1. Executive Summary

Climate change is one of the most critical challenges the world faces today. In light of the climate impacts being experienced globally, systematic climate data collection and modeling as well as climate risk assessment have emerged as priority areas of research. The resultant global studies and analyses have yielded and continue to yield relevant findings for the UAE and the wider Arab region, while regional climate research and modeling is growing.

The purpose of this report is to review the results of research and modeling studies, and advance the understanding of the Arab region's changing climate and its impacts. Synthesizing key country-level and regional results, this report reviews available findings on (1) observed and projected climatic changes in the UAE and the wider Arab region, and (2) critical sectoral impacts of climate change. It acts as a summary of select major studies, encompassing changes in temperature, rainfall, seawater properties, sea level rise, and extreme weather. With regard to climate risks and impacts, the report focuses on infrastructure, public health, water and agriculture, and the environment.

A review of literature on the UAE and the region suggests that while some climatic projections are available, and future trends can be discerned, gaps in climate data and knowledge remain, calling for more region-specific studies. Climate modeling in the region has been sparse, and datasets and results are often difficult to compare, given differing assumptions, model choices, study boundaries and timeframes. Often, there is a high degree of uncertainty in the models and their projections due to limited data availability.

Climate Change Projections

Studies focused on the UAE and the Arabian Peninsula agree that average temperatures have risen and will continue to rise, even though the extent of the increase may differ across different parts of the Peninsula. Concomitantly, the surface water temperature in the Arabian Gulf will also rise, along with a smaller increase in the temperature of the deep waters of the Gulf (as heat does not travel well down the water column). In addition to temperature, other seawater properties will also register change. Seawater salinity and pH are projected to increase with increased water evaporation and higher absorption of CO_2, respectively.

Sea level in the Arabian Gulf is expected to rise due to deglaciation and thermal effects. Melting of ice caps and transfer of large amounts of ice to the water body of oceans is the biggest contributor to sea level rise. As global temperatures increase, ice mass loss in the Greenland and Antarctic ice sheets is expected to exacerbate sea level rise in the Gulf and elsewhere.

Projections for precipitation in the Arab region present a large uncertainty, and total average rainfall may either increase or decrease. It is indicated that rainfall may become less frequent, but the intensity of precipitation events may increase.

In addition to extreme temperatures, weather events such as droughts, sandstorms, and cyclones are a source of concern due to their devastating impacts. Extreme events such as hailstorms are expected to increase, especially in and around mountainous areas. Similarly, cyclonic activity in the Arabian Sea is expected to increase in frequency as well as severity.

Climate Impacts

Changes in the region's climate are already impacting people and infrastructure. An understanding of these impacts is vital for building adaptive capacity and enhancing climate resilience. Protecting lives and livelihoods as well as the gains of economic growth requires the integration of climate risks into development planning at the outset. Gulf countries have made a start in assessing climate risks and associated impacts, and defining adaptation plans to address them. As part of its National Climate Change Adaptation Program, the UAE has undertaken climate risk assessments for four priority sectors: energy, infrastructure, health, and the environment. This report captures key sectoral risks relevant for the UAE and the region.

Infrastructure facing risks from climate change includes buildings, transport links, energy assets, desalination plants, water supply lines, and sanitation and waste management facilities. Vital transport and energy links may be disrupted due to extreme temperatures as well as weather events, causing loss of economic opportunities. Gulf countries are home to extensive coastal and offshore infrastructure, which faces risks from sea level rise and storm surges as well as increased seawater salinity and pH.

On the health front, very high temperatures are a key risk factor for people residing in hot and arid countries of the region. Climate change may also increase the spread of vector-borne diseases and, with its impact on the prevalence of ozone and aeroallergens, cause a rise in the incidence of respiratory problems.

Climate's impact on surface water availability and groundwater recharge directly affects water access. Due to the acceleration of seawater intrusion owing to sea level rise, the quality of fresh groundwater resources in coastal aquifers will also be affected. These changes will hold consequences for communities, industry, and ecosystems. Decrease in freshwater availability implies that more freshwater will need to be produced from desalination of seawater, and hence the number and capacity of desalination plants in the UAE and the region may need to increase to respond to freshwater requirements. The agricultural sector, which in the Arab region depends highly on groundwater for irrigation, will be particularly affected. In addition to water scarcity, the sector will witness climate impacts on crop yields, suitability of locations for farming of traditional plants and crops, and livestock productivity and health.

Marine, terrestrial, and freshwater ecosystems, and the species and habitats integral to them, will be affected by rising temperatures, changes in precipitation patterns, sea level rise, and inland intrusion of saltwater. Regional studies on the vulnerability of species suggest serious consequences in the form of habitat loss and even extinction of species. Observations and modeling have indicated that coral reefs in the Arabian Gulf are already impacted by climate change through bleaching and disturbance regimes, the incidence of which may increase with changes in temperature and ocean properties.

A strengthened climate data collection effort is needed to better understand observed changes and improve modeling prospects in the UAE and the region. Increasing the scope of data collection and research, enhancing data quality, and developing models with varied scenarios and assumptions would allow the climate system to be better documented and better accounted for in policymaking. Robust climate science, and proactive adaptation planning for human wellbeing and sustained economic growth is needed to ensure that the UAE and the wider region are well-equipped to address climate risks and impacts.

2. Introduction

Climate change poses a critical challenge to the world today. It is estimated that human activities have caused global average temperature to rise by 1°C above pre-industrial levels, with a likely range of 0.8°C to 1.2°C (IPCC, 2018). If global warming continues at the current rate, it is likely to reach 1.5°C between 2030 and 2052 (IPCC, 2018)[1]. The changing climate is putting communities and ecosystems at risk globally, and the UAE and the Gulf region are no exception. The hot and arid desert climate of the region contributes to making it especially vulnerable to climate impacts.

The years 2020 and 2016 are tied as the warmest since temperature records began. Continuing the warming trend, the globally averaged temperature in 2020 was 1.02°C warmer than the baseline 1951-1980 mean (NASA, 2021). A UNDP (2010) report concluded that MENA is one of the regions most vulnerable to climate change impacts. It is projected that groundwater salinity in the region will increase, more land degradation will occur, and biodiversity on land and in Gulf waters will be affected. Rising sea levels will affect coastlines and could impact desalination plants, which are a vital source of freshwater in the UAE and the region. Climate change is expected to increase the frequency and intensity of extreme climate conditions and related disasters, leading to droughts, floods, hurricanes, and dust storms, and exposing people and infrastructure to risk. While the Arab region has been adapting to changes in rainfall and temperature for thousands of years, the pace at which the climate is now changing is challenging existing coping mechanisms.

The impacts of climate change are evident already, and the risks these pose are likely to compound over time. Changes in climate variables hold consequences for human safety and wellbeing, income, and employment. Safety and reliability of infrastructure (including transport links, energy and industry assets, and buildings), agricultural production and yield, freshwater availability, and ecosystems' health are expected to be impacted by the changing climate. Human health and sustenance will be threatened directly by climate impacts, such as rising temperatures, and indirectly by climate impacts on air, water, and food systems.

In order to mitigate risks, science-based climate adaptation policies are needed, and building the adaptive capacity of communities and economic sectors requires robust climate data and information. While strong evidence of rising average temperature, warming of the ocean's surface, sea level rise, glacial ice melt, and depth of seasonal permafrost thaw undeniably establishes that the Earth's climate is changing, uncertainty remains around the pace and possible impacts of climate change in the UAE and the Gulf region.

As the UAE works to build climate resilience, this report is a step towards enhancing the understanding of projected climatic changes in the UAE and the wider region, and their potential impacts. It synthesizes available findings and reviews published research in the field of climate change pertaining to the region.[2] The report aims to identify knowledge gaps and provide guidance for further locally relevant climate research.

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1 The Paris Agreement commits Parties to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC, 2015).

2 While an attempt has been made to include major relevant research studies and publications, the report is not intended to be exhaustive in its coverage of published literature.

Box 1: A Brief Introduction to Climate Models

The research findings cited in this report draw on a wide set of studies that employ different climate models. Climate models vary in design, complexity, and function, depending on the purpose for which they are developed, and the data, time, and resources available. As models become more complex, the number of calculations required to simulate atmospheric and oceanic interactions increases significantly (Bralower & Bice, 2021).

The simplest type of climate model, known as an Energy Balance Model (EBM), is designed to simulate the balance of solar energy entering the Earth's atmosphere and the escaping heat radiating from the Earth. With a little more complexity, it is possible to upgrade from an EBM to a Radiative Convective Model (RCM), which also takes into consideration the process of convection, and transfer of heat and vapor vertically in different layers of the atmosphere.

Further, for an in-depth understanding of the climate, researchers General Circulation Models (GCMs), also referred to as Global Climate Models. These types of models also consider the physics of the Earth's climate, and the flow of air and water along the Earth's atmosphere and oceans. GCMs, unlike RCMs, operate along 3D grids, and all calculations consider the exchange of properties in between every grid cell to simulate the transfer of energy, air, and water. As such, the smaller the grid cells and higher the resolution, the higher the number of calculations and computing time required to complete the model's simulation. For added detail, an Earth System Model (ESM) is employed, which is a GCM that captures intricate systems such as the carbon cycle, nitrogen cycle, GHG emissions, atmospheric chemistry, oceanic processes, and vegetation (Goosse et al., 2008). ECMs have received their name due to the building of Earth systems and biochemical cycles (interactions between biological organisms and their environment) into GCMs (Flato et al., 2013). ESMs are the most commonly used models for climate change projections. To reduce computational cost, it is possible to use an Earth System Model of Intermediate Complexity (EMIC), which is a simplified and coarser form of an ESM but more complex than an EBM. RCMs also fall within the category of EMICs (Goosse et al., 2008).

As GCMs and ECMs must consider interactions across the planet, the resolution of the models is often low (~250-600km) (Data Distribution Centre, 2021). To rectify this, it is possible to develop and use an RCM, which works at a much higher resolution. Typically, RCMs maintain a resolution of a few to tens of kilometers per grid box (Gutowski et al., 2020). As RCMs still need to take into consideration changes in the climate outside of the borders of the region, they are run in coordination with GCMs. With downscaling, a GCM is used to simulate global climate with the resolution increased substantially over the region of interest (Giorgi, 2019).

Over the years, it has become standard practice to opt for ensemble models as a means to better account for potential biases and deviations in individual models (Pincus et al., 2008). Ensemble modeling is a process of running multiple GCMs and ECMs together, and averaging the results to provide a more rounded impression of how the climate is likely to change.

One final model type is the Weather Forecast Model (WFM), which is primarily used for weather projections in the short term but with a significantly higher resolution and detail than its climatological counterparts. Although WFMs are not used for climate change-related projections, they can be utilized in conjunction with GCMs and ECMs to provide a seasonal analysis of future climate (Aseh & Woma, 2013).

Box 2: Modeling scenarios developed by the IPCC

IPCC's SRES Socio-Economic Scenarios

Prior to the release of the IPCC's Fifth Assessment Report (AR5), research primarily focused on climate modeling using the storylines and scenarios presented in the IPCC's Special Report on Emissions Scenarios (SRES) (2000). Each scenario family represents a set of assumptions for how the future could potentially change by 2100 (IPCC, 2000). Classified as the A1, A2, B1, and B2 storylines and scenario families, these describe the relationships between emission-driving forces and their evolution, and add context for scenario quantification. Each storyline represents different demographic, social, economic, technological, and environmental developments, while each scenario represents a specific quantitative interpretation of one of the four storylines (IPCC, 2000).

