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LIVING ON THE EDGE

The implications of climate change for six countries in the Middle East North Africa region

A man looks at wildfires tearing through a forest in the region of Chefchaouen in northern Morocco on August 15, 2021.

Photo by FADEL SENNA_AFP via Getty Images

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The implications of climate change for six countries in the Middle East North Africa region.

A traditional Marsh Arab canoe abandoned on the dry earth of the southern marshes of Iraq during a harsh summer drought.

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Key demands by Greenpeace

Middle East North Africa

Demands written by Greenpeace MENA staff

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This report, 'Living on the Edge: The implications of climate change for six countries in the Middle East North Africa region', illustrates that the Middle East North Africa (MENA) region, a highly water-scarce region, is warming nearly twice as fast as the global average. The MENA region is extremely vulnerable to the impacts of climate change, which are driving and exacerbating risks on food and water security.

Although most countries in the MENA region have historically contributed very little to climate change, it is possible and necessary for us to choose alternative development pathways that are locally attuned and culturally relevant, and can lead towards sustainable energy sovereignty. We are in no means tied or due the same path that was chosen by the Global North over the past 50 years and which has significantly led to the global climate disaster.

On the one hand, the transition from fossil fuels towards renewable energy is necessary to safeguard the health of our ecosystems and a dignified life for future generations. Renewable energy is a safe and clean solution to the region's exacerbating challenge of energy-poor populations, of which about half either have no access to electricity or suffer from prolonged power outages and undersupply1, despite the accelerated pace at which the fossil fuel industry is growing (especially in the Gulf). It is important to recognise that vulnerability to climate change is very much interlinked to other social injustices, such as energy injustice, social exclusion, conflicts and political instability, to name a few, to which the fossil fuel industry has directly contributed.

Our recommendations to governments and/or decision makers in the run-up to COP27 and beyond is for a dignified and prosperous future for our region and the world. Lives are being lost, homes are being destroyed, crops are failing, livelihoods are disrupted and cultural heritage is being wiped out, but the historic polluters who have contributed to these losses and damages are refusing to adhere to the 'polluter pays' principle. Impacted communities are owed reparations to account for the losses and damages endured, as well as adaptation and mitigation finance, and technology and knowledge transfer, utilised for the implementation of scientifically and locally developed strategies.

It is also the responsibility of the MENA region's governments to ensure that locally developed adaptation strategies are inclusive and that funding is adequately and justly distributed to those least resilient and frontline communities. Adaptation strategies must prioritise communities and marginalised groups that have been made vulnerable because of climate change impacts by ensuring their needs, cultural heritage and local traditional knowledge are a central part of adaptation plans. Until climate finance and technology and knowledge transfer is secured, a major barrier will remain in place for MENA countries and others in the Global South to adapt to the climate change impacts outlined in this report and make the transition towards an alternative, just, more sustainable and resilient future.

In summary, Greenpeace MENA's demands are:

For Global North and historic emitter governments

- Set-up a loss and damage finance facility, and fund it accordingly in which sources of funding will include penalties from climate polluters such as international oil companies.
- Adhere to and expand upon past pledges made for climate finance for adaptation and mitigation, as well as knowledge and technology transfer, based on scientific recommendations, and make sure these adhere to alternative development pathways (for example, in the form of grants instead of loans).

For MENA governments

- Draft and implement high quality adaptation strategies and implementation plans that prioritise the most vulnerable communities.
- In the pursuit of sustainable energy sovereignty, social justice and resilience to climate impacts (to name a few), draft and adhere to just transition plans and alternative development pathways.

For all world leaders

- A just transition away from fossil fuels, by strengthening and implementing climate commitments.

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[1]. Olawuyi, Damilola S., 'Energy Poverty in the Middle East and North African (MENA) Region: Divergent Tales and Future Prospects', in Iñigo del Guayo and others (eds), Energy Justice and Energy Law (Oxford, 2020; online edn, Oxford Academic, 18 June 2020). Doi: 10.1093/oso/9780198860754.003.0015. Accessed September 27, 2022.

Iconic cedar forests in the Tannourine nature reserve of North Lebanon suffer the consequences of climate change.

Executive summary

The Middle East – North Africa (MENA) region is geographically as well as sociopolitically diverse, including high mountain ranges, fertile river valleys, coastal plains and lagoon ecosystems alongside the more predominant semi-arid and arid conditions. Much of the region is characterised by scarcity of freshwater, whether surface or groundwater, and by limits to land suitable for agriculture. It is also a region in which populations continue to grow (projected to reach 1 billion by the end of this century), especially in major cities (expected to be home to as much as 70% of the region's people by 2050), and one in which consumption of energy, water and food are consequently also expected to continue to rise.

Given the diversity and extent of the MENA region, stretching from Morocco in the West to the Gulf states in the East and bordering the distinct ecosystems of the Mediterranean Sea, the Red Sea and the Persian/Arabian Gulf, there are dangers in over-generalisation in relation to historic, current or projected future conditions for the climate, for nature and for the lives of its people. Nevertheless, it is self-evident that many of the countries in the region naturally experience very warm and dry conditions relative to other parts of the world, making life challenging from the outset. Furthermore, although there is considerable variability in weather patterns and climate year on year, it is also now clear that the region as a whole is warming fast under a climate changing world, with an accelerated rate of 0.4 °C per decade since the 1980s, nearly twice the global average.

By focusing on six countries in the MENA region (Morocco, Algeria, Tunisia, Egypt, Lebanon and the United Arab Emirates), this report provides an overview of the evidence available from scientific studies and assessments relating to past trends, ongoing observations and future projections of climate change and its impacts on the natural world and on human societies across a region within which temperature and water stress and threats to food security are already a daily reality. Rather than attempting to provide a comprehensive analysis of the threats facing the entire region, the report draws on examples from each country to illustrate the impacts of a changing climate and the vulnerabilities of human societies experiencing them.

Across North Africa, including the countries of Morocco, Algeria, Tunisia and Egypt, climate change-induced warming is already more pronounced in the summer, with some evidence also for the wet seasons becoming progressively dryer over time, with recent multi-year droughts being unprecedented for at least the past 500–900 years. Climate models under all scenarios project further increases both in average temperature and in the number, length and severity of extreme heat and drought events across North Africa, and for further reductions in average precipitation, though modelling results for rainfall are subject to greater uncertainties than for temperature. The combination of warming and drying is expected to further increase the pressure on agricultural production across much of the region, especially in those countries in which there is heavy reliance on rain-fed agriculture.

Despite the naturally higher temperatures and lower rainfall across the Arabian Peninsula, trends of further warming and drying are also evident and are expected to worsen over the coming decades, including in the UAE. Lebanon's geography and Eastern Mediterranean climate make it naturally much less arid compared to the other MENA countries considered in this report, though even here water stress is rapidly increasing due to a combination of factors, including rapid warming.

All of these observed and projected changes have implications for wildlife and whole ecosystems, as well as for humans, but in many parts of the MENA region data on the distribution, population health and climate responsiveness of species remain extremely limited.

Despite observed and projected future reductions in rainfall, warming in coastal countries in the region is expected to be accompanied by increases in humidity as the seas also warm. This combination of high temperature and high humidity can, at best, make life increasingly uncomfortable for human populations, especially those groups without access to natural shade and green spaces or to air conditioning, and at worst can present serious threats to health as survivable thresholds are exceeded. These risks could be particularly severe in large cities in which the 'urban heat island' effect exacerbates such exposures, especially during periods in which high temperatures are sustained through the nights. At the same time, the understandable increased demand for air conditioning of buildings is expected to increase demands for energy and water across the region.

While the overall trend is for reduced precipitation, especially in those countries bordering the Mediterranean, model projections of rainfall patterns are more uncertain than those for temperature change in part because of the complexity of the interactions between weather features and geography in landscapes in which rainfall is already scarce. The scientific consensus suggests that ongoing drying throughout this century is likely. Rain in some places is increasingly associated with short, high intensity events, which can cause localised flooding and which may lead to lower replenishment of depleted groundwater reserves over time.

Dramatic ecological changes and rising sea levels are threatening Egypt's Nile Delta which provides a third of the country's crops.

The climate change-related trends and projections outlined above present serious implications for agriculture and food security and for the natural environment in all six countries examined in this report, especially when considered against a background of other pressures. For example:

Morocco is already experiencing unprecedented droughts, and the drying and loss of oasis ecosystems is increasingly being documented, due to a combination of climate change and other human-induced changes. Drying of the climate is also projected to occur across the Souss-Massa basin, which is critical for agricultural production in the country.

In Algeria, rising temperatures and reduced rainfall are also expected to impact key agricultural areas, including those around Algiers and in the Bourj Bou Arreridj region in the northeast of the country. Coastal aquifers are expected to become more saline over time as a result of continued abstraction combined with sea level rise.

Tunisia is also expected to warm further, though models are less certain in terms of future rainfall patterns.Given the country's heavy reliance on rain-fed agriculture, any future disturbance in rainfall patterns may be anticipated to increase stresses on domestic production and necessitate even greater reliance on food imports.
Agriculture in Egypt is less rainfall dependent, because much depends on irrigation from the waters of the Nile. However, models project significant decreases in water flow in the Nile under a range of climate change scenarios. The situation is further complicated by upstream controls of flow arising from dam developments in countries further to the south, which could decrease overall water availability for irrigation and lead to progressive inundation of the delta with more saline waters. Furthermore, threats of flooding along the Mediterranean coast are becoming ever more pressing, with studies suggesting that some of the most vulnerable communities are also those with the lowest resilience in socioeconomic terms.

Although Lebanon is naturally far more abundant in water resources than the other countries examined in this report, it is projected to undergo rapid warming and drying in the coming decades. River flows have, on average, already declined by around one-quarter since the 1960s, in part because of overexploitation and in part because of declines in the fall of both rain and snow. Extreme summer heat and dryness has increased the risk of forest fires, further depleting the cedar forests, which might ultimately be restricted to small high altitude areas in the north of the country.

The United Arab Emirates has always relied heavily on food imports and on desalination for supplies of drinking water, though the limited areas of agricultural production place a heavy demand on what limited supplies of groundwater there are, supplies that fell by an estimated 5mm per year over the period from 2003–2012. Average temperatures in the UAE are expected to continue to increase from the already high baseline, with extreme heatwaves expected to present an increasing hazard, especially in the urban heat islands of major cities.

Just as on land, increasing temperatures affect marine ecosystems, especially in relatively shallow coastal waters. For example, under all climate change scenarios, marine heatwaves are expected to become more frequent and to last longer in the Mediterranean Sea, with severe implications for wildlife and for coastal communities reliant on marine ecosystems for their livelihoods.

Furthermore, the coral reefs of the Red Sea, recognised globally as a hotspot for biodiversity, are also under increasing threat from sea surface temperatures that are rising faster than the global average. Despite showing some greater natural resilience than in other regions, coral bleaching events have become increasingly common here in recent decades in response to elevated temperatures, and there are suggestions that the full extent and severity of the problem has, so far, been under-reported.

In the waters of the Gulf off the coast of the UAE, corals are known to be even more adapted to high temperatures, resulting in ecosystems with naturally much lower diversity of both corals and other species. However, given that these ecosystems are already at the very limits of their temperature tolerance, recovery from past bleaching events has often been slow and incomplete, a problem that may be exacerbated in the future.

In all these marine regions, climate change may be acting as a 'threat multiplier', superimposed on the pressures arising from rapid coastal development, an increase in industrial activities on the coast and at sea and a rise in brine discharges from desalination plants to produce water for ever growing populations. Even tourism can take a significant toll on the very natural ecosystems around which its development is often centred.

Given the central importance of climate change to the rising threats faced within the MENA region, the trends and projections can only be slowed and ultimately reversed through concerted global action to cut emissions of greenhouse gases rapidly and deeply. In common with other regions of the globe already experiencing some of the most rapid changes and impacts, and already living on the edge in terms of resilience and adaptability, most MENA countries have made only a small contribution to greenhouse gas emissions to date.

Inevitably, however, the speed and severity of ongoing change will mean that those MENA countries that are the focus of this report, in common with countries across the region, cannot simply wait for emission cuts to take effect, and there is therefore also an immediate need for greater focus on measures to reduce vulnerabilities, support disadvantaged and low resilience communities and adapt ways of living in as sustainable way as possible. Food imports are likely to remain a necessity and will inevitably be subject to the unpredictabilities of international events. Some adaptation of domestic agricultural practices may be possible in the short term, such as changing the types or varieties of crops grown and improvements in management of soil and water, but to make these changes widely accessible and impactful is likely to need both regional cooperation and international assistance. Likewise, action across the region will be necessary to ensure that urban environments are more amenable to human comfort and survivability going forward, and are better protected from the threats of flooding from both sea level rise and extreme rainfall events.

Recognising that climate change is a threat multiplier, any actions that can be taken to reduce other pressures from human activities, such as chemical pollution and the physical degradation and loss of ecosystems, will be vital to increase the resilience of the natural systems and processes on which both wildlife and humans depend. An increased focus on monitoring and documenting those ecosystems across the region, and the threats to them arising from a range of human activities, would provide an even stronger scientific evidence base to improve not only projections of future change but also the the design of strategies to reduce impacts and work towards a more sustainable future.

Heavy rain caused dramatic flash flooding in the city of Tétouan in northern Morocco on March 2021

Take-home MESSAGES

MENA CLIMATE

PAST MENA CLIMATE

Assessments of detailed historical climate trends in the Middle East and North Africa (MENA) are limited because of the lack of consistency in space and time data sets across most of the region (Lelieveld et al., 2016; Zittis, 2018). However, some broad observations on the region's climate can be made, such as those from using paleoclimate proxies. The climate of North Africa, the Arabian peninsula and the Nile basin has, over the past 2,000 years, been mostly arid or semi-arid. Conditions in the east Mediterranean became cooler and rainier during the period 1400 to 1850, and the past 120 years has shown a strong warming trend (i.e., the year 2022 on its own on the line).

PRESENT MENA CLIMATE

The Mediterranean basin and North Africa are highly vulnerable to climate change. North Africa has a wet season (October to April) and dry summer months. There is natural climate variability between the years, which means that some years are wetter than others (IPCC, 2022). The Eastern Mediterranean region has a range of climates, from desert and semi-arid to sub-tropical and temperate, and has experienced a warming trend over the past several decades that is projected to continue through this century (Zittis et al., 2022). There has been a drying trend in the Arabian Peninsula since the 1970s (Almazroui et al., 2020a).

FUTURE MENA CLIMATE

Stark projections in IPCC AR6 include that through the twenty-first century, north Africa and the east Mediterranean region will become increasingly dry because the region is expected to receive less rainfall than in previous decades (IPCC, 2022). The projections for the Arabian Peninsula are slightly different because the trend in the mid- to late twenty-first century is for increased precipitation (Almazroui et al., 2020b).

Eastern Mediterranean. The region, including Lebanon, will continue to warm for the rest of the twenty-first century (Zittis et al., 2019). The warming is projected to stabilise by 2050, only if substantial mitigation measures are implemented (Zittis et al., 2022). Current emission trajectories imply faster warming, more pronounced during the summer season resulting in more frequent and intense heat waves (Zittis et al., 2016; Zittis et al., 2021a). In such a scenario, rainfall will likely decline, and the combination of drying and strong warming will result in severe agricultural and ecological droughts.

Heat extremes. Summers in the MENA countries are already scorching, any intensification of heat extremes will pose additional challenges to the vulnerable ecosystems and populations of the region (Zittis et al., 2021a).

Floods. Increased frequency of heavy rainfall brings flood risks (IPCC, 2022). The Maghreb region of North Africa is projected to be at particular risk of floods (Zittis et al., 2021b).

Water security. In all six countries discussed in this report, there will be a very high risk of water scarcity in all regions, which will negatively affect agriculture and human health. The IPCC's most recent report, AR6, concludes that there is "...high confidence that strong and rapid mitigation initiatives are needed to avert the manifestation of climate change in all components of the global water cycle." (IPCC, 2022).

Food security The region relies on food imports which could be exacerbated if drought and water scarcity impact crop yields in future decades. The UAE and Lebanon both currently import 80% of food; Egypt imports 40% of its food; Algeria, Morocco and Tunisia all rely on imported grain.

Vulnerability of subsistence farmers. People who are already vulnerable, such as those who are living on low incomes, disadvantaged or who are subsistence farmers, are at particular risk of rising temperatures, increasing water scarcity and extreme weather events because (i) these communities are generally less equipped to adapt largely due to their financial situation; and (ii) they depend disproportionately on agriculture to survive.

Rain-fed crops. Agriculture in Algeria, Morocco and Tunisia currently rely heavily on rainfall to grow crops. Changes in precipitation patterns risk impacting growing patterns and yields in those regions.

Irrigated crops. Agriculture in Egypt, Lebanon and the UAE depend heavily on irrigation. Egypt's food systems rely on the River Nile for irrigation water, which is used to grow cereals (FAO, 2020). Approximately half of Lebanon's agricultural land is irrigated (FAO, 2022e). The UAE has only a limited area of land suitable for growing arable crops because approximately 80% of the UAE land is sandy soils not suitable for agriculture; only an estimated 6.81% of the total land area of UAE is suitable for irrigated agricultural production (Aldababseh et al., 2018).

Human physiological threshold. Under a high emissions RCP8.5 scenario, by the end of the century, 80% of the densely populated cities in the MENA region are likely to suffer from heat waves for at least 50% of the warm season (Varela et al., 2020). Under high-emission pathways in some locations in the Middle East and the Gulf region, peak temperatures during extreme future heatwaves could exceed 56 °C (Ntoumos et al., 2022; Zittis et al., 2021a).

SECTION I

This section of the report gives a general overview of past, present and future climate impacts on the Middle East North Africa region, and how the changing climate might affect the environment, human populations and biodiversity.

1.0 Introduction

This report focuses on six Middle East and North Africa (MENA) countries, listed west to east: Morocco, Algeria, Tunisia, Egypt, Lebanon and the United Arab Emirates. The countries covered in this report reflect the efforts of Greenpeace MENA to shed light on the many serious, interrelated impacts of climate change in the MENA region. Given limited resources, the focus is on the countries in which Greenpeace has a physical and / or digital presence and is connected with local allies and audiences. Greenpeace aspires to expand its research scope in the future as capacity grows.

The aim of this report is to give an overview of the problems arising from climate change, including on human populations, food and water security, ecosystems and ocean basins.

Anthropogenic climate change means that, due to human activities (for example, the release of greenhouse gases in the atmosphere and extensive land-use changes), most regions of the world are predicted to experience average temperatures that are higher than those in historical reference periods or present values. Mean annual, and particularly summer, temperature is of relevance because as the global climate becomes hotter, some regions – including countries in MENA – may become too hot for human habitation.

The MENA countries included in this report wholly or partially experience arid and semi-arid conditions. In future decades, countries in MENA are projected to experience frequent periods of increased temperatures, and extreme heat will exceed critical thresholds for health and agriculture (IPCC, 2022).

A highway in the city of Mornag, South Tunis, Tunisia

Climate change, coupled with the projected population increases in many regions, is expected to increase the risk of food insecurity and the inability to meet national food demand (Terwisscha van Scheltinga et al., 2021), particularly if problems also arise in grain imports (as has been the case following the Russia–Ukraine war). The MENA region is socioeconomically diverse, which also means that vulnerability to and ability to adapt to a changing climate will vary between countries (World Bank, 2014). Data from the World Bank (World Bank, 2022) show that with the exception of the United Arab Emirates, the MENA countries featured in this report had a GDP per capita in 2021 of less than US$5,000, which would suggest low adaptive capacity to cope with changing climate conditions.

None of the six MENA countries in this report have achieved more than 8.2% electricity generation from renewables. However, it presents an opportunity, perhaps, to cultivate the renewable energy sector in MENA, particularly given that the region will be a hotspot for climate vulnerability with increased heat, aridity and drought conditions in future decades (see also Appendix 5).

When scientists project how climate changes may impact resources such as water, they also take human activities into consideration because land-use change, agricultural practices and irrigation regimes affect water availability (Tramblay et al., 2018). Another sector with a high rate of water use is energy generation. As MENA's population increases and more people move to cities, energy consumption across the region is projected to continue to rise, which also signals an increase in the water usage by the energy industry. Production and use of fossil fuels consume high quantities of water, but research suggests that significant quantities of water are also lost from reservoirs at hydropower plants. By contrast, non-hydro renewable energy production has very low usage of water (Sanchez et al., 2020) (for more details, see section 3.6 on energy). Tourism is also cited as a use of water resources (Tekken et al., 2013).

This is an evidence-based technical report whose content is based on findings published in the scientific peer-reviewed literature. A key point to note is the lack of empirical long-term data on the physical and social aspects of climate change and vulnerability in Middle East and North African countries. A simple literature search of the scientific literature on topics mentioned for the MENA countries in this report and selected Global North countries illustrates the research priorities.

For example, the number of academic research papers that mention both the 'United States' and 'climate' in either the title, abstract, or article keywords is 29,275, yet when this search is repeated to search for 'Algeria' and 'climate' there are 1,114 results; for Egypt there are 1,641 results and for Lebanon there are 353 results. Although this exercise is necessarily only a limited overview of the extent of research output on climate issues, it illustrates the need for more research output in MENA countries. The information presented in Appendix 1 displays more results and includes all six MENA countries considered in this report.

