Sultanate of Oman

وزارة البيئة والشؤون المناخية
MINISTRY OF ENVIRONMENT AND CLIMATE AFFAIRS

National Strategy for Adaptation and Mitigation to Climate Change for the Sultanate of Oman

(2020-2040)

April 2018

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(2020-2040)

National Experts

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AR5	Fifth Assessment Report
CFSR	Climate Forecast System Reanalysis
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon dioxide
COP	Conference of the Parties
CPUE	Catch Per Unit Effort
CSP	Concentrating solar power
CVI	Coastal Vulnerability Index
DEM	Digital Elevation Model
EEZ	Exclusive Economic Zone
EIA	Energy Information Administration (US)
EMS	Energy management system
FAO	Food and Agriculture Organization of the United Nations
GCF	Green Climate Fund
GDP	Gross Domestic Product
GFDL	Geophysical Fluid Dynamics Laboratory model
GHG	Greenhouse gas
GOW	Global Ocean Wave
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre Simon Laplace model
Km	kilometer
kTOE	thousand tonnes of oil equivalent
kW	kilowatts (thousand watts)
kWh	kilowatt-hours (thousand watt-hours)
mm	millimeter
MW	megawatts (10^6 watts)
MWh	megawatt-hours (10^6 watt-hours)
O3	Ozone
MPHRU	Medical & Public Health Response Unit
NorESM	Norwegian Earth System Model
PAEW	Public Authority for Electricity & Water
PISCES	Pelagic Interaction Scheme for Carbon and Ecosystem Studies
PM	Particulate matter
ppm	parts per million
RCP	Representative Concentration Pathway
SLR	Sea level rise
TWh	Terawatt-hours (10^12 watt-hours)
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

FOREWORD

Climate change may be humanity's greatest environmental and economic challenge. Already, coastal waters have warmed, temperatures have risen, and rainfall patterns have noticeably been altered. Globally, sea levels and temperatures are predicted to rise further, and extreme weather is expected to become more common. This is resulting in increasingly visible and heavy tolls.

Changing climatic patterns are already being experienced in Oman. While the country is well-known for its very hot summers and low annual rainfall, it has become even hotter over the past decades. Moreover, much of the Oman's population, infrastructure and economic activity are located in coastal zones and are vulnerable to sea-level rise, salt-water intrusion, and more frequent extreme weather events.

Oman is committed to taking decisive action in the face of these threats from climate change. Bold actions within our own borders will be needed to adapt to the looming risks as well as to actively share in the global burden of reducing greenhouse gas emissions that threaten the climate system.

Civil society, the private sector, and government agencies will need to work together to modify wasteful consumption and production patterns to encourage more sustainable practices. To achieve this, the public's awareness of climate change will need to be raised and strengthening the capacity of Omani institutions will be crucial. The ultimate objective is climate-resilient green growth.

The National strategy for Adaptation and Mitigation to Climate Change for the Sultanate of Oman provides a roadmap to guide adaptation and mitigation efforts over the next 20 years. The strategy is built upon sound scientific research and analysis of national policies, strategies, and international treaties requirements; it provides a framework for protecting Oman's vulnerable sectors, systems, and populations to climate change, while also establishing a feasible strategy for reducing greenhouse gas emissions. This Strategy has benefitted from the active participation of key stakeholders, including government agencies, private sector and academia. Thus, I would like to thank all the experts who contributed to the preparation of this strategy.

In conclusion, the Strategy declares that The Sultanate Oman is ready to take up the challenge of climate change. The implementation of the strategic actions described in the following pages will reduce the risks associated with adverse impacts of climate change while also substantially reducing greenhouse gas emissions. In the process, the actions can contribute to economic development through increased productivity, market transformation, and job creation.

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EXECUTIVE SUMMARY

The primary goal of the Strategy is to identify the strategic actions necessary for adaptation and mitigation with climate change. This involves addressing the adverse impacts across all national vulnerable sectors, as well as addressing the priority measures for controlling GHG emissions to achieve the transition to a low-carbon emission economy.

The major five objectives of the Strategy are: promote institutional capacity; raise awareness; undertake systematic climate research; coordinate action across agencies; and promote strategic research and cooperation opportunities. These objectives are essentially cross-cutting goals that apply to all strategic action streams and represent both the short- and long-term vision for climate change policy in Oman.

The main structure of the Strategy consists of three major themes: Climate science; Vulnerability and adaptation; and Greenhouse gas mitigation. Each of these themes aims to support and promote the cross-cutting goals of the Strategy, as illustrated in Figure ES-1.

Developing the Strategy consisted of three major activities over a 3-year period. First, scientific research was carried out to better understand Oman's future climatic conditions, climate change risks, and adaptation opportunities. Second, scoping studies were undertaken to identify cost-effective technologies and practices to achieve ambitious GHG emission reductions. Third, extensive stakeholder consultations in the form of a set of workshops were convened to establish strategic actions that enjoyed broad consensus across public/private sector entities in response to the research and scoping studies.

The implementation of the Strategy will require concerted institutional action at multiple administrative levels and across multiple stakeholder groups. The Strategy is intended to be the country's primary policy statement guiding national climate change discussions, both in the short- and long-term. It is important to note that the Strategy is a high-level treatment of a national response to the challenge of climate change. As such, it does not define specific arrangements that define the distribution of institutional responsibilities to enact the Strategy's strategic actions.

The strategic context for adaptation is rooted in Oman's ineluctable exposure to intensifying tropical cyclones, increasing temperatures, and rising sea levels. Understanding land use, climate, water resources, and agriculture/fisheries is an essential context for identifying, designing and implementing preparedness/response measures to reduce the vulnerability of communities, resources, and systems.

The strategic context for mitigation is rooted in the recognition of the need to control a trend of greenhouse gas emissions growth. A review of population growth, economic trends, and energy supply/demand represents the essential context for efforts to prioritize, finance, and implement cost-effective efficiency and renewable energy strategies that can slow the growth in national greenhouse gas emissions.

The Climate Science theme of the National Strategy for Adaptation and Mitigation to Climate Change for the Sultanate of Oman 2020-2040, focuses on the use of state-of-the-art methods and tools to establish historical climatic trends and to better understand future climate change in Oman under various reasonable scenarios of global greenhouse gas emissions. Effective adaptive responses will need to rely on a sound knowledge of anticipated changes. Therefore, a high priority for research must be the generation of reliable projections of likely climatic changes spatially (i.e., at the regional level for the Sultanate of Oman) and temporally (i.e., accounting for seasonal differences). Thus, four strategic actions of the Climate Science stream have been identified: Awareness-raising; Data development; Research capacity and capacity building.

The Vulnerability & Adaptation theme of the Climate Change Strategy focuses on five key sectors: water resources; marine biodiversity and fisheries; agriculture, urban areas, tourism & infrastructure; and public health. For each of these sectors, vulnerability assessments were undertaken to identify the potential physical impacts of climate change relative to future changes regarding temperature, rainfall, and sea-level rise. On the basis of these assessments, a set of strategic adaptation actions were identified and are incorporated into this Strategy, as summarized in the bullets below:

- *Water Resources:* There are five streams of strategic actions. These actions focus on Knowledge generation; Wastewater management; Surface water management; Capacity building; and Governance.
- *Marine biodiversity and fisheries:* There are two streams of strategic actions. These actions focus on Knowledge management and Governance.
- *Agriculture:* There are three streams of strategic actions. These actions focus on: Knowledge management; Capacity building; and Governance.
- *Urban areas, tourism, & infrastructure:* There are three streams of strategic actions. These actions focus on: Knowledge management; Capacity building; and Governance.
- *Public health:* There are three streams of strategic actions. These actions focus on: Knowledge management; Capacity building; and Governance.

The Greenhouse Gas Mitigation theme of the Oman Climate Change strategy focuses on the energy, industrial, waste and agriculture sectors, the sectors responsible for the largest share of GHG emissions in Oman. Thus, four sets of strategic mitigation actions that have been incorporated into this Strategy: Energy; industry; waste and agriculture sectors.

In conclusion, the Sultanate of Oman is a committed partner in the global effort to address the climate change challenge. This Strategy is a fundamental step that signals how Oman plans to move forward in the fulfillment of the aspirations of the Paris Agreement of COP-21. To achieve the vision and mission outlined in the Strategy, collective action among the range of national stakeholders will be essential, as will partnerships with the international community to facilitate the flow of technical and financial resources for implementing the vision.

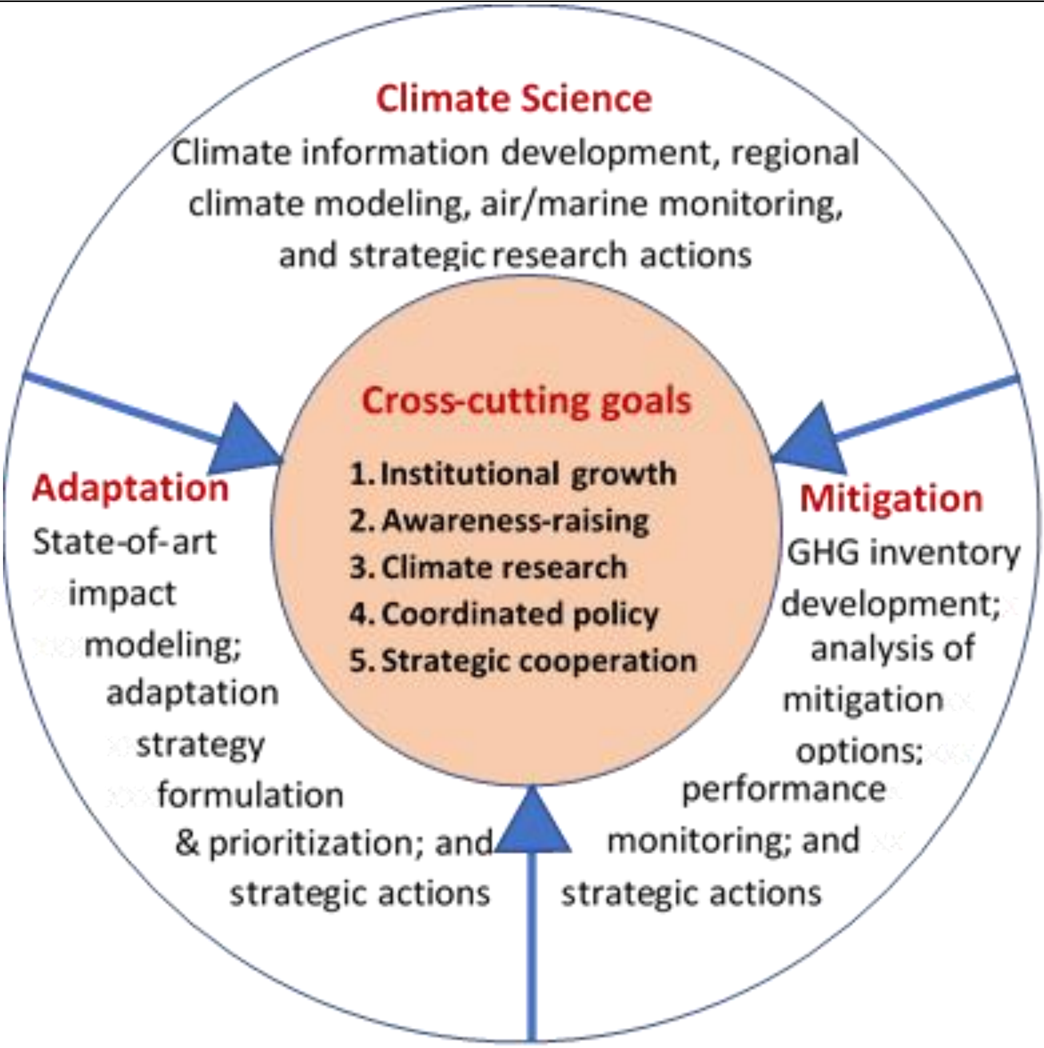


Figure ES-1: Themes and cross-cutting goals of Oman's Climate Change Strategy

SECTION I: INTRODUCTION

1. National Strategic Context

Land use

Oman's land area encompasses about 309,500 km^2 and is characterized by a diverse range of topography including mountain ranges, arid deserts, and fertile plains. Situated at the southeastern corner of the Arabian Peninsula, Oman's coastline varies from precipitous cliffs near the shore of Musandam in the far north to shallow sandy beaches in the Al Batinah governorate along the Sea of Oman and the Al Wusta and Dhofar governorates along the Arabian Sea.

Mountain ranges in the north and southwest occupy about 15% of the country. Coastal plains occupy about 3%, extending from the Al Batinah governorate to the Salalah Plain, and serve as important agricultural areas. Interior areas occupy the remaining 82% and consist of sandy, wasteland desert with elevations up to 500 meters above sea level.

Climate

Oman is an arid region, with several local-climates due to its large latitudinal extent and complex topography. Temperature is affected by major air masses that occur in the Arabian Peninsula, with the Polar Continental air mass in winter bringing cold temperatures and high pressure and the Tropical Continental air mass in summer bringing hot and very dry air. Average annual temperatures typically fluctuate between 10°C to 30°C.

Average summer rainfall during the months of June through September is between zero and 20 mm for most of the country. Average winter rainfall during the months of November through April is between 20 and 60 mm for northern parts of the country, and between zero and 20 mm for the rest.

Extreme weather events associated with tropical cyclones in the north Indian Ocean and the Arabian Sea afflict Oman from time to time. There have been destructive tropical depressions, tropical cyclonic storms and severe cyclonic storms that have tracked toward Oman over the past decades. Such storms typically occur during the pre-monsoonal period (May-June) and the post-monsoonal period (October-November).

Water resources

Oman is a water-stressed country, with less than 1,000 cubic meters in freshwater availability per person per year (UNEP, 2008). Keeping water supply and demand in equilibrium is a constant challenge. There are four main types of water resources, as described in the bullets below.

- *Groundwater* accounts for roughly 80% of water supply. Most is renewable in nature, being recharged annually by rainfall or through surface water infiltration. Non-renewable groundwater exists in the interior regions of Oman in the Al Najd, Al Masarat and Al Sharqia Sands (SoO, 2013).
- *Desalinated water* accounts for the next highest share of water supply, about 15%. Currently, there are nearly 100 desalination plants in Oman with roughly a 50-50 split regarding seawater or brackish water as the feedstock (SoO, 2013).

- *Surface water* accounts for about 6% of the total water supply. Annual average wadi flow is estimated at 211 million m3. While average rainfall is estimated at 9.5 billion m3 per year, about 80% of this precipitation evaporates (SoO, 2013).
- *Treated wastewater* accounts for the remaining 1% of the total water supply. In the Muscat Governorate, the current treatment capacity of 25 million cubic meters per year is projected to increase to 100 million cubic meters per year by 2030 (SoO, 2013).

Agriculture & fisheries

Agricultural production is wholly dependent on irrigation. The cultivated area under cultivation stood at about 74,000 feddan in 2016 (National Centre for Statistics Information, 2017). Most of the cultivated area is located in coastal areas, with the most intensely farmed areas located along a 320 km stretch in the Al Batinah coastal region northwest of Muscat, and a 100 km long stretch in Salalah coastal plain in the Dhofar governorate. Other major areas for agricultural production include the interior plains, oases, and the land adjacent to wadis (SoO, 2013).

Fisheries represent an important element of Oman's culture and economy. As one of the biggest fish producers in the region, fisheries are a significant national income resource after oil. A total of 991 fish species have been identified in Oman’s national waters of which about 50 species are of key importance to the traditional and commercial fishing sectors. In 2009, total landings from traditional fisheries were estimated to reach 158,000 tonnes with a value of US$ 268 million (SoO, 2013).

Population growth

Table 1 provides a summary of some key demographic indicators. Oman is a fast-growing country in terms of its population. Over the period 1993-2016, the population grew at a rate of 3.5% per year, with most of the growth-focused on urban areas. Much of the population is concentrated along the Sea of Oman coast in the Muscat and the Al-Bathina regions. Other major population centers include the regions of Ad Dharirah, Ad Dakhliyah, and Ash Sharqiyah in the Al Hajar Mountains. Most the remaining population resides in the Dhofar region near the southwestern part of the country.

Oman has a large and increasing percentage of its population between 15 and 64 years of age. Illiteracy has decreased substantially in recent decades, reaching 4% by 2016. The government currently spends roughly 6.3% of total annual expenditures on health care or roughly 182 Omani rials per person per year. All public health indicators show good trends in life expectancy, child mortality rate, and maternal mortality rate, consistent with rates in other GCC countries.

Table 1 : Major demographic indicators for Oman (source: National Statistics Report, 2016)

Indicator		1993	2003	2010	2016
Total Population	Thousand people	2,018,074	2,340,815	2,773,479	4,414,051
Per Capita Income	PPP, US$	12,671.54	16,895.39	25,438.71	41,320.00
Urban Population	% of total	71.7	71.5	75	78.1
Population by gender	Gender Ratio	140.2	127.8	138.8	189
Population less than 15 years old	%	41	33.8	27.8	21.9
Population between 15-64 years old	%	56.7	63.6	69.5	74.1
Population 65 and older	%	2.3	2.6	2.7	4
Illiteracy	% of total population	30.5	15.9	11.7	4
Total labor force	Thousand people	704,798	873,466	1,245,573	2,255,409
Employed Omanis, Public Sector	%	NA	62.6	53.3	83.89
Employed Omanis, Private Sector	%	NA	27.4	39.7	11.56

Economic trends

Oman has the fifth largest economy in the GCC region. In 2015, GDP reached 27.57 billion Omani rials compared to US$ 17.94 billion in the year 2006 (constant 2010 rials; Statistical Year Book, 2016). The average GDP annual growth rate over the period 2006 to 2015 was nearly 5%, ranging between -1.1% from 2010 to 2011 and a high of 9.3% from 2011 to 2012. Over this same period, gross national income per capita grew at an average rate of 3.6% per year, from 4,439 to 6,107 Omani rials (constant 2010 rials).

The structure of the Omani economy has changed significantly over the years. In 2000, the oil and gas sector represented the largest share of GDP at nearly 48%. By 2016, preliminary estimates from the Central Bank of Oman indicate that the oil and gas share had dropped by nearly half, to only 27.4% of GDP. During this period, the share of services and industry has exhibited notable increases, while the agriculture share of GDP has stayed relatively flat. These trends are summarized in Figure 3.

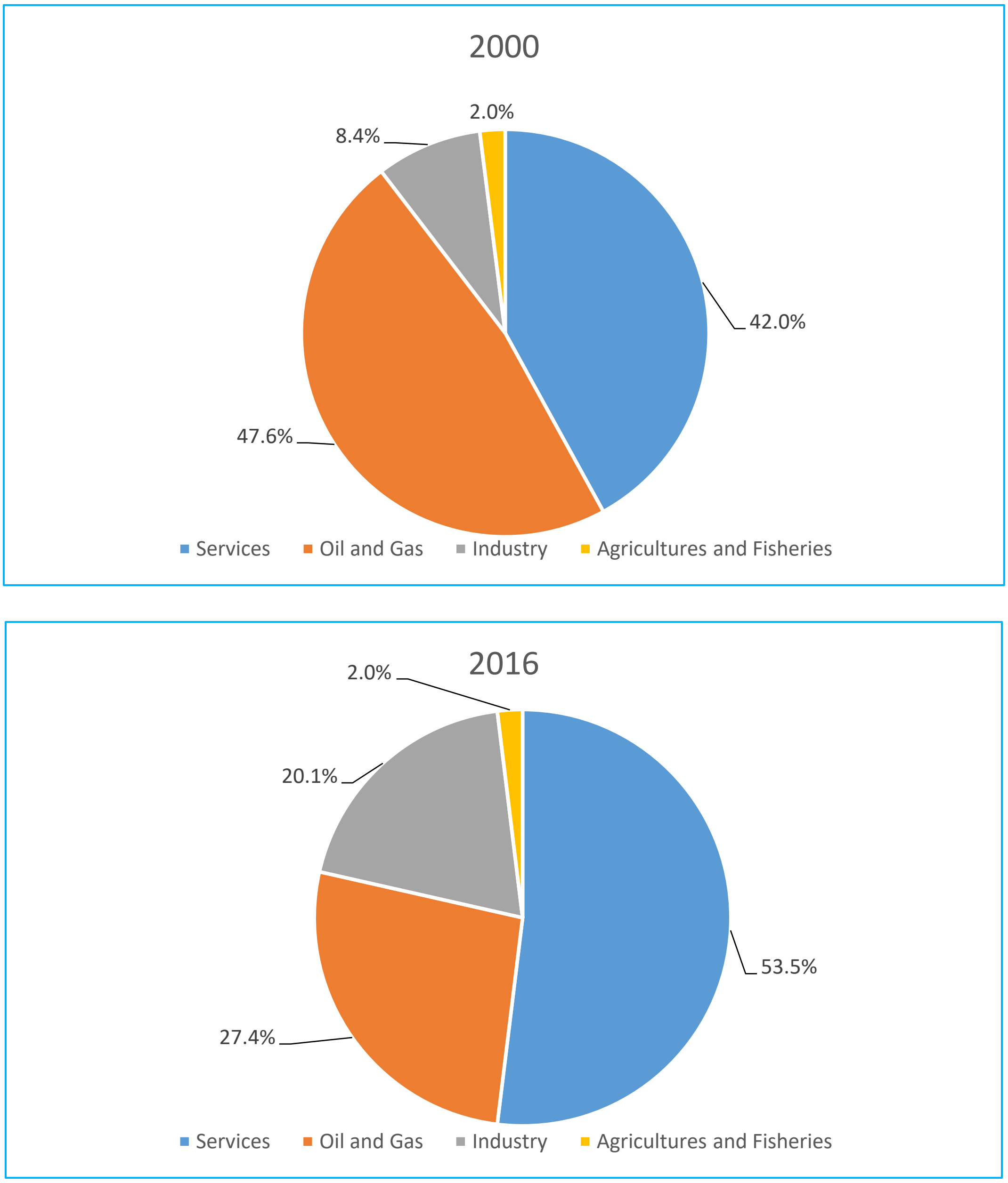


Figure 1: Sector share contributions to GDP in Oman in 2000 (upper) and 2016 (bottom) (Central Bank of Oman, 2016)

Energy supply & demand

Oman is a fossil fuel exporting country. In 2016, the nation exported 912,500 b/d of crude oil and condensate, its highest level since 1999 (EIA, 2017). Oman is a member of the Gas Exporting Countries Forum (GECF) and exports natural gas as LNG through its Oman LNG facilities near Sur, in the Sea of Oman. In 2016, the nation exported 358 Bcf of natural gas (EIA, 2017).

Electricity in Oman is primarily produced by the combustion of domestic natural gas. Electric generation increased rapidly between 2006 and 2016, from 13 TWh to 33 TWh, with electricity consumption over the same period growing at a similar pace, from 10 TWh to 30 TWh (EIA, 2017). Oman is a part of the Gulf Cooperation Council's (GCC) grid interconnection system, which allows for bulk power transfers between the six connected countries.

Regarding refined petroleum products, Oman consumed 186,000 b/d of petroleum and other liquids in 2016, most of which were petroleum products refined at Oman's refineries and a small amount that was imported (EIA, 2017). There are two refineries, Mina al Fahal (106,000 b/d) and Sohar (116,000 b/d), with plans underway to complete an upgrade to the Sohar facility in 2017 (EIA, 2017).

2. Purpose, Vision, and Objectives

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize GHG concentrations at a level that would prevent dangerous anthropogenic (human-induced) interference with climate change system. In 1997, the Kyoto Protocol implemented the objective of the UNFCCC to fight global warming by reducing GHG emissions.

In Paris in 2015, the global community came together as part of the 21st meeting of the Conference of the Parties to the United Nations Framework Convention on Climate Change in common cause to reduce greenhouse gas emissions that contribute to climate change and to intensify adapting to its adverse effects. The results of the meeting - keeping global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius - charts a new course in the global effort to confront climate change.

The Sultanate of Oman is a committed partner in this global effort. The nation has signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and also signed the Pairs Climate Accord on 22 April 2016. Oman has also submitted its Initial National Communications (with its Second National Communications to be submitted in the near future) as well as its Intended Nationally Determined Contributions (INDCs) report in accordance with decision 1/CP.19 of the Conference of the Parties.

This Strategy is a fundamental step that shows Oman is moving forward in the fulfillment of the aspirations of the Paris Agreement of COP-21. To achieve the vision outlined in the Strategy, collective action among stakeholders within Oman will be essential, as will partnerships with the international community to facilitate the flow of technical and financial resources for implementing the vision.

Undertaking action on climate change depends on an understanding of the strategic context for adaptation and mitigation activities. On the one hand, the country's need to build resilience to climate change is rooted in exposure to adverse impacts of climate change such as increasing temperatures, rising sea levels intensifying tropical cyclones.

Understanding land use, climate, water resources, and agriculture/fisheries is essential context for identifying, designing and implementing preparedness/response measures to reduce the vulnerability of communities, resources, and systems.

On the other hand, the strategic context for mitigation is rooted in the recognition of the need to control a trend of greenhouse gas emissions growth. To slow the growth in national greenhouse gas emissions, it needs to review the population growth, encourage low carbon economy and technology, and implement cost-effective efficiency and renewable energy projects.

Purpose

Oman understands that local action against climate change must now be a national development priority that should be coordinated across government agencies, the private sector, and civil society. Hence, the purpose of this National Climate Change Strategy is to outline Oman's long-term vision on climate change. It seeks to inform future policy dialogues by laying out clear strategic actions on adaptation and mitigation. When implemented, the strategy will put Oman on a path to low-emission, climate-resilient growth that promotes job creation for its population, climate risk management for the most vulnerable, and sustainable management of its precious natural resources.

Vision

The vision underlying the Climate Change Strategy is comprised of three major themes, as briefly described in the bullets below and illustrated in Figure 1.

- Climate science: This focuses on an assessment of historical climatic trends for Oman and projections of future climate change relative to a set of Representative Concentration Pathways.
- Vulnerability and adaptation: This focuses on the vulnerability of five key sectors to climate change forms the basis for a set of strategic adaptation actions in each sector. These sectors are water resources; marine biodiversity and fisheries; agriculture, urban areas, tourism & infrastructure; and public health.
- Greenhouse gas mitigation: This focuses on the identification of five key areas in which specific strategies contribute to a low-emission development trajectory. These areas are energy supply, energy demand, research and development, labor, and the water-food-energy nexus.