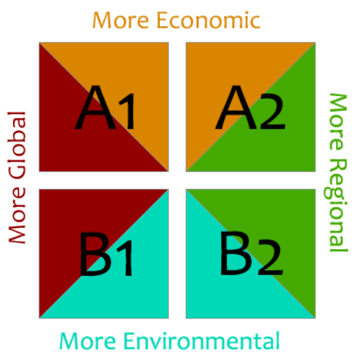
Representative Concentration Pathways (RCPs)

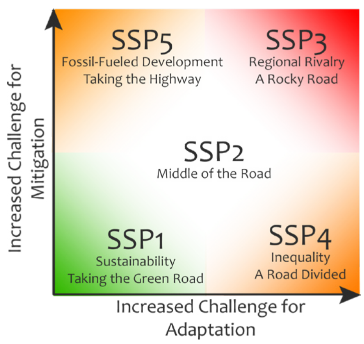
In 2014, the IPCC released the AR5, which described four different 21st-century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions, and land use, known as Representative Concentration Pathways (RCPs) (IPCC, 2014). Different concentrations are associated with radiative forcing increasing by a certain amount by 2100. To account for a range of potential emission scenarios, the forcing is set at 2.6, 4.5, 6.0, and 8.5 watts per square meter ($W\ m^{-2}$). RCPs were developed using integrated assessment models as input to a range of climate model simulations in order to project their consequences for the climate system. The scenarios are used to assess the risks and costs associated with emission reductions that are consistent with specific pathways.

RCP2.6 is a stringent mitigation scenario that aims to keep global average temperature rise to below 2°C above pre-industrial levels. RCP4.5 and RCP6.0 represent two intermediate scenarios, and RCP8.5 represents one with very high GHG emissions (IPCC, 2014).

Shared Socio-Economic Pathways (SSPs)

In 2016, a new set of socio-economic scenarios was developed to provide a replacement for the outdated SRES scenarios, however, the development is a very involved process, and therefore the scenarios have not seen much use in the early years. Nevertheless, with continuous refinements, the shared socio-economic pathways (SSPs) are now set to be integrated into the Coupled Model Intercomparison Project (CMIP6) in preparation for the IPCC's Sixth Assessment Report (AR6). The SSP scenarios, unlike the RCPs, reintegrate how socio-economic changes and initiatives can lead to different routes, which allows researchers to consider both RCPs and SSPs as complementary metrics for how the planet will respond to changes in environmental forcing and socio-economic changes. The five scenarios can be broken down as seen in the infographic below (Pinnegar et al., 2021).





3. Climate Projections for the UAE & the Gulf

The body of research on observed and projected climatic changes in the UAE and the region is limited yet growing. Existing literature on the subject relies on a variety of modeling frameworks, reflecting the diversity of models being employed globally to develop climate change scenarios (Box 1). Global models are used primarily due to the interconnected and dynamic nature of the atmosphere and oceans. Current modeling studies mostly take into account Representative Concentration Pathways (RCPs) that are defined on the basis of climate forcing. Box 2 summarizes the three sets of scenarios/storylines developed by the IPCC.

The climate projections available for the UAE and the wider region that are included in this report result from a range of different models, as indicated here. In essence, models are mathematical representations of the Earth's climate system, however, the system may ultimately prove to be too complex to model accurately. Therefore, results from climate models need to be validated or tested against real-world data to increase confidence in the projections produced.

This section captures the main research findings on historical records and trends as well as predictions of climate-related changes in the future with a focus on the following key parameters: temperature; rainfall; seawater temperature, salinity, and pH; sea level rise; and extreme weather events.[3]

Figure 1 summarizes key findings on climate variables most relevant to the region. Climate models largely project hotter, drier, and less predictable climate.

3 This section draws on the report 'Review of the Current Status of Climate Change Modeling in the UAE and the Region', prepared by a team of researchers from the United Arab Emirates University in 2019.

Climate Projections for the UAE & the Region

	2050	2100	
SALINITY	▲▲▲▲		Salinity will increase with higher evaporation and desalination
RAINFALL	▲ OR ▼▼	▲▲ OR ▼▼▼▼	Rainfall may increase slightly or decrease. The wide range is due to large uncertainties
HUMIDITY	▲		Average and maximum humidity will increase due to higher evaporation
SEA LEVEL RISE	▲▲		Sea levels will rise due to melting polar ice caps and thermal expansion of seawater
TEMPERATURE	▲▲▲	▲▲▲▲▲	Further warming through an intensified greenhouse effect
GROUNDWATER	▼▼		Lower recharge due to less rainfall. Some reservoirs will also be lost due to salt intrusion from rising sea levels. Uncertainties remain very high
EXTREME EVENTS			Increase in Arabian Sea cyclones and hailstorms in mountainous areas
OCEAN ACIDIFICATION	▼	▼▼▼	Decreasing pH due to increased carbonic acid formation with the added atmospheric CO_2

Rise	Drop	Very Low	Very High
▲	▼	▼▼▼▼▼	▲▲▲▲▲

Figure 1: Summary of modeled projections for different climate properties in the UAE and surrounding region

Temperature

Available field measurements confirm with certainty that the average global temperature has increased over time. The IPCC (2018) estimates that the global mean surface temperature has increased by 1.0±0.2°C since pre-industrial times, and predicts an increase of up to 1.5°C between 2030 and 2052.[4] The number of hot days is projected to increase in most land regions, with the highest increases in the tropics. Estimated human-induced global warming is currently increasing at 0.2°C (likely between 0.1°C and 0.3°C) per decade due to past and ongoing emissions.

Complementing global research, a set of findings is available for the UAE and the region. Figure 2 presents the observed changes in UAE surface temperature relative to 1951-1980 average temperatures. The data was prepared using the University of East Anglia Climatic Research Unit (CRU) Time Series (TS) Version 4.01 archives, ranging from 1901 to 2018. It is built on the basis of recorded observations, Angular Distance Weighting (ADW)[5], and interpolation where appropriate (University of East Anglia CRU, 2017). Based on the results illustrated in Figure 2, recent temperature records of the UAE show an increase of 2°C relative to 1950-1980. The results depict a rising trend from 1910 to 1960, followed by a 30-year period of roughly consistent average temperatures and subsequently a sharper increase in temperatures from 1990 to 2018. Figure 2b illustrates the R_2 values for the periods prior to and post-1980 to provide a statistical analysis of the scatter of the points. The period post-1980 shows both a steeper rise and a higher statistical significance, indicating more intense warming. Figure 2C was prepared as a means to analyze the influence of the warming on the varying seasons, indicating an intensification of warming in the summer months.

4 Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature for the decade 2006-2015 was 0.87°C (likely between 0.75°C and 0.99°C) higher than the average over the 1850-1900 period (IPCC, 2018).

5 ADW is a common interpolation approach used to take an irregular network of meteorological variables and apply them to a regular grid (Hofstra & New, 2009).

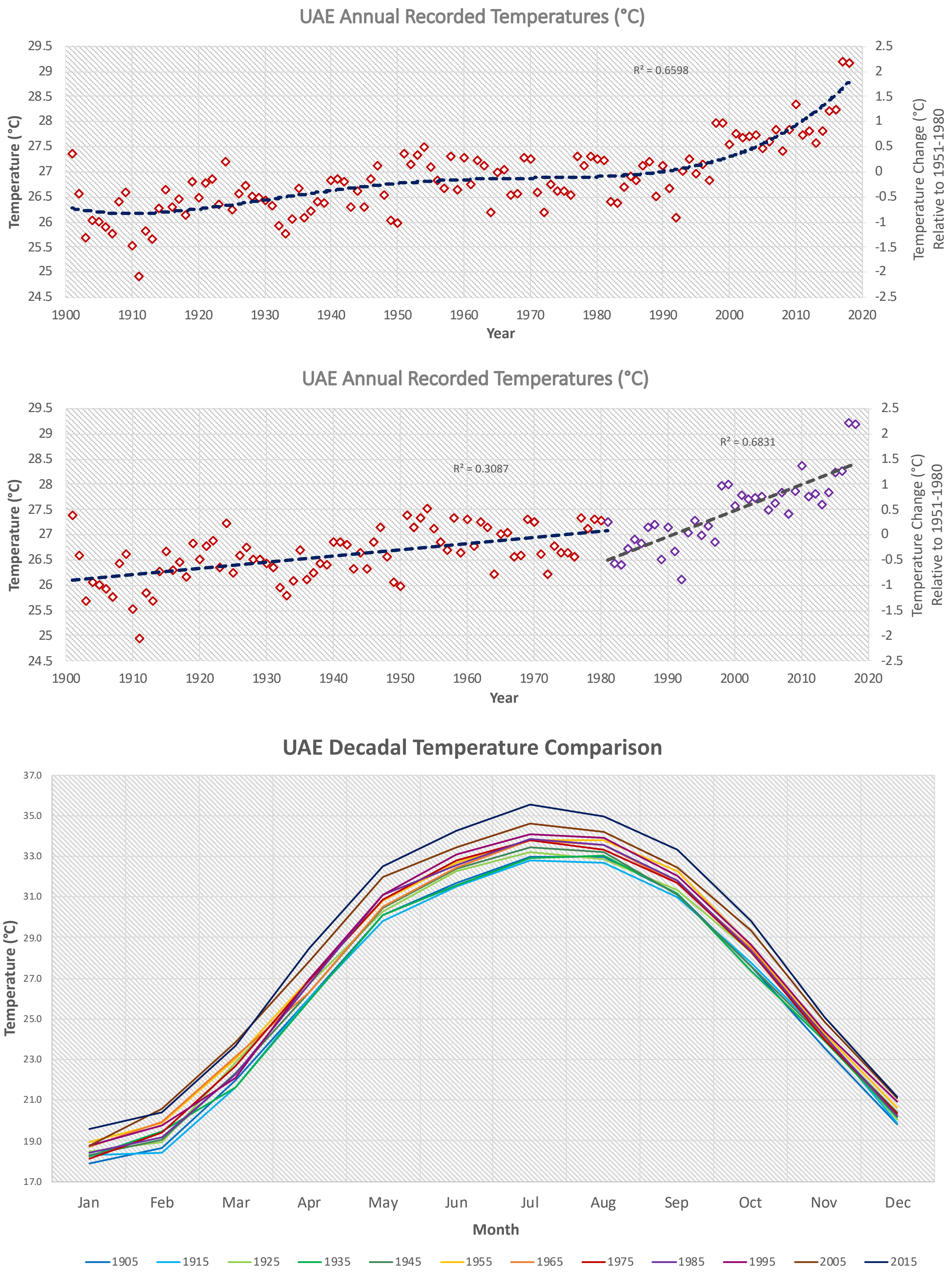


Figure 2: Change in the UAE surface temperature relative to 1980-1951. In figures A and B, the left Y-axis represents the mean annual recorded temperature, while the right Y-axis denotes how far each point deviates in relation to the 1980-1951 average benchmark. Figure C shows seasonal decadal temperatures. The data used is available on the University of East Anglia CRU website (University of East Anglia CRU, 2017).