Nomads in Mhamid el Ghizlane Oasis, Morocco draw water from a drying well.

1.1 An overview of regional climates in the Middle East North Africa region

The Middle East North Africa (MENA) region's varied terrain and topography include coastal ecosystems along North Africa's Mediterranean coast, the Red Sea and the Gulf, extensive arid and semi-arid lands, as well as high mountains, for example in Morocco and Lebanon. In terms of climate characteristics, it would be inappropriate to apply generalisations across the entire region, although we do know that the average temperature across the MENA region (in common with the rest of the world) is increasing. This section gives an overview of what we can say about current climate trends and projections for the region during the twenty-first century.

1.1.1 Sahara region, southern Mediterranean: Morocco, Algeria, Tunisia, Egypt

Recent past

The north Africa region has a wet season in winter (October to April) and dry summer months. There is natural climate variability between the years, which means that some years are wetter than others. It is important to take into consideration the long-term climate trends when looking at past and future climate in the region (IPCC, 2022).

The Mediterranean climate is temperate with a hot or warm dry summer season (June to August). Precipitation varies on an annual cycle and is highly temporal and local. The Mediterranean receives less rainfall in the south of its basin than in the north. Mediterranean droughts have a high impact on water availability by decreasing groundwater levels and water in dams and surface reservoirs. Low levels of precipitation, combined with high temperature, can affect multiple areas, such as agriculture and biodiversity, particularly in rain-fed regions of North Africa and the Middle East. The region lies in a transitional zone, being influenced by the presence of large water bodies, sub-tropical processes and mid-latitude westerlies (Giorgi & Lionello, 2008).

Current trends

North Africa is experiencing an overall significant warming trend, more pronounced during the summer season (Cherif et al., 2020). Precipitation trends are less robust (Donat et al., 2014; Zittis, 2018), however, there are indications for wet-season (October to March) drying. Although all regions of North Africa already have scarce water supplies, Algeria, Tunisia and Egypt are expected to be the more vulnerable countries to such changes (Schilling et al., 2020).

Future climate

Climate change projections, based on global and regional climate models, highlight a further increase in average temperature and an intensification of extreme heat and drought events across the region.

The magnitude of changes and associated impacts strongly rely on the future emission trajectories and socio-economic development pathways, nevertheless the Mediterranean is expected to continue to warm faster than the global mean rates (Zittis et al., 2019; Cherif et al., 2020; Lionello & Scarascia, 2020).

According to future climate projections, the Mediterranean will be susceptible to climate change, earning the region the label of 'a climate change hot spot' (Tuel & Eltahir, 2020). This is mostly because temperature and precipitation are projected to change in a different direction, and because of pronounced changes in the variability of these parameters, also influencing extremes (Zittis et al., 2019; Cherif et al., 2020). Due to the complexity of weather, the mechanisms underlying these processes are not fully understood (Tuel & Eltahir, 2020). Future climate change scenarios project drying in the Mediterranean region, with countries in the south and east of the basin particularly affected (which would include Algeria, Morocco, Egypt, Tunisia and Lebanon)(Zittis et al., 2019; Almazroui et al., 2020a; Zittis et al., 2021a). In these regions, the drying will be more pronounced during the wet part of the year, which is the most critical season for replenishing the scarce water resources. The impact of future droughts in the region will depend to a certain extent on human activities (for example, water management and implementation of adaptation measures) and the frequency of events. For example, recurrent droughts could lead to increased use of groundwater, which could impact crop yields, or imply additional requirements for desalination, which could increase the energy demand substantially. Likewise, a shortage of water could shorten the growing cycle of crops, further impacting yield. The nature of drought and therefore the forecasting of the occurrence of droughts are complex because natural climate variations as well as socioeconomics and human activities need to be taken into consideration when projecting water availability. Adaptation to increased drought situations will require a suite of solutions (Tramblay et al., 2020).

The region will also be subject to extreme heat waves of unprecedented duration and magnitude (Lelieveld et al., 2016; Zittis et al., 2021a). This is a robust finding under all emission scenarios.

1.1.2 Eastern Mediterranean: Lebanon

Recent past

The Eastern Mediterranean region has a range of climates, from semi-arid to sub-tropical and temperate. Summers are usually hot and dry, and most of the precipitation falls during the mild winter season . The northern part, which includes Lebanon, is largely temperate.

Current trends

The Eastern Mediterranean and the Middle East region has experienced a warming trend over the past century. Up to the 1980s, this warming was very close to the global trends. In the past four decades, this has accelerated to a rate of more than 0.4 °C per decade, which is nearly two times the average global rate (Zittis et al., 2022). The region was recently impacted by multi-year droughts, unprecedented at least during the past 500 to 900 years (Lelieveld et al., 2012; Cook et al., 2016). Besides their direct effect on ecosystems, such prolonged events have major socio-economic impacts that challenge the wellbeing of the region's population (Kelley et al., 2012).

Future climate

The eastern Mediterranean, including Lebanon, will continue to warm for the rest of the twenty-first century (Zittis et al., 2019). The warming is projected to stabilise by 2050, only if substantial mitigation measures are implemented (Zittis et al., 2022). Current emission trajectories imply faster warming, more pronounced during the summer season resulting in more frequent and intense heat waves (Zittis et al., 2016; Zittis et al., 2021a). In such a scenario, rainfall will probably decline, and the combination of drying and strong warming will result in severe agricultural and ecological droughts.

1.1.3 Arabian peninsula, the Gulf: United Arab Emirates

Recent past

The historical trends in data collected between 1978 and 2019 show that the Arabian Peninsula has become dryer (precipitation decreased by 6.3mm per decade) and warmer (the annual temperature increased by 0.51 °C per decade). Average annual precipitation (after 1998) is 96.92 mm (Almazroui et al., 2020b).

Current trends

UAE has a predominantly arid climate with rainfall levels among the lowest on Earth. Rainfall has high intra- and interannual variability and most rainfall is during the wet season (October to May). Some areas of the Peninsula have a mean annual temperature that exceeds 30 °C, although that's the exception; 90% of the Arabian Peninsula has a mean annual temperature of 20 °C (Kotwicki & Al Sulaimani, 2009).

Future climate

Regarding temperature, the projections for the Arabian Peninsula agree with the rest of the MENA region. The observed warming is expected to continue throughout the twenty-first century, unless timely global mitigation actions are implemented (Zittis et al., 2022). This warming will be more pronounced in the summers and, combined with increased humidity, will result in uncomfortable conditions for prolonged periods throughout the year. There is less confidence in the precipitation projections due to the local nature of rainfall events; nevertheless, most models suggest a drying in the northern parts and a precipitation increase in the south. The significance of this wettening in terms of water resources for the region is still questionable.

1.2 Climate projections and extreme weather in the Middle East North Africa region

The projections for the MENA region are clear trends of warming and drying. **Table 1.1** shows the figures extracted from the IPCC WGI Interactive Atlas, which should serve as a clear warning of the danger of continued greenhouse gas emissions (IPCC, 2021).

SSP1–2.6 This scenario assumes low greenhouse gas emissions with CO_2 emissions declining to net zero around 2050.

SSP2–4.5 This scenario assumes intermediate greenhouse gas emissions. The projections are temperature increases in all three regions relative to the baseline period 1850–1900. This intermediate scenario assumes CO_2 emissions to be similar to present-day levels up to 2050.

SSP5–8.5 This scenario assumes very high greenhouse gas emissions in which CO_2 emissions are approximately double those from present-day levels by 2050. Note that this scenario is a high-emissions scenario that assumes no policy interventions on greenhouse gas emissions and should not necessarily be regarded as 'business-as-usual'.

	Near future (2021–2040)			Mid-term future (2041–2060)			Far future (2081–2100)		
SSP scenario	SSP1–2.6	SSP2–4.5	SSP5–8.5	SSP1–2.6	SSP2–4.5	SSP5–8.5	SSP1–2.6	SSP2–4.5	SSP5–8.5
Mediterranean region	1.8 °C	1.9 °C	1.9 °C	2.1 °C	2.4 °C	2.9 °C	2.2 °C	3.3 °C	5.5 °C
Sahara region	2.1 °C	2.2 °C	2.3 °C	2.5 °C	2.8 °C	3.4 °C	2.5 °C	3.8 °C	6.3 °C
Arabian Peninsula region	2.1 °C	2.2 °C	2.3 °C	2.5 °C	2.8 °C	3.4 °C	2.5 °C	3.8 °C	6.3 °C

Table 1.1. Climate projections for the MENA region showing median temperature increase, per region, in °C, relative to the baseline period 1850–1900. Source: IPCC WGI Interactive Atlas (https://interactive-atlas.ipcc.ch/).

1.2.1 Heat extremes

A robust outcome of future climate projections is an increase in the frequency and intensity of heat waves in the region. Because summers in the MENA countries are already scorching, any intensification of heat extremes will pose additional challenges to the vulnerable ecosystems and populations of the region. Human health, agriculture, tourism, water and energy management, are only some of the vital socio-economic sectors that will be impacted. Extreme events that occurred only rarely in the recent past are projected to become commonplace in the second half of the twenty-first century (Lelieveld et al., 2014; Molina et al., 2020; Zittis et al., 2021a). In a 'business-as-usual' RCP8.5 future, the coolest summers will likely be comparable to or even hotter than the warmest summers of the recent past (Zittis et al., 2021a). Such a scenario implies that, by the end of the century, 80% of the densely populated cities of the region are likely to suffer from heat waves for at least 50% of the warm season (Varela et al., 2020). Compared to present-day standards, extreme heatwave characteristics in the eastern Mediterranean and the Middle East are projected to increase tremendously (Zittis et al., 2016) **(Fig. 1.1)**. The annual number of events is projected to increase by 3–6 times, their amplitude to increase by 6 °C–7 °C, while the duration of the longest-lasting heat waves could be several weeks. In high-emission pathways, some locations in the Middle East and the Gulf region, peak temperatures during extreme future heatwaves could exceed 56 °C (Ntoumos et al., 2022; Zittis et al., 2021a). The current state-of-the-art climate models do not resolve local feedbacks, such as the 'urban heat island' phenomenon. As a result, the simulated temperature over large urban centres is typically underestimated and these estimations can be conservative. Warm nights are projected to also increase (Lelieveld et al., 2016; Ntoumos et al., 2022). A combination of extreme high temperatures and increased humidity levels, particularly in the Gulf region, will dramatically increase thermal discomfort **(Fig. 1.2)**. At least for the warmer months, such conditions might exceed critical thresholds for human adaptability (Pal & Eltahir, 2016; Ahmadalipour & Moradkhani, 2018).

Sand dunes of the desert of Swaihan, the United Arab Emirates.

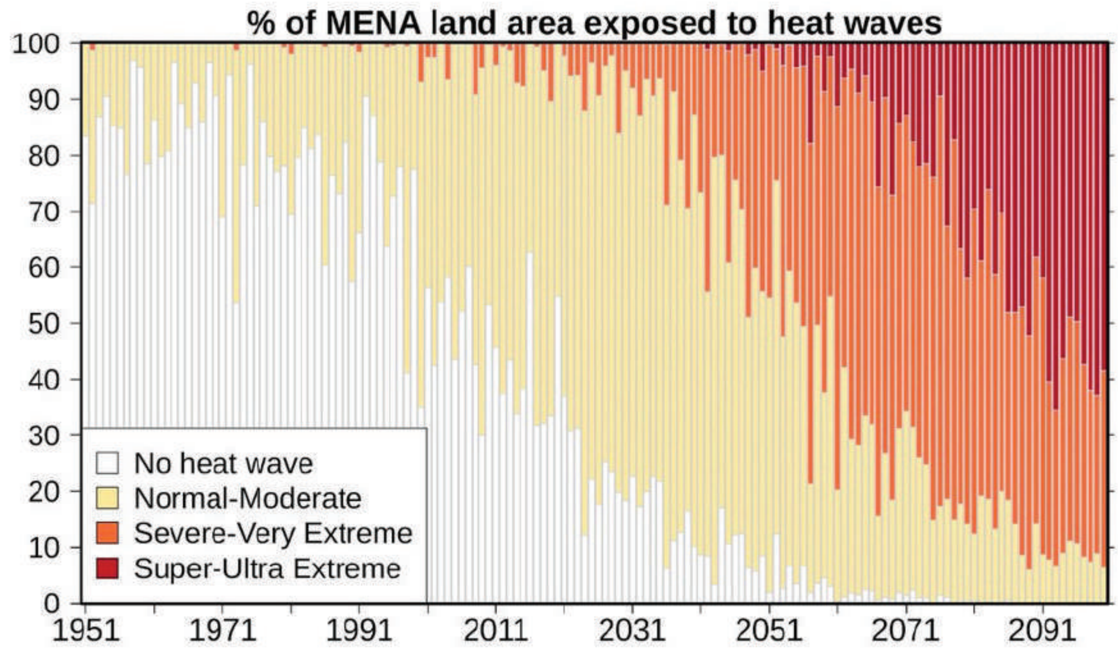


Figure 1.1. *Percentage of Middle East North Africa (MENA) land area annually exposed to several heatwave categories for the period 1951–2100. Projections correspond to pathway RCP8.5. (Source: Zittis et al., 2021a).*

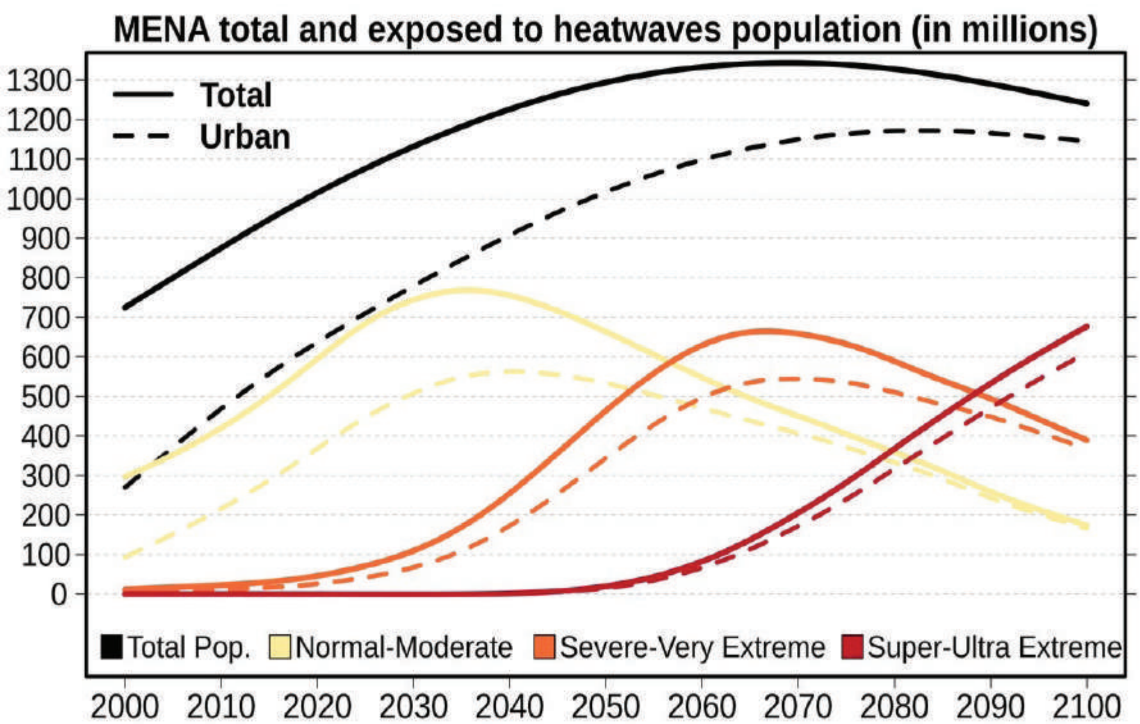


Figure 1.2. *Total Middle East North Africa (MENA) population according to the SSP5 narrative and population that is projected to be exposed to events with heatwave events of various magnitudes. Solid curves represent the total and dashed curves represent the urban population. Projections correspond to pathway RCP8.5. (Source: Zittis et al., 2021a).*

heatwave events of various magnitudes. Solid curves represent the total and dashed curves represent the urban population. Projections correspond to pathway RCP8.5. (Source: Zittis et al., 2021a).

The MENA region is expected to become warmer over the course of the twenty-first century. To give an idea of the temperature increase that could be experienced, Lelieveld et al. (2016) performed computer modelling for the wider MENA region (encompassing 29 countries, including all Middle Eastern and Maghreb countries). Model projections from that study suggest that, under the RCP8.5 scenario, maximum daytime temperatures could increase to 47 °C by 2050 and to 50 °C by 2100 in comparison to a maximum of 43 °C in the reference period from 1986 to 2005. (Note that the RCP8.5 scenario has attracted some criticism as being unrealistic and representing an unlikely scenario (for example, Hausfather & Peters, 2020). (See also the Glossary of terms for a full explanation of the RCP scenarios.) Even under the more ambitious RCP4.5 scenario, in which net greenhouse gas emissions are substantially decreased after 2050, maximum daytime temperatures could still increase to 45 °C by 2050 and up to 47 °C by 2100 **(Fig. 1.3).**

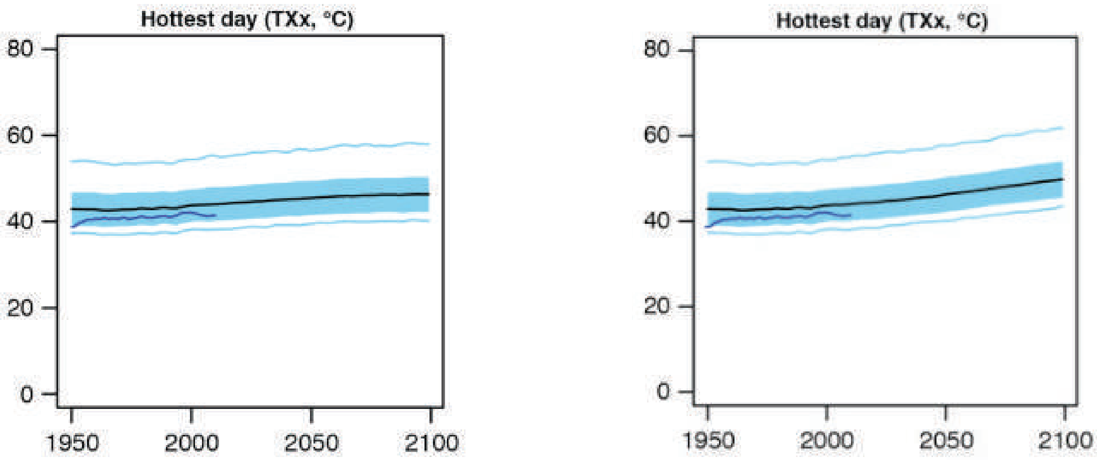


Figure 1.3: *Projected maximum daytime temperature increase in Middle East North Africa (MENA) under (left) RCP 4.5 and (right) RCP8.5. x-axis = year; y-axis = °C. (Source: adapted from Fig. 4 in Lelieveld et al., 2016. Licenced for use under Creative Commons: http://creativecommons.org/licenses/by/4.0/).*

The study by Lelieveld et al. (2016) also modelled the projected change in the number of warm nights in the region as an annual percentage. The number of warm nights per year is projected to increase sharply under both scenarios to the middle of the century – under RCP8.5 the number warm nights per year may exceed 200 by the end of the century, in comparison the reference period (1986–2005) when the average duration of warm days is 16 days. (Readers interested in the formula used to determine warm nights are directed to the Lelieveld et al. (2016) paper, which provides a detailed explanation) **(Fig. 1.4).**

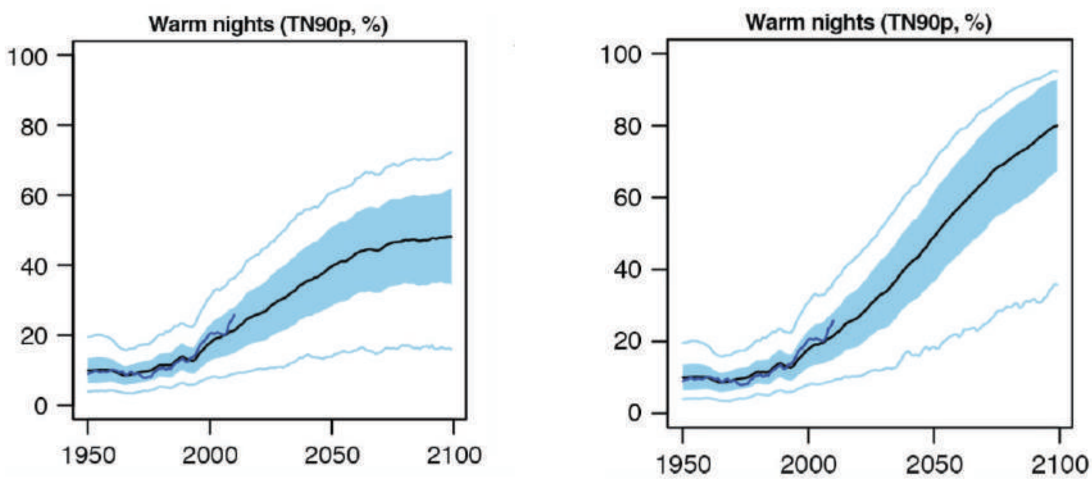


Figure 1.4: *Projected number of warm nights this century in Middle East North Africa (MENA) under (left) RCP 4.5 and (right) RCP8.5. x-axis = year; y-axis = %. (Source: adapted from Fig. 4 in Lelieveld et al., 2016. Licenced for use under Creative Commons: http://creativecommons.org/licenses/by/4.0/).*

1.2.2 Precipitation

Precipitation projections are less robust, and inter-model agreement is lower than for temperature (Lelieveld et al., 2106; Zittis et al., 2019; Zittis et al., 2021b). This is mainly related to the small-scale processes involved in the formation of clouds and rainfall and the misrepresentation of complex orography and coastlines. The current climate models cannot fully resolve these critical processes. In addition, rainfall events are very local in the arid and semi-arid parts of the MENA region and often occur on short time scales.