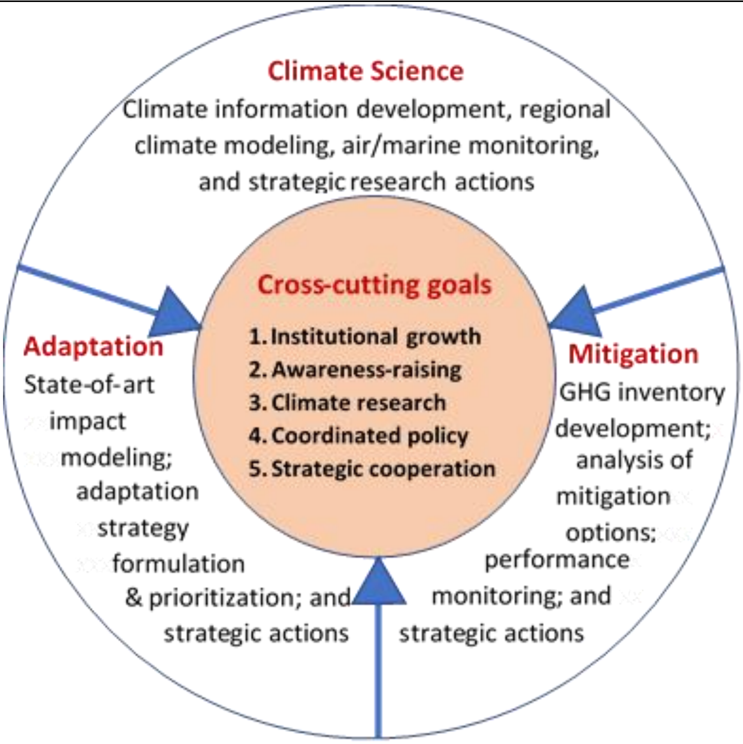


Figure 2: Themes and cross-cutting goals of Oman's Climate Change Strategy

Goal and objectives

The primary goal of this National Climate Change Strategy is to identify the strategic actions necessary to transition Oman to a low-emission, climate-resilient development trajectory. This involves addressing the adverse impacts across all vulnerable sectors due to climate change, as well as addressing the priority measures for reducing the growth in future GHG emissions.

There are five (5) major objectives underlying the Strategy, as outlined in the bullets below. These are cross-cutting goals that apply to all strategic actions and represent both the short- and long-term vision for climate change policy.

- *Institutional growth:* Build institutional capacity for addressing the climate change challenge and enhance the effectiveness of inter-ministerial coordination and cooperation;
- *Awareness-raising:* Promote a culture of action in combating climate change across all relevant public and private sector stakeholder groups;
- *Climate research:* Design and undertake a systematic programme of climate research that builds and improves access to data and information for climate science, vulnerability & adaptation, and mitigation;
- *Coordinated policy:* Ensure that sector-specific policies are developed within an integrated management approach that reduce risks of maladaptive action; and
- *Strategic cooperation:* Develop national and international networks to identify and promote strategic research and cooperation opportunities.

3. Elaboration Process

The process for the development of the strategy consisted of three major activities over a 3-year period:

- First, scientific research was carried out to better understand Oman's future climatic conditions, climate change risks and adaptation opportunities.
- Second, scoping studies were undertaken to identify cost-effective technologies and practices to achieve ambitious GHG emission reductions.
- Third, extensive stakeholder consultations in the form of a set of workshops were convened to establish strategic actions that enjoyed broad consensus across public/private sector entities in response to the research and scoping studies.

The Ministry of Environment and Climate Affairs (MECA) led the preparation of this climate change strategy. The ministry was established on 9 September 2007 by Royal Decree No. (90/2007). It is responsible for raising awareness about climate change among all segments of the population, as well as promoting overall environmental protection activities through the promulgation of laws and regulations.

Financial support has been provided by MECA. Technical and scientific inputs that inform this Strategy document have been developed in large part by senior researchers at Sultan Qaboos University as well as some contributions from other related national stakeholders under the oversight of MECA. Moreover, technical and capacity building support has been provided by the United Nations Environment Programme (UNEP).

The Strategy presents the state of the art concerning an understanding of the vulnerability of key sectors and systems in Oman, and the latest developments regarding viable GHG mitigation opportunities. All sources used to develop the Strategy are referenced throughout the document.

4. Implementation Modalities

The implementation of the Strategy will require concerted institutional action at multiple administrative levels and across multiple stakeholder groups. The Strategy is intended to be the country's primary policy statement guiding national climate change discussions, both in the short- and long-term. It is important to note that the Strategy is a high-level treatment of a national response to the challenge of climate change.

Regarding general implementation principals, going forward, it will be important to design implementation modalities consistent with three objectives:

- First, there should be detailed action plans to each sector to implement the strategy.
- Second, flexible processes should be developed in order to modify/update strategic actions in response to any new and emerging scientific findings.
- Third, regulatory systems should be examined and revised as needed to address and remove barriers.

For all of these objectives, it will be desirable to closely partner with the international community on the implementation of capacity building initiatives regarding scientific research, policy analysis, and the adoption of effective monitoring and verification protocols.

Climate Law

The Strategy approaches climate change as a cross-cutting development challenge. Based on the sultanate national circumstances and in accordance with Oman commitments under UNFCCC, Kyoto protocol and Paris agreement on climate change and in the absence of any climate change law in the country , it is important to develop climate change law in the country based on main elements such as adaptation and mitigation national policies, research and studies, monitoring/verification issues, climate change information and awareness and market mechanisms, taking into consideration coordination with multiple stakeholders across government institutions, civil society, and the private sector .

Market-based instruments

Market-based instruments are indirect regulatory instruments, which impact the way producers and consumers view their economic incentives. To achieve GHG mitigation goals, market-based instruments include, for example, carbon taxes, emissions trading, and removal of perverse incentives/subsides. To achieve adaptation goals, there is growing interest in instruments such as catastrophe bonds and realigned insurance pools. To date, there has not been any experience in Oman with the use of such instruments to reduce GHG emissions or increase resilience.

Climate change awareness

Building awareness about the threat of climate change is vital in order to enable Omani society and institutions to recognize its significance in everyday decisions. Such decisions range from household choice to purchase an energy-efficient appliance; to power sector planning regarding the amount of demand side management to include in capacity expansion plans; to government regulations and standards for real estate development in high risk coastal areas. Building awareness in Oman regarding climate change will involve several activities, including:

- Encouragement of efforts to reduce household- and agency-level GHG emissions through conserving energy and more efficient use of resources;
- Development of booklets and programmes concentrating on the important role of families and schools for reducing emissions;
- Use of social media to communicate climate change information and alerts to Omani society in real time; and
- Promoting social participation in climate change related information events such as public meetings and open forums.

Monitoring and verification issues

Protocols for Measurement, Reporting, and Verification (MRV) together with Monitoring and Evaluation (M&E) will need to be developed to ensure proper tracking of the impact of implementing mitigation and adaptation strategic actions called for in the Strategy. These protocols will serve to build a transparent and comparable framework for documenting the success - or failure - of interventions, as well as pointing to specific areas that require changes in design or implementation modalities.

Institutional arrangements

Currently, General Directorate is the primary entity that is responsible for administrative and regulatory action in response to national and international requirements regarding climate change. In recent years, the Directorate has prioritized national capacity building in adapting to climate change by supporting programs to monitor and limit the adverse impacts of climate change among vital sectors.

Legal frameworks for enabling the implementation of the strategy require the institutional strengthening and regulatory enforcement, significant steps were taken in this direction:

- *Update of the organizational structure for implementing Oman's climate change strategy*

In 2016, the structure of the Directorate General for Climate Affairs has been updated as indicated in Figure 3. The updated organizational structure introduce specialized programs to track GHG emissions, increase energy efficiency, support the integration of renewable energy into the energy mix, conducting research on regional climate modeling, mitigation, and adaptation and monitor the implementation of the ozone layer protection programs in the concerned sectors

- *Update of the Climate Affairs Management Regulation*

In 2016, the Ministry of Environment and Climate affairs updated the climate affairs management regulation by the Ministerial Decision number 20/2016.

The updated Climate Affairs management regulation targeted the biggest stationary sources of GHG emission in the country. A technical guideline and calculation tools for reporting and measuring GHG emission according to Scope 1, 2 and 3 was designed in order to harmonize GHG emission reporting.

Under the new regulation, the facilities and companies are also required to provide information on current and future risks to changing climate and to develop a proactive approach to enhance adaptation and resilience. A detailed guideline was developed to assist facilities and companies to report their exposure to the risks of climate change.

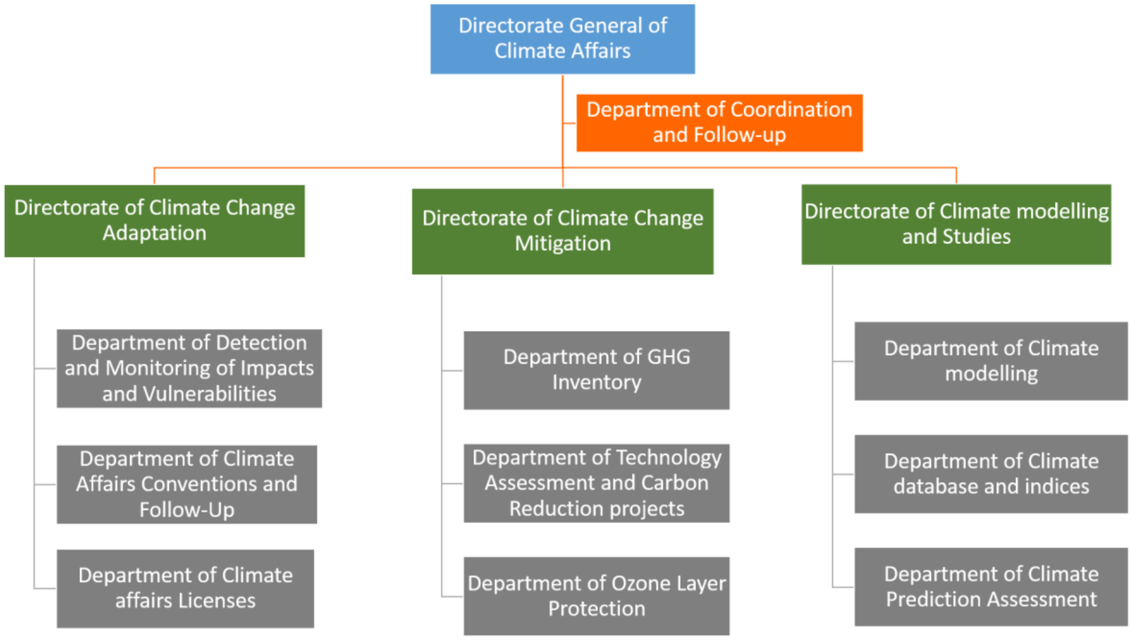


Figure 3: Organizational structure for implementing Oman's climate change strategy

SECTION II: CLIMATE SCIENCE

In its Fifth Assessment Report (AR5), the Intergovernmental Panel on Climate Change (IPCC) concluded unequivocally that human activity is the dominant cause of observed warming in the climate system. Many of the recent observed changes are unprecedented, having occurred over decades instead of millennia. Signs of a changing climate are overwhelming, evidenced by retreating glaciers, rising sea levels, more frequent extreme storm events, and warming of the atmosphere and the oceans. Each of the last three decades has been successively warmer than any preceding decade since 1850. In Oman, a strategy is needed to ensure that government agencies are able to monitor, analyze, and effectively respond to these unfolding developments.

The Climate Science theme of the Oman Climate Change strategy focuses on the use of state-of-the-art methods and tools to establish historical climatic trends and to better understand future climate change in Oman under various plausible scenarios of global greenhouse gas emissions. The rest of this section provides a review of the current understanding of how climate change will unfold in Oman, together with a set of strategic actions to build the knowledge base regarding future climatic change.

1. Recent climatic trends

Oman's climate has clearly changed during the past three decades (Charabi, et al., 2015). This is consistent with recent studies for the Arabian Peninsula and vicinity (Almazroui et al., 2012; Athar, 2012; AlSarmi and Washington, 2013; Donat et al., 2013; Hartmann et al., 2013; Zarenistanak et al., 2014). Over the period 1980 - 2013, meteorological stations throughout Oman showed evidence of a clear warming trend, with the highest trends around Khasab, Sohar, Saiq, Seeb and Sur and northwards; and the weakest warming trends along the southeastern coast. On average, annual temperatures have increased in Oman by around 0.4°C per decade (see Table 2). This increase shows a large variation across the country, ranging from 0.2°C per decade around Masirah to about 1.1°C per decade around the Sur region.

There is also clear evidence that extreme temperatures in Oman – both maximums and minimums - have been increasing over the past decades. Figure 4a shows the change in mean maximum temperature range from -0.6°C per decade around Sohar to about 1.2°C per decade around Khasab. Figure 4b shows the change in minimum annual temperatures ranges from 0.2°C per decade around Saiq to about 1.7°C per decade around Sur. On average, mean minimum temperatures have increased by around 0.5°C per decade across all areas of Oman. Other notable trends include the increase of nighttime temperature extremes which have been evident across the country, while the increases of daytime temperature extremes more evident in the north. Rainfall patterns over the past three decades has also been changing. However, unlike temperature, trends are far less robust. There is a high change in rainfall from year to year, with Saiq showing high fluctuations during the 1980s and 1990s. Overall, rainfall has been decreasing during the 1980-2013 period.

Table 2: Stations and regional annual mean temperature trends for the period 1980-2013 (Al Maskari et al, 2015)

Station/Area	Trend/Year	per/decade
Khasab	0.05	0.5
Sohar	0.05	0.5
Saiq	0.03	0.3
Sur	0.11	1.1
Masirah	0.02	0.2
Thumrait	0.02	0.2
Salalah	0.01	0.1
ALL Oman	0.04	0.4
Non MONSOON	0.06	0.6
MONSOON	0.016	0.2

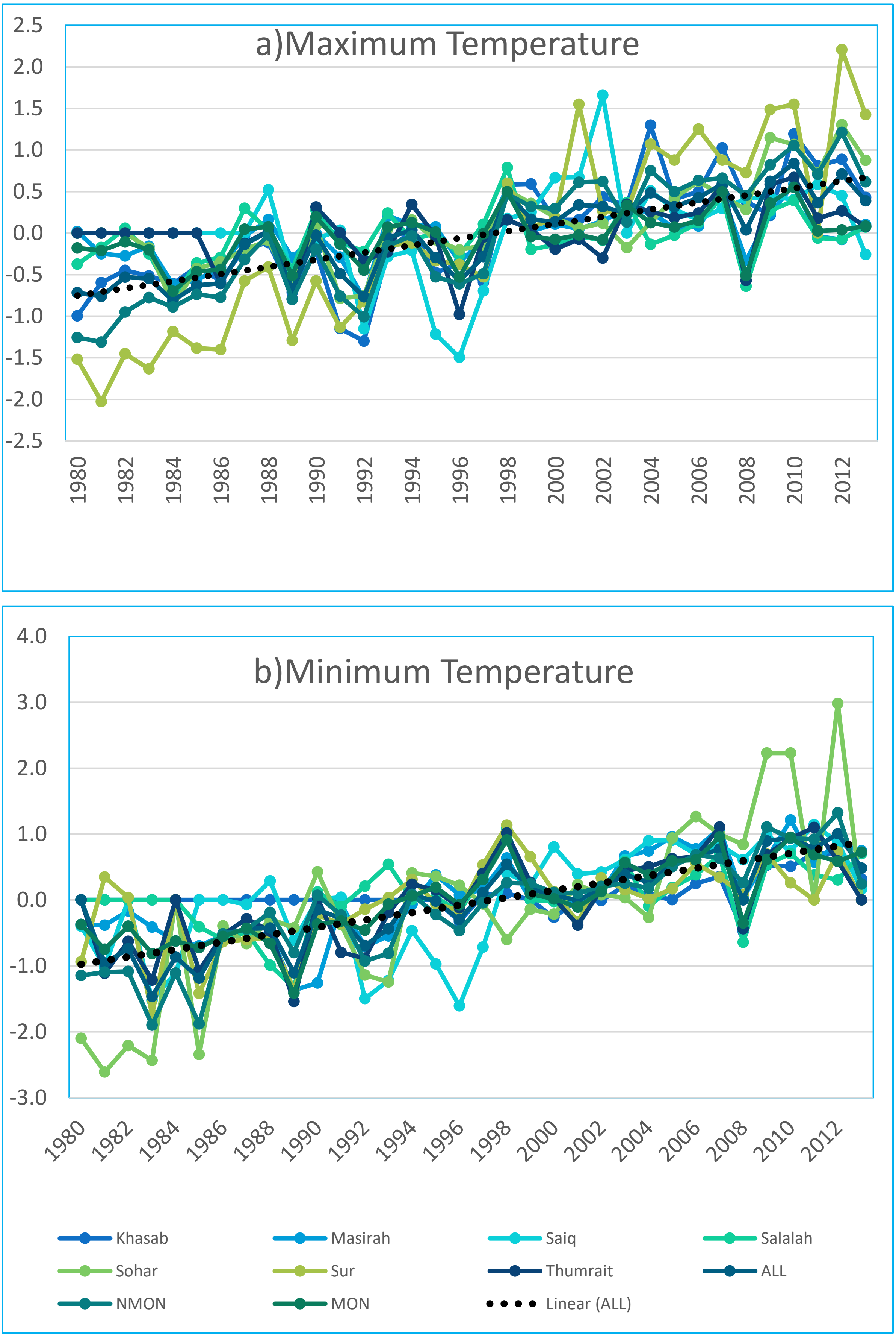


Figure 4: Temperature trends in Oman (AL Maskari et Al, 2015)

2. Future climatic projections

Representative Concentration Pathways, or RCPs, are greenhouse gas (GHG) concentration pathways used by the IPCC as a basis by which to explore future climatic projections. RCPs are GHG concentration - as opposed to emission - trajectories the IPCC used in its 5th Assessment Report and supersede the previous GHG storylines (e.g., A1, B1). RCP8.5 can be considered analogous to a business-as-usual scenario. RCP2.6 assumes stabilization of GHG emission concentration in the atmosphere by 2100.

Four RCPs were considered to explore future climate in Oman: RCP8.5, RCP6, RCP4.5, and RCP2.6. Figure 5 shows global GHG concentrations for each of the RCPs, and identifies the two periods – 2041-2060 and 2061-2080 that were considered to assess Oman's future climate under each RCP. The period 1950-2000 was assumed to be the historical climatic period.

At the methodological level, Oman's future climate was projected by statistical downscaling and interpolating the coarse resolution HadGEM2 general circulation model to a finer resolution. Bias correction techniques were applied to ensure that the model closely matched historical climatic conditions in Oman. Further details of the methodological approach are available in Al Maskari, et al (2015).

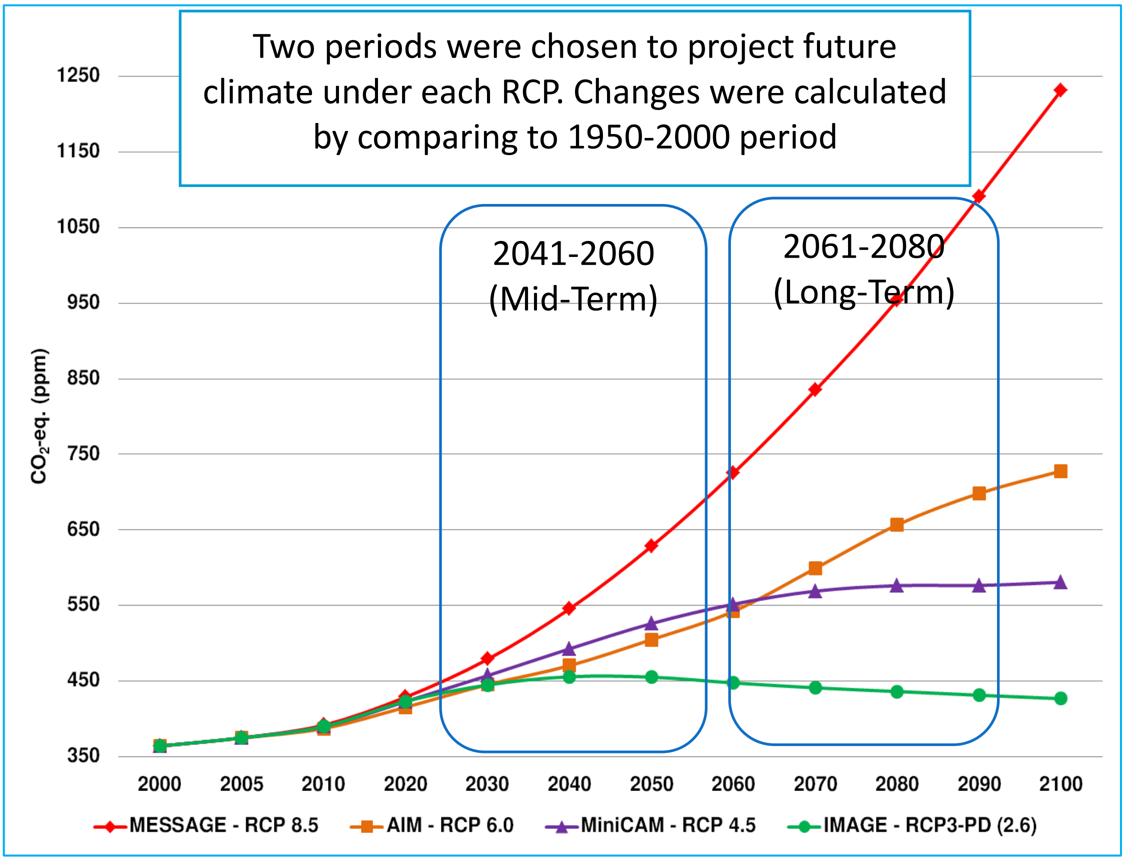


Figure 5: Assessment framework to project Oman's future climate (Al Maskari et al, 2015)

Figure 6 illustrates the change in maximum annual temperature by the middle of the 21st century relative to the historical period for each of the RCPs. As can be seen in these maps, Oman's future climate will be considerably different that its historical climate. By the middle of the 21st Century, maximum annual temperatures will have increased substantially regardless of RCP.

In the best case (RCP 2.6), maximum temperatures are expected to rise by at least 2°C along southern coastal areas. In the worst case (RCP 8.5), maximum temperatures are expected to reach 4°C above historical levels in the interior and north, including Musandam.

The least change in projected maximum temperature across all scenarios corresponds to the east and southeastern coast. The maps also show that maximum temperature increases from the coastal (i.e., eastern) areas to the inland (i.e., western) areas over the country across all RCPs.

Figure 7 illustrates the change in maximum annual temperature between the middle and end of the 21st century for each of the RCPs. By the late-21st Century, maximum annual temperatures will have continued to change substantially. In the worst case (RCP 8.5), maximum temperatures are expected to further increase by 1.0°C over mid-21st Century levels, and reaching 5.0°C above historical levels. These increases are projected for all inland areas of Oman, as well as some of its coastal areas in the northern parts of the Sea of Oman and western parts of the Arabian Sea.. Notably, in the best case (RCP 2.6), maximum temperatures are not expected to increase further by the late 21st century in most areas of the country. In fact, some areas in the Al Hajar mountains in the far north and near Ramlat Amilhayt in the west are projected to experience temperature decreases by up to 0.5°C.

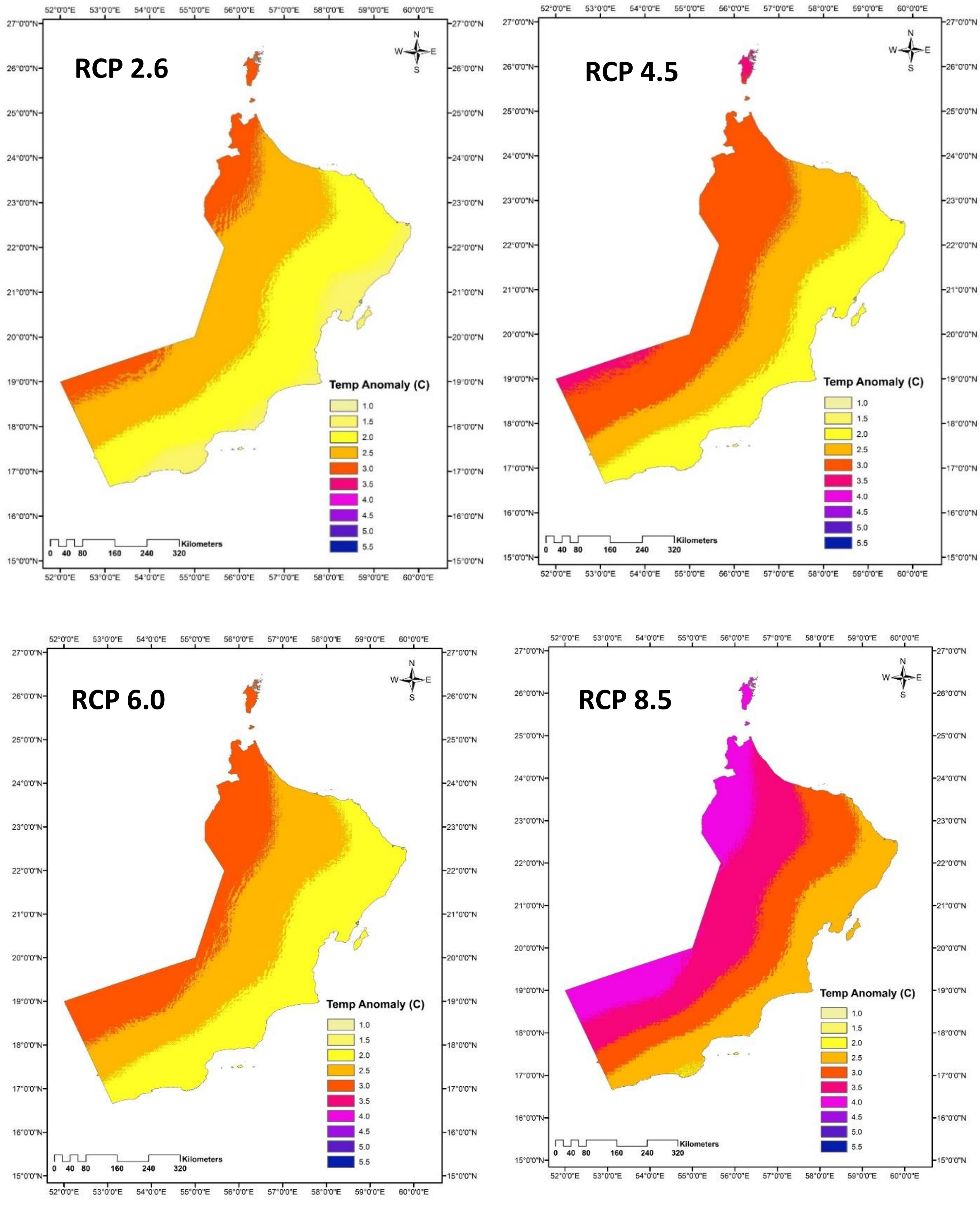


Figure 6: Maximum temperature change by 2041-2060 relative to historical period, for all RCPs (Al Maskari et al, 2015)

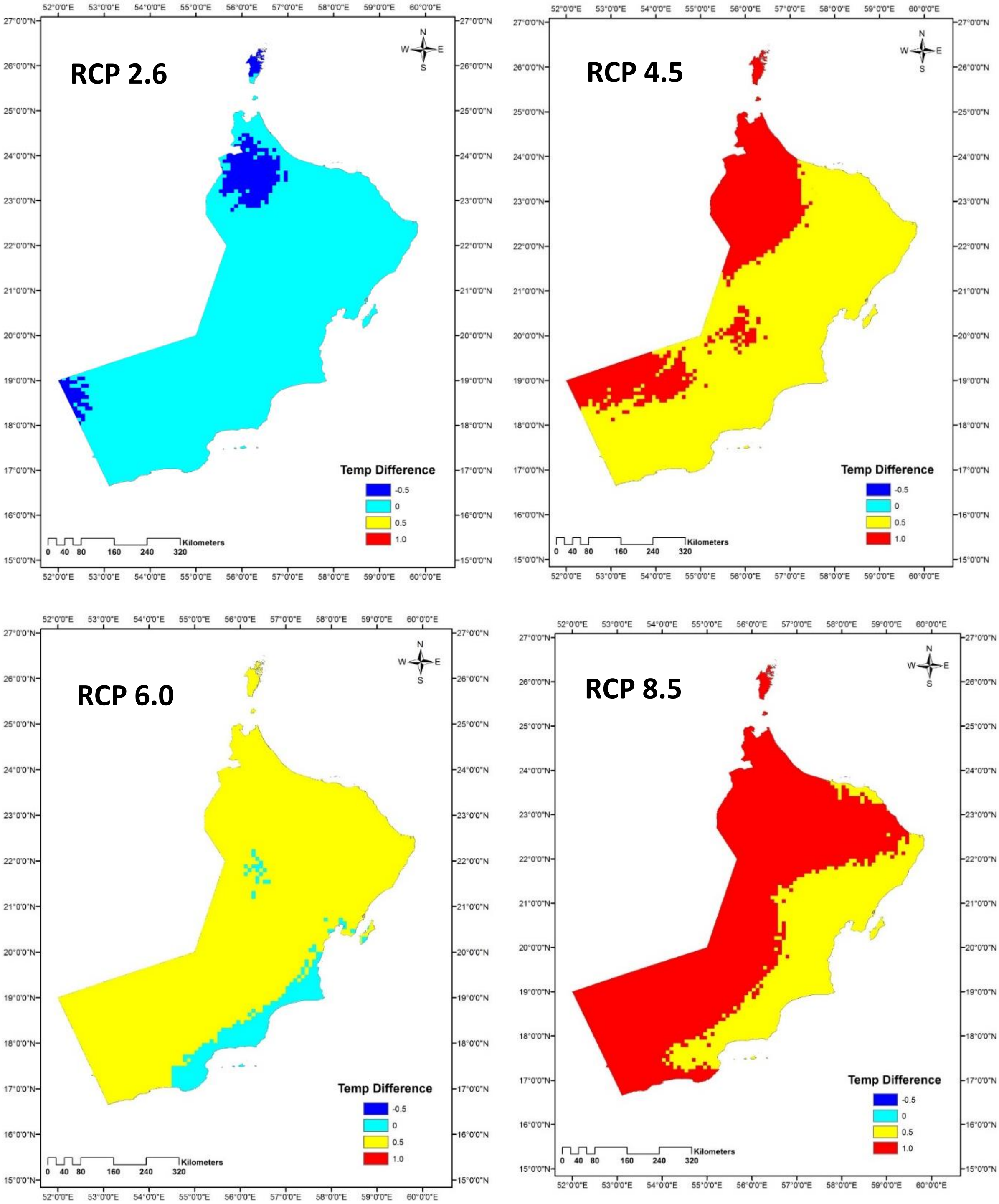


Figure 7: Maximum temperature change by 2061-2080 relative to the 2041-2060 period, for all RCPs (Al Maskari et al, 2015)

Figure 8 illustrates the change in minimum annual temperature by the middle of the 21st century relative to the historical period for each of the RCPs. By mid-21st Century, minimum annual temperatures will have increased substantially regardless of RCP. In the best case (RCP 2.6), minimum temperatures are expected to rise by at least 2°C along all southern coastal areas along the Arabian Sea, as well as the southern limits of the Sea of Oman. In the worst case (RCP 8.5), minimum temperatures are expected to reach 4.5°C above historical levels in the interior and far north in Musandam. It is important to note that all coastal areas in Oman are projected to experience an increase in minimum temperatures of at least 2.5°C.