Period	Western UAE	Central & Northeastern UAE	Eastern UAE
2050	2.29-2.38°C	2.26-2.29°C	2.21-2.25°C
2100	3.80-3.91°C	3.73-3.79°C	3.64-3.72°C

Table 1: Summary of UAE temperature projections as presented in Dougherty et al. (2009)

In terms of projections, the Stockholm Environment Institute generated a set of results for the UAE using Model for the Assessment of Greenhouse Gas-Induced Climate Change (MAGICC) and Regional Climate SCENario GENerator (SCENGEN). The models developed a regional climate baseline (1960-1991), and projected regional temperature and rainfall (Dougherty et al., 2009). A total of 17 GCMs were included in MAGICC/SCENGEN, and 36 IPCC emission scenarios were developed, grouped into four major categories: A1, B1, A2, and B2 (Box 2). The projections are summarized in Table 1.

A study by AGEDI (2015a) utilized the Community Earth System Model (CESM)[6] of the US National Center for Atmospheric Research (NCAR), which indicated warmer and wetter conditions throughout the Arabian Peninsula. In comparison with the 1986-2005 baseline, by 2060-2079 under the RCP8.5 scenario, the predicted average future temperature will increase by 2-3°C in the land area, with slightly smaller increases projected for coastal areas. The change is consistent across winter and summer seasons (AGEDI, 2015a). In order to increase the resolution of the model, AGEDI (2015a) employed the NCAR Weather Research Forecast (WRF)[7] model to dynamically downscale the Community Climate System Model Ver. 4 (CCSM4[8]). Results indicated an annual cycle of temperature in the Arabian Peninsula with a cold bias[9] of less than 1°C in the spring and early summer months, and a warm bias[10] of ~3°C during autumn and winter months.[11] In the AGEDI study in particular, it is unclear what caused the cold bias (projections for temperature underestimated the recorded values), however, it may be attributed to a positive rainfall bias during autumn and winter months. The biases were accounted for using the bias-corrected CCSM4 dataset to improve the WRF projections, which was shown to provide realistic results when compared with observations (AGEDI, 2015a).

The MENA region was further explored in a paper by Bucchignani et al. (2018), using the Centro Euro-Mediterraneo sui Cambiamenti Climatici Climate Model (CMCC-CM), a GCM, as the base, while regionally downscaling for the MENA region using a regional model developed by the Consortium for Small-scale Modeling in Climate Mode (COSMO-CLM[13]). Bucchignani et al. (2018) reported an increase in temperature of 2.5°C in winter months and 4°C in summer months under an RCP4.5 scenario by 2100 in comparison with the 1979-2005 baseline.

In a paper by Almazroui et al. (2016), an assessment of the CMIP3[14] GCMs utilized in the IPCC Fourth Assessment Report was conducted over the Arabian Peninsula. The study was designed to identify how the Arabian Peninsula was projected to be influenced by climate change over the succeeding decades via an examination of the ensemble of GCM data from the CMIP3. The projections for the B1, A1B, and A2 scenarios show a temperature increase of 0.37°C (northern Arabian Peninsula) and 0.35°C (southern Arabian Peninsula) per decade in comparison with the 1970-1999 base period. It was found that warming was more pronounced in the summer season compared with the winter season over the whole peninsula, however, the summer warming in the northern Arabian Peninsula was found to exceed the summer warming of the southern region. A similar study was conducted the following year (Almazroui et al., 2017) in an assessment of the projections of the ensemble GCMs used in the fifth phase of the Coupled Model

6 CESM is a fully coupled global climate model designed to provide simulations of the Earth's past, present, and future climate (NCAR, 2021).
7 WRF models are mesoscale numerical weather prediction systems designed to operate for both atmospheric research and operational forecasting due to their flexibility and the ability to use observations as well as idealized conditions (UCAR, 2021).
8 CCSM4 is a subset of the CESM and is designed to run five separate models simultaneously to simulate the Earth's atmosphere, oceans, land, land ice, and sea ice. The model allows for simulations of the Earth's past, present, and future climate states (Vertenstein et al., 2010).
9 Modeled temperatures when compared with observed temperatures in test years were found to be lower. This is identified by using the model to project over a period where data was recorded and validating how close the projections line up with the observations.
10 Modeled temperatures were warmer than observed temperatures in test years.
11 Biases occur when a model overestimates or underestimates any projections when its results are validated against observed data. They need to be corrected to ensure that over-/underestimations are not carried over into future projections.
12 CMCC-CM is a coupled atmosphere-ocean general circulation model (AOGCM) (Scoccimarro et al. 2011).
13 COSMO-CLM was developed as a hydrostatic model to produce forecasts at a resolution where convection could be simulated (Steger & Bucchignani, 2020)
14 CMIP3 is the third phase of the Coupled Model Intercomparison Project, designed as an experimental protocol for the analysis of output from coupled atmosphere-ocean general circulation models (AOGCMs).

Intercomparison Project (CMIP5) presented in the IPCC Fifth Assessment Report (AR5). The study analyzed temperature trends for the RCP4.5 and RCP8.5 scenarios. A warming of 0.23°C and 0.60°C was projected per decade in the northern Arabian Peninsula for RCP4.5 and RCP8.5 respectively in comparison with the 1970-1999 base period. In the southern Arabian Peninsula, warming was slightly lower at 0.20°C and 0.53°C for RCP4.5 and RCP8.5. Over the entire peninsula, the projections could be summarized as a decadal warming of 0.22°C and 0.57°C for RCP4.5 and RCP8.5 respectively.

The CMIP5 ensemble modeling approach was further utilized by the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) (ESCWA, 2017). RICCAR's projections also made use of the RCP4.5 and RCP8.5 scenarios utilizing three of the CMIP5's GCMs. The models include the EC-EARTH[15], CNRM-CM5[16], and GFDL-ESM2[17]. The GCMs were used to inform the Rossby Centre Regional Atmospheric Model (RCA4[18]) of atmospheric conditions outside of the region. The RCA4 model has been incorporated over the domain of the MENA region. The study took into consideration a comparison of the reference period (1986-2005) against a mid-term (2046-2065) and long-term projection (2081-2100).

RICCAR's projections evaluated annual and seasonal trends in warming and identified a universal warming in both scenarios. Projections show a warming of 1.2-1.9°C for RCP4.5 and 1.5-2.3°C for RCP8.5 in the mid-term. By the end of the century, projections revealed a warming of 1.7-2.6°C for RCP4.5 and 3.2-4.8°C for the RCP8.5 scenario. It should be noted that the study included a seasonal analysis of temperature trends, however, analysis had indicated a cold bias, particularly in winter months, and a warm bias in the summer in the southeastern region of the Arabian Peninsula. These biases were corrected with the use of the Distribution-Based Scaling (DBS[19]) method, and the annual results have been derived from the corrected values (ESCWA, 2017).

Using a similar set of RCP scenarios, in a paper by Al Blooshi et al. (2019), temperature changes in three areas spanning two UAE emirates were investigated using a combination of 17 models as part of the MarkSimGCM system. With a reference to the 1960-1990 base period, the study examined the maximum projected temperatures in Abu Dhabi, Al Ain (part of the Abu Dhabi emirate), and Sharjah under the RCP4.5 and RCP8.5 scenarios. Readings for 2095 show a considerable increase in temperature for the three emirates compared to the baseline, extending up to 5.35°C for the RCP8.5 scenario in Sharjah. The results have been summarized in Table 2.

Almazroui et al. (2020a) returned to the multi-model ensemble of the CMIP5 in order to model temperature changes in the Arabian Peninsula using 22 models over three representative timeframes. The projections were broken down to short-term (2030-2039), mid-term (2060-2069), and long-term (2090-2099) for the RCP4.5 and RCP8.5 scenarios. The projections were further broken down into seasonal analyses. The results of the projections have been summarized in Table 3 and show the increase in temperature relative to the 1971-2000 base period. Validation efforts on part of the research indicated temperature biases in the summer and winter seasons, whereas the spring and autumn projections were more in line with observations. Annually, the projected increase in temperature is highest in the central region.

Emirate/Area	RCP4.5	RCP8.5
Abu Dhabi	2.44°C	4.56°C
Al Ain	3.48°C	4.74°C
Sharjah	3.38°C	5.35°C

Table 2: Summary of projected warming by 2095 (Al Blooshi et al., 2019)

15 EC-EARTH – a GCM developed to utilize the seasonal prediction configuration of the European Centre for Medium-Range Weather Forecasts (ECMWF) as the base of the climate model (EC-Earth, 2021).
16 CNRM-CM5 – a GCM developed by the Centre National de Recherches Météorologiques – Groupe d'études de l'Atmosphère Météorologique and Cerfacs to contribute to the CMIP5 (Voldoire et al., 2013).
17 GFDL-ESM2 – the Geophysical Fluid Dynamics Laboratory's Earth System Model, upgraded to incorporate explicit and consistent carbon dynamics (Dunne et al., 2012).
18 RCA4 – developed from the numerical weather prediction High-Resolution Limited-Area Model (HIRLAM) (ESCWA, 2017).
19 DBS is a bias correction method applied to climate models to improve their suitability for climate impact assessment. DBS matches observed and simulated frequency distributions of data, and applies a variable-dependent theoretical distribution (Yang et al., 2010).

Season	Period	RCP4.5	RCP8.5
Winter	2030-2039	1.472-1.790°C	1.695-2.125°C
	2060-2069	2.254-2.934°C	3.620-4.156°C
	2090-2099	2.551-2.895°C	5.206-5.582°C
Spring	2030-2039	1.258-1.718°C	1.493-1.969°C
	2060-2069	2.289-2.667°C	3.499-3.811°C
	2090-2099	2.592-2.892°C	5.224-5.734°C
Summer	2030-2039	1.489-1.831°C	1.723-2.109°C
	2060-2069	2.413-2.761°C	3.484-4.178°C
	2090-2099	2.779-2.959°C	5.684-6.072°C
Autumn	2030-2039	1.504-1.896°C	1.689-2.203°C
	2060-2069	2.739-3.303°C	4.027-4.721°C
	2090-2099	3.029-3.271°C	5.802-6.352°C

Table 3: Summary of seasonal temperature increase projections for the Arabian Peninsula in the short, mid, and long term for RCP4.5 and RCP8.5 scenarios (Almazroui et al., 2020)

Almazroui et al. (2020b) continued analysis of the CMIP multi-model datasets by exploring the sixth phase of the Coupled Model Intercomparison Project (CMIP6) and the projected changes to temperature over the Arabian Peninsula. The updated analysis included an assessment of the ensemble of 31 CMIP6 models under three new shared socio-economic pathways (SSPs): SSP1, SSP2, and SSP5 (Box 2). A near-term period (2030-2059) and a far period (2070-2099) were taken into consideration and compared against the base period of 1981-2010. Results over the peninsula under the projected timeframes and scenarios have been summarized in Table 4. The results have also indicated increased projected warming in the summers compared to winters and additional warming in the northern Arabian Peninsula compared with the southern region by 2100.

Across research studies, there is a consensus on an increase in average temperatures in the Arab region. This increase becomes more pronounced in high-emission scenarios and the further the results extend into the future. The degree of warming varies from study to study, however, some trends become apparent, including higher warming in summers compared to winters and a higher degree of warming in the northern Arabian Peninsula in comparison with the South.

Precipitation

Projected global trends suggest that as global surface temperatures increase, most wet tropical regions and mid-latitude land masses will experience a higher intensity and frequency of extreme precipitation events (IPCC, 2014a). Rainfall is often harder to model and predict than temperature. Depending on the initial assumptions a model is set up to use, rainfall projections for a region often vary widely.