The consensus in IPCC AR6 and several regional studies is that overall, north Africa, like the rest of the Mediterranean will experience a decrease in precipitation (IPCC, 2022; Zittis et al., 2019; Almazroui et al., 2020a; Cherif et al., 2020; Lionello & Scarascia, 2020; Zittis et al., 2021b; Waha et al., 2017; Driouech et al., 2020). For the end of the current century, this decrease is likely to be between -10 and -30% **(Fig. 1.5).**

The expected precipitation decline is not always significant (that is, the magnitude of changes is comparable to interannual variability). Exceptions are profound precipitation decreases in the Maghreb and Levant regions, mainly projected for the second half of the twenty-first century and under high-emission scenarios. In the Mediterranean coast, the number of rainy days per year and the length of wet spells (consecutive days with precipitation greater than 1 mm) are also projected to decrease (Giorgi et al., 2014; Dosio et al., 2018). In contrast, the length of dry spells (number of consecutive dry days) will probably increase (Raymond et al., 2019; Lionello & Scarascia, 2020; Coppola et al., 2021).

Despite the overall drying, the most extreme rainfall events will probably intensify throughout the region (Giorgi et al., 2014; Donat et al., 2019; Giorgi et al., 2019; Zittis et al., 2021b). In the most arid parts of northern Africa, a considerable fraction of annual precipitation results from one-day extreme events (Zittis et al., 2021b). This fraction is expected to increase in a warmer world, posing additional challenges to ecosystems and water management.

For the southern parts of the Arabian Peninsula and Egypt, climate models indicate a precipitation increase of up to 50% (Lelieveld et al., 2016; Almazroui et al., 2020a; Zittis et al., 2022). Although the percentage increase seems large, it is not always significant in terms of rainfall amounts.

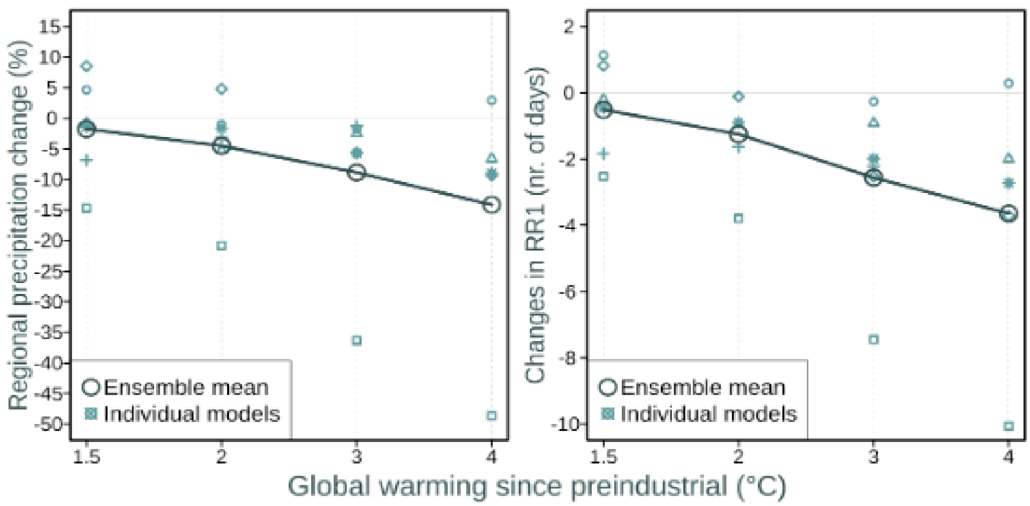


***Figure 1.5.** Projections of regional changes in annual precipitation (left panel) and number of rainy days per year (RR1: right panel) for different global warming levels, averaged for the MENA countries. (Courtesy of George Zittis. Data source: MENA-CORDEX simulations under RCP8.5. More information on models in Zittis et al., 2021a).*

A woman collecting water in the parched wetlands of the Central Marshes of southern Iraq.

1.2.3 Drought

In the AR6, the IPCC projects an increased risk of drought in North Africa and the western Sahel, and increased aridity over West Central Asia in the future decades of this century under a climate heating scenario of 2 °C (Arias et al., 2021).

Drought can cause economic loss, bring crop failures, put food security at risk, and can lead to a shortage of safe, clean drinking water. Drought is an extended period of time in which a region receives less precipitation than expected. But attributing a drought – as with other extreme weather events – to just one cause is not straightforward because extreme events are usually caused by several different (albeit interacting) factors.

Of the six MENA countries focused on in this report, Morocco is the most dependent on agriculture for economic income making it, therefore, highly vulnerable to drought (Schilling et al., 2020; World Bank, 2021). The increasing frequency and intensity of drought in Morocco in previous decades has already significantly affected the country's cereal production. For example, the total cereal production (wheat and barley) was severely reduced by drought in the November 2015–spring 2016 season with a total harvest of 3.4 million tons – much less than previous three seasons in which the average cereal production was 9.3 million tons. Cereal crops, some of which are used to feed livestock, are grown in the central belt of Morocco and are rainfed, which makes them less resilient to climate variation than the more varied crops of fruit trees and vegetables in the north of the country. As annual average temperatures in Morocco are projected to increase this century, with uncertainties about future precipitation patterns, Morocco's agricultural sector will face increasing water shortage challenges (Verner et al., 2018).

Of the North Africa countries, Schilling et al. (2020) identified Algeria as having the greatest water scarcity and being the most vulnerable because the country has low adaptive capacity. In other words, Algeria's population is less well equipped than other countries to cope and adapt with changes in climate.

It is clear that all the MENA countries covered in this report will be affected by global heating and certainly from a world perspective, North Africa is a 'climate change hot spot'. All countries in the region are considered water scarce. All the North African countries – apart from Egypt – rely on rainfall for agriculture. A decline in precipitation, therefore, could have serious implications for food security (Schilling et al., 2020).

BOX: Future population trends in the Middle East North Africa region

Global population figures are projected to increase through the twenty-first century, but the distribution of those population increases will vary markedly between different countries and regions. In the tropical and equatorial latitudes of Africa, the Mediterranean region, and hot dry (western and central) and humid (southern and southeastern) Asia, the combination of population increase and climate change may mean that more energy will be needed to both heat and cool environments under any RCP–SSP modelling scenario combinations (Spinoni et al., 2021).

Projections for the MENA region as a whole are that, by the end of the twenty-first century, the population of MENA countries will exceed 1 billion, greater than the projected population of China in 2100. Egypt has long been – and will likely remain – a key population centre, largely because of the Nile River. In Egypt, future population growth is projected to be concentrated in the Nile basin.

By 2050, approximately 70% of the MENA population is expected to be living in cities, although this will vary by country and region. The relevance of the projection is that it could have an impact on agricultural production and, in turn, food security, for reasons that include (i) if urban development begins to encroach on agricultural land and (ii) because of increased demand for food from the bigger cities. A knock-on impact of urbanisation and imported food is increased consumption of processed foods, unhealthy lifestyles and increased risk of developing non-communicable diseases such as diabetes and heart disease (McKee et al., 2017).

2.0

Summary of findings from the Intergovernmental Panel on Climate Change Sixth Assessment Report

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) consists of reports from three working groups that each focus on a different aspect of the science behind climate change:

- ☐ **Working Group I – The Physical Science Basis;**
- ☐ **Working Group II – Impacts, Adaptation and Vulnerability;**
- ☐ **Working Group III – Mitigation of Climate Change.**

The main findings from AR6 build upon previous Assessment Reports that climate changes are already happening, most global land areas will become hotter through the twenty-first century, and that many of the changes are as a result of human activity. One of the main findings is that since the previous report, the Fifth Assessment Report (AR5), the global surface temperature has warmed strongly, with the past five years (2016–2020) being the hottest on record since at least 1850. Since AR5 there has been an increased frequency of extreme weather events on a global level, such as precipitation that causes floods, tropical cyclones, and heat extremes that lead to wildfires.

In relation to North Africa, AR6 projections indicate a likely decrease in total precipitation in the northernmost regions, increasing aridity and drought. Climate heating will bring an increased risk of extreme and lethal heat events to North Africa. In Lebanon and the UAE, aridity is projected to increase, particularly from the middle of the century. A key point found by Working Group (WG) III, which looks at mitigation of climate change, is that among African individuals and households there is low motivation to alter their energy consumption behaviour. The WG III findings are that changes will need to be structural and cultural and will need to involve psychological variables such as awareness, perceived risk, subjective and social norms, values, and perceived behavioural control. The Working Group (WG) III report, which looks at mitigation of climate change, notes that both structural and cultural changes will be needed in order to properly address energy consumption patterns in Africa, including attention to the psychological aspects of awareness, perceived risk, subjective and social norms, values, and perceived behavioural control.

The IPCC interactive atlas (https://interactive-atlas.ipcc.ch) is a useful visual tool to see how regions might be affected by heat and precipitation under different climate warming scenarios.

Table 2.1 contains some of the key points copied verbatim from the Technical Summaries of the IPCC AR6 reports in more detail, with reference to the relevant section numbers of those summaries.

Regions in IPCC reports

The IPCC Assessment Reports discuss regions on a continental basis rather than on a country-by-country basis. In the reports, the six countries in this report fall under two different categories:

- ☐ Countries in Africa: Morocco, Tunisia, Algeria, Egypt
- ☐ Countries in West Central Asia: Lebanon, UAE

Table 2.1. *A summary of findings from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) Technical Summaries. (Please see Appendix 2 for the full list together with AR6 section references.)*

	Observed changes	Projected changes
Working Group I – The Physical Science Basis (Arias et al., 2021)		
Global changes	"High confidence that climate changes, such as a decrease in total precipitation and an increase in aridity, have already happened and medium confidence that many of the changes are due to human activities."	"It is likely that most land areas will experience further warming of at least 4 °C compared to a 1995–2014 baseline by the end of the 21st century." "High confidence that because of the frequent increasing warming levels, extreme heat will exceed critical thresholds for health and agriculture."
Africa	"North East Africa has experienced a decrease in rainfall since 1980."	"High confidence in projected decrease in total precipitation in the northernmost regions of Africa." "High confidence in heavy precipitation in most African areas that will lead to floods." "Medium to high confidence that there will be increasing aridity and drought is projected for North Africa." "Northern Africa is likely to have a reduction in precipitation." "High confidence in a decrease in mean wind, extreme winds and the wind energy potential in North Africa." "High confidence that because of the frequent increasing warming levels, extreme heat will exceed critical thresholds for health and agriculture."
Asia	"There has been a decline in annual precipitation over the Arabian Peninsula since the 1980s of 6.3 mm per decade. In contrast, there has been an increase in precipitation of between 1.3 mm and 4.8 mm per decade from 1960 to 2013 over the high parts of eastern West Central Asia."	"There is medium confidence that in West Central Asia, aridity will increase, especially beyond the middle of the twenty-first century and global warming levels beyond 2 °C."

Working Group II – Impacts, Adaptation and Vulnerability (Pörtner et al., 2021)		
Water systems and water security	"Droughts, floods and rainfall variability have contributed to reduced food availability and increased food prices, threatening food and nutrition security, and the livelihoods of millions globally (high confidence), with the poor in parts of Asia, Africa and South and Central America being disproportionately affected (high confidence)."	"Above 2 °C, the frequency and duration of meteorological drought are projected to double over North Africa, the western Sahel and southern Africa (medium confidence)."
Ecosystems and biodiversity		"Global warming of 3.0 °C–3.5 °C increases the likelihood of extreme and lethal heat events in western and northern Africa (medium confidence) and across Asia."
Health and well-being		"Tens of thousands of additional deaths are projected under moderate and high global warming scenarios, particularly in north, west and central Africa, with up to year-round exceedance of deadly heat thresholds by 2100 (RCP8.5) (high agreement, robust evidence)."
Cities		"Asian and African urban areas are considered high-risk locations from projected climate, extreme events, unplanned urbanisation and rapid land use change (high confidence)."
Maladap-tation	"Awareness of anthropogenic climate change ranges between 23% and 66% of people across 33 African countries, with low climate literacy limiting potential for transformative adaptation (medium confidence)."	
Working Group III – Mitigation of Climate Change (IPCC, 2022)		
Urban emissions	"For 2000 to 2015, the urban emissions share increased from 28% to 38% in Africa, and from 57% to 62% in West Central Asia." "From 2000 to 2015, global urban GHG emissions per capita increased from 5.5 to 6.2 tCO_2-eq per person (an increase of 11.8%). Emissions in Africa increased from 1.3 to 1.5 tCO_2-eq per person (22.6%). And in West Central Asia from 6.9 to 9.8 tCO_2-eq per person (40.9%)."	"Medium confidence that urban land areas will increase: the highest rate of urban land growth is projected to occur in Africa, Eastern Europe and West-Central Asia."

3.0

Impacts of climate change and extreme weather events on societies

The text in this section (3.0) is based on text published in the Greenpeace Research Laboratories technical report, Weathering the Storm (Miller et al., 2020), with some updates to reflect developments in scientific understanding and assessment since that publication.

Climate observations and models broadly agree that – on a global level – extreme weather events are likely to occur more frequently and/or with greater intensity as the twenty-first century progresses (Niang et al., 2014). Extreme weather will clearly have an impact on the way we live our lives.

Photo by AHMAD AL-RUBAYE_AFP via Getty Images

A man stands by fans spraying air mixed with water vapour in Iraq's capital Baghdad, during a severe heat wave in the summer of 2021.

3.1 Human health and heat exposure

Heat affects human health, mainly because exposure to extreme conditions can exacerbate underlying health problems. Deaths can and do occur following periods of extreme heat, and while many people can cope with one single day of extreme temperatures, mortality rates increase during prolonged heatwave events that last for more than two days. The greatest health problems are during extended periods of extreme heat, when temperatures during the night and the day are high, because there is then no period for humans to recover or recuperate (Perkins, 2015). The human body thermoregulates to maintain core temperature at typically 36.5 °C–37.5 °C. Overheating can lead to hyperthermia. Typically, overheating happens with fever but also if the external temperature is hot for a long period and the body is not able to cool down. A core body temperature of 38 °C is considered high and if it reaches 40 °C it becomes life threatening (NHS, 2020).

If ambient temperature is more than 37 °C then the body will accumulate heat and is likely to become hyperthermic. Sweating to dissipate heat becomes ineffective at high relative humidity, which means that in high humidity even a lower ambient temperature can be deadly (Mora et al., 2017). A wet-bulb temperature of 35 °C (a measure of relative humidity) marks the upper physiological limit for human survival (Raymond et al., 2020). Analysis of the combined effect of temperature and humidity on human health found that the high mortality rates in India and Pakistan during separate extreme heat events in 2015 were because of the combination of high temperatures and high humidity, a situation compounded because hospitals were over-capacity with patients suffering from heat-related illness (Wehner et al., 2016). In coastal regions of MENA (for example., in the Gulf countries), such atmospheric conditions are typical during the warm months of the year.

Heat-related health impacts can include increased morbidity through ischemic heart disease, ischemic stroke, cardiac dysrhythmia, dehydration, acute renal failure, heat illness, diarrhoea and heat stroke (Hopp et al., 2018). A loss of productivity is anticipated with sustained periods of heat particularly if combined with high humidity (Levy et al., 2016; Perkins-Kirkpatrick & Gibson, 2017).

Extreme heat events are known to cause heat-related deaths – the death toll from the European-wide heatwave in 2003 reached tens of thousands and peaked in France, Germany and Italy (Christidis et al., 2014; Mora et al., 2017). Studies analysing exposure to extreme temperatures found that extreme heat events generally cause excess mortality within a few days. By contrast, extreme cold weather events cause excess mortality over a longer period of up to 25 days. Susceptibility to extreme weather events is influenced by factors including: the ability of a person to acclimatise, age, socioeconomic conditions, whether the setting is urban or rural and access to air conditioning (Anderson & Bell, 2009). High excess human morbidity and mortality rates are associated more with sustained periods of moderate temperatures rather than one-off very hot days (Gasparrini et al. 2015; Perkins-Kirkpatrick & Gibson, 2017).

BOX: What is an extreme weather event?

Adapted from Miller et al. (2020).

No universally accepted definition of 'extreme weather' exists, even though an extreme weather event might be described as such by those who experience unusual weather. The nature of 'extreme' is relative to the normal or prevailing conditions and can include heatwaves, droughts, torrential rains, or other types of extreme weather phenomena. Extreme weather events are also described as rare events (and humans are not well adapted to cope with them) or severe events (that create loss or damage to infrastructure and/or ecosystems). An extreme weather event generally involves a number of parameters that include a combination of climate variables and drivers, while the location, timing of such an event and exposure of assets will determine its overall impact (Stephenson, 2008). Extreme weather may cause injuries or casualties, starvation, damage to ecosystems, housing, infrastructure and agriculture, and may lead to evacuation or migration of inhabitants or crop failure. Events and issues associated with or caused by periods of extreme weather that are covered in this report include those to human health, food and water security, and biodiversity.

Extreme events are usually described by percentage-based definitions (for example, events with a probability of occurrence lower than 95 or 99%) or by the exceedance of predefined thresholds (for example, relevant for agriculture or human health).

Attributing extreme weather events to one specific cause is not straightforward. Extreme weather events can be caused by natural variability within the climate system, human activity or a complex interplay between the two. The certainty is that extreme weather events are occurring more frequently and that they are leading to an increase in human suffering (Coumou & Rahmstorf, 2012).

3.1.1 Human survival in a hot and humid future

Nomad and his herd of camels in Mhamid el Ghizlane Oasis, Morocco.

Humans have adapted to live within a broad temperature range of between 4 °C and 35 °C. However, research has found that since the mid-Holocene (6,000 years before the present day) a majority of humans have chosen to live in regions with an average annual temperature of 11 °C to 15 °C (Xu et al., 2020). Global climate modelling projects that under a high-emissions scenario (for example, RCP8.5/SSP3), by 2070, the global mean human-experienced temperature increase will be 7.5 °C compared to the pre-industrial period (Xu et al., 2020). (For an explanation of RCP and SSP scenarios, please see the Glossary of terms.)

Not every continent is projected to experience a surface temperature rise of such magnitude, but the modelling projection incorporates population growth under Shared Socioeconomic Pathway 3 (SSP3), and population growth is projected to increase faster in hotter regions. The worst-case scenario projection, using the RCP8.5/SSP3 scenario and not allowing for migration, is that 3.5 billion people globally will be living in regions with a mean annual temperature of around or exceeding 29 °C, which could be regarded as being (or at least verging on being) uninhabitable. So, a region with a mean annual temperature of 13 °C in 2020 might experience a mean annual temperature of 20 °C in 2070 – such as the climate presently found in North Africa. But even if greenhouse emissions are on a downward trajectory towards net zero in 2100 – the RCP2.6 scenario – the projections are that, by 2070, around 2.6 billion people around the globe could still be displaced due to inhospitable ambient temperatures.

