# Climate risk report for the Middle East and North Africa (MENA) region

**Authors:** Katy Richardson, Amy Doherty, Rebecca Osborne, Leigh Mayhew, Kirsty Lewis, Guy Jobbins, Cathryn Fox, Hannah Griffith, Sherine El Taraboulsi-McCarthy

**Reviewers:** Richard Jones, Sarah Opitz-Stapleton, Jane Strachan, Stephen Mooney, Nikolaus Clemenz , Rebecca Berry, Hammou Laamrani , Tamara Janes

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## Contents

# Executive summary

Understanding future climate risks depends on analysing both future climate conditions and the socio-economic vulnerabilities exacerbated by those conditions. Climate risks threaten human wellbeing and development through their impact on systems such as food security, livelihoods, water resources, infrastructure, and human health.

This broader perspective informs this report. We have identified key climate risks by considering both climate change model projections from the present day to the 2050s, and their interaction with regional socio-economic vulnerabilities. The report highlights the headline risks to consider in any climate-resilient development planning.

The region's climate is characterised by hot and dry conditions, with some significant local variations. The current climate is around 1-1.5˚C warmer than pre-industrial times, and there is high confidence of further warming in the future, particularly at the hottest times of year. There is less confidence about how rainfall has changed in the past or may change in the future. However, future projections indicate little overall change in annual rainfall amounts in most areas, and a small decrease in others. However, when combined with increasing temperatures, there is high confidence that regional water resource quantity and quality will reduce.

As mentioned, climate change is just part of the picture. We also need to consider its interaction with human systems and how this influences development trends and adaptation choices. This region is already water stressed, and heat stress limits daily life for much of the year. Not only that, but local food production has also limited scope for expansion, so dependency on food imports is high. Other trends, such as increasing urbanisation, demographic change and continued conflict and instability further exacerbate potential climate risks.

Most risks identified in this report are not new for the region, but they are growing as the climate changes. People, animals, agriculture, and the natural environment have already made substantial adaptations to survive in such inhospitable conditions. This makes the areas of concern highlighted here particularly pertinent.

Our analysis identifies the following key risks as the most critical across the MENA region. Brief summaries by sector are included here and more in-depth summaries are in the 'Main climate risks to the MENA region' infographic on page 4. Bear in mind that these risks are interdependent. Also note that this is a regional analysis: risks at a national level may vary and would require a more detailed country level analysis.

**Water security**

The MENA region contains more water-stressed countries than any other region in the world. It does not have enough water to supply current demand in a sustainable way. Focus has historically been on supply rather than effective management and access to water is inequitable. Climate change will degrade natural water stores and ecosystems still further and exacerbate the stresses of human impacts. At the same time, heat stress from rising temperatures will considerably increase the demand for water from humans and agriculture.

Agricultural production is the biggest contributor to water stress across the region. Increased irrigation and water demand is driving unsustainable water exploitation and depleting groundwater reserves. This rising demand and diminishing availability imply an increase in water stress in a warming climate and is a prominent climate risk across the region.

There are further risks to water security. Springtime snowmelt feeds many key rivers in the region and rising temperatures will decrease streamflow and availability of freshwater. Flow in the River Nile, an important and politically sensitive source of water for Egypt, will be affected by changes in rainfall over the Ethiopian Highlands but also, crucially, by greater evaporation along its course (see Section 4.1 for water stress risk analysis). Without careful management, such conditions may intensify the transboundary and sector-focused competition over depleting water resources.

**Food security**

Agricultural production is constrained by a lack of both water and arable land, with some regions constrained by temperature as well. By the 2050s, there is high confidence that warming will occur over all seasons, with increases in mean, minimum and maximum temperatures, higher evapotranspiration and in some locations more variable rainfall. All this increases exposure to water stress, drought risk and harvest failure. In many areas, growing seasons will shorten as plants divert resources to managing heat stress rather than growth. This will be especially acute in already vulnerable agricultural systems that experience high temperatures today. Reduced crop yields will increase the reliance on food imports even more, leaving the region more vulnerable to global price volatility and climate impacts on agriculture production elsewhere (see 4.2 for food security risk analysis).

**Health**

High temperatures are already a significant health issue across the region in the summer months, particularly in urban environments and especially for coastal cities where humidity is highest. Climate change will exacerbate this further. Given the physiological limits of humans to withstand extreme heat, some areas may cease to be habitable. Demographic trends, including an aging population, urban migration and the large proportion of workers – particularly migrant workers – in unregulated, informal employment, all contribute to the increase in overall risks associated with thermal stress.

Air pollution, particularly related to dust storms, is a fact of life in many areas of the MENA region. How climate change may affect the occurrence of dust storms is an area of ongoing research: while there is only indirect evidence that climate change could increase their occurrence, it is clear that dust storms will remain a continued threat to human health (see 4.3 for urban areas and human health risk analysis).

**Cities and infrastructure**

Economic opportunities will continue to attract new arrivals to the region's urban centres. Rising temperatures will likely reduce outdoor labour productivity in summer, particularly where access to artificial cooling is limited. As urban areas grow, often in an informal way, demand for water will increase and put more pressure on sanitation services. Not only that, but extreme heat events also place significant strain on power generation and transmission, roads, and other critical infrastructure, with health and economic consequences. In other regions, particularly low- and middle-income countries, the critical limitation may be investment in the development of infrastructure to manage limited water resources (see 4.3 for urban areas and human health risk analysis).

**Coasts**

MENA's cities, populations and infrastructure are highly concentrated in coastal areas. Rising sea levels together with more frequent and intense coastal storms increase direct risks to coastal cities and infrastructure. Growing rates of coastal erosion may exacerbate this further. As sea levels rise, the intrusion of sea water in areas such as the Nile Delta, will increase salination of agricultural land, groundwater degradation, and potentially damage economically important assets. For those communities that depend on fisheries, overexploitation, pollution, and coastal development already threaten existing fish stocks. Rising sea temperatures will have a further detrimental impact on marine life and threaten the viability of fisheries and aquaculture.

# Main climate risks in the MENA region

## Food security

Rising temperatures over all seasons, increased evapotranspiration, and, in some locations, more variable rainfall, will contribute to greater drought risk and harvest failure.

Agricultural production is constrained by limited water, temperature and suitable arable land. By the 2050s, this will be exacerbated to increase crop water stress, drought risk and harvest failure.

Shorter growing seasons in many areas is expected. This will be especially acute in already vulnerable agricultural systems that experience high temperatures in the present day.

Greater reliance on food imports will leave food systems vulnerable to price volatility in global markets, potentially raising food prices.

Increasing reliance on food imports also creates vulnerability to climate impacts on agricultural production in global breadbaskets.

## Water security

Increasing temperatures and less or more variable rainfall leads to increased heat stress. This will raise human and animal demand for water.

Increasing demand for irrigation to maintain some agricultural production is a significant water stressor in the region.

Rising temperatures will impact springtime snowmelt which feeds many key rivers, decreasing freshwater availability.

Climate change in combination with poor water management and degradation of natural water stores, will reduce water supply.

## Cities and infrastructure

Water demand and sanitation services will increasingly come under pressure as urban areas continue to grow.

Rising temperatures will reduce water supply and expanding urban areas will further increase water demand.

Extreme heat events place significant stress on power generation and transmission, roads, and other critical infrastructure, creating knock-on health and economic consequences.

Increased demand on energy for artificial cooling is expected where temperatures are above human tolerable limits of more than 50°C.

## Health

Rising temperatures will increase heat stress, for example outdoor labour productivity is likely to be reduced in summer months, particularly where access to artificial cooling is limited.

Dust storms will remain a continued threat to human health with associated air pollution.

High summer temperatures and humidity are already a health issue in the region. Climate change will exacerbate this, threatening basic habitability of some areas, where outside conditions become life-threatening.

Demographic trends in the region such as an aging population and urban migration, combined with many workers working in unregulated employment, will mean that the poorest and most vulnerable will be disproportionally affected by increased heat stress risk.

## Coasts

As sea levels rise and coastal storms increase with climate change there will be greater risks to cities and infrastructure situated in coastal areas, such as coastal flooding, inundation and erosion.

Intrusion of sea water with rising sea levels will increase salination of agricultural land and groundwater degradation.

Rising sea temperatures will have further impacts on marine life and present risks to the viability of fisheries and aquaculture.

## Country summaries

***These summaries are intended to help direct reading towards the relevant sections within the report by country; they are not a complete assessment of the full range of risks at a country level.***

### Algeria

Algeria is located on the Mediterranean coast of North Africa and divided between two zones in this report: Zone 1 (see 3.3.1) and Zone 2 (see 3.3.2).

Zone 1 includes the temperate Mediterranean climate zone in the northern part of Algeria. Most of Algeria's population lives here, both in major cities such as Algiers and Oran, and in rural areas. Agricultural production is important, both rainfed and dryland mixed, and there are also some highland farming systems in the Aurès Mountains where snowmelt is an important water source. Zone 1 has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence the region will be at least 2-3°C warmer than the current climate throughout the year, with larger increases during the hottest summer months. We also expect the region to be drier than the current climate. There is less confidence around rainfall, but our analysis suggests that isolated downpours are projected to become more intense, with the amount of rainfall continuing to vary from year to year and over longer timescales. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Zone 2 includes the large inland area of Algeria that has a hot desert climate. Fewer people live there and most of the limited agricultural production is pastoral. Zone 2 has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence this region will be at least 2-4°C warmer than the current climate throughout the year, with larger increases during the hottest months. There is less confidence around rainfall amounts, but our analysis suggests little change.

Regional level risks affecting Algeria include water availability (see 4.1) and food security (see 4.2).

### Bahrain

Bahrain is an island in the Persian Gulf and included in Zone 5 in this report (see 3.3.5). Most people live in the north and in major cities such as Manama and Riffa, and there is little agricultural production.

Bahrain experiences a hot desert climate where rain tends to fall in isolated heavy downpours. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Bahrain will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in summer and autumn. There is less confidence around rainfall, but our analysis suggests that while the amount of annual rainfall may not change, downpours are projected to become more intense. Sea levels will rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Regional level risks affecting Bahrain include heat stress (see 4.3) and coastal impacts (see 4.4).

**Egypt**

Egypt is located on the Mediterranean and Red Sea coast in the north-east of North Africa and is included in Zone 2 (see 3.3.2). Most people live along the River Nile and Nile Delta and in major cities such as Cairo and Alexandria. Most agricultural production takes place in the Nile basin, which is irrigated by the Nile and relies entirely on transboundary water originating in Ethiopia and other sub-Saharan nations. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Egypt will be at least 2-4°C warmer than the current climate throughout the year, with larger increases during the hottest months. There is less confidence around rainfall amounts, but our analysis suggests little to no change, such that the region is projected to remain dry. Sea levels will rise; this, together with rising sea surface temperatures and more intense Mediterranean storms, will impact coastal regions in the north.