For the purposes of this report, a primary assessment of observed changes in rainfall in the UAE was undertaken. Data spanning the period 1982-2017, available with the UAE's National Center of Meteorology, was utilized, and the available records of six main rainfall stations in the UAE, including the international airports of Abu Dhabi,

Period	SSP1	SSP2	SSP5
2030-2059	1.2-1.9°C	1.4-2.1°C	1.8-2.7°C
2070-2099	1.2-2.1°C	2.3-3.4°C	4.1-5.8°C

Table 4: Projected warming in the Arabian Peninsula based on an assessment of the 31 CMIP6 models (Almazroui et al., 2020b)

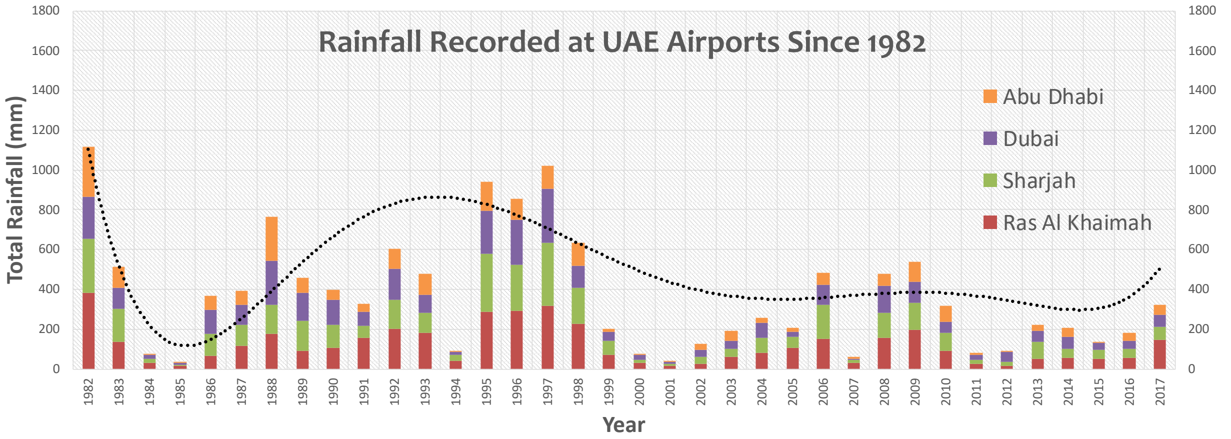


Figure 3: Historical rainfall trends recorded at six airport weather stations in the UAE (collected by the National Center for Meteorology)

Al Ain, Dubai, Sharjah, Fujairah, and Ras Al Khaimah, were considered (Figure 3). The graph shows that rainfall in the UAE does not exhibit a clear increasing or decreasing trend over the years, even though post-1999, it does not appear to spike as high as during some of the previous years. Nevertheless, the short timeframe implies that there is not enough evidence to conclude if the observed changes in rainfall patterns can be attributed to climate change or to natural variations and cyclical patterns.

Basha et al. (2015) investigated precipitation trends in the UAE using a stochastic model (allowing for fluctuations in historical data) and reported rainfall projections. It was shown that post-1960, precipitation exhibits an oscillatory trend, whereby rainfall increases for a 20-year period and declines over the next 20, continuing to follow this pattern. Rainfall in the UAE was projected to continue to decrease post-2015 to a minimum in 2035 and then increase thereafter. With rainfall trends following a 20-year pattern, it would be difficult to identify the influence of climate change on rainfall in the region without a rainfall dataset for a longer duration.

While focused on a small geographical area, based on the results of a culmination of 36 IPCC models grouped into the A1, B1, A2, and B2 scenarios, the range of precipitation change for the Abu Dhabi emirate was projected to be between -21.20% and +10.33% for 2050 and between -37.8% and +18.4% for 2100, relative to the 1961-1990 annual average (Dougherty et al, 2009).

AGEDI (2015a) reports that according to CCSM4 simulations as run for the IPCC AR5, for the period 1986-2005, daily precipitation in the Arabian Peninsula stood at 0.5 mm/day and has been projected to increase by ~0.1 mm/day by 2100. AGEDI's work on regional climate modeling, downscaled from the CESM (which includes the CCSM4), indicated that rainfall is projected to increase over much of the UAE and the Hajar Mountains (AGEDI, 2015a). By 2060-2079 for the RCP8.5 scenario, AGEDI projects an increase of 50-100% from the baseline of 1986-2005 for parts of Dubai, Sharjah, and northern Abu Dhabi. The surrounding regions are expected to witness a rainfall increase of about 25% (AGEDI, 2015a[20]). Decreasing rainfall is predicted over much of Oman and eastern Saudi Arabia. An increase in rainfall is predicted over the Arabian Gulf and Gulf of Oman. Additionally, according to AGEDI's analysis, while the increase over the Arabian Gulf waters occurs during the winter season, in the UAE, the increase in rainfall during the summertime is larger than the increase during the winter period in both absolute value and percentage change (AGEDI, 2015a).

The AGEDI (2015a) analysis also projects that more rain will fall in general but in fewer rain events. Despite the projected increase in rainfall over much of the UAE, the number of wet days is projected to decrease. Rain events will be more intense when it does rain, however, there will be a higher tendency towards longer dry spells. This is primarily due to the influence of warming of the air. Warmer air can hold more moisture, and hence it would

20 AGEDI notes that the CCSM4 model projects wetter conditions for the Arabian Peninsula as compared to the ensemble of the CMIP5. Therefore, regional results may also overestimate rainfall.

take more evaporation for the air to reach its vapor-carrying capacity and for condensation to occur. When it does rain, the added moisture will result in more extreme rain events (Patz et al., 2014).

The AGEDI study extends into humidity projections as well and identifies that changes in humidity are expected to be greater in summer months, associated with higher evaporation due to warming temperatures. Humidity is projected to increase by about 10% over the Arabian Gulf under the RCP8.5 scenario, with a slightly lower increase in humidity in most parts of the UAE (AGEDI, 2015a).

Almazroui et al. (2016) assessed the CMIP3 GCMs utilized in the IPCC's Fourth Assessment Report to identify how the precipitation over the Arabian Peninsula would alter over time. The projections for the B1, A1B, and A2 scenarios showcase that the changes in precipitation will not be uniform across the entirety of the region. Projections across all three scenarios show a decrease in precipitation of 1.35% per decade in the northern Arabian Peninsula with reference to the 1970-1999 base period. In contrast, the southern Arabian Peninsula shows a decadal increase in precipitation of +1.21%. A similar study was conducted the following year (Almazroui et al., 2017) using the CMIP5 projections as part of the IPCC's Fifth Assessment Report under the RCP4.5 and RCP8.5 scenarios. Projections displayed trends similar to the 2016 study with respect to precipitation in the northern and southern regions of the Arabian Peninsula. The results showed a decadal decrease in precipitation over the northern Arabian Peninsula of -1.18% and -0.14% for the RCP4.5 and RCP8.5 scenarios respectively. In contrast, the southern Arabian Peninsula showed a decadal increase in precipitation of +0.34% and +2.99% for the RCP4.5 and RCP8.5 scenarios. On an average, the entire Arabian Peninsula was projected to experience a trend of -0.27% and +2% in precipitation for the RCP4.5 and RCP8.5 scenarios respectively per decade.

The precipitation results from Almazroui et al. (2017) were in agreement with projections of the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) (ESCWA et al., 2017). RICCAR's projections also made use of the RCP4.5 and RCP8.5 scenarios and ensemble modeling, however, only three of the CMIP5's GCMs were utilized as part of the report. The study compared the reference period (1986-2005) with a mid-term (2046-2065) and a long-term projection (2081-2100). The results of the RICCAR study (ESCWA et al., 2017) show that precipitation changes vary across different parts of the MENA region, and therefore no conclusive results can be drawn on average annual or seasonal changes across the region. As such, the use of a mean, annual change in rainfall over the MENA region would be misleading, as there are more pronounced changes in localized areas. Over the Arab region, both RCP scenarios show a decrease in monthly precipitation in the mid-term and an overall monthly decrease of up to 8-10mm by the end of the century in coastal regions near the Euphrates and Tigris rivers. On the other hand, further south, some regions have been projected to experience an increase in precipitation, which includes the southeastern Arabian Peninsula. This could be attributed to the potential shift in the Intertropical Convergence Zone (ITCZ[21]), which has been suggested to migrate further northwards in response to a warming climate (ESCWA et al., 2017).

In a paper published two years later, Al Blooshi et al. (2019) made use of an ensemble modeling approach to investigate precipitation changes over three areas spanning two of the UAE's emirates, using the MarkSimGCM as a means to utilize the combination of the 17 models embedded within it. The study made use of the RCP4.5 and RCP8.5 scenarios. Readings for 2095 show a general trend towards an increase in precipitation, however, the trends are not uniform over the study area. The results are summarized in Table 5.

	RCP4.5	**RCP8.5**
Abu Dhabi	+3.28 mm	-0.92 mm
Al Ain	+0.14 mm	+1.12 mm
Sharjah	+1.90 mm	+2.32 mm

Table 5: Summary of projections for precipitation changes by 2095 (Al Blooshi et al., 2019)

21 The ITCZ represents a belt of warm, rising air and converging winds found near the equator. The warm, rising air develops thick cloud activity, rainfall, and frequent thunderstorms (Schneider et al., 2014).

Almazroui et al. (2020b) conducted an assessment of an ensemble of 31 CMIP6 models and their projections for precipitation over the Arabian Peninsula. The study incorporated the new SSPs (Box 2) that are due to supersede RCPs in the IPCC's Sixth Assessment Report (AR6). The scenarios considered include SSP1, SSP2, and SSP5 with projections into the near term (2030-2059) and long term (2070-2099) in comparison with the 1981-2010 base period. Results over the Arabian Peninsula under all considered scenarios and timeframes have been summarized in Table 6. The researchers have also noted that the results show a robust increase in the mean annual precipitation over the southern Arabian Peninsula with a decrease in the North.

Period	SSP1	SSP2	SSP5
2030-2059	5-28%	5-31%	1-38%
2070-2099	-3-29%	4-49%	12-107%

Table 6: Projections of precipitation changes in the Arabian Peninsula on the basis of an assessment of the 31 CMIP6 models (Almazroui et al., 2020b)

Notably, in recent years, the UAE has embarked on cloud seeding as part of its rainfall enhancement program (Breed et al., 2005). It is difficult to determine how much of the observed rainfall in recent years can be attributed to cloud seeding; concomitantly, a comparison between recent observations and previous records may not lead to accurate trends.

Overall, precipitation projections over the region have been shown to be more dynamic and sporadic than temperature projections. The majority of studies undertaken suggest that identifying precipitation patterns over the region would not provide an accurate representation of changes, as climate change's influence on precipitation is more localized and not uniform across the region. Projections across the northern and southern Peninsula vary. Research also suggests that it is likely that the region will witness a decrease in rain frequency with an increase in intensity.

Seawater – Temperature, Salinity & pH

Under the influence of a warming climate, seawater properties have registered change, and will continue to do so. Over the course of the 21st century, the ocean is projected to witness unprecedented conditions characterized by increased temperatures, greater upper ocean stratification, and further acidification (IPCC, 2019). Oceans are regarded as buffers, and unlike the atmosphere, natural changes in seawater temperature, acidity, and salinity (with the exception of estuaries) occur gradually and with minor shifts. Aquatic organisms are not well-suited to cope with large shifts: findings from laboratory, field, and modeling studies, in addition to evidence from geological records, indicate that "marine ecosystems are highly susceptible to increases in oceanic CO_2 and the corresponding decreases in pH and carbonate ion" (IPCC, 2013). Climate-induced changes are therefore likely to put these organisms at increased risk. Moreover, changes of larger magnitude are more likely to occur as the ocean's ability to buffer weakens with constant pressure from climate change.