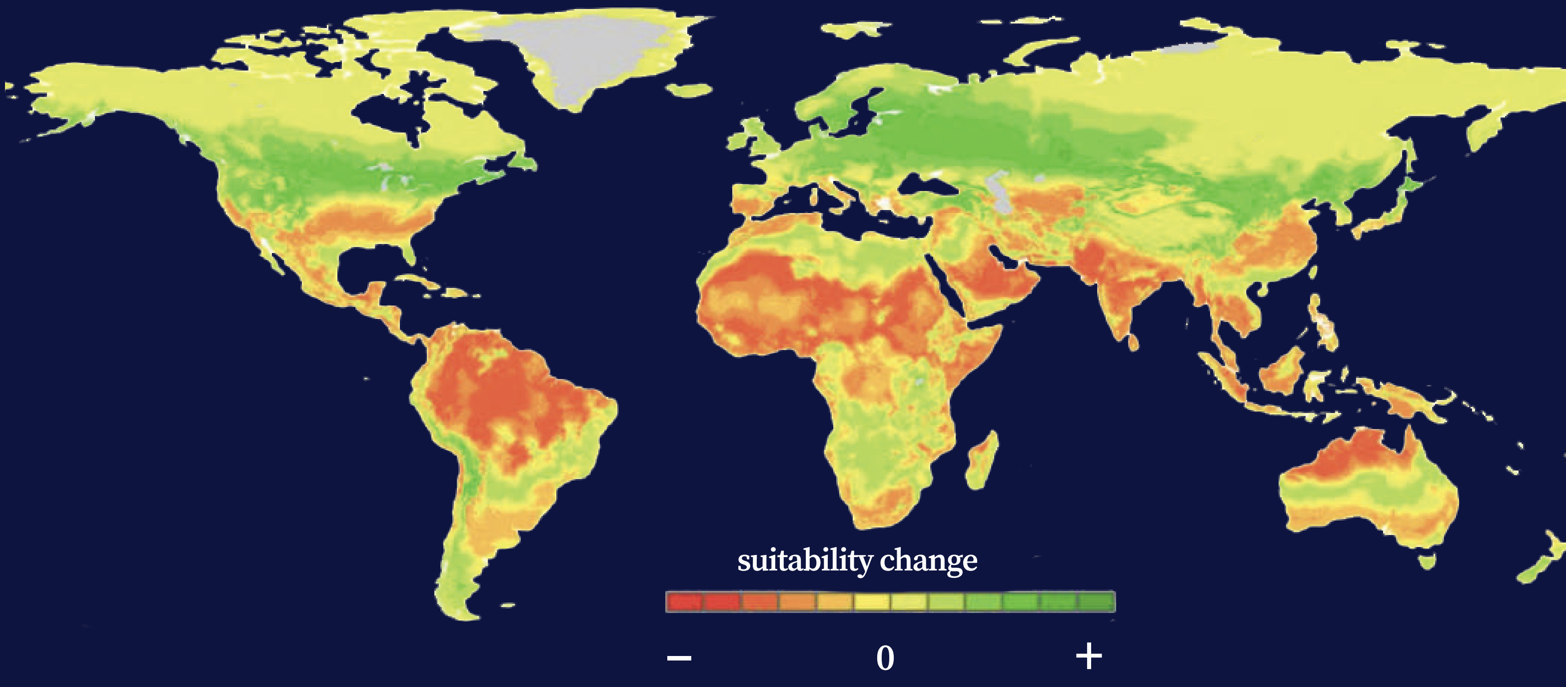
The map in Fig. 3.1 shows projected 'niche displacement' of people affected by land suitability for human habitation in 2070, modelled under RCP8.5 and with population changes under the SSP3 scenario. If the majority of humans continue to live in regions with mean annual temperatures of around 11 °C to 15 °C, as has historically been the case, then the projection is that some regions of the world will become less suitable for humans and other regions will become more suitable. If the human population is distributed according to the mean annual temperature, then in 2070 the projection is that the trend in human migration will be from the regions on the map shaded red to those shaded green (Xu et al., 2020).

Other studies have similarly suggested that an increasingly hot climate may contribute to human migration in future decades (Lelieveld et al., 2016; Cattaneo & Peri, 2016; Missirian & Schlenker, 2017; Abel et al., 2019). If the RCP8.5/SSP3 projections were to be realised (that is, that greenhouse gas emissions continue on a business-as-usual basis through the twenty-first century), regions of MENA, including Morocco, Algeria, Tunisia, the far north of Egypt, Lebanon and the UAE could experience decreases in the area of land suitable for human habitation by the final decades of the twenty-first century. For example, the present-day mean annual temperature in some regions in MENA is around 20 °C; those regions are projected to become hotter in future decades. Some regions that have a present-day mean annual temperature of 13 °C are projected to have a mean annual temperature of 20 °C by 2070. Projections indicate that some parts of MENA, including the UAE, could experience mean annual temperatures of more than 29 °C **(Fig. 3.2)** (Xu et al., 2020). Widespread movement of people could lead to cultural and political tensions within and beyond the regions worst affected.

In addition, some MENA countries, in particular Algeria and Egypt, could experience further increases in population as a result of people migrating from other worse-affected countries in the region, with the added possibility that a high proportion of those migrating will be subsistence farmers or people otherwise on low incomes.

In practical terms, however, the ability to migrate may be more restricted to those with sufficient finances, in which case poorer people will be unable to move and risk being trapped in an increasingly difficult climate scenario, risking even greater heat-related illnesses, food insecurity and malnutrition (World Bank, 2014). Questions have been raised by researchers looking at human migration, in particular whether it would likely be permanent or temporary for different groups.

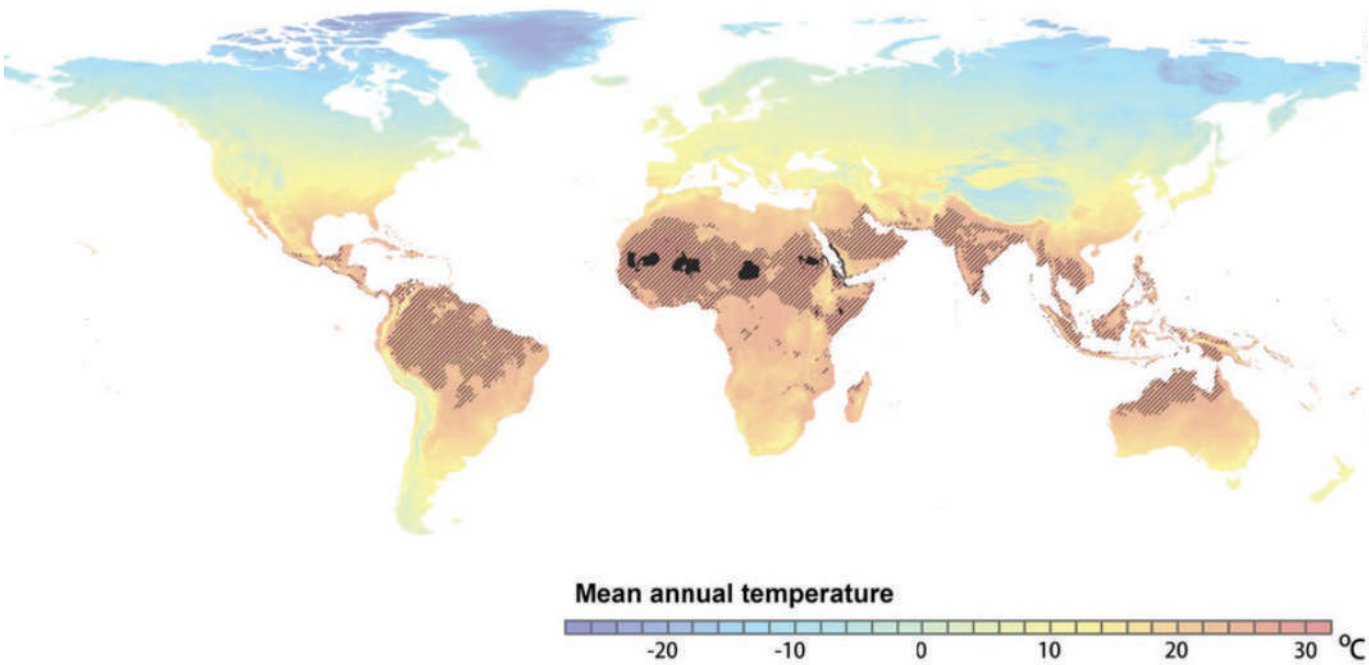
Figure 3.1. Change to land suitable for human habitation. *By the late twenty-first century, circa 2070, human populations could be displaced from the red shaded regions, where the climate is projected to become inhospitable, to green shaded regions (Source: Xu et al., 2020; original material published under a CC BY-NC-ND license; http://creativecommons.org/licenses/by/4.0/).*



The number of people affected by heat will depend upon the extent to which the global climate warms compared to pre-industrial levels – there is a big difference between the number of people impacted by a 2 °C average global temperature increase in comparison to a 1.5 °C increase.

Even so, limiting the global average temperature rise to no more than 2 °C above pre-industrial levels is still not likely to prevent an increase in the frequency and intensity of extreme heat events (Diffenbaugh & Scherer, 2011).

__Figure 3.2. Global annual average temperature projections.__ In the present day, regions with a mean annual average temperature of more than 29 °C are shaded black, and occur in the Sahara region. Projections for 2070 under the RCP8. 5 scenario suggest that mean annual temperatures of more than 29 °C will extend throughout the shaded area. (Source: Xu et al., 2020; original material published under a CC BY-NC-ND license; http://creativecommons.org/licenses/by/4.0/).



Countries that surround the Mediterranean Sea are projected to experience strong warming and drying in 2080–2099 compared to 1980–2099. In currently arid regions along the southern shore of the Mediterranean (the North African countries), the sea will nonetheless likely provide a source of greater humidity, which may add to the health concerns arising from extreme heat for reasons noted above. This is also the case for the shallower waters of the Red Sea and the Gulf. A modelling study by Drobinski et al. (2020) uses the humidex index to quantify the change in humidity and heat and the impact on human health. The study found that in 2070-2100 the Humidex index in the southern Mediterranean will be +2 in comparison to the present climate, taking the Sahara region to Humidex Category 4 (dangerous levels), which is a risk to human health. High humidity reduces the evaporation of sweat from the body, which can have an impact on health. The humidex index is on 4 levels: 1-2 are slight discomfort; 3 is avoid exertion; 4 is heat stroke likely.

Climate change has contributed to an increase in the frequency, intensity and duration of heatwaves. Analysis of data from the past 20 years looked at which northern hemisphere countries were exposed to heat stress (which can cause premature death in humans) during the month of August in 2003, 2010 and 2020. Countries where extreme heat stress was experienced – that is, the temperature exceeded the Universal Thermal Climate Index (UTCI) extreme heat threshold of 46 °C – were those in the Sahara and Arabian Peninsula and include Algeria, Tunisia and the UAE. Another finding from the analysis was the lack of heatwave data reporting in some regions. The emergency events database listed most data for European countries, none in Latin America and only two in Africa. Another key take-home message is that, globally, more people are likely to be exposed to heat stress because heat events are increasing in frequency in numerous countries, and the population is ageing. People aged over 65 or individuals with pre-existing illnesses are at a greater risk of mortality from exposure to heat extremes. Note that the UTCI heat stress threshold is 26 °C, but there will be different acclimatisation between residents of different countries (Brimicombe et al., 2021).

Mounir Laadouli's farm in the city of Mornag (South Suburb of Tunis)

3.2 Urbanisation

Research suggests that urbanisation can compound problems such as flood risk and heat exposure because cities commonly lack both green spaces to absorb rainfall and trees to provide shade. For example, typical cities in the region are about 3 °C to 4 °C hotter than the surrounding rural areas (Santamouris, 2015), a phenomenon described as the urban heat island. Urbanisation along coastlines may create particular problems for communities, which may then experience and have to cope with storm surges and coastal erosion, as well as more widespread structural problems such as poor sanitation. Inhabitants of Africa's largest cities are at increased risk of exposure to dangerous levels of heat as the urban population expands (Lwasa et al., 2018; Rohat et al., 2019). Some of North Africa's coastal lagoons have been negatively impacted by development (Mahrad et al., 2020) (see section 3.5.1 of this report).

Problems can often be disproportionately felt in the poorest communities whose residents tend to live in slums and shanties in the city margins. These may be particularly susceptible to flooding and also lack access to air conditioning or adequate shade. Rapid urbanisation coupled with land-use change and deforestation exacerbates the problems of a warming climate on local residents (Orimoloye et al., 2019), expanding the phenomenon of the 'urban heat island' into adjoining areas even less able to cope. The number of people living in Greater Cairo in 2020 was 20.9 million, which is projected to increase to 28.5 million by 2035. To put these figures into context, in 1950 the population of Cairo was 2.49 million (Our World in Data, 2022). As cities expand, construction of residential accommodation and infrastructure takes over the city's green spaces and agricultural land, increasing the pressure on water availability and waste management. Keeping Egypt as an example, an estimated 900,000 square metres of green space in Cairo was lost to urban development in the three years from 2017 to 2020 (Aly & Dimitrijevic, 2022).

Few regional studies are available on the evolution of urban heat islands under a changing climate. A population-driven urban warming estimation in fo ur Israeli cities suggests that from 2015 to 2060, the urban heat island intensity will increase further by 2°C to 4°C (Itzhak-Ben-Shalom et al., 2016). Another approach uses coupled climate simulations and reduced-order urban modelling to project local urban climates (Zhao et al., 2021). For a high-emission scenario, cities in the Middle East may experience additional warming of 4 °C, on top of the regional warming due to anthropogenic climate change.

A farm in Sweihan in Al Ain, United Arab Emirates, the hottest city on earth according to The National in June 2021, with a peak temperature of 51.8°C.

3.3 Agriculture, food and water security

Agricultural yields in all MENA countries are highly likely to be affected by climate changes. Precipitation is particularly important because in MENA, 70% of crops are rain-fed (Waha et al., 2017). By the end of the century, the population of the MENA region will exceed 1 billion, which is greater than the projected population of China in 2100. This population increase will put added pressure on food and water supplies, and exacerbate the impacts of climate change (see Box: Future population trends in the MENA).

The impact on human societies is likely to be varied and likely to be different depending upon the country. In general, as temperature increases and precipitation patterns change there will be increased aridity and the increased risk of low yields, leading to both food and water insecurity. Increasing heat, particularly extended periods of hot night-time temperatures, and humidity will affect human health, and some regions may experience the emergence of tropical diseases.

Areas of the Arab region (Western Asia, Northern Africa, the Maghreb, the Horn of Africa, and the Indian Ocean) that are expected to be highly vulnerable by the middle to the end of the century, according to a vulnerability assessment by the ESCWA (2017). These are the upper Nile Valley, the south-western Arabian Peninsula and the northern Horn of Africa. These regions have low adaptive capacity and the populations most affected will be those reliant on livestock and rain-fed agriculture, which will be significantly affected by drought. The same analysis found that when comparing only the Arab countries, those with the highest adaptive capacity (that is, most able to cope with changes to climate) were in the western Mediterranean, coastal Maghreb and the coastal Levant.

A farm in Sweihan in Al Ain, United Arab Emirates, the hottest city on earth according to The National in June 2021, with a peak temperature of 51.8°C.

3.4 Conflict

A boy lives outdoors with his family in a camp for displaced people due to the war in Yemen.

There is much debate in the scientific literature concerning the causal relationships between climate, weather extremes and violent conflicts with no overall apparent consensus. In general terms, overexploitation of natural resources coupled with climate change is expected to increase the risk of violent conflict (Niang et al., 2014). In a region such as MENA, where in many places resources are limited, additional stresses from climate change could exacerbate political instability and poverty. Drought in the region has already led to decreased agricultural yields in some countries leading to a decrease in income, which is a driver of social unrest (for example, Gleick, 2014). Climate change can act as a 'threat multiplier', in other words that climate change can exacerbate problems, especially in regions that are already experiencing political instability (Sofuoğlu & Ay, 2020).

Tension and conflict could arise in the event of migration of people moving away from areas that begin to suffer the impact of extreme events such as heatwaves, flooding or drought (Matthews et al., 2017; Xu et al., 2020). There is an ongoing debate among academics surrounding the notions of 'climate migration' and 'climate refugees' and assumptions of mass migration from the Global South to the Global North. Research suggests that the reasons people migrate are complex and multifactorial, incorporating cultural and political factors as well as climate, and that more research is needed to understand any relationship between climate and violent conflict (Boas et al., 2019; Schilling et al., 2020). Others have discussed situations in which climate change may not be a direct cause of human–human conflict but the changing climate conditions can exacerbate volatile situations or can indirectly cause conflict, particularly in regions that do not have strong state support mechanisms. The IPCC AR6 states that climate change may increase the risk of violent conflict within a country and the countries most at risk are those with low economic development, high social marginalisation and fragile governance. (TS.C.8.3 in Pörtner et al., 2021). There is only weak evidence that extreme weather has impacted the duration or severity of conflicts to date, displacement and movement away from increasingly frequent extreme weather events can increase the vulnerability of communities or populations to other stressors.

Research is beginning to look at non-violent conflict and climate-related issues. For example, a study on drought-related conflict in the MENA region by Ide et al. (2020) concluded that drought can increase the risk of non-violent, small-scale conflicts (such as a protest) particularly if there are socio-economic tensions, water cuts or an autocratic political system in combination with a period of drought. In such cases, the drought tends to exacerbate underlying tensions or issues rather than being the main driver of the conflict.

Some of the text in this section (3.4) has been adapted from Miller et al. (2020).

Cedars reforestation in Barouk Cedar reserve

3.5 Biodiversity

Researchers agree that climate change has had – and will continue to have – an overall negative effect globally on the number and diversity of species. Studies have found that some species are able to tolerate changing conditions more than others. However, the consensus is that in the recent past and present it is human-driven land-use change, especially to clear land for agriculture, that has been a major driver of biodiversity loss globally. Furthermore, research suggests that as humans experience the effects of climate change, human adaptation and changes in the ways that humans use natural resources could lead to further negative impacts on biodiversity (Pacifici et al., 2015).

Despite the high temperatures and scarce rainfall, parts of the broader Mediterranean, Middle East and north Africa consist of biodiversity hotspots of conservation priority (Myers et al., 2000; Mallon, 2011).

Changes in rainfall and temperature regimes, including extremes, are highly likely to impact biodiversity. However, limited baseline and ongoing monitoring of native plants and animals mean that it is difficult to determine trends in relation to species abundance or distribution of species in response to climate changes (Niang et al., 2014; Siddig, 2019).

Land-use change – in particular urbanisation, agriculture and forestry activities – can have a significant negative impact on biodiversity. Research that analysed data from 2000-2011 found that in Africa, 26% of impacts to biodiversity were driven by consumption in other world regions, citing cattle farming as a major factor (note that the analysis is of the entire African continent) (Marques et al., 2019).


Beekeeper from Ariana, Tunisia

3.5.1 Coastal lagoons

Coastal lagoons in North Africa reach from the west coastline of Morocco to the south coastline of the Mediterranean Sea, passing through Morocco, Algeria, Tunisia, Libya and Egypt. As well as playing an important part in the health of the ecosystem by providing wildlife habitat, the lagoons form an important buffer against sea level rise.

North Africa has 22 lagoons – shallow bodies of water linked to the sea through tidal channels that are important wetland ecosystems. Human activities in the lagoons include artisanal fishing, aquaculture (shellfish and fish farming), tourism (sailing and nature watching) and extraction industries (such as mining).

Climate change increases the risk of stress on lagoon ecosystems. For example, increased ambient air temperature can lead to increased evaporation rates and, in conjunction with sea level rise that causes an influx of seawater to the lagoon, increasing the lagoon salinity. Coastal lagoons respond to sea-level rise by moving further inland, but accelerated sea level rise may not give lagoons sufficient time to adapt and the lagoon may become inundated with seawater, affecting salinity and potentially leading to species migration. Ambient (air) temperature can have an impact on shallow coastal lagoons, which are expected to warm more rapidly than deep bodies of water or estuaries that are continuously flushed with cooler water. The intensity and frequency of precipitation can affect the salinity of freshwater lagoons by increasing or decreasing freshwater input, therefore a change in precipitation patterns could alter the ecological balance of many coastal lagoons (Anthony et al., 2009).

Modelling by Eladawy et al. (2013) investigated how climate change could affect Egypt's second largest lagoon, Burullus, under different future climate scenarios. The results of the projections of all future scenarios agree an increase in ambient air temperature will increase the evaporation of water from the lagoon. (Note that the research uses IPCC modelling scenarios described in IPCC (2000)). Under the 'A1F1' modelling scenario, which assumes a fossil-intensive future and is the highest emission scenario, the projections by Eladawy et al. (2013) are that the salinity of the lagoon could increase by 17% by 2100 in relation to the present day conditions, with the evaporation rate increasing by 14% in 2100. Under the 'B1' scenario, which assumes the adoption of clean and resource-efficient technologies after 2050 and is the most optimistic pathway, the evaporation


Cedars reforestation in Barouk Cedar reserve

Dakhla lagoon, Morocco

rates would be slightly lower, but could still increase by 10% by 2100 in relation to the present day (Eladawy et al., 2013).

Pressures from climate change are exacerbated by other human activity and could impair the natural processes through which lagoons adapt to changing conditions. For example, lagoons migrate inland in response to rising sea levels (as mentioned in a previous paragraph) but human development that occupies the inland space adjacent to the edge of a lagoon could be a barrier to the adaptation process. The impact of urbanisation can be seen in several North Africa lagoons. For example, the Monastir lagoon in Tunisia was drained to reclaim land for buildings, and others have been modified to accommodate hotels and marinas – Bizerte lagoon in Tunisia has four harbours, and major construction is underway to build houses, apartments and other buildings around Morocco's Nador lagoon. The Khenifiss lagoon in Morocco, has been designated a world heritage site by the United Nations Educational, Scientific and Cultural Organization (UNESCO). Land-use change, removal of natural resources (metals and fish, for example) and other stressors resulting from anthropogenic activities, such as runoff from agricultural pollutants (such as artificial fertiliser) and wastewater/sewage can create intense pressure on lagoon biodiversity. Some of North Africa's lagoons (including Morocco's Sidi Moussa and Algeria's El Mellah) are contaminated because domestic sewage treatment systems are either inadequate or non-existent. There is a risk that provisioning services, such as for fishing, could be negatively impacted in future both economically in terms of fish catch and for human health if fish are contaminated (Mahrad et al., 2020).