Figure 9 illustrates the change in minimum annual temperature between the middle and end of the 21st century for each of the RCPs. By the late-21st Century, minimum annual temperatures are projected to change substantially. In the worst case (RCP 8.5), minimum temperatures are projected to increase by 1.5°C above mid-21st Century levels -or a total of 5.5°C above historical levels - in the far northern areas of the Al Hajar mountains. Most of the rest of Oman will experience an additional increase in minimum temperatures between 0.5°C and 1.0°C above mid-21st Century levels.

In the best case (RCP 2.6), minimum temperatures are expected to decrease from the middle to the late portions of the 21st century for most areas of the country. In fact, some areas in the interior part of the country are projected to experience decreases in minimum temperature by up to 1.5°C.

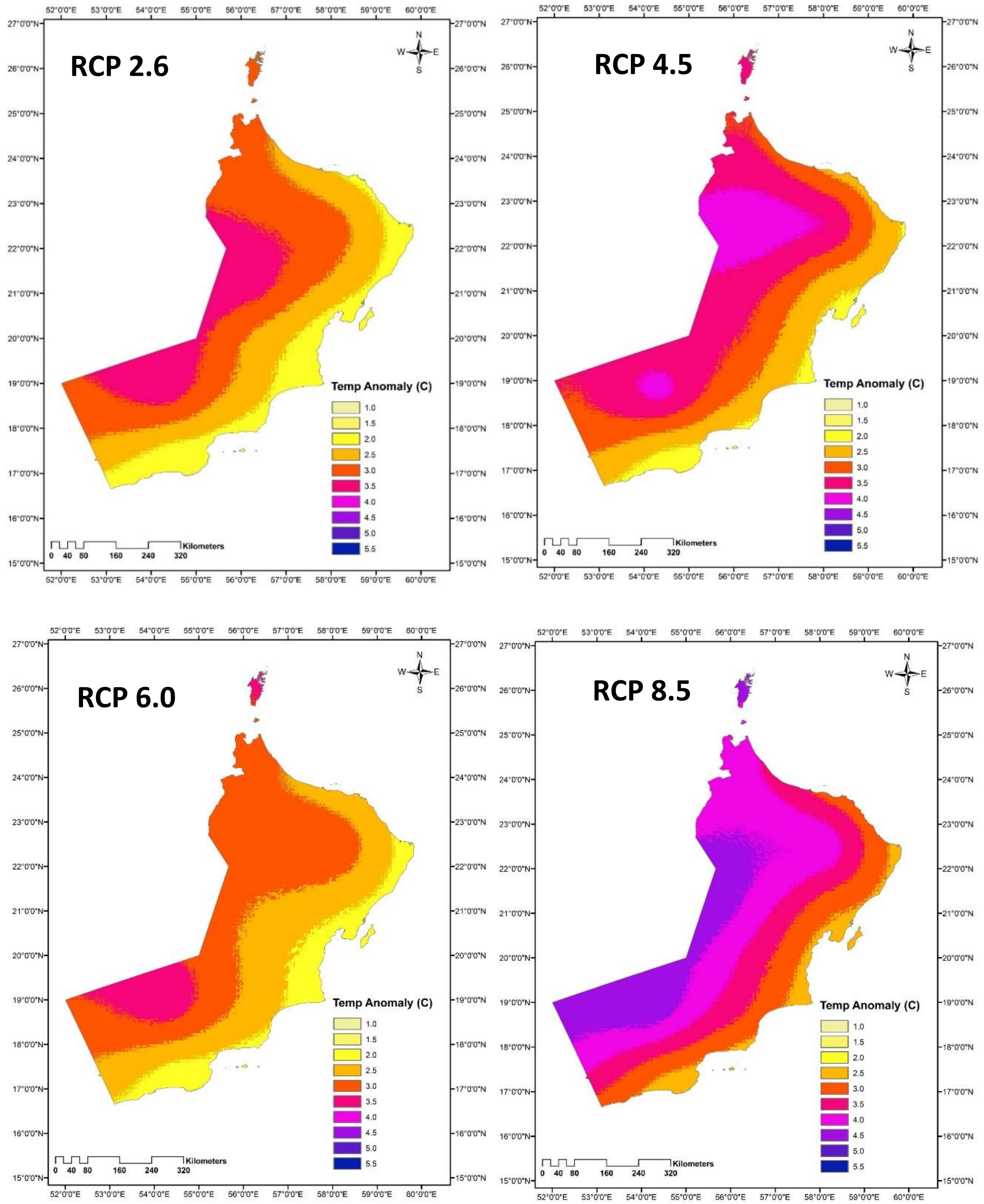


Figure 8: Minimum temperature change by 2041-2060 relative to historical period, for all RCPs (AL Maskari et al, 2015)

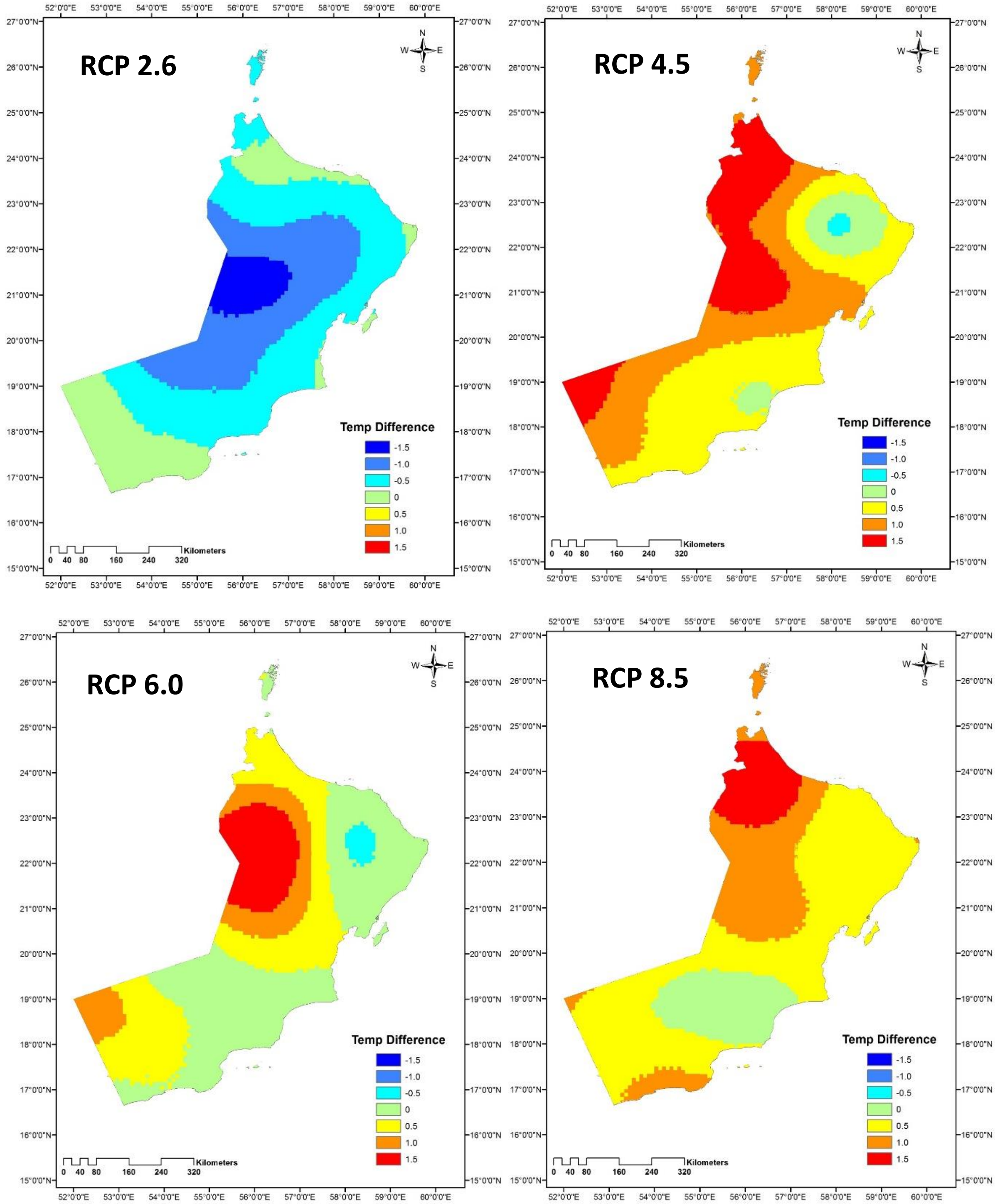


Figure 9: Minimum temperature change by 2061-2080 relative to the 2041-2060 period, for all RCPs (AL MAskari et al, 2015)

Unlike projected temperature changes, the change in annual average rainfall shows mixed results under climate change. Figure 10 illustrates the change in average annual rainfall by the middle of the 21st century relative to the historical period for each of the RCPs. In the best case (RCP 2.6), the change in average annual rainfall is expected to be between zero and 10 mm/year more in most areas. In the worst case (RCP 8.5), average annual rainfall decreases by up to 10 mm/year in most areas, with only the areas in the vicinity of the southwestern and eastern coastlines showing a change in the range from zero to an additional 10 mm/year.

Figure 11 illustrates the change in average annual rainfall between the middle and end of the 21st century for each of the RCPs. By the late-21st Century, average annual rainfall will have changed substantially across Oman. In the best case (RCP 2.6), average annual rainfall is expected to further decrease by up to an additional 10 mm/year in interior areas south of the Al Hajar mountains. Only in the Al Hajar mountains does average annual rainfall either remain the same as mid-21st century levels or slightly increase. In the worst case (RCP 8.5), average annual rainfall decreases in most areas by up to an additional 10 mm/year below mid-21st Century levels. Only in portions of the Dhofar Governorate does average annual rainfall either remain the same as mid-21st century levels or slightly increase.

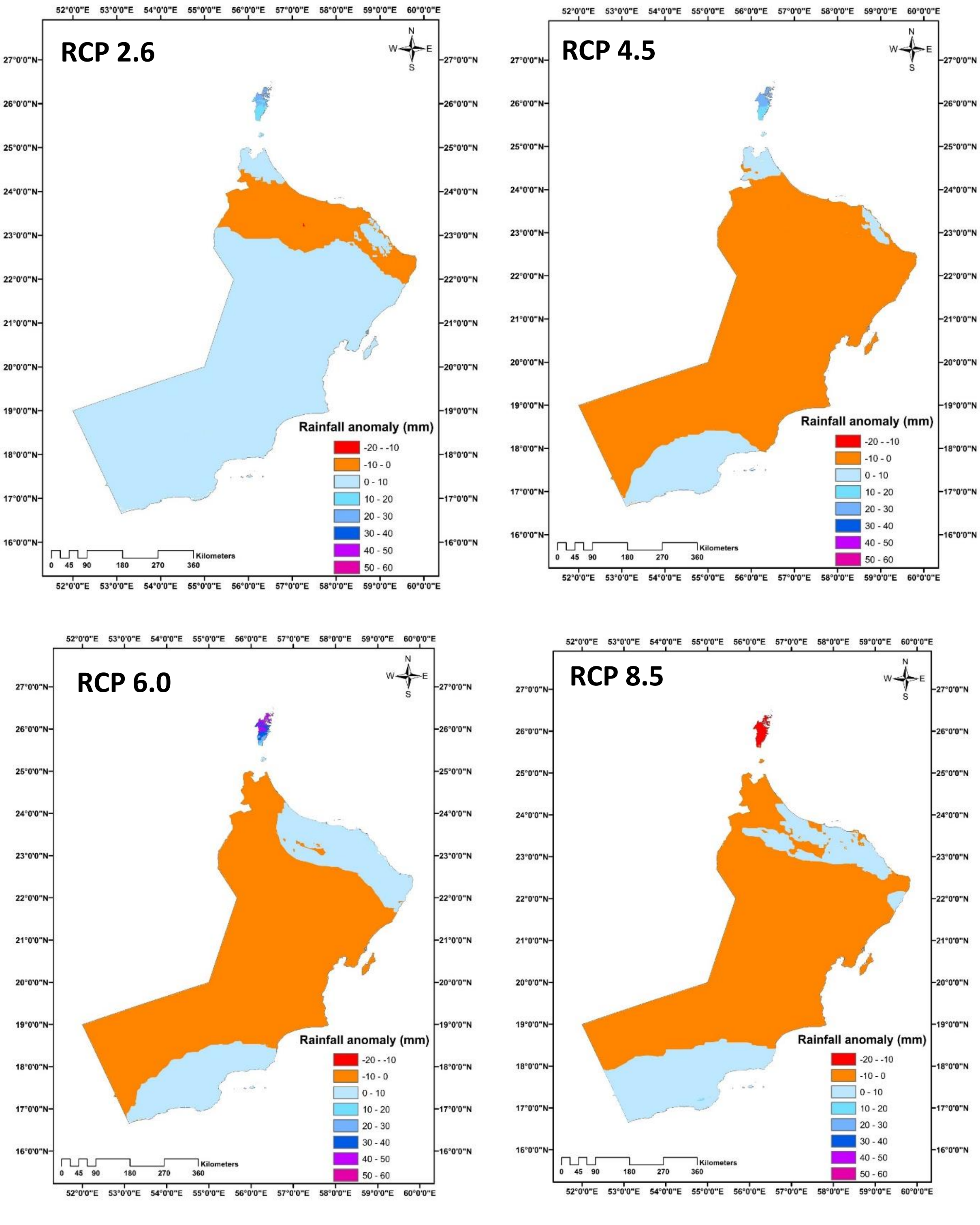


Figure 10: Average annual rainfall change by 2041-2060 relative to historical period, for all RCPs (AL Maskari et al, 2015)

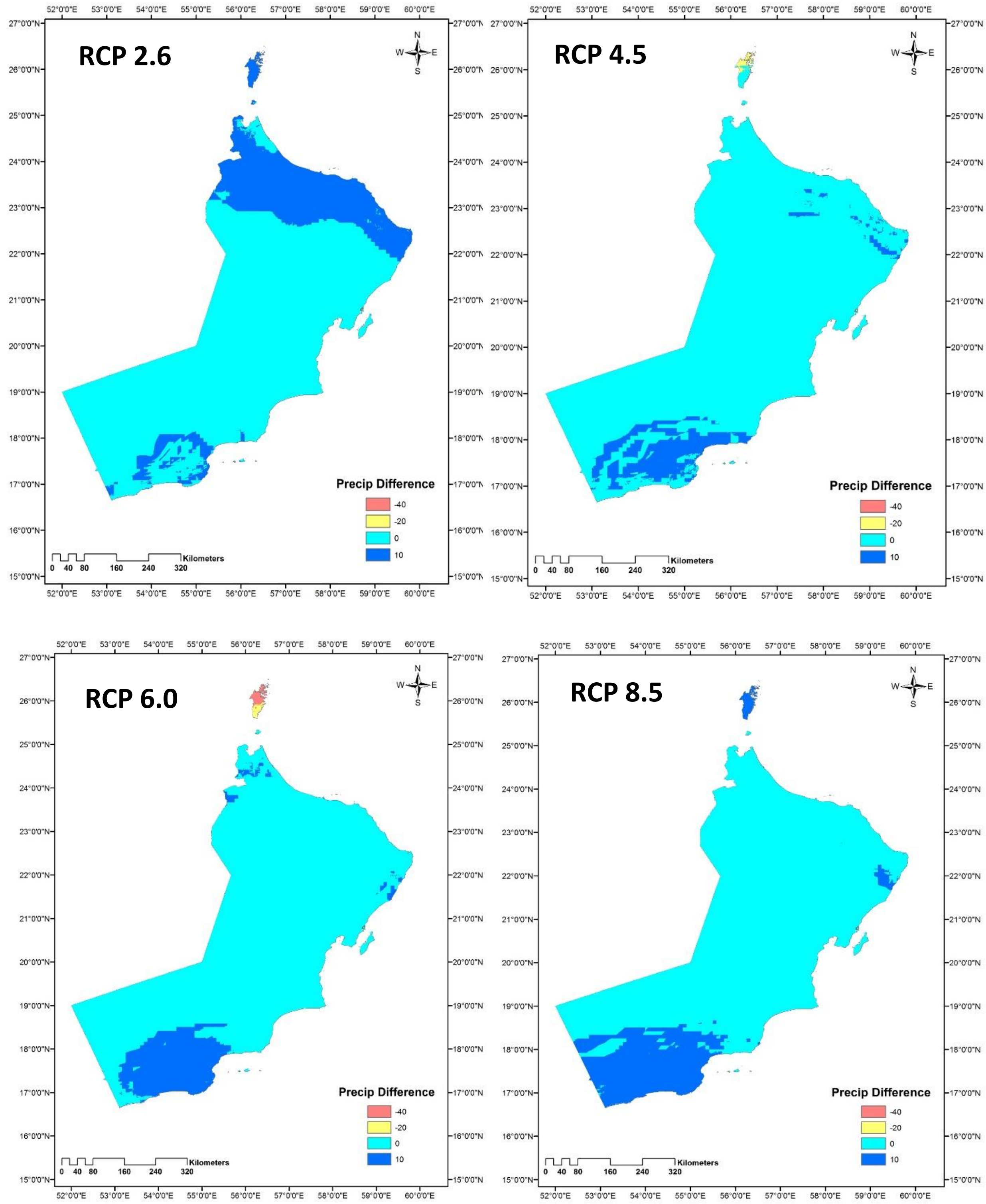


Figure 11: Average annual rainfall change by 2061-2080 relative to the 2041-2060 period, for all RCPs (Al Maskari et al, 2015)

3. Strategic actions

Effective adaptive responses in Oman will need to rely on sound knowledge of anticipated changes. Therefore, a high priority for research must be the generation of reliable projections of likely climatic changes spatially (i.e., at the regional level) and temporally (i.e., accounting for seasonal differences). The results point to several promising areas of future research building off the datasets generated by the study. There are four (4) distinct streams of initiatives that encompass the Climate Science (CS) stream of strategic actions, as outlined below.

Stream CS-1: Awareness-raising

This involves building awareness and improving access to information by:

a) ensuring effective communication of climate change information as well as industry-specific and region-specific information;

b) developing awareness-raising program on climate change; and

c) providing easy access to complete information on climate change risks, hazards, guidance to adaptation for private sector, and the public at large.

Stream CS-2: Data development

This involves strengthening climate data development and monitoring by:

a) maintaining effective climate data collection, distribution and analysis systems to link into ongoing evaluation and adaptation;

b) developing climate projections that can be downscaled to be relevant to farm, catchment and coastal scales; and

c) accessing bilateral/international funding.

Stream CS-3: Research capacity

This involves strengthening the research and development base (i.e., people, skills, institutions) to enable ongoing evaluation of climate change impacts and to streamline R&D responses regarding new adaptation responses or climate change scenarios by Conduct additional scientific studies regarding:

a) the costs and benefits of adaptation to climate risks;

b) the development of a streamlined database of adaptation options implemented at different spatial and temporal scales;

c) interactions across adaptation and mitigation activities;

d) critical thresholds beyond which social and/or ecological systems are unable to adapt to climate change;

e) adaptation to extreme events such as droughts, floods, intense storms, and heat waves; and

f) Enhance climate modeling and studies department in MECA to conduct scientific research, develop and fund capacity building programmes; and identify training and education requirements.

Stream CS-4: Capacity building

This involves strengthening capacity building of the staff in the General Directorate of Climate Affairs, specifically in the following areas:

a) Long term training programme strategy on climate modeling;

b) Develop cooperation for climate modeling training programme with international organizations;

c) Develop framework for continuous improvement of the existing computational capacity and software infrastructure.

d) Integrate capacity on development and use of Geographical information techniques within the General Directorate of Climate Affairs.

SECTION III: VULNERABILITY, RISKS & ADAPTATION

The IPCC defines vulnerability in terms of susceptibility and as a “function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (Burkett, et al., 2014). Absent effective adaptation, climate change impacts could undo past development achievements; lead to human and environmental insecurity; and lead to negative synergies.

Coping with risks of climate change will involve a portfolio of adaptation initiatives. The IPCC concluded that (1) neither adaptation nor mitigation alone can avoid all climate change impacts; (2) adaptation is necessary in the short and longer term to address impacts, even for the lowest stabilization scenarios assessed; (3) unmitigated climate change would likely exceed the adaptive capacity of natural, managed, and human systems in the long term; and (4) delayed emission reductions diminish prospects for reducing severe climate change impacts (IPCC, 2007).

The Vulnerability & Adaptation theme of the Climate Change strategy focuses on five key sectors: water resources; marine biodiversity and fisheries; agriculture, urban areas, tourism & infrastructure; and public health. The rest of this section provides a review of the magnitude of vulnerability in these sectors together with a set of strategic adaptation actions in each sector.

1. Water resources

Introduction

Due to climate change, Oman will likely experience adverse impacts to its precious water resources, both surface water and groundwater. The frequency of destructive flash flooding is already evidenced by an increased frequency of extreme wadi flows while future sea level rise is projected to impose serious adverse impacts on groundwater quality in some of Oman’s most important aquifers.

Objective and goals

The impacts of climate change on water resources and their management are mainly due to the observed and projected increases in sea level, temperature, and precipitation variability/extremes (Bates et al. 2008; Jiménez Cisneros, 2014). Climate change also poses indirect impacts on groundwater supplies as higher evaporation and transpiration rates will lead to increased water demand for irrigation of crops.

Hence, the key objective of the water resource vulnerability and adaptation assessment is to better understand the vulnerability of surface and groundwater to climate change. The key goals are to:

a) Update existing water resource strategies to cope with future climate change impacts,

b) identify clear links to development priorities, groundwater extraction protocols, monitoring systems, crop choice, etc and

c) establish a priority list of strategic actions.

Vulnerability and risk context

Surface water

Oman is an arid and semi-arid country. Conditions of chronic water stress, catastrophic flooding and prolonged drought prevail, making the country particularly vulnerable to the impacts of extreme climate events. Recent experience with Cyclone Gonu in 2007 emphasized the destructiveness of extreme weather in Oman. The cyclone caused 50 deaths and about $4.2 billion in damage due to heavy rainfall near the eastern coastline.

Over 2000-2014, meteorological stations in Oman showed evidence of a clear change in the intensity of extreme rainfall events, with the highest positive change in 1-hour events around Adam, Masirah, and Thumrait; and highest positive change in 1-day events around Masirah and Thumrait (Hewawasam and Al-Rawas, 2015).

Figure 12 compares the percentage of rainfall that was considered extreme in Oman for two periods, 2000-2008 and 2009-2014. The maps show that the frequency of these potentially destructive events increased in Oman during 2009-2014 compared to the 2000-2008 period. The changes are less than 10% near Rustaq, Bahla, Adam and Ibri, while the Qalhat area shows a significant decline in extreme rainfall events. On the other hand, there is a strong increase in extreme rainfall events in Masirah and Thumrait areas, as evidenced by the dark blue contours in Figure 12 for both the 1-hour and 1-day rainfall events.

These findings are central to strategic considerations for coping with surface water. Were these trends to continue into the future under a changed climate, population and infrastructure would be at significant risk from overflowing wadis throughout Oman. That is, extreme weather events will affect the frequency and magnitude of destructive wadi flows which can lead to erosion, flooding, and infrastructure damage. The likelihood of more frequent and intensive wadi flows correlates closely with future patterns of more frequent extreme weather events with climate change.

Estimates of maximum daily wadi flows for different return periods offer insight into the risk of flash flooding. Figure 13 shows projected maximum daily wadi flow for the periods 2040-2059 and 2080-2099 for one important river basin in Oman: the Al-Khod waterbasin near Muscat. By combining the outputs of GCM ensembles from the Coupled Model Intercomparison Project Phase 5 (CMIP5) with local flow data, maximum daily wadi flows across all return periods were estimated.