Sea Surface Temperature & Salinity

Since 1970, the ocean has warmed unabated and has stored more than 90% of the excess heat in the climate system (IPCC, 2019). With ocean warming being the largest near the surface, over the period 1971-2010, the upper 75 m warmed by 0.11°C (between 0.09 and 0.13°C) per decade (IPCC, 2014a). Global projections drawn from the CMIP5 indicate a rise in global sea surface temperature of 0.8°C by 2050 and 1.2°C by 2100, relative to 1870-1899 temperatures for RCP2.6; and a rise of 1.5°C by 2050 and 3.2°C by 2100, relative to the same time period, for RCP8.5 (IPCC, cited in Foresight, 2017).

For the Arabian Gulf, Shirvani et al. (2015) reported that the Gulf water temperatures have warmed by about 0.57°C during the 1950-2010 period. Readings were calculated using an Autoregressive Integrated Moving Average (ARIMA) model. Although a significant trend was not evident for the 1950-1969 and 1970-1989 periods, the Arabian Gulf sea surface temperatures have abruptly increased thereafter. There is an increase in sea surface temperature by 0.7°C/decade along the western side of the Gulf with reference to the 1950-2006 period used to develop the model and the 2007-2011 period used to test the model.

Piontkovski and Queste (2016) investigated changes to the physical and biochemical properties of the upper 300 m of the western Arabian Gulf, using the NCEP/NCAR reanalysis database[22] with records spanning 1950-2010. The results made use of the same timeframe as Shirvani et al. (2015) but expanded on the research by introducing the component of depth to seawater temperature changes. Piontokovski and Queste (2016) identified a decadal increase in surface water temperatures of 0.6°C in the western Arabian Gulf in the mixed layer (upper ~30 m) with a slightly lower value of ~0.4°C at depth (300 m).

Further, in terms of future trends, Noori et al. (2019) investigated the influence of climate change on the Arabian Gulf and the Gulf of Oman under the RCP8.5 scenario. Projections considered warming by 2030, 2050, 2070, and 2100 in comparison with the control period of 2016-2018. The projection was calculated based on historical changes in regional sea surface temperature and with the use of a Proper Orthogonal Decomposition (POD[23]) model. An annual assessment of the results showed that the north coast of the UAE and south coast of the Strait of Hormuz will experience the greatest warming by 2100, reaching temperatures of up to 32°C. For comparison, the mean Arabian Gulf seawater temperature is projected to rise from 28.5°C in 2015 to 30.7°C in 2100, while maximum temperatures are set to rise from 29.9°C in 2015 to 31.8°C in 2100. Additionally, for each of the projected years, the maximum projected increase in temperature in the Arabian Gulf was found to be 2.1°C (May 2030), 2.8°C (May 2050), 3.4°C (August 2070), and 4.3°C (August 2100) (Noori et al., 2019).

The results had also indicated that warming will be more intense during the summer season in both the Arabian Gulf and Gulf of Oman, which falls well in line with the atmospheric temperature projections that also show an intensification of summertime warming by the end of the century (Almazroui et al., 2020a, 2020b; Al Blooshi et al, 2019; Bucchignani et al., 2018).

Notably, under warming conditions posed by climate change, marine life is not well-adapted to adjust. Adverse impacts may include a decrease in the body size of ectotherms (Audzijonyte et al., 2020) and thermal bleaching of corals (Burt et al., 2019; Paparella et al., 2019).

In addition to seawater warming, climate-related changes in ocean properties include shifts in salinity. According to the IPCC, it is very likely that regional precipitation trends have increased the mean geographical contrasts in sea surface salinity since the 1950s: "saline surface waters in evaporation-dominated mid-latitudes have become more saline, while relatively fresh surface waters in rainfall-dominated tropical and polar regions have become fresher" (Rhein et al., 2013). Increased evaporation with rising temperatures also leads to changes in salinity. Understanding changes in ocean salinity is critical not only as an indicator of precipitation/evaporation over the ocean but also because salinity changes affect circulation and stratification, in turn impacting the ocean's biological productivity, in addition to its capacity to store heat and carbon (Rhein et al., 2013).

In the Arabian Gulf, salinity is likely to increase due to the increase in evaporation with the warming atmosphere. Additionally, it is expected that the expansion of seawater desalination facilities will increase the already high level of salinity. AGEDI (2015b, 2015c) reported that with climate change, the Arabian Gulf will become even more stressed, with significant increases in temperature across the Gulf, coupled with zones of large salinity increases.

Acidity (pH)

With increased concentration of GHGs in the atmosphere, another important change in seawater properties includes ocean acidification or a decrease in seawater pH due to the ocean's increased sequestration of atmospheric CO_2 content. The ocean has taken up 20-30% of anthropogenic CO_2 emissions since the 1980s, leading to acidification (IPCC, 2019). Since the beginning of the Industrial Revolution in the early 1800s, the pH of surface ocean waters has fallen by 0.1 units, however, despite the small value, pH units operate on a logarithmic scale, and a pH decrease of 0.1 constitutes an increase in acidity of ~30% (NOAA, 2020b). Open ocean surface pH has declined by a very likely range of 0.017-0.027 pH units per decade since

22 Climate reanalysis is the process of collecting records of past observations and using a model to fill in the gaps in the records to provide a more comprehensive and consistent rendition of the historical climate.

23 A POD model is a numerical method applied to reduce the complexity of computationally intensive simulations, such as those in fluid dynamics (Luo & Chen, 2018).

the late 1980s (IPCC, 2019).

Investigation of trends based on data gathered on the western Arabian Sea from oceanographic expeditions and remote sensing for the period 1950-2010 has indicated a decrease in pH by roughly 0.1 in the upper 30 m of the western Arabian Gulf between 1960-2000 (Piontkovski & Queste, 2016). The drop in pH was more pronounced at depth (300 m) with a decrease of 0.2 in the same 40-year span on the basis of pH measurements taken over a four-year period (2007-2010).

Sea Level Rise

Sea levels are expected to rise due to a number of factors, including thermal effects and deglaciation (Pardaens et al., 2011). Deglaciation is generally caused by ice melting and the transfer of huge amounts of ice to the water body of oceans. The melting of ice represents a major contribution towards sea level rise (Rignot et al., 2011). The thermal effect is attributed to the expansion of water with the increase in temperature: the water bodies of oceans and seas act as sinks of heat, and hence the water expands, occupying more space (McKay et al., 2011). Notably, there is a time lag between the change in temperature and sea level rise, as the water body continues to absorb heat for a long period after the stabilization of air temperature (Gregory & Oerlemans, 1998).

According to Lindsey (2020), based on the data captured by the National Oceanic and Atmospheric Administration (NOAA), sea levels rose by 1.4 mm/year over most of the 20th century, and the process accelerated to 3.6 mm/year as per 2006-2015 data.

When considering future projections, modeling sea level rise requires the use of coupled ice-atmosphere-ocean general circulation models. IPCC (2018) model-based projections of global mean sea level rise (relative to 1986-2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C of global warming, and 0.36-0.88 m for 2°C. The following year, the IPCC (2019) projected a higher increase of 0.61-1.1 m by 2100 under the RCP8.5 scenario. Sea levels will continue to rise well beyond 2100, and the magnitude and rate of this rise will depend on future emission pathways.

With respect to the rate of growth, a recent study conducted by Nerem et al. (2018) revealed that global sea level rise is accelerating incrementally over time rather than increasing at a steady rate. The accelerated rate of sea level rise lowers opportunities for adaptation in human and ecological systems. The study is based on 25 years of NASA and European satellite data. Results show that since 1993, global mean sea level has been rising by ~3±0.04 mm/year, however, using the data coupled with considerations for interannual and decadal variability, the rate of sea level rise was shown to be accelerating by 0.084 ±0.025 mm/year^2 as calculated using the 25 years of data. In other words, sea levels have been shown to be rising by slightly more every year compared with the previous year. With the use of extrapolation, readings implied global mean sea level could rise by 650±120 mm by 2100 compared with 2005 sea levels if the rate of ocean rise continues to change at the current pace. It has also been suggested that had the rate of rise remained consistent at 3 mm/year, the global sea level would only rise by roughly half of what is currently projected for 2100 (Nerem et al., 2018). The results are in line with the projections shared by the IPCC (2018) AR5 report and hovering at the lower end of the projected range of sea level rise in the IPCC (2019) Special Report on the Oceans and Cryosphere in a Changing Climate.

When considering more regional-scale research on sea level rise, a paper by Alothman and Ayhan (2010) summarizes the results of a study that takes into account in-situ tide gauge data in the Arabian Gulf as well as Global Navigation Satellite System (GNSS) measurements. Thirteen tide gauge stations were selected along the eastern coasts of Saudi Arabia and Bahrain with data spanning 11-26 years where available in an effort to utilize the stations with the longest records of data. Given that tidal gauge data alone would provide a poor representation of the changing sea levels due to the influence of other factors, the authors have made use of the ICE-5G v1.2 VM4 Glacial Isostatic Adjustment (GIA) model[24] as a means to correct for contamination by vertical land motion. To further correct for crustal motion[25], the authors included the weekly GPS time series for the vertical component measured at the Mina Sulman (Bahrain) IGS-GPS station from 1998 to 2008. The calculations hence operate under

24 The ICE5-G v1.2 VM4 is an ice sheet reconstruction glacial isostatic model, used to adjust relative sea level variations to account for the redistribution of mass on the planet that accompanied deglaciation (Jet Propulsion Laboratory – California Institute of Technology, 2021).

25 Crustal motion refers to deformations and movement of the continental crust as a result of tectonic activity.

the assumption that all other stations within the scope of the study experienced similar vertical components as those calculated at Mina Sulman. Table 7 presents the measured change in relative sea level with the use of raw tidal gauge data after correcting for the GIA and GPS.

The authors focused their analysis on the four stations with records spanning 20+ years in an effort to provide the best estimates. Table 7 shows the selected stations in orange (Column 1). Based on the results of the multiple stations after corrections, the average rate of sea level rise in the west Arabian Gulf was computed to reach ~2.42±0.21 mm/year. It must be noted that variance in sea level records as shown in Table 7 could be attributed to fluctuations based on seasonal shifts and pressure systems among other atmospheric and oceanographic interferences.

In 2014, a follow-up paper (Alothman et al., 2014) was released, making use of a larger range of years spanning 1979-2007 for a set of seven coastal tide gauges. These include the four from the previous study in addition to three stations that were previously not considered in the final analyses. Table 7 highlights the original four stations in orange and the three additional stations in green (Column 1). Utilizing the seven stations, it was found that

Station Name	Alothman & Ayhan (2010)	Alothman et al. (2014)
	Relative Sea Level Rise (mm/year)	Relative Sea Level Rise (mm/year)
Mina Sulman	3.68	2.97 ± 0.51
Abu Ali Pier	2.20	1.18 ± 0.63
Ras Tanura	2.31	0.74 ± 1.11
Juaymah Pier	2.47	1.29 ± 0.73
Qurayyah Pier	3.75	2.00 ± 0.99
Tanajib Pier	5.05	2.97 ± 1.73
Safaniya Pier	3.88	2.85 ± 0.80

Table 7: Summary of the corrected tidal gauge station results, prepared by Alothman and Ayhan (2010). The sea level rise takes into consideration both the GIA and crustal motion adjustments. The final column summarizes the relative sea level results from Alothman et al. (2014). The stations in orange were used in both studies for the final analysis, while the ones in green were only used in the 2014 study. The 2014 results do not include elevated land corrections. All stations were selected due to having +20 years of recorded data.

a relative sea level rise of 2.2±0.5 mm/year had taken place over the period of 1979-2007. However, after factoring in the vertical land motion derived from the subsidence of six GPS stations within a 100 km radius of the tide gauge stations, the absolute sea level rise was found to reach 1.5±0.8 mm/year in the western Arabian Gulf. The authors have stated that there was no evidence of significant progressive acceleration of sea level rise over the years. Alothman et al. (2017) investigated three new stations for analysis – KUHR, KUWT, and RASZ – however, the additional data did not influence the results obtained in Alothman et al. (2014). The corrected results presented by Alothman et al. (2014) at 1.5±0.5 mm/year are also in close alignment with the global results for the 20th century presented in Lindsey (2020), with results reaching 1.4 mm/year.

