelines

7.5.3.1 Guideline A:

Calculation of the GHG can be calculated by using the GHGprotocol.org calculation sheet provided below. These sheets have emission factor based on the 5th assessment report of Intergovernmental Panel on Climate Change. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.

Transport_Tool_v2_6.xlsx

7.5.3.2 Guideline B

International Maritime Organisation has developed a detailed GHG report for maritime traffic which also includes specific emission factors (snapshot given below).

CO_2 baseline

The carbon content of each fuel type is constant and is not affected by engine type, duty cycle or other parameters when looking on the basis of kg CO_2 per tonne fuel. The fuel-based CO_2 emissions factors for main and auxiliary engines at slow, medium and high speeds are based on MEPC 63/23, annex 8, and include:

HFO	$EF_{baseline}\ CO_2$ = 3,114 kg CO_2/tonne fuel
MDO/MGO	$EF_{baseline}\ CO_2$ = 3,206 kg CO_2/tonne fuel
LNG	$EF_{baseline}\ CO_2$ = 2,750 kg CO_2/tonne fuel

http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

7.5.3.3 Guideline C:

The spreadsheet from ghgprotocol.org – Use energy as sector and fuel as diesel

Stationary_combustion_tool_(Version4-1).xls

7.5.3.4 Guideline: Power Consumption

Indirect emissions can be calculated using API compendium 2009 emission factors for Oman.

tonnes/10^6 W-hr			
	2005 Weighted Emission Factors		
Country	**CO_2**	**CH_4**	**N_2O**
Middle East (cont.)			
Oman	0.519	3.37E-05	7.41E-05

The Table 7-1 of the API GHG Compendium for Oman (Figure 7-3 below) can be used to calculate indirect CO_2 emissions based on the power generation in Duqm power plant (combined cycle and natural gas)

Table 7-1. Electricity Usage Emission Factors by Method of Generation

Method of Generation	Fuel Type	Carbon Dioxide[a]		Methane[b]		Nitrous Oxide[b]	
		lb/ 10^6 W-hr	tonnes/ 10^6 W-hr	lb/ 10^6 W-hr	tonnes/ 10^6 W-hr	lb/ 10^6 W-hr	tonnes/ 10^6 W-hr
Advanced combustion turbine	Natural Gas	1,102.31	0.50	No Data			
	Distillate Oil	1,499.14	0.68	No Data			
	Residual Oil	1,609.37	0.73	No Data			
Advanced gas / oil combined cycle	Natural Gas	815.71	0.37	No Data			
	Distillate Oil	1,124.36	0.51	No Data			
	Residual Oil	1,212.54	0.55	No Data			
Combined cycle[c]	Natural Gas	881.85	0.40	0.015	6.80E-06	0.063	2.86E-05
	Distillate Oil	1,190.49	0.54	0.013	5.90E-06	0.268	1.22E-04
	Residual Oil	1,300.73	0.59	0.013	5.90E-06	0.268	1.22E-04
Combustion turbine[d]	Natural Gas	1,278.68	0.58	0.16	7.26E-05	0.24	1.09E-04
	Distillate Oil	1,741.65	0.79	0.021	9.53E-06	0.276	1.25E-04
	Residual Oil	1,873.93	0.85	0.021	9.53E-06	0.276	1.25E-04

Figure 7-3: Extract from API Compendium for GHG

7.6 Sector: Oil and Gas / Refinery

7.6.1 Scope and background

A key industry in SEZD is the 260,000 barrels per day refinery which is being built and will be operational by end of 2022. A refinery will require a lot of energy to refine the crude which will be obtained from either direct power or through generation of steam through boilers.

Natural gas usage can also lead to flaring scenarios due to over pressure and other emergency situations leading to GHG emissions.

7.6.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Production capacity;
b) Quantity of natural gas used for combustion sources such as gas turbines, gas engines, furnaces, boilers, etc.;
c) Operation data for each equipment type;
d) Flaring quantity of natural gas;
e) Quantity of diesel oil used for diesel generators; and
f) Power consumption records.

7.6.3 Calculation Guidelines

7.6.3.1 Guideline:

Most of the oil and gas establishments across globe use the API compendium 2009 for calculation of the GHG emissions from their facilities. A new version of the compendium is in development which can be used after release.

https://www.api.org/~/media/files/ehs/climate-change/2009_ghg_compendium.ashx

7.6.3.2 Guideline: Power Consumption

Indirect emissions can be calculated using API compendium 2009 emission factors for Oman.

tonnes/10⁶ W-hr			
	2005 Weighted Emission Factors		
Country	**CO_2**	**CH_4**	**N_2O**
Middle East (cont.)			
Oman	0.519	3.37E-05	7.41E-05

Table 7-1 of API Compendium for GHG as below can be used to calculate indirect CO_2 emissions based on the power generation in Duqm power plant (combined cycle and natural gas)

Table 7-1. Electricity Usage Emission Factors by Method of Generation

Method of Generation	**Fuel Type**	**Carbon Dioxide** [a]		**Methane** [b]		**Nitrous Oxide** [b]	
		lb/ 10^6 W-hr	**tonnes/ 10^6 W-hr**	**lb/ 10^6 W-hr**	**tonnes/ 10^6 W-hr**	**lb/ 10^6 W-hr**	**tonnes/ 10^6 W-hr**
Advanced combustion turbine	Natural Gas	1,102.31	0.50	No Data			
	Distillate Oil	1,499.14	0.68	No Data			
	Residual Oil	1,609.37	0.73	No Data			
Advanced gas / oil combined cycle	Natural Gas	815.71	0.37	No Data			
	Distillate Oil	1,124.36	0.51	No Data			
	Residual Oil	1,212.54	0.55	No Data			
Combined cycle [c]	Natural Gas	881.85	0.40	0.015	6.80E-06	0.063	2.86E-05
	Distillate Oil	1,190.49	0.54	0.013	5.90E-06	0.268	1.22E-04
	Residual Oil	1,300.73	0.59	0.013	5.90E-06	0.268	1.22E-04
Combustion turbine [d]	Natural Gas	1,278.68	0.58	0.16	7.26E-05	0.24	1.09E-04
	Distillate Oil	1,741.65	0.79	0.021	9.53E-06	0.276	1.25E-04
	Residual Oil	1,873.93	0.85	0.021	9.53E-06	0.276	1.25E-04

7.7 Sector: Heavy, Medium and Light Industries

7.7.1 Scope and background

The various industries proposed in the economic zone is likely to be the biggest contributor of GHG emissions. The industry is classified into heavy, medium and light industry which will require high energy either in the form of direct power or natural gas. The natural gas will be used for heating in furnaces, boilers, dryers or driving rotating equipment such as gas engines, gas turbines, etc.

Specific industries such as adipic acid, nitric acid and refrigerant manufacturing facilities can emit N2O which is a GHG. Separate calculators are available to estimate the GHG emissions. Natural gas usage can also lead to flaring scenarios due to over pressure and other emergency situations leading to GHG emissions.

7.7.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Production capacity;
b) Quantity of natural gas used for combustion sources such as furnaces, boilers, incinerators, dryers, etc.;
c) Natural gas flaring quantities;
d) Quantity of diesel oil used for diesel generators; and
e) Power consumption records.

7.7.3 Calculation Guidelines

7.7.3.1 Guideline A:

Specific industry calculators are available at https://ghgprotocol.org/calculation-tools. The calculators available are for the following industries which have potential for CO_2 emissions.

a) Aluminum
b) Ammonia
c) Adipic acid
d) Cement
e) Iron and Steel
f) Refrigerant: HCFC – 22
g) Nitric acid

h) Pulp and paper

i) Semiconductors

j) Wood

k) Lime

7.7.3.2 Guideline B:

The spreadsheet from ghgprotocol.org – Use appropriate sector (manufacturing, construction, fisheries) and fuel as natural gas or diesel.

Stationary_combustion_tool_(Version4-1).xls

7.7.3.3 Guideline: Power Consumption

Indirect emissions can be calculated using API compendium 2009 emission factors for Oman.

tonnes/10^6 W-hr			
	2005 Weighted Emission Factors		
Country	**CO_2**	**CH_4**	**N_2O**
Middle East (cont.)			
Oman	0.519	3.37E-05	7.41E-05

Table 7-1 of API Compendium for GHG as below can be used to calculate indirect CO_2 emissions based on the power generation in Duqm power plant (combined cycle and natural gas)

Table 7-1. Electricity Usage Emission Factors by Method of Generation

Method of Generation	Fuel Type	Carbon Dioxide [a]		Methane [b]		Nitrous Oxide [b]	
		lb/ 10^6 W-hr	tonnes/ 10^6 W-hr	lb/ 10^6 W-hr	tonnes/ 10^6 W-hr	lb/ 10^6 W-hr	tonnes/ 10^6 W-hr
Advanced combustion turbine	Natural Gas	1,102.31	0.50	No Data			
	Distillate Oil	1,499.14	0.68	No Data			
	Residual Oil	1,609.37	0.73	No Data			
Advanced gas / oil combined cycle	Natural Gas	815.71	0.37	No Data			
	Distillate Oil	1,124.36	0.51	No Data			
	Residual Oil	1,212.54	0.55	No Data			
Combined cycle [c]	Natural Gas	881.85	0.40	0.015	6.80E-06	0.063	2.86E-05
	Distillate Oil	1,190.49	0.54	0.013	5.90E-06	0.268	1.22E-04
	Residual Oil	1,300.73	0.59	0.013	5.90E-06	0.268	1.22E-04
Combustion turbine [d]	Natural Gas	1,278.68	0.58	0.16	7.26E-05	0.24	1.09E-04
	Distillate Oil	1,741.65	0.79	0.021	9.53E-06	0.276	1.25E-04
	Residual Oil	1,873.93	0.85	0.021	9.53E-06	0.276	1.25E-04

7.8 Sector: Residential Buildings

7.8.1 Scope and background

Large number of residential buildings are built in SEZD which are likely to be managed by housing complexes. These houses consume power for all their needs. These will lead to indirect GHG emissions due to power consumption.

7.8.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Power consumption records

7.8.3 Calculation Guidelines

7.8.3.1 Guideline: Power Consumption

Indirect emissions can be calculated using API compendium 2009 emission factors for Oman.

tonnes/10^6 W-hr			
Country	**2005 Weighted Emission Factors**		
	CO_2	**CH_4**	**N_2O**
Middle East (cont.)			
Oman	0.519	3.37E-05	7.41E-05

Table 7-1 of API Compendium for GHG as below can be used to calculate indirect CO2 emissions based on the power generation in Duqm power plant (combined cycle and natural gas)

Table 7-1. Electricity Usage Emission Factors by Method of Generation

Method of Generation	**Fuel Type**	**Carbon Dioxide [a]**		**Methane [b]**		**Nitrous Oxide [b]**	
		lb/ 10^6 W-hr	**tonnes/ 10^6 W-hr**	**lb/ 10^6 W-hr**	**tonnes/ 10^6 W-hr**	**lb/ 10^6 W-hr**	**tonnes/ 10^6 W-hr**
Advanced combustion turbine	Natural Gas	1,102.31	0.50	No Data			
	Distillate Oil	1,499.14	0.68	No Data			
	Residual Oil	1,609.37	0.73	No Data			
Advanced gas / oil combined cycle	Natural Gas	815.71	0.37	No Data			
	Distillate Oil	1,124.36	0.51	No Data			
	Residual Oil	1,212.54	0.55	No Data			
Combined cycle [c]	Natural Gas	881.85	0.40	0.015	6.80E-06	0.063	2.86E-05
	Distillate Oil	1,190.49	0.54	0.013	5.90E-06	0.268	1.22E-04
	Residual Oil	1,300.73	0.59	0.013	5.90E-06	0.268	1.22E-04
Combustion turbine [d]	Natural Gas	1,278.68	0.58	0.16	7.26E-05	0.24	1.09E-04
	Distillate Oil	1,741.65	0.79	0.021	9.53E-06	0.276	1.25E-04
	Residual Oil	1,873.93	0.85	0.021	9.53E-06	0.276	1.25E-04

7.9 Sector: Commercial, Government Buildings

7.9.1 Scope and background

The economic zone consists of several commercial buildings, offices, government buildings, police, security buildings and others which will support the industries and other establishment. Most of these buildings consume power and also use diesel for official transportation vehicles. These emit GHG emissions which will be part of the SEZD GHG emissions.

7.9.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Power consumption records
b) Diesel used or kilometer driven by official vehicles

7.9.3 Calculation Guidelines

7.9.3.1 Guideline:

Refer to transportation sector for calculation of emissions from vehicles.

7.9.3.2 Guideline:

Power Consumption, and indirect emissions can be calculated using API compendium 2009 emission factors for Oman.

tonnes/10^6 W-hr			
	2005 Weighted Emission Factors		
Country	**CO_2**	**CH_4**	**N_2O**
Middle East (cont.)			
Oman	0.519	3.37E-05	7.41E-05

Table 7-1 of API Compendium for GHG as below can be used to calculate indirect CO_2 emissions based on the power generation in Duqm power plant (combined cycle and natural gas)

Table 7-1. Electricity Usage Emission Factors by Method of Generation

Method of Generation	Fuel Type	Carbon Dioxide[a] lb/ 10^6 W-hr	Carbon Dioxide[a] tonnes/ 10^6 W-hr	Methane[b] lb/ 10^6 W-hr	Methane[b] tonnes/ 10^6 W-hr	Nitrous Oxide[b] lb/ 10^6 W-hr	Nitrous Oxide[b] tonnes/ 10^6 W-hr
Advanced combustion turbine	Natural Gas	1,102.31	0.50	No Data			
	Distillate Oil	1,499.14	0.68	No Data			
	Residual Oil	1,609.37	0.73	No Data			
Advanced gas / oil combined cycle	Natural Gas	815.71	0.37	No Data			
	Distillate Oil	1,124.36	0.51	No Data			
	Residual Oil	1,212.54	0.55	No Data			
Combined cycle[c]	Natural Gas	881.85	0.40	0.015	6.80E-06	0.063	2.86E-05
	Distillate Oil	1,190.49	0.54	0.013	5.90E-06	0.268	1.22E-04
	Residual Oil	1,300.73	0.59	0.013	5.90E-06	0.268	1.22E-04
Combustion turbine[d]	Natural Gas	1,278.68	0.58	0.16	7.26E-05	0.24	1.09E-04
	Distillate Oil	1,741.65	0.79	0.021	9.53E-06	0.276	1.25E-04
	Residual Oil	1,873.93	0.85	0.021	9.53E-06	0.276	1.25E-04

7.10 Sector: Tourism, Hotels, Resorts

7.10.1 Scope and background

The economic zone consists of several tourism related hotels and resorts which provides relaxation options to public in Duqm and also other public coming from outside Duqm. Most of these hotels consume power and also use diesel for official transportation vehicles including leisure boats. These emit GHG emissions which will be part of the SEZD GHG emissions.

The hotels and restaurants may also used liquified petroleum gas (LPG) for cooking. The use of LPG may lead to GHG emissions. However, these are excluded as these emissions will be limited and not negligible.

7.10.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Power consumption records; and
b) Diesel used or kilometer driven by business vehicles

7.10.3 Calculation Guidelines

7.10.3.1 Guideline:

Refer to transportation sector for calculation of emissions from vehicles.

7.10.3.2 Guideline:

Power Consumption, and indirect emissions can be calculated using API compendium 2009 emission factors for Oman.

tonnes/10^6 W-hr			
Country	2005 Weighted Emission Factors		
	CO_2	CH_4	N_2O
Middle East (cont.)			
Oman	0.519	3.37E-05	7.41E-05

Table 7-1 of API Compendium for GHG as below can be used to calculate indirect CO2 emissions based on the power generation in Duqm power plant (combined cycle and natural gas)

Table 7-1. Electricity Usage Emission Factors by Method of Generation

Method of Generation	Fuel Type	Carbon Dioxide [a]		Methane [b]		Nitrous Oxide [b]	
		lb/ 10^6 W-hr	tonnes/ 10^6 W-hr	lb/ 10^6 W-hr	tonnes/ 10^6 W-hr	lb/ 10^6 W-hr	tonnes/ 10^6 W-hr
Advanced combustion turbine	Natural Gas	1,102.31	0.50	No Data			
	Distillate Oil	1,499.14	0.68	No Data			
	Residual Oil	1,609.37	0.73	No Data			
Advanced gas / oil combined cycle	Natural Gas	815.71	0.37	No Data			
	Distillate Oil	1,124.36	0.51	No Data			
	Residual Oil	1,212.54	0.55	No Data			
Combined cycle [c]	Natural Gas	881.85	0.40	0.015	6.80E-06	0.063	2.86E-05
	Distillate Oil	1,190.49	0.54	0.013	5.90E-06	0.268	1.22E-04
	Residual Oil	1,300.73	0.59	0.013	5.90E-06	0.268	1.22E-04
Combustion turbine [d]	Natural Gas	1,278.68	0.58	0.16	7.26E-05	0.24	1.09E-04
	Distillate Oil	1,741.65	0.79	0.021	9.53E-06	0.276	1.25E-04
	Residual Oil	1,873.93	0.85	0.021	9.53E-06	0.276	1.25E-04

7.11 Sector: Wastewater treatment facilities, landfill, etc.

7.11.1 Scope and background

OPAZ/SEZD has a central wastewater treatment facility and a landfill for waste disposal within the economic zone. These facilities will also need power for operations. In addition, these treatment facilities and landfills will generate fugitive emissions which include methane emissions. The design of the landfill can be to capture the methane and use it for power generation in a small turbine. However, these details needs to be obtained and incorporated during GHG emission estimation.

7.11.2 Monitoring data

The key monitoring data required for this sector are the following:

a) Power consumption records;

b) Landfill gas; and

c) Wastewater treatment loads.

7.11.3 Calculation Guidelines

7.11.3.1 Guideline A:

The spreadsheet from ghgprotocol.org – Use appropriate sector (energy) and fuel as landfill gas.