Regional level risks affecting Egypt include heat stress – particularly in cities like Cairo where humidity is high (see 4.3) – water availability caused by increasing evaporation rates (see 4.1), and coastal inundation and erosion in the Nile Delta (see 4.4).

**Iran**

Iran is in the Middle East with coastlines on the Caspian Sea to the north and the Persian Gulf and Gulf of Oman to the south. It is divided across two zones in this report: Zone 3 (see 3.3.3) and Zone 4 (see 3.3.4).

Zone 3 includes the cooler, wetter highland regions, home to most of the population and major cities, such as Mashhad, Tehran, Isfahan. Highland mixed farming systems are important here, and snow and glacial melt from areas above 4000m are important for river flows and irrigation. Zone 3 has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that highland regions will be at least 2-3°C warmer than the current climate throughout the year, with larger increases during the hottest summer months. It is uncertain how precipitation will change, though there is some indication that the region may become drier on average. The Caspian Sea level is projected to drop, and increasingly intense storms will impact coastal areas.

Zone 4 includes the hotter, drier lowlands of Iran where fewer people live, and farming is mostly pastoral. This zone has already experienced a significant amount of warming. There is high confidence that the region will be at least 2-4°C warmer than the current climate throughout the year, with larger increases during the hottest summer months. There is no clear trend around changes in precipitation: both increases and decreases are plausible. Coastal areas along the Persian Gulf and Gulf of Oman will be impacted by rising sea levels as well as more frequent, more intense storms in the Persian Gulf.

Regional level risks affecting Iran include agriculture (see 4.2) and water availability, due to increased evaporation (see 4.1).

**Iraq**

Iraq is in the Middle East and is considered across two spatial analysis zones in this report: Zone 3 (see 3.3.3) and Zone 4 (3.3.4).

Zone 3 includes the cooler, wetter highland regions in the north, home to cities such as Erbil, Kirkuk, and Mosul. Both rainfed and dryland mixed farming systems are important, as well as irrigated areas along the Tigris River. Zone 3 has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that this region will be at least 2-3°C warmer than the current climate throughout the year, with larger increases during the hottest summer months. There is uncertainty as to whether precipitation will increase or decrease, though there is some indication the region may become drier on average.

Zone 5 includes the hotter, drier lowlands of Iraq where rain tends to fall in isolated heavy downpours. The region is home to major cities such as Baghdad and Basrah, as well as much of the Tigris-Euphrates river system. Zone 5 has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that this region will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in summer and autumn. There is less confidence around rainfall, but our analysis suggests that while the amount of annual rainfall may not change, individual downpours are projected to become more intense. A decline in the discharge of the Tigris and Euphrates rivers is highly likely. Rising sea level and sea surface temperatures will impact the small coastline on the Persian Gulf.

Regional level risks affecting Iraq include water availability as demand for water increases; this is likely to lead to water shortages (see 4.1).

### Israel

Israel is in the Levant region and has a Mediterranean coastline to the west. Included in Zone 7 in this report (see 3.3.7), Israel experiences a temperate Mediterranean climate characterised by hot, dry summers and mild, humid winters. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Israel will be at least 2-4°C warmer than the current climate throughout the year. There is less confidence around rainfall amounts, but our analysis suggests little change. Sea levels will rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal areas.

Regional level risks relevant to Israel include increasing water stress (see 4.1) and extreme heat in urban areas (see 4.3).

### Jordan

Jordan is in the Levant region and has a small coastline on the Red Sea. Included in Zone 7 in this report (see 3.3.7), Jordan experiences a hot desert climate in the east and a temperate Mediterranean climate in the west, where most people live in cities such as Amman. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Jordan will be at least 2-4°C warmer than the current climate throughout the year. There is less confidence around rainfall amounts, but our analysis suggests little change. Sea levels will rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Regional level risks affecting Jordan include water supply (see 4.1) as the discharge rate of rivers decreases (including the Jordan) and groundwater is depleted, and food security (see 4.2).

### Kuwait

Kuwait is in the north-east of the Arabian Peninsula with a coastline on the Persian Gulf to the east. Included in Zone 5 in this report (see 3.3.5), it has a hot desert climate where rain tends to fall as isolated heavy downpours. Most people live along the coast and in major cities, such as Kuwait City. There is little agricultural production. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Kuwait will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in summer and autumn. There is less confidence around rainfall, but our analysis suggests that while the amount of annual rainfall may not change, individual downpours are projected to become more intense. Sea levels will rise; this, together with sea surface temperatures and more intense storms will impact coastal regions.

Regional level risks affecting Kuwait include heat stress (see 4.3) and coastal impacts (see 4.4).

**Lebanon**

Lebanon is in the Levant region and has a Mediterranean coastline to the west. Included in Zone 7 in this report (see 3.3.7), its temperate Mediterranean climate is characterised by hot, dry summers and mild, humid winters. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Lebanon will be at least 2-4°C warmer than the current climate throughout the year. There is less confidence around rainfall amounts, but our analysis suggests little change. Sea levels will rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal areas in the west.

Regional level risks relevant to Lebanon include water availability, due to increased evaporation and changes in snowmelt which will reduce river recharge (see 4.1).

**Libya**

Libya is located on the Mediterranean coast of North Africa and is included in Zone 2 in this report (see 3.3.2). Most people live in major coastal cities such as Tripoli and Benghazi, and there are relatively small but socially important dryland and pastoral farming systems. Much of the region experiences very hot, dry desert conditions. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Libya will be at least 2-4°C warmer than the current climate, with larger increases during the hottest months. There is less confidence around rainfall amounts, but our analysis suggests little to no change, so the region is projected to remain dry. Sea levels will rise; this, together with more intense Mediterranean storms, will impact coastal regions.

Regional level risks affecting Libya include water availability (see 4.1) due to rising temperatures and increased evaporation. Increased demand for water and heat stress in coastal cities are also key risks (see 4.3).

**Morocco**

Morocco is in the north-west region of North Africa with coastlines on the Mediterranean Sea and the Atlantic Ocean. It is considered across two zones in this report: Zone 1 (see 3.3.1) and Zone 2 (see 3.3.2).

Zone 1 includes the temperate Mediterranean climate in the northern part of Morocco, where most people live in major cities such as Marrakesh and Casablanca, as well as in rural areas. Agricultural production is important and features rainfed and dryland mixed farming systems, together with highland farming systems in the High Atlas Mountains where snowmelt is an important water source. Zone 1 has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that this region will be at least 2-3°C warmer than the current climate throughout the year, with larger increases during the hottest summer months. There is less confidence around rainfall, but our analysis suggests that while the region is projected to become drier, downpours are projected to become increasingly intense, with the amount of rainfall continuing to vary year to year.

Zone 2 includes the hotter desert climate in the south of Morocco where fewer people live, and the limited agricultural production is pastoral. This zone has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that the region will be at least 2-4°C warmer than the current climate, with larger increases during the hottest months. There is less confidence around rainfall amounts, but our analysis suggests little change. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Regional level risks affecting Morocco include impacts on food security (see 4.2), water availability and environmental degradation (see 4.1).

**Occupied Palestinian Territories (OPTs)**

The OPTs are in the Levant region, with coastline on the Mediterranean Sea in the Gaza Strip. Included in Zone 7 in this report (see 3.3.7), their temperate Mediterranean climate is characterised by hot, dry summers and mild, humid winters. The region has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that the OPTs will be at least 2-4°C warmer than the current climate throughout the year. There is less confidence around rainfall amounts, but our analysis suggests little change. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal areas in the west.

Regional level risks affecting the OPTs include water availability (see 4.1). This is due to the stream flow decreasing in the River Jordan combined with increases in temperature and evaporation.

### Oman

Oman is in the south-east of the Arabian Peninsula with coastlines on the Gulf of Oman to the north-east and the Arabian Sea to the south-east. Included in Zone 5 in this report (see 3.3.5), it has a hot desert climate where rain tends to fall as isolated heavy downpours. Most people live in the north-east and in major coastal cities, such as Muscat. There is little agricultural production in this region. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Oman will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in summer and autumn. There is less confidence around rainfall, but our analysis suggests that while the amount of annual rainfall may not change, the intensity of individual downpours is projected to increase. Oman's coast on the Arabian sea has local climate zones which may see small scale variations in temperature and rainfall. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact all coastal regions.

Regional level risks affecting Oman include heat stress (see 4.3) and the impact of increasing water temperatures in the Gulf of Oman on nearby ecosystems and fisheries (see 4.4).

### Qatar

Qatar is located on the eastern coast of the Arabian Peninsula and is mostly surrounded by the Persian Gulf. Included in Zone 5 in this report (see 3.3.5), it has a hot desert climate where rain tends to fall as isolated heavy downpours. Most people live in the east and in major cities, such as Doha on the east coast. There is little agricultural production in this region. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Qatar will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in summer and autumn. There is less confidence around rainfall, but our analysis suggests that while the amount of annual rainfall may not change, the intensity of downpours is projected to increase. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Regional level risks affecting Qatar include heat stress (see 4.3) and coastal impacts (see 4.4).

### Tunisia

Tunisia is located on the Mediterranean coast of North Africa and is considered across two zones in this report: Zone 1 (see 3.3.1) and Zone 2 (see 3.3.2).

Zone 1 includes the temperate Mediterranean climate in the north, where most people live in major cities such as Tunis and Sfax, as well as in rural areas. Agricultural production features both rainfed and dryland systems and is important in this region. Zone 1 has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that this region will be at least 2-3°C warmer than the current climate throughout the year, with larger increases during the hottest summer months. There is less confidence around rainfall, but our analysis suggests that while the region is projected to become drier, downpours are projected to become increasingly intense, with the amount of rainfall continuing to vary from year to year and over longer timescales. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions in the north.

Zone 2 includes the southern inland area of Tunisia that experiences a hot desert climate. Fewer people live there, and the limited agricultural production is pastoral. This zone has already experienced a significant amount of warming. In the 2050s there is high confidence that the region will be at least 2-4°C warmer than the current climate, with larger increases during the hottest months. There is less confidence around rainfall amounts, but our analysis suggests little change.

Regional level risks affecting Tunisia include heat stress, particularly in coastal cities (see 4.3), other coastal impacts associated with sea level rise and increasing ocean temperatures (see 4.4), water availability (see 4.1) and food security (see 4.2).