Management and conservation strategies for North Africa's coastal lagoons suggested by Mahrad et al. (2020) include educating and working with communities to promote sustainable practices and implement coastal protection policies.

3.6 Energy

Energy consumption in the MENA countries varies between nations. A stark indicator of the discrepancies between nations in the MENA region is the total per capita electricity consumption in 2014 in the United Arab Emirates was far higher than the combined per capita energy consumption in the same year of Morocco, Algeria, Tunisia, Egypt and Lebanon (World Bank, 2022) (see also Appendix 5).

Energy from fossil fuels is an obvious climate concern because greenhouse gas emissions contribute to global heating and therefore phasing-in sustainable energy technologies is important in MENA and elsewhere. At present, however, renewable energy production and consumption comprises only a small percentage of total energy use and consumption in all six MENA countries featured in this report. With the exception of Morocco and Tunisia (which, in 2019, consumed a renewable energy share of 12.2% and 10.69%, respectively), none of the MENA countries consumed more than a 5.5% share of renewable energy as a proportion of their total energy consumption (World Bank, 2022) (see also Appendix 5).

The energy sector is a heavy user of freshwater. Energy produced from fossil fuels is particularly dependent on freshwater in processes that include slurry transport and washing (for coal), drilling, refining and fracturing (oil and gas), and for cooling at power plants (Spang et al., 2014). Fuelwood is highly water dependent, though this fuel use applies mainly to sub-Saharan Africa

Africa's greatest onshore wind farm, 131 wind turbines generate a total of 301 MW of electric power.

Photo by: © Paul Langrock / Greenpeace

(Sanchez et al., 2020). Water use in the energy sector is highly relevant for MENA countries because water is scarce. According to the International Energy Agency, almost 95% of electricity generation in the Middle East and North Africa is from oil and gas (as an aside, the Russia–Ukraine war is incentivising non-Russian suppliers of gas to supply the world market) (Al-Saffar & Wanner, 2022).

The current situation in Africa is that 86% of water withdrawal is used for agriculture, 10% for municipal purposes and 4% for industry, including energy. As the population of MENA countries increases, and people move to urban locations, energy demands are projected to increase. Across the African continent, energy demand is twice the global average according to the International Hydropower Association (https://www.hydropower.org/region-profiles/africa).

Hydroelectric provides power to a number of African countries (particularly to those with the largest reservoirs which are Egypt in MENA and, in sub-Saharan Africa, Ghana, Zambia, Mozambique and Zimbabwe). In North Africa, hydro provides almost 3,000MW electricity to Egypt and more than 1,700MW to Morocco. Some researchers (Sanchez et al., 2020) argue that the downside of hydro is evaporation of water from reservoirs, which in Africa in 2016 was estimated to be 42 billion cubic metres. Other researchers (Spang et al., 2014) have an opposing view that because reservoirs have other uses, such as water supply storage or flood control, assigning all evaporation from reservoirs to hydro can be misleading.

3.6.1 Desalination

The MENA region is extremely water-scarce and has a network of desalination facilities that meet demand for water by treating saline water. Briefly, desalination is achieved using different technologies (membrane, thermal and other, emerging, processes), is energy intensive and is detrimental to the environment because of impacts. These include the trapping and mortality of small organisms in water intakes pre-desalination, and the post desalination production of brines. These negatively impact water quality and marine life when discharged into the sea (Elsaid et al., 2020). Some MENA countries including the UAE, Saudi Arabia, Kuwait, Qatar, Bahrain and Oman already rely heavily on desalinated water. The capacity of desalinated water in Gulf Cooperation Council (GCC) countries was 3,000 million m^3 per year in 2000 and is expected to be around 9000 m^3 per year in 2030. Research into solar powered desalination plants suggests that it is a promising technology that would significantly decrease greenhouse gas emissions (Salameh et al., 2022).

3.6.2 Air conditioning

A valid concern is the impact of rising ambient temperatures on day-to-day living and how it will affect people's health. One example of a negative impact of high temperatures during the day and, increasingly, during the night, is that people will look to technology to help them to keep cool indoors when external temperatures become hotter. Air conditioning units are commonplace in high-income regions that experience high temperatures and help people to keep cool at home and work, but air conditioning units are heavy users of energy.

The fastest rate of growth in energy consumption in future decades is expected to be in low- and middle-income countries as household incomes in those regions rise. A significant proportion of energy usage in hot countries will be climate-driven as people adopt the use of air conditioning units (Davis & Gertler, 2015). Energy usage for air conditioning units in high-income MENA countries is significant. For example, a press article (Mufson, 2019) describes the sophisticated outdoor air conditioning technology used to cool the air in outside spaces including in the Al Janoub stadium, markets and malls in Qatar to make the increasingly hot environment less hostile. Although air conditioning makes the environment inside a building more comfortable, the energy needed to power the technology is high and generated greenhouse gas emissions if the electricity that is used to power the units is fossil-derived.

Analysis by Davis & Gertler (2015) found that there is a large increase in the consumption of energy as air temperature increases. The authors used the case study of Mexico, a middle-income country, and found that for each day at temperatures above 90 °F (32 °C), electricity use increased by 3.2%. This is attributed to the use of electric fans and other equipment to keep people cool. They project that in Mexico under RCP4.5, adoption of air conditioning units will be 71% by 2100, and electricity consumption will have increased by 64% compared to the present day. Although the Davis & Gertler (2015) study was in Mexico, the authors expect that the situation will be similar in middle- and low-income countries around the world. The study also found that as income increases, so does adoption of air conditioning – interestingly, the results of their study found that it is income, rather than temperature, that is the major driver of adoption of air conditioning. In Mexico, the ownership of air conditioning units increased by 27% for every US$10,000 of household income. Davis & Gertler (2015) conclude that high-income countries have reached saturation point in households owning air conditioning units, and project that low- and middle-income countries will invest in the technology.

Reducing the need for air conditioning units will require long-term measures. Davis & Gertler (2015) add that reducing the need for air conditioning and/or mitigating greenhouse gas emissions will require the use of renewable energy, innovative housing design and air conditioning with reduced energy consumption. According to the International Energy Agency (IEA, 2018), buildings constructed with traditional materials such as earth or stone typically do not require artificial cooling, and buildings made with modern materials with insulation can reduce the heat that enters the building, therefore reducing the amount of artificial cooling.

SECTION II

The second section of the report focuses on six countries in detail, presented west to east, outlining the main climate trends past, present and future, and how the food and water security of those six countries is projected to be affected by the future climate. Climate-relevant information is included for the MENA countries, see Appendix 5 for a comparison with selected other countries.

Nomad, Mhamid el Ghizlane Oasis, Morocco.

4.0 MOROCCO

Population

- Current population data for 2022 estimate 37.8 million inhabitants in Morocco, projected to increase to 46.2 million by 2050 and then to decrease to 44.7 million by 2100.
- The population density in 2022 is estimated at 84.6 people per km^2, making Morocco one of the more densely populated countries in the world.
- GDP per capita in 2021 US$3,500 (World Bank, 2022).

Land

- Morocco covers 710,850 km^2 (274,461 $miles^2$) (BBC, 2021b).
- East of the country's two mountain ranges, the Rif and the Atlas, are semi-arid lowlands. Thanks to the mountain ranges, the country has a rich supply of streams and rivers.

Climate

- The north of the country has a Mediterranean climate, defined by hot and dry summers and pronounced winter precipitation. The south and southeast regions, which are towards the Sahara, are classified as arid and hot deserts.
- Depending on the season, the average daytime temperatures range between 17 °C and 32 °C. In some parts of the country the temperature rises to 38 °C. In the colder months and depending on the region, the temperature lowers to
- 7 °C in a month's average.

Climate-relevant information (most recent figures)

- CO_2 emissions per capita in 2019 = 2.0 metric tons (World Bank, 2022).
- Electricity production in 2015 from renewables (excluding hydroelectric), which includes geothermal, solar, tides, wind, biomass and biofuels = 8.2% (World Bank, 2022).
- The country is highly vulnerable to climate change, particularly from drought, which will impact agricultural production (World Bank, 2021).

4.1 Food security

- Morocco is dependent on grain imports, in part because the country's grain yield is highly dependent on rainfall. The 2022 harvest was well below average and for this reason grain imports in 2022/2023 are expected to rise. The reason for the fall in yield was drought conditions during the 2022 growing season. 15% of agricultural land is irrigated by local dams, with the remaining 85–90% being rain-fed (FAO, 2022c; Schilling et al., 2012).

4.1.1 Impacts on agricultural crops - future projections

- The main crops are barley, wheat, potatoes and maize (FAO, 2022c).

- The agriculture sector in Morocco is an important part of the country's economy and employs approximately 50% of the population. Morocco is particularly susceptible to climate changes because it has low adaptive capacity – income in Morocco is low and the effect of decreased agricultural yields could increase social inequality. To help cope with fluctuations in rainfall, barley may be planted instead of wheat because it needs less water. Planting lentils after the rains helps to mitigate fluctuations in rainfall during the planting season (Schilling et al., 2012).

- The north-west region of the African continent, which includes Morocco, is projected to experience dryer conditions and increasing mean annual temperatures in the future decades of this century, which will impact food production (IPCC, 2022).

- Climate projections suggest that there will be a decline in average agricultural productivity in Morocco by 2080 due to changing rainfall patterns. Irrigated land can be negatively impacted through salinization, when the water evaporates leaving a high concentration of salts on the soil surface. Poorer members of the Moroccan population are likely to be most affected by salinization because they rely on agriculture for income (Schilling et al., 2012).

- In response to the shift in climate, in particular in rainfall patterns, Schilling et al. (2012) suggest that modifying planting times for certain crops might contribute to some level of reduction in the impacts of climate change.

4.2 Water availability

- Conditions were dry in Morocco from September 2019 to May/June 2020, and the WMO reported that the "rainy season was one of the four driest years since 1981" (WMO, 2021).

- All climate models project a decline in precipitation in Morocco in the decades to 2100. However, water catchments in southwest Morocco are projected to experience the country's greatest reduction in precipitation. The region is already experiencing arid conditions therefore this could have a significant impact on agriculture (Tramblay et al., 2018).

- Over the past century evidence suggests that around two-thirds of Morocco's oasis habitat has been lost, together with such habitat from neighbouring countries. The decline in the oases systems has been driven by both natural and anthropogenic processes. The decline appears to have accelerated in recent years and has been accompanied by the drying up of major rivers (El Mokhtar et al., 2022).

- Projections suggest warming trends in Morocco's central-western region (the Souss-Massa basin, bordered by the High Atlas mountains to the north and the Anti-Atlas mountains to the south). The region is an important agricultural area in Morocco. 93% of the water abstracted from the Souss-Massa basin water is used for agricultural purposes, with the remainder used for drinking and industrial purposes. A review by Attar et al. (2022) of climate projections noted significant interannual variability in precipitation between 1933 and 2015. Against that backdrop, however, this review of studies of projections under both RCP4.5 and RCP8.5 models suggest a significant decline in precipitation in the region through the rest of this century. All models also project an average annual increase in temperature across the region under both scenarios. As an example, the 2100 projections under RCP8.5 suggest an annual decrease in precipitation of 80% and by 60% under RCP4.5, coupled with increased interannual precipitation variability (Attar et al., 2022).

- Limitations to water resource management in Morocco's Souss-Massa basin include lack of measurements on temperature and evapotranspiration from meteorological stations (Attar et al., 2022).

- In north-east Morocco, measures such as improved irrigation, waste-water reuse and avoiding open-channel irrigation will be needed to conserve water resources. However, the declining availability of water is cited as being primarily human caused not climate caused. The use of water by the tourism industry (valuable for the economy) is also cited as potentially problematic (Tekken et al., 2013).

4.3 Extreme weather events

- High-impact extreme events for the future include unprecedented heat waves that will span beyond the summer season (Molina et al., 2020; Zittis et al., 2021a). Such events will directly affect human health and agriculture and dramatically increase energy and water demand in the warm part of the year. Considering the moderating effect of the Atlantic Ocean and the Mediterranean Sea, these events will be more severe in the southern and southeastern parts of Morocco.

- The broader Mediterranean region, and particularly the southwest, is a future drought hotspot area (Driouech et al., 2017; Waha et al., 2017; Spinoni et al., 2021). Morocco is expected to experience unprecedented droughts affecting ecosystems, agriculture, domestic water supply, and other socioeconomic sectors. Besides the overall drying trends, individual rainfall events can be of greater intensity than the historical records (Zittis et al., 2021b).

Palm trees from the dying Oasis in Mhamid el Ghizlane

5.0 ALGERIA

Population

- Current population data for 2022 estimate 45 million inhabitants in Algeria, projected to increase to 61 million by 2050 and 71 million by 2100.
- The population density in 2022 is estimated at 19.04 people per km^2.
- Note that population data in this section are from Roser, 2013, which uses UN World Population Prospects medium-variant scenario.
- GDP per capita in 2021 = US$3,700 (World Bank, 2022).

Land

- Algeria covers 2.4 million km^2 (919,595 $miles^2$).
- Four-fifths of the land lies within the Sahara desert (BBC, 2019a).

Climate

- The climate in Algeria is subtropical ranging from desert in the south to hot summer Mediterranean-type in the north. So it is much drier and warmer than in the many countries in the world. Only in a few humid months per year the intensity of rain is a bit higher, particularly in the north.
- Depending on the season, the average daytime temperatures range between 17 °C and 37 °C. In some parts of the country the temperature rises to 42 °C. In the colder months, and depending on the region, the temperature lowers to 5 °C in a month's average.

Climate-relevant information (most recent figures)

- CO_2 emissions per capita in 2019 = 4 metric tons (World Bank, 2022)
- Electricity production in 2015 from renewables (excluding hydroelectric), which includes geothermal, solar, tides, wind, biomass and biofuels = 0.1% (World Bank, 2022).

5.1 Food security

- Wheat is the major food crop; sorghum and barley are also important (FAO, 2022a).
- Cereal crops are rainfed and therefore yields depend on the rainfall and distribution (FAO, 2022a).
- 2022 cereal production is slightly below average (FAO, 2022a).
- In spite of domestic grain production, the country relies heavily on imports of grain (soft wheat, maize and barley), which amount to approximately 70% of domestic consumption (FAO, 2022a).

5.1.1 Impacts on agriculture – future projections

- 50% of the country's agricultural crops are cereals, primarily durum wheat. Durum wheat *(Triticum turgidum)* is used to make couscous. The country relies on cereals but its own agricultural system produces 25-30% of the population's needs. The rainfed agricultural sector strongly relies on precipitation. Therefore any rainfall decline will impact yields. Climate projections (under a modelling scenario similar to RCP 6.0) in the future (2071–2100) suggest that two agricultural sites, Algiers in the central region of north Algeria, and Bordj Bou Arreridj in northeast Algeria, will increase in temperature and receive a net decrease in precipitation. Under such a scenario, the projected changes for Algiers in the future (2070–2100) are a decrease in annual rainfall by -18% and an increase in annual temperature by +2.8 °C in comparison to the reference period from 1978 to 2007. The projections for Bordj Bou Arreridj are a decrease in annual rainfall by -8% and an increase in annual temperature by +3.8 °C in comparison to the reference period from 1980 to 2009. The findings suggest that Algiers will become less favourable for durum wheat cultivation and that in Bordj Bou Arreridj in the future, early sowing of crops may be needed as a strategy to avoid the crop succumbing to drought later in the season (Chourghal et al., 2016).

5.2 Water availability - future projections

- Besides a robust and significant warming (ranging from 1.5 to 5 °C according to the scenario and future period), Algeria will likely become drier (Zittis et al., 2019). According to a low-emission pathway, this decline will not exceed -10% with respect to the recent past (1986–2005). On the contrary, under RCP8.5 scenarios, this decline is more robust. It is expected to reach up to -30%, with the greatest changes in the north and northwest part of the country, which is also the most densely populated.

- The synergistic effect of precipitation reduction (most significant during winter and spring) and substantial temperature increase will lead to more severe and frequent droughts (Waha et al., 2017; Driouech et al., 2020; Spinoni et al., 2020). Such events will be more devastating under high-emission scenarios and towards the end of the current century. As a result, the water resources of Algeria will be critically challenged (Tramblay et al., 2018). In addition, coastal aquifers will likely also be affected by salt intrusion due to the increased levels of the Mediterranean sea (Waha et al., 2017).

Heavy rain caused dramatic flash flooding in the city of Tétouan in northern Morocco in March 2021.

5.3 Extreme weather events

- High-impact extreme events for the future include unprecedented heat waves that will span beyond the summer season (Molina et al., 2020; Zittis et al., 2021a). Such events will directly affect human health and agriculture and dramatically increase energy and water demand in the warm part of the year. Considering the moderating effect of the Mediterranean, in terms of magnitude and duration, these events will be more severe in the southern parts of the country.

- The broader Mediterranean region is a future drought hotspot area (Spinoni et al., 2021). Algeria is also expected to experience unprecedented droughts affecting ecosystems, agriculture, domestic water supply, and other socioeconomic sectors. Besides the overall drying trends, individual rainfall events can be greater intensity than the historical records (Zittis et al., 2021b).

6.0 Tunisia

Population

- Current population data for 2022 estimate 12 million inhabitants in Tunisia, projected to increase to 13.8 million in 2050 and then to decrease to 13 million in 2100.
- The population density in 2022 is estimated at 77.5 people per km^2, making Morocco one of the more densely populated countries in the world.
- GDP per capita in 2021 = US$4,000 (World Bank, 2022).

Land

- Tunisia covers 164,150 sq km (63,378 sq miles) (BBC, 2020).

Climate

- The north of Tunisia has a Mediterranean climate with mild, wet winters and dry summers. The central and south of the country is classified as a hot desert.
- Depending on the season, the average daytime temperatures range between 17 °C and 35 °C. In some parts of the country the temperature rises to 39 °C. In the colder months and depending on the region, the temperature lowers down to 7 °C in a month's average.

Climate-relevant information (most recent figures)

- CO_2 emissions per capita in 2019 = 2.6 metric tons (World Bank, 2022).
- Electricity production in 2015 from renewables (excluding hydroelectric), which includes geothermal, solar, tides, wind, biomass and biofuels = 2.5% (World Bank, 2022).
- The country is highly vulnerable to climate change, particularly from increasing temperature and aridity, decreasing precipitation and rising sea levels (World Bank, 2021).

6.1 Food security

- Potatoes and durum wheat are main crops, followed by barley (FAO, 2022d).
- Tree crops (especially olives and dates) are also important for export (Chebil et al., 2019).
- Cereal production in 2022 is around the average for the country (FAO, 2022d).
- Press reports have said that exceptionally high temperatures (circa 47 °C) and wildfires have damaged the wheat crop, which may reduce the overall yield (Reuters, 2022).
- Crop production varies year to year because it is primarily rain-fed; only approximately 10%-15% of crops are irrigated (FAO, 2022d).
- The country relies heavily on grain imports, even in years with a good domestic grain yield. Imports for 2022/2023 will be slightly above average (FAO, 2022d).

6.1.1 Impacts on agricultural crops - future projections

- The trend is increasing annual average temperature. In 2020, the average temperature was 20.2 °C, making it Tunisia's third hottest year since 1950, after 2016 and 2014 (WMO, 2021).

- Climate projections indicate that the north African region will receive less precipitation in the future decades. In Tunisia, a reduction in precipitation will negatively impact rain-fed agriculture, which represents 88% of total agriculture. Irrigated agriculture occupies approximately 10%-15% of Tunisia's agriculture. Rainfall typically varies on an annual basis. Average annual temperatures increased in Kairouan, central Tunisia, between the years 1951–2002, although there were no discernable trends in rainfall data over the same period (Mougou et al., 2011).

- Tunisia depends on agricultural production for employment and economic growth, therefore a decrease in productivity as a result of changes to the climate could have negative impacts and affect the country's food security. A potential consequence of increased food security is migration of people to urban areas in search of employment or elsewhere in the region where climatic conditions are more favourable to agriculture (Mougou et al., 2011).

- Climate variability has a large impact on Tunisia's agricultural yields, as illustrated with the varied yields: total cereal production was 2.9 million tons in 1996, 0.5 million tons in 2002, and 2.9 million tons in 2003 (Chebil et al., 2019).

6.2 Water availability

- Water scarcity is a future threat to Tunisia. Mitigation measures to help adjust to the decline in available water for crop irrigation include improved technology to deliver irrigation (Chebil et al., 2019). [The study did not present the effectiveness of changing cropping patterns as an adaptation measure.]

- Tunisia's agricultural sector accounts for more than 75% of the country's total water use. Improving the efficiency of irrigation water can improve performance of the irrigation water and increase the duration of the irrigation (Chebil et al., 2019).

- Climate model projections for precipitation in Tunisia to 2100 suggest some uncertainty – some models project a decline in precipitation whereas some models project a slight increase in precipitation. The uncertainties are greater for eastern Tunisia (Tramblay et al., 2018).

Olives from a farm in the south of Tunis.