In the UAE, there were initial efforts to measure sea levels prior to 1971, with the Abu Dhabi Company for Onshore Oil Operations operating a tidal gauge at Jebel Dhanna between 1963 and 1966. The data from this gauge is publicly available but has its limitations, as the stored data has not been reviewed for quality (PSMSL, 2020). In addition to the stations shared in Table 7, several tide gauges and GPS stations have been used to estimate changes in sea level since 1979. Dubai currently operates six automated tide gauges at Mina Seyahi, Jumeirah Beach Hotel, Shindagha, Dubai Festival City, Jebel Ali, and Mamzar. These gauges provide observations dating back to 2004, however, tidal data alone would not be a reliable measure of sea level changes, and despite the availability of data in recent years, appropriate data correction measures are yet to be undertaken with the use of appropriate models for stations bordering the UAE.

Further work is needed to understand the extent of sea level rise in the Arabian Gulf and the projected increase. Overall, the modeled projections agree that sea levels may rise over the coming decades, with an acceleration in the speed of the rise as deglaciation increases.

Extreme Weather Events

The devastating impacts of extreme weather events and climate extremes make them a subject of serious public and policy concern. At the same time, the investigation of extreme weather events and their relation to climate change and spatial variability is one of the most challenging areas in climate research and future climate predictions. The challenges associated with severe weather event modeling and research include inadequacy of historical records, limitations in statistical and other tools used to analyze observed changes in extremes, and limitations in the understanding of weather processes (Zwiers et al., 2013). Despite these inherent challenges, research on extreme weather events as well as their attribution to climate change has been an integral component of global climate studies (Alexander et al., 2006; Bador et al., 2015; Bellprat et al., 2019; Doblas-Reyes et al., 2013; Herring et al., 2014; Kundeti et al., 2015; Sheffield et al., 2012; Trenberth et al., 2015; amongst others). Extreme weather research has primarily focused on statistical theory underpinning extreme value analysis, detection and attribution of observed changes in the frequency and/or intensity of extremes, and the identification of the cause(s) of events and the physical mechanisms that are involved in amplifying and/or extending the duration of specific extreme events, such as heat waves.

The IPCC notes that changes in extreme weather and climate events have been observed since 1950. A decrease in cold temperature extremes, increase in warm temperature extremes, rise in sea levels, and increase in the number of heavy precipitation events in a number of regions are some of the changes that have been linked to human influences (IPCC, 2014a). The IPCC also concludes that it is very likely that in the future, heat waves will occur more often and last longer, and that many regions will experience an increase in the intensity and frequency of extreme precipitation events (IPCC, 2014a).

The available literature provides initial insights into past trends as well as projections for the UAE and the region. AlSarmi and Washington (2014) report a consistent pattern of trends in daily temperature extremes over the Arabian Peninsula during 1943-2008 that is related to significant warming, with cold extremes decreasing and warm extremes increasing. The average yearly maximum temperatures, average yearly minimum temperatures, highest yearly minimum temperatures, as well as highest yearly maximum temperatures all had statistically significant increasing trends over the Arabian Peninsula. The study reported that a remarkable increase in very warm nights was seen during the period 1986-2008 in particular. With higher average temperatures projected for the region, episodes of extreme temperatures are likely to become more frequent in the future.

Similarly, with regard to cyclonic activity, based on an analysis of monthly cyclonic storm days and accumulated cyclone energy (ACE), Evan and Camargo (2011) conclude that starting in the early 1990s, there has been an increase in the number, duration, and intensity of Arabian Sea cyclones. Figure 4 presents the yearly time series and monthly scatterplot of ACE over the Arabian Sea for the period 1979-2008 (Evan & Camargo, 2011). Murakami et al. (2017) applied a suite of high-resolution global coupled model experiments to simulate the climatological distribution of extremely severe cyclonic storms, concluding that it is likely that anthropogenic forcing has increased the probability of late-season cyclonic storms in the Arabian Sea since pre-industrial times.

While the observed late-season storms of 2014 and 2015 were attributed to stochastic processes, the research showed that the role of natural variability in the observed increase in storms was minimal, and increased human-induced forcing will heighten the risk of cyclones, making these events more frequent and severe (Murakami et al., 2017). Tropical cyclone events, such as Phet and Gonu that impacted the Arabian Peninsula in 2007 and 2010 respectively, are predicted to continue to propagate (UNDP, 2018). Strong winds are also likely to raise more dust, posing greater risks from sand and dust storms, and affecting concentrations of particulate matter in the air (Hergersberg, 2016).

Another study developed a global hail hazard algorithm based on hail observations in the US, and tested its performance over the US, Australia, and Europe, relying on data for the period 1979-2015. Four key predictors, including atmospheric instability, freezing level height, 0-3 km wind shear, and storm-relative helicity (SRH)[26], allow discrimination of large hail frequencies on a regional scale, and the research utilizes these variables to develop a hail algorithm, which provides probabilities for large hail occurrence from regional to global scales and

26 SRH refers to the potential for a right-moving supercell to develop cyclonic updraft rotation. SRH is calculated for the lowest 3-1 km layers above the ground (Thompson et al., 2003).

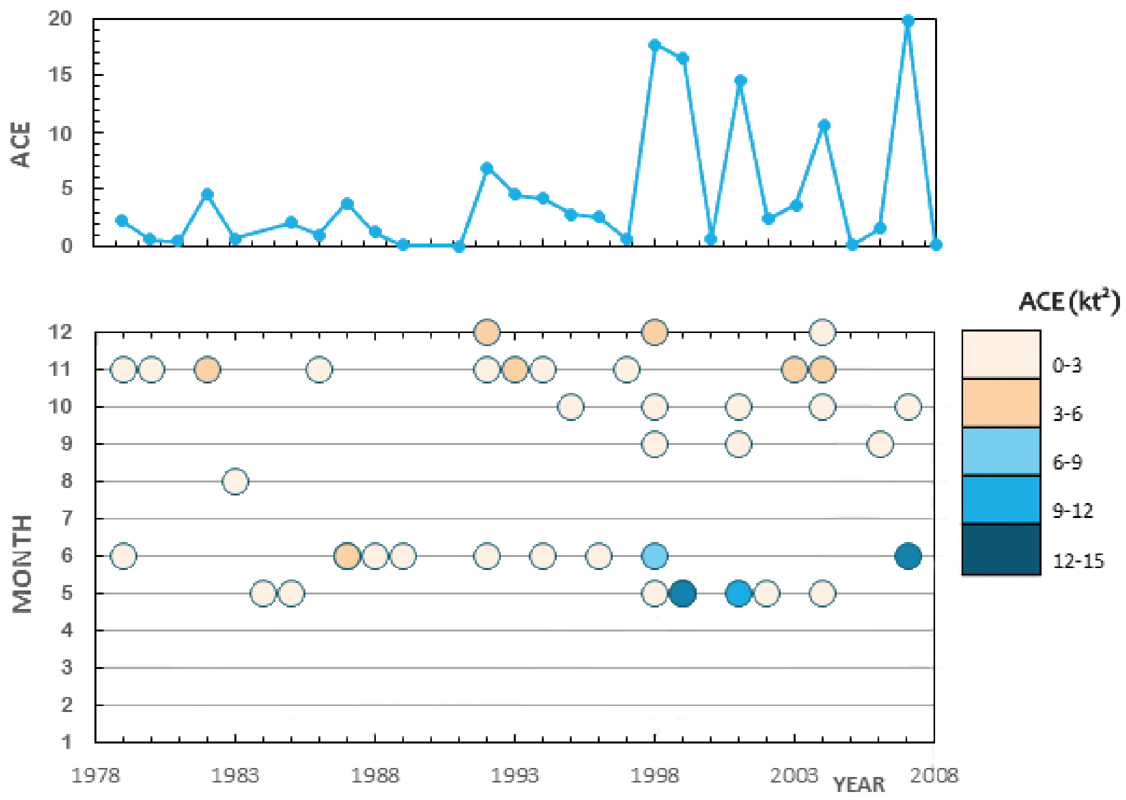


Figure 4: Annual time series (top) and monthly scatterplot of accumulated cyclone energy (ACE) in nautical miles per hour (kt2) over the Arabian Sea for the period 2008-1979. The ACE (at the bottom) is indicated by the fill color in each circle (Evan & Camargo, 2011).

from daily to climate timescales. The study identified the mountains of the Arabian Peninsula (UAE and Oman) as a hotspot for hailstorms at present (Prein & Holland, 2018).

4. Sectoral Impacts of Climate Change

The climatic changes being already observed, and those being projected for the near and long term, have attendant impacts. A comparison of projected changes in climate characteristics and impacts between a warming scenario of 1.5°C and 2°C reveals significantly higher risks with incremental changes in temperature (IPCC, 2018). According to the IPCC (2014b), in urban areas, climate change is projected to "increase risks for people, assets, economies, and ecosystems". These include risks from heat stress, extreme precipitation, floods and droughts, sea level rise, storm surges, and landslides (IPCC, 2014b).

Even while knowledge gaps remain in climate data and research focused on the UAE and the Gulf region, trends in temperature, precipitation, and seawater properties can be discerned. These changes in the UAE and the Gulf region's climate will lead to a range of impacts on critical sectors, including energy, infrastructure, health, agriculture, and the environment. A review of literature suggests that research on climate risks and impacts in the region remains scarce. The Gulf countries have made a start in assessing risks and associated impacts, and defining adaptation action plans to address them. As part of its National Climate Change Adaptation Program, the UAE has undertaken climate risk assessments for four priority sectors: energy, infrastructure, health, and the environment. Led by the UAE Ministry of Climate Change and Environment, the assessments are informed by available data, extensive research, and stakeholder consultations. The UAE Sectoral Climate Risk Assessment Framework incorporates a multi-step process, including stocktaking of climate trends and sectoral issues, identification of potential sectoral impacts, evaluation of the magnitude and likelihood of impacts, assessment and prioritization of risks, and identification of potential adaptation actions.

This section captures sectoral risks and impacts relevant for the UAE and the region. It draws, in part, from the work undertaken as part of the National Climate Change Adaptation Program.[27] Figure 5 summarizes the key sectoral impacts.

Infrastructure

Infrastructure facing risks from climate change includes buildings, transport links, energy assets, desalination plants, water supply lines, and sanitation and waste management facilities. Changes in sea levels, and seawater acidity and salinity will especially affect coastal and offshore infrastructure.