### Turkey

Turkey is in the north of the Middle East region with coastlines on the Black Sea to the north and Mediterranean Sea to the south. Included in Zone 6 in this report (see 3.3.6), its temperate Mediterranean climate has warm to hot summers and cool, wet winters. Farming systems include a mix of rainfed and dryland as well as highland farming in the eastern mountains. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Turkey will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in the hottest months. Overall, the region may become drier than the current climate. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact both the Black Sea and Mediterranean coasts. Discharge from the Tigris and Euphrates rivers, which are fed by spring-time snowmelt in the Turkish mountains, is projected to drop by as much as 12%.

Regional level risks affecting Turkey include the reductions in river flow impacting water availability (see 4.1) and agriculture and food security (see 4.2).

**Saudi Arabia**

Saudi Arabia is in the Arabian Peninsula, with coastlines on the Persian Gulf to the east and on the Red Sea to the west. Included in Zone 5 in this report (see 3.3.5), it has a hot desert climate where rain tends to fall in isolated heavy downpours. Most people live on the south and west coasts in major cities, such as Riyadh and Jeddah, and there is little agricultural production. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Saudi Arabia will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in summer and autumn. There is less confidence around rainfall, but our analysis suggests that while the amount of annual rainfall may not change, the intensity of downpours is projected to increase. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Regional level risks affecting Saudi Arabia include heat stress (see 4.3) and coastal impacts (see 4.4).

**Syria**

Syria is in the Levant region with a Mediterranean coastline to the west. Included in Zone 7 (see 3.3.7), it experiences a mix of hot desert climate in the east and a temperate Mediterranean climate in the west. Populations are denser in the west in major cities such as Aleppo and Homs, and conflict continues to cause population instability and migration (see 2). There is a mix of rainfed and dryland farming systems, as well as irrigated agriculture along the Euphrates River. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Syria will be at least 2-4°C warmer than the current climate throughout the year. There is less confidence around rainfall amounts, but our analysis suggests little change. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal areas in the west.

Regional level risks affecting Syria include water security (see 4.1) due to reduced discharge in the Euphrates compounded by upstream damming and withdrawals in Turkey.

**United Arab Emirates (UAE)**

The UAE is in the east of the Arabian Peninsula with coastlines on the Persian Gulf to the north. Most people live in the north-east and in major coastal cities such as Dubai and Abu Dhabi. Included in Zone 5 in this report (see 3.3.5), UAE experiences a hot desert climate where rain tends to fall as isolated heavy downpours. There is little agricultural production. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that UAE will be at least 2-4°C warmer than the current climate throughout the year, with larger increases in summer and autumn. There is less confidence around rainfall, but our analysis suggests that while the amount of rainfall may not change, downpours are projected to become more intense. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Regional level risks affecting UAE include heat stress (see 4.3) and coastal impacts (see 4.4).

**Western Sahara**

Western Sahara is located on the western coast of North Africa and is included in Zone 2 in this report (see 3.3.2). With its hot, desert climate, few people live here and there is little agricultural production. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Western Sahara will be at least 2-4°C warmer than the current climate throughout the year, with larger increases during the hottest months. There is less confidence around rainfall amounts, but our analysis suggests little to no change, such that the region is projected to remain dry. Sea levels will continue to rise; this, together with more frequent and more intense Atlantic storms, will impact coastal regions.

Regional level risks affecting Western Sahara include heat stress (see 4.3) and water availability (see 4.1).

**Yemen**

Yemen is located at the south-western end of the Arabian Peninsula with coastlines on the Red Sea to the west and the Gulf of Aden to the south. Included in Zone 5 in this report (see 3.3.5), much of the country has a hot, desert climate. The higher ground in the south-west experiences highly variable microclimates due to orographic and coastal effects, and this makes projections for this region uncertain. The country has already experienced a significant amount of warming since pre-industrial times up to the present-day. In the 2050s, there is high confidence that Yemen will be at least

2-4°C warmer than the current climate throughout the year, with larger increases in the summer. However, the magnitude of changes will vary by location, so pockets of cooler, wetter conditions may persist in some areas. Sea levels will continue to rise; this, together with rising sea surface temperatures and more intense storms, will impact coastal regions.

Regional level risks affecting Yemen include water stress (see 4.1), food security (see 4.2) and the impact of increasing water temperatures in the Gulf of Oman on nearby ecosystems and fisheries (see 4.4). Yemen is a fragile state and food security, water conflict and drought all lead to complex compound risk.

# Glossary

### Acronyms

| | |
|---|---|
| AMO | Atlantic Multidecadal Oscillation |
| AR5 | IPCC 5th Assessment Report |
| CORDEX | CoOrdinated Regional climate modelling Downscaling EXperiment |
| ENSO | El Niño Southern Oscillation |
| ETC | Extratropical Cyclones |
| FCDO | Foreign, Commonwealth & Development Office (UK Government) |
| GBV | Gender Based Violence |
| GCM | Global Climate Model |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gases |
| GMST | Global Mean Surface Temperature |
| IPCC | Intergovernmental Panel on Climate Change |
| LUC | Land Use Changes |
| MENA | Middle East North Africa |
| MHW | Marine Heat Waves |
| NAO | North Atlantic Oscillation |
| ODI | Overseas Development Institute |
| OPTs | Occupied Palestinian Territories |
| PET | Potential Evapotranspiration |
| RCM | Regional Climate Model |
| RCP | Representative Concentration Pathway |
| SES | Semi-Enclosed Seas |
| SLR | Sea Level Rise |
| SRES | Special Report on Emissions Scenarios |
| SST | Sea Surface Temperature |
| TAR | Third Assessment Report |
| TEW | Tigris-Euphrates Watershed |
| UAE | United Arab Emirates |
| UNFCCC | United Nations Framework Convention on Climate Change |

## Technical terms

These definitions have been taken from the IPCC reports from 2001, 2013, 2014, 2018 and 2019; the Met Office website (www.metoffice.gov.uk/weather/learn-about; https://www.metoffice.gov.uk/hadobs/monitoring/climate_modes.html); Wikipedia, the World Atlas (https://www.worldatlas.com) and the Cambridge dictionary (https://dictionary.cambridge.org/).

| Term | Definition |
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| Adaptation | In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects. |
| Aerosols | A suspension of airborne solid or liquid particles, with a typical size between a few nanometres and 10 μm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: through both interactions that scatter and/or absorb radiation and through interactions with cloud microphysics and other cloud properties, or upon deposition on snow- or ice-covered surfaces thereby altering their albedo and contributing to climate feedback. |
| Anomaly | The deviation of a variable from its value averaged over a reference period. |
| Anthropogenic | Resulting from or produced by human activities. |
| Atlantic Multidecadal Oscillation/Variation (AMO/AMV) | The Atlantic Multidecadal Oscillation/Variation (AMO/AMV) has two phases, a positive phase where sea-surface waters in the North Atlantic are warmer than average and a negative phase when they are colder than average. There are a number of ways of calculating an AMO "index" which depend on the way that the longer-term trend seen in the observed record is dealt with. It is not entirely clear what causes changes in the AMO. Long records of the AMO from non-instrumental sources suggest that it is a long-lived natural fluctuation generated spontaneously within the ocean-atmosphere system. However, there is also evidence that switches in phase can be driven by changes in the output of manmade pollution. The different phases of the AMO have been associated with a variety of impacts. The positive phase has been associated with reduced Arctic sea ice, melting of the Greenland ice sheet, increased hurricane activity in the North Atlantic and increased rainfall over the Sahel region of sub-Saharan Africa. The cold negative phase has the opposite impacts: cooling at high latitudes, reduced hurricane activity and a drier Sahel. |
| Atmosphere | The gaseous envelope surrounding the earth, divided into five layers – the *troposphere* which contains half of the Earth's atmosphere, the *stratosphere*, the mesosphere, the thermosphere, and the exosphere, which is the outer limit of the atmosphere. |

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| Baseflow | The portion of the streamflow that is sustained between precipitation events, fed to streams by delayed pathways. Also called drought flow, groundwater recession flow, low flow, low-water flow, low-water discharge and sustained or fair-weather runoff. |
| Baseline | The state against which change is measured. It might be a 'current baseline,' in which case it represents observable, present-day conditions. It might also be a 'future baseline,' which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines. |
| Baseline Water Stress | The ratio of total water withdrawals to available renewable water supplies. Water withdrawals include domestic, industrial, irrigation and livestock consumptive and non-consumptive uses. Available renewable water supplies include surface and groundwater supplies and considers the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users. |
| Carbon Dioxide (CO2) | A naturally occurring gas, CO2 is also a by-product of burning fossil fuels (such as oil, gas and coal), of burning biomass, of land-use changes (LUC) and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance. |
| Climate | In a narrow sense, climate is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. |
| Climate Change | A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. |
| Climate Feedback | An interaction in which a perturbation in one climate quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced. |
| Climate Impacts | Impacts describe the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. |
| Climate Mitigation | A human intervention to reduce the sources or enhance the sinks of greenhouse gases. |

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| Climate Model | A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties. |
| Climate Projection | The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHG) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. |
| Climate Risk | The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence. |
| Climate System | The highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere and the interactions between them. |
| Climate Variability | Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. |
| Crop Water Deficit | A water deficit occurs whenever water loss exceeds absorption. The use of total water potential as the best single indicator of plant water status has its limitations while attempting to understand the effect of water deficits on the various physiological processes involved in plant growth. Water deficits reduce photosynthesis by closing stomata, decreasing the efficiency of the carbon fixation process, suppressing leaf formation and expansion, and inducing shedding of leaves. |
| Downscaling | A method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses. |
| El Niño Southern Oscillation (ENSO) | The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to |

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| | about seven years, is known as the El Niño-Southern Oscillation (ENSO). The cold phase of ENSO is called La Niña. |
| Emissions Scenario | A plausible representation of the future development of emissions of substances that are radiatively active (e.g., greenhouse gases (GHGs), aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy and land use) and their key relationships. |
| Enhanced Greenhouse Effect | The process in which human activities have added additional greenhouse gases into the atmosphere, this has resulted in a 'stronger' greenhouse gas effect as there are more gases available to trap outgoing radiation. |
| Evapotranspiration | The process in which water moves from the earth to the air from evaporation (= water changing to a gas) and from transpiration (= water lost from plants). |
| Exposure | Exposure describes the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected. |
| Fifth Assessment Report (AR5) | The latest series of IPCC reports published in 2013-2014, reports are divided into publications by three working groups. |
| Fossil Fuels | Carbon-based fuels from fossil hydrocarbon deposits, including coal, oil, and natural gas. |
| Global Breadbasket | The term "breadbasket" is used to refer to an area with highly arable land. The breadbaskets of the world are the regions in the world that produce food, particularly grains to feed their people as well as for export to other places. |
| Global Warming | The estimated increase in global mean surface temperature (GMST) averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue. |
| Greenhouse Effect | Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. |
| Greenhouse Gas (GHG) Concentrations | Lead to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect. |