6.3 Extreme weather events

- High-impact extreme events for the future include unprecedented heat waves that will span beyond the summer season (Molina et al., 2020; Zittis et al., 2021a). Such events will directly affect human health and agriculture and dramatically increase energy and water demand in the warm part of the year. Considering the moderating effect of the Atlantic Ocean and the Mediterranean Sea, these events will be more severe in the southern parts of Tunisia.

- The broader Mediterranean region, and particularly the southwest, is a future drought hotspot area (Driouech et al., 2017; Waha et al., 2017; Spinoni et al., 2021). Besides the overall drying trends, individual rainfall events can be of greater intensity than the historical records (Zittis et al., 2021b).

7.0 Egypt

Population

- Current population data for 2022 estimate 106.16 million inhabitants in Egypt, projected to increase to 159.9 million by 2050 and 224.7 million by 2100.
- The population density in 2022 is estimated at 106.64 people per km^2, making Egypt one of the more densely populated countries in the world.
- 97% of Egypt's population lives on 4% of the land (NWRP, 2005).
- GDP per capita in 2021 = US$3,800 (World Bank, 2022).

Land

- Egypt covers 1 million km^2 (386,874 $miles^2$).
- Most of the country is desert; settlements are concentrated along the river Nile and the Nile Delta (BBC, 2019b).

Climate

- The climate in Egypt is subtropical, characterised by dry and warm conditions (hot desert). Only in the winter months (mainly December and January) the intensity of rain is a bit higher.
- Depending on the season, the average daytime temperatures range between 21 °C and 37 °C. In some parts of the country the temperature rises to 43 °C. In the colder months and depending on the region, the temperature decreases to 9 °C in a month's average.

Climate-relevant information (most recent figures)

- CO_2 emissions per capita in 2019 = 2.5 metric tons (World Bank, 2022).
- Electricity production in 2015 from renewables (excluding hydroelectric), which includes geothermal, solar, tides, wind, biomass and biofuels = 0.9% (World Bank, 2022).
- The country is particularly vulnerable to climate change, particularly water security and agricultural production (World Bank, 2021).

7.1 Food security

- The agricultural sector in Egypt is an important part of the country's economy (Schilling et al., 2012).
- Maize, rice and wheat are major food crops, with barley and millet also important (FAO, 2022f).
- Irrigation is used to grow cereals, which means that yields are (or have been in the past been) relatively stable year-on-year (FAO, 2022f).
- In 2021, the cereals harvest was average and the cereal imports were slightly above average (FAO, 2022f).
- Egypt imports 40% of its food (FAO, 2020).

7.1.1 Impacts on agricultural crops - future projections

- In future decades, water availability for agricultural crops will become a key issue and will impact Egypt's food security (Omar et al., 2021).
- A modelling study found that climate change-induced changes to the water in the Nile river would negatively affect food security. A reduction of water flow in the Nile Delta would be expected to increase water salinity and reduce net agricultural productivity and would impact availability of work for farmworkers, in turn affecting socioeconomic status through decreased income (Omar et al., 2021).
- Solutions proposed to prevent food security problems include cropping pattern adaptation measures to create fixed crop areas for orchards, lentils, maize, onion, tomatoes, and vegetables. The authors suggest that fixing areas for particular crops increases the total area of crops, ensures supply of that crop and provides food security (Omar et al., 2021).
- Measures will be needed to ensure water use efficiency and water supply to prevent food security problems arising due to water shortages in future decades.

7.2 Water availability

- Agriculture uses approximately 86% of total water resources in Egypt (Omar et al., 2021).
- The majority of Egypt's crops are irrigated by Nile River water, either through direct canal irrigation or indirectly through groundwater (Terwisscha van Scheltinga et al., 2021), with the exception being in a small region along the Mediterranean coast. Climate changes are expected to put pressure on Egypt's limited water resources by (i) increased water scarcity as Nile water level diminishes and (ii) increasing salinity of irrigation water (Omar et al., 2021).
- More water will be needed to irrigate farmland as demand continues to grow. Water needed for agricultural irrigation is also likely to increase due to increasing temperatures, according to a study by Mostafa et al. (2021). The study's modelling projections suggest that average annual temperature in central Egypt will have risen by 2.12 °C by 2050 and by 3.96 °C by 2100, compared to the 1990s baseline, using a scenario in which emissions increase through 2030, and subsequently decline to levels similar to those in 1990. The projected increase in irrigation water for winter crops (barley, wheat, faba bean,

potatoes, tomatoes) ranges from 6.1% to 7.3% by 2050 and from 11.7% to 13.2% by 2100. The projected increase in irrigation water for summer crops (cotton, maize, sunflower, potatoes, tomatoes) ranges from 4.9% to 5.8% by 2050 and from 9.3% to 10.9% by 2100 (Mostafa et al., 2021).

- The water supply situation opens up the potential for water conflict to arise from Nile river water used by Egypt given that the river's source is not within its national borders (conflict is discussed in section 3.4 of this report).

- Some projections indicate a future increase in precipitation in southern Egypt (Zittis et al., 2022). Nevertheless, this is mainly driven by short-duration extreme rainfall events that could not be enough to replenish the water resources.

- Availability of water in Egypt (and Sudan) is expected to be negatively impacted by a hydroelectric dam (Grand Ethiopian Renaissance Dam (Gerd)), under construction by Ethiopia. Egypt is asking for a guarantee that it will receive an agreed quantity of water, because the country relies so heavily on the Nile for its water needs (Zane, 2021).

- Sea level rise and climate changes are projected to impact coastal systems – and water availability – towards the end of the century. Saltwater intrusion can degrade groundwater supplies and inundate low-lying coastal areas with water. A study by Elshinnawy & Almaliki (2021) analysed the impact that a 73cm rise in sea level by 2100 could have on the Gamasa Ras El Bar area in Egypt's Nile Delta. The results of the study suggest saltwater intrusion would impact approximately 271 km^2 (60%) of the area if the freshwater–saltwater interface were to move inland by around 1 kilometre. Rising groundwater would negatively affect drainage and cause waterlogging.

7.3 Extreme weather events

- Unprecedented heat waves will also affect Egypt (Molina et al., 2020; Zittis et al., 2021a). In a high emissions future world, peak temperatures during heat waves are projected to exceed 55 °C. Such events will directly affect human health and agriculture and dramatically increase energy and water demand in the warm part of the year. Considering the moderating effect of the Mediterranean, in terms of magnitude and duration, these events will be more severe in the southern parts of the country. Nevertheless, in the megacities of Cairo and Alexandria, the Urban Heat Island phenomenon can act synergistically to increase impacts.

- The broader Mediterranean region is a future drought hotspot area (Spinoni et al., 2021). Egypt is also expected to experience unprecedented droughts affecting ecosystems, agriculture, domestic water supply, and other socioeconomic sectors. Besides the overall drying trends (mainly in northern Egypt), individual rainfall events can be greater intensity than the historical records (Zittis et al., 2021b).

Al Qulaan is one the last two remaining fishing villages on the Red Sea, Egypt. The village is now equipped with solar power, allowing for the fish caught to be kept in freezers.

8.0 LEBANON

Population

- Current population data for 2022 estimate 6.7 million inhabitants in Lebanon, projected to slightly decrease to 6.5 million by 2050 and further to 5.71 million by 2100.
- The population density in 2022 is estimated at 653.5 people per km², making Lebanon one of the most densely populated countries in the world.
- GDP per capita in 2021 = US$2,600 (World Bank, 2022).

Land

- Lebanon covers 10,452 km² (4,036 sq miles) (BBC, 2021a).
- Lebanon has a central mountainous region and coastal plains that extend to the Mediterranean Sea. The Litani River runs through the fertile Bekka Valley.
- The Lebanon cedar trees cover only a small portion of what once was a predominantly forested country.

Climate

- The climate in Lebanon is subtropical, described as a hot summer Mediterranean type. There is a profound precipitation maximum during the winter months, while summers are typically dry.
- Depending on the season, the average daytime temperatures range between 14 and 33 °C. In some parts of the country the temperature rises to 35 °C. In the colder months, and depending on the region, the temperature lowers to 6 °C in a month's average or below freezing point in the highest mountains.

Climate-relevant information (most recent figures)

- CO_2 emissions per capita in 2019 = 4.1 metric tons (World Bank, 2022)
- Electricity production in 2015 from renewables = 0% (World Bank, 2022).
- Rising sea levels will affect biodiversity and ecosystems; extreme weather events will have negative impacts including to infrastructure, human health and agricultural production (World Bank, 2021).

8.1 Food security

- Lebanon has a Mediterranean climate, fertile soils and a relatively abundant water supply (Skaf et al., 2019).
- Main crops are barley and wheat (FAO, 2022b).
- 46% of Lebanon's cultivated land is in the Bekka Valley, where the primary crops are grains, sugar beet and grapes, and where livestock production is also concentrated (Verner et al., 2013).
- Food insecurity is rising due to the ongoing economic crisis (FAO, 2022b).
- Domestic cereal production provides less than 20% of the population's needs (FAO, 2022b).
- Since the mid-twentieth century, Lebanon's agricultural production has changed from low-input farming to intensive farming, which has degraded soil quality and Lebanon's agricultural output has decreased over the period with the result that Lebanon imports 80% of its food. Imported food is expensive, leading to social inequality and food poverty (Skaf et al., 2019).
- Food security in the future will depend on the success of food producers (in Lebanon and globally) to adapt to changing conditions (Verner et al., 2013).

8.1.1 Impacts on agricultural crops - future projections

- Climate models suggest that Lebanon will warm more rapidly than the global average and that by the middle of the century, mean annual temperatures could increase by 1.3 °C–2.7 °C and precipitation could be reduced by 10–20 % (Verner et al., 2013). Updated projections, based on a high-emission pathway (Zittis et al., 2022), indicate a strongest mean warming (greater than 4.5 °C) and precipitation reduction of up to 30% with respect to the recent past (1986–2005) conditions.
-
- Rising annual mean temperatures and decline in wet-season rainfall will increase the risk of impact to agricultural yields, particularly to wheat, which is sensitive to drought conditions (Verner et al., 2013; Constantinidou et al., 2016).

8.2 Water availability

- Lebanon has a relatively rich water supply, with 2,000 rivers (Verner et al., 2013).
- Approximately half of Lebanon's agricultural land is irrigated, according to the 2010 census (FAO, 2022e). Irrigation contributes to Lebanon's agricultural productivity (that is, because the region's agriculture does not fully rely on rain-fed crops, it means that there is reliable water supply to agricultural regions) (Verner et al., 2013).
- An estimated 60-70% of Lebanon's available water is used for agriculture (Verner et al., 2013).
- Evidence suggests that Lebanon has experienced a decrease in water availability since the 1960s but the decrease has not only been due to changing climate but also to increased pressure from human populations (increased population, lack of water infrastructure, private wells, overexploitation of aquifers) and natural climate variability: since the 1960s, water availability from rivers and groundwater decreased by 23–29%; precipitation (rain and snow) decreased by 12–16% (Shaban, 2009; Verner et al., 2013).

- If the trend in the decline in water availability in Lebanon continues, the risk will be that the country enters a water deficit (Verner et al., 2013).
- In their analysis of the issues facing water availability for agriculture in Lebanon, Verner et al. (2013) recommend the following: (i) implementation of drip irrigation in Lebanon to help to economise on the use of water resources in agriculture; (ii) introduction of water storage and irrigation infrastructure would help to conserve rainwater for use at other times in the year; and (iii) planting crop varieties that are resilient to drought.

8.3 Extreme weather events

- The eastern Mediterranean will be impacted by severe heatwaves, even under intermediate-forcing scenarios (Zittis et al., 2016; Hochman et al., 2022; Zittis et al., 2021a). The annual number of heatwave events is projected to increase by 3–6 times, their amplitude to increase by 6 °C–7 °C, while the duration of the longest-lasting events will likely be several weeks to months.
- According to future climate projections, the area will be affected by droughts of increased frequency and duration (Spinoni et al., 2021; Hochman et al., 2022). This will be augmented by the synergistic effect of strong warming. Besides the overall drying, an expansion of the dry season is projected for Lebanon, where particularly in high-emission scenarios, by the end of the century this expansion could reach one month (Zittis et al., 2022).
- Forest fires in Lebanon's northern highlands have been exacerbated by the extreme heat and dryness in the summer months (Reuters, 2021; Zittis et al., 2022). As in most Mediterranean forests, the risk of forest fires will be increased in a warmer and drier environment. In addition, the fire season is expected to expand towards the spring and autumn months.

BOX: Lebanon's cedar trees

The cedar is Lebanon's national emblem and the tree appears on the country's flag. Concerns have been raised about the survival of Lebanon's cedar trees in future decades due to climate heating and changing weather patterns, both in the scientific press (Hajar et al., 2010; Cheddadi & Khater, 2022) and international news media (Soussi, 2012; Barnard, 2018).

The main points, in summary:

- **The Lebanon cedar (Cedrus libani) grows in the country's mountainous regions of Mount Lebanon (Fig. B1) (Hajar et al., 2010; Cheddadi & Khater, 2022).**
- **Palynological studies have shown that C. libani forests have been present in Lebanon for the past 15 millennia. Historically, the ancient forests covered 70% of Lebanon, but the current estimate is that the forest coverage has shrunk to less than 14% because of land-use change (urbanisation and grazing), tourism and felling for timber (Cheddadi & Khater, 2022).**
- *C. libani* **trees are listed as 'Vulnerable' on the International Union for Conservation of Nature's Red List of Threatened Species (Gardner, 2013).**
- **Modelling to project the future geographical distribution of C. libani suggests that only a few of the existing cedar forests will survive in the mountainous northern region of Mount Lebanon, because the changing climate is expected to make the area more arid (Hajar et al., 2010), though in some parts of the region, forests may be able**

Iconic cedar forests in the Tannourine nature reserve of North Lebanon suffer the consequences of climate change.

to expand to higher altitudes. The study concludes that the creation of areas to protect cedars from livestock grazing and land-use change will be needed to help maximise the adaptive capacity of the trees and preserve **C. libani** populations.

- Other research suggests establishing conservation measures in a corridor along the Mount Lebanon range to help the long-term survival of **C. libani** populations (and two other endemic species, **Abies cilicica** and **Juniperus excelsa**). Establishing corridors of 'microrefugia' could help to facilitate seed dispersal, species migration and the flow of genes between **C. libani** populations, which could ultimately help to build genetic diversity and climate resilience (Cheddadi & Khater, 2022).

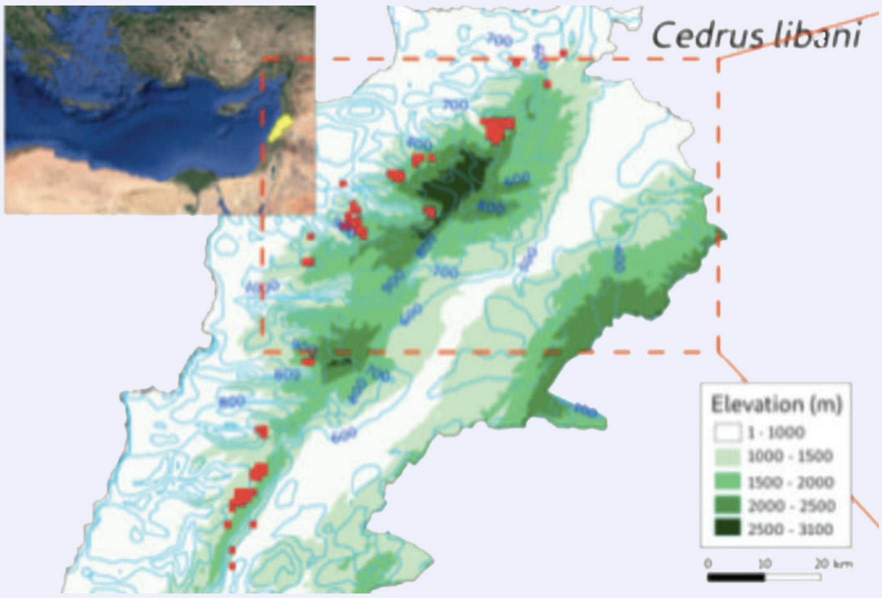


Fig. B1. *A map of Lebanon showing the geographical distribution of Lebanon cedar* **(Cedrus libani)** *forests (shaded red). (Source: Figure 1 from Cheddadi & Khater, 2022; Licenced for use under Creative Commons: http://creativecommons.org/licenses/by/4.0/).*

9.0 UNITED ARAB EMIRATES

Population

- Current population data for 2022 estimate 10.1 million inhabitants in the United Arab Emirates (UAE), projected to increase to 10.4 million by 2050 and to increase further to 12.9 million by 2100.
- The population density in 2022 is estimated at 142 people per km^2, making the UAE one of the more densely populated regions in the world.
- GDP per capita in 2020 = US$36,000 (World Bank, 2021).

Land

- The UAE covers 77,700 km^2 (30,000 sq miles).
- The UAE is predominantly desert, with vast sand dunes and no natural lakes or streams and annual rainfall of around 10-15 cm.

Climate

- The climate is hot and humid on the coast, and hot and dry inland, with an average January temperature of 18 °C and an average July temperature of 33 °C (Britannica, 2022).

Climate-relevant information (most recent figures)

- CO_2 emissions per capita in 2019 = 19.3 metric tons per capita (World Bank, 2022).
- Electricity production in 2015 from renewable sources (excluding hydroelectric), which includes geothermal, solar, tides, wind, biomass, and biofuels = 0.2 % of total electricity (World Bank, 2022).
- Rising sea levels could damage the country's desalination facilities; increasing temperature and decreasing precipitation could be detrimental to agriculture (World Bank, 2021).

9.1 Food security

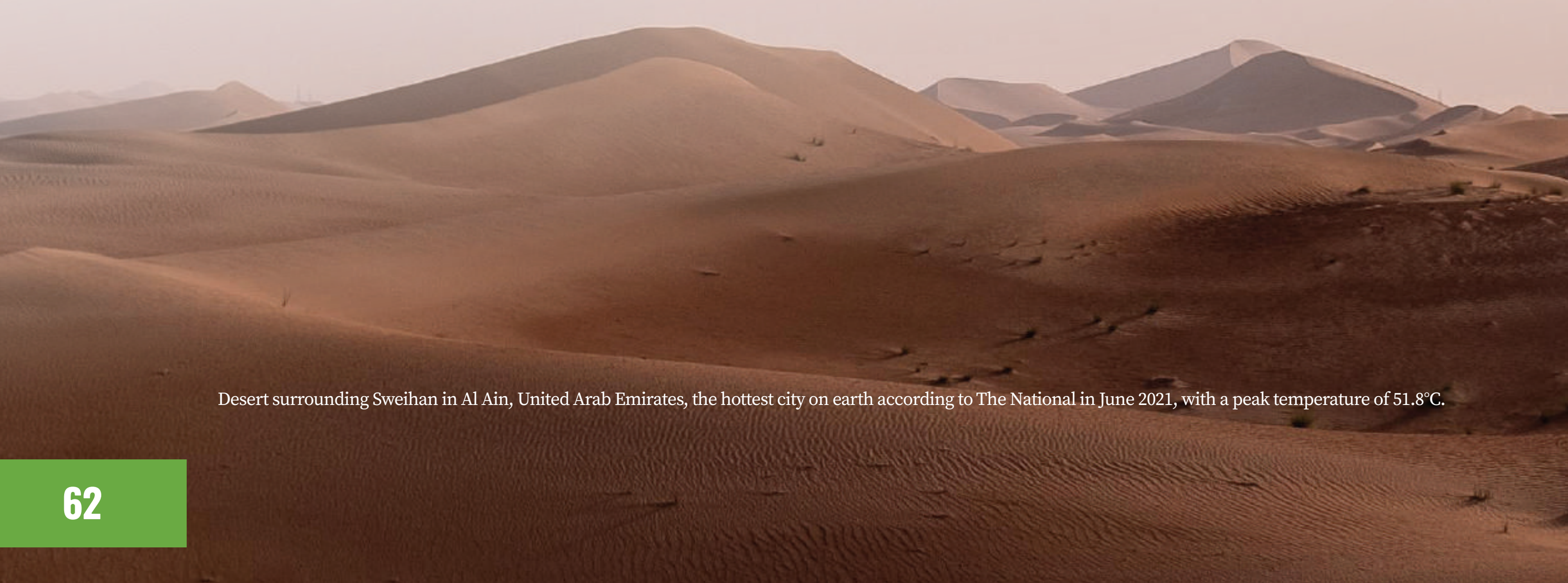
- The UAE has limited land suitable for growing arable crops and the agricultural industry is very small in terms of the country's gross domestic product (Manikas et al., 2022).
- An estimated 6.8% of the total land area of UAE is suitable for irrigated agricultural production; therefore food security is a potential problem (Aldababseh et al., 2018).
- UEA is heavily dependent on food imports: 80% of the UAE food requirements are from imported food. Grain imports to the UAE have been affected by the Russia–Ukraine war (Manikas et al., 2022).
- A study suggested that crops most suited to the arid environment, that could be cultivated without using excessive groundwater, are jojoba, sorghum, date palm and fruits (Aldababseh et al., 2018).

9.1.1 Impacts on agricultural crops - future projections

- Approximately 80% of the UAE land is sandy soils that are unsuitable for growing crops. High temperatures and dust storms are also adverse conditions for crops (Aldababseh et al., 2018).