Stationary_combustion_tool_(Version4-1).xls

7.11.3.2 Guideline B: Fugitive emissions from wastewater treatment

GHG emissions can be calculated using 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

7.11.3.3 Guideline: Power Consumption

Indirect emissions can be calculated using API compendium 2009 emission factors for Oman.

tonnes/10^6 W-hr			
	2005 Weighted Emission Factors		
Country	**CO_2**	**CH_4**	**N_2O**
Middle East (cont.)			
Oman	0.519	3.37E-05	7.41E-05

Table 7-1 of API Compendium for GHG as below can be used to calculate indirect CO_2 emissions based on the power generation in Duqm power plant (combined cycle & natural gas)

Table 7-1. Electricity Usage Emission Factors by Method of Generation

		Carbon Dioxide [a]		Methane [b]		Nitrous Oxide [b]	
Method of Generation	**Fuel Type**	**lb/ 10^6 W-hr**	**tonnes/ 10^6 W-hr**	**lb/ 10^6 W-hr**	**tonnes/ 10^6 W-hr**	**lb/ 10^6 W-hr**	**tonnes/ 10^6 W-hr**
Advanced combustion turbine	Natural Gas	1,102.31	0.50	No Data			
	Distillate Oil	1,499.14	0.68	No Data			
	Residual Oil	1,609.37	0.73	No Data			
Advanced gas / oil combined cycle	Natural Gas	815.71	0.37	No Data			
	Distillate Oil	1,124.36	0.51	No Data			
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Combined cycle [c]	Natural Gas	881.85	0.40	0.015	6.80E-06	0.063	2.86E-05
	Distillate Oil	1,190.49	0.54	0.013	5.90E-06	0.268	1.22E-04
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Combustion turbine [d]	Natural Gas	1,278.68	0.58	0.16	7.26E-05	0.24	1.09E-04
	Distillate Oil	1,741.65	0.79	0.021	9.53E-06	0.276	1.25E-04
	Residual Oil	1,873.93	0.85	0.021	9.53E-06	0.276	1.25E-04

8 GHG EMISSION REDUCTION STRATEGIES

8.1 Country Wide Initiatives

The government of Sultanate of Oman has already carried out several commitments and actions to address the challenges of Climate Change. First, in Paris in 2015, Oman committed to the goal of reducing GHG emissions by 2% by 2030.

Major renewable energy resources in Oman consist of solar, wind, and biogas. Other resources include geothermal and wave energy, though at levels below economic viability. The introduction of even modest amounts of renewable generation could readily achieve Oman’s voluntary target to reduce GHG emissions by 2% by 2030.

8.2 Integrated Approach by OPAZ/SEZD

The usage of renewable energy in SEZD is promoted using reserved area for power generation in the form of solar and wind. OPAZ/SEZD can invite tenders from large solar power companies to install power plants which can feed energy into the grid. This will ensure the overall power generation in Oman has a larger portion of renewables. OPAZ/SEZD will have to discuss the commercial and other requirements with both electricity provider in Oman along with the potential solar power generators.

Biogas can be tapped in SEZD due to the expected population within the free zone. Biogas can be generated in two major ways as detailed below

a) Sewage treatment plants: large sewage treatment plants can use anaerobic digester to produce biogas. Instead of flaring this gas, this can be used for power generation in a micro turbine or a gas engine. This can suffice the majority of power generation for STP operations.

b) Waste: organic waste from houses, hotels, cafeterias and other places are a rich source of bio gas. Waste segregation from point of waste generation is important to achieve recycling of waste. Wet waste or organic waste containing food materials can be collected via waste handlers. This can be composted and used as fertilizer or used in a digester to produce bio gas. Based on the quantities, this can be used to drive micro turbines or gas engines to produce electricity. This can be linked to the grid to provide renewable energy.

The other initiatives which can be developed by SEZD are the following

a) Provision of electrical charging points across the zone to encourage electrical mobility which in turn can be powered by solar power leading to zero emissions
b) Use of LNG as fuel for heavy machinery to reduce GHG footprint compared to diesel fuel. Availability of LNG as an alternate fuel in fuel retailers will ensure continuous supply to facilities and their fleet.

8.3 Energy Efficiency and Conservation

There is ample scope for improving the efficiency by which energy is consumed in Oman, together with opportunities for conservation. Initial screening has shown that several types of measures in the industrial, commercial, governmental, and residential sectors have great potential in Oman for reducing energy use.

The key measures identified by MECA are the following:

a) Energy Management System
b) Labelling System
c) Building Codes
d) Smart meters

8.4 Energy Management System (EMS)

EMS is a system that calls for energy auditing and integrated management of all energy consuming equipment at large buildings, factories, and other facilities across the industrial, commercial, and government sectors. Participating sites develop an energy efficiency plan and submit periodic reports that track the progress in the implementation of energy efficient devices for all energy end uses.

The key aspects in energy management in industries using power and natural gas as fuel are the following:

a) Maintenance of natural gas fired equipment such as boilers, heaters, furnaces, gas engine, gas turbines as per manufacturer specifications.
b) Ensure optimum gas to air ratio is maintained to ensure effective burning of fuel and thereby achieve maximum heat into the systems.
c) Insulation of hot or cold systems to achieve losses to the environment.

d) Use of waste heat recovery from the fuel gases to increase the efficiency of the system. An open cycle gas turbine and a closed cycle gas turbine will increase the efficiency from 25% to 50+%.
e) Use solar panels on roofs and other areas to increase solar power generation. This can be utilised within the facility based on demand or exported to grid using smart meters.
f) Use of electric vehicles for company maintained fleet for movement of goods / people.
g) Use of high efficient systems such as central cooling or heating systems for large spaces.
h) Use of LED lighting in all places for reduction of power and also attain brighter lighting.

8.5 Labelling System

Energy rating labels provide consumers with information on the energy efficiency of a product. There are two main types of labels – comparison labels, which allow consumers to compare the energy consumption of similar products and endorsement labels which offer a seal of approval (e.g., Energy Star). These are relevant for lighting in the commercial and governmental sectors, and for lighting, air conditioning, and refrigeration in the residential sector.

8.6 Building Codes

A building code (also building control or building regulations) is a set of rules that specify the standards for constructed objects such as buildings and nonbuilding structures. These codes regulate the design and construction of structures when adopted into law. They are applicable to building design (e.g., insulation) for industrial, commercial, and governmental sectors, and for air conditions for the residential sector.

The worldwide largely applied building code related to sustainability is LEED rating system developed by United States Green Building Council (USGBC) in 1993. Several buildings, industries, townships, developments are certified for LEED certification.

The various LEED certification available for sectors are listed below:

a) BD+C (Building Design and Construction) – This includes New Construction and major renovation, Core & Shell, applications for: Schools, Retail, Hospitality, Data Centers, Warehouses & Distribution Centers and Healthcare

b) ID+C (Interior Design and Construction) - For complete interior fit-out projects and includes commercial interiors and applications for Retail and Hospitality.

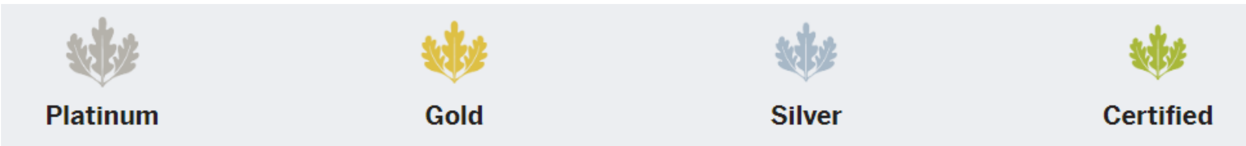
c) O+M (Building Operations and Maintenance) - For existing buildings that are undergoing improvement work or little to no construction. This includes applications for Schools, Retail, Hospitality, Data Centers, and Warehouses & Distribution Centers.

d) ND (Neighborhood Development) - For new land development projects or redevelopment projects containing residential uses, nonresidential uses, or a mix. Projects can be at any stage of the development process, from conceptual planning to construction. This includes Plan and Built Project.

e) Homes - For single family homes, low-rise multi-family (one to three stories) or mid-rise multi-family (four to six stories). Homes and residential buildings that are greater than six stories use LEED BD+C

f) Cities and Communities - For entire cities and sub-sections of a city. LEED for Cities projects can measure and manage their city's water consumption, energy use, waste, transportation and human experience. Learn more about LEED for Cities.

Projects pursuing LEED certification earn points for various green building strategies across several categories based on the number of points achieved, a project earns one of four LEED rating levels: Certified, Silver, Gold or Platinum.



8.7 Smart Meters

A smart meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the central system. While they are applicable to all sectors, they have only been considered to be applicable to the residential sector for the period of the assessment.

8.8 Best Available Techniques

It is expected that all facilities in SEZD are built new and fitted with latest technology and development to reduce the GHG emissions. Best Available Techniques are guidelines used generally to ensure adoption of these techniques in the various sectors.

The European Integrated Pollution Prevention and Control (IPPC) Bureau (EIPPCB) was set up in 1997 to organise an exchange of information between Member States, industry and non-governmental organisations promoting environmental protection on Best Available Techniques (BAT), associated monitoring and developments in them. The EIPPCB organises and coordinates the exchange of information that leads to the drawing up and review of BAT reference documents according to the dispositions of the Guidance document on the exchange of information. The EIPPCB is an output-oriented organisation which produces reference documents on Best Available Techniques, called BREFs. BREFs are the main reference documents used by competent authorities in Member States when issuing operating permits for the installations that represent a significant pollution potential in Europe.

The various BREF can be accessed at https://eippcb.jrc.ec.europa.eu/reference and available for the following sectors. These provide information on environment protection including effective usage of fuel and power which lead to lower GHG emissions. The energy efficiency provides significant insights to all facilities.

a) Ceramic manufacturing industry
b) Common Waste Gas Treatment in the Chemical Sector
c) Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector
d) Economics and Cross-media Effects
e) Emissions from storage
f) Energy Efficiency
g) Ferrous Metals Processing Industry
h) Food, Drink and Milk Industries
i) Industrial Cooling Systems
j) Intensive Rearing of Poultry
k) Iron and Steel Production
l) Large Combustion Plants
m) Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers
n) Large Volume Inorganic Chemicals – Solids and Others Industry
o) Manufacture of Glass
p) Manufacture of Organic Fine Chemicals
q) Monitoring of Emissions to Air and Water from IED Installations

r) Non-ferrous Metals Industries
s) Production of Cement, Lime and Magnesium Oxide
t) Production of Chlor-alkali
u) Production of Large Volume Organic Chemicals
v) Production of Polymers
w) Production of Pulp, Paper and Board
x) Production of Speciality Inorganic Chemicals
y) Refining of Mineral Oil and Gas
z) Smitheries and Foundries Industry
aa) Surface Treatment Of Metals and Plastics
bb) Surface Treatment Using Organic Solvents including Wood and Wood Products Preservation with Chemicals
cc) Tanning of Hides and Skins
dd) Textiles Industry
ee) Waste Incineration
ff) Waste Treatment
gg) Wood-based Panels Production

It is to be noted that these are guidelines and not standards to be used by industries / other establishment in SEZD.

9 CARBON NEUTRALITY

Carbon Neutral is a term used to describe the state of an entity (such as a company, service, product or event), where the carbon emissions caused by them have been balanced out by funding an equivalent amount of carbon savings elsewhere in the world.

The strategy of carbon neutrality is to minimize the GHG or carbon emissions to the lowest possible level and then offsetting the remaining.

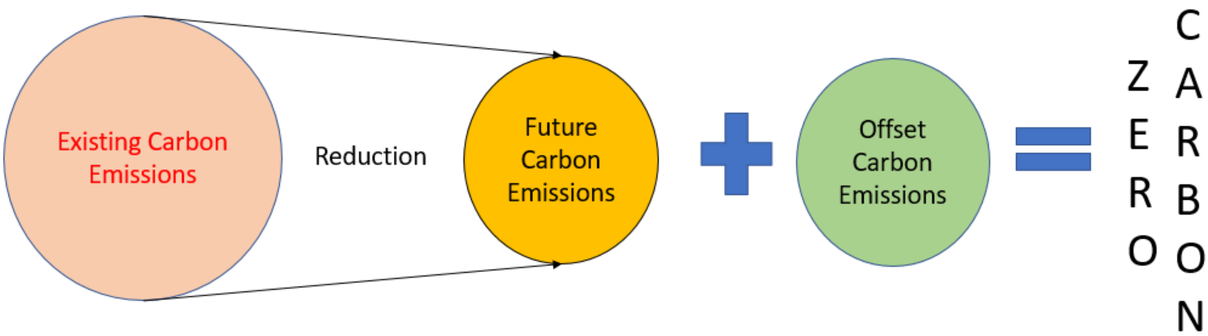


Figure 9-1: Carbon Neutrality Strategy

This can be achieved in steps over a long period in line with international commitments made by company or the country. Several organisations and countries have pledged to become carbon neutral by the year 2050. This provides 30 years of timeline to achieve the same.

For certain organisations it can be very simple. An example is a hotel or an office which has power usage and vehicle movement using fossil fuels. The organisation can obtain green energy generated by renewables from a provider combined with changing all vehicles to electric. This will enable the company to become zero carbon. They can also procure all purchases which are certified and is provided by companies which market zero carbon products. The availability and the economics of obtaining zero carbon products will improve as more and more companies adopt to this.

For large organisation, moving to zero carbon will require offsets which may obtaining carbon credits from other organisations or developing carbon sinks such as forests or sending carbon into deep reservoirs. These are complex and will need long periods and costs significant capital.

9.1 Economics

In general, reduction of energy in any establishment is linked to reduction of operation costs. Any capital expenditure is offset by the maintenance costs or bills paid for the reduction of energy. However, the return of investment varies from few days to several years. It is expected that large return periods are generally not implemented by establishments.

Carbon tax is introduced in several countries to enable shift towards lower carbon. A carbon tax is defined as a tax directly sets a price on carbon by defining a tax rate on greenhouse gas emissions or on the carbon content of fossil fuels. In short, for each ton of CO_2 released from the facility to the atmosphere, a tax needs to be paid to the government. The carbon tax levied various across countries with lowest from 1 USD / ton CO_2 in Mexico to 131 USD / ton CO_2 in Sweden. Oman has zero carbon tax at the moment.

10 DISCUSSIONS ON THE IMPLEMENTATION MODEL

The growth of SEZD and the Duqm area is anticipated to occur in the following three phases:

Phase	Time Period	Description
Startup Phase	2020 - 2024	Period until DRPIC is commissioned and operations gets stabilized. During this period, infra-construction activities primarily take place
Growth Phase (Roll-out, Monitoring and Training phase)	2025 - 2040	After commissioning of DRPIC and start of *Duqm* Petrochemical Project (DPP) and other downstream industries
Maturity Phase	2041 - 2060	Stabilization of the key industries established in Duqm and start of allied/ ancillary operations

The industries will be required to support and/or participate in managing climate change and GHG emission aspects. This would include consideration of climate change adaptations recommended in this report as well as reporting requirements for GHG emissions. Some of the initiatives related to climate monitoring (e.g., weather station, monitoring buoys, etc.) can be supported through CSR or related commitments. These initiatives would be a requirement for Category A industries that typically entail financing whereby commitment and implementation of sustainable goals are required. Small-scale industries and hospitality sector shall ensure reporting of GHG KPIs as per the recommendations of this report so that OPAZ/SEZD can monitor performance of such emissions for the SEZ.

The responsible party for implementing and reporting aspects related to climate and GHG emissions rest with the Director General of Control and Compliance (DGCC) and responsibility to monitor implementation and performance rests with the ESMS Focal Point at SEZD. To implement the action items of the report, necessary institutional arrangements are to be developed during the startup phase as indicated above. The theme of this phase is 'Rollout, Monitoring, and Training' to create the capacities and building the expertise required within the core ESMS governance functions to manage climate and GHG related aspects.

Most of the development at SEZ are in their initial stages or under planning, design, and construction phases. Furthermore, with the current situation of the global economy, uncertainties of the COVID pandemic in CY 2020, these effects may last until the end of 2021 or beyond. Therefore, it is expected that several of the institutional arrangements at SEZD internally would be in force after this period. Simultaneously, stakeholder consultations would be conducted with major industries during this time to plan for roll-out, with maturity of the system taking shape beyond CY 2023.

10.1 **Concluding Remarks**

The findings and recommendations of this report will need significant internal discussions and consultation on prioritization, rollout, resourcing and capacity building before OPAZ/SEZD is able to commit to specific actions and timelines. Due to the nature of force majeure events and ensuing dull economic projections all around, these programmes will require an extended implementation timeline. As a starting point for internal discussions, the following staged implementation process is being discussed:

1. A 3-stage process of implementation is being discussed – Start-up (2020 to 2024); Growth Phase (2025 to 2040); and Maturity Phase (2041 to 2060).
2. The focus on the ESMS, climate adaptations and GHG reporting are geared towards the Start-up Phase, which culminates with the key anchor industry of DRPIC being fully commissioned to stable operations. The theme of this phase is 'Rollout, Monitoring, and Training' to create the capacities and building the expertise required within the core ESMS governance functions before launching into the Growth Phase of CY 2025. The implementation proposal being considered for now is that all E&S programs will be resourced for 'Start-up Phase' in Roll-out, Monitoring and Training mode. The detailed mechanics of implementation will come out in the ensuing months and will be adopted by the end of this year in a phased manner. In the interim, an internal 'Step-Out' mechanism will be adopted for implementation of ESMS governance – besides internal consultations with the leadership, SEZD will engage with the lenders and agree on an action plan for the this phase first and subsequently by CY 2024, develop an agreed action plan for the 'Growth Phase' of 2025 to 2040.
3. For ESAP items/programs, an environmental/compliance budget may need to be set aside for the 15-year duration against the USD 1.7 billion loan amount. At a modest 2%, this works out to RO 13.08 million or about USD 34 million. This will be proposed to the Ministry of Finance and the lenders so that the amounts are ring-fenced as 'Environmental Funds' against which local banks are able to provide debt arrangements to approve large CAPEX projects for co-financing projects/initiatives being implemented by tenants. These funds will also enable OPAZ/SEZD to privatize sustainability projects such as Biodiversity Offsets, weather stations, marine buoys, Centralized Waste Treatment, etc., through low-cost green bonds.

The above 3 points are at initial stages of discussions and need greater consultations which are beyond the scope of the current timelines. However, the 3rd point above on creating budgets is extremely important for the viability of applicable E&S programs and overall compliance with equator principles to reduce and manage such risks. Assuming that a negotiated understanding can be reached on the budgets, the process of instituting them within SEZD as 'Environmental Funds' for co-financing projects and issuance of green bonds are likely to take time and need to be factored in as well.