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| Greenhouse Gases (GHGs) | The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour ($H_2O$), carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$) and ozone ($O_3$) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside $CO_2$, $N_2O$ and $CH_4$, the Kyoto Protocol deals with the GHGs sulphur hexafluoride ($SF_6$), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). [IPCC, 2018] |
| Hazard | The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. |
| Ice sheet | An ice body originating on land that covers an area of continental size, generally defined as covering >50,000km$^2$, and that has formed over thousands of years through accumulation and compaction of snow. [IPCC, 2019] |
| Impacts | Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. |
| Intergovernmental Panel on Climate Change (IPCC) | The leading international body for the assessment of climate change. Scientists come together approximately every six years, to assess peer-reviewed research in working groups to generate three reports including the Physical Science Basis, impact adaptation and vulnerability, and Mitigation of Climate Change. |
| Mitigation | A human intervention to reduce the sources or enhance the sinks of greenhouse gases. |
| North Atlantic Oscillation (NAO) | The North Atlantic Oscillation (NAO) is a large-scale atmospheric process that governs local weather patterns as it influences the intensity and location of the North Atlantic jet stream. It is defined as the pressure difference between the Azores islands and Iceland: a positive (negative) NAO is associated with higher (lower) than average pressure difference. |
| Paris Agreement | The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted on December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on 4 November 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is 'Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', recognising that |

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| | this would significantly reduce the risks and impacts of climate change. Additionally, the Agreement aims to strengthen the ability of countries to deal with the impacts of climate change. |
| Projection/projected | A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised. |
| Radiative Forcing | The change in the net, downward minus upward, radiative flux (expressed in W m-2) at the tropopause or top of atmosphere due to a change in a driver of climate change, such as a change in the concentration of carbon dioxide ($CO_2$) or the output of the sun. |
| Reanalysis | Atmospheric and oceanic analyses of temperature, wind, current and other meteorological and oceanographic quantities, created by processing past meteorological and oceanographic data using fixed state-of-the-art weather forecasting models and data assimilation techniques. |
| Representative Concentration Pathways (RCPs) | Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover. |
| Resilience | The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation. |
| Risk | The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard. |
| Runoff | The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and/or snow/ice melt that does not evaporate or refreeze and is not transpired. |
| Scenario | A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions. |
| Signal | Climate signals are long-term trends and projections that carry the fingerprint of climate change. |

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| Special Report on Emissions Scenarios (SRES) | A report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000. The SRES scenarios, as they are often called, were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007. |
| Storm surge | The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. [IPCC, 2019] |
| Uncertainty | A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. In climate change analysis, it may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of human behaviour. |
| United Nations Framework Convention on Climate Change (UNFCCC) | The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in May 1992 and opened for signature at the 1992 Earth Summit in Rio de Janeiro. It entered into force in March 1994 and as of May 2018 had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' The provisions of the Convention are pursued and implemented by two treaties: the *Kyoto Protocol* and the *Paris Agreement*. [IPCC, 2018] |
| Vulnerability | The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm, and lack of capacity to cope and adapt. |
| Weather | The conditions in the air above the earth such as wind, rain, or temperature, especially at a particular time over a particular area. |

# 1 Introduction

## 1.1 Purpose of this report

This report provides an evidence base on the Middle East and North African (MENA) region's current climate and its variability and looks at how this is expected to change by the 2050s. It also identifies how these changes could impact socio-economic development within individual countries. The aim is to inform and support development programming and policy dialogue in each country.

This is the first in a series of climate risk reports for the UK Government's Foreign, Commonwealth & Development Office (FCDO). In this series we are standardising how we process and interpret climate information to support FCDO offices and climate assured development planning in different regions. This provides consistency both within the specified region and across regions. It also ensures we are consistent with other climate information such as briefing notes and monthly outlooks that the Met Office, the UK's meteorological service, provides to FCDO country offices.

This report takes a methodological approach for translating and communicating climate information, applying it to socio-economic contexts that development planners need to consider.[1] It combines the Met Office's climate science expertise with socio-economic analysis of the MENA region provided by Overseas Development Institute (ODI). FCDO regional representatives have also provided input to ensure it is both usable and relevant. Collaborating in this way has allowed us to tailor and frame future climate projections so that they are easier to include in development planning. See Appendix A for more information about the key stages in this methodology.

The region considered in this report includes the following countries (as shown in Figure 1, top panel):

- *Middle East:* Lebanon, Jordan, Occupied Palestinian Territories, Syria, Iraq, Iran, Israel, Turkey, Gulf states (Saudi Arabia, Kuwait, Qatar, Bahrain, United Arab Emirates, Oman), Yemen
- *North Africa:* Egypt, Tunisia, Libya, Algeria, Morocco, Western Sahara

Key aspects of the region also included in the analysis, such as the geography of the region and population densities, are also shown in Figure 1 (middle and bottom panels).

[1] A report documenting the Met Office Climate in Context methodology is in preparation and due to be published in 2021.

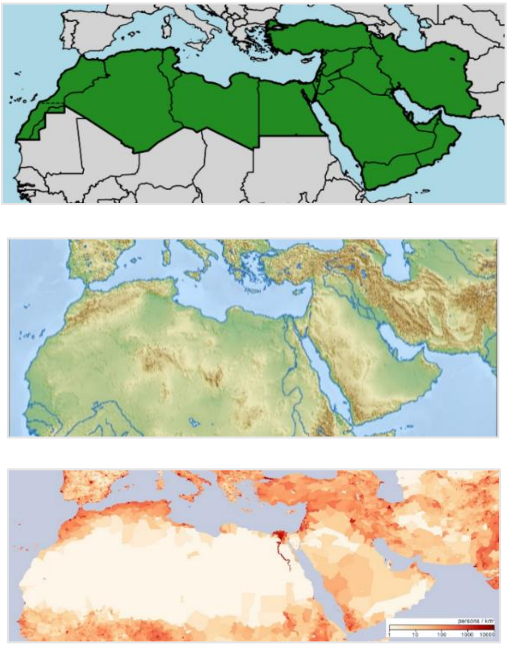

*Figure 1: The Middle East and North Africa (MENA) region considered in this report. Top panel: countries included in the analysis, middle panel: geography of the region, bottom panel: population density. Source: © Robert Simmon, NASA's Earth Observatory, based on data provided by the Socioeconomic Data and Applications Center (SEDAC), Columbia University, Public Domain)*

### 1.1.1 Methods and data

#### *1.1.1.1 Socio-economics methods and data*

The socio-economic contributions to this report draw on a review of the relevant literature and key interviews with climate and agronomy experts within the MENA region. We used this to identify appropriate livelihood groupings and key socio-economic variables, as well as suitable climate indicators to support the climate data analysis.

#### *1.1.1.2 Climate methods and data*

This report draws on bespoke climate data analysis in the selected zones (see Section 3.2 and relevant scientific literature).

This involved processing gridded reanalysis[2] data to characterise the current climate over the 1981-2010 baseline period, and climate model projections to assess the projected trends in average temperature and precipitation for the 2050s (using the 2041-2070 future time period compared to the baseline period). The analysis focuses on quantifying projected changes in annual, seasonal and monthly means in the spatial analysis zones. We drew information on the projected changes in other climate variables and indicators – such as Sea Surface Temperatures (SSTs), Sea Level Rise (SLR) and relevant climate extremes – from relevant scientific literature, noting where baseline and future time periods differ from the bespoke analysis.

[2] A gridded dataset that blends climate observations and model data to present the current climate for use as a baseline in future climate assessments.

To characterise the baseline climate, we processed temperature and precipitation data from ERA5[3] (Hersbach et al., 2020) over the 1981-2010 baseline period. Using this dataset and time period keeps this report consistent with FCDO climatology briefing notes provided to FCDO offices for many of the countries in the MENA region.

We used global and regional climate model simulations to assess the projected change in temperature and precipitation for the 2050s under the RCP8.5[4] scenario (van Vurren et al., 2011). This future time period and scenario combination represents an increase in global average temperature of around 2.5˚C compared to pre-industrial levels. This is higher than the target of limiting warming to well below 2˚C set by the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement. The baseline period considered in this report represents an observed increase of around 1°C in global average temperature.

We used the following model simulations in this analysis:

- 30 Global Climate Model (GCM) simulations from the World Climate Research Project (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012), used to inform the most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5; IPCC, 2013). The resolution of these models varies by model, ranging from 100-200km.
- 7 Regional Climate Model (RCM) simulations from the WCRP CoOrdinated Regional climate modelling Downscaling EXperiment (CORDEX; Giorgi & Gutowski, 2015). Of these RCM simulations, five were at a resolution of 50km, and two were at a resolution of 25km.

See Appendix B for more details on the specific model simulations included.

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[3] All observational and reanalysis datasets have associated uncertainties and limitations. For example, reanalysis datasets may underestimate observed extremes, and cannot fully represent localised features such as intense precipitation caused by complex topography, partly due to their limited resolution in space and time. Additionally, ERA5 precipitation fields are derived from 'forecast' output and are therefore more affected by imperfections within the underlying model. The benefit, however, of using reanalyses is that they provide a systematic approach to producing gridded, dynamically consistent datasets for climate monitoring, particularly over data-scarce regions. Some small biases have been identified in the ERA5 data for the MENA region (Gleixner et al., 2020). However, the use of these data to characterise climatological means for the purpose of this analysis is largely uninfluenced by these biases, and the benefits of using a dataset that is globally consistent and consistent with other climate information products outweighs this.

[4] The RCP8.5 Representative Concentration Pathway represents a future pathway of on-going and substantial increases in future global emissions of greenhouse gases. Other pathways represent stabilisation or reduction of future emissions, however there is little difference in the projected climate change between these pathways in the 2050s time period. Analysis of the RCP4.5 scenario was also conducted and results were broadly consistent with those presented here for RCP8.5.

## 1.2 How to use this report

This report presents climate information in the context of the socio-economic challenges of the MENA region, framed in terms of the key climate risks. The aim is to help development planners focus in on areas that may need attention and to identify the questions they need to ask when considering climate risks in their development plans. This report does not include every climate risk, rather, it brings MENA's most prominent regional climate risks to the fore. Bear in mind that climate risks are not isolated threats: how they interact with and compound other sources of risk can be hard to disentangle. The climate analysis and subsequent discussion outline the needs of a development pathway between the present day and the 2050s, so they have been designed to highlight the key risks to consider in future development plans. The country summaries provided in the executive summary outline prominent climate risks for each country within the regional context. However, these summaries do not provide a national level analysis; additional climate risks may apply at a national scale and these should also be considered in a national or subnational development plan. This report offers a starting point for better understanding some of the key regional risks relevant to development programming within FCDO. For individual programmes where relevant risks are identified, or where national or sub-national scale risk information is required, additional climate and socio-economic analysis is recommended.