9.2 Water availability

- The UAE has high water consumption and rainfall is scarce. The majority of water production is from desalination plants, which use high quantities of energy. The production of desalinated water is expected to increase this century as the population increases. The average per capita water consumption per day in UAE in 2016 was 550 litres, of which 96.4% is produced from desalinated sea water, 1.4% from desalinated ground water and 2.2% from ground water with no desalination (Saleh et al., 2019). The need to reduce CO_2 emissions from desalination plants is recognized but no detailed solutions are presented in the paper.
- In the UAE, groundwater (51% of demand) is mainly used for irrigation; desalinated water (37% of total water) is mostly used by domestic consumption. A study by Gonzalez et al. (2016) found an average decrease



Desert surrounding Sweihan in Al Ain, United Arab Emirates, the hottest city on earth according to The National in June 2021, with a peak temperature of 51.8°C.

of 0.5cm per year in the level of groundwater during the study period 2003 to 2012. The study found that most precipitation was lost to evapotranspiration, and the groundwater supplies were not replenished by precipitation because of human use, especially for irrigation.

- The UAE is the second highest consumer of desalinated water, after Saudi Arabia (Aldababseh et al., 2018).

- In 2015, groundwater supplies provided 51% of the country's total water supply. 9% of the country's total water supply was recycled water; desalinated water made up 40% of the total water supply (Saleh et al 2019).

- Limitations to accurate data from water research in UAE include the lack of a well-structured groundwater monitoring network and that only a few stations monitor precipitation – therefore other tools are needed to assess groundwater reserves (Gonzalez et al., 2016).

- Temperatures over the Arabian Peninsula are projected to increase throughout the century: modelling under three different Shared Socioeconomic Pathways (see Glossary of terms for a definition) suggest that the average annual temperature over the Arabian Peninsula will increase by 1.7 °C – 2.2 °C for the period 2030–2059, and by 2.9 °C – 5.3 °C in the period 2070–2099, in comparison to the baseline period 1981–2010. There is some uncertainty about precipitation patterns through the century, with a projected increase in annual precipitation in the south of the peninsula and a decrease in annual precipitation in the north of the peninsula as the century progresses (Almazroui et al., 2020b). This paper states that "the annual mean precipitation averaged over the Arabian Peninsula is likely to increase by 3.76–31.83% by the end of the twenty-first century". More recent regional studies corroborate these findings (Zittis et al., 2022).

9.3 Extreme weather events

- According to most modelling studies and future climate projections, extreme heatwaves will be a major challenge for the Gulf countries (including the UAE). Such events will be of unprecedented frequency, duration and peak temperatures (Zittis et al., 2016; Zittis et al., 2021a). These are projected to exceed 56 °C during the hottest events or even higher in large cities because of the urban heat island effect. In addition, because of the increased evaporation from the shallow surrounding water, humidity is expected to increase, augmenting the extreme discomfort conditions.

10.0 OCEAN BASINS

The countries in this report together border three ocean basins: the Red Sea; the Mediterranean Sea; and the Persian/Arabian Gulf (referred to here as the Gulf). This section considers how each of these three basins are currently, and might be in future, affected by climate change and sea-level rise in addition to the human-induced pressures they are already facing. A key point is that ecological stressors in oceans cross national boundaries, such that addressing and removing the source of a stressor(s) need(s) a coherent management strategy (Gladstone et al., 2013).

Each ocean basin is enclosed, and has its own unique ecosystem and habitat types and will react differently to the changes brought about by climate heating and anthropogenic activities. This section is intended as an overview to highlight the main issues that have arisen to the present day and those that may occur in future decades in relation to one or more of the following: increase in sea surface temperature (including 'marine heatwaves'), sea-level rise, ocean acidification, desalination, and other human activities.

One of the major concerns for marine life, in the MENA region and globally, is the increased frequency of marine heatwaves. Enclosed ocean basins – such as those in the MENA region – are particularly susceptible to marine heatwaves. Globally, the number of marine heatwaves (see Glossary of terms for a definition) increased by 50% during the twentieth century. As the climate continues to heat, marine heatwaves are projected to increase further in frequency and intensity in future decades. Anthropogenic climate heating is highly likely to be the major driver of marine heat waves (Oliver et al., 2018). Marine heatwaves can be extremely damaging to marine flora and fauna, particularly for species that are not mobile and therefore are not able to move horizontally or vertically to more favourable conditions. Although mobile marine fauna, including many invertebrates and fish populations, may be able to move to a cooler region of the water column (Hobday et al., 2016; Oliver et al., 2019), this movement in itself can have implications on ecosystem structure and on socioeconomics. For example, shifting distributions of fish populations could impact commercial and subsistence fisheries if species shift to deeper waters or move polewards; the redistribution of plants and animals to more favourable conditions may lead to changes in predation, species interaction, plant-animal interaction, which can potentially alter ecosystem productivity and carbon storage (Pecl et al., 2017). High sea surface temperatures can have particularly negative impacts on vulnerable coastal and shallow water ecosystems such as seagrass meadows, mangrove forests and coral reefs.

Coral reef in the Red Sea

10.1 The Intergovernmental Panel on Climate Change on ocean systems

The first IPCC special report on oceans and the cryosphere (Pörtner et al., 2019) largely considers the trends and threats facing ocean ecosystems from a global perspective, but many of the findings are relevant to the MENA region more specifically and relevant findings are presented in brief below.

Over the past five decades, the global ocean has warmed consistently and has absorbed more than 90% of the excess heat in the climate system (Pörtner et al., 2019). The warming trend is projected to continue through this century (Bindoff et al., 2019). Burning fossil fuels has released significant quantities of carbon dioxide into the atmosphere, much of which has been absorbed by the ocean and has led additionally to acidification. Global mean sea level is rising, but the rise will vary between regions. Over the past century, sea levels have risen by 1 to 2 mm per year in most regions. The rate of global mean sea level rise has increased over the past two centuries, and many regions are seeing an increase in sea level rise of 3 mm to 4 mm per year. The projected sea level rise in mid- to late century will depend on the extent to which emissions are reduced. By 2100, under RCP2.6, the rise could be 4 mm to 9 mm per year; under RCP8.5 the rise could be 10 mm to 20 mm per year (Oppenheimer et al., 2019). Coral reefs and coastal wetlands, which provide essential ecosystem services (such as carbon sequestration), are projected to be negatively impacted by climate heating and changes to the ocean.

Coral reefs are expected to deteriorate even under a low emissions scenario in which global average temperatures are limited to 2 °C above pre-industrial levels (section 5.3.4 in Bindoff et al., 2019). Globally, almost 50% of global wetlands have been lost since the pre-industrial era, largely because of non-climate anthropogenic drivers such as agricultural development, aquaculture and urbanisation. The remaining area of global coastal wetlands is projected to decline by 20-90% by 2100 depending on the emissions scenario (Bindoff et al., 2019). A key point to note is that human activities such as overfishing and coastal development have a significant negative impact on coastal ecosystems and wetlands, and climate change will exacerbate the pressures on these natural systems, decreasing their resilience.

See Appendix 3 for a more detailed list of relevant ocean-related findings from the IPCC.

10.2 Mediterranean Sea

This section focuses primarily on the southern and eastern part of the ocean basin.

- **Sea surface temperature.** The Mediterranean basin sea surface temperature is projected to increase by +1.5 °C to +3 °C at the end of the twenty-first century (2070–2100) relative to historical average annual sea surface temperature (1961–1990), with the wide range in projections relating to the different emission scenarios and representative concentration pathways (RCPs) (Adloff et al., 2015).

- **Marine heatwaves.** Modelling projections suggest that marine heatwaves in the Mediterranean Sea could be particularly intense by mid-century under RCP8.5, with sea surface temperatures increasing by +2 to +4 °C relative to a 1982–2005 baseline period. Oliver et al. (2019) used models to project that all ocean regions would experience increased frequency of marine heatwaves by mid-century (2031–2060).

Modelling scenarios investigated by Darmaraki et al. (2019) paint a stark warning of increasing marine heatwave trends in the Mediterranean Sea under climate heating, in comparison to the reference period 1976–2005. The results project that, in the final decades of the twenty-first century (2071–2100), the Mediterranean Sea could experience extended periods of extreme sea surface temperatures from June to October under both RCP4.5 and RCP8.5. The scenario under RCP2.6 is that marine heatwaves will occur much more frequently during the period 2071–2100, but there will be 'breaks' in between heatwave events.

- **Coastal development.** Analysis by Abdrabo & Hassaan (2015) identified 11 urban centres in Egypt's Nile Delta that are potentially vulnerable to sea-level rise. Modelling under different scenarios (sea level rise of 140 cm, 95 cm and 75 cm) suggested that the total area of each urban centre that could be affected by sea level rise differs depending on the extent of sea level rise. Under all sea level rise scenarios, the four cities most susceptible to being inundated are Alexandria (projected area affected ranging from 85–95 km^2, depending on the scenario), Edku (23–38 km^2), Port Said (43 km^2 under all three scenarios) and Port Fouad (14–16 km^2). The authors argue, however, that rather than simply pointing out the vulnerability of each urban centre, it is helpful to focus on the resilience of those communities to respond to and cope with such events, and devised an index to determine how each urban centre might be affected by taking into account the following factors: socioeconomic, physical, environmental, institutional and climate change hazards. The study identified four urban centres with the lowest resilience to any amount of sea-level rise (namely Kafr El Dawar, Rosetta and Edku, in the Governate of Behaira, and Gamasa, in the governorate of Dakahlyia), as in all scenarios these areas ranked particularly low in terms of demographic and socioeconomic characteristics, environmental quality, and to a lesser extent in relation to infrastructure and provision of services.

10.3 Red Sea

- **Coral reefs** *(from Miller et al., 2022).* The Red Sea is regarded as a global biodiversity hotspot, in part because it contains more than 16,000 km^2 of coral reef that supports a high number of endemic species (that is, they are not found elsewhere) (DiBattista et al., 2016). The Red Sea coastline amounts to around 4,000 km, almost all of which are lined with fringing coral reefs as well as offshore island reefs, making the Red Sea reefs one of the longest continuous living reefs in the world (Kleinhaus et al., 2020a; Kleinhaus et al., 2020b). Such reefs are essential habitats for fish and invertebrates. The Red Sea is home to around 365 scleractinian coral species, of which 19 (5.5%) are endemic (DiBattista et al., 2016). Some of the Red Sea corals are very unusual because they can withstand relatively wide fluctuations in sea temperature. The ability to adapt to an increase in sea temperature, a result of the Earth's changing climate, could be important for the survival of the Red Sea reef system. Coral reefs across the world are at risk of bleaching (which causes corals to die) because of increasing sea temperatures and increased frequency and intensity of natural climatic events such as El Niño (Hughes et al., 2018). Studying the unique corals of the Red Sea and the Gulf of Aqaba could help researchers to understand how these organisms survive increased heat. Importantly, the heat-resilient Red Sea corals could be one of the only reef ecosystems to survive if other reefs are badly affected by warming ocean temperatures (Savary et al., 2021).

- **Biodiversity** *(from Miller et al., 2022).* The Red Sea region has more than 1,000 species of fish, of which 14% are endemic (DiBattista et al., 2016). Fifteen percent of Red Sea crustaceans are endemic, and so are 211 described echinoderms (starfish, sea urchins and sea cucumbers) (DiBattista et al., 2016). Five of the world's seven species of turtle are found in the Red Sea (Mancini et al., 2015). Dugongs can also be seen throughout the Red Sea, and they are listed as vulnerable to extinction on the International Union for Conservation of Nature's Red List because they get caught in fishing nets and also because they feed on seagrasses, a habitat that is under threat from coastal development (Nasr et al., 2019). Sixteen species of cetacean (whales and dolphins) have been recorded in the Red Sea, although only nine have been observed regularly (Notarbartolo di Sciara et al., 2017).

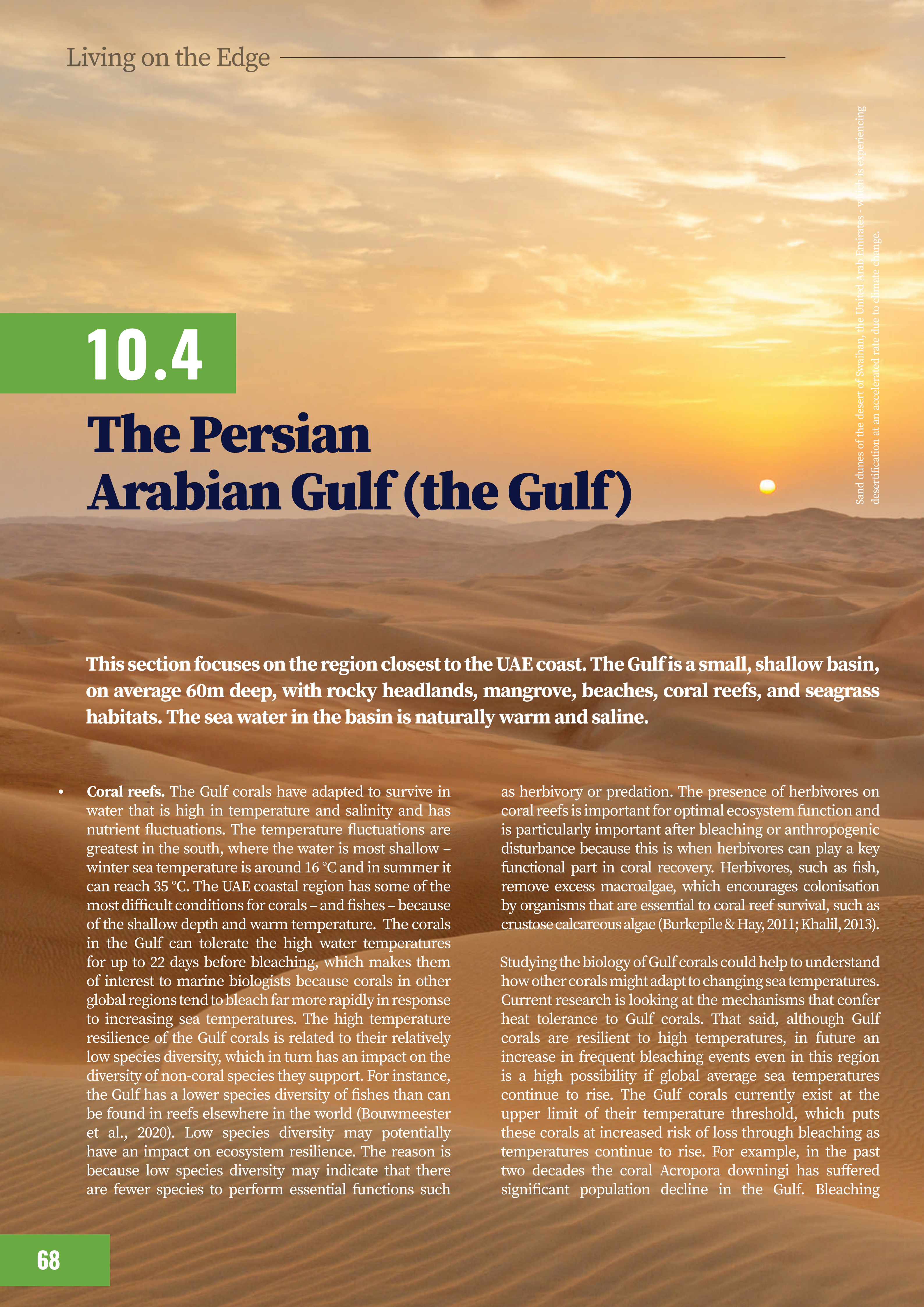
- **Marine heatwaves.** High sea surface temperature can have a detrimental impact on corals and cause 'bleaching' (loss of symbiotic microalgae from the coral structure), which can result in corals being more susceptible to damage or death, and can have other long-term impacts if repeated or prolonged. Bleaching events in Red Sea corals have been observed with increased frequency in the past several decades, with particular events noted in 2007, 2010, 2012 and 2015 (Furby et al., 2013; Monroe et al., 2018). Research

Coral reef in the Red Sea

suggests that bleaching events caused by extreme marine heatwaves in the Red Sea may be under-reported due to lack of long-term monitoring data. Marine heatwaves have been more frequent in the north Red Sea than the south Red Sea, and the sea surface temperature in the north Red Sea is rising faster than other regions of the Red Sea (Genevier et al., 2019). Research by Chaidez et al. (2017) suggest that on a decadal basis, the rate of warming of the sea surface temperature in the Red Sea is 0.17 °C per decade, which is faster than the rate of 0.11 °C per decade at which the global ocean is warming. That said, there have been more coral bleaching events in the south and central regions of the basin than in the north. The reason is that the corals in the south and central regions are living closer to their thermal limit than the northern Red Sea corals, therefore a fluctuation in temperature to those corals has a significant detrimental impact. Monitoring will help to determine the likelihood and occurrence of marine heatwaves in different regions of the Red Sea. The warming trend seems likely to continue, which suggests that coral bleaching will be observed throughout the Red Sea in future decades (Genevier et al., 2019).

- **Tourism, urbanisation and industry.** The economic value of coastal and marine tourism and of industry in the region is significant. The diversity of the Red Sea coral reefs, the number of associated endemic species and their extension to deeper waters (even up to 2,000m deep in the northern section) makes the region popular with divers in particular. Impacts from human activity include construction of walkways, converting rocky shores to artificial beaches, converting shores to buildings, creation of artificial lagoons, construction of artificial islands, and smothering caused by sediment from such artificial beaches and islands. Chemical and thermal pollution from desalination plants, and contamination – including the potential threat from leaks – from industrial activities and the oil and gas industry, and improper sewerage systems can also have negative impacts. Tourist boats and divers can cause direct damage to corals. Coastal developments will, in general terms, have a detrimental impact on coastal ecosystems because they inevitably add further stresses to natural systems (Gladstone et al., 2013).

- **Future projections.** Projecting the future conditions in the Red Sea is challenging because of the complex interactions between weather systems and, in turn, between atmospheric conditions and the underlying water column . To explain this in more detail, the air and sea surface temperature in the northern Red Sea is affected by the frequency and intensity of cold northerly winds from the Mediterranean. In the past 30 years, the decrease in wind speed has corresponded to an increase in sea surface temperature. Therefore, if the wind naturally cools the sea surface, a decrease in cool winds will have an effect that could lead to an increased rate of water evaporation that, in turn, could have an impact on the deep water circulation in the Red Sea. Research by Langodan et al. (2020) suggests that the future conditions in the northern region of the Red Sea will depend on the storm track in the Mediterranean. The tentative conclusion is that the long term will see a decrease in winds in the Mediterranean and the northern Red Sea. However, the balance between weather systems is delicate and difficult to project with any certainty and other global events can have an influence. The ongoing melting of the north polar ice cap is likely to have an impact on meteorological patterns far from the Arctic and could, therefore, affect existing climate projections even in the MENA region.



Sand dunes of the desert of Swaihan, the United Arab Emirates - which is experiencing desertification at an accelerated rate due to climate change.

10.4

The Persian Arabian Gulf (the Gulf)

This section focuses on the region closest to the UAE coast. The Gulf is a small, shallow basin, on average 60m deep, with rocky headlands, mangrove, beaches, coral reefs, and seagrass habitats. The sea water in the basin is naturally warm and saline.

- **Coral reefs.** The Gulf corals have adapted to survive in water that is high in temperature and salinity and has nutrient fluctuations. The temperature fluctuations are greatest in the south, where the water is most shallow – winter sea temperature is around 16 °C and in summer it can reach 35 °C. The UAE coastal region has some of the most difficult conditions for corals – and fishes – because of the shallow depth and warm temperature. The corals in the Gulf can tolerate the high water temperatures for up to 22 days before bleaching, which makes them of interest to marine biologists because corals in other global regions tend to bleach far more rapidly in response to increasing sea temperatures. The high temperature resilience of the Gulf corals is related to their relatively low species diversity, which in turn has an impact on the diversity of non-coral species they support. For instance, the Gulf has a lower species diversity of fishes than can be found in reefs elsewhere in the world (Bouwmeester et al., 2020). Low species diversity may potentially have an impact on ecosystem resilience. The reason is because low species diversity may indicate that there are fewer species to perform essential functions such as herbivory or predation. The presence of herbivores on coral reefs is important for optimal ecosystem function and is particularly important after bleaching or anthropogenic disturbance because this is when herbivores can play a key functional part in coral recovery. Herbivores, such as fish, remove excess macroalgae, which encourages colonisation by organisms that are essential to coral reef survival, such as crustose calcareous algae (Burkepile & Hay, 2011; Khalil, 2013).