Annexure 1: Clarifications on scoping report

Section Ref.	Comment MIGA	Response – SEZAD / CTEC – March 2020	LIMESTA Comment (Advisian)	Response based on the progress since my last communication
3.1.1	o The scope of work currently includes climate predictors for daily maximum temperature, daily minimum temperature and daily rainfall only. This should be extended to include extreme winds as tropical cyclone risk is significant for the region. Minimum temperature can be dropped as this is not likely to result in material impacts to operations in the SEZ. The SPEI index and WRI's Aqueduct should be used to assess future drought and water scarcity risk. o It is important to emphasize that this assessment focus on an analysis of extremes and not average conditions, as such it would be helpful if the scope included a list of climate statistics that will be used to express the climate hazards under assessment, for e.g. ▪ Rainfall • Nth-year maximum 1-day/5-day/30-day precipitation – or for e.g. *the 100-year 1-day maximum precipitation in the baseline and future climate periods* • Change in Nth-year return period for maximum 1-day precipitation – or for e.g. *the annual exceedance probability of the baseline 100-year return level of the maximum 1-day precipitation amount in the specified future climate period* • Annual exceedance probability of days with daily rainfall exceeding 25/50mm ▪ Wind • Number of high wind days – or for e.g. *the average # of days per year with daily mean wind speed >= 15 m/s* • The annual exceedance probability of experiencing Saffir-Simpson Hurricane Scale Category 1 winds (60-sec gust 10-m wind speed of at least 64 kt) as a result of a tropical cyclone • The annual exceedance probability of experiencing Saffir-Simpson Hurricane Scale Category 3 winds (60-sec gust 10-m wind speed of at least 96 kt) as a result of a tropical cyclone • Change in 100-year return period for tropical cyclone winds – or for e.g. *the annual exceedance probability of the current 100-year return level of the tropical cyclone winds in the specified future climate regime* ▪ Temperature • Daily mean temperature of the warmest month of each year • The average hottest daily maximum temperature in the year • The average number of days per year with daily maximum temperature >= 40 degC	Can be done in current effort. Can be done in current effort Can be done in current effort Please note that it is not reliable to use GCM results as they are without downscaling. No downscaling software is capable of handling the wind speed. Therefore, It needs to be done manually. This will take a considerably long time. I believe additional two months' time will be needed for wind projections and calculations. *This would require authorisation for the additional effort.*	LIMETA having a call with CTEC/SEZAD 31 March 2020 to discuss the methodology and comments. Clarify which comments from CTEC fit with comments from MIGA. Practicalities of addressing MIGA's comments within existing contracted scope, data restrictions and implications to the assessment as described by CTEC adjacent.	Number of **drought** events were calculated based on SPEI index for Observation (2004-2019) period and RCP4.5 (2040-2059), RCP4.5 (2060-2079), RCP8.5 (2040-2059), and RCP8.5 (2060-2079) periods under three categories as follows. Extreme (SPEI $\leq$ -2), Severe ($-2 <$ SPEI ≤ -1.5) and Moderate ($-1.5 <$ SPEI ≤ -1). Considering the initial request from MIGA, GCM simulations from **all five GCM models** were considered and impacts were separately calculated for all models and scenarios. In the last stage, they were combined to two scenarios and two future periods (altogether 4 scenarios) considering the GCMs' ability to simulate climate conditions during baseline period (2004-2019). Accordingly, a weighting factor was assigned for the each GCM. Following climate statistics were found for the **extreme rainfall**. **1.** 100-year 1-day maximum rainfall **2.** Annual exceedance probability of the **baseline** 100-year return level of the maximum 1-day precipitation amount (%) **3.** Annual exceedance probability of a day with daily rainfall exceeding 25 mm (%) **4.** Annual exceedance probability of a day with daily rainfall exceeding 50 mm (%) IDF curves were developed for observations and 4 scenarios in the future considering five models. In addition, they were compared with the IDF curves from Highway Design Standards for Oman. Similar calculations were performed for 5**-days rainfall**. **No calculations were done for 30-days** as it is not practical to discuss monthly maximum rainfall in arid regions.

	o **A modelled baseline from the climate models should be included as the observed baseline is only from 2012-2018**	Can be done in the current effort Can be done in the current effort Can be done in the current effort		Following climate statistics were found for the **Wind**: **1.** The average number of days per year with maximum wind speed (1-hr gust) more than 15 m/s. **2.** Annual exceedance probability (%) of Category 1 and Category 3 winds (60-sec gust) based on Saffir-Simpson Hurricane Scale and **3.** Annual exceedance probability of 100-year return level estimated from observations All calculations were done for observations and 4 scenarios in the future considering five models.
	o **Suggest using all 5 climate models** instead of just 2 unless there is clear evidence these 2 models outperform the others. Suggest using the p50 or p75 of all 5 models for the risk assessment.	This comment is not clear. Please note that baseline period is selected based on the availability of the observations for downscaling. In fact, we have made the precipitation projections in 5 stations using 2012-2018 observations. Unfortunately, future projections are not reliable when compared with the rainfall intensities that have been used in designing channels and dams (IDF curves from Oman Highway standards). Therefore, we will use data from Masirah island which is the only station has data (2004-2018) for a reliable projection. **Please confirm this.**		Following climate statistics were found for the **maximum temperature**: **1.** Monthly averaged daily maximum temperature of the warmest month, **2.** Maximum daily temperature estimated for different percentiles starting from 90th to 99.9th. **3.** The average number of days per year with daily maximum temperature above 40˚C **4.** Number of heat waves in each periods. **5.** Yearly probability of occurrence of heat waves, at least one time, at least two times, at least three times and more than three times. All calculations were done for observations and 4 scenarios in the future considering five models.
	o **Please confirm the spatial resolution of the climate outputs to be assessed**, I understand some downscaling will be performed.	We will use 5 models to select the best two models capable of projecting climate variables in arid countries. Climate projections in arid regions are subjected to a greater level of uncertainty. Therefore, selecting all five model will increase the uncertainty of the projections. Secondly, working with 5 models will significantly increase the computational time. Please be noted that Oman's Second National Communication Report has used only a single GCM and 2 RCPs in their simulations.		As mentioned in my previous response, only the data from Masirah island is long enough for climate projections. Therefore, no spatial variation can be discussed. All results are based on downscaled GCM variables considering observations in Masirah island (2004-2019).

		As mentioned earlier, only the data from Masirah island is long enough for climate projections. Therefore, we will not be able to produce any results varying spatially. All calculations will be done based on projections at Masirah island. **Please confirm this.** This issue with data availability has been mentioned in design reports as follows. Sering International, 2011. CONSULTANCY SERVICES FOR THE PREPARATION OF A DRAINAGE MASTER PLAN IN TERMS OF MATHEMATICAL MODELLING AND HYDRODYNAMIC AND SEDIMENT TRANSPORT MODELLING FOR INTEGRATION INTO THE DUQM DEVELOPMENT LAND - USE MASTER PLAN: page 4, "According to the limited number of available stations in the area, as resulted from a specific data collection phase, **it was agreed with SCTP to refer mainly to the recent review of the Highway Design Standards** (2010)". Renardet SA & Partners, 2015. CONSULTANCY SERVICES FOR FEASIBILITY STUDY, DETAILED DESIGN AND CONSTRUCTION SUPERVISION OF THE DUQM DEVELOPMENT DRAINAGE NETWORK AND PROTECTION SCHEMES - PHASE 1 JURF DAM DETAILED DESIGN – AUGUST2015: Page 59, "**Although the authorised rainfall figures are not yet available we used published rainfall figures for the rainfall experienced at Masirah to update the PMP and PMF figures**".		
3.2.4	Not 100% clear which RCP scenarios will be used, please ask for clarification	RCP4.5 and RCP8.5 will be used.	Ok - 4.5 intermediate and 8.5 very high scenario capturing range of scenario and worse case.	
3.2.5	o As more than 60% of the coastline of the Al-Wusta Governorate is highly vulnerable to sea-level rise and coastal storm surge, it is important this risk is assessed here. The scope of work notes that 40m resolution may be too coarse and recommend an additional project to do a 5m flood model	Effect of sea level rise will be assessed based on 5 m resolution DEM. Scenarios as mentioned in the Oman's Second National Communication Report will be used. 0,5m-1.0 m will cover the RCP 8.5 scenario which projects between 0.52-0.98 m of sea level rise.	At small spatial scales (<10 m), topographic surfaces can be complex, owing to the prevalence of un-autocorrelated topographic variation, which contributes to the rough appearance of many LiDAR DEMs. Small-scale surface roughness adds complexity to a	Inundation area considering 5 m resolution DEM, **which has been used in previous projects in Duqm**, were estimated for sea level rise of 0.5 m, 1.0 m, 1.5 m, 2.0 m, 2.5 m,

	assessment. **We suggest conducting the assessment using the 40m data.**	Also, we will assess the inundation from 1.0 m to 4-0 m sea level rise at 0.5 m intervals due to possible effects of storm surge.	DEM and it is often undesirable because of its impact on the characterization of larger-scale topography and because it confounds the measurement of geomorphometric indices, e.g., slope, aspect, curvature, and flow directions. However, surface roughness can be removed from DEMs using various de-noising or smoothing techniques, most commonly including data reduction (e.g., grid resampling and generalization) and low-pass filters. Lets discuss.	3.0 m, 3.5 m and 4.0 m. No surface roughness effect was considered. If the MIGA suggest on using 40 m DEM, **please provide them** and will repeat the estimations. In that way, these minor effects of surface roughness (considering large scale of the study area) can be neglected.
3.3	o Please confirm rationale for excluding sub-projects 1 through 5 from the GHG assessment o Please confirm if any specific GHG accounting tool will be used, e.g. IFC's CEET	The scope in the request for proposal only allowed for GHG calculations for sub-projects 6 and 7. Inclusion of sub-projects 1 through 5 would be a variation from the agreed scope and current contract. Since this is a roads projects, the GHG computation can be made using excel sheets. CEET would be more useful for wider (or complex) applications such as industrial set up. In addition, we will use calculation sheets from ghgprotocol.org along with estimation factors from USEPA, UK DEFRA or other widely accepted methods as necessary.	The requirements for GHG operational assessment as included within the pre-financial close due diligence assessment (WSP 16 May 37461700 page 259) Resource Efficiency - Greenhouse Gases (GHG) are below. Calculation of GHG calculations for sub-projects 1 and 5 were not included within the ESAP items and hence excluded from CTEC's / SEZAD on-going commitments related to GHG assessments. The scope and methodology presented by CTEC appears to address ESAP item 16B, 16E and 16F only has highlighted green. The other items also due by 31 Jan 2020 appear not be included within CTEC's scope. See note on point 16D. *LIMESTA will revert to SEZAD for discussion on assessment of emissions for seven infrastructure projects 16C.* A) SEZAD will ensure Sub-Projects 3 and 6 retrospectively capture, or make best estimate of fuel consumption data in construction phase for compliance with SEZAD Requirements – *ESAP item 16A completed and closed.*	

			B) In line with national requirements, SEZAD will develop a GHG methodology *- ESAP item 16B – within scope presented by SEZAD / CTEC.* C) SEZAD will assess GHG emissions' footprint of the construction of the seven infrastructure projects. *ESAP item 16C – GHG emissions have been estimated for some of the projects as part of monthly monitoring requirements i.e. 1, 5 and 6. Projects, 2 and 3 missing. LIMESTA to follow up with SEZAD.* D) SEZAD will review the calculations of the GHG data from Sub-Projects 4 and 5. –. *ESAP item 16D not within scope presented by SEZAD / CTEC. These assets are inactive no GHG emissions during operation. Construction GHG emissions were presented as part of monthly construction monitoring reports from the EPC. Lenders to confirm what is required for this assessment / what was requested during pre-financial close due diligence.* E) SEZAD will estimate the GHG emissions (for operations) from Sub-Projects 6 and 7 to complete a combined GHG emissions' footprint for the seven infrastructure projects. –. *ESAP item 16D the report provided and under review is this methodology for this assessment. Approach and responses on use of excel sheets for the service corridor and road is consider acceptable by the LIMESTA.* F) SEZAD to prepare an overall GHG emissions' footprint for the SEZ. In the long-term SEZ Environmental strategy, SEZAD to include guidance on the type of information required from new tenants to inform a GHG emissions' footprint. *ESAP item 16F – deadline Jan 2021 –included in the scope of GHG presented by CTEC and under discussion. Methodology acceptable.*	

Annexure 2: Downscaling wind speed

Weibull distribution can be considered when downscaling model-simulated projections to obtain a more realistic future. It assumes that the difference between the control (*m*) and future (*mf*) model outputs is the same as for observed (*o*) and projected data. Accordingly, the ‘‘future observed (*of*)’’ shape parameter can be written as

$$\beta_{of} = \frac{\beta_o \beta_{mf}}{\beta_m} \qquad \text{(A-1)}$$

The bias-corrected scale parameter is defined in terms of the ratio of the scale parameters between the future and control simulations and also depends on the ratio of shape parameters as follows.

$$\alpha_{of} = \alpha_o \left(\frac{\alpha_{mf}}{\alpha_m}\right)^{\beta_m/\beta_o} \qquad \text{(A-2)}$$

When two variables, such as observed and model simulated wind speeds, come from the same family of distributions, then the common form of the distribution provides a simple way of mapping one variable to have the same distribution as the other. It can be shown that if a random variable X is Weibull distributed with scale parameter α and shape parameter β, then $Z=(X/\alpha)^{\beta}$ will be exponentially distributed. Hence, X can be transformed into a Weibull variable X^* having scale and shape parameters α^* and β^* by the following power-law transfer function (Tye et al., 2014):

$$X^* = \alpha^* \left(\frac{X}{\alpha}\right)^{\beta/\beta^*}. \qquad \text{(A-3)}$$

Weibull Distribution for Wind

Table A2: Parameters of the Weibull distribution estimated for the wind projections.

	α		**β**	
Observations (2004-2019)	2.72		26.47	
	RCP 4.5		**RCP 8.5**	
	α	**β**	**α**	**β**
ACCESS1 (2040-2059)	2.75	28.15	2.71	27.96
ACCESS1(2060-2079)	2.17	27.62	2.92	28.46
Can_ESM2 (2040-2059)	3.71	26.75	3.62	28.22
Can_ESM2 (2060-2079)	3.30	27.15	3.79	27.55
GFDL_ESM2M (2040-2059)	2.19	27.34	1.41	28.66
GFDL_ESM2M (2060-2079)	2.48	26.90	1.46	27.46
INM-CM4 (2040-2059)	2.28	27.24	2.23	26.30
INM-CM4 (2060-2079)	1.81	28.71	2.50	27.19
IPSL-CM5A-LR (2040-2059)	2.56	27.07	2.87	26.75
IPSL-CM5A-LR (2060-2079)	2.49	27.11	2.59	27.83

Annexure 3: Downscaled Results and Calculated Weights

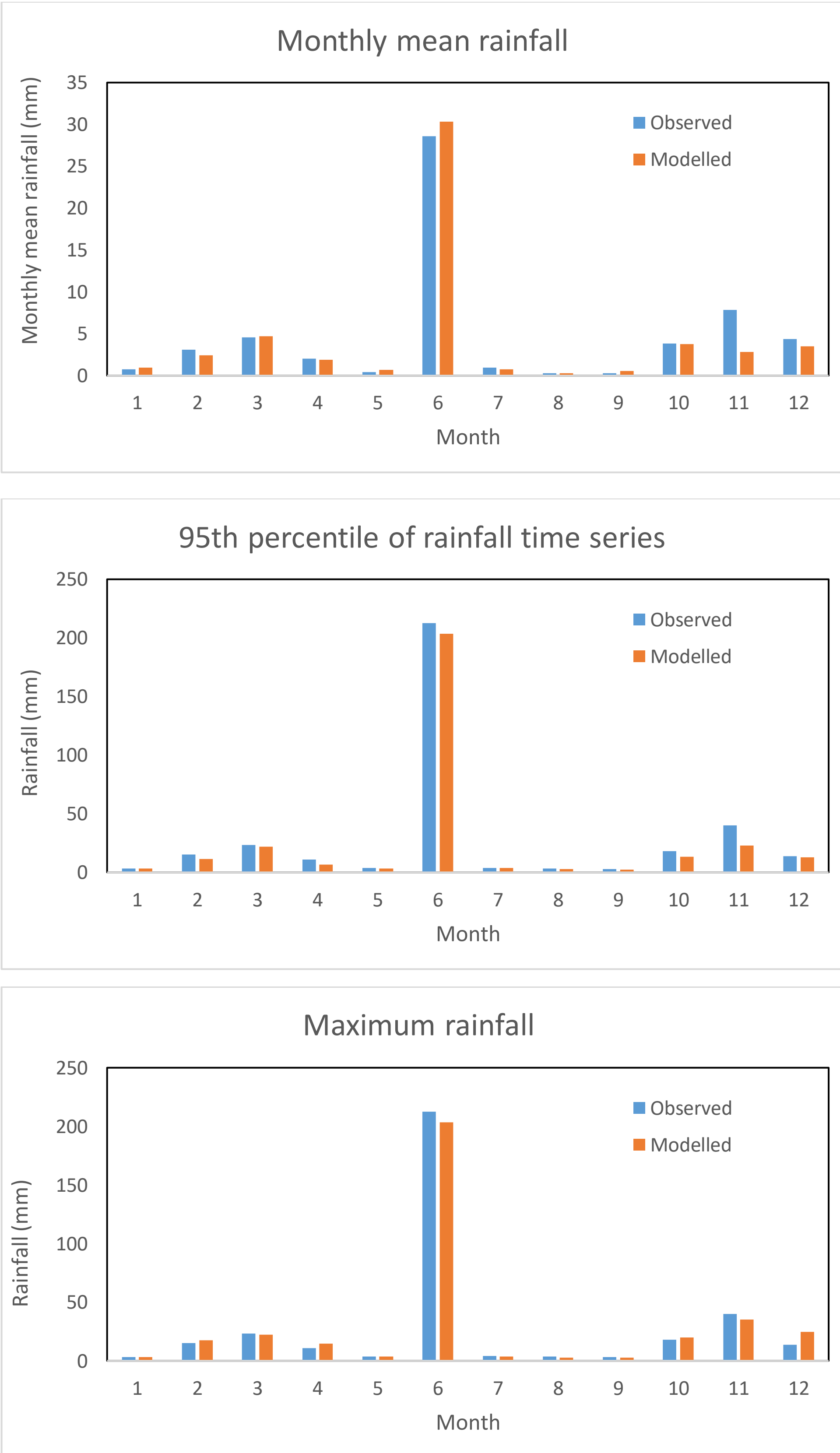


Figure A3-1: Comparison of observed and LARSWG generated rainfall data.