Section 2 sets the scene with an overview of the current vulnerability and climate resilience in the MENA region. The current climate already includes large areas where some aspects of human and ecological systems are already at their limits, or are not well adapted to the harsh environment they are in. This section justifies the need for an intersectional approach when it comes to interpreting compound risks associated with, or exacerbated by, climate change.

Section 3 focuses on the current and future climate projections for the MENA region and takes a geographical approach. It includes a summary of the region's climate and explains how the region is divided into seven bespoke spatial analysis zones. The remainder of this section is organised by spatial analysis zone. In each zone the baseline climate is presented in context with the socio-economic situation of the zone, followed by the future projections and how they apply to zone-specific future climate risks. There is also a look-up table that relates countries to the specific zones (see Table 1).

Section 4 presents the interpretation of the climate projections in terms of climate risk factors. It is structured by four key development themes: food security, water resources, urban and human health, and coastal regions. Each development theme features an overview of the relevant socio-economic trends and a summary of the relevant climate projections from Section 3. This is followed by a discussion on the implications and potential compound risks involved for each of the prominent climate risks we've identified.

# 2 Vulnerability and climate resilience in the MENA region: an intersectional approach

Significant political, social and economic upheaval over the last decade has had devastating short and long-term implications for the MENA region. Conflicts in Iraq, Libya, Syria and Yemen have killed thousands and displaced millions (Eaton et al., 2019). While the region holds 5% of the world population, it hosts 37% of the world's uprooted persons, including refugees, migrants, and internally displaced persons (Abououn and El Taraboulsi-McCarthy, 2021). About 250 million people out of 400 million across ten Arab countries are classified as poor or vulnerable[5], with millions living with poor basic sustenance and limited political voice (Khouri, 2019): realities that have made the region suffer from deep inequalities. Against this background, the COVID-19 pandemic is expected to push as many as 45 million more people in the MENA region into poverty over the next two years (Abououn & El Taraboulsi-McCarthy, 2021).

Weak governance and political and economic instability have also impacted the region's ability to respond to climate variability and change through adaptation (Delaimy, 2020; Sowers, 2017). Existing literature on climate variability, climate-society relations, and climate resilience and adaptation in the MENA region reveals multi-layered vulnerabilities resulting from the compound effects of climate change. It also reveals socioeconomic issues such as: political instability, weak governance, deepening inequalities and a lack of inclusivity, and limited investments in economic and infrastructure resilience and human capital. For example, although the region is water scarce, it is mismanagement, poor governance and political failures that have led to unsustainable water consumption, pollution and widening water deficits (Waha et al., 2017). Similarly, conflict in the region is displacing people from their land, undermining agricultural production, ecological management and local economies. This in turn undermines people's ability to deal with shocks, making them more vulnerable to the impacts of climate change (World Bank, 2018).

Historical development choices undertaken by governments in both the colonial and post-colonial period have also undermined the region's adaptive capacity. Water and land management in the region has been shaped by historical decision making. In the modern period, large investment in water infrastructure, such as dams, inter-water basin transfer schemes, reservoirs and irrigation systems, have boosted economic growth, yet have stimulated unsustainable demand for a limited resource (Allan, 2012). This system of water management has 'locked-in' climate vulnerability and constrained options for adapting to changing climate risks (Di Baldassare et al., 2018; Weinthal and Sowers, 2020). Similarly, policies encouraging intensive agriculture have led to

[5] The definition of poverty and vulnerability is taken from Khouri 2019, which refers to the 2019 Global Multidimensional Poverty Index (MPI).

further issues, such as the widespread clearance of land for mechanised farming, the removal of trees, and the abandonment of traditional and sustainable land management practices, all of which have contributed to land degradation and desertification processes (World Bank, 2018).

These arguments highlight that in the MENA region, climate and development are not separate entities, but are inextricably linked. Climate change is not the only driver of change in the region; its effects and adaptation options are best understood in terms of past, present and future development trends.

***Focus box 1: Exposure, vulnerability and development***

A climate or disaster hazard does not in itself create risk. Risk is a function of both an individual's or community's exposure and vulnerability to a hazard (Figure 2, IPCC, 2014). Exposure and vulnerability are separate, yet both emerge from socio-economic contexts and are exacerbated by uneven development dynamics such as: rapid urbanisation and demographic change, environmental degradation, weak governance, and lack of economic opportunity (Figure 2, IPCC, 2014; UNDRR, 2015). Climate vulnerability and poverty are often mutually reinforcing; a growing body of evidence highlights the role of climate risk in persistent poverty and poverty traps (Hansen et al, 2019; Sachs et al., 2004). This is a challenge exacerbated by the political marginalisation of many poor and climate vulnerable people (Wisner et al., 2003).

Climate change is interwoven with development challenges and across the Sustainable Development Goals. As factors such as economic inequality, education, gender, nutrition, and health, shape the risk profile of individuals and communities, supporting sustainable development indirectly supports their capacity for managing climate risk (Wisner et al., 2003; Schipper and Pelling, 2006).

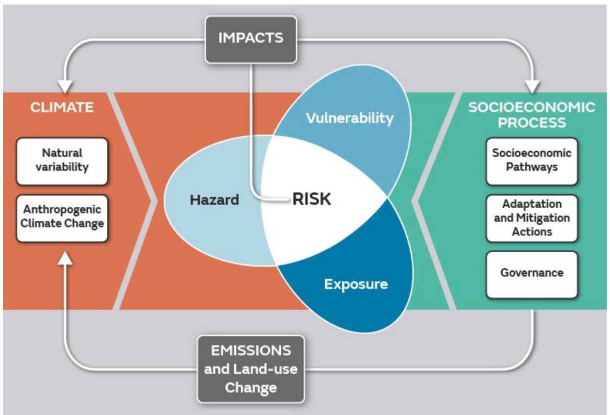


*Figure 2: Climate risk is the product of the hazard, vulnerability to the hazard and exposure to the hazard. Image adapted from IPCC (2014).*

## 2.1 Key risk factors

The interpretation of climate projections in this report is informed and framed by six factors that explore the interlinkages between climate risk and development trends:

- Good governance (accountability, transparency, legitimacy, rule of law)
- Capacity and human capital (skills, employment, access to technology, education)
- Security context (local grievances, Gender Based Violence (GBV), intrastate violence, non-state armed groups)
- Political stability (absence of violence, legitimacy, accountability)
- Economic growth and infrastructure (healthcare services, institutions, climate management policies)
- Inclusivity (generational, ethnic, class, disabled groups)

***Focus box 2: Risk-informed development***

There is increasing recognition that development is exposed to multiple, intersecting threats (Opitz-Stapleton et al., 2019). However, identifying risks to development programming is often the result of single threat analysis, meaning that it fails to be risk-informed (Opitz-Stapleton et al., 2019). In order to be risk-informed, programme decision making must undertake multi-threat analysis that considers how different threats merge with existing and changing socioeconomic contexts to create complex risk (Opitz-Stapleton et al., 2019). In practice, this means that climate-resilient development must not only consider threats to programme outcomes from climate and environmental degradation, but also economic and financial instability, cyber and technology, transboundary crime and terrorism, geopolitical volatility, conflict and global health pandemics (Opitz-Stapleton et al., 2019).

Risk-informed development requires us not only to think about risks to development but also risks from development (Opitz-Stapleton et al., 2019). Development outcomes are uneven, creating opportunities for some and risks for others. Risk-informed development must account for trade-offs inherent in development choices, including climate adaptation and mitigation (Opitz-Stapleton et al., 2019). Such decisions are inherently political, involving the redistribution of resources and navigating unequal power structures (Eriksen et al., 2015).

# 3 Climate in context: current and future climate in the MENA region

## 3.1 Climate overview for the MENA region

The MENA region is climatologically diverse, strongly influenced by the Sahara Desert and the surrounding bodies of water (Atlantic Ocean, Mediterranean, Black Sea, Red Sea, Caspian Sea and Arabian Sea). While most of the area has an arid or semi-arid climate with high annual mean temperatures and scarce precipitation, coastal and high-altitude areas experience slightly cooler temperatures year-round. Annual average precipitation amounts, and annual average minimum, mean and maximum temperatures are shown in Figure 3. These maps represent the average annual values over the 30-year baseline climate period (1981-2010).

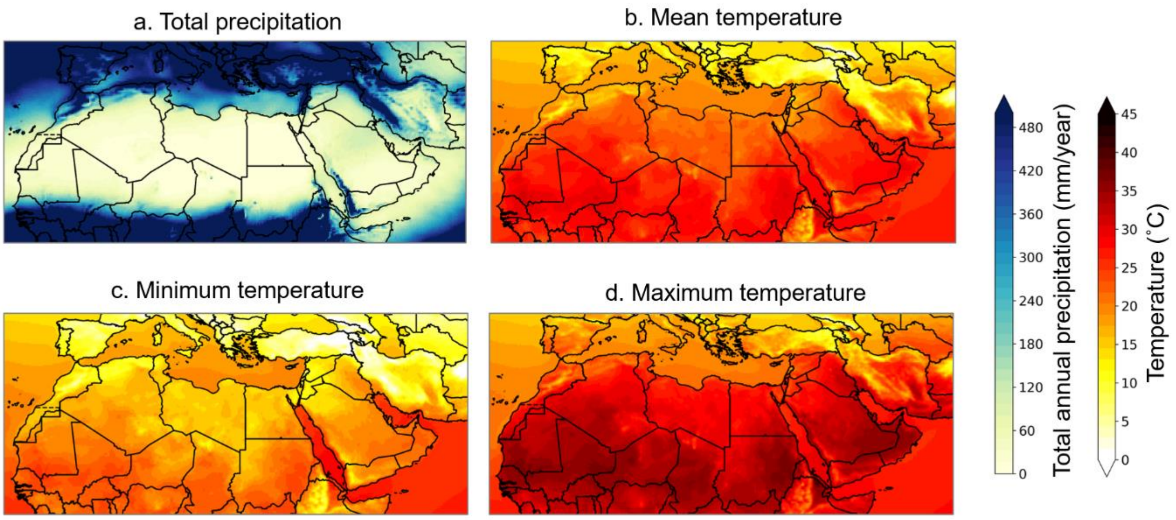


*Figure 3: Baseline climate for the MENA region from the ERA5 reanalysis[3] data for the period 1981-2010. Maps show climatological average values of annual mean a) total precipitation (mm/year), b) mean temperature (°C), c) minimum temperature (°C) and d) maximum temperature (°C).*

Northern and western coastal areas have a more temperate Mediterranean climate, with precipitation falling predominantly in the winter months, while the southerly regions are hotter and more arid. The Gulf states (defined in Table 1below) are typically hot and humid, while Turkey and northern Iran are the most temperate areas in the region, with precipitation occasionally falling as snow in northern Iran and north-eastern Turkey. Maps showing the seasonal variation in precipitation and daily mean temperature across the four seasons (December-February, March- May, June-August and September- November) are in Figure 4 and Figure 5 below.