The “return period”, shown as the horizontal axis in Figure 13, is simply the years before an extreme maximum wadi flow event returns. A high value of maximum daily wadi flow in the future compared to the past indicates a greater potential for flash flooding during extreme weather events. The charts show that maximum daily wadi flows across all return periods are roughly 1.3 times the historical rate by 2040-2059 and up to 1.6 times the historical rate by 2080-2099.

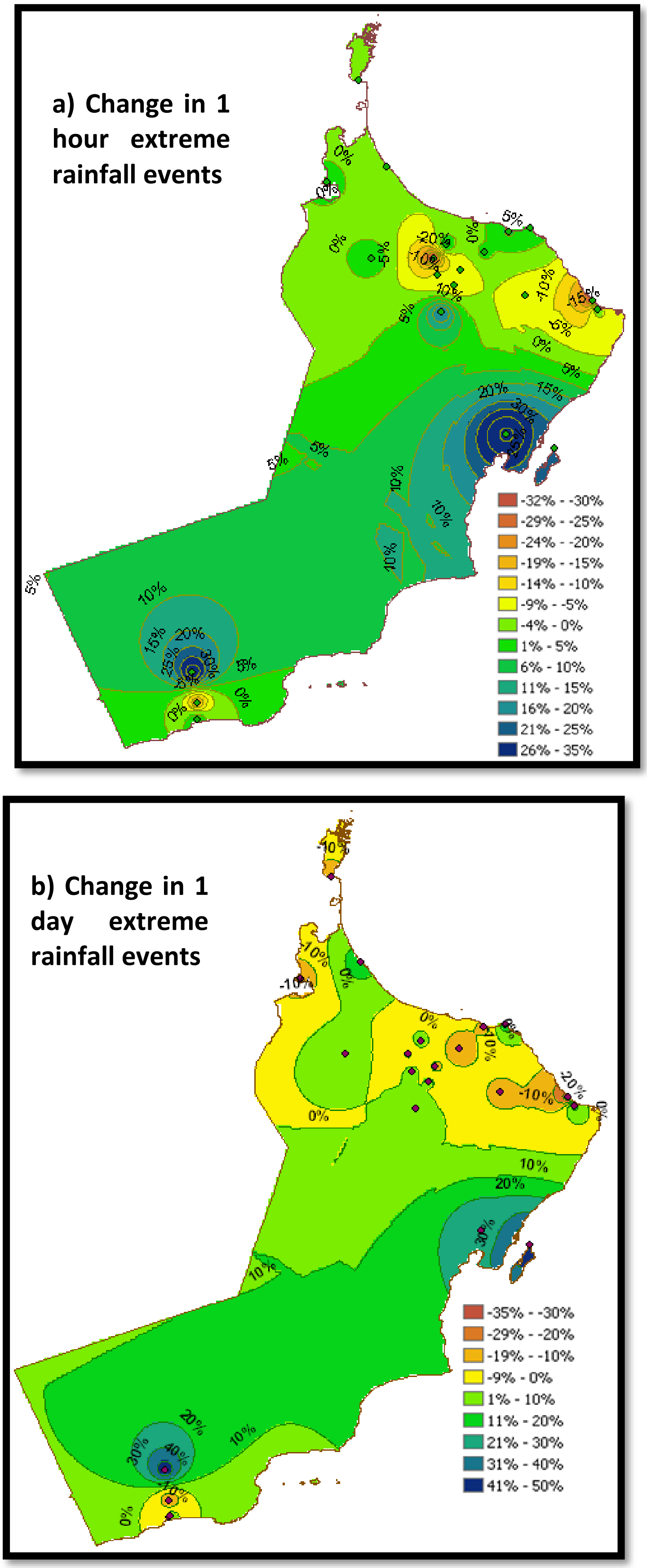
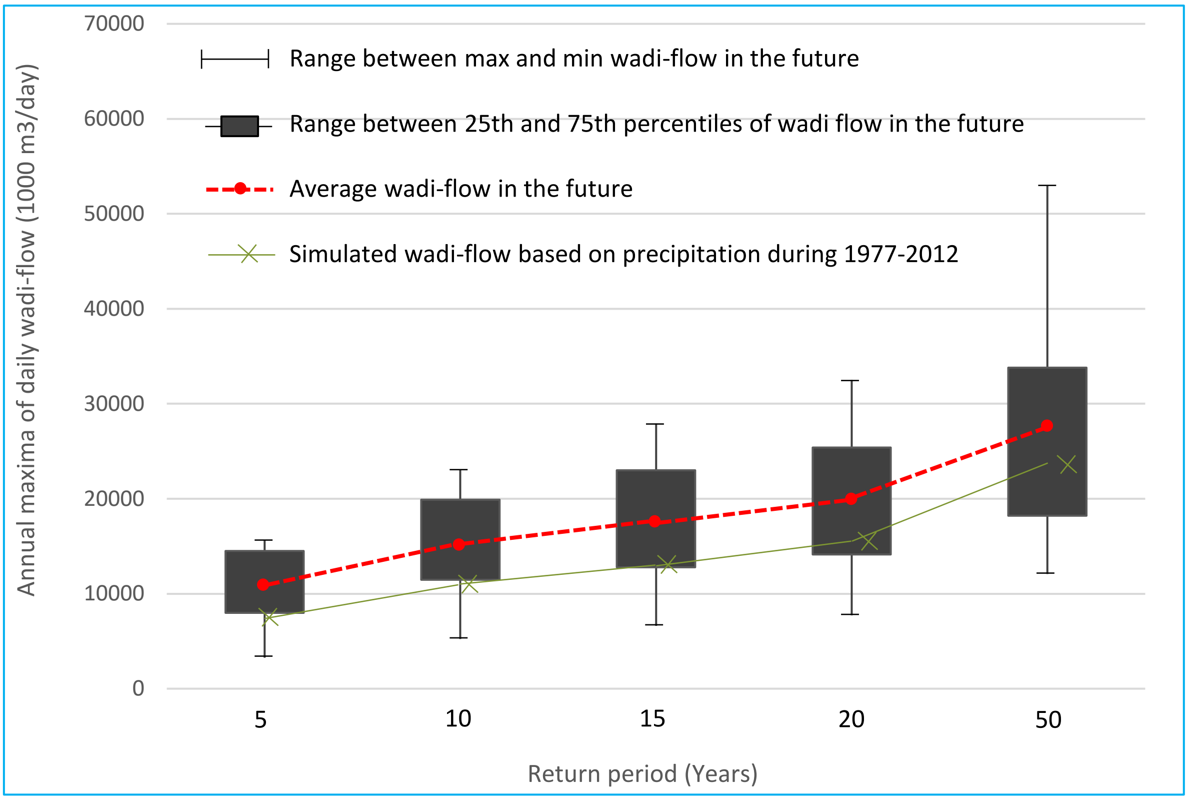


Figure 12: Change in extreme rainfall events during 2009-2014, relative to the 2000-2008 period (Hewawasam and Al-Rawas, 2015)



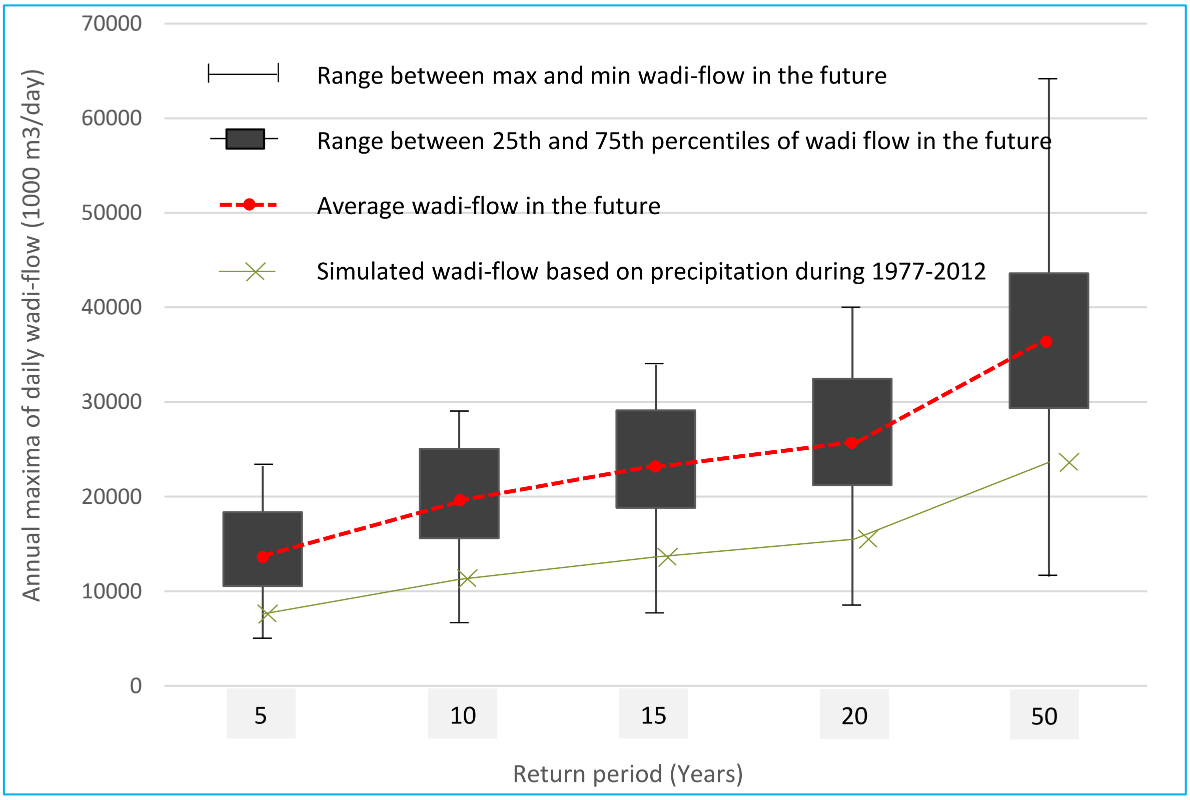


Figure 13: Maximum daily wadi flow in Al-Khod waterbasin near Muscat for the periods 2040-2059 and 2080-2099 (Hewawasam and Al-Rawas, 2015)

Groundwater

Climate change-induced sea level rise is due to dynamic sea level rise, global thermal ocean expansion, and glacier melting. While much uncertainty underlies the magnitude of the latter two key factors, even current low estimates of sea level rise suggest serious risks to groundwater in the form of deteriorating water quality (Hewawasam and Al-Rawas, 2015).

Figure 14 shows the effect of sea level intrusion on the Jamma aquifer in south Al-Batinah area. This region represents about 50% of the total agricultural land in Oman, with groundwater from the intensively developed Jamma aquifer providing the only water supply source for agricultural activities. Using the current (low) IPCC estimates for sea level rise, three impacts are evident by 2070 across all RCPs, as outlined in the bullets below:

- The 1,500 ppm iso-concentric line is projected to shift inland by nearly 1 kilometer (time series plot);
- About 8 km^2 of valuable agricultural land will become salinized and unsuitable for cultivation using groundwater from the Jamma aquifer (pie chart); and
- Nearly 2 billion cubic meters of groundwater will become unsuitable for irrigating agricultural lands (bar chart).

Figure 15 shows the effect of sea level intrusion on the Samail lower catchment aquifer near Muscat. Groundwater from the Samail lower catchment aquifer is used mainly for domestic water supply, with only about 15% of annual withdrawals for irrigation purposes. Unlike the Jamma aquifer, it has not been intensively developed and is currently a healthy aquifer with groundwater flows toward the sea. Using the same IPCC estimates for sea level rise, only negligible impacts were discovered by 2050 and 2070 across all RCPs, as outlined in the bullets below:

- Only about an additional 0.005 million cubic meters of seawater intruding on the aquifer;
- There is only about 0.008 million cubic meters per day of additional evapotranspiration; and
- Only around 25 centimeters of additional water table height from seawater intrusion.

Continued protection of the Samail lower catchment aquifer is essential to maintaining its function under rising seas.

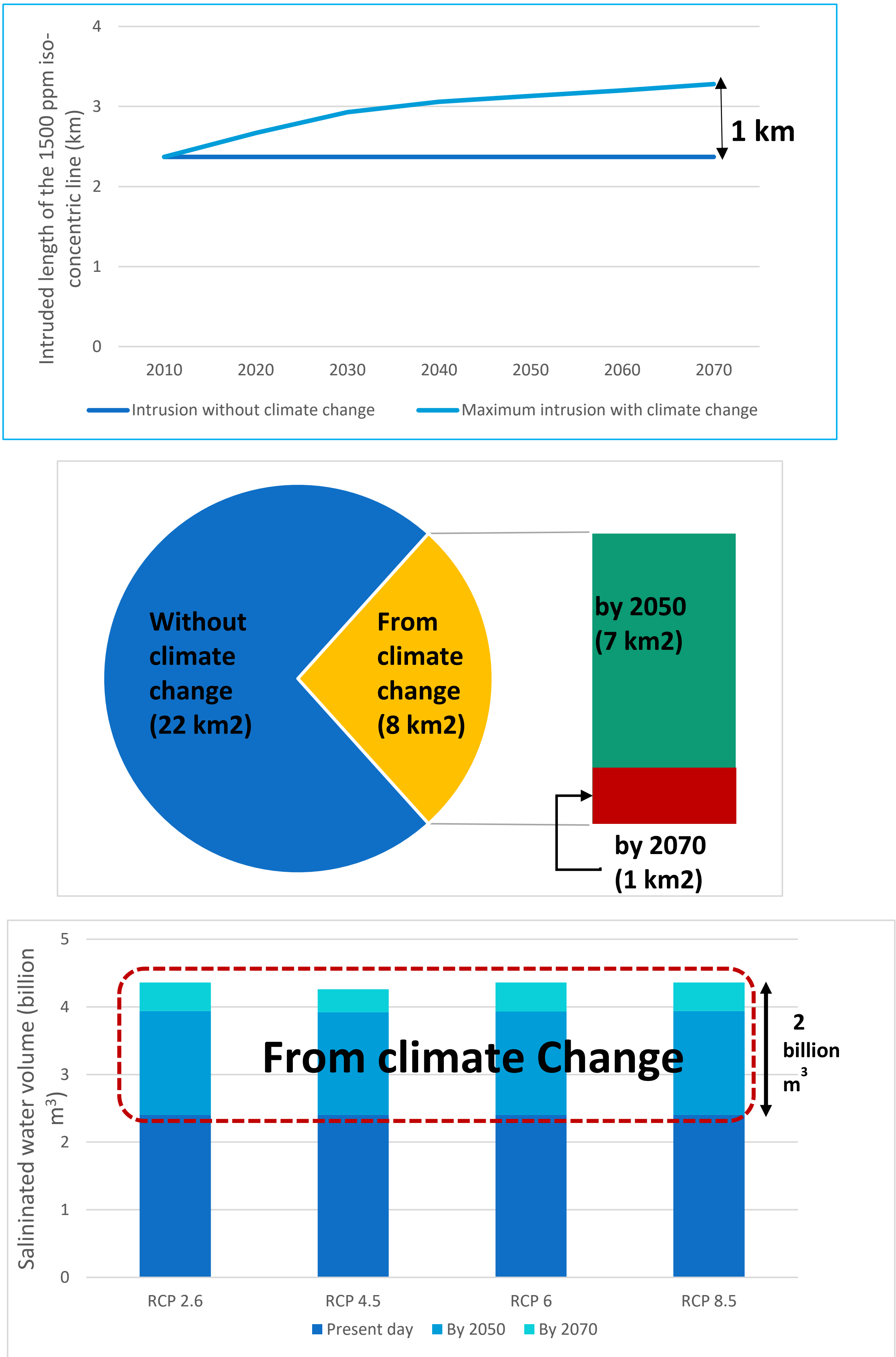


Figure 14: Impacts of sea level intrusion in the Jamma aquifer in south Al-Batinah area by 2070 (Al Maktoumi et al, 2015)

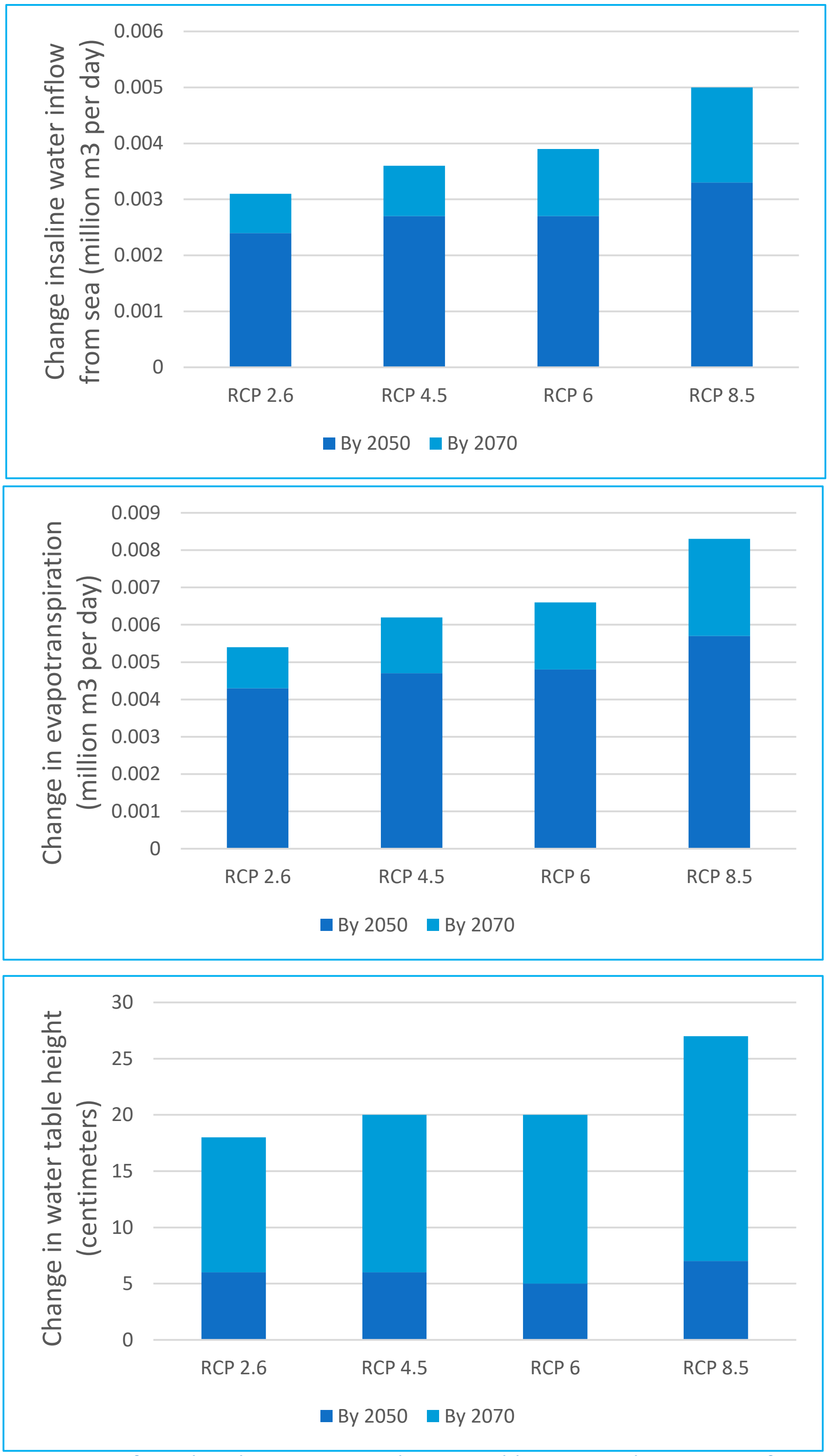


Figure 15: Impacts of sea level intrusion in the Samail lower catchment aquifer near Muscat by 2050 and 2070 (Hewawasam and Al-Rawas, 2015)

Strategic actions

Water resources throughout Oman are vulnerable to climate change impacts due associated with an increased frequency and magnitude of extreme rainfall events, as well as seawater intrusion into aquifers due to sea level rise. Effective adaptation should first involve the development and implementation of an integrated water resource management system that accounts for the interdependency of water and other sectors of the economy. Within this planning framework, there are five (5) distinct streams of initiatives that encompass the Water Resource (WR) stream of strategic actions, as outlined below.

Stream WR-1: Knowledge generation

This involves improving knowledge for managing vulnerable groundwater resources by:

a) conducting similar vulnerability studies for other regions for different climatic conditions;
b) improving data quality management; and commissioning a study on the economic benefits of the implementation of the adaptation responses.

Stream WR-2: Wastewater management

This involves improving management of treated sewage water through:

a) injecting treated wastewater into coastal aquifers on a pilot basis;
b) establishing water quality standards for coastal aquifers into which treated sewage water has been injected; and
c) designing and implementing a groundwater quality monitoring program.

Stream WR-3: Surface water management

This involves improving management of surface water through:

a) expanding gauge station infrastructure for wadi flow monitoring;
b) updating flood hazard maps;
c) assessing flash flooding risks under climate change;
d) updating zoning plans to account for additional flash flooding risks under climate change;
e) install storm drainage infrastructure in projected flash flood zones; and
f) introducing measures to reduce erosion potential under flash flooding events.

Stream WR-4: Capacity building

This involves strengthening capacity to manage water resource management risks by:

a) improving technical capacity for conducting climate change impact studies using state- of-the-art methods and tools;
b) implementing knowledge exchange programmes with other countries on effective adaptation responses;
c) developing a prioritized list of adaptation ideas in water resource management;
d) accessing adaptation funding from the Green Climate Fund (GCF) and other funding sources; and e) implementing a flood warning system (including early warning) and emergency planning (including evacuation).

Stream WR-5: Governance

This involves Improving governance on adaptation policy through:

a) integrating climate change vulnerability into policymaking and planning;
b) enhancing governmental collaboration/coordination on flood risk management;
c) introducing measures to encourage development outside high flood risk zones and measures to discourage development inside high flood risk zones; and
d) encouraging new development (enforce existing zoning protocols) in higher elevations (e.g, along foothills instead of adjacent to wadis.

2. Marine biodiversity & fisheries

Introduction

Marine ecosystems house a large proportion of earth's biodiversity, and provide a wide range of ecosystem goods and services to humans. One of the most important services that humans obtain from the ocean, besides the production of oxygen and absorption of carbon dioxide, is through fisheries. Gross revenues from FAO marine capture fisheries worldwide are currently estimated up to $85 billion annually (2011; Sumaila et al. 2007; World Bank 2008).

Objective and goals

Climate change is projected to lead to changes in the physical and chemical properties of the western Arabian Sea. Such changes may pose important threats to the future sustainability of the annual catch of sardines and yellowfin tuna, two species that are central to the commercial fishing industry of Oman.

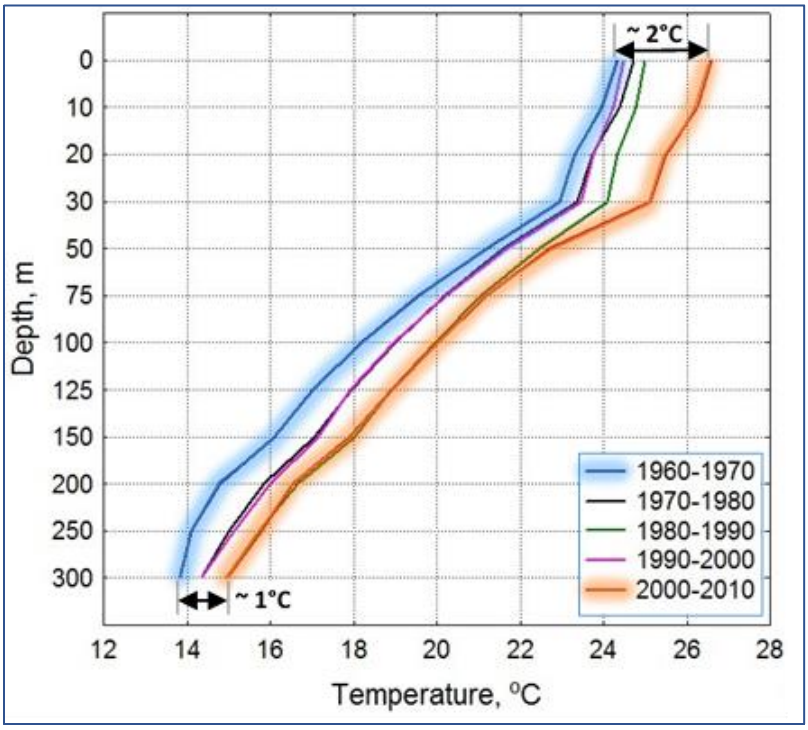
Hence, the key objective of the marine biodiversity and fisheries vulnerability and adaptation assessment is to better understand the vulnerability of the marine environment and key marine species to climate change. The key goals are to a) establish recent trends of physical properties in the Arabian Sea, b) characterize past and projected fish landings of yellowfin tuna and sardines and c) establish a priority list of strategic actions to build resilience.

Vulnerability and risk context

Recent changes in the Arabian Sea

The Western Arabian Sea encompasses an area of about 900,000 square kilometers and is home to diverse ecosystems and biota. Oceanographically, it is a highly complex region influenced by strong monsoon winds, climatically-driven ocean current patterns, the Indian Ocean Dipole and the El Niño Oscillation (Piontkovski, 2015c). The Arabian Sea is also characterized by its high primary productivity which is driven by summer monsoon-driven upwelling along the Somali and Oman coastal areas, with a peak in the summer Monsoon.

These characteristics lead to productive fisheries, a large concentration of mesopelagic fish, high marine biodiversity, and an extended oxygen-rich minimum zone. However, over the past several decades, data from local and international sources showed evidence of clear changes in the physical and chemical properties of the Western Arabian Sea, suggesting ecological consequences to Oman's marine biodiversity and commercial fisheries.



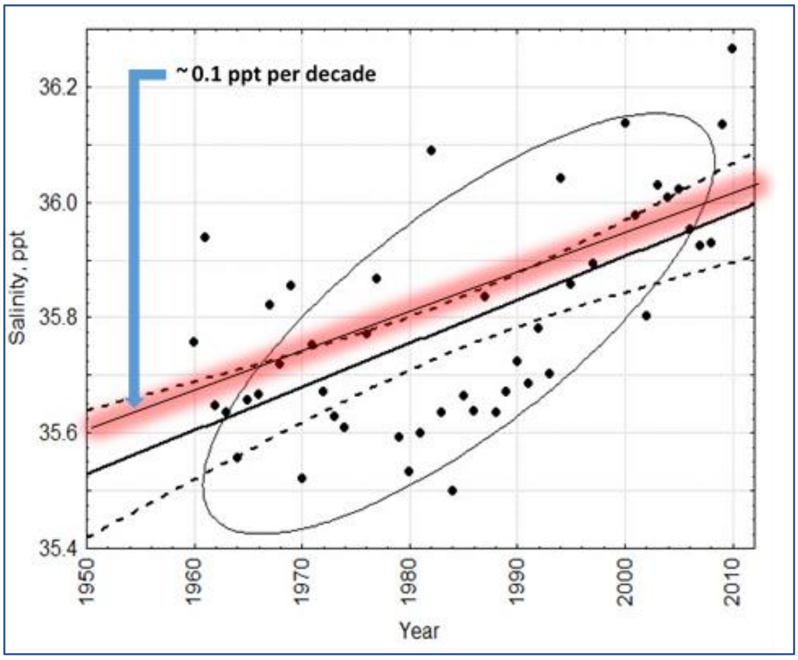


Figure 16: Change in temperature and salinity in the Western Arabian Sea (Piontkovski, 2015a)

Based on the results of an analysis of data maintained by the National Center for Atmospheric Research in the US, it is clear that the waters of the Western Arabian Sea have been changing over the past 50 years or so (Piontkovski, 2015). Figure 16 shows that the physical properties of the Western Arabian Sea have become both warmer and more saline, as detailed in the bullets below:

- Average sea temperatures in the summer have risen since 1960 by over 2°C at the surface and about 1°C at a depth of 300 meters.
- Average salinity at lower depths has been increasing at a rate of about 0.1 parts per thousand per decade since 1950.