Studying the biology of Gulf corals could help to understand how other corals might adapt to changing sea temperatures. Current research is looking at the mechanisms that confer heat tolerance to Gulf corals. That said, although Gulf corals are resilient to high temperatures, in future an increase in frequent bleaching events even in this region is a high possibility if global average sea temperatures continue to rise. The Gulf corals currently exist at the upper limit of their temperature threshold, which puts these corals at increased risk of loss through bleaching as temperatures continue to rise. For example, in the past two decades the coral Acropora downingi has suffered significant population decline in the Gulf. Bleaching events off the western coast of the UAE in 1996 and 1998 were temperature related (Riegl, 2003; Riegl et al., 2018; Bouwmeester et al., 2020). Recovery from those two events has not been uniform across the Gulf and many Gulf corals still show signs of deterioration (Sheppard, 2016). The concern is that bleaching events in the Gulf may increase in frequency in future decades as a result of climate change, but without comprehensive baseline monitoring it will be difficult to fully assess the extent of any impact (Ben-Hasan & Christensen, 2019).

- **Fisheries.** The Gulf's fisheries are an important regional economic resource. But the marine environment in the region is under pressure from threats including the oil and gas industry, coastal development/dredging that removes habitat, pollution such as from sewage/wastewater, high sea surface temperatures of 34 °C and 36 °C in summer, and increasing salinity (particularly in the north Gulf). The effects of climate change are expected to exacerbate these impacts (Ben-Hasan & Christensen, 2019).

- **Coastal development.** Following the 1970s oil drilling expansion, huge coastal construction projects had a detrimental impact on the marine environment in the Gulf. Unfortunately, many baseline surveys to assess ecosystems in the region were carried out by construction companies and remain confidential, such that the information has not been shared and, as a result, the Gulf ecosystems are not well understood. Compounding this is the fact that there is little communication on environmental issues between governments (Sheppard et al., 2012). Coastal developments coupled with damage to or removal of reef systems and coastal wetlands destroy habitats that provide essential services. As well as providing breeding grounds for marine life and acting as a carbon store, these ecosystems provide resilience to climate change and rising sea levels.
Construction along the coasts leads to vast environmental damage, which includes dredging intertidal flats, removing mangrove forests, coral reefs and seagrass beds (all three of which are essential carbon storage ecosystems), and sandy embayments. Arguably, poor environmental regulation and lack of a coherent Gulf-wide management strategy in past decades has allowed such practices to take place (Sale et al., 2011).

  A major threat to the Gulf marine ecosystems is coastal development, which includes dredging to create residential areas. Artificial islands have been built off the UAE coastline. Impacts from tourism overlap with impacts from other activities, for example industrial pollution, fishing, litter and the oil and gas industry (Sale et al., 2011; Gladstone et al., 2013).

- **Desalination**. The majority of water production in the UAE is from desalination plants. These plants produce thermal pollution and concentrated waste brine, as well as introducing pre- and post-treatment chemicals which can be extremely damaging to ecosystems if released into the sea. The full impact of desalination plants in the region is still not yet fully understood and more research is needed (Sale et al., 2011).

11.0 Concluding remarks

In this report we have highlighted how the climate crisis is impacting the entire MENA region. Evidence from scientific studies and observational data indicate that weather patterns and climate have already changed. The MENA region is warming almost twice as fast as the global average and projections are that the temperature across the region will continue to rise through the twenty-first century. Climate model projections of future rainfall patterns are less certain but the indications are of an increase in the length and severity of drought events in North Africa in future decades. As the average annual temperature rises across the region, the risk to human health increases. Prolonged heatwaves lead to excess human death from non-communicable disease such as heart disease, stroke and dehydration, and changes in conditions can lead to the emergence of tropical diseases.

The implications for biodiversity in both terrestrial and marine ecosystems is significant. Some species will be able to adapt to the changing conditions, or migrate to more favourable areas, but the long-term lack of baseline monitoring in the MENA region means that it is difficult to predict with any certainty how species will react to climate change. For example, some Red Sea corals are already at the limit of heat tolerance and continued increase in sea surface temperature could lead to widespread bleaching.

The overall picture is of a need for urgency to help vulnerable communities across the MENA region to adapt to their changing climate, address the inevitable losses and damages associated with climate change and to take the necessary steps to stop all greenhouse gas emissions and transition to a renewable energy-powered world.


Luxor, Egypt - September 2018: woman washing her cow in Nile river

12.0 Glossary of terms

Some of the entries in this section are from Miller et al. (2020).

Ambient temperature In the context of weather, the ambient temperature is the air temperature. The temperature that a person feels may also be influenced by humidity or wind speed, but those will not affect the air temperature.

Extreme weather events These are climate-related events, primarily heat waves, floods, droughts, tropical storms or extreme extra-tropical cyclones (but not other types of natural hazards such as earthquakes or landslides).

Heatwave The World Meteorological Organisation defines a heatwave as: “A period of marked unusual hot weather (maximum, minimum and daily average temperature) over a region persisting at least three consecutive days during the warm period of the year based on local (station- based) climatological conditions, with thermal conditions recorded above given thresholds.” This definition works on the understanding that different regions of the world and the local communities will be adapted to slightly different temperatures, therefore establishing a set heatwave threshold to cover all regions of the world would not be appropriate.

Marine heatwave Hobday et al. (2016) suggest a definition of marine heatwaves to be a discernible period of at least five days of unusually warm water, relative to the baseline period or temperature at the time of year in the region.

Representative Concentration Pathways (RCP) The Representative Concentration Pathways were developed by the Intergovernmental Panel on Climate Change (IPCC) for the Fifth Assessment Report (AR5). RCP8.5 is a widely used pathway and is also the strongest of the four RCP scenarios. RCP8.5 is a very high-emissions global heating scenario and was developed as a ‘worst-case’ scenario, that imagines no climate mitigation policies are implemented, fossil fuel use is widespread and no measures are taken to reduce carbon emissions. RCP8.5 assumes 8.5 W/m^2 radiative forcing by 2100. Three other scenarios were developed to predict the outcome of future emissions: RCP2.6, RCP4.5 and RCP6. RCP4.5 assumes that anthropogenic emissions peak by 2040 and then stabilise, with atmospheric CO_2 at approximately 500 parts per **million;** RCP8.5 assumes that anthropogenic emissions continue to rise through the twenty-first century, with atmospheric CO_2 at approximately 900 parts per million.

The RCP scenarios do not make consistent socioeconomic assumptions and RCP8.5 has attracted controversy in the literature for being unrealistic, but analysis has found that of the four RCP pathways, RCP8.5 is the best match for emissions

between 2005–2020 (Schwalm et al., 2020). When used in conjunction with the Shared Socioeconomic Pathways (SSPs) a more comprehensive prediction is possible.
A full explanation of climate modelling scenarios and their development is available from Carbon Brief at:
https:// www.carbonbrief.org/explainer-the-high-emissions-rcp8- 5-global-warming-scenario

Shared Socioeconomic Pathways (SSP) Five different scenarios or 'pathways' that consider how social, economic and demographics might change globally in the future. The SSPs imagine scenarios in which no climate mitigation policy exists. They range from SSP1, which predicts a rise of 3-3.5 °C by 2100 to SSP5, which predicts global heating of 4.7–5.1 °C above pre-industrial levels. The pathways were published in 2016 and are now beginning to be used in climate A full explanation of climate modelling scenarios and their development is available from Carbon Brief at: https:// www.carbonbrief.org/ explainer-the-high-emissions-rcp8-5-global-warming-scenario

13.0

List of maps, figures and boxes

Appendix 1:
Peer review literature

Tables A1 and A2, below, show the number of publications on different topics in named MENA countries. The contents of the tables show the number of research papers found following a search on the Web of Science Core Collection database of journals, and is a general idea of research output from all available years. The terms indicated in the table below were searched for inclusion in the article's topic, which shows whether the terms are mentioned in the title, abstract, author keywords, and keywords plus. So, for example, 'Algeria' + 'food security'; 'Egypt' + 'climate'; 'Tunisia' + 'temperature' and so on. The search was correct as of September 2022.

Not all papers are relevant to the research aims of this report, but this search gives a broad overview of research focus and regions in which there may be knowledge gaps. Importantly, because of the inclusion of Global South countries, it gives an idea of research funding focus. What the table doesn't give, which is a key point to consider, is the location of the institutions that conducted the research on a given country.

Search terms	Food security	Water Availability	Extreme weather events	Climate	Temp-erature	Preci-pitation
Algeria	46	88	7	1114	1249	410
Egypt	216	226	18	1641	2077	477
Lebanon	72	50	4	353	253	121
Morocco	122	166	23	1720	1545	556
Tunisia	74	168	9	1087	1203	373
United Arab Emirates	49	28	5	370	341	110
Australia	684	2041	428	19476	15885	4575
France	147	595	166	6524	7492	2202
United Kingdom	110	86	69	2149	1357	467
United states	1734	1982	944	29275	21556	12982

Table A1: Number of results from a Web of Science Core Collection search – land.

Search terms	Climate change	Extreme weather
Red Sea	46	88
Mediterranean Sea	216	226
Persian Gulf / Arabian Gulf	72	50

Table A2: Number of results from a Web of Science Core Collection search – sea.

Appendix 2:

Notes from the Intergovernmental Panel on Climate Change Sixth Assessment Report

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) consists of reports from three working groups. This section contains material copied directly from the IPCC documents and is in quotation marks.

Technical Summary from Working Group I
The Working Group I contribution to the Sixth Assessment Report, Climate Change 2021: The Physical Science Basis was released on August 9, 2021 (Arias et al., 2021).

Section TS 4.3.1 Generic global changes
Observed change
- "High confidence that climate changes, such as a decrease in total precipitation and an increase in aridity, have already happened and medium confidence that many of the changes are due to human activities."

Projected changes
- "It is likely that most land areas will experience further warming of at least 4°C compared to a 1995–2014 baseline by the end of the 21st century."
- "High confidence that because of the frequent increasing warming levels, extreme heat will exceed critical thresholds for health and agriculture."

Section TS.4.3.2.1 Regional changes to Africa:
Observed change
- "North East Africa has experienced a decrease in rainfall since 1980."

Projected changes
- "High confidence in projected decrease in total precipitation in the northernmost regions of Africa."
- "High confidence in heavy precipitation in most African areas that will lead to floods."
- "Medium to high confidence that there will be increasing aridity and drought is projected for North Africa."
- "Northern Africa is likely to have a reduction in precipitation."
- "High confidence in a decrease in mean wind, extreme winds and the wind energy potential in North Africa."

Section TS 4.3.2.2 Asia

Observed change

• "There has been a decline in annual precipitation over the Arabian Peninsula since the 1980s of 6.3 mm per decade. In contrast, there has been an increase in precipitation of between 1.3 mm and 4.8 mm per decade from 1960 to 2013 over the high parts of eastern West Central Asia."

Projected change

• "There is medium confidence that in West Central Asia, aridity will increase, especially beyond the middle of the twenty-first century and global warming levels beyond 2°C."

2.2 Technical Summary from Working Group II

The Working Group II contribution, Climate Change 2022: Impacts, Adaptation and Vulnerability was released on 28 February 2022 (Pörtner et al., 2021).

Section TS.B.4.6 Water systems and water security

Observed changes

Section TS.C.2.1 Ecosystems and biodiversity

Projected change

• "Global warming of 3.0°C–3.5°C increases the likelihood of extreme and lethal heat events in western and northern Africa (medium confidence) and across Asia."

Section TS.C.4.4 Water systems and water security

Projected change

• "Above 2°C, the frequency and duration of meteorological drought are projected to double over North Africa, the western Sahel and southern Africa (medium confidence)."

Section TS.C.6.3 Health and wellbeing

Projected change

• "Tens of thousands of additional deaths are projected under moderate and high global warming scenarios, particularly in north, west and central Africa, with up to year-round exceedance of deadly heat thresholds by 2100 (RCP8.5) (high agreement, robust evidence)."

Section TS.C.9.2 Cities, settlements and infrastructure

Projected change

• "Asian and African urban areas are considered high-risk locations from projected climate, extreme events, unplanned urbanisation and rapid land use change (high confidence)."

Section TS.D.2.4 Maladaptation

Observed change

• "Awareness of anthropogenic climate change ranges between 23% and 66% of people across 33 African countries, with low climate literacy limiting potential for transformative adaptation (medium confidence)."

2.3 Technical Summary from Working Group III

The Working Group III contribution, Climate Change 2022: Mitigation of Climate Change was released on 4 April 2022 (IPCC, 2022).

NOTE: The Technical Summary is approved but it is not the final version.

Section TS 5.2 Urban emissions

Observed changes

• "For 2000 to 2015, the urban emissions share increased from 28% to 38% in Africa, and from 57% to 62% in West Central Asia."

• "From 2000 to 2015, global urban GHG emissions per capita increased from 5.5 to 6.2 tCO2-eq per person (an increase of 11.8%). Emissions in Africa increased from 1.3 to 1.5 tCO2-eq per person (22.6%). And in West Central Asia from 6.9 to 9.8 tCO2-eq per person (40.9%)."

• Projected change

• "Medium confidence that urban land areas will increase: the highest rate of urban land growth is projected to occur in Africa, Eastern Europe and West-Central Asia.

Appendix 3:

Notes from the IPCC report – 'The Ocean and Cryosphere in a Changing Climate: A Special Report of the Intergovernmental Panel on Climate Change'

This section contains notes copied directly from Pörtner et al., 2019.

Summary for Policymakers

- A.2 "It is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system (high confidence). Since 1993, the rate of ocean warming has more than doubled (likely). Marine heatwaves have very likely doubled in frequency since 1982 and are increasing in intensity (very high confidence). By absorbing more CO2, the ocean has undergone increasing surface acidification (virtually certain). A loss of oxygen has occurred from the surface to 1,000 m (medium confidence).
- "Global mean sea level (GMSL) is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets (very high confidence), as well as continued glacier mass loss and ocean thermal expansion. Increases in tropical cyclone winds and rainfall, and increases in extreme waves, combined with relative sea level rise, exacerbate extreme sea level events and coastal hazards (high confidence)."

A.3.4 "Sea level rise is not globally uniform and varies regionally."

From Ch 4. Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities (Oppenheimer et al., 2019).

Executive Summary

- "Global mean sea level (GMSL) is rising (virtually certain) and accelerating (high confidence)"
- "Non-climatic anthropogenic drivers, including recent and historical demographic and settlement trends and anthropogenic subsidence, have played an important role in increasing low-lying coastal communities' exposure and vulnerability to SLR and extreme sea level (ESL) events (very high confidence)."
- "In coastal deltas, for example, these drivers have altered freshwater and sediment availability (high confidence)."
- "Adaptation can be undertaken in the short- to medium-term by targeting local drivers of exposure and vulnerability."
- "Coastal ecosystems are already impacted by the combination of SLR, other climate-related ocean changes, and adverse effects from human activities on ocean and land (high confidence)…. as a consequence of human actions that fragment wetland habitats and restrict landward migration, coastal ecosystems progressively lose their ability to adapt to climate-induced changes and provide ecosystem services, including acting as protective barriers (high confidence)."
- "Future rise in GMSL caused by thermal expansion, melting of glaciers and ice sheets and land water storage changes, is strongly dependent on which Representative Concentration Pathway (RCP) emission scenario is followed."
- "Due to projected GMSL rise, ESLs that are historically rare (for example, today's hundred-year event) will become common by 2100 under all RCPs (high confidence). Many low-lying cities and small islands at most latitudes will experience such events annually by 2050."
- "Non-climatic anthropogenic drivers will continue to increase the exposure and vulnerability of coastal communities to future SLR and ESL events in the absence of major adaptation efforts compared to today (high confidence)."
- "The expected impacts of SLR on coastal ecosystems over the course of the century include habitat contraction, loss of functionality and biodiversity, and lateral and inland migration. Impacts will be exacerbated in cases of land reclamation and where anthropogenic barriers prevent inland migration of marshes and mangroves and limit the availability and relocation of sediment (high confidence)."

Section 4.1

- "After an increase of sea level from 1–2 mm yr–1 in most regions over the past century, rates of 3–4 mm yr–1 are now being experienced that will further increase to 4–9 mm yr–1 under RCP2.6 and 10–20 mm yr–1 at the end of the century under RCP8.5."

Section 4.1.3

- "Rising mean and increasingly extreme sea level threaten coastal zones through a range of coastal hazards including (i) the permanent submergence of land by higher mean sea levels or mean high tides; (ii) more frequent or intense coastal flooding; (iii) enhanced coastal erosion; (iv) loss and change of coastal ecosystems; (v) salinisation of soils, ground and surface water; and (vi) impeded drainage."

Chapter 5 Changing Ocean, Marine Ecosystems, and Dependent Communities (Bindoff et al., 2019).

Executive Summary

- "The ocean has warmed unabated since 2005."
- "It is likely that the rate of ocean warming has increased since 1993."
- "By 2100 the ocean is very likely to warm by 2 to 4 times as much for low emissions (RCP2.6) and 5 to 7 times as much for the high emissions scenario (RCP8.5) compared with the observed changes since 1970."
- "Expected coastal ecosystem responses over the 21st century are habitat contraction, migration and loss of biodiversity and functionality. Pervasive human coastal disturbances will limit natural ecosystem adaptation to climate hazards (high confidence). Global coastal wetlands will lose between 20–90% of their area depending on the emissions scenario with impacts on their contributions to carbon sequestration and coastal protection (high confidence)."
- "Almost all coral reefs will degrade from their current state, even if global warming remains below 2oC (very high confidence), and the remaining shallow coral reef communities will differ in species composition and diversity from present reefs (very high confidence). These declines in coral reef health will greatly diminish the services they provide to society, such as food provision (high confidence), coastal protection (high confidence) and tourism (medium confidence)."

Adaptation strategies (in the Executive Summary)

- "Coastal blue carbon ecosystems, such as mangroves, salt marshes and seagrasses, can help reduce the risks and impacts of climate change, with multiple co-benefits. Some 151 countries around the world contain at least one of these coastal blue carbon ecosystems and 71 countries contain all three. Below-ground carbon storage in vegetated marine habitats can be up to 1000 tC ha–1, much higher than most terrestrial ecosystems (high confidence). Successful implementation of measures to maintain and promote carbon storage in such coastal ecosystems could assist several countries in achieving a balance between emissions and removals of greenhouse gases (medium confidence). Conservation of these habitats would also sustain the wide range of ecosystem services they provide and assist with climate adaptation through improving critical habitats for biodiversity, enhancing local fisheries production, and protecting coastal communities from SLR and storm events (high confidence). The climate mitigation effectiveness of other natural carbon removal processes in coastal waters, such as seaweed ecosystems and proposed non-biological marine CO2 removal methods, are smaller or currently have higher associated uncertainties. Seaweed aquaculture warrants further research attention. "
- "The potential climatic benefits of blue carbon ecosystems can only be a very modest addition to, and not a replacement for, the very rapid reduction of greenhouse gas emissions."

Section 5.3.4 Coral Reefs

- "Human activities and warming have already led to major impacts on shallow water tropical coral reefs caused by species replacement, bleaching and decreased coral cover while warming, ocean acidification and climate hazards will put warm water corals at very high risk even if global warming can be limited to 1.5oC above pre-industrial level."
- "…coral reefs globally are projected to greatly decline at 2oC warming relative to pre-industrial level."
- "…it has not yet been established whether coral and coral associated biota adaptation may hold beyond 1.5oC warming."
- "…coral reefs are projected to decline by a further 70–90% at 1.5 C (very high confidence) with larger losses (>99%) at 2oC (very high confidence)."

Appendix 4:

The Intergovernmental Panel on Climate Change on climate change mitigation

11.3 IPCC AR6 WG III

The Intergovernmental Panel on Climate Change (IPCC) Working Group III contribution, Climate Change 2022: Mitigation of Climate Change was released on April 4, 2022 (IPCC, 2022).

- "TS p48: The benefits of mitigation costs to limit global average temp increase to 2 °C outweigh the mitigation costs."
- "TS p69: community-based solutions such as solar sharing, mobility as a service and community charging can help facilitate low-carbon transport systems."

•"TS p103: Individuals and households have low motivation to alter energy consumption behavior. Changes need to be structural and cultural and will involve psychological variables such as awareness, perceived risk, subjective and social norms, values, and perceived behavioural control."
•"TS p111: Sub-national actors are important for mitigation."
•"TS p130: Sustainable development and climate change present dual challenges to countries. Cultural factors strongly influence how / when changes will be implemented."
•"TS p138: A broad spectrum of mitigation strategies are more robust and resilient."

Appendix 5:

World Development Indicators

To illustrate a comparison between the six MENA countries featured in this report and selected countries in the Global North (Source: World Bank, 2022).

	GDP per capita in 2021 (US$)	CO2 emissions per capita in 2019 (metric tons)	Electric power consumption in 2014 (kWh per capita)	Renewable energy consumption in 2019 (% of total)	Electricity production in 2015 from renewable sources (% of total) *
Algeria	3,500	2	904	10.69	8.2
Egypt	3,700	4	1,363	0.16	0.1
Lebanon	4,000	2.6	1,455	12.2	2.5
Morocco	3,800	2.5	1,683	5.3	0.9
Tunisia	2,600	4.1	2,589	5.46	0
United Arab Emirates	36,000	19.3	11,088	0.67	0.2
Australia	60,000	15.2	10,071	10.13	8.3
France	43,500	4.5	6,940	15.53	6.2
United Kingdom	47,000	5.2	5,130	12.24	23
United states	69,000	14.7	12,994	10.42	7.4

* Excluding hydroelectric, including geothermal, solar, tides, wind, biomass, and biofuels.

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