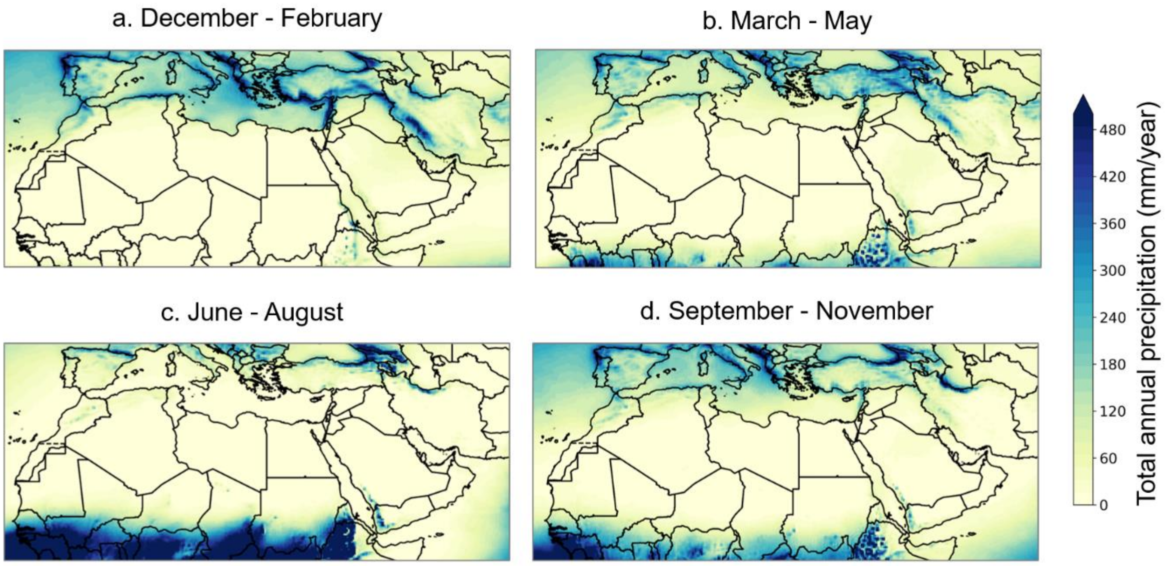


*Figure 4: Seasonal total precipitation for the MENA region over the baseline period (1981-2010) from ERA5 reanalysis3.*

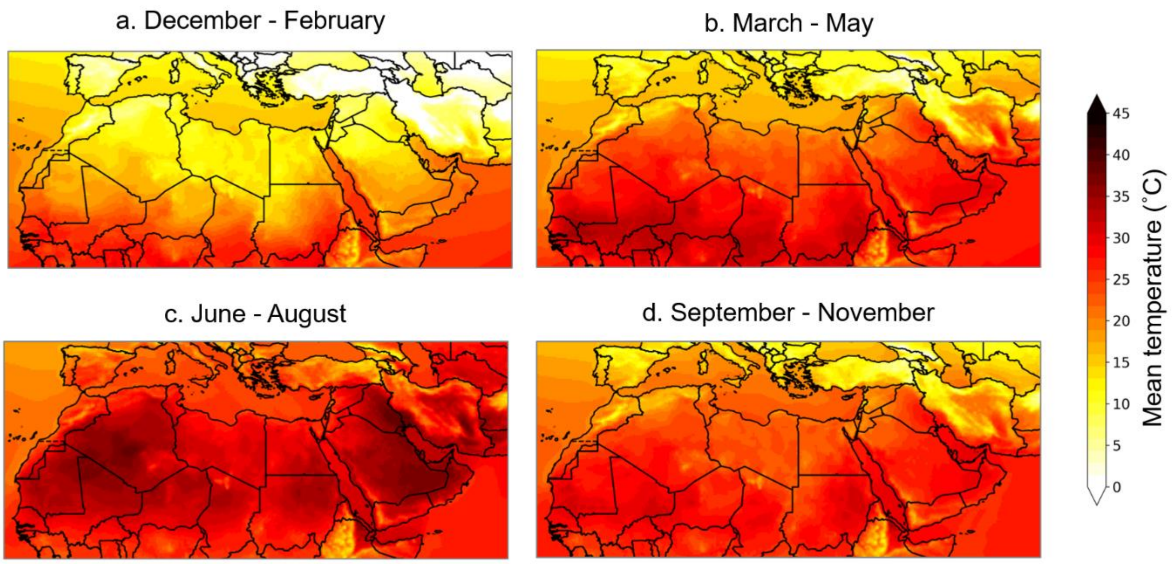


*Figure 5: Seasonally averaged mean temperature for the MENA region over the baseline period (1981-2010) from the ERA5 reanalysis[6].*

A number of winds affect the region, which are often associated with low pressure and can cause dust and sandstorms in this dry, arid region:

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[6] All observational and reanalysis datasets have associated uncertainties and limitations. For example, reanalysis datasets may underestimate observed extremes, and cannot fully represent localised features such as intense precipitation caused by complex topography, partly due to their limited resolution in space and time. Additionally, ERA5 precipitation fields are derived from 'forecast' output and are therefore more affected by imperfections within the underlying model. The benefit, however, of using reanalyses is that they provide a systematic approach to producing gridded, dynamically consistent datasets for climate monitoring, particularly over data-scarce regions.

I. The Kahmaseen or Khamsin period (March to May) sees extra tropical cyclones moving east in the southern Mediterranean Sea causing dry, dusty winds to blow into north-east Africa, affecting Egypt and countries in the Levant. The Khamsin winds (also called Chili or Ghibli, amongst other names) pick up moisture as they blow across the Mediterranean where they are known as Sirocco winds.
II. The Shamal is a north-westerly wind which can occur in both summer and winter, although most common in summer. It blows over Iraq and the Gulf states, often causing large sandstorms in Iraq.
III. Nashi is a cold, dry north-eastern wind that occurs in winter over UAE, Oman and Iran, often causing dust storms.

### 3.1.1 Drivers of climate variability

The maps in Figure 3 and Figure 4 show the average values over a 30-year time period, known as a climatological mean. The actual annual and seasonal rainfall and temperature values vary from year to year, resulting in hotter, drier, cooler and wetter periods in relation to the climatological mean. This happens because the local weather is influenced by larger scale processes in the climate system that influence regional and local climate over different timescales.

Year-to-year climate variability in the MENA region is influenced by large-scale processes such as the North Atlantic Oscillation (NAO). The positive phase of the NAO is linked with cooler and drier conditions in the region, particularly during the winter months. The El Niño Southern Oscillation (ENSO) also influences the region's climate. The El Niño phase is linked with cooler winters in the Arabian Peninsula and warmer, drier summers in tropical parts. The La Niña phase is linked with warmer winters in the Arabian Peninsula and cooler, wetter summers in tropical parts (Dogar and Sato, 2018). ENSO changes phase on a two to seven-year cycle, whereas the NAO has no regular oscillation.

The region's climate is also influenced by the strength of the Indian Summer Monsoon (ISM): cooler, wetter conditions are typically experienced during stronger monsoon years, with warmer, drier conditions typically experienced when the monsoon is weaker (Dogar and Sato, 2018). The strength of the ISM is influenced by these large-scale atmospheric processes. Variability on longer multi-decadal timescales has also been observed, driven by the Atlantic Multidecadal Oscillation (AMO) (Sun et al., 2017).

### 3.1.2 Observed climate trends

The region's current climate has already experienced 1-1.5°C of warming compared to pre-industrial times, as a result of human-induced climate change (IPCC, 2014). There has been no significant trend in precipitation across the region. However, it is more difficult to quantify trends in precipitation due to lack of reliable data and variability on multiple timescales (as discussed in Section 3.1.1).

***Focus box 3: Weather, climate variability and climate change***

The weather varies from day to day and season to season, within a range which describes the climate. The climatic range at a location is usually defined by the statistical characteristics of weather over a 30-year period. Climate change is therefore the difference between two 30-year climate periods. It is both the shift in the annual climate range through the year, from one period to another, as well as a change in the frequency, intensity and duration of extreme events, such as heavy rainfall and extreme temperatures.

The climate itself does vary naturally over shorter periods of several years, and this natural variability can often compound the longer-term climate change signal. As average conditions change, the variability around that average can result in an increase in events that in the past were rare or extreme. There is also some evidence that climate change will make some aspects of the climate itself more variable. So, for example, climate change will mean both more heavy rainfall events and increase the occurrence of very dry conditions (IPCC, 2012).

## 3.2 Spatial analysis zones approach

To assess the scale and direction of projected climate trends it is useful to spatially aggregate gridded climate data over climatologically similar regions. As the MENA region represents a large, meteorologically diverse area, it is not useful to average the climate data over this large region, as the resulting values will not reflect the climate diversity. Nor is it always useful to average the climate data by country borders, as these do not reflect the climate and some countries may experience a range of climate types. Therefore, the region is divided into seven sub-regional spatial analysis zones that reflect the different climate types.

The zones were selected using a combination of the Köppen-Geiger climate classifications (Figure 6) and the Natural Earth[7] country borders (v4.1.0).

[7] https://www.naturalearthdata.com/

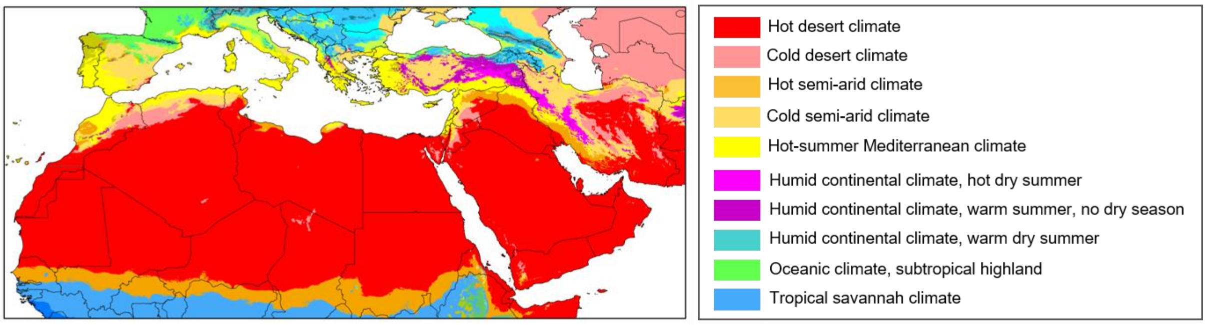



*Figure 6: Köppen-Geiger climate classification map for the MENA region, adapted from Beck et al. (2018)*

The seven zones used for the spatial analysis are shown in Figure 7. North Africa is divided into two spatial analysis zones (Zones 1 and 2 in Figure 7) based on the boundary between the hot desert climate classification (red shading in Figure 6) and the more temperate regions along the Mediterranean coast in the north west.