Air, land, and water transport systems, including roads, rails, runways, waterways, and traffic facilities, may see damage and/or deterioration due to rising temperature, possible changes in seawater acidity and salinity, sea level rise, and extreme weather events, including sandstorms. High temperatures may cause roads and pavements to soften and expand, and rail tracks to buckle (US EPA, 2016). Occurrence of sandstorms and fog may impact visibility, and therefore safety of all modes of travel. Air and maritime transport are particularly vulnerable to changes in average weather conditions – wind direction and speeds, and storm surges at sea, respectively.

In the same vein, energy infrastructure, such as power plants and transmission lines, may be damaged by climatic changes, causing disruptions in power supply. Also, extreme conditions and high variability may push the operational capacity of power facilities and equipment beyond thresholds.[28]

According to the risk assessment undertaken as part of the National Climate Change Adaptation Program, impacts that pose a high level of risk to the energy sector based on their magnitude and likelihood include the following: energy efficiency losses in power plants when temperatures exceed standard design criteria, reduced power output due to warmer cooling water in plants, and deterioration of power facilities leading to reduced reliability and increased maintenance costs.

Water-related infrastructure, i.e. desalination plants, dams, and reservoirs, faces climate risks that may result in disruptions in water supply. The Gulf region houses more than half of the world's seawater desalination capacity (ESCWA, 2019). Desalination plants are at physical risk from changes in seawater properties and levels, and also find their operations impacted by seawater temperature rise and higher salinity. Brine discharge from these plants interacts with climate-induced changes, exacerbating the situation. Further, sanitation and wastewater management facilities are at risk from extreme precipitation events and seawater inundation, with resultant impacts on public amenities and health.

Climate change is also likely to cause damage to and deterioration of building infrastructure, including public and private residential, commercial, and industrial facilities, impacting reliability and safety of buildings, their durability, and real estate value. The design, construction, and retrofitting of buildings will need to take into account imminent and projected risks (while reducing buildings' emissions). During the operational phase, space conditioning requirements and patterns of energy use are likely to see changes.

The Gulf region's coastline is home to extensive infrastructure, including power and desalination plants; oil and gas platforms, rigs, and pipelines; ports and harbor facilities; and communication cables. Maritime activity is a vital part of the Gulf countries' economies, with trade and shipping, sea-based travel and tourism, and coastal and offshore energy and water infrastructure development as essential and thriving sectors. Increased air and sea temperatures, sea level rise and shoreline retreat, episodes of high salinity, seawater acidification, and more frequent and intense storm surges pose risks to existing infrastructure and planned projects.

For the energy sector, the occurrence of weather extremes is also relevant as a determinant of demand for space conditioning. Hotter summers and increased demand for cooling in the Arabian Peninsula will require enhancement of energy infrastructure as well as improved peak demand management.

27 Sectoral reports for the UAE are available at https://www.moccae.gov.ae/en/knowledge-and-statistics/climate-change.aspx

28 For instance, the turbine power output and efficiency of thermal power plants may be affected by variations in ambient temperature and humidity – an increase in temperature raises the air specific volume, increasing energy consumption in the compressor and reducing the amount of net energy generated in each cycle (Schaeffer et al., 2012). The quantity and quality of water supply may impact steam cycle-based thermal generation as well as nuclear plants that require cooling water (Farouk et al., 2013; Schaeffer et al., 2012). The capacity and reliability of power transmission lines too may be affected by rising temperatures and extreme weather events (Schaeffer et al., 2012), calling for transmission and distribution assets and facilities to be adapted and upgraded for the changing climate.

Sectoral Impacts of Climate Change in the UAE

Infrastructure

- Damage to coastal and offshore infrastructure
- Reduced safety and loss of business opportunities due to transport infrastructure damage and disruptions
- Reduced efficiency and reliability of energy infrastructure
- Damage to and deterioration of buildings
- Physical and operational disruptions in desalination infrastructure
- Physical and operational disruptions in sanitation and drainage facilities
- Increased infrastructure maintenance costs

Public Health

- Increased heat-related morbidity and mortality
- Increased spread of vector-borne and water-borne diseases
- Higher incidence of respiratory illnesses
- Reduced productivity of outdoor workers due to heat stress

Water & Agriculture

- Reduced availability of surface water and groundwater
- Decreased recharge of stored water in dams
- Increased demand for desalinated water
- Deterioration in groundwater quality
- Reduced agricultural production and yield
- Changes in agricultural production sites
- Reduced livestock production and productivity

Environment

- Reduced species diversity and deterioration of health
- Species habitat loss
- Altered species distribution
- Increased stress on ecosystem services

Figure 5: Summary of key sectoral impacts of climate change in the UAE

Overall, it is expected that the adverse impacts on infrastructure may lead to reduced reliability, increased maintenance costs, and loss of business opportunities due to disruptions. The construction sector itself faces climate impacts, with extreme weather leading to construction delays and increased costs, and more rebuilding and repair work to be undertaken (Chalmers, 2014).

Public Health

There are three ways in which climate change affects human health: direct impacts, which relate mainly to changes in frequency of extreme weather events, including heat, drought, and heavy rain; effects that are mediated through natural systems, e.g. water-borne diseases, air pollution and disease vectors; and effects that are heavily mediated by human systems, e.g. occupational impacts and undernutrition (Smith et al., 2014). According to the World Health Organization, between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per annum from malnutrition, vector-borne diseases, diarrhea, and heat stress (WHO 2018).

The incidence of very high temperatures is a key risk factor for public health in hot, arid regions. There is now evidence to show that average temperature levels as well as variability in temperature affect human health (Smith et al., 2014). There is an observed link between heat and premature mortality, with excess deaths attributable to increase in temperatures differing across geographies (Honda et al., 2013; Kinney, 2018). In the Arabian Peninsula, cases of heat-related illnesses and mortality may increase with extreme heat and higher average temperatures. Susceptibility to heat stress depends on several factors, including physiological adaptation to the local environment, and socio-economic status determining vulnerability of exposed populations; host factors such as age and co-morbidities may also exacerbate heat-related problems (Portier et al., 2010).

Climate change in the Gulf region may worsen cardiovascular and respiratory illnesses too. Globally, changing temperatures affect both the incidence and mortality of respiratory infections (Mirsaeidi et al., 2016). High temperatures raise the levels of ozone and other pollutants in the air as well as the levels of pollen and other aeroallergens (WHO 2018). Also, desertification and associated increase in the concentration of suspended particulate matter may contribute to a rise in respiratory problems (Meltzer et al, 2014). Further, climate change may trigger outbreaks of vector-borne diseases (such as malaria) owing to higher temperature and humidity, though more research is needed to understand the probability and intensity of such occurrences. Given that the epidemiology of climate-sensitive pathogens may be altered, it is suggested that climate change, with its effect on vectors as well as host immune responses, could alter the occurrence and severity of some respiratory infections (Mirsaeidi et al., 2016).

Notably, the health impacts of climate change imply productivity losses with reduced person-hours of work. This holds particularly true for outdoor workers engaged in manual labor, e.g. at construction sites and farms. According to Dunne et al. (2013), environmental heat stress has reduced labor capacity[29] to 90% in peak months over the past few decades, and by 2200, under RCP8.5, labor capacity is projected to reduce to less than 40% in peak months, with extreme levels of climatological heat stress experienced in most tropical and mid-latitudes. A large segment of the population living in hot regions in particular will experience significantly reduced work capacity due to climate change, with the Arabian Gulf region classified as high-risk (Kjellstrom et al., 2016).

29 Labor capacity here is measured as an acclimated individual's occupational capacity to safely perform sustained labor under environmental heat stress (Dunne et al., 2013).

Water & Agriculture

Countries of the Arabian Gulf are characterized by high temperatures, low overall precipitation, high evaporation rate, low groundwater recharge rate, and no reliable, perennial surface water sources (Odhiambo, 2017). Groundwater resources are already under strain in the Gulf region, where irrigation for agriculture accounts for the largest use of groundwater (Odhiambo, 2017). In the already water-scarce region, climate change is expected to modify the hydrological cycle and affect freshwater resources, with attendant impacts on agriculture.

Freshwater

According to the IPCC (2014), it is projected that climate change will significantly reduce renewable surface water and groundwater in most of the dry subtropical regions, with competing uses in agriculture, community settlements, natural ecosystems, and industry. UNDP (2010) states that the MENA region will become more arid over time, with higher temperatures and less rainfall reducing surface water availability and slowing groundwater recharge. Climate models project hotter, drier, and less predictable climate, resulting in a drop in water runoff by 10-30% in the Middle East region by 2050, mostly due to rising temperature and lower precipitation (Milly et al. 2005). A number of recharge and storage dams have been constructed in the Gulf countries, but reduced precipitation may significantly decrease the amount of water collected. An overall reduction in recharge of stored water as well as groundwater resources will likely lead to an increase in demand for desalinated water (Odhiambo, 2017).

Investigating future water requirements for crop production and making a case for sustainable agricultural practices, Shahin and Salem (2015) conclude that the UAE's groundwater resources could be exhausted as early as in 2030. In the UAE and the region, the direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge from rainfall events. A study focused on Saudi Arabia estimated that changes in precipitation and evapotranspiration will lead to reduction in soil moisture even while higher temperatures increase the water demand for agriculture by 5-15% (Chowdhury and Al-Zahrani, 2013).

Climate change would not only affect groundwater quantity but also its quality. Sea level rise is likely to lead to saltwater intrusion into coastal aquifers, affecting groundwater quality. Once saltwater has intruded into the fresh groundwater system, it is difficult to remedy groundwater.[30] In the UAE, the coastal aquifers that have freshwater resources, including Fujairah and Ras Al Khaimah, could be affected.[31] Moreover, extreme precipitation events may mobilize pollutants, and carry pathogens and other contaminants into waterways through runoff and flooding (DeNicola et al., 2015). Water supply is intricately linked to hygiene and sanitation, and crop agriculture, secondary impacts on which can increase the burden of disease (DeNicola et al., 2015).

Agriculture

The health of the climate is intricately tied with the sustenance and growth of the agricultural sector. The Food and Agriculture Organization (FAO) estimates that globally, agricultural production (crops, livestock, fisheries, and aquaculture) will need to rise by about 60% by 2050 to feed the world's growing population. At the same time, climate change is projected to considerably reduce the global yield of key staples, such as rice, wheat, maize, and soybean (FAO, 2016). According to the IPCC (2014a), the agricultural sector is expected to experience impacts on production and associated income, including shifts in production sites of food and non-food crops.

In the UAE and the surrounding region, unfavorable climatic conditions, scarcity of water, and soils with poor water- and nutrient-holding capacity are impediments to traditional agriculture and food production. Arable land is limited, and local agriculture largely relies on the use of non-renewable groundwater for irrigation (Brown, J. et al., 2018). Changes in agro-climatic conditions will impact prevalent agricultural methods and production, although the pace and direction of change is uncertain and will vary across different parts of the region. Increase

30 According to the Ghyben-Herzberg relation, a one-meter height of free water table above mean sea level leads to about 40 m of freshwater below the sea level. Likewise, a 1 m rise in the sea level will cause a 40 m reduction in the freshwater thickness (Sherif & Singh, 1999).

31 The groundwater in the coastal aquifers of Abu Dhabi will not be affected as much, as it is already saline (EAD, 2018).

in temperatures and reduced overall rainfall in the region will likely hold adverse consequences for open-field agriculture.