In addition to these physical changes, the Western Arabian Sea has experienced significant change in some of its chemical properties over the past 50 years. Acidity, dissolved oxygen, and nitrate concentrations are some of the key chemical properties that underlie the productivity of marine biodiversity and commercial fisheries and have significantly changed over the past decades.

Based on local data derived from local oceanographic stations near Oman, Figure 17 illustrates that the chemical properties of the waters of the Western Arabian Sea have changed significantly, as briefly outlined below:

- Waters have become more acidic as evidenced by pH dropping by 0.1 units at the surface and 0.2 units at a depth of 350 meters (top plot);
- The concentration of nitrates has declined by about 30% over the past 30 years, as evidenced by the difference between the blue, for 1960-1970, and red lines, for 1990-2010 (second from top plot).
- There has been a decline in dissolved oxygen concentration, with levels of 1 milligram per liter now at a depth of about 75 meters as opposed to 120 meters in the 1960s (third from top plot); and
- The chlorophyll-a concentration has declined by about 40%, from 1950s to 2010, as evidenced by the red trend line (bottom plot).

The above chemical changes have all contributed to increased fish kill incidents and compressing of habitats of large and small pelagic fishes over Omani shelf. Moreover, the decline in the concentration of nitrates in the upper layer has likely limited primary production (i.e., free-living microscopic organisms called phytoplankton, including mesopelagic micronekton). The parallel changes in temperature and salinity can affect the patterns of marine biodiversity, the structure and dynamics of ecosystems and the productivity of fisheries (Brander 2007; Cheung et al. 2010).

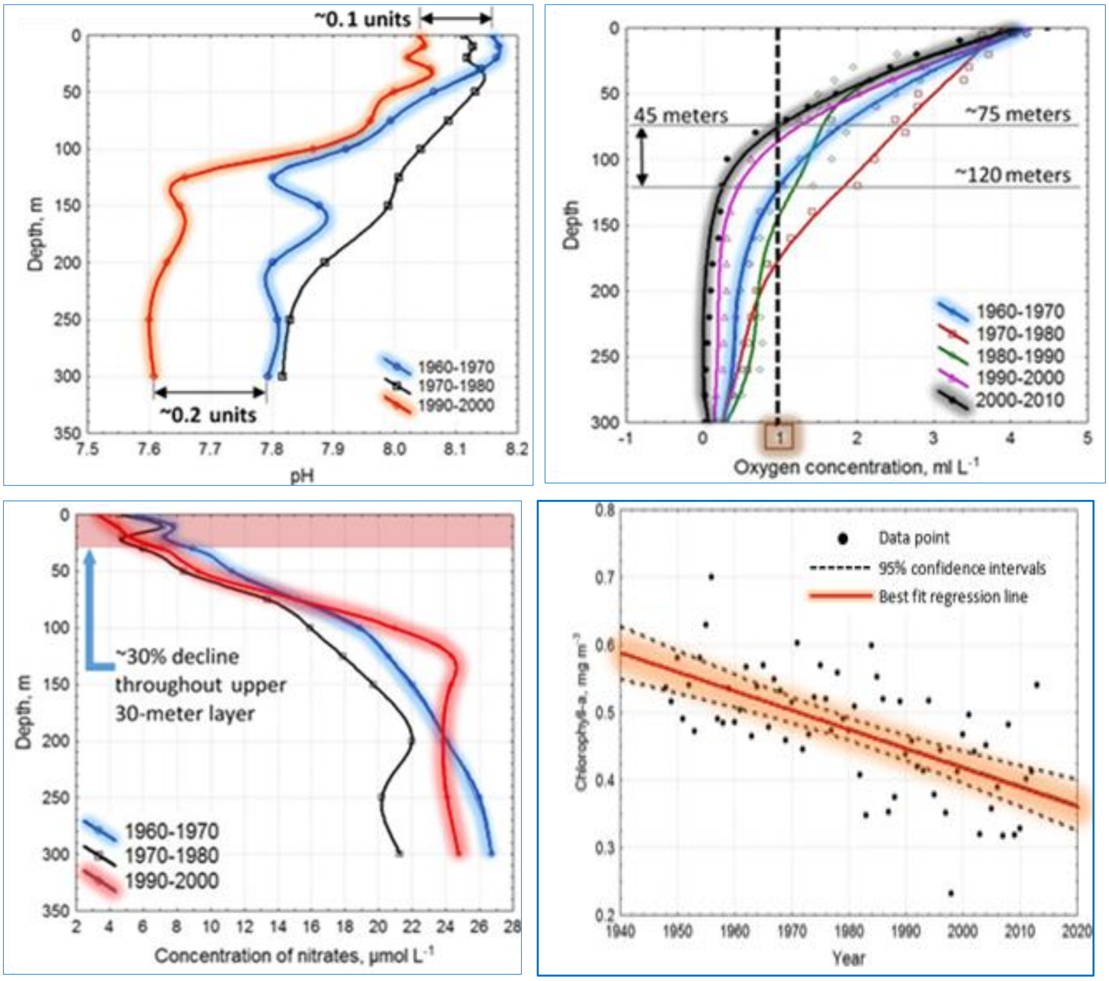


Figure 17: Change in pH, dissolved oxygen, nitrates, and chlorophyll-a in the Western Arabian Sea (Piontkovski, 2015a)

Past fish landings

There are two fish species - yellowfin tuna and sardines - that are of critical importance to commercial fisheries in Oman. Intermediate size yellowfin tuna (*Thunnus albacares*) are abundant in artisanal fisheries in the Arabian Sea where they concentrate for feeding. The Indian oil sardine *(Sardinella longiceps)* is a species of ray-finned fish that contributes approximately 80% of all sardine landings from traditional fisheries in Oman. Collectively, sardine species account for over 50% of total landings (or total fish catches) reported for the western and eastern sides of the Arabian Sea.

A variety of factors account for the magnitude of the annual fish landings. For yellowfin tuna landings, climatic factors such as variations in Siberian high meridional winds, salinity and dissolved oxygen concentrations in the upper layers are ecologically important factors. For sardines, fluctuations of outgoing long-wave radiation, rainfall trends, sea surface temperatures, availability of phytoplankton biomass, and the North Atlantic Oscillation index are key factors (Piontkovski, 2015b).

There is growing evidence that suggest a decline in Oman's yellowfin tuna and sardine annual fish catch. The metric catch per unit effort (CPUE) is an indirect measure of the abundance of a fish species that was used to evaluate catches of sardines and yellowfin tuna in the Western Arabian Sea. Changes over time for this metric imply that there are changes to these species' true abundance.

For sardines and yellowfin tuna, an analysis of a multi-decade artisanal fish catch data record for the period from 1991 to 2013 for the western Arabian Sea reveals a trend showing a sharp decline in CPUE. Figure 18 illustrates the extent to which fish catch has declined in the Western Arabian Sea, as briefly outlined in the bullets below.

- Annual sardine landings declined sharply at the rate of nearly 2.0 CPUE per year during the 1991-1997 period and declined at a lower rate of about 0.1 CPUE per year during the 1997-2013 period. On average, annual sardine landings have declined about 0.56 CPUE per year;
- Annual yellowfin tuna landings declined sharply at the rate of nearly 0.03 CPUE per year during the 1991-1997 period. Landing rebounded between 1997 and 2003, then continued to decline at the rate of 0.03 CPUE per year from 2003 to 2013.

It is important to note that the above findings are preliminary because they are based on a 22-year record which is a shorter than desired time series record. Typically, a minimum data record of 60 years is considered to be best practice. While the specific role of climate change in these findings remains unclear at this time, there is a strong statistical signal in the decline that warrants strategic action going forward.

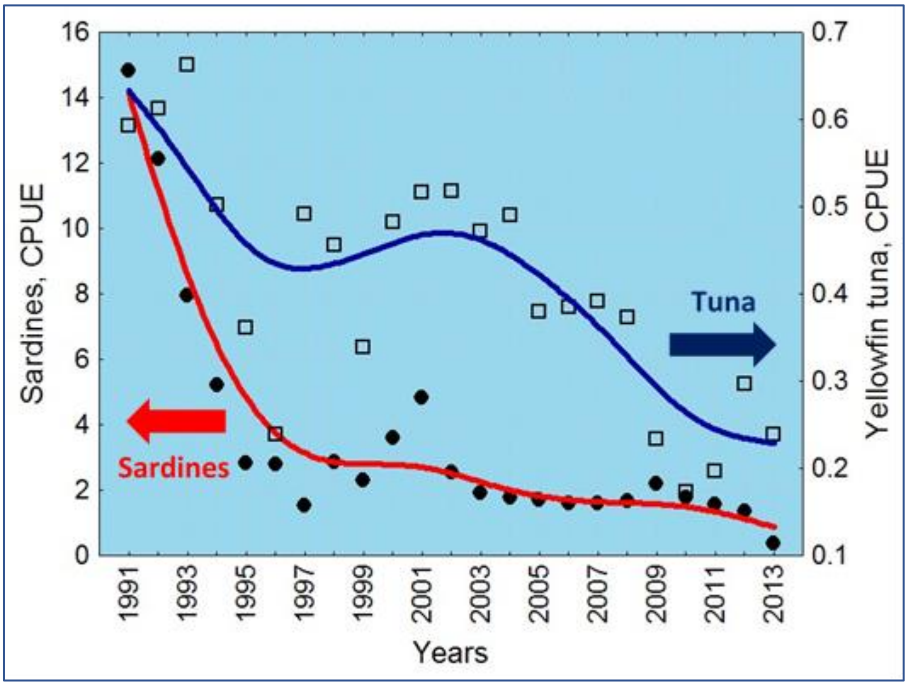


Figure 18: Trends in sardine and yellowfin tuna landings in the Western Arabian Sea (Piontkovski, 2015b)

Projected fish landings

There was sufficient data to conduct an analysis of the impacts of climate change on yellowfin tuna. A pragmatic approach was used that involved the use of the outputs of three different earth climate models under RCP8.5 to drive a coupled ocean circulation-biogeochemical model (Piontkovski, 2015c).

The earth climate models used were the Institut Pierre Simon Laplace model (IPSL), the Geophysical Fluid Dynamics Laboratory model (GFDL), and the Norwegian Earth System Model (NorESM). The biogeochemical model used was the Pelagic Interaction Scheme for Carbon and Ecosystem Studies (PISCES). The historical period used for model validation was 1980-2010. Model projections were made for the period 2010-2100 for two regions: Oman's Exclusive Economic Zone (EEZ) and the Arabian Sea (see Figure 19). To isolate the impact of climate change, the projections were carried out assuming no fishing was conducted in these regions.

Projected ocean temperature and primary production under climate change in the Arabian Sea and Oman EEZ show quite similar trends. Across the three earth climate models there is an increase in temperature for the upper 200 meters of the ocean where there is enough sunlight to allow photosynthesis. The temperature increase is mild between 2010 and 2060, and steeply increases after 2060, ranging between 1.0°C and 2.5°C above historical sea temperatures by 2100.

In addition, there is a decrease in primary production across the three earth climate models. This is due to the increase in water temperature which produces greater stratification of the upper water column which reduces the supply of nutrients from deeper layers and thus the productivity by photosynthesis. Between 2010 and 2100, primary production in the Arabian sea and Oman EEZ is projected to decrease by about 30% compared to historical primary production levels.

Figure 19 shows the impact of climate change on adult yellowfin tuna density in the Arabian Sea and Oman EEZ. Across all three earth climate models, yellowfin tuna stock declines significantly over 2040 to 2100. These projections closely follow the decline in the production of mesopelagic micronekton, suggesting a strong link to this part of the food supply.

Figure 19 also shows that by the end of the century, the decline in yellowfin tuna stock by 2100 in the Arabian Sea ranges from about 40% under the GFDL model to about 65% under the IPSL model (middle plot). The results are similar for the Oman EEZ by 2100, ranging from a decline of about 28% under the GFDL model to about 68% under the IPSL model (middle plot).

It is important to note that the results described above are based on simulations without fishing impacts. Past and future levels of fish catches would likely have a significant impact on these results. It should be noted also that yellowfin catch data are under- or simply not reported by several national fisheries in the region. This could also have a serious impact on the results.

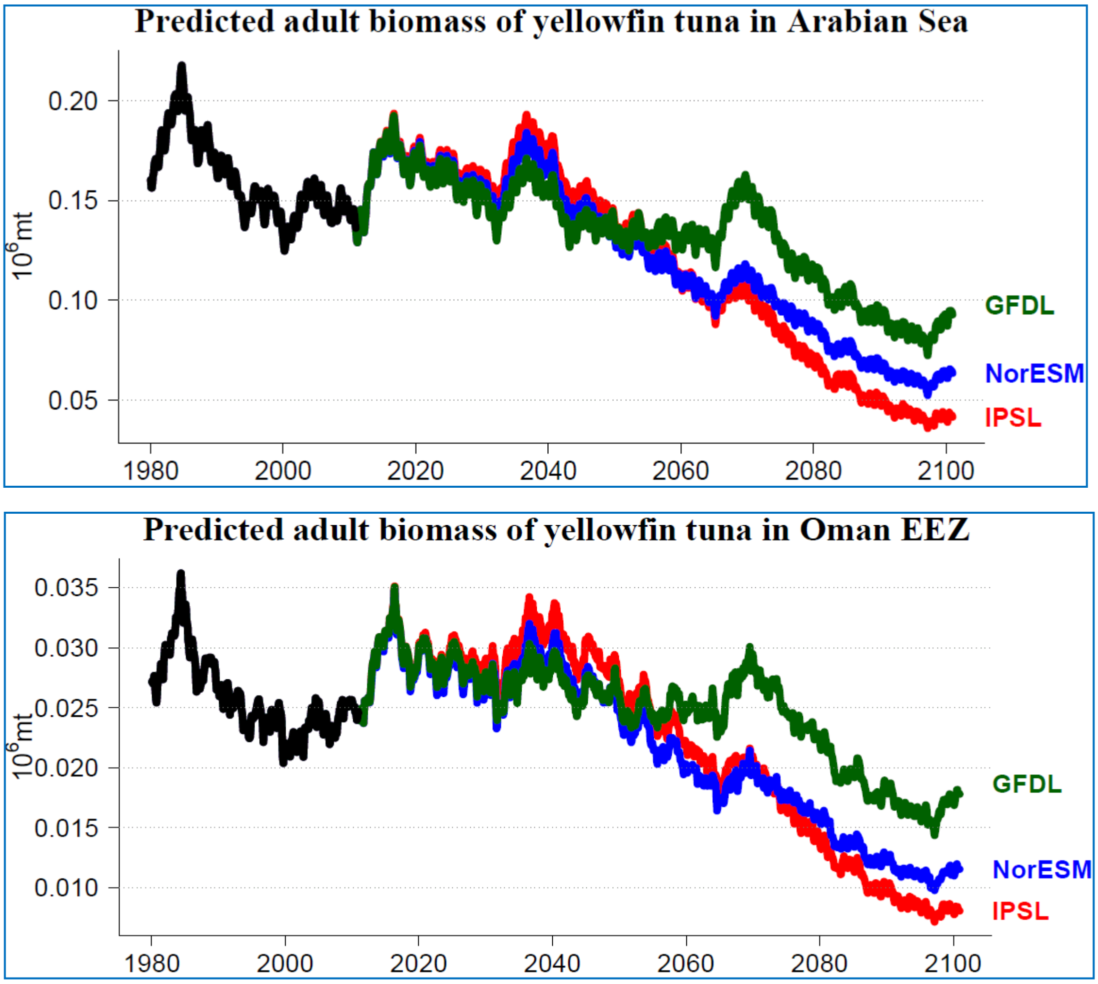


Figure 19: Spatial domains for the modeling (upper plot), productivity of adult yellow tuna in Arabian Sea (middle plot) and Oman EEZ (bottom plot) (Piontkovski, 2015c)

Strategic actions

Marine resources and fisheries in the Arabian Sea and Oman EEZ are vulnerable to climate change impacts due to changes in marine physical properties (i.e., temperature, salinity) and chemical properties, (i.e., pH, dissolved oxygen, nitrates, chlorophyll-a). Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning. Within this planning strategy, there are two (2) distinct streams of initiatives that encompass the Marine Biodiversity (MB) stream of strategic actions, as outlined below.

Stream MB-1: Knowledge management

This involves improving knowledge for managing vulnerable marine resources by:

a) collecting and analyzing data on the impacts of climate variability and trends on marine biology;
b) assessing climate change impacts on fisheries giving priority to threatened and endangered species;
c) monitoring climate change effects on coral reefs as a biological indicator;

d) developing robust genetic strains for aquaculture species that perform well in future environments, and examine industry locations and opportunities under future climate scenarios;
e) investigating regional case studies in the Sultanate for the impacts of climate change on the biological, social and economic relationships in fisheries and aquaculture;
f) developing a downscaled climate change prediction impact model on marine ecosystem and fisheries resources; and
g) strengthening capacity for assessing vulnerability of marine biodiversity and evaluating adaptation options by establishing and/or engaging with international collaborative networks for transboundary fisheries under climate change.

Stream MB-2: Governance

This involves improving governance and planning in Oman through:

a) encouraging diversification of livelihoods and income sources, including activities unrelated to fishing and aquaculture;
b) analyzing the costs and benefits of a range of potential adaptation options by harvesters, processors, and dependent communities seeking to respond to lower fish productivity under climate change; and
c) Conduct additional marine biodiversity vulnerability and adaptation studies.

3. Agriculture

Introduction

Oman's agricultural sector depends overwhelmingly on irrigation from high quality groundwater resources. There is no rain-fed agricultural production in the country and virtually no surface water available for irrigation. Of the critical elements that affect yields in Oman, ensuring timely supplies of good quality irrigation water is among the most critical.

Objective and goals

Rising sea levels will lead to seawater intrusion into aquifers, thereby degrading the quality of water extracted for irrigated agriculture. Sea level rise may also lead to inundated areas, rendering current agricultural area unfit for cultivation.

Hence, the key objective of the agriculture vulnerability and adaptation assessment is to better understand the vulnerability of the agriculture sector to climate change. Specifically, the impact of climate change was evaluated for the Jamma aquifer in the south Al-Batinah governorate, one of Oman's productive agricultural regions Key goals are to a) establish recent trends (groundwater quality, crop water requirements, farmer incomes); b) quantify the impact of evapotranspiration on crop water requirements; c) determine the loss of cultivatable land due to groundwater quality deterioration from sea level rise; and d) establish a priority list of strategic actions to build resilience.

Vulnerability and risk context

Currently, there are about 72,820 hectares of irrigated land in Oman, roughly 0.2% of the total land area (Zekri, 2015). Major crops consist of date palms and other fruits (45%); perennial forage/fodder crops (29%); vegetables (19%); and field crops (7%). Small farms, less than 1 hectare is size dominate agricultural production at 72% of all farms; less than 0.2% of farms exceed 100 hectares in size. The agricultural sector grew at a rate of 2.3% per year over the 2006-2010 period, with higher growth rates evident in recent years associated more efficient practices, different crops, and the introduction of better technology (Zekri, 2015).

Most groundwater for irrigation is obtained through the traditional *falaj* system, in which a vertical shaft is dug from the surface to reach water in porous rock. From the bottom of this shaft, a gently sloping tunnel is dug to tap the water and allow it to flow to an underground cistern, from which it is withdrawn by bucket or pump.

While the future changes in temperature and precipitation discussed previously are expected to have very small impacts on agricultural productivity in Oman, climate change still poses enormous risks to the future sustainability of Oman's agricultural sector. As agricultural productivity depends entirely on groundwater, rising sea levels will lead to seawater intrusion into aquifers, thereby degrading the quality of water extracted for irrigation. Sea level rise also imply a steady decline in crop land available for cultivation as cultivatable land becomes inundated. Together these impacts will impose substantial economic losses to farmer households.

The impact of climate change was evaluated for the Jamma aquifer in the south Al-Batinah governorate (see Figure 20). This is one of the most important and most productive agricultural regions in Oman, having vast plantations of date palms; papaya, lime, and mango trees grown along the coast in irrigated farms, which also produce vegetables and some cereal grains. Many of these cultivated areas are deteriorating, due to seawater intrusion caused by excessive pumping from the aquifer. Fodder crops are now beginning to replace deteriorating date palm plantations, being more tolerant to more saline groundwater.

Groundwater quality

Water supply for the nearly 6 square kilometers of cropland currently under cultivation in the south Al-Batinah region relies exclusively on fresh groundwater having salinity less than 1,500 mg per liter. Two RCPs, RCP8.5 and RCP2.6, were considered to explore future impact on the Jamma aquifer due to seawater intrusion associated with sea level rise.

The MODFLOW groundwater transport and flow model was used to simulate the extent of irrigated area in Al Batinah that would be affected by groundwater deterioration under climate change for two future years, 2050 and 2070. The year 2015 was assumed to be the Base Year for the assessment (Zekri, 2015).

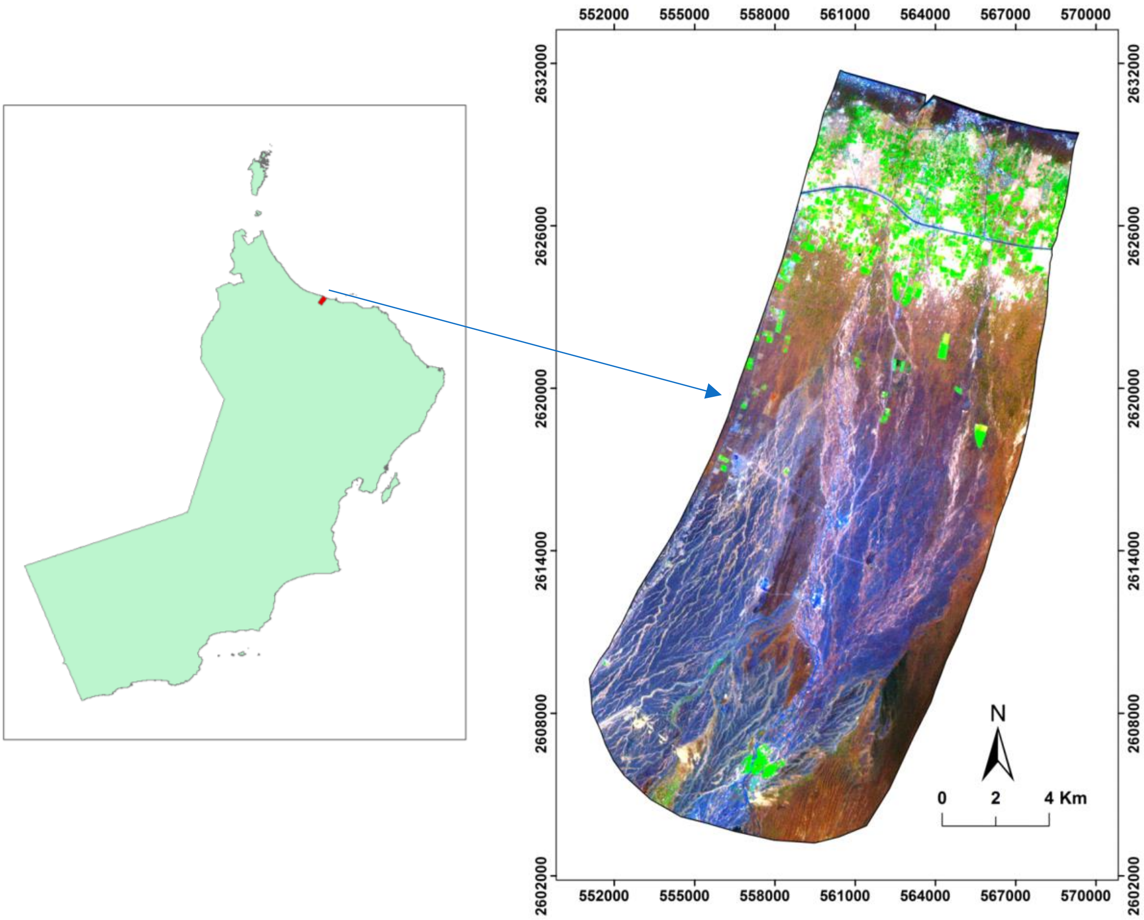


Figure 20: Location of Jamma aquifer

Sea level rise assumptions were integrated into the analysis consistent with the IPCC projections reported in their 5th Assessment report. For RCP2.6, sea level rise was assumed to be 0.24 meter and 0.40 meters above current levels by 2050 and 2070, respectively. For RCP8.5, sea level rise was assumed to be 0.30 meter and 0.63 meters above current levels by 2050 and 2070, respectively (Zekri, 2015).

Figure 21 shows the impact of seawater intrusion on the Jamma aquifer and the extent of cultivatable land impacted. With sea level rise, the extent of land that is underlain by low-quality groundwater (i.e., salinity greater than 10,000 mg/liter and hence unsuitable for groundwater irrigation absent costly desalination equipment), increases from 2 km^2 to 7 km^2 in 2050 and to 8 km^2 in 2070. Moreover, the extent of land that is underlain by high-quality groundwater (i.e., salinity less than or equal to 1,500 mg/liter), and hence suitable for direct groundwater irrigation, decreases from 6 km^2 to 2 km^2 in 2050 and to 1 km^2 in 2070.

Currently, about 53% of all cultivatable land in the south Al-Batinah region relies on irrigation with high quality groundwater. By 2070, only 7% of currently cultivatable land will be able to be irrigated by groundwater from the Jamma aquifer. Notably, these results are the same for both RCPs, indicating that even a small rise in sea level will severely compromise the agricultural productivity of this fertile region and require serious changes to current agricultural practices.