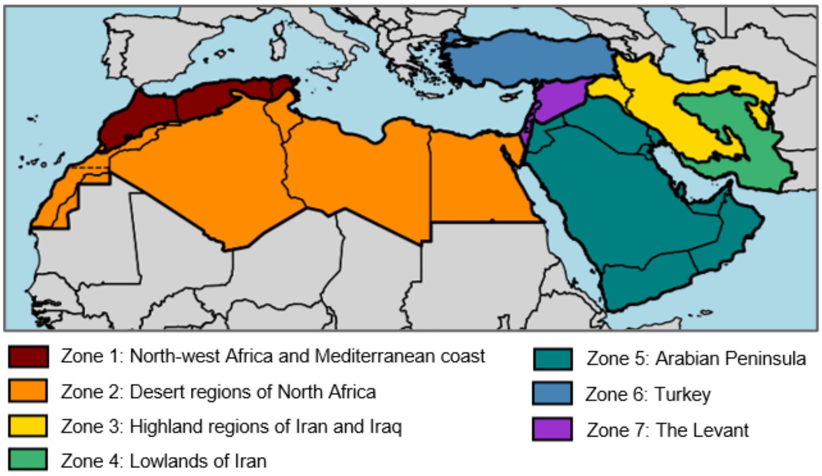



*Figure 7: The seven spatial analysis zones across the MENA region*

The Middle East is divided into five spatial analysis zones following a similar approach by separating the hot desert climate regions of the Arabian Peninsula (Zone 5 in Figure 7) and the lowlands of Iran (Zone 4 in Figure 7). The highland regions of Iraq and Iran are combined into one spatial analysis zone (Zone 3 in Figure 7). Turkey is treated as one of the seven spatial analysis zones, as there is no clear way to divide the country based on climate classification (Zone 6 in Figure 7). The remaining countries (Syria, Lebanon and the OPTs) comprise the final zone, often called the Levant (Zone 7 in Figure 7). Table 1 relates the countries to the spatial analysis zones for reference.

Baseline and future climate data analysis is conducted in each of these seven spatial analysis zones. Here, the baseline is the period 1981-2010, and the future is the period 2041-2070. The analysis focuses specifically on temperature and precipitation climate variables (more detail and plots provided in Appendix B). For other relevant climate variables and metrics such as sea level rise and sea surface temperature, information is gathered from relevant scientific literature. In the following sections, summaries of the baseline climate and future projections relevant to the socio-economic context are presented for each of the spatial analysis zones.

*Table 1: Countries in the MENA region and the spatial analysis zones (defined in Figure 7) that cover them*

| **Country** | **Climate analysis zones that cover the country** |
|---|---|
| Algeria | Zones 1 and 2 |
| Bahrain | Zone 5 |
| Egypt | Zone 2 |
| Israel | Zone 7 |
| Iran | Zones 3 and 4 |
| Iraq | Zones 3 and 5 |
| Jordan | Zone 7 |
| Kuwait | Zone 5 |
| Lebanon | Zone 7 |
| Libya | Zone 2 |
| Morocco | Zones 1 and 2 |
| Occupied Palestinian Territories | Zone 7 |
| Oman | Zone 5 |
| Qatar | Zone 5 |
| Saudi Arabia | Zone 5 |
| Syria | Zone 7 |
| Tunisia | Zones 1 and 2 |
| Turkey | Zone 6 |
| United Arab Emirates | Zone 5 |
| Western Sahara | Zone 2 |
| Yemen | Zone 5 |

## 3.3 Baseline and future climate by zone

In this section the climate in context analysis for the baseline and future climate is presented by zone. Summaries of the findings are presented in the zone summary infographics in Figure 8 and Figure 9.

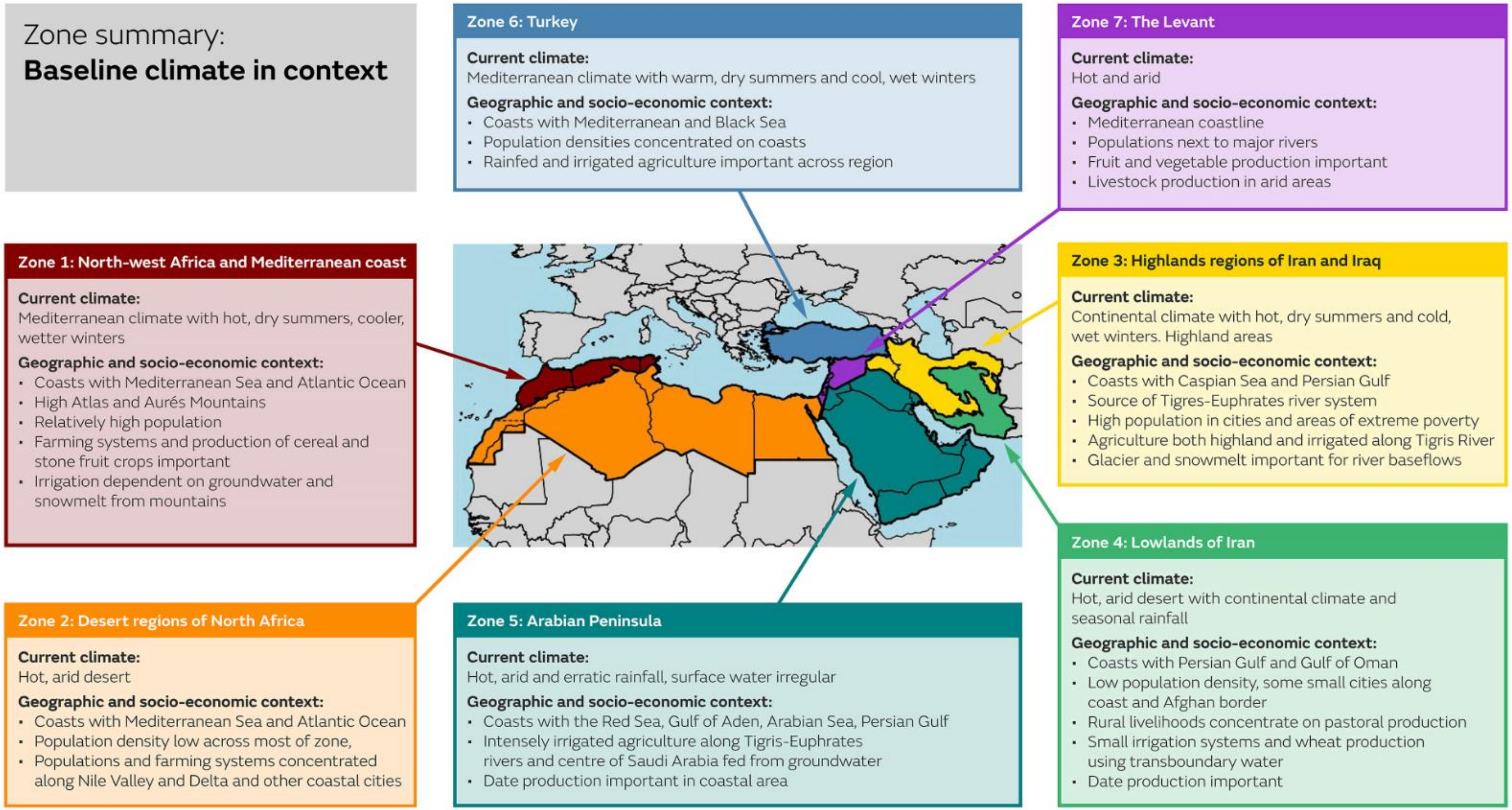



*Figure 8: Summary of the baseline climate in context across the seven zones.*

## Zone summary: Future climate trends and relevant risks

### Zone 6: Turkey

**Future climate trends:**

- Hotter throughout the year, larger increases during hottest months and days above 35˚C more frequent
- Drier on average, particularly during the wettest months. Rainfall events may be more intense
- Sea level rise across Mediterranean and Black Seas, increases in intensity of coastal storms and rising sea surface temperatures

**Relevant risks:**

- Decreased water availability due to reduced rainfall, reduced snowmelt contributions to Tigris and Euphrates river system and higher evapotranspiration in dams and lakes
- Crop production impacted by heat stress, particularly fruit crops, reduced rainfall for rainfed crops, and affects of flash flooding
- Coastal risks including increased coastal inundation and marine heatwaves affecting fish stocks

### Zone 7: The Levant

**Future climate trends:**

- Hotter throughout the year, larger increases during hottest months and extended summer season with days above 40ºC more frequent
- Little change in rainfall, heavy downpours will continue and may be more intense
- Sea level rise across Mediterranean Sea, increases in intensity of coastal storms and rising sea surface temperatures

**Relevant risks:**

- Decreased water availability due to increased evapotranspiration and decreased streamflow of Euphrates, Orontes and Jordan rivers
- Crop production impacted by heat stress, particularly fruit crops, reduced rainfall for rainfed crops, and affects of flash flooding
- Coastal risks including increased coastal inundation and erosion, and marine heatwaves affecting fish stocks

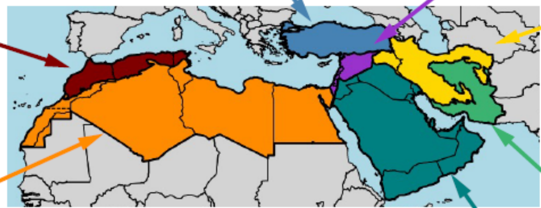
### Zone 1: North-west Africa and Mediterranean coast

**Future climate trends:**

- Hotter throughout the year, larger increases during hottest months and days above 35˚C more frequent
- Drier on average, but rainfall events may be more intense
- Sea level rise across Mediterranean and Atlantic, increases in intensity of coastal storms and rising sea surface temperatures

**Relevant risks:**

- Decreased water availability due to reduced rainfall, groundwater stores and river flows
- Crop production impacted by heat stress, particularly fruit crops, reduced rainfall for rainfed crops, and affects of flash flooding
- Coastal risks including increased inundation and erosion, and marine heatwaves affecting fish stocks