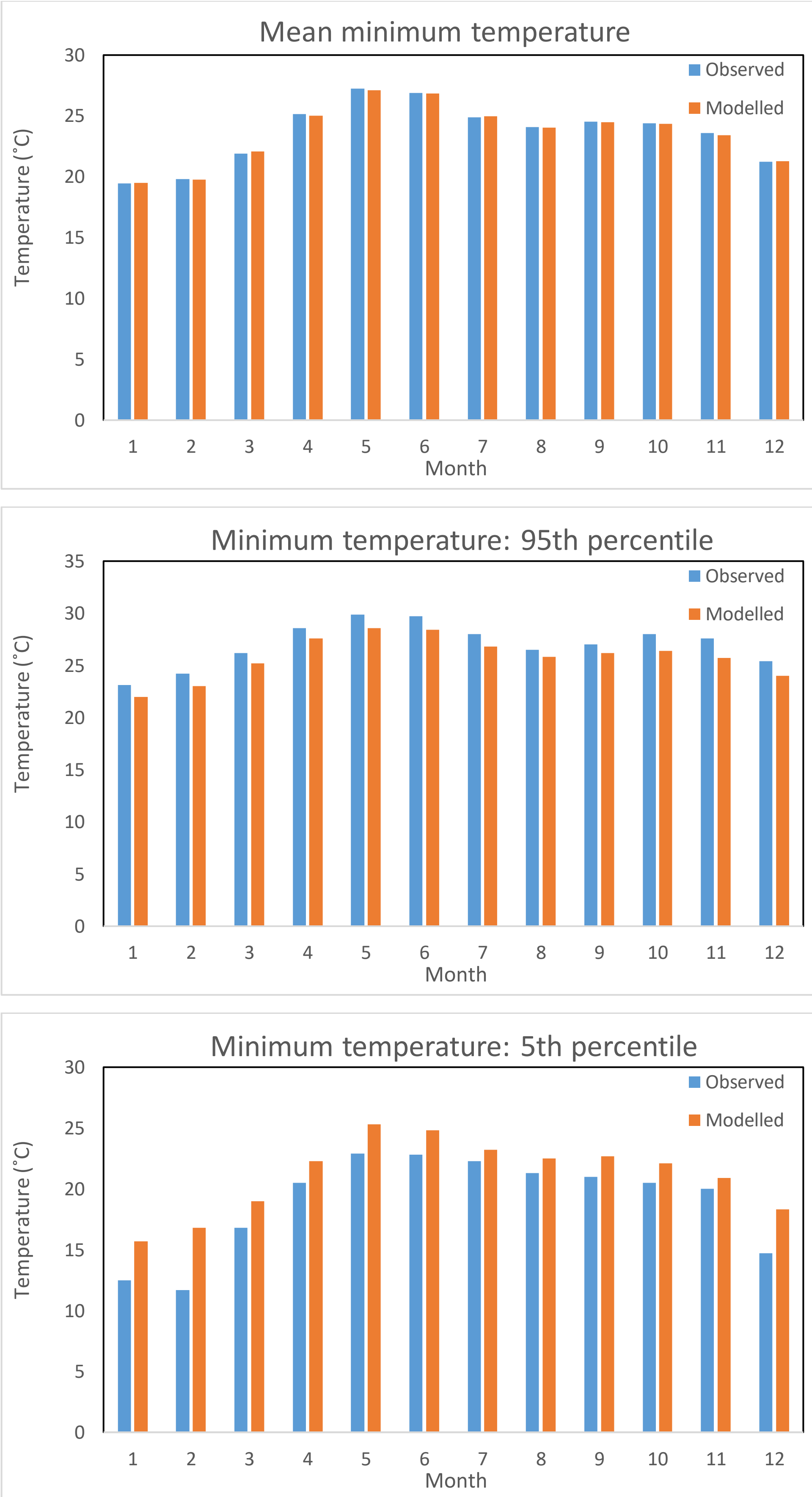


Figure A3-2: Comparison of observed and LARSWG generated minimum temperature.

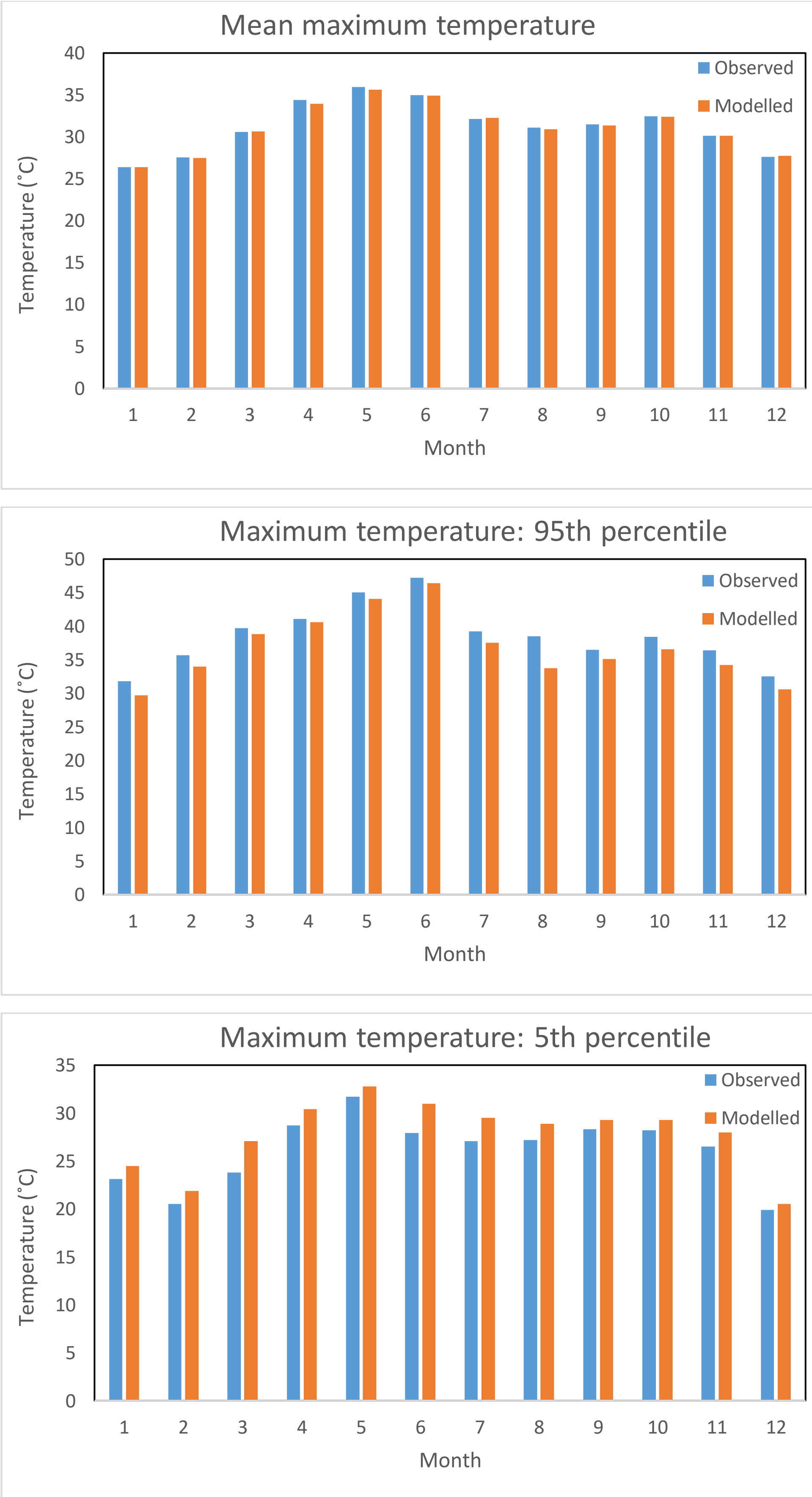


Figure A3-3: Comparison of observed and LARSWG generated maximum temperature.

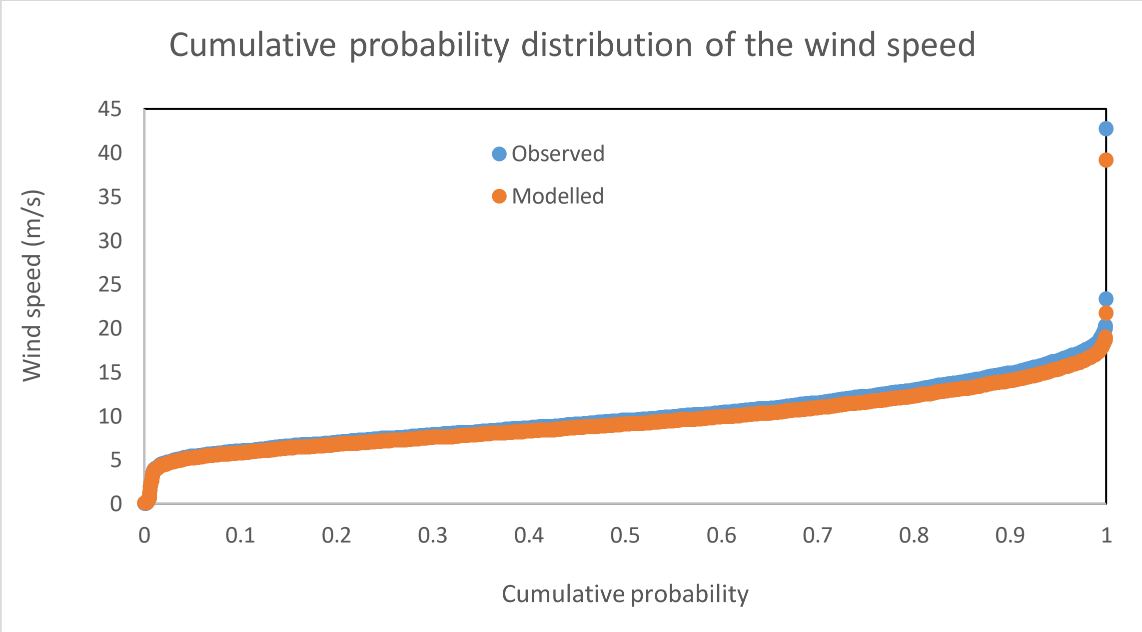


Figure A3-4: Comparison of observed and Weibull distribution generated wind speed.

Table A-3.1: Normalized weights for extreme rainfall.

GCM	1-day rainfall		5-days rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
ACCESS1	0.0220	0.0358	0.0024	0.0072
Can_ESM2	0.0068	0.0968	0.0063	0.0172
GFDL_ESM2M	0.7864	0.1092	0.5822	0.2928
INM-CM4	0.0898	0.5574	0.2908	0.5362
IPSL-CM5A-LR	0.0951	0.2007	0.1183	0.1465

Table A-3.2: Normalized weights for wind speed.

GCM	RCP 4.5	RCP 8.5
ACCESS1	0.1450	0.2962
Can_ESM2	0.5047	0.4273
GFDL_ESM2M	0.2226	0.1676
INM-CM4	0.0627	0.0534
IPSL-CM5A-LR	0.0650	0.0555

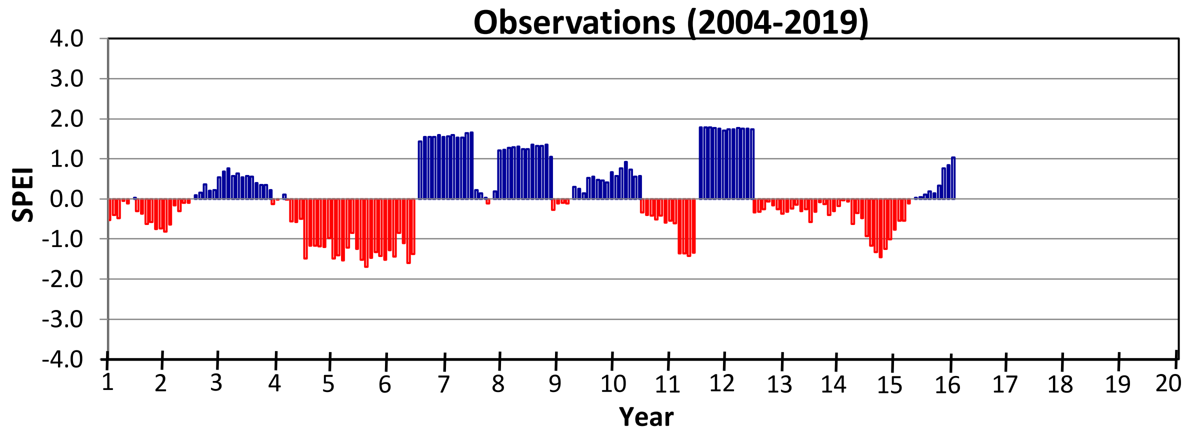
Table A-3.3: Normalized weights for droughts.

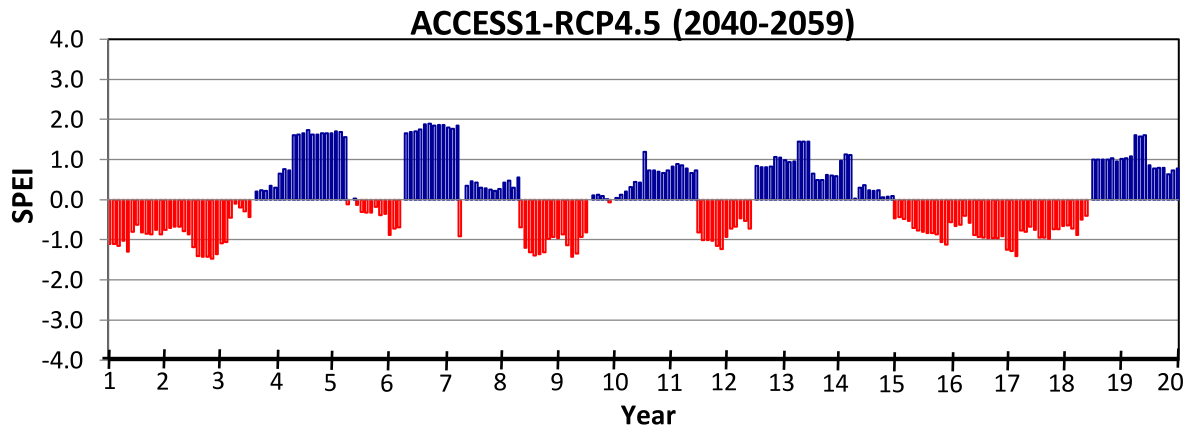
GCM	RCP 4.5	RCP 8.5
ACCESS1	0.2108	0.2077
Can_ESM2	0.2230	0.0628
GFDL_ESM2M	0.1636	0.4069
INM-CM4	0.1623	0.0890
IPSL-CM5A-LR	0.2403	0.2336

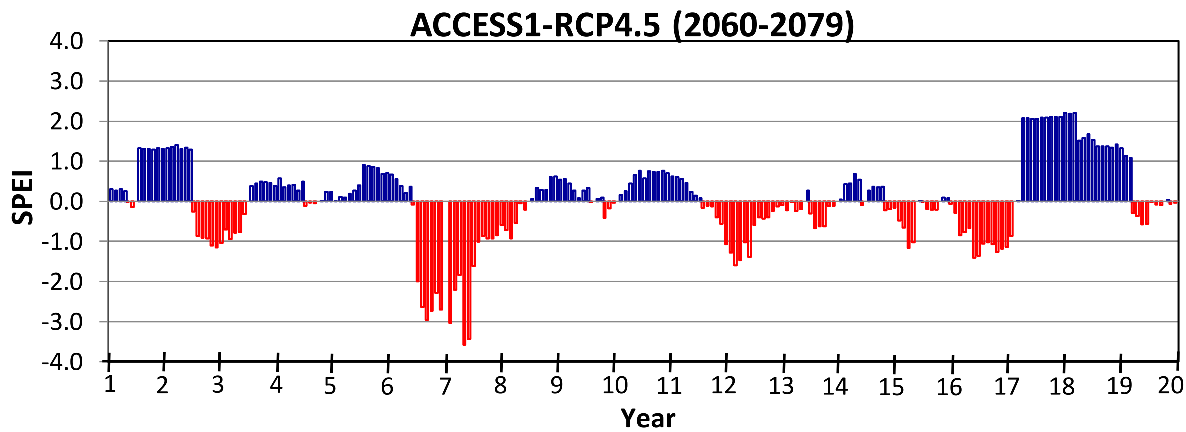
Table A-3.4: Normalized weights for maximum temperature.

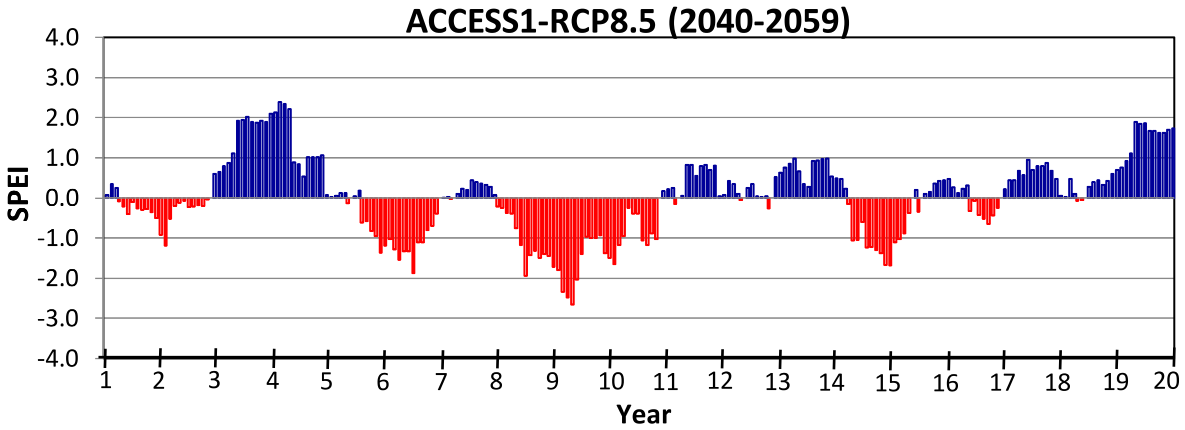
GCM	RCP 4.5	RCP 8.5
ACCESS1	0.1540	0.1280
Can_ESM2	0.0911	0.0830
GFDL_ESM2M	0.0516	0.0686
INM-CM4	0.2794	0.2927
IPSL-CM5A-LR	0.4240	0.4276