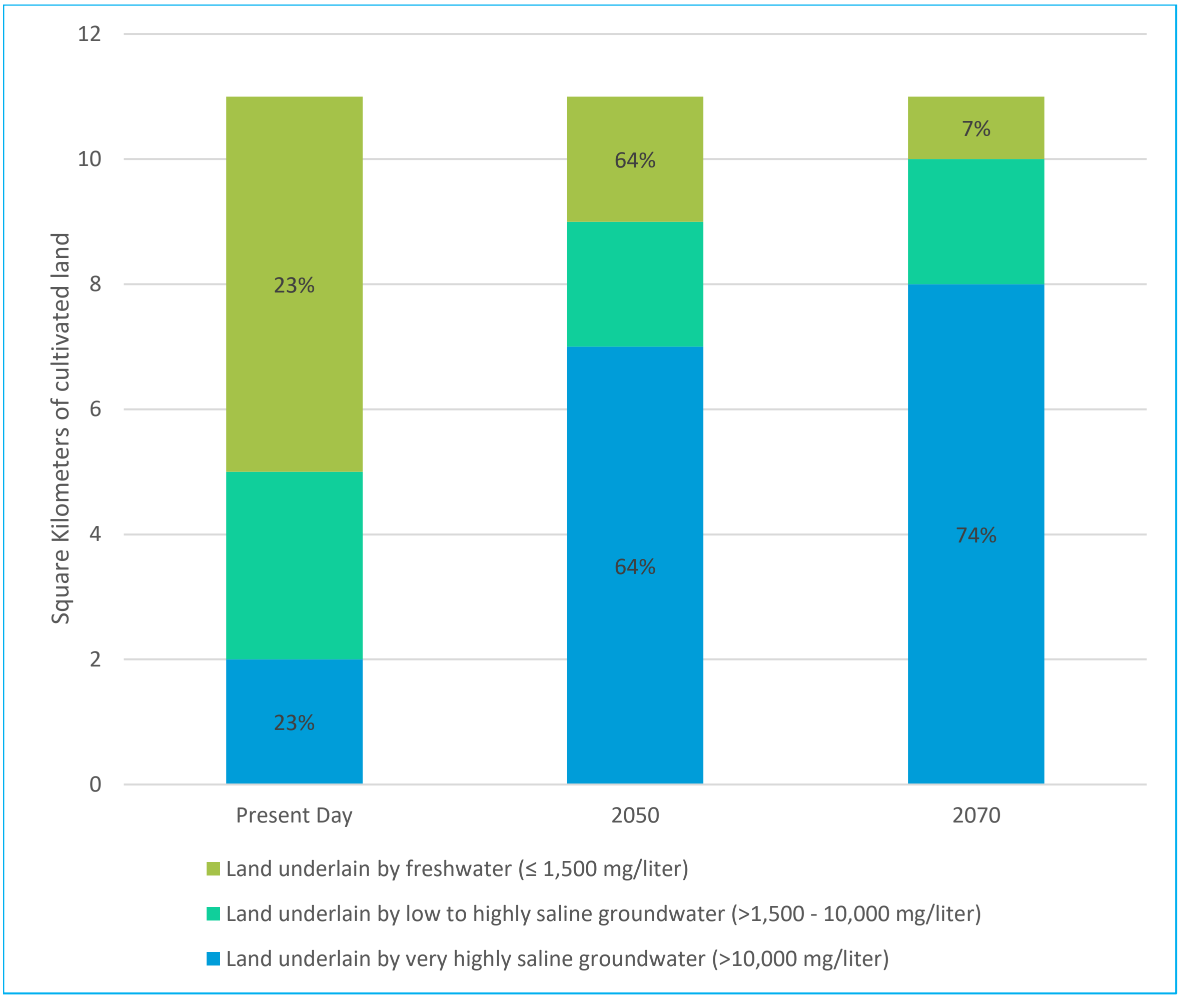


Figure 21: Loss of cultivatable land due to groundwater quality deterioration from sea level rise in Al Batinah (Zekri, 2015)

Crop water requirements

In addition to sea level rise impacts, changes in evapotranspiration will also likely affect agricultural production throughout Oman under climate change. Evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants. Under climate change, an increase in temperature in an arid area such as the Arabian Peninsula could lead to an increase in evapotranspiration by 10% to 27% (Chowdhury, et al., 2013), thereby increasing crop water requirements in order to maintain current crop yields.

Figure 22 shows the potential impacts on evapotranspiration under climate change for various crops. With significantly higher temperatures forecasted for Oman in the future, evapotranspiration rates could also increase substantially. Based on research conducted on Arabian Peninsula, this could lead to additional water requirements of 6.0%, 5.6%, 6.3%, and

7,2% for dates, vegetables, clover, and field crops, respectively (Zekri, 2015) just to maintain current harvest yields.

Hence, climate change is projected to adversely affect agriculture in Oman through two mutually reinforcing process. On the one hand, sea level rise will contribute to groundwater quality deterioration through seawater intrusion, resulting in sharply less cultivatable land with access to irrigation using good quality groundwater. On the other hand, increased evapotranspiration rates will contribute to the need for withdrawing more groundwater for the crops on remaining cultivatable lands relying on good quality groundwater.

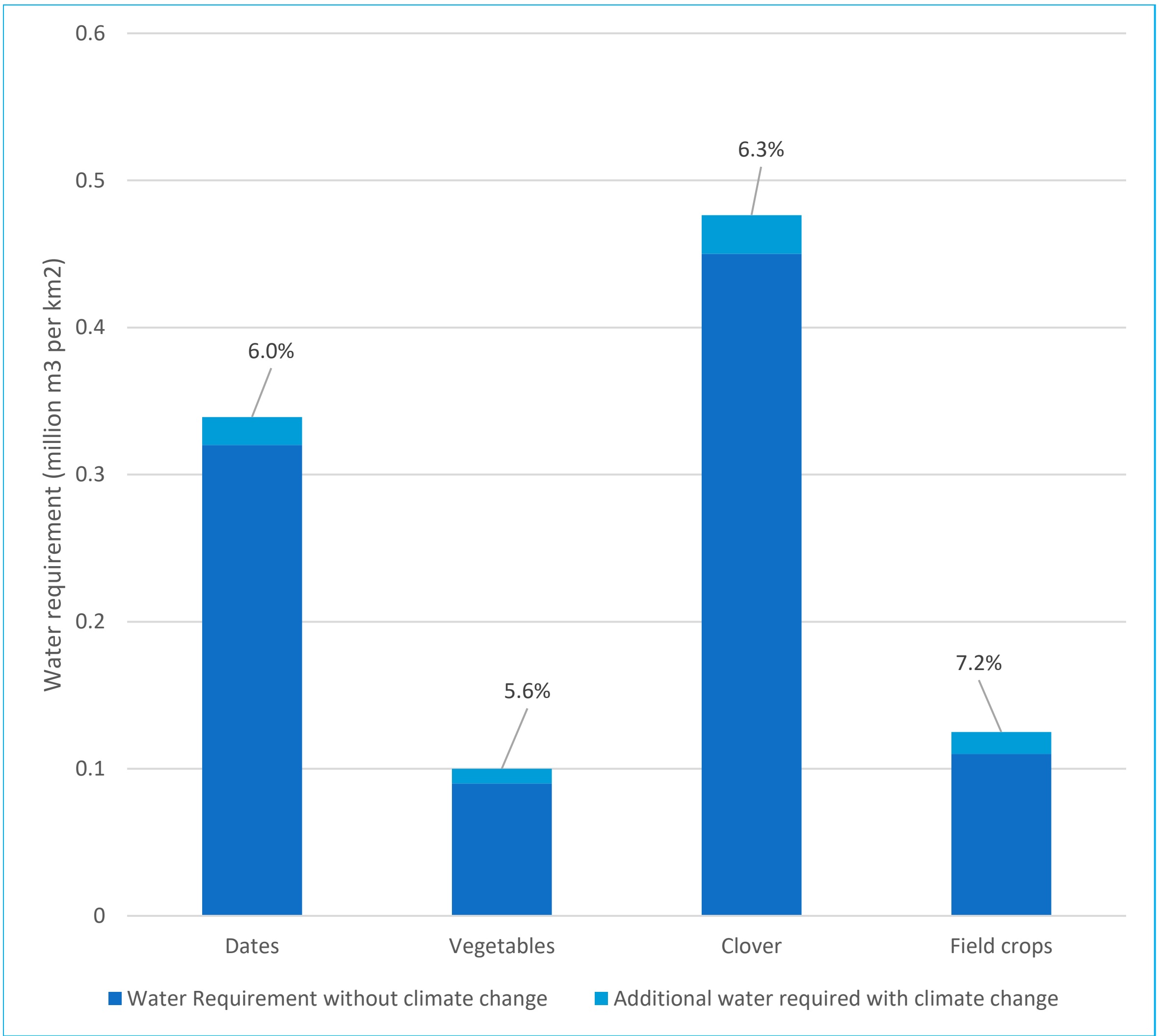


Figure 22: Impact of evapotranspiration on crop water requirements in Oman (Zekri, 2015)

Farmer incomes

There will be economic impacts associated with groundwater deterioration and higher evapotranspiration rates under climate change. The annual incomes of small farmers in south Al-Batinah will be adversely affected by the reduction in arable land and increased crop water requirements. The losses are beginning now and absent adaptation interventions are projected to steepen with oncoming sea level rise in the Sea of Oman.

The same two RCPs, RCP8.5 and RCP2.6, were considered to explore economic impacts on agricultural production relying on the Jamma aquifer under climate change. A simple damage costing methodology was carried out that monetized lost income associated with the reduction in cultivable land from seawater intrusion. The costs and benefits associated with potential adaptation remedies to improve groundwater quality (e.g., brackish water desalination units) were not considered in the analysis

Figure 23 shows the impact on net income from climate change. As cultivable land relying on high quality groundwater declines - and cultivatable lands that can no longer be irrigated increases – annual net incomes are projected to drop from the current level of $790/ha to $467/ha by 2070 for RCP8.5. Of the $330/ha lost due to climate change, most of it, $250/ha, occurs by 2050. These results are very similar for RCP2.6.

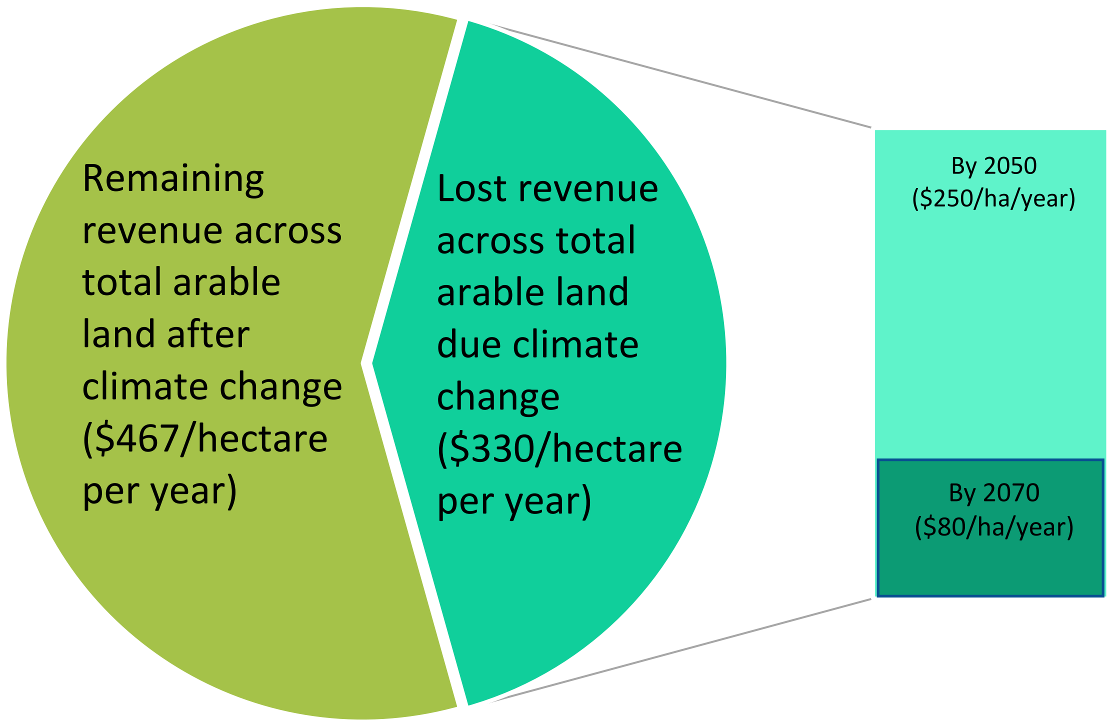


Figure 23: Impacts on net income from agriculture in Al-Batinah by 2070 under RCP8.5 (Zekri, 2015)

Strategic actions

Agricultural production along coastal areas in Oman are vulnerable to climate change impacts due to sea level rise leading to seawater intrusion to freshwater aquifers, as well as increased evapotranspiration rates leading to higher crop water requirements. Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning. Within this overall framework, there are three (3) distinct streams of initiatives that encompass the Agriculture (AG) stream of strategic actions, as outlined below:

Stream AG-1: Knowledge management

This involves improving knowledge for managing coastal aquifers by:

a) Developing simulation models of different primary crops & continued economic viability under different climate scenarios;
b) Strengthening research to develop new crop varieties (saline, water stress and heat/ temperature tolerant crops);
c) Strengthening, collecting and conserving indigenous plant, crops, and animal genetic resources;
d) Developing behavior simulation models of pests and diseases under different climate conditions;
e) Assessing potential emerging problems and develop a risk map for the most persistent and impactful pests and diseases;
f) Researching sustainable management approaches for agricultural pests, diseases, and invasive species; and
g) Strengthening research on water management in agriculture under drought and saline conditions.

Stream AG-2: Capacity building

This involves strengthening capacity for assessing vulnerability of irrigated agricultural production by:

a) Establishing and/or engaging with international collaborative networks for relevant emerging issues in agriculture; and
b) Conducting training in agro-ecological technologies and practices on issues related to climate change.

Stream AG-3: Governance

This involves improving governance and planning in Oman through:

a) Developing policies concerning challenging agribusiness issues in the face of climate change;
b) Identifying cost-effective short-, mid- and long-term agricultural adaptive strategies for key crops and livestock;
c) Increasing on-farm resilience to climate vulnerabilities in affected areas;
d) Undertaking analysis and planning for the conservation and development of agricultural lands affected by climate change;
e) Encouraging adoption of adequate technologies for water use efficiency in agriculture; and

f) Encouraging adoption of integrated adaptation and mitigation measures in agriculture through climate smart agriculture.

4. Urban areas, tourism, & infrastructure

Introduction

Urban areas are characterized by high concentrations of people, infrastructure, business and industry. Such areas can be vulnerable to extreme climatic events and other disaster-inducing events in the absence of adequate planning and governance (Satterthwaite et al. 2009).

Objective and goals

Urban areas can be exposed to series of hazards. For example, an extreme rainfall event can lead to flash flooding, which can in turn lead to contamination of water-supply and also adversely affect other services such as telecommunication and banking services.

Hence, the key objective of the urban areas, tourism, & infrastructure vulnerability and adaptation assessment is to better understand the nature and magnitude of these hazards under climate change. Key goals are to a) develop a coastal vulnerability index for the entire coastline; b) quantify the magnitude of land inundated by sea level rise; c) characterize storm surge risks from tropical cyclones; and d) establish a priority list of strategic actions to build resilience.

Vulnerability and risk context

The scale of the devastation to urban populations and economies caused by extreme weather events in recent years highlights their vulnerabilities. Worldwide, there has been a rapid growth in the number of people killed or seriously impacted by storms and floods, accompanied by steadily increasing economic damages (Satterthwaite et al. 2009).

Coastal development has increased dramatically over recent decades in Oman, a trend that seems certain to continue through the 21st century. According to the census of 2010, 80% of the Omani population lives in low-lying areas such as coastal plains which are considered high-risk flood-prone zones (Charabi et al, 2015). Moreover, nearly 60% of the population is concentrated in Muscat and in the Al-Bathina coastal plain. As shown in Figure 24, there is a high concentration of the country's building stock along the Sea of Oman.

As a result, there are substantial amounts of vulnerable urban infrastructure located in close proximity to flooding prone areas, or subject to coastal inundation and storm surge associated with sea level rise. In 2007, the Tropical Cyclone of Gonu showing the potential impact of an extreme climatic event on an urban center by its high toll in loss of life, infrastructure destroyed, and economic damage.

With climate change, Oman's low-lying urban areas along the coast will be vulnerable to flooding from the combined impact of sea level rise and storm surge associated with extreme weather events. In addition, flash flooding magnitude and frequency could increase in the future from heavy rainfall events. Oman's development plans for urban areas and infrastructure should be reevaluated to account for these risks.

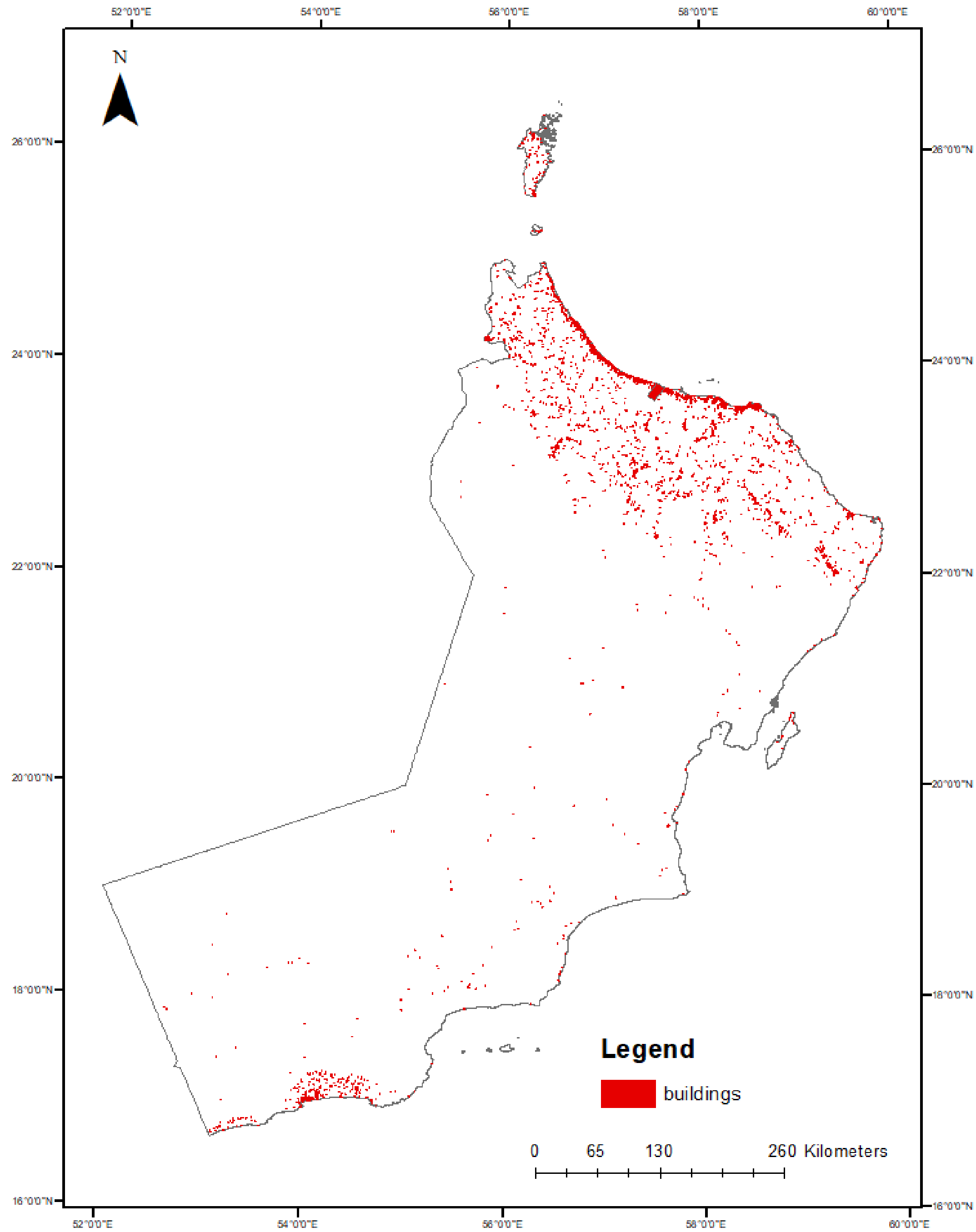


Figure 24: Spatial Distribution of Built-Up area by Governorates (Government of Oman, 2010)

Flash flooding risks

Urban expansion in Omani cities has typically not accounted well for even historical risks of flooding, much less the greater flooding risks that will accompany climate change (Charabi et al, 2015). Today, the impact of floods in the built-up area of Sohar, Saham, Al-Khaburah, As-Suwayq and Muscat can cause serious damage on urban area and infrastructure such as government and private properties, transportation system and power & water supply. These risks have increased substantially over the past 50 years.

Figure 25 illustrates the links between urban expansion and flash food risk in Muscat. Combining urban cover maps with flood risk maps shows that built up areas are situated in close proximity to recurring flooding episodes. This pattern has yielded a nearly 10-fold increase in the urban areas at-risk over the period 1960-2010. With climate change, these risks are projected to increase still further, especially if current patterns of development in high-risk flood-prone zones continue.

Sea level rise risks

Changes in sea level occur over a broad range of temporal and spatial scales, with many contributing factors making it an integral measure of climate change (Milne et al., 2009; Church et al., 2010). The primary contributors to contemporary sea level change are the expansion of the ocean as it warms and the transfer of water currently stored on land to the ocean, particularly from land ice (glaciers and ice sheets) (Church et al., 2013).

Global sea levels are projected to continue to rise as the world warms, increasing mean sea level rise at the local level. The IPCC's Fifth Assessment Report projected that 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 meters of sea level rise are projected for RCP2.6 by 2100, between 0.52and 0.98 meters of sea level rise are projected under RCP8.5 by 2100. Estimates of regional sea level rise can differ from global estimates for a number of reasons. Deviations in sea level are caused by the influence of localized processes such as sediment compaction and tectonics.

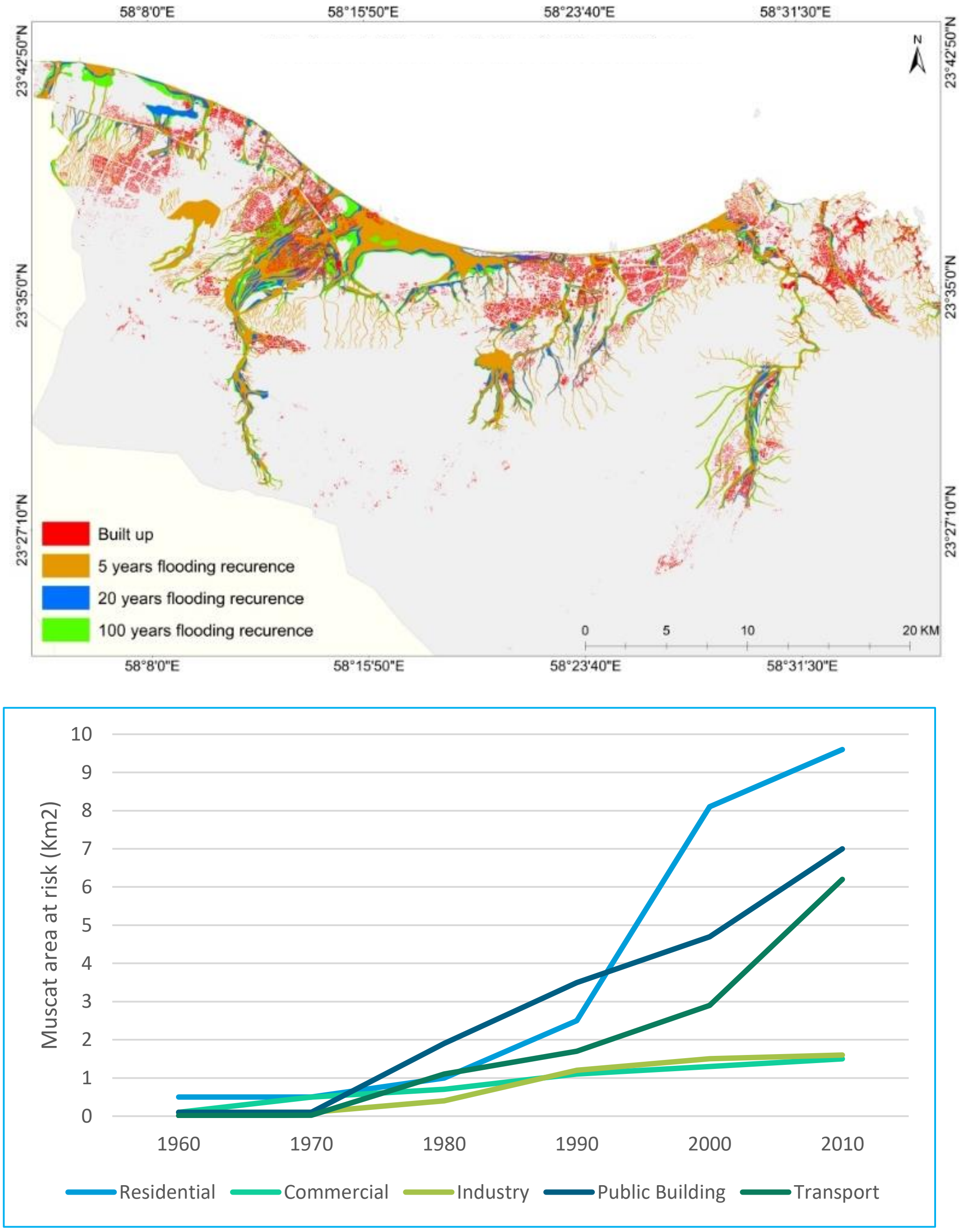


Figure 25: Location of built up areas and flood zones in Muscat (upper plot) and increase of flood risk areas in Muscat between 1960 and 2010 (bottom plot) (Charabi et al, 2015)

Oman has an extended coastline extending for about 3,165 km, including a number of bays and islands. Most of this coastline is soft and low-lying shore subject to the dynamics of sediment transport and landward retreat of the shoreline caused by anthropogenic factors such as coastal engineering activities, as well as natural processes such as sea level rise associated with climate change.

Despite their buffer role and resilience, low-lying sandy coasts and the associated tidal inlets, coastal lagoons and numerous salt flats and coastal sabkhas may not be stable in the long term. They are subject to change in their morphology by coastal geomorphic processes of erosion and accretion caused by sea level changes which continuously modify the shoreline.

Moreover, sea level rise can exacerbate existing infrastructure development challenges, including coastal erosion, seawater intrusion into aquifers, and effective storm-water drainage during hide tide. Understanding potential hotspots is necessary in order to effectively inform future planning.