Based on IMPACT[32] model runs performed in 2015, agricultural production in countries of the Gulf is expected to be negatively affected by climate change (AGEDI, 2015d). Open-field production in the UAE is restricted to the cool season, which would become shorter as the average temperature rises. In addition, the elevated temperature would increase evapotranspiration, and thus the need for irrigation water supply. In areas where farmers use brackish groundwater for irrigation, this would also speed up soil and groundwater salinization. It is notable that these impacts on traditional agriculture and arable land underscore the importance of agricultural technology and innovation not only in optimizing production and yield from traditional farming but also in the advancement of alternative agriculture methods, such as hydroponics, in addition to diversification of sources of food imports.[33]

Date palm cultivation and date farming is a significant agricultural activity in the region, serving domestic as well as international markets. Modeling how global warming would affect areas suitable for date palm production, Shabani et al. (2014) and Shabani et al. (2015) found that in the Gulf region, date palm production in parts of Saudi Arabia is projected to decline. Production sites may become concentrated in the areas that remain suitable for date cultivation (Abdulkader et al., 2016 and Shabani et al., 2015).

In addition to impacts on crops and cropland, McDonnell et al. (2012) posit that climate change will exacerbate risks for pastured livestock with water scarcity and potential rise of animal pests. Reduced animal feeds, higher heat stress, and increased risk of infection and disease will impact animal production and productivity in the Gulf region. This will potentially lead to increased movement in search of better grazing land as well as a shift to non-agricultural sources of income (Lewis et al., 2018).

Ecosystems

Though they serve as effective means of combating climate change through the provision of services that enable mitigation and/or adaptation, ecosystems themselves are being affected by climate change. Marine, terrestrial, and freshwater ecosystems, and the species and habitats integral to them are all affected by rising temperatures, changes in precipitation patterns, sea level rise, and inland intrusion of saltwater. Climate change can push the tolerance levels of some organisms to the extent of causing shifts in species composition, migration, or even extinction. The IPCC (2018) reports that of the 105,000 species studied, 6% of insects, 8% of plants, and 4% of vertebrates are projected to lose more than half of their geographic range at warming of 1.5°C, compared with 18% of insects, 16% of plants, and 8% of vertebrates for warming of 2°C, illustrating the impact of incremental changes in temperature on biodiversity.

Climate change alters the dynamic equilibrium of terrestrial ecosystems with its impact on ecosystem productivity, production of biomass, hydrological balance, and trophic interactions (Surasinghe, 2011). The attendant changes directly influence wildlife behavior, such as foraging, migration, reproduction, and growth, and determine exposure to pathogens and disease-causing agents, in effect changing the structure of terrestrial ecosystems (Surasinghe, 2011). In the UAE and the region, terrestrial mammals are already close to temperature thresholds and have access to limited amount of water (EAD, 2017). Reduced access to water, loss of terrestrial wetlands due to extreme temperature and drought events, loss of inland habitats due to sea level rise, and increased soil erosion and land degradation can potentially affect terrestrial species. Climate-led changes in vegetation will also likely impact birds.

An AGEDI study on Regional Terrestrial Biodiversity Vulnerability to Climate Change modeled the impact of climate change at both the priority species level and the community level across the Arabian Peninsula. A Species

32 The International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) integrates various economic, water, and crop models to analyze climate change effects on diverse components of the food supply chain.

33 An AGEDI study on the UAE's food security concluded that the food security situation of low-income households is set to worsen with changes in global agricultural markets, including production and prices. The study utilized the IMPACT model. The UAE outputs took into account a -50 year span from 2000 to 2050, and are built on a business-as-usual scenario simulating agricultural productivity under a stable climate versus a set of varying scenarios that account for potential impacts of climate change (AGEDI, 2015d).

Distribution Model, MaxEnt, was used at the priority species level, and a generalized dissimilarity modeling (GDM) system was used at the community level, with the models incorporating information on current and future climate conditions based on an ensemble approach (Figure 6).[34] The study results indicated that breeding birds, mammals, and amphibians were projected to have the most extensive reductions in suitable habitats, while non-breeding birds, plants, and reptiles were projected to gain habitats across much of the Arabian Gulf region (AGEDI, 2016). For the 75 priority species for which MaxEnt models (measuring distribution of species occurrence) were used as part of the study, loss of suitable habitat was projected to be most pronounced in the South of the region, including the UAE, Qatar, Yemen (including the island of Socotra), Oman, and the western coast of Saudi Arabia. On the other hand, gains in suitable habitat were seen in north-central Saudi Arabia and Iraq, though the exploitation of these gains by species remains uncertain, and longer-term projections (i.e. up to 2080) indicate that gains may be temporary. GDM findings suggested that reptiles are the subject of the most widespread and highest adverse impacts of any of the taxonomic groups. When considered together, the model results agree that climate change may cause widespread changes in species composition across terrestrial environments of the Gulf region: MaxEnt results indicate that these changes may be largely driven by local extinction in the South and increases in species richness in the North, while GDM results suggest that the lowest overall changes may be limited to the southwestern part of the Arabian Peninsula (AGEDI, 2016).

Additionally, the Arabian Gulf's diverse coastal and marine ecosystems, such as mangroves, seagrass beds, sabkhas and coral reefs, are at the frontline of climate impacts. These ecosystems contribute to the maintenance of biological and genetic diversity in the marine environment, in addition to providing vital ecological and economic functions as feeding and nursery grounds for marine organisms (Naser, 2014). Climate change triggers disruptions in these natural habitats through ocean acidification, stratification, eutrophication, and thermal expansion. With progressive increase in temperature, marine and coastal species may be first pushed beyond their thermal optima and then beyond their upper thermal limits. Storm surges and coastal erosion may impact coastal nesting species, such as turtles (EAD, 2017).

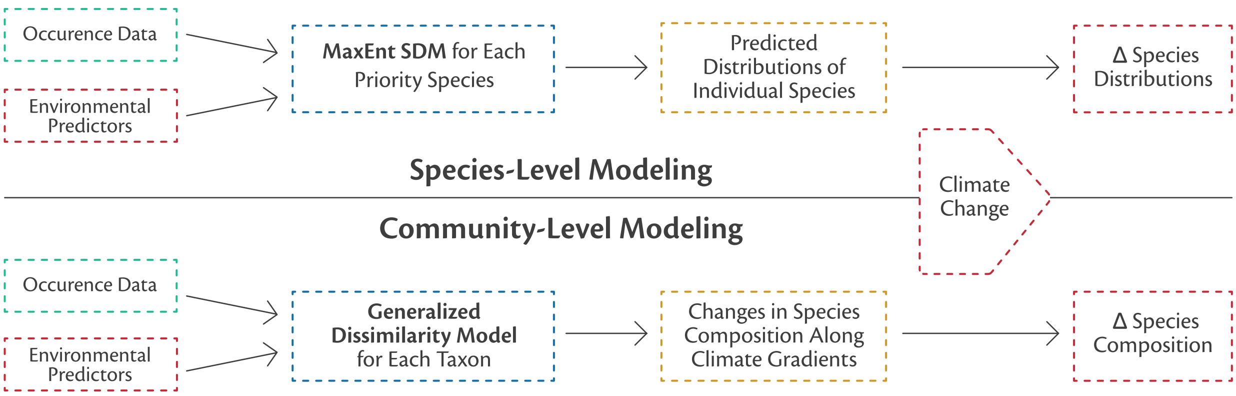


Figure 6: Modeling approaches used to assess terrestrial biodiversity's vulnerability to climate change in the Arabian Peninsula (AGEDI, 2016)

Wabnitz et al. (2018) adopted three niche modeling approaches to assess the future suitability of the Arabian Gulf as a habitat for 55 priority species. The research also included a vulnerability assessment of economies to climate impacts on fisheries. The research outputs suggested a high rate of local extinction (up to 35% of initial species richness) by 2090 relative to 2010. Projected local extinctions were highest in the southwestern part of the Gulf, off the coast of the UAE, Saudi Arabia, and Qatar. Reduced future fish catch potential was also

34 MaxEnt focuses on priority species and provides estimates of changes in habitat suitability (gains and losses) for each species. GDM estimates the expected percentage change in species composition at each location as a function of how much the climate is expected to change in that particular location, weighted by the importance of different climate gradients in determining current biodiversity patterns (AGEDI, 2016). The modeling approaches thus complement each other.

indicated for several countries on the western side of the Gulf (Wabnitz et al., 2018).

A widespread and concerning impact on the environment is the increased frequency of coral bleaching events. Risk assessment for the environment sector, undertaken as part of the UAE's National Climate Change Adaptation Program, identified these as high-risk climate impacts on the country's environment. Though the Gulf's corals are seen to be much more resilient than their counterparts elsewhere, observations and modeling have indicated that coral reefs in the Arabian Gulf are already impacted by climate change through bleaching and other environmental disturbances (Riegl, Riegl and Purkis, and Riegl et al, cited in Ben-Hasan and Christensen, 2019). According to Paparella et al. (2019), there is strong evidence that interannual variability in the occurrence and magnitude of coral bleaching events in the southern Arabian Gulf is linked to the summer shamal wind regime, as shamal events cool temperatures below bleaching thresholds. Given that summer shamals are caused by the pressure gradient that develops between the eastern Mediterranean and northwestern India during the summer monsoon, it is likely that any climatic changes that influence the strength of the Indian Ocean monsoon will affect wind conditions over the Gulf. The interactions of these changes in wind patterns with warming temperatures will hold consequences for coral health (Paparella et al. 2019). Increase in seawater salinity and pH will exacerbate the situation.

5. Conclusion & Way Forward

Climate change modeling and research for the UAE and the region is limited but growing. Relatedly, more work is being undertaken to understand the impacts of the region's changing climate. This report synthesizes results from available literature, forming a repository of research findings on the changing climate in the Arab region and its impacts on key sectors. It serves as a useful regional reference for climate researchers as well as policymakers interested in the topic. While reflecting the state of regional climate research, it also provides specific results for climate variables of interest to the region, and the impacts that countries are witnessing and are projected to see. The available literature on climate parameters reveals a wide range of projections for the region on temperature, precipitation, seawater properties, sea level rise, and extreme weather events, though it presents a useful set of initial results and lays the ground for further research and policy efforts. Initial conclusions can also be drawn about the current and projected climate impacts for key sectors.

Challenges remain in the advancement of climate science in the region. The lack of long-term data and records in the UAE and the region constitutes a major obstacle in the calibration and validation of climate change models. There is also limited empirical research on the socio-economic impacts of climate change in the region.

Therefore, a strengthened data collection effort is imperative to improve modeling prospects. Archives of historical meteorological data need to be built, with data sourced from reputed platforms that offer quality assurance. Increase in the resolution of the data captured would also help enhance the accuracy of local and regional modeling results.

In this context, regional collaborations aimed at creating a methodologically diverse research environment would be greatly beneficial. Increasing the scope of data collection and research, enhancing data quality, and developing models with varied scenarios and assumptions would allow the climate system in the UAE and the surrounding region to be better documented and studied. This would help build upon currently available findings, enabling a comprehensive understanding of the state of climate in the UAE and beyond.

Additionally, it is imperative to enhance the understanding of climate's impacts on the economy as well as the safety and welfare of communities. Climate risks and impacts need to be accounted for in development plans in order to build climate-safe, resilient societies and economies. As the understanding of the changing climate improves, this knowledge needs to inform short-term as well as long-term plans in order to address imminent climate risks and prepare for risks of the future under different scenarios of global warming. Infrastructure, health, agriculture, and the environment are at the forefront of climate impacts. More localized assessments are needed across the region to prioritize high-risk sectors and further identify priority risks within, on the basis of magnitude and likelihood, with these results then mainstreamed into policymaking.

Mutually informed climate science and adaptation planning is needed to ensure that the UAE and the wider region are well-equipped to address climate risks and impacts.