Annexure 4: Temporal Variation and SPEI Values





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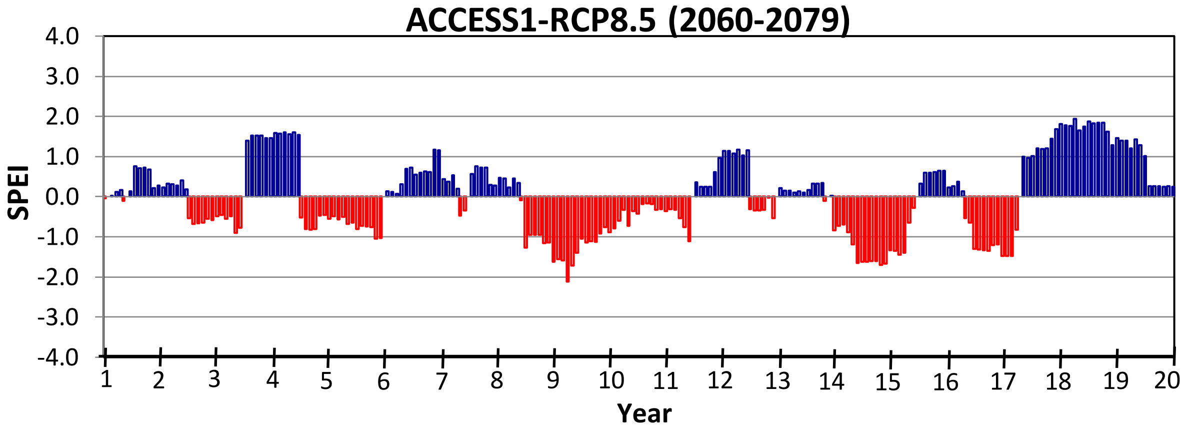
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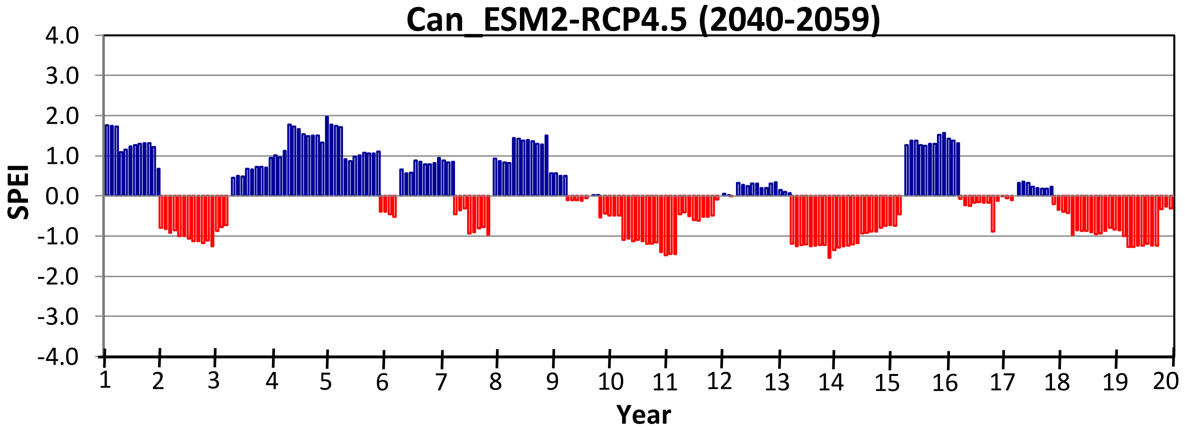
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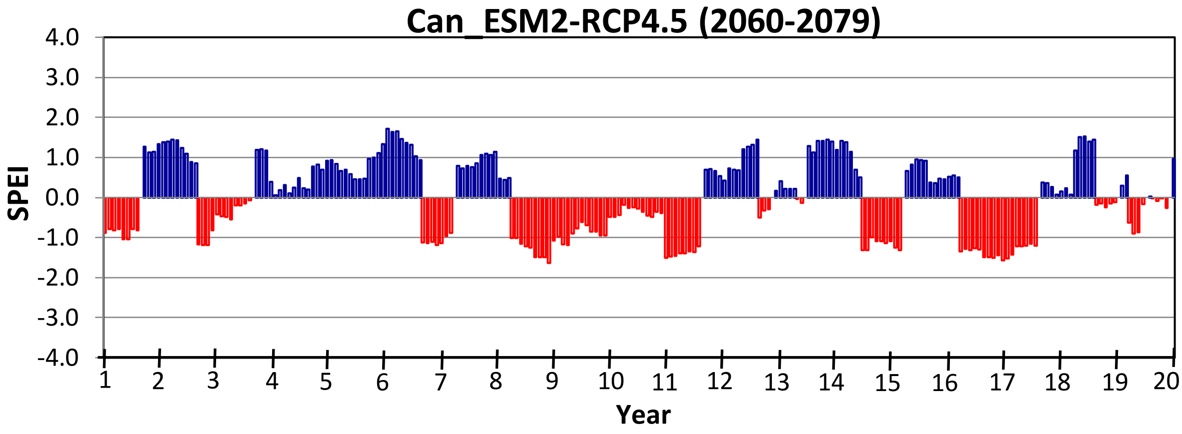
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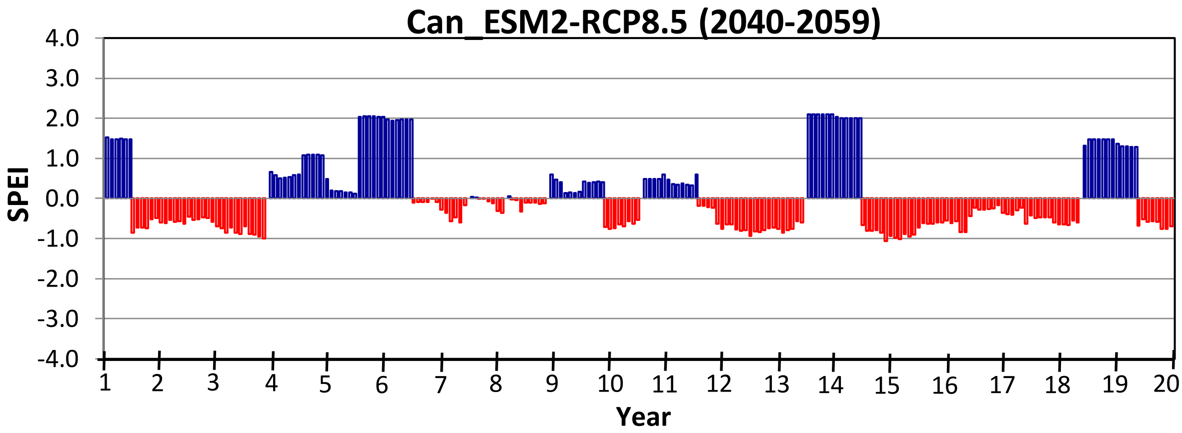
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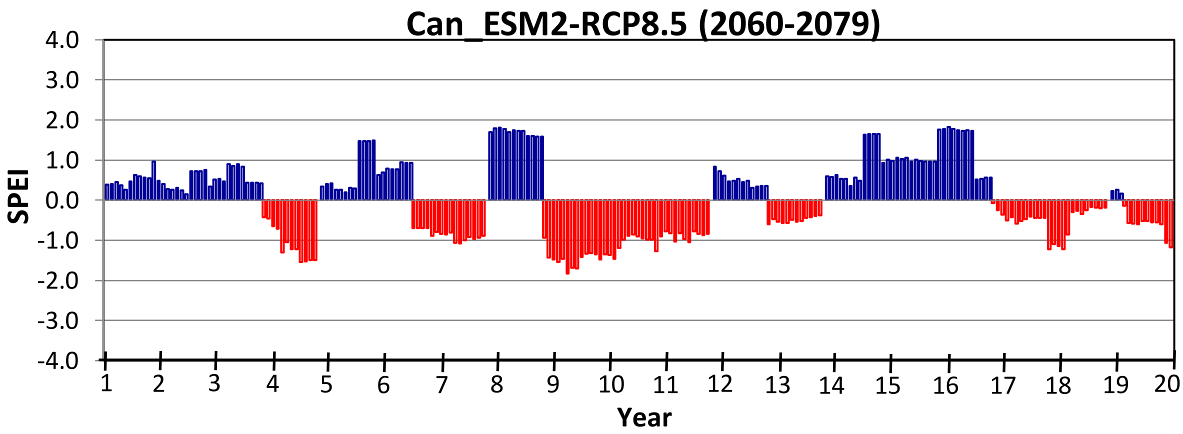
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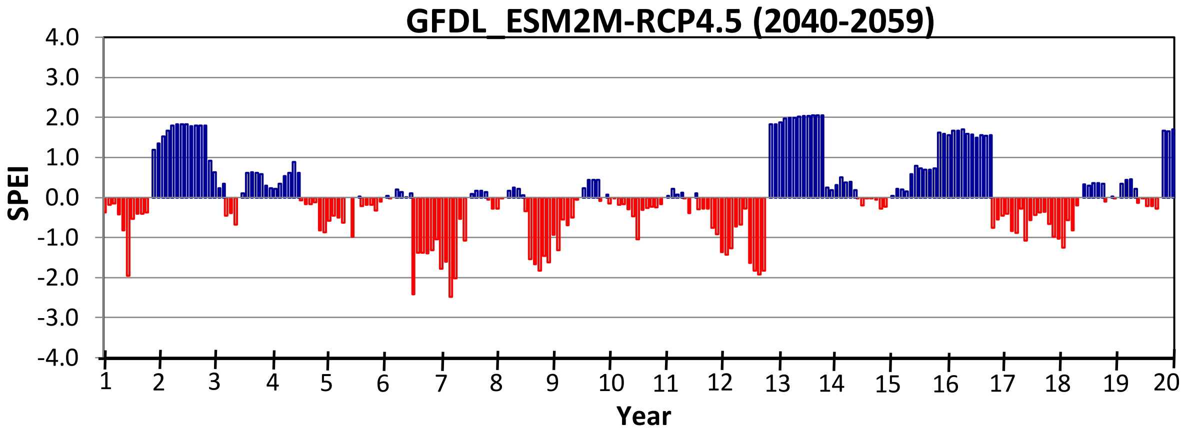
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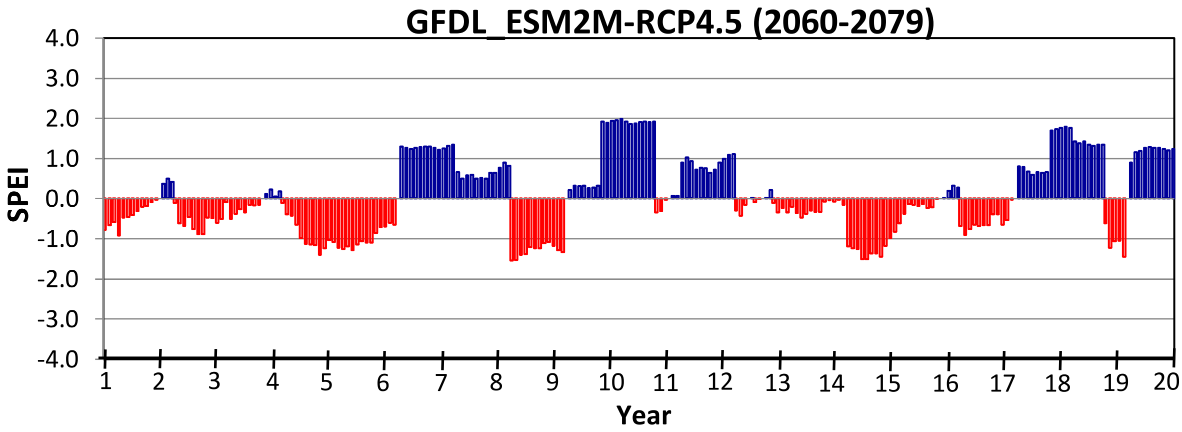
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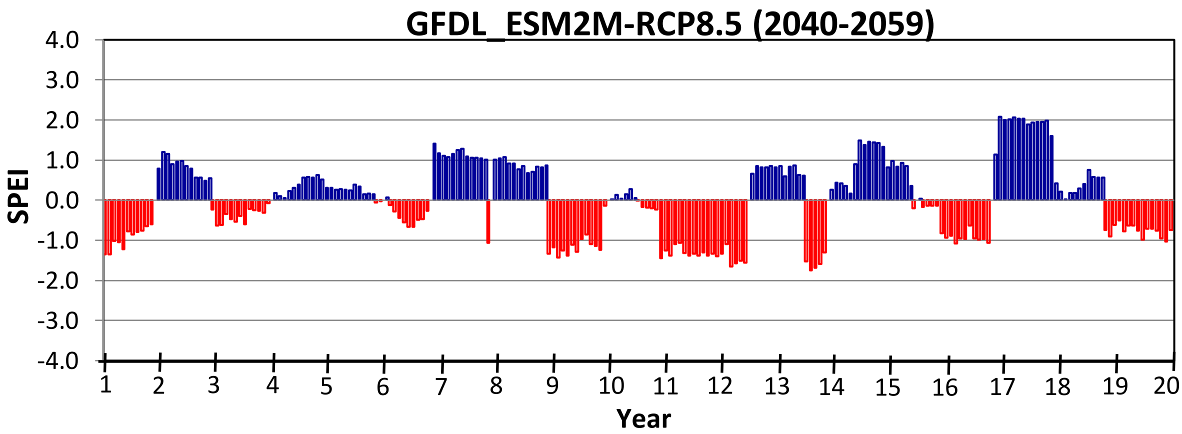
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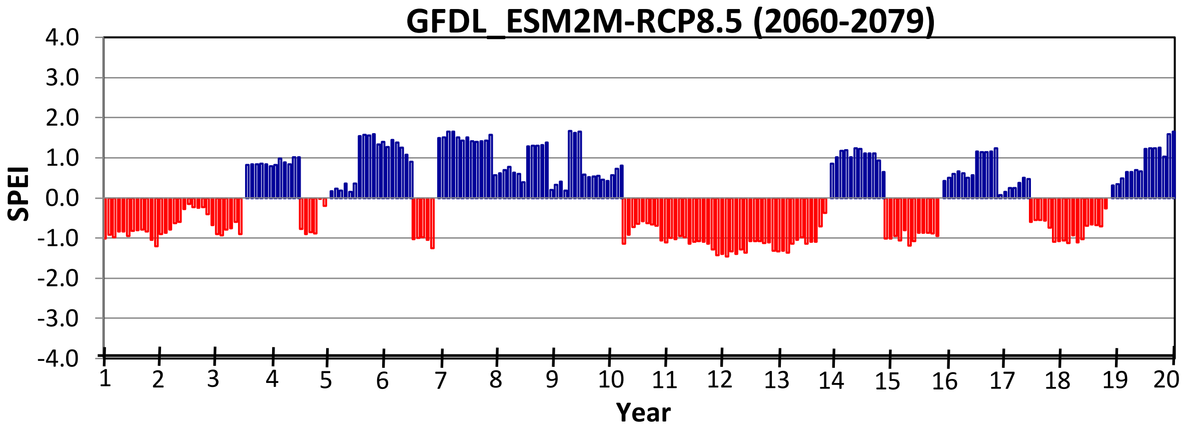
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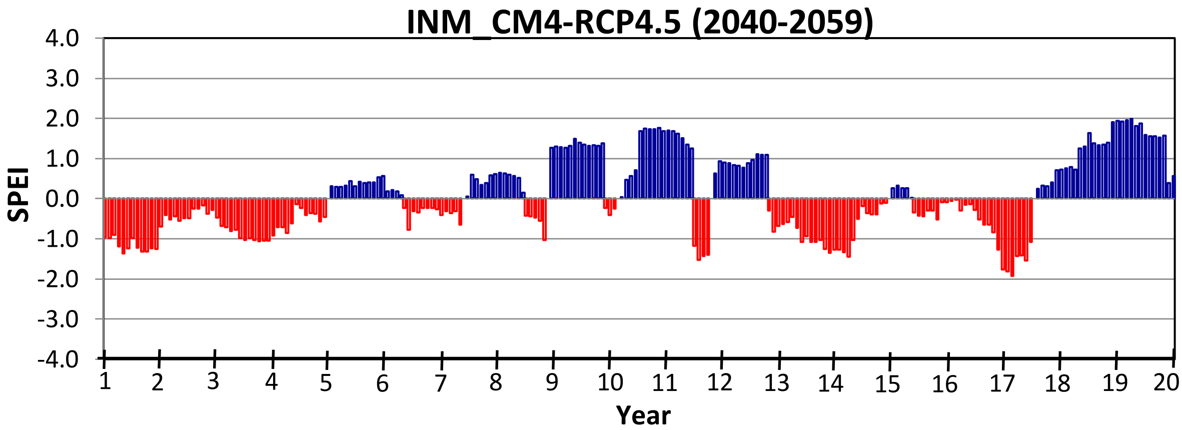
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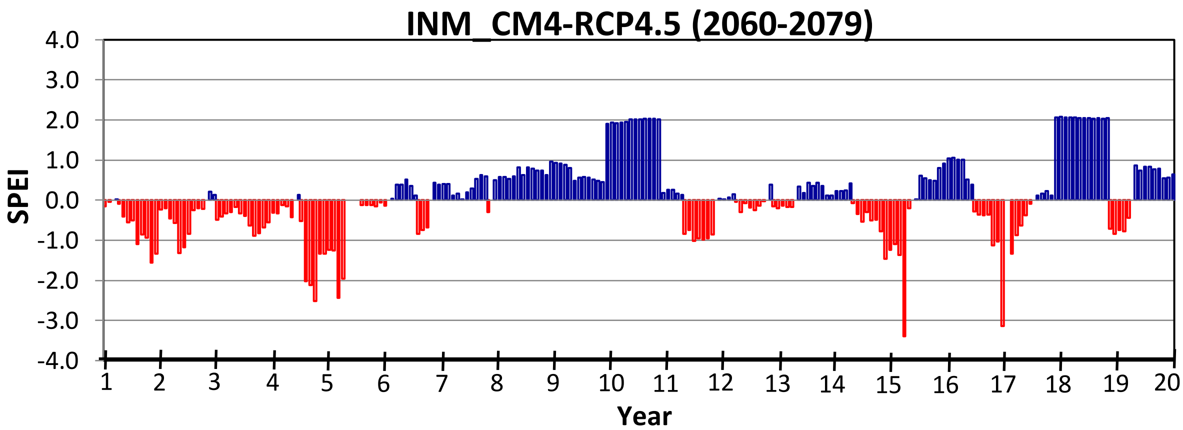
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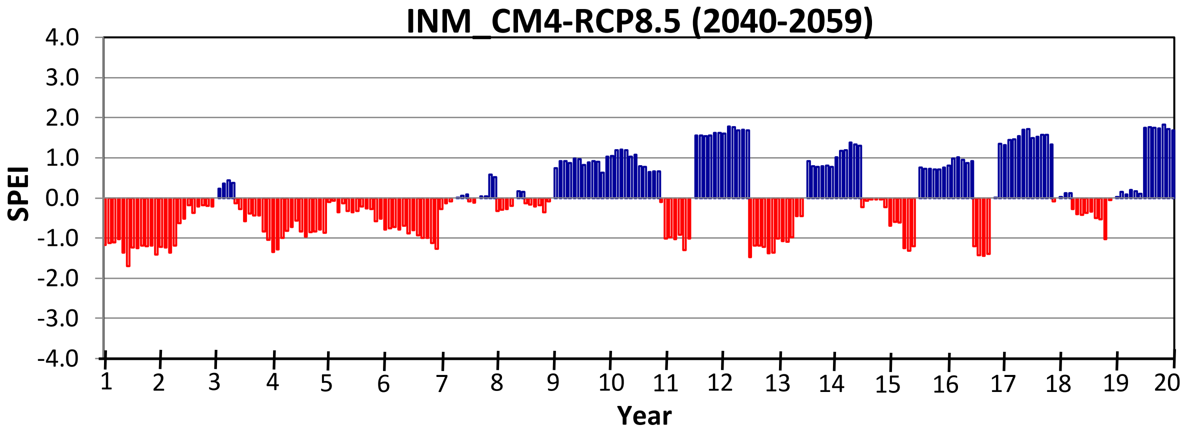
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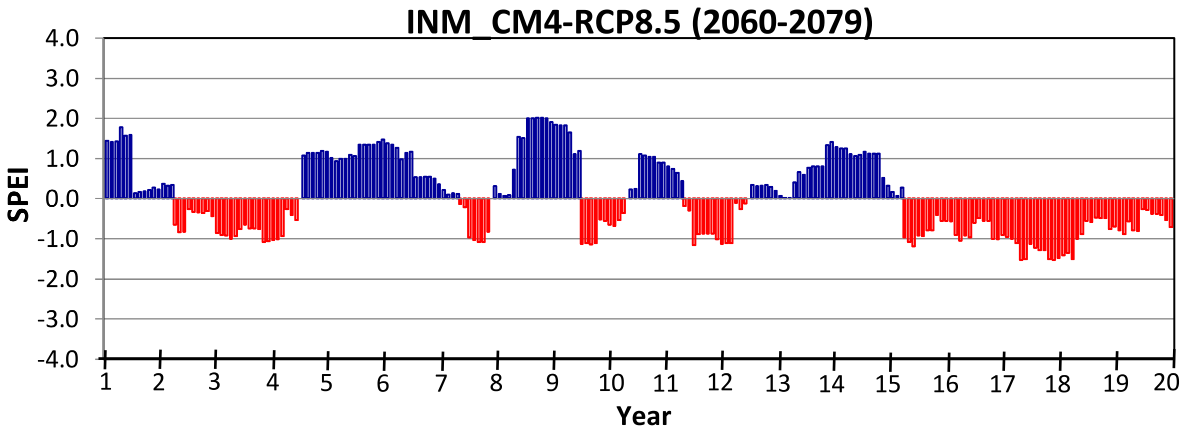
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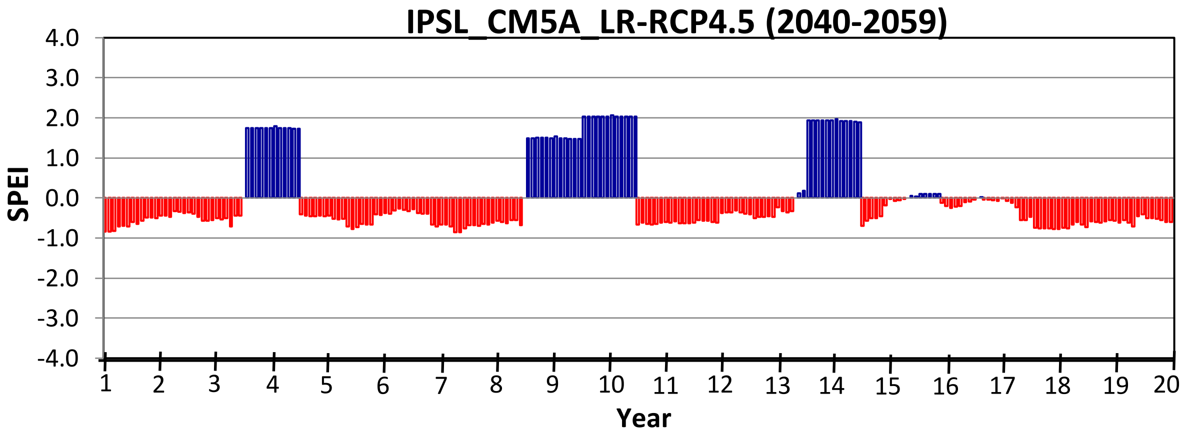
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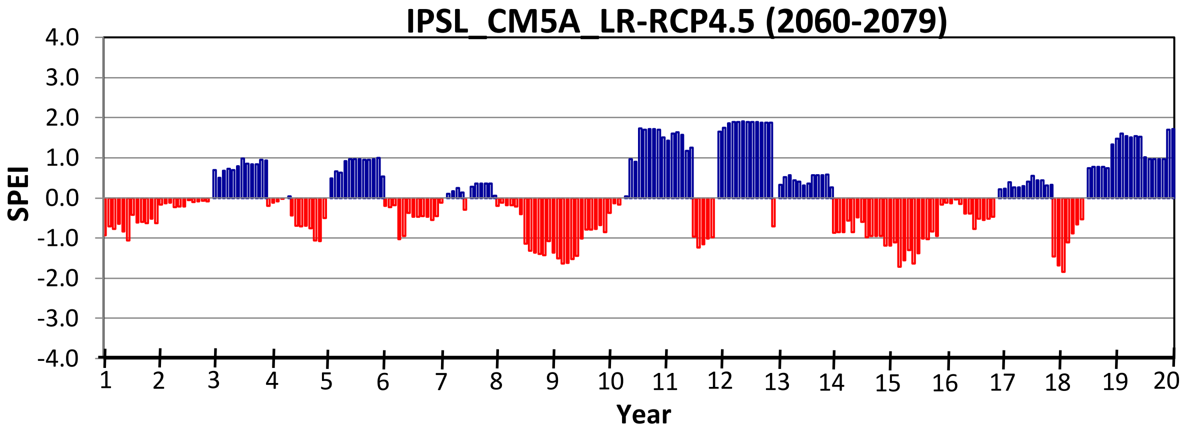
Year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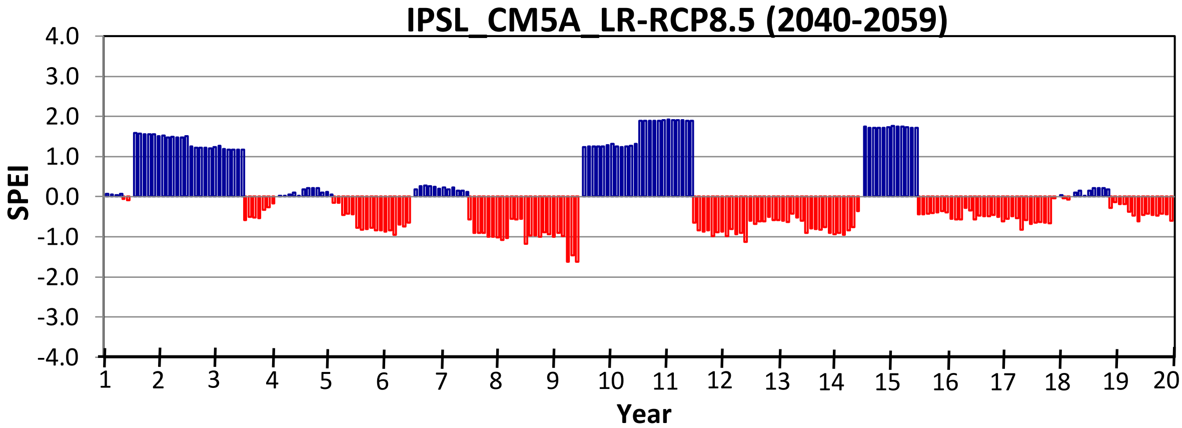
Year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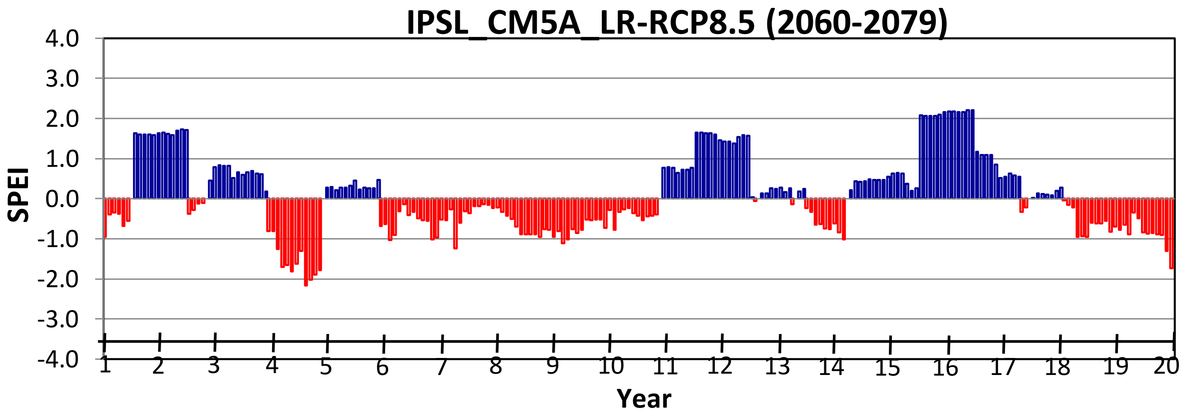
Year