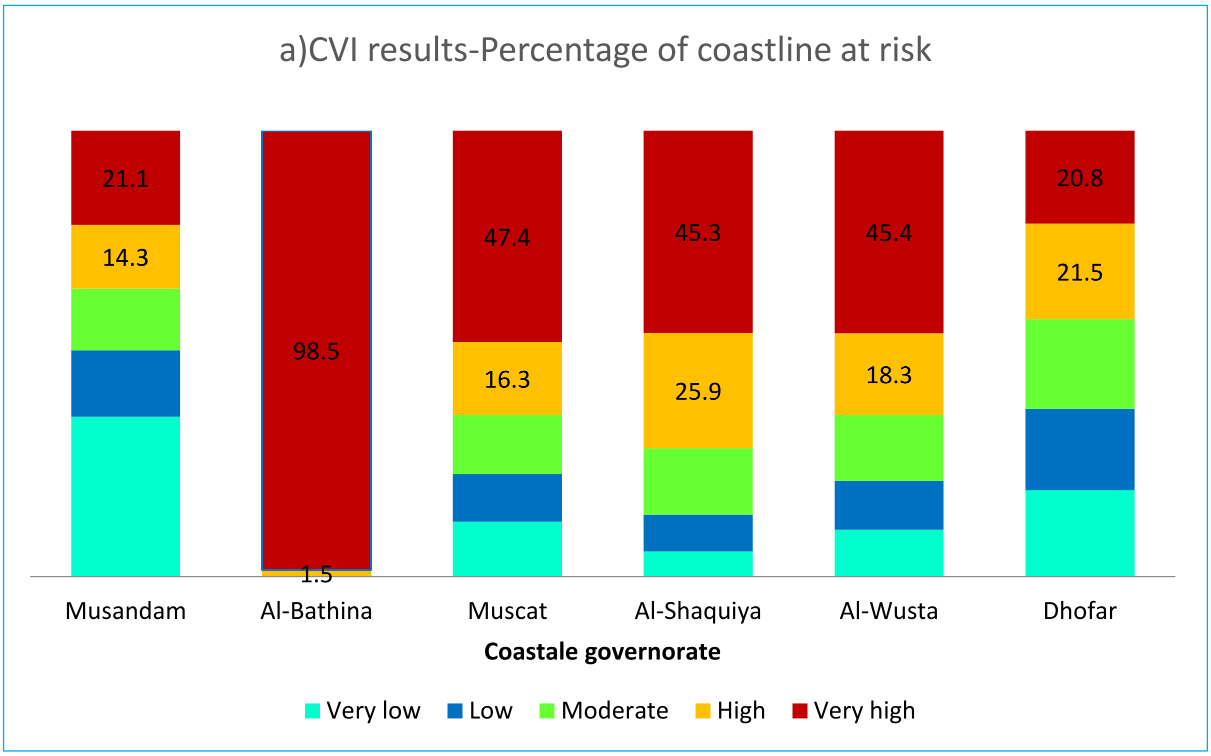
The vulnerability of Oman's urban areas to sea level rise was evaluated through the development of a Coastal Vulnerability Index (CVI). Such an index identifies areas of highest risk from a variety of factors including sea level rise. Six parameters were used to construct the index for the entire Omani coastal zone, namely geomorphology, coastal slope, rate of relative sea-level rise, rate of shoreline erosion/accretion, mean tide range, and mean significant wave height. (Charabi al, 2015).

The vulnerability of Oman's urban areas to sea level rise was further evaluated through the development of estimates of the extent of inundated land that would be associated with a set of sea level rise scenarios for the year 2100; 0.2, 0,5 and 1 meters added to mean high tide. This involved the development of a Digital Elevation Model (DEM) with a horizontal spatial resolution of 40 meters and a precise database of elevation benchmarks throughout the 3,165 km of Oman's coastline. Sea level scenarios were overlain on land use/elevation datasets to estimate the inundation risk among all land use categories (Charabi et al, 2015).

Figure 26 summarizes the results of the assessments. The figure 26 (a) corresponds to the CVI results and the right side of the plot corresponds to the inundation results. A summary of key findings is provided in the bullets below:

CVI: Al-Batinah is projected to be the most vulnerable area in Oman, with 98.5% of its area classified as a "very high" risk zone according to the CVI. Musandam is projected to be the least vulnerable, with only 21.1% of its coastal area being "very high" risk zones.

Inundation: Total inundated land from sea level rise ranges from about 386 km2 with sea level rise under 0.5 meters to over 500 km2 under sea level rise of 1 meters.



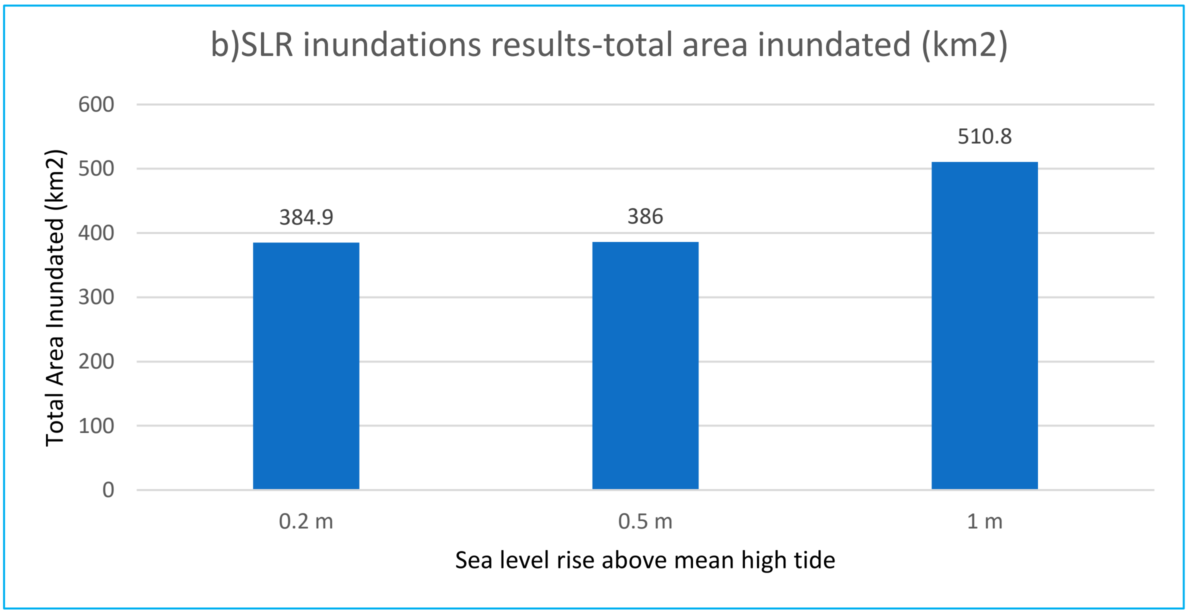


Figure 26: Results of the Coastal Vulnerability Index assessment (a) and extent of inundated land under a set of sea level rise scenarios by 2100 (b) (Charabi et al, 2015)

Tropical cyclone risks

Coastal flooding associated with tropical cyclones has become a major concern in low-lying populated areas in Oman. Gonu in 2007 which led to 50 deaths in Oman, plus over US$ 4 billion in property damage was the best warning of the need for preparing for such extreme weather events.

The vulnerability of Oman's infrastructure to tropical cyclones was evaluated through an analysis of the maximum potential storm surge depth associated with historical cyclones (DGM, 2015). The analysis was complex and involved a combination of long-term wave and surge reanalysis for the marine climate together with steps to characterize the potential frequency and intensity of tropical cyclones that have hit the Omani coastline.

The long-term wave and surge reanalysis for the marine climate was based on the existing Global Ocean Wave (GOW) reanalysis database (Reguero et al., 2012), the Climate Forecast System Reanalysis (CFSR) wind and sea level pressure database (Saha et al., 2010). Together, these resources provided information on regional wave and storm surge at high resolution along the Omani coast.

Developing an understanding of the historical frequency and intensity of tropical cyclones was based on the synthetic generation of hypothetical and plausible tropical cyclones using state-of-the-art trajectory stochastic models (Minguez et al., 2012). It also involved data collection and review of historical tropical cyclone tracks in recent years from events such as Gonu and Phet.

Once the marine climate and tropical cyclone dynamics were characterized, the extent of coastal flooding was simulated using a high-resolution numerical hydrodynamic model to evaluate the storm surge - defined as the rise in seawater level caused solely by a storm - associated with each cyclone event. It is important to note that modeling was conducted assuming historical mean sea levels under the influence of astronomical tides. As future sea level rise scenarios were not integrated into the analysis, the results should be viewed as a lower estimate of potential storm surge associated with tropical cyclones under climate change.

Figure 27 shows the results of the assessment. From the over 800 tropical cyclone paths that have entered the Arabian Sea, two were considered as having the potential for maximum impact on infrastructure in Oman (upper plot). Two left and right plots characterize storm surge hotspots along the entire Omani coast. Minimum storm surge from the analysis of all potential cyclone tracks is between 3 and 4 meters high. Maximum storm surge height reaches nearly 6 meters in parts of the Al Wusta governorate, with South Al Sharquiya also being highly exposed to storm surges between 4.5 and 5.0 meters. Any infrastructure located along the coastline where the highest storm surge is projected is clearly at high risk during future cyclonic events.

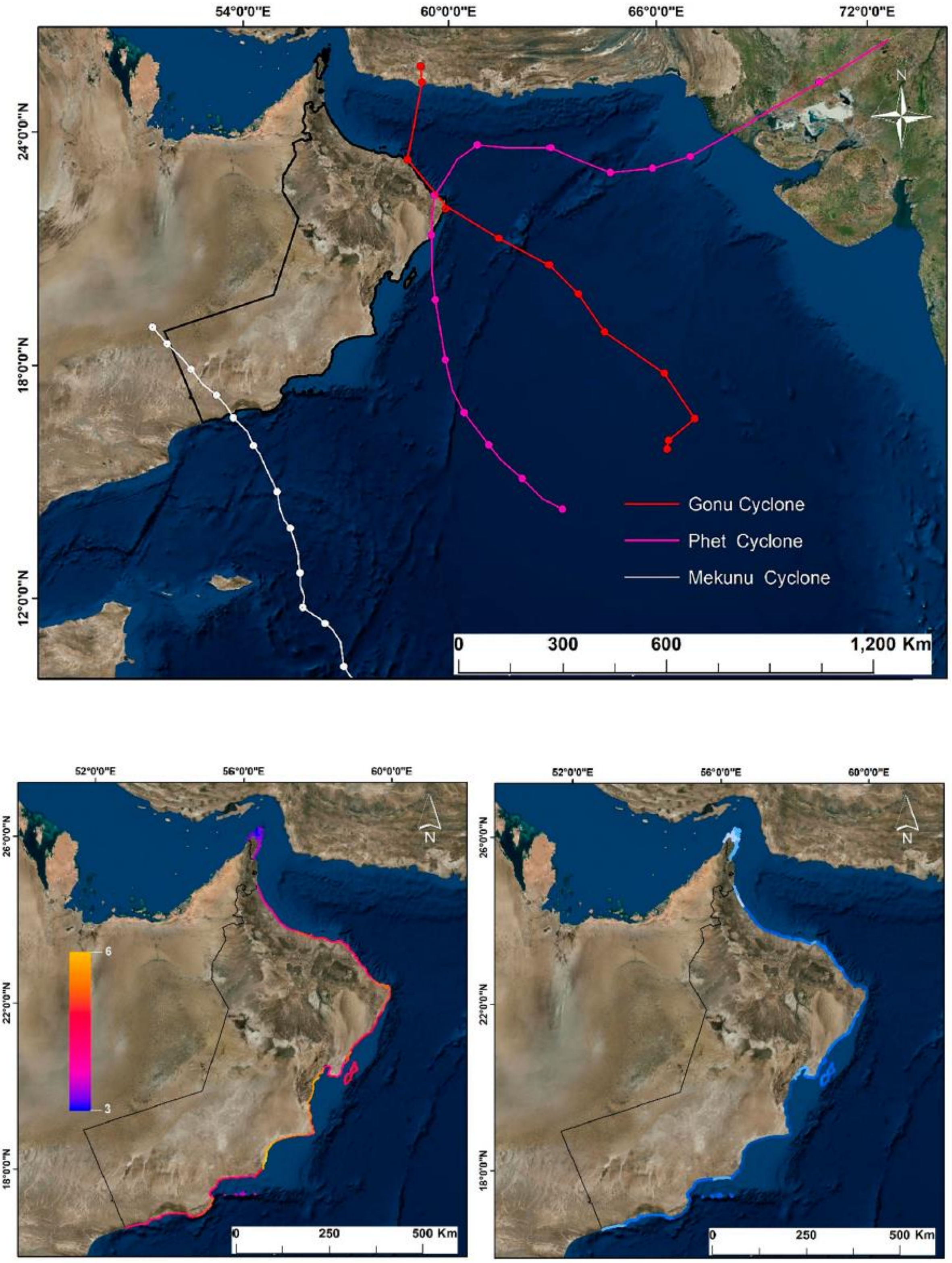


Figure 27: Highest-impact cyclone tracks (upper plot), plus minimum (right plot) and maximum (left plot) projected storm surge height from an assessment of all potential tropical cyclone tracks (DGM, 2015)

Strategic actions

Urban areas, tourism facilities and infrastructure along coastal areas in Oman are vulnerable to climate change impacts due to sea level rise and tropical cyclones. Effective adaptation should focus on knowledge generation, capacity building, and improved governance, planning and risk-reducing options. Within this overall framework, there are three (3) distinct streams of initiatives that encompass the Urban Areas, Tourism, & Infrastructure (UA) stream of strategic actions, as outlined below:

Stream UA-1: Knowledge management

This involves improving knowledge for managing climate change risks to urban areas, touristic facilities, and infrastructure by:

a) Ensuring that all hazards maps are updated to reflect designs extreme events under climate change;
b) Updating coastal zone setback line to incorporate climate change risks to Infrastructure;
c) Ensuring that existing infrastructure exposed to unacceptable climate change risks are evaluated to address subsequent rehabilitation or other risk-reducing options; and
d) Conducting climate change impact assessment by tourist region, focusing on the most vulnerable sectors and locations.

Stream UA-2: Capacity building

This involves strengthening capacity for assessing vulnerability of urban areas, touristic facilities, and infrastructure by:

a) Improving technical capacity for conducting climate change impact studies using state- of-the-art methods and tools;
b) Facilitating exchange of experience and knowledge with other countries on effective adaptation responses;
c) Developing a prioritized list of adaptation initiatives in hotspot areas; and
d) Accessing adaptation funds available through the Green Climate Fund (GCF) and other funding sources.

Stream UA-3: Governance

This involves improving governance and planning in Oman through:

a) Update regulatory and legislative systems/procedures to ensure that all master plans and subdivision plans (>30 hectares) incorporate climate change risk assessments;
b) Ensure that all proposed infrastructure projects incorporate climate change risks into project design; and
c) Develop national building and design codes to promote resiliency of communities to mitigate storm and flood damage.

5. Public health

Introduction

Weather and climate can profoundly affect human health. Climate change threatens to exacerbate today's health problems – deaths from extreme weather events, cardiovascular and respiratory diseases, infectious diseases and malnutrition – whilst undermining Oman's social protection systems.

Objective and goals

The key objective of the public health vulnerability and adaptation assessment is to better understand the threat of climate change to the public health in Oman. Key goals are to a) estimate the impact of adaptation of reducing risks from sea level rise;

b) estimate the number of people at risk from an increase in malaria;

c) determine the number of people at risk from heat stress under high temperature conditions;

d) estimate the co-benefits of GHG mitigation; and

e) establish a priority list of strategic actions to build resilience.

Vulnerability and risk context

The scale of the devastation to urban populations and economies caused by extreme weather events in recent years highlights their vulnerabilities. Worldwide, there has been a rapid growth in the number of people killed or seriously impacted by storms and floods, accompanied by steadily increasing economic damages (Satterthwaite et al. 2009).

Sea level rise

About 81,300 people are projected to be affected by flooding due to sea level rise and extreme weather events between 2070 and 2100 in the absence of the introduction of effective adaption measures. If there is a major scale up in the introduction of such measures, the affected population could be reduced to about 100 people between by 2100, as illustrated in Figure 28.

Malaria

By 2050, roughly 200,000 people would be at risk of malaria in Oman, a decline from the baseline value of just over 681,000. Under RCP 8.5 (high global GHG emissions), these gains would be reversed as the Omani population at risk from malaria would double to about 400,000. RCP 2.6 (low global GHG emissions), malaria risks would continue to decline to just over 6,100 by 2070, as illustrated in Figure 29.

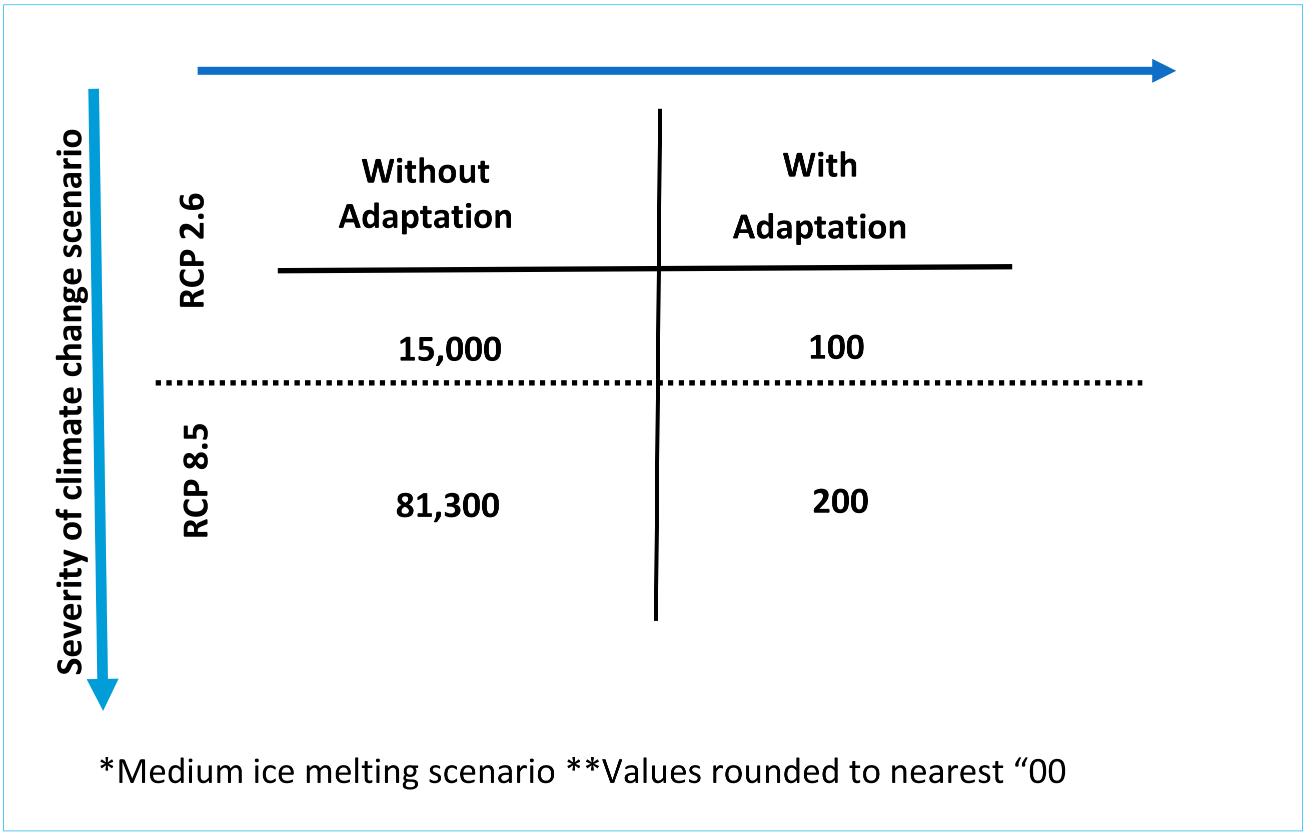


Figure 28: Potential public health benefits of adapting to sea level rise (WHO, 2015)

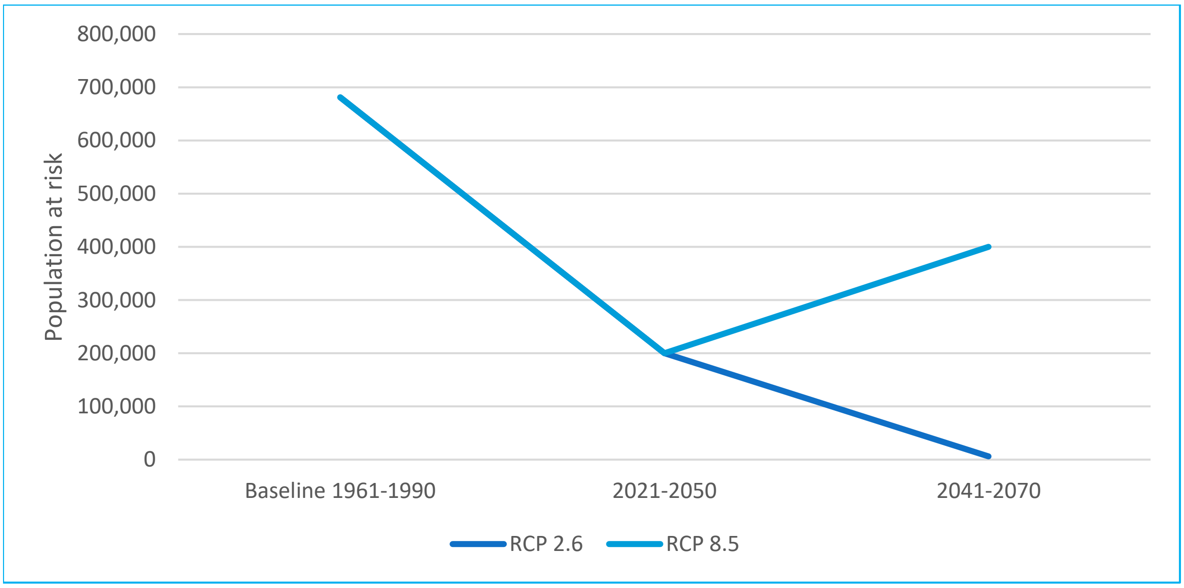


Figure 29: Potential public health benefits of adapting to malaria under climate change (WHO, 2015)

Heat stress

Under a high emissions scenario, heat-related deaths in the elderly (65+ years) are projected to increase to about 34 deaths per 100,000 by 2080 compared to the estimated baseline of just over 3 deaths per 100,000 annually between 1961 and 1990, as illustrated in Figure 30. A rapid reduction in emissions could limit heat-related deaths in the elderly to about 7 deaths per 100,000 in 2080.

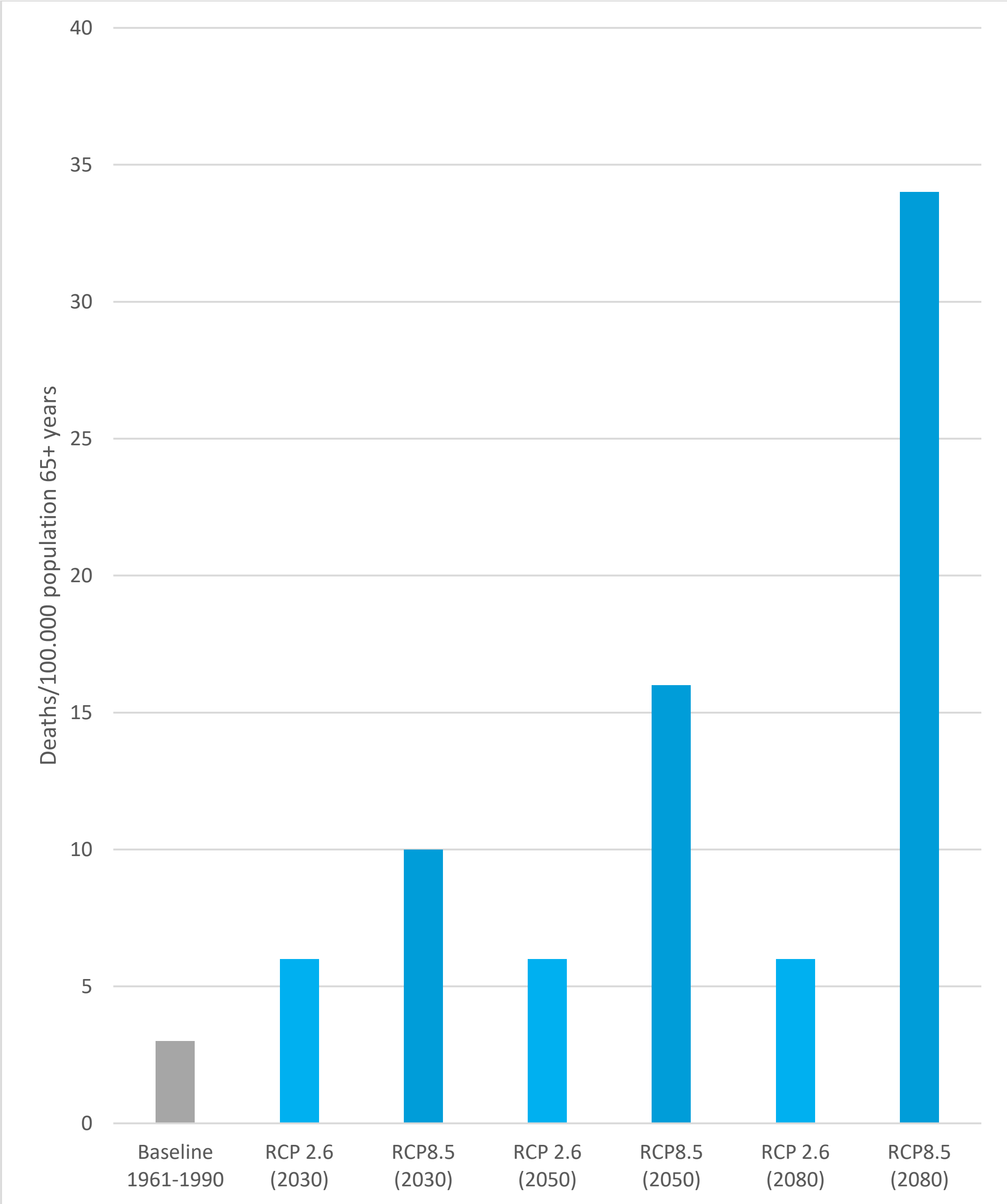


Figure 30: Impact of climate change induced heath stress deaths among the elderly under RCP2.6 and RCP8.5, by 2030, 2050, and 2080 (WHO, 2015)

Co-benefits of greenhouse gas mitigation

There are strong linkages between greenhouse gas emissions that contribute to global climate change and air pollution, which contributes to affect local public health. Air pollution contributes to a range of diseases, symptoms and conditions that impair the health and quality of life for urban residents. Numerous epidemiological studies have reported associations between an increase in daily levels of ozone (O3) and particulate matter (PM), and an increase in the rates of mortality and hospital admissions predominantly related to respiratory and cardiovascular diseases.

GHG mitigation policies can lead to public health "co-benefits", or unintended positive side effects. Specifically, energy efficiency and renewable energy in the electricity and transport sectors can offer a diverse range of health co-benefits, including sharp reductions in morbidity and mortality risks.

Strategic actions

Public health in Oman is vulnerable to climate change impacts due to sea level rise, increased malaria incidence, and heat stress. Moreover, low carbon development strategies can also yield health co-benefits for individuals and societies. Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning. Within this overall framework, there are three (3) distinct streams of initiatives that encompass the Public Health (PH) stream of strategic actions, as outlined below.

Stream PH-1: Knowledge management

This involves improving knowledge for managing climate change impacts on human health by:

a) Raising public awareness on the detrimental effects of climate change on human health and intensify disease prevention and health promotion.
b) Expanding knowledge on science of climate change and its effects on human health, as well as increasing the research capacity in this area (e.g., assessing the health impacts of climate change in Oman).