IPSL_CM5A_LR-RCP8.5 (2060-2079)
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-4.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Year

Annexure 5: Inundation Scenarios

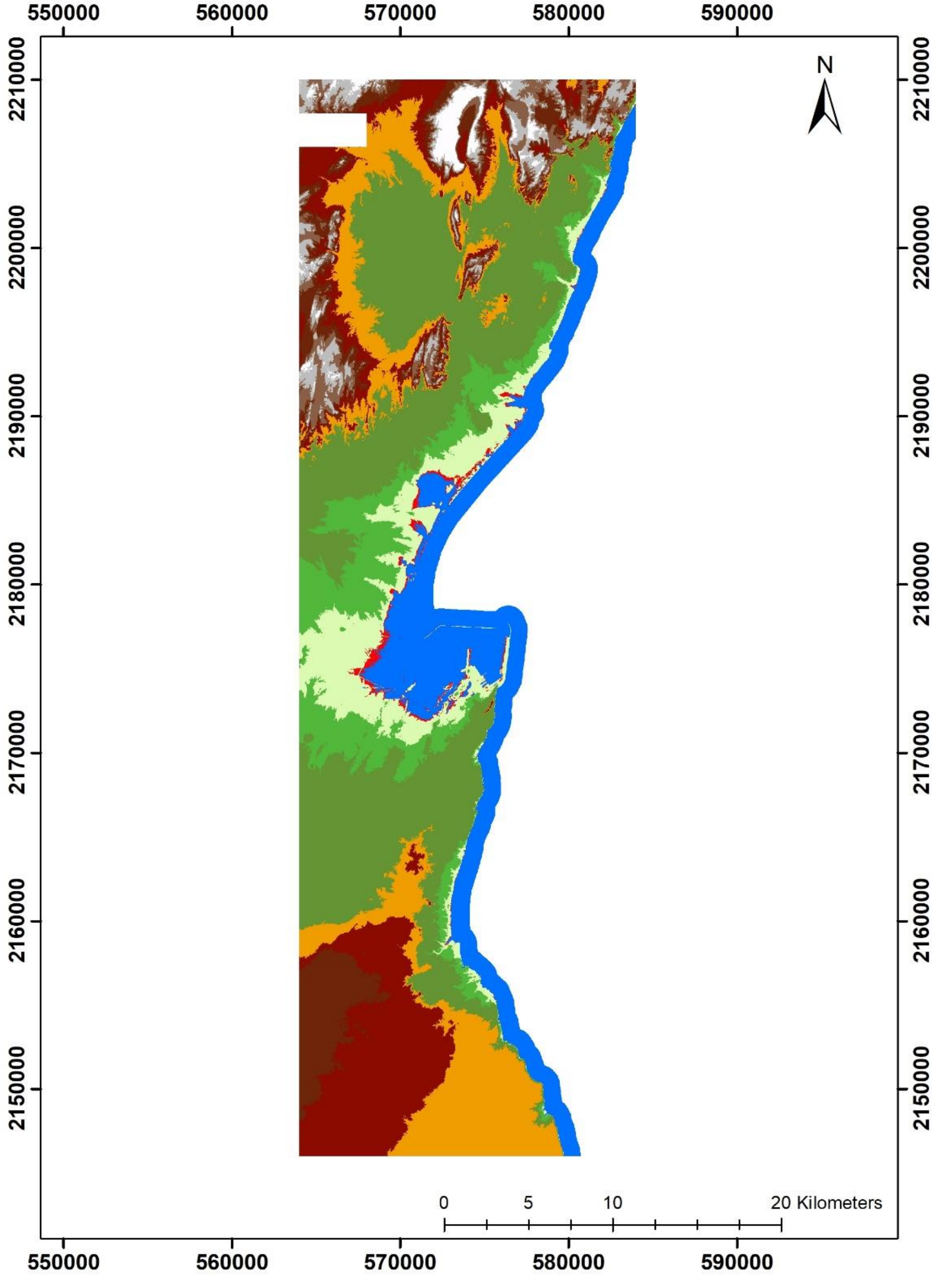

Figure A5-1: Inundation due to 0.5 m sea level rise.

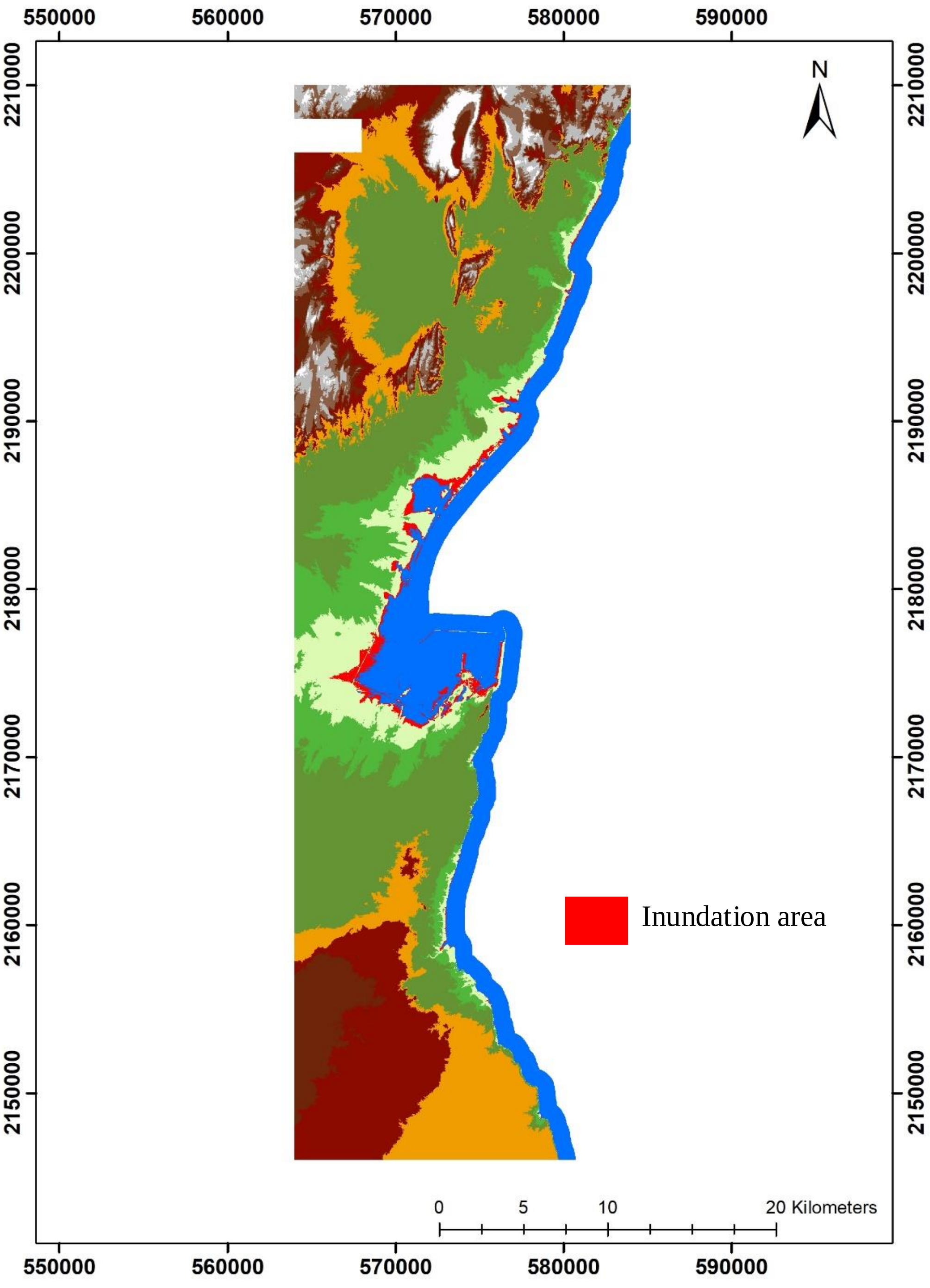

Figure A5-2: Inundation due to 1.0 m sea level rise.

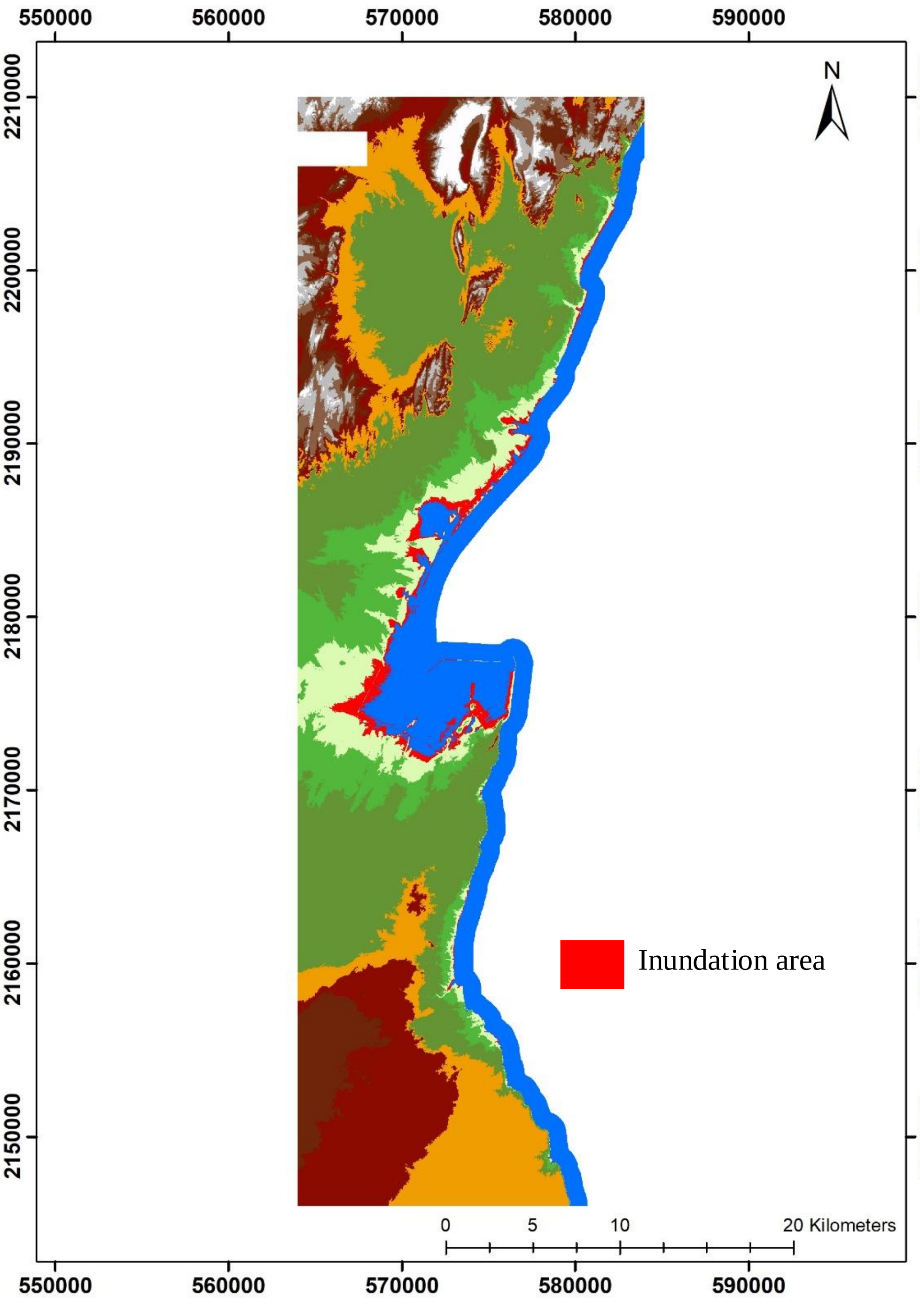

Figure A5-3: Inundation due to 1.5 m sea level rise.

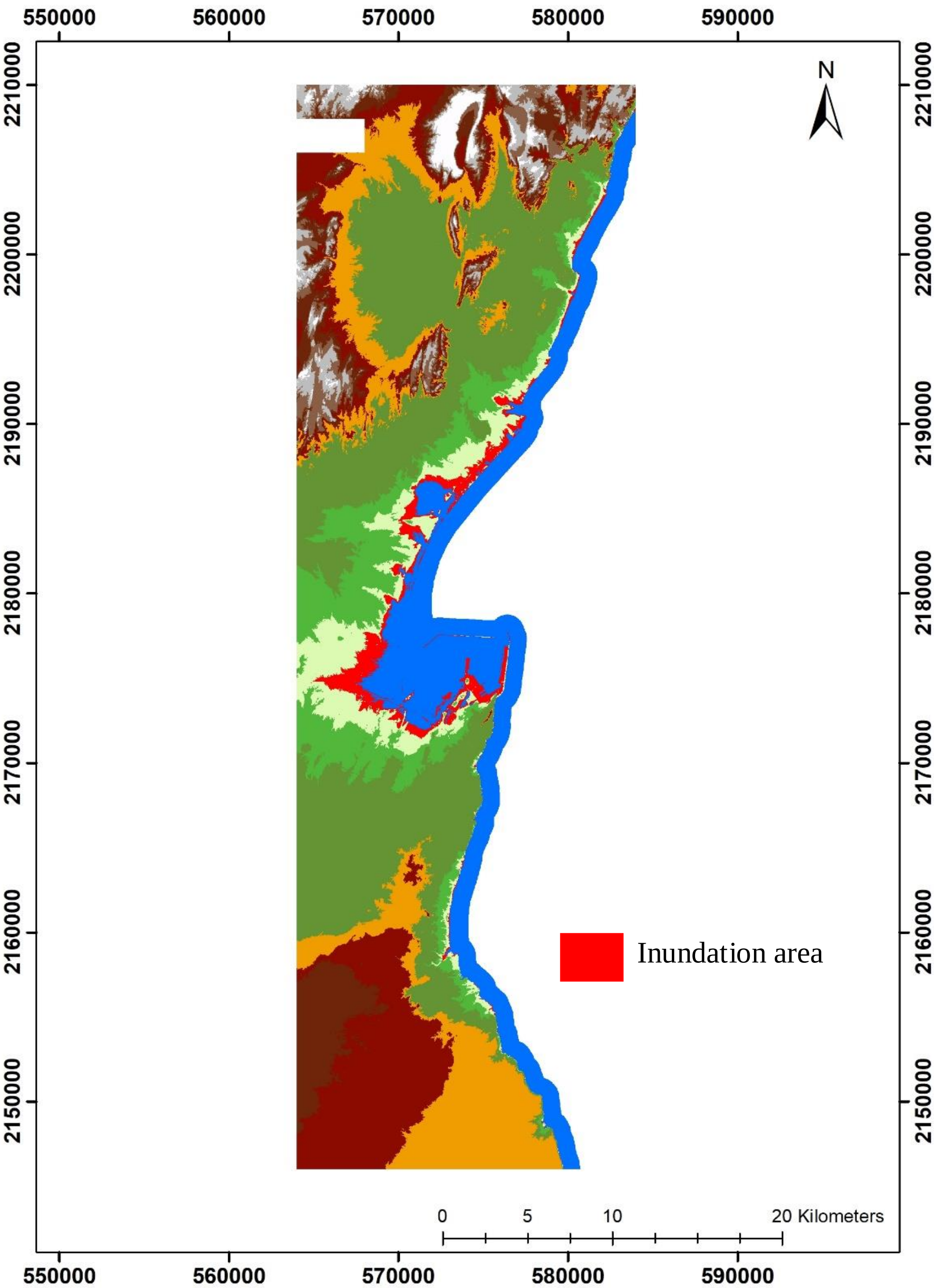

Figure A5-4: Inundation due to 2.0 m sea level rise.

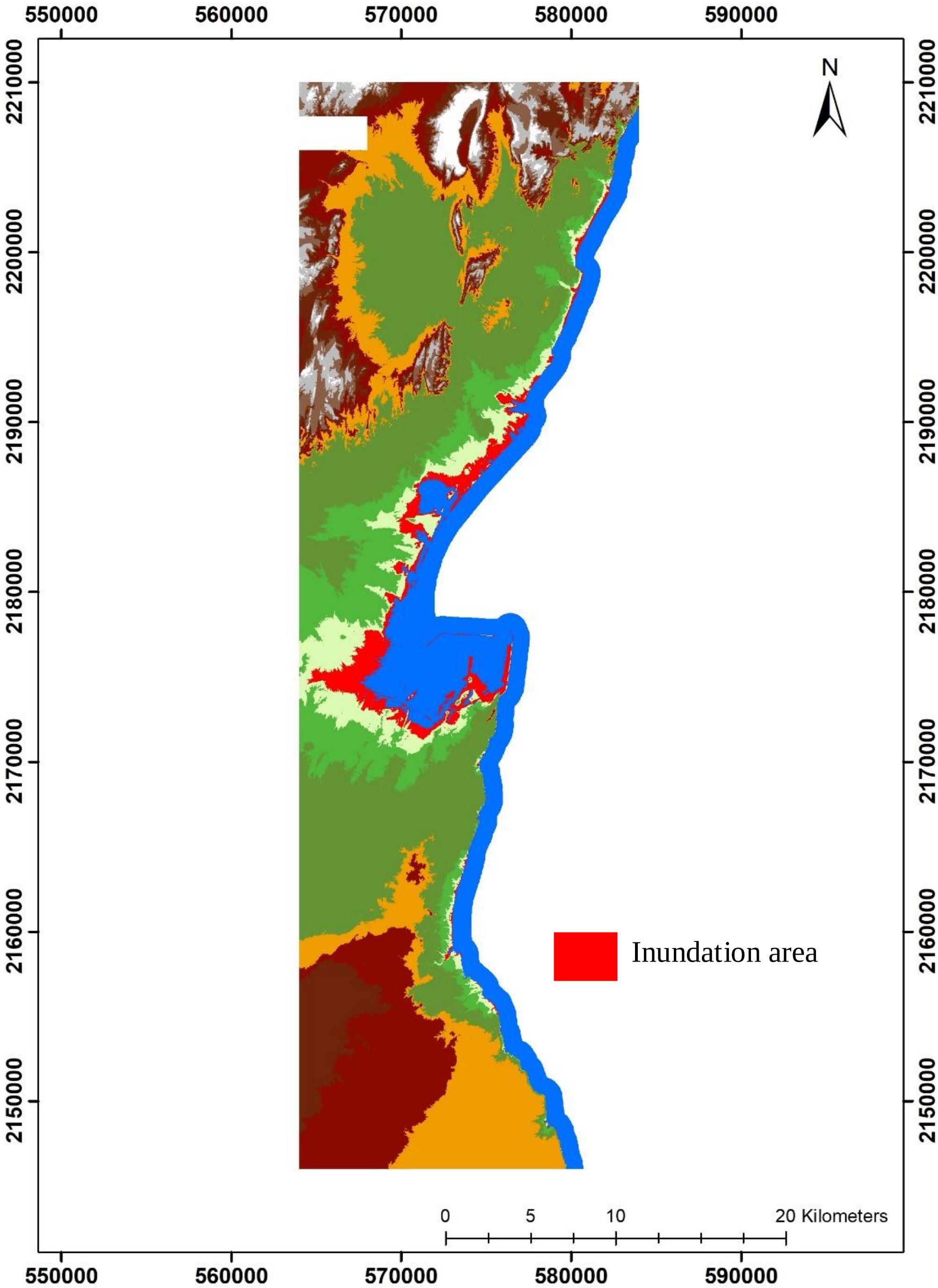

Figure A5-5: Inundation due to 2.5 m sea level rise.

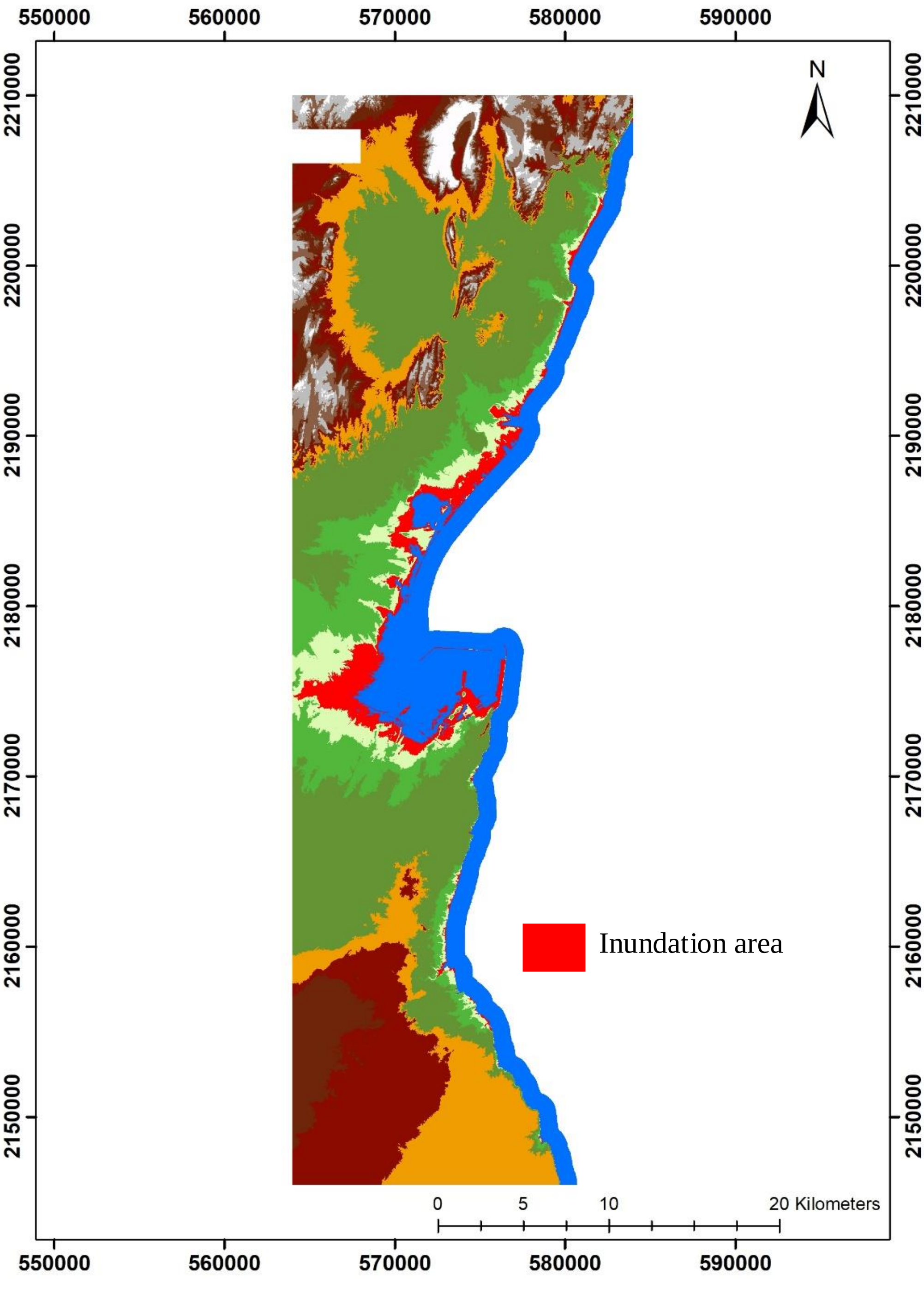

Figure A5-6: Inundation due to 3.0 m sea level rise.

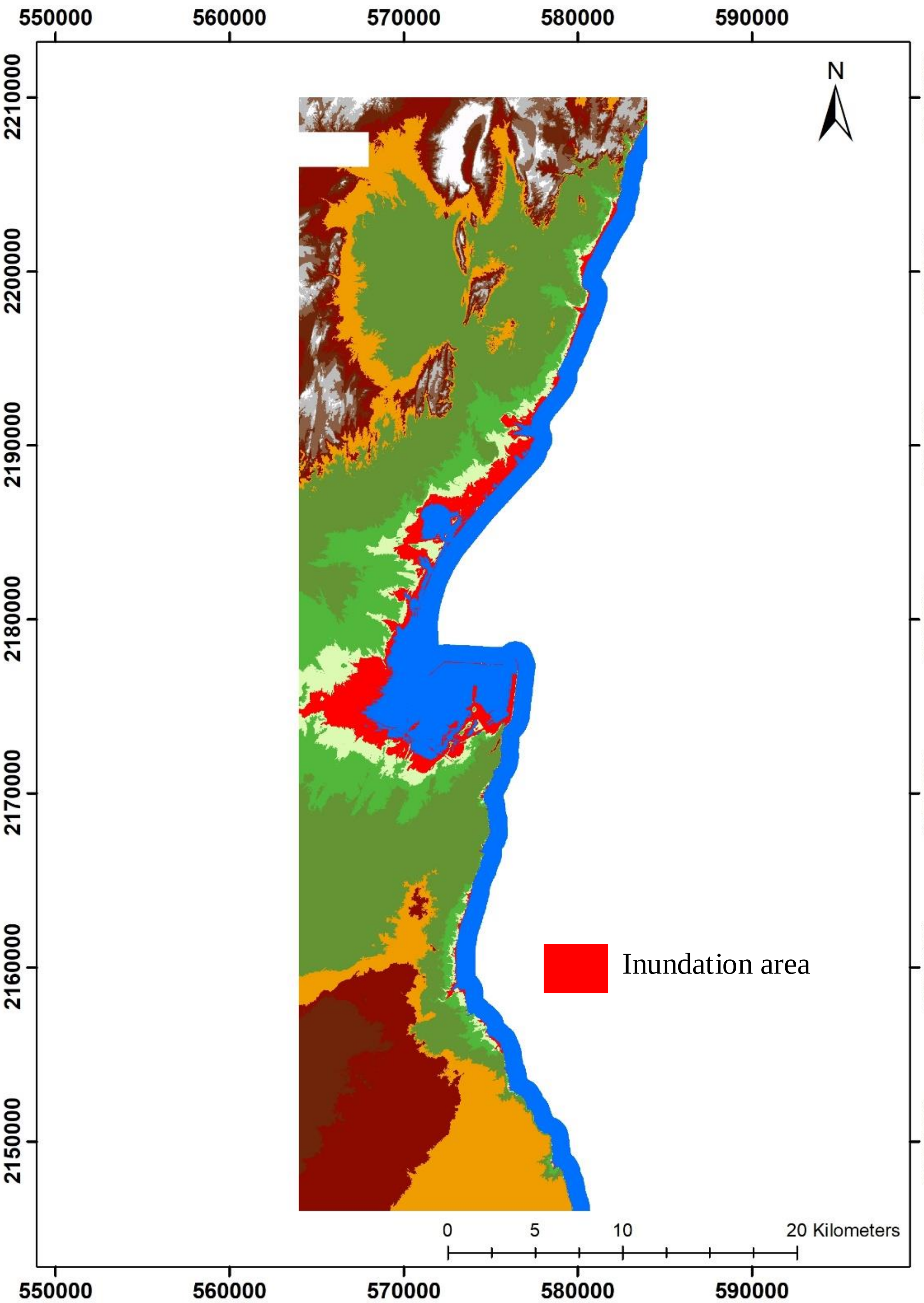

Figure A5-7: Inundation due to 4.0 m sea level rise.

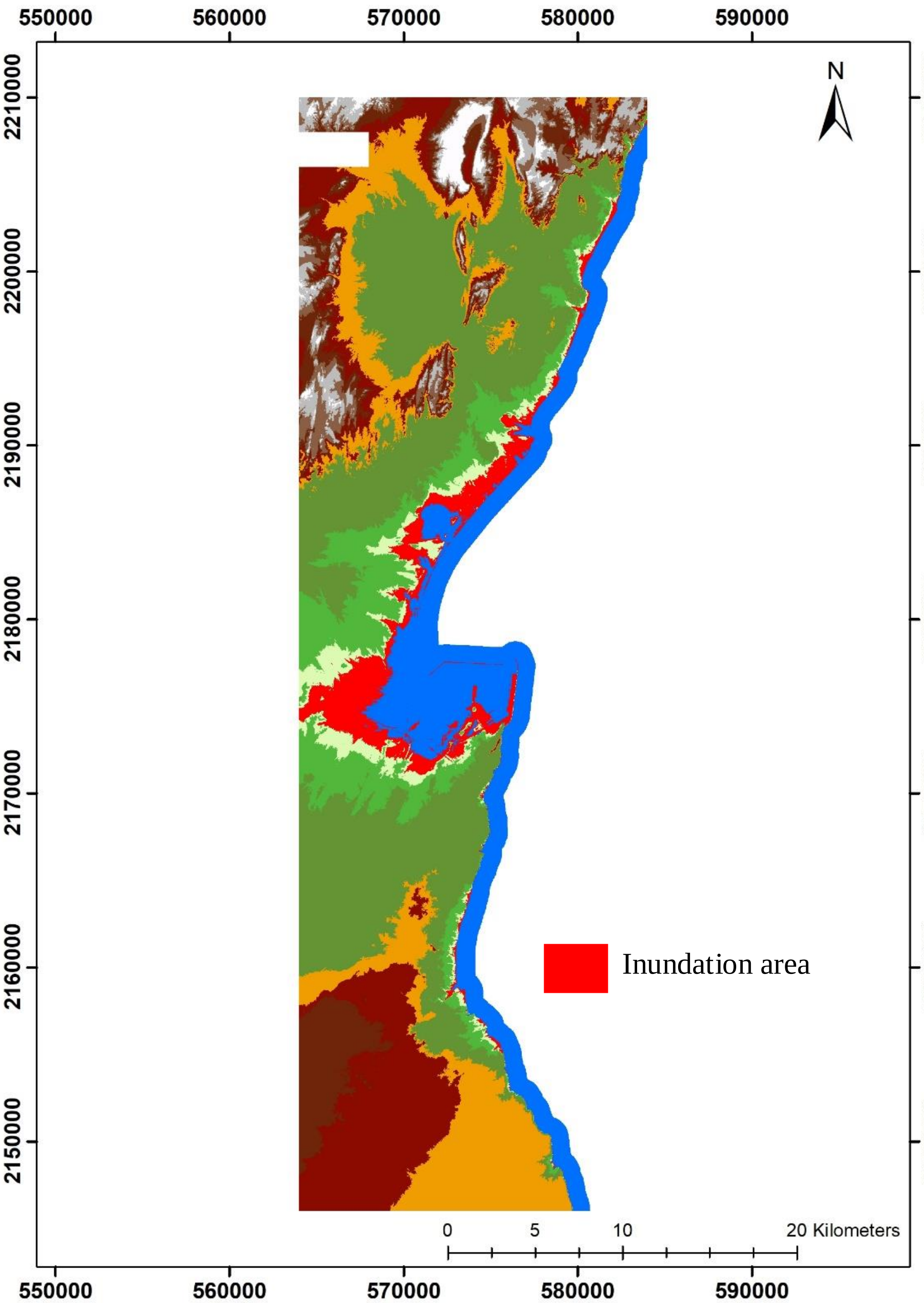

Figure A5-8: Inundation due to 5.0 m sea level rise.