Stream PH-2: Capacity building

This involves strengthening capacity for assessing vulnerability of key segments of the population by:

a) Enhancing capacities for health-related resilience to climate change by both preparedness and response strategies.
b) Strengthening health surveillance and health management information systems; and
c) Developing a local data-driven modeling framework for assessing the public health co-benefits of GHG mitigation measures.

Stream PH-3: Governance

This involves improving governance and planning in Oman through the following strategic actions:

a) Developing strong partnerships, coordination and collaboration with the concerned agencies at national, regional and international levels linked to climate change and health issues".

b) Developing a multi-sectoral, integrated surveillance system to better monitor and respond to disease events triggered by climatic episodes.

SECTION IV: GREENHOUSE GAS MITIGATION

Oman faces the challenge of harmonizing its aspirations for rapid economic growth with a pressing need to address low-carbon, climate-resilient development. In response, it has undertaken domestic efforts to better understand ways to reduce its greenhouse gas emissions.

Oman understands the need to transition to a low carbon future that reflects new thinking, new frameworks, and new methods. The transition will also need to find practical ways to promote clean energy initiatives, facilitate access to new low-carbon technologies, and develop long-term partnerships to exploit sustainable energy opportunities. Through such actions, Oman seeks to reflect its solidarity with the international community, as well as its long-term commitment to promote greenhouse gas mitigation in a carbon-constrained world.

The Greenhouse Gas Mitigation theme of the Oman Climate Change strategy focuses on the energy, industrial, waste and agriculture sectors, the sectors responsible for the largest share of GHG emissions in Oman. The rest of this section provides a review of the GHG emission patterns, together with a set of strategic mitigation actions.

1. Greenhouse gas emissions

GHG emission inventories for 1994 (reference year for the Initial Communication of Oman to UNFCC), 2000 (reference year for the Second communication of Oman to UNFCCC) and 2015 (Reference year for the first Biannual Update report of Oman to UNFCCC) are used in the following section to highlight the trend.

The methodology used to develop GHG emission inventory for 1994, is based on the Revised 1996 Guidelines for National Greenhouse Gas Inventories, as well the revised as the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Good Practice Guidance) prepared by the Intergovernmental Panel on Climate Change (IPCC). The revised 2006 Guidelines for National Greenhouse Gas Inventories of IPCC, is used for the GHG inventories of 2000 and 2015. In the following paragraphs, GHG emissions are reported in units of CO2-equivalent by applying 100-year GWPs of 1 for CO2, 28 for CH4, and 265 for nitrous oxide from the IPCC's Fifth Assessment Report.

Figure 31 shows the total GHG emissions and emission shares for the reference years 1994, 2000, and 2015 according to the four main IPCC categories: Energy, Industrial Processes, and Product Use (IPPU), Forestry and Other Land Use (AFOLU) and Waste.

Figure 32a presents the trend in total GHG emissions by type of GHG for the years 1994, 2000, and 2015. Over the 1994-2015 period, total emissions have increased by nearly 4.6 times; from 20.719 Mt CO2e in 1994 to about 96.072 Mt CO2e in 2015, or roughly 8%/year. Emissions of CH4 are increasing slightly above this rate, roughly 9% per year. Notably, HFC emissions accounted for about 13.4% of all CO2e in 2015, compared to no HFC emissions in 1994 and 2000.

Figure 33b presents the trend in net GHG emissions by the emitting sector for the Base Year 2006 and projected GHG emissions in 1994, 2000 and 2015. Energy remains the main component responsible for the overall increasing trend in GHG emission levels. Over the 1994-2015 period, CO2e emissions from energy use have increased over 4 times, or about 8% per year, due primarily to increased energy use for electricity generation, desalinated water production, and process heat in manufacturing. Notably, CO_2e emissions from Industrial Processes and Product Use (IPPU), though less than 31% of total emissions in 2015, increased by nearly 50 times, or about 20% per year. A large portion of this increase is associated with new industrial operations coming online during the intervening years (i.e., aluminum, methanol, and ammonia production facilities).

It is important to note that GHG emissions have been growing at a rate significantly above the population growth rate (3.1%/year) and approximately at the same level of the GDP growth rate (8.4%/year) over the 1994-2015 period (see Table 3). This indicates that Oman's economy still carbon-intensive over time, slightly decreasing from 1.6 to 1.4 kg CO_2 per dollar of output. At the same time, the population's consumption patterns are also becoming more carbon-intensive, increasing from 9.5 to about 22.9 tonnes CO_2-equivalent per person per year.

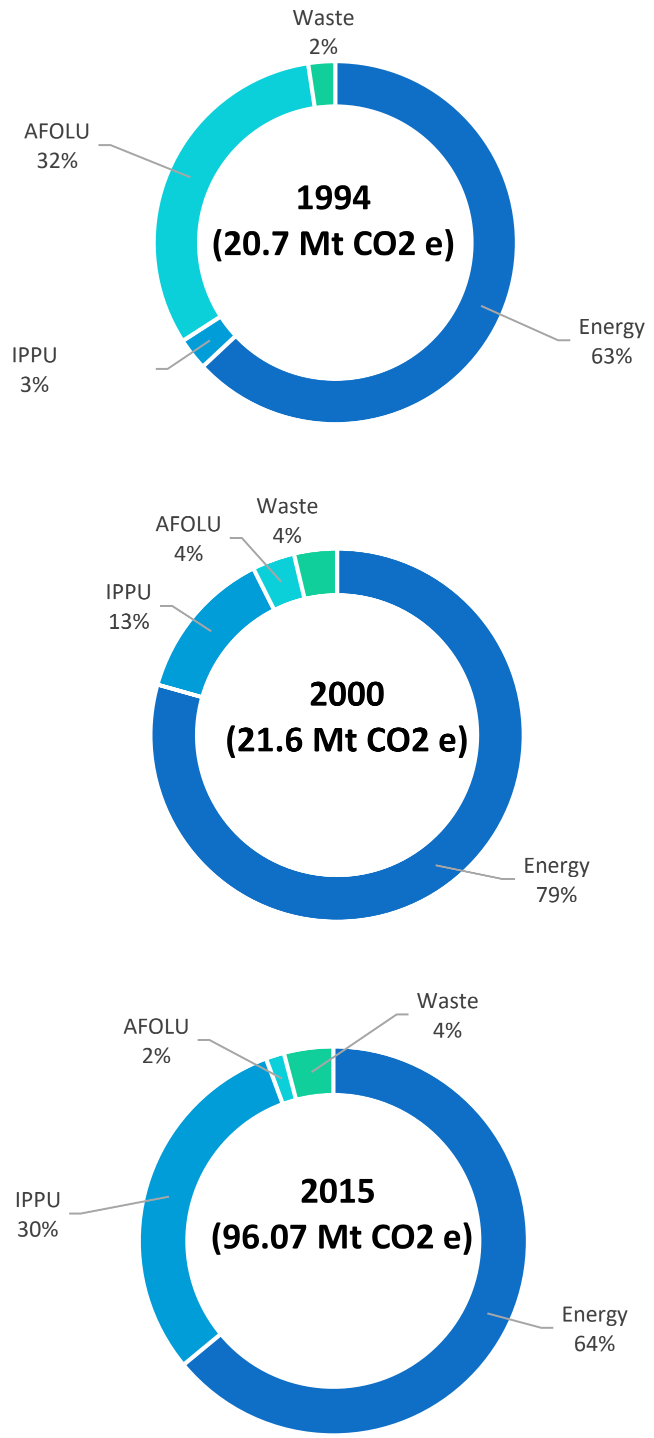
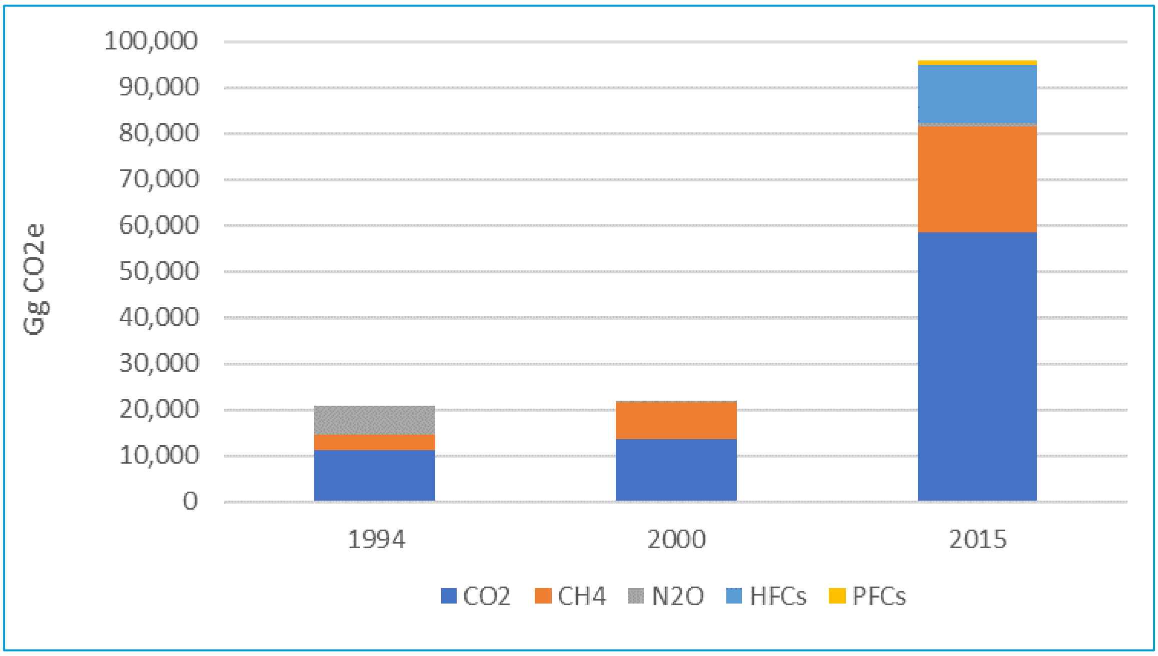
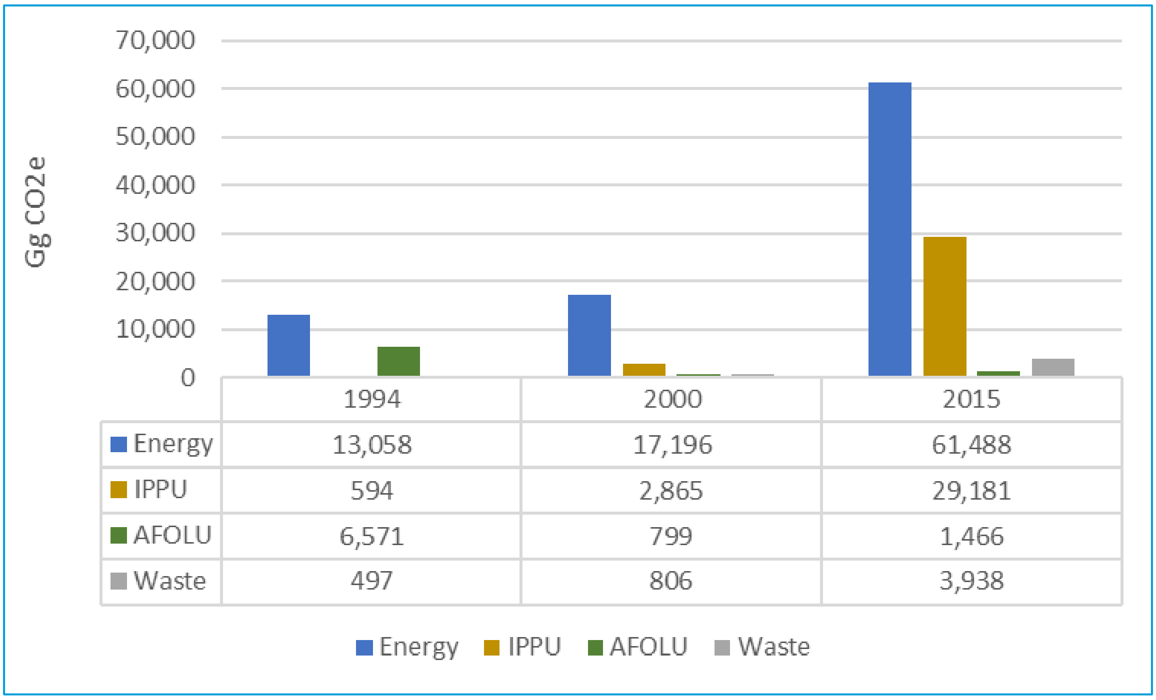


Figure 31: Total GHG emissions and emission shares, 1994, 2000, and 2015 (SoO, 2013 for 1994; Charabi, 2017 for 2000 and 2015)

a) Net emission trend by gas type, 1994, 2000, 2015



b) Net emission trend by emitting sector, 1994, 2000, 2015



	1994	2000	2015
Energy	13,058	17,196	61,488
IPPU	594	2,865	29,181
AFOLU	6,571	799	1,466
Waste	497	806	3,938

Figure 32: Trends in total GHG emissions by gas type and emitting sector (SoO, 2013 for 1994; Charabi, 2017 for 2000 and 2015)

Table 3: GHG emissions and carbon intensity indicators for Oman, 1994, 2005, and 2015 (Charabi, 2017)

Year	Emissions (MtCO2e)	GDP (Billion US$)	Population (Million)	CO2 intensity Kg/$	tCO2e/cap
1994	20.88	12.92	2.2	1.6	9.5
2000	21.66	19.51	2.6	1.1	8.3
2015	96.07	69.83	4.2	1.4	22.9
Growth,1994-2015 (%/year)	7.5%	8.4%	3.1%	-0.6%	4.3%

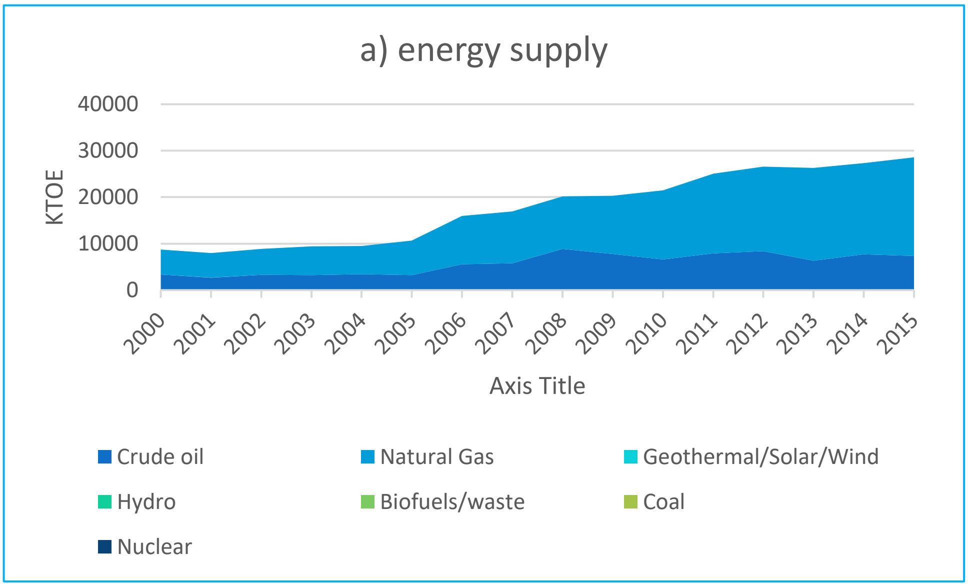
2. Energy

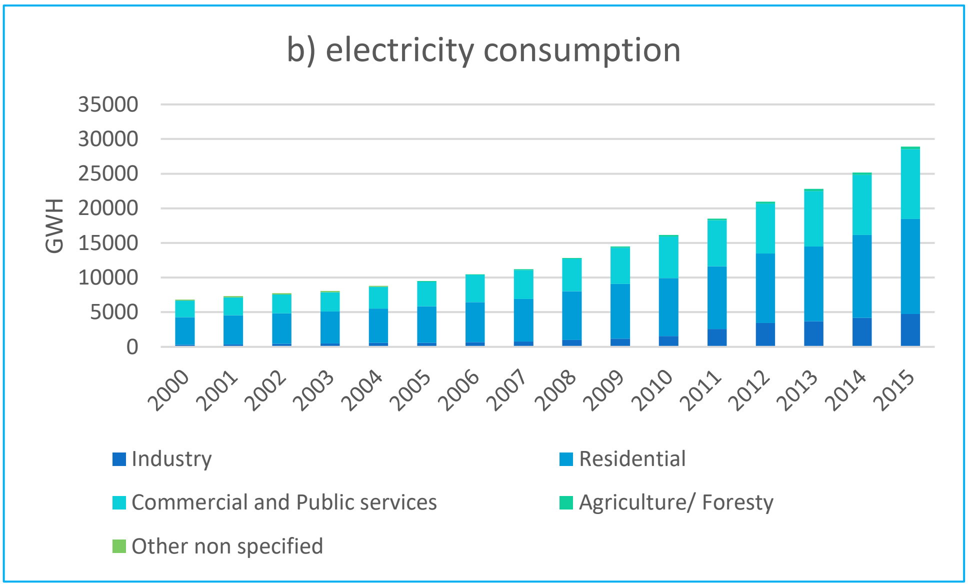
Oman's production of oil and natural gas plays an important in the national economy. In 2014, crude oil extraction operations accounted for 46,228 kTOE, most of which was exported - 39,221 kTOE, or 85% of total domestic supply (IEA, 2017). Most of the remaining oil that is consumed in Oman converted into refined oil products – diesel, gasoline, and jet kerosene – for use in the transport sector. Natural gas production shows far different characteristics, with the extraction of 30,103 kTOE, most of which is consumed within Oman (19,885 kTOE, or 67% of total domestic supply) for power generation and industrial applications (i.e., smelters, refineries).

Figure 33a shows that from the early 1970s to the present day, the total primary energy supply has relied exclusively on diesel oil and natural gas (IEA, 2017). There are no coal, biofuel/waste, renewable, or nuclear resources used in Oman. Total energy supply has grown rapidly between 1994 and 2014, from 6 to 24 kTOE, or 7.2% per year. Most of this growth is attributed to increasing shares of natural gas in the energy system. From a share of 58% in 1994, natural gas provided 81% of all energy supply in 2014.

Figure 33b shows electricity use by sector from 1994 to 2014 (IEA, 2017). Currently, there are fourteen (14) power stations in Oman, comprised of open-cycle gas turbines and combined cycle units for the co-production of water and desalinated water. Electricity production from these units is dominated by natural gas at over 97%. Transmission and distribution losses have declined from 14% in 1994 to 11% over the period 1994-2014. Total net electricity generation has increased rapidly during this period, from 4.8 TWh in 1994 to 25.2 TWh in 2014, or 8.6% per year. The highest growth has been in the industrial sector average 15% per year.

Figure 33c shows trends in the consumption of refined oil products from 1994 to 2104 (IEA, 2017). Gasoline, diesel, and heavy fuel dominated consumption from 1994 through 2004. Since then, heavy fuel oil has been replaced entirely by natural gas. The transport sector has grown in prominence, accounting in recent years for the highest share of refined oil use, averaging over 70%.





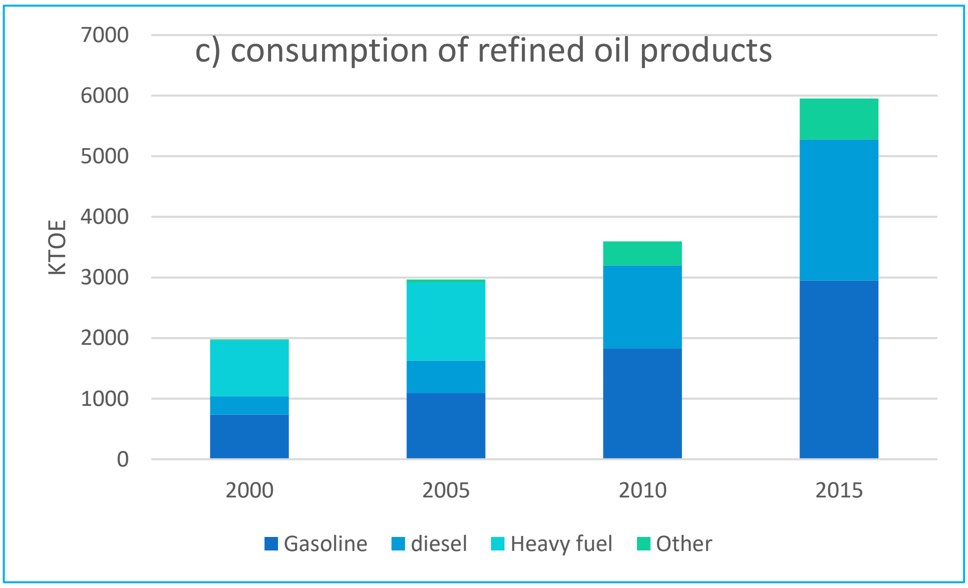


Figure 33: Total primary energy supply in Oman, 1994-2014 (IEA, 2017)

Renewable energy resources

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. If Oman's major renewable resources were to be gradually exploited and integrated into the electricity system, the carbon intensity of electricity generation could be significantly decreased. A review of the resource potential for each major and minor renewable resource type is summarized in the bullets below (Authority for Electricity Regulation, 2008).

- Solar: Total solar energy resources in Oman are huge and could, in theory, fully meet all domestic electricity demands and be available for export as well. High solar energy densities are available in all regions of Oman, ranging from 4.5 to 6.1 kWh/m^2 per day which are some of the highest in the world. The highest solar energy density is found in desert areas and the lowest are in coastal areas in the south. Photovoltaic and concentrating solar power (CSP) technologies are highly applicable.
- Wind: Oman boasts a long coastline that is exposed to strong summer and winter monsoon winds. Average wind speeds are slightly over 5 m/s with an estimated 2,463 hours of full load per year, making wind power a plentiful resource in Oman. Several locations are suitable for wind power development, namely locations at Thumrait, Masirah, Joba, Sur, and Quiroon Hariti. At the Thumrait and Qayroon Hyriti sites alone, 750 MW of wind power is economically viable, conservatively capable of generating 2.3 TWh, or about 8% of Oman's gross electricity production in 2014.
- Biogas: Oman has a large number of farm animals which theoretically could be used to produce electricity from methane in the wastes. Biogas plants can be located in food industries and at big farms with at least 100-200 stabled milk cows or camels. The total technical potential for electricity generation by biogas in Oman is about 35,000 MWh/year corresponding to a continuous power capacity of 4 MW.

Energy efficiency & conservation

There is a wide scope for improving 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 which will mitigate the growth of GHG emissions such as Energy management system, Labeling systems, Building codes, and Smart meters. Table 3 indicates major energy efficiency and conservation measures applicable to Oman (JICA, 2013). The GHG reduction benefits from these measures will result in a reduction of approximately 23 million tones of CO2- equivalent by 2035.

Transport activity in the Sultanate of Oman has grown rapidly in parallel with economic activity. The large increase in transport emissions in Oman was driven by growth in road transport demand. The main pathway to reduce emissions in the transport sector is related to the development of coherent and comprehensive sets of land use and urban expansion policies aimed at reducing the dependence on passenger vehicles. Lowering the GHG intensity from the future transport growth can be achieved in the Sultanate of Oman by adopting policies to encourage a shift to transport modes with lower emissions, by shifting passengers to traffic buses, rail or metro and freight to rail.

Table 4: Major energy efficiency and conservation measures applicable to Oman (JICA, 2013)

Sector	Energy efficiency & conservation measure	Potential	Rate of improvement
Industry	Energy management system	90%	1% per year
Commercial	Energy management system	60%	1% per year
	Labeling system for lighting	22%	90%
	Buidling codes	40%	25%
Governmental	Energy management system	60%	1% per year
	Labeling system for lighting	22%	9%
	Buidling codes	40%	25%
Residential	Labeling system (air conditioning, lighting, refigerators)	12% to 39%	9% to 23%
	Buidling codes (air conditioning)	39%	28%
	Smart meters	70% to 80%	2% to4%

Strategic actions

Several energy efficiencies and conservation measures in Oman will lead to substantial reductions in GHG emissions. There are two streams strategic actions for energy sectors as outlined below:

Stream E-1: Energy supply

GHG reductions can be achieved through diversification of its energy supply and exploiting Oman's extensive renewable energy resources. Specific strategic actions are indicated in the bullets below:

a) Create, adopt and implement a comprehensive energy action plan that can facilitate the immediate implementation of renewables;

b) Promote Solar and wind Power Generation in the country.

Stream E-2: Energy demand

As discussed earlier, substantial levels of GHG reductions can be achieved by providing an enabling environment for the introduction of energy efficiency and conservation measures. Specific strategies are indicated in the bullets below:

Removal of barriers to promoting energy efficiency and conservation.

a) Develop and implement national awareness-raising programmes on the benefits of energy efficiency and conservation.

Stream E-3: Water-food-energy nexus

Energy is closely linked to water resource management and agricultural development. The "water-food-energy nexus" is a framework that views water and food as part of an integrated system, rather than as independent resources. Energy is required to extract, convey, purify, and deliver water for agricultural productions and other end users in the economy. It is also used to treat municipal and industrial wastewater. Specific strategies are indicated in the bullets below:

a) Explore the costs and benefits of renewable energy-based seawater desalination for promoting energy and water security; and
b) Enforce building codes and standards for a sustainable building to promote water savings and energy efficiency.

3. Industry

The GHG emission form the industrial sector has grown steadily during the last two decades. The following strategic actions can lead to reducing GHG emissions.

Strategic actions

a) Increase the adoption of low carbon technologies in the industry.
b) Promote carbon emission management in new industrial projects.
c) Improving industrial energy efficiency through the implementation of waste heat recovery systems.

4. Waste

Over the course of 21 years (from 1994 to 2015), the GHG emission from the waste sector grew from 2% to 4%. The annual growth rate is 10.7% and this positive trend will continue in the future. The following strategic action can contribute to reducing GHG emissions.

Strategic actions

a) Development and implementation of domestic and industrial recycling systems.
b) Encourage the development of a programme for Methane generation and recovery.
c) Development of pilot projects for electricity generation with Methane Gas.

5. Agriculture

The following strategic action can contribute to reducing GHG emissions from the Agriculture sector in the Sultanate of Oman.

Strategic actions

a) Increase the adoption of low-carbon technologies for irrigation systems and other processes in the sector.
b) Develop an effective policy to control the use of pesticides and fertilizers.
c) Promote the current programs for rehabilitation of grazing land.

6. General strategic actions

General strategic actions aim to provide a strategic capability to identify, develop, and implement innovative research and technology to address the pressing challenges identified in climate change mitigation strategy:

Stream GSA-1: Research & Development

Diversifying the way in which Oman controls GHG emissions from various sources will depend on its institutional research and development capacity to exploit economic opportunities. Specific strategies are indicated in the bullets below:

a) Narrow the gap between industry and academia to establish an enhanced R&D culture in order to foster private-partner partnerships and synergies;

b) Establish research clusters and incubators with universities across Oman that are linked with promotional entities.

Stream GSA-2: Capacity building:

This involves strengthening the capacity building of the staff in the General Directorate of Climate Affairs, specifically in the following areas:

a) Measurement Reporting, and Verification (MRV).
b) Nationally Appropriate Mitigation Actions (NAMAs).
c) GHG inventory according to a higher tier method (Tier 2 and Tier 3).
d) Low-carbon technologies.

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