Annexure 6: Results of the climate risk assessment

Table A6-1: Risk assessment findings: RCP 4.5 2040-2059 period.

Hazard	Risk statement	L	C	Risk
Maximum temperature and heat waves	Affect the machinery, equipment and construction materials, which are located outside due to overheating (Aivalioti 2015; Finkel 2017). This includes; **1.** efficiency of generator operation, **2.** transmission and distribution components of the electricity system, **3.** functioning of power and instrument transformers, **4.** spikes in electricity demand, and **5.** durability and the strength of the construction materials.	L2	C2	R2
	6. Affect the health and productivity of construction workers (Wen and Chan, 2017; Xiang et al., 2014). **7.** Increase the morbidity and mortality of elderly and very young people in residential areas and persons with existing chronic health conditions (Coates et al., 2014).	L2	C2	R2
	8. Impacts on livestock include stock deaths, reduced fertility, and lower milk yield (Nidumolu et al., 2010)	L2	C1	R1
	Impact the tourism sector by **9.** disruption of electricity services, which affect hotels under accommodation, restaurants under food, and shopping centers under retail trade, and **10.** altering the quality of the recreational experiences in beaches, national parks and other natural ecosystems.	L2	C2	R2
High intensity extreme rainfall	**1.** Damage to the bridges and culverts. **2.** The high waters in streams/rivers parallel to road may erode or scour beneath the road or expose buried pipelines (Baglee et al., 2012).	L1	C4	R2
	3. Damage side-drains and pavement. **4.** Enhance soil erosion, which leads to reduce the capacity of flood control dams and reservoirs.	L2	C2	R2
	5. Flooding of port land and/or buildings may reduce efficiency and increase handling times. **6.** Workforce can be injured or their safety can be at risk due to flash flood (RRP NAU 48480-003, 2017).	L1	C2	R1
	7. Increased maintenance work due to damages and sediment deposition. **8.** Tourist attractions, hotels and other facilities damaged by floods.	L2	C2	R2
Increases in prolonged (5-days) rainfall intensity	**1.** Flooding of road for several days may leading to sections of the road cut off for lengthy periods. **2.** High water table under or next to road facilitates leading to pavement failure and slope failure in particular to bridge abutments (Baglee et al., 2012).	L2	C3	R2

Hazard	Risk statement	L	C	Risk
	3. High water table and flood retain for lengthy periods may disrupt airport operation and maintenances. **4.** The flooding port area may result in damage to cargo. **5.** Flooding industrial area may damage buildings, machinery and equipment.	L2	C4	R3
	6. Affects structural integrity and value of property of residential settings (Ganguli and Merz, 2019).	L2	C2	R2
Droughts	**1.** Decrease in groundwater table due to decrease in groundwater recharge may affect for pumping water demand. **2.** Saline intrusion into groundwater, reducing quality.	L4	C2	R3
	3. Crop yield loss.	L4	C1	R2
	4. Decrease soil moisture content may affect flora and fauna in unique desert ecosystems such as Arabian Oryx Sanctuary. **5.** Decrease frequency of ephemeral flow in wadis may affect coastal habitats and sabkha, which effect on migrant birds (Mehr et al., 2020, Tan et al., 2020).	L4	C2	R3
Extreme wind and cyclone	Extreme wind effects on port operations include (RRP NAU 48480-003, 2017) **1.** Difficulties to position and hold the ship, which affects for the efficiency of loading and unloading the cargos. **2.** Increased wave run-up and/or overtopping of the shoreline leads to inundation of buildings, damage of cargos and risk for personal working in the port.	L1	C2	R1
	Extreme wind effects on various structures include **1.** Damages on buildings due to high velocity wind and dust storms, **2.** Stability issues of electricity poles and communication towers. **3.** Coastal erosion, and damages of tourism infrastructures and attractions	L1	C2	R1
	4. Extreme wind effects on public health include respiratory health effects due to dust caries by strong wind (Samarkandi, et al., 2017; WHO, 2010)	L5	C2	R4
Sea level rise	**1.** Higher water levels and sea spray corrode structures, resulting in the need for regular maintenance (RRP NAU 48480-003, 2017). **2.** Higher water levels in the seaside may affect river flows and water levels by backwater effects or by reversing the seaward flow of river during flood events. This effect can exacerbate inundation (Ganguli and Merz, 2019).	L1	C4	R2
	3. Coastal erosion and shoreline retreat affect on tourism infrastructures and coastal ecosystems (Thiéblemont et al., 2019).	L1	C4	R2
	4. Loss of freshwater and agricultural yield due to aquifer and soil contamination by saltwater intrusion (Shammas and Jacks, 2007).	L2	C2	R2

Table A6-2: Risk assessment findings: RCP 4.5 2060-2079 period

Hazard	Risk statement	L	C	Risk
Maximum temperature and heat waves	Affect the machinery, equipment and construction materials, which are located outside due to overheating (Aivalioti 2015; Finkel 2017). This includes; **1.** efficiency of generator operation, **2.** transmission and distribution components of the electricity system, **3.** functioning of power and instrument transformers, **4.** spikes in electricity demand, and **5.** durability and the strength of the construction materials.	L4	C2	R3
	6. Affect the health and productivity of construction workers (Wen and Chan, 2017; Xiang et al., 2014). **7.** Increase the morbidity and mortality of elderly and very young people in residential areas and persons with existing chronic health conditions (Coates et al., 2014).	L4	C2	R3
	8. Impacts on livestock include stock deaths, reduced fertility, and lower milk yield (Nidumolu et al., 2010)	L4	C1	R2
	Impact the tourism sector by **9.** disruption of electricity services, which affect hotels under accommodation, restaurants under food, and shopping centers under retail trade, and **10.** altering the quality of the recreational experiences in beaches, national parks and other natural ecosystems.	L4	C2	R3
High intensity extreme rainfall	**1.** Damage to the bridges and culverts. **2.** The high waters in streams/rivers parallel to road may erode or scour beneath the road or expose buried pipelines (Baglee et al., 2012).	L1	C4	R2
	3. Damage side-drains and pavement. **4.** Enhance soil erosion, which leads to reduce the capacity of flood control dams and reservoirs.	L2	C2	R2
	5. Flooding of port land and/or buildings may reduce efficiency and increase handling times. **6.** Workforce can be injured or their safety can be at risk due to flash flood (RRP NAU 48480-003, 2017).	L1	C2	R1
	7. Increased maintenance work due to damages and sediment deposition. **8.** Tourist attractions, hotels and other facilities damaged by floods.	L2	C2	R2
Increases in prolonged (5-days) rainfall intensity	**1.** Flooding of road for several days may leading to sections of the road cut off for lengthy periods. **2.** High water table under or next to road facilitates leading to pavement failure and slope failure in particular to bridge abutments (Baglee et al., 2012).	L1	C3	R2

Hazard	Risk statement	L	C	Risk
	3. High water table and flood retain for lengthy periods may disrupt airport operation and maintenances. **4.** The flooding port area may result in damage to cargo. **5.** Flooding industrial area may damage buildings, machinery and equipment.	L1	C4	R2
	6. Affects structural integrity and value of property of residential settings (Ganguli and Merz, 2019).	L1	C2	R1
Droughts	**1.** Decrease in groundwater table due to decrease in groundwater recharge may affect for pumping water demand. **2.** Saline intrusion into groundwater, reducing quality.	L5	C2	R4
	3. Crop yield loss.	L5	C1	R3
	4. Decrease soil moisture content may affect flora and fauna in unique desert ecosystems such as Arabian Oryx Sanctuary. **5.** Decrease frequency of ephemeral flow in wadis may affect coastal habitats and sabkha, which effect on migrant birds (Mehr et al., 2020, Tan et al., 2020).	L5	C2	R4
Extreme wind and cyclone	Extreme wind effects on port operations include (RRP NAU 48480-003, 2017) **1.** Difficulties to position and hold the ship, which affects for the efficiency of loading and unloading the cargos. **2.** Increased wave run-up and/or overtopping of the shoreline leads to inundation of buildings, damage of cargos and risk for personal working in the port.	L1	C2	R1
	Extreme wind effects on various structures include **3.** Damages on buildings due to high velocity wind and dust storms, **4.** Stability issues of electricity poles and communication towers. **5.** Coastal erosion, and damages of tourism infrastructures and attractions	L1	C2	R1
	6. Extreme wind effects on public health include respiratory health effects due to dust caries by strong wind (Samarkandi, et al., 2017; WHO, 2010)	L5	C2	R4
Sea level rise	**1.** Higher water levels and sea spray corrode structures, resulting in the need for regular maintenance (RRP NAU 48480-003, 2017). **2.** Higher water levels in the seaside may affect river flows and water levels by backwater effects or by reversing the seaward flow of river during flood events. This effect can exacerbate inundation (Ganguli and Merz, 2019).	L2	C4	R3

Hazard	Risk statement	L	C	Risk
	3. Coastal erosion and shoreline retreat affect on tourism infrastructures and coastal ecosystems (Thiéblemont et al., 2019).	L2	C4	R3
	4. Loss of freshwater and agricultural yield due to aquifer and soil contamination by saltwater intrusion (Shammas and Jacks, 2007).	L2	C2	R2

Table A6-3: Risk assessment findings: RCP 8.5 2040-2059 period

Hazard	Risk statement	L	C	Risk
Maximum temperature and heat waves	Affect the machinery, equipment and construction materials, which are located outside due to overheating (Aivalioti 2015; Finkel 2017). This includes; **1.** efficiency of generator operation, **2.** transmission and distribution components of the electricity system, **3.** functioning of power and instrument transformers, **4.** spikes in electricity demand, and **5.** durability and the strength of the construction materials.	L2	C2	R2
	6. Affect the health and productivity of construction workers (Wen and Chan, 2017; Xiang et al., 2014). **7.** Increase the morbidity and mortality of elderly and very young people in residential areas and persons with existing chronic health conditions (Coates et al., 2014).	L2	C2	R2
	8. Impacts on livestock include stock deaths, reduced fertility, and lower milk yield (Nidumolu et al., 2010)	L2	C1	R1
	Impact the tourism sector by **9.** disruption of electricity services, which affect hotels under accommodation, restaurants under food, and shopping centers under retail trade, and **10.** altering the quality of the recreational experiences in beaches, national parks and other natural ecosystems.	L2	C2	R2
High intensity extreme rainfall	**1.** Damage to the bridges and culverts. **2.** The high waters in streams/rivers parallel to road may erode or scour beneath the road or expose buried pipelines (Baglee et al., 2012).	L1	C4	R2
	3. Damage side-drains and pavement. **4.** Enhance soil erosion, which leads to reduce the capacity of flood control dams and reservoirs.	L3	C2	R2
	5. Flooding of port land and/or buildings may reduce efficiency and increase handling times. **6.** Workforce can be injured or their safety can be at risk due to flash flood (RRP NAU 48480-003, 2017).	L1	C2	R1
	7. Increased maintenance work due to damages and sediment deposition.	L3	C2	R2

Hazard	Risk statement	L	C	Risk
	8. Tourist attractions, hotels and other facilities damaged by floods.			
Increases in prolonged (5-days) rainfall intensity	**1.** Flooding of road for several days may leading to sections of the road cut off for lengthy periods. **2.** High water table under or next to road facilitates leading to pavement failure and slope failure in particular to bridge abutments (Baglee et al., 2012).	L1	C3	R2
	3. High water table and flood retain for lengthy periods may disrupt airport operation and maintenances. **4.** The flooding port area may result in damage to cargo. **5.** Flooding industrial area may damage buildings, machinery and equipment.	L1	C4	R2
	6. Affects structural integrity and value of property of residential settings (Ganguli and Merz, 2019).	L1	C2	R1
Droughts	**1.** Decrease in groundwater table due to decrease in groundwater recharge may affect for pumping water demand. **2.** Saline intrusion into groundwater, reducing quality.	L4	C2	R3
	3. Crop yield loss.	L4	C1	R2
	4. Decrease soil moisture content may affect flora and fauna in unique desert ecosystems such as Arabian Oryx Sanctuary. **5.** Decrease frequency of ephemeral flow in wadis may affect coastal habitats and sabkha, which effect on migrant birds (Mehr et al., 2020, Tan et al., 2020).	L4	C2	R3
Extreme wind and cyclone	Extreme wind effects on port operations include (RRP NAU 48480-003, 2017) **1.** Difficulties to position and hold the ship, which affects for the efficiency of loading and unloading the cargos. **2.** Increased wave run-up and/or overtopping of the shoreline leads to inundation of buildings, damage of cargos and risk for personal working in the port.	L1	C2	R1
	Extreme wind effects on various structures include **3.** Damages on buildings due to high velocity wind and dust storms, **4.** Stability issues of electricity poles and communication towers. **5.** Coastal erosion, and damages of tourism infrastructures and attractions	L1	C2	R1
	6. Extreme wind effects on public health include respiratory health effects due to dust caries by strong wind (Samarkandi, et al., 2017; WHO, 2010)	L5	C2	R4

Hazard	Risk statement	L	C	Risk
Sea level rise	**1.** Higher water levels and sea spray corrode structures, resulting in the need for regular maintenance (RRP NAU 48480-003, 2017). **2.** Higher water levels in the seaside may affect river flows and water levels by backwater effects or by reversing the seaward flow of river during flood events. This effect can exacerbate inundation (Ganguli and Merz, 2019).	L2	C4	R3
	3. Coastal erosion and shoreline retreat affect on tourism infrastructures and coastal ecosystems (Thiéblemont et al., 2019).	L2	C4	R3
	4. Loss of freshwater and agricultural yield due to aquifer and soil contamination by saltwater intrusion (Shammas and Jacks, 2007).	L2	C2	R2

Table A6-4: Risk assessment findings: RCP 8.5 2060-2079 period

Hazard	Risk statement	L	C	Risk
Maximum temperature and heat waves	Affect the machinery, equipment and construction materials, which are located outside due to overheating (Aivalioti 2015; Finkel 2017). This includes; **1.** efficiency of generator operation, **2.** transmission and distribution components of the electricity system, **3.** functioning of power and instrument transformers, **4.** spikes in electricity demand, and **5.** durability and the strength of the construction materials.	L5	C2	R4
	6. Affect the health and productivity of construction workers (Wen and Chan, 2017; Xiang et al., 2014). **7.** Increase the morbidity and mortality of elderly and very young people in residential areas and persons with existing chronic health conditions (Coates et al., 2014).	L5	C2	R4
	8. Impacts on livestock include stock deaths, reduced fertility, and lower milk yield (Nidumolu et al., 2010)	L5	C1	R3
	Impact the tourism sector by **9.** disruption of electricity services, which affect hotels under accommodation, restaurants under food, and shopping centers under retail trade, and **10.** altering the quality of the recreational experiences in beaches, national parks and other natural ecosystems.	L5	C2	R4
High intensity extreme rainfall	**1.** Damage to the bridges and culverts. **2.** The high waters in streams/rivers parallel to road may erode or scour beneath the road or expose buried pipelines (Baglee et al., 2012).	L1	C4	R2

Hazard	Risk statement	L	C	Risk
	3. Damage side-drains and pavement. **4.** Enhance soil erosion, which leads to reduce the capacity of flood control dams and reservoirs.	L3	C2	R2
	5. Flooding of port land and/or buildings may reduce efficiency and increase handling times. **6.** Workforce can be injured or their safety can be at risk due to flash flood (RRP NAU 48480-003, 2017).	L1	C2	R1
	7. Increased maintenance work due to damages and sediment deposition. **8.** Tourist attractions, hotels and other facilities damaged by floods.	L3	C2	R2
Increases in prolonged (5-days) rainfall intensity	**1.** Flooding of road for several days may leading to sections of the road cut off for lengthy periods. **2.** High water table under or next to road facilitates leading to pavement failure and slope failure in particular to bridge abutments (Baglee et al., 2012).	L2	C3	R2
	3. High water table and flood retain for lengthy periods may disrupt airport operation and maintenances. **4.** The flooding port area may result in damage to cargo. **5.** Flooding industrial area may damage buildings, machinery and equipment.	L2	C4	R3
	6. Affects structural integrity and value of property of residential settings (Ganguli and Merz, 2019).	L2	C2	R2
Droughts	**1.** Decrease in groundwater table due to decrease in groundwater recharge may affect for pumping water demand. **2.** Saline intrusion into groundwater, reducing quality.	L5	C2	R4
	3. Crop yield loss.	L5	C1	R3
	4. Decrease soil moisture content may affect flora and fauna in unique desert ecosystems such as Arabian Oryx Sanctuary. **5.** Decrease frequency of ephemeral flow in wadis may affect coastal habitats and sabkha, which effect on migrant birds (Mehr et al., 2020, Tan et al., 2020).	L5	C2	R4
Extreme wind and cyclone	Extreme wind effects on port operations include (RRP NAU 48480-003, 2017) **1.** Difficulties to position and hold the ship, which affects for the efficiency of loading and unloading the cargos. **2.** Increased wave run-up and/or overtopping of the shoreline leads to inundation of buildings, damage of cargos and risk for personal working in the port.	L1	C2	R1

Hazard	Risk statement	L	C	Risk
	Extreme wind effects on various structures include **3.** Damages on buildings due to high velocity wind and dust storms, **4.** Stability issues of electricity poles and communication towers. **5.** Coastal erosion, and damages of tourism infrastructures and attractions	L1	C2	R1
	6. Extreme wind effects on public health include respiratory health effects due to dust caries by strong wind (Samarkandi, et al., 2017; WHO, 2010)	L5	C2	R4
Sea level rise	**1.** Higher water levels and sea spray corrode structures, resulting in the need for regular maintenance (RRP NAU 48480-003, 2017). **2.** Higher water levels in the seaside may affect river flows and water levels by backwater effects or by reversing the seaward flow of river during flood events. This effect can exacerbate inundation (Ganguli and Merz, 2019).	L2	C4	R3
	3. Coastal erosion and shoreline retreat affect on tourism infrastructures and coastal ecosystems (Thiéblemont et al., 2019).	L2	C4	R3
	4. Loss of freshwater and agricultural yield due to aquifer and soil contamination by saltwater intrusion (Shammas and Jacks, 2007).	L3	C2	R2