### Zone 3: Highlands regions of Iran and Iraq

**Future climate trends:**

- Hotter throughout the year, days above 35˚C more frequent
- Drier on average, particularly during the wettest months. Rainfall events may be more intense
- Caspian sea level dropping

**Relevant risks:**

- Reduced river flows in Tigris and Karkheh Rivers due to reduced snow pack and increased evapotranspiration. Rainfall will become more important than snow pack for sustaining river flows
- Crop production impacted by reduced rainfall in rainfed areas, and irrigated crops affected by changes in river flow and seasonality

### Zone 2: Desert regions of North Africa

**Future climate trends:**

- Hotter throughout the year, larger increases during hottest months and days above 35˚C more frequent
- Little change in rainfall as region remains dry
- Sea level rise across Mediterranean and Atlantic, increases in intensity of coastal storms and rising sea surface temperatures

**Relevant risks:**

- Decreased water availability in arid regions due to increased evaporation and reduced groundwater stores. Water stress a particular issue in Lower Nile Basin due to increased demand
- Heat stress in cities, particularly coastal areas with high humidity
- Coastal risks including increased inundation and erosion, particularly in the Nile Delta, and marine heatwaves affecting fish stocks

### Zone 5: Arabian Peninsula

**Future climate trends:**

- Hotter throughout the year larger increases during hottest months and extended summer season with days above 40ºC more frequent
- Little change in rainfall, heavy downpours will continue and may be more intense.
- Sea level rise across Red Sea, Gulf of Aden, Arabian Sea and Persian Gulf, increases in intensity of coastal storms and rising sea surface temperatures

**Relevant risks:**

- Heat stress increases uninhabitable land without significant energy demand for ventilation
- River flows reduced due to increased evapotranspiration and reduced snowmelt contributions where river systems originate
- Coastal risks including increased inundation and erosion, particularly in Yemen and Oman, and marine heatwaves affecting fish stocks in Persian Gulf and the Red Sea

### Zone 4: Lowlands of Iran

**Future climate trends:**

- Hotter throughout the year, larger increases during hottest months and days above 35˚C more frequent
- Both wetter and drier futures plausible. Rainfall events may be more intense
- Sea level rise across Persian Gulf and Gulf of Oman Sea , increases in intensity of coastal storms and rising sea surface temperatures

**Relevant risks:**

- Decreased water availability due to increasing evapotranspiration, particularly in spring. Droughts could be more frequent and long-lasting.
- Coastal risks including increased inundation and erosion

*Figure 9: Summary of the future climate trends and relevant risks identified across the seven zones*

### 3.3.1 Zone 1: North-West Africa and Mediterranean coast

***Baseline climate in context***

Zone 1 encompasses the coastal plain of the Maghreb, bordered by the Mediterranean to the north and the Atlas mountain range to the south, which form a natural barrier to the arid desert interiors. This zone contains the major ports and cities, and most of the rural population of Morocco, Algeria and Tunisia. The current climate in this region has a distinct seasonal pattern with a warm to hot and dry summer period, and a cooler, wetter winter period (annual cycles of precipitation and temperature are shown in Figure 10). The hottest period of the year (June to August) often sees average daily maximum temperatures exceed 35°C. The lowest temperatures are found in December to February with lows occasionally dropping to 0°C. There has been an observed warming trend in mean, minimum and maximum temperature over the duration of the baseline period.

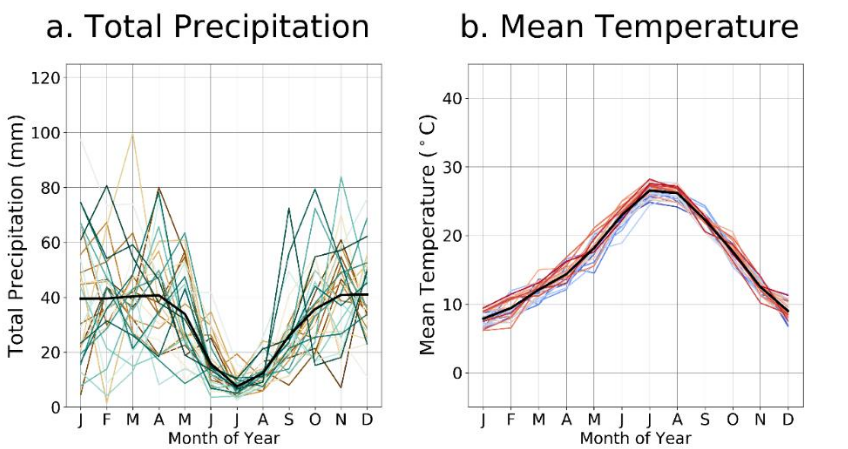



*Figure 10: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 1. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period). The bold black line indicates the average of the 30-year period.*

Most precipitation occurs between August and March when temperatures are cooler (Figure 10). Precipitation mostly falls as rain across this region, although some falls as snow over higher ground, such as in the High Atlas Mountains of Morocco and the Aurès Mountains of Algeria. There is high interannual variability in total precipitation, with some wetter and some drier years, and no clear trend over the baseline period.

Rural areas are dominated by mixed rainfed agricultural systems, with significant areas of dryland farming and pastoral rangelands – particularly in the zone's southwest portion in Morocco, the southern and eastern parts of the zone in Algeria, and the southern parts of the zone in Tunisia. Highland farming systems are found in the High Atlas Mountains and the Aurès Mountains. Large irrigation schemes are found in areas of all three countries, and increasingly individual farms are adopting groundwater irrigation systems to grow more profitable crops and reduce vulnerability to agricultural drought. The highlands are important sources of surface and groundwater flows. In many rivers, streamflow into the late spring and summer relies on snowmelt from the mountains.

***Future climate projections***

The climate change signal for this region is for increasing temperatures, particularly in the hottest months, and an overall reduction in total annual precipitation. Figure 11 shows high confidence[8] in a projected increase in annual average daily mean temperature of around 2-3°C. The models project a clear decrease in total annual precipitation, but there is less agreement on the amount of change, as demonstrated by the large multi-model spread.

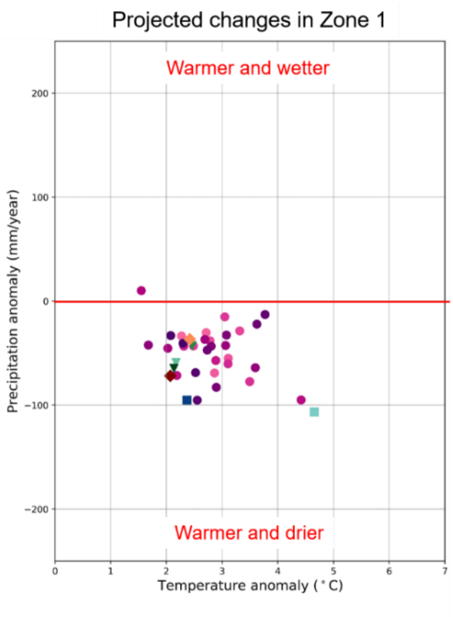



*Figure 11: Projected change in average annual precipitation and temperature in Zone 1 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change. Similar plots for projected trends in seasonal means are in Appendix B.*

Temperatures are projected to increase across the seasons in all months of the year, with increases of up to 6°C during the summer months (see Appendix B). The minimum, mean and maximum temperature values are all increasing, including overnight minima. This can increase the incidence of heatwave conditions, particularly in the summer months. Periods where the daily maximum temperature is above 35°C will be more frequent and last longer. Overnight minimum temperatures will more often exceed 20°C and may even reach 25°C during June-August. The hottest monthly temperatures experienced in the current climate are likely to be average monthly temperatures in the 2050s. This means that for some years in the 2050s, monthly temperatures could be higher than experienced in the current climate.

[8] High confidence is assigned when the majority of models agree on the direction of change.

The projected decrease in annual rainfall is seen in most, but not all climate models. The seasonal pattern of rainfall in the climate model projections remains similar to the pattern in the present climate: for example, there is no indication of changes in the timing of the onset of winter rains. However, drier on average conditions will impact rainfed cropping systems in particular. The projected reduction in average rainfall totals occurs in the context of continuing year-to-year variability in rainfall amounts, meaning that not all years in the future will be drier than the current climate. In addition, there is also evidence that rainfall events will be more intense in a future climate (IPCC, 2013), which can lead to flash flooding events affecting highland and urban areas and waterlogging of soils.

The combination of lower average rainfall and higher temperatures will cause greater evaporation, thereby reducing the amount of surface water available for use. The reduction in water availability could be from both rainwater and groundwater stores where other anthropogenic factors such as mining will also interact with aquifer recharge (Abdelmohsen et al., 2019; Abu-Bakr, 2020; Mazzoni et al., 2018). Rivers show projected trends for lower flows and storage levels in dams will be adversely affected (Tramblay et al., 2018). Higher temperatures will also mean that the period when precipitation falls as snow will decrease. This is important as snow acts as a water store, sustaining baseflows through snowmelt over the warmer months. Taken together, these imply that drought frequency, intensity and duration are expected to increase relative to present day risk.

The northern coast of Morocco, Algeria and Tunisia is projected to experience sea level rise and increasing sea surface temperatures as the Mediterranean reacts to the changing climate. Sea surface temperatures (SST) are projected to increase by as much as 1.2°C between 1980 and 2040 (IPCC, 2019) with increases in the frequency of marine heat waves (MHW). MHW cause mass mortality of invertebrates that underpin the marine food chain (Lewandowska et al., 2014), potentially devastating fish stocks. They also cause coral bleaching and increase the likelihood and intensity of algal blooms. Sea level may rise by up to 0.5m over the course of the 21st century (EEA, 2020). Whether the number of extratropical cyclones (ETC) in the North Atlantic basin and Mediterranean will increase or decrease is uncertain: recent trends have shown an increase in frequency, but some model projections reported in the literature indicate that this may reverse in the coming century (Knutson et al., 2021). The severity of storms when they do occur is projected to increase, with high confidence in these projections (Knutson et al., 2021).

### 3.3.2 Zone 2: Desert regions of North Africa

***Baseline climate in context***

Zone 2 is dominated by the Sahara Desert, bordered to the north by the Mediterranean and the Atlas Mountains. Most of the zone experiences a hot desert climate and is dry all year round with no distinct rainy season (annual cycles of precipitation and temperature are shown in Figure 12). The hottest period of the year (June-August) sees average daily maximum temperatures above 35°C across the region, with some areas, such as southern Algeria experiencing temperatures above 40°C. Overnight, minimum temperatures are around 25°C across the region, and the hottest parts currently experience night-time minima up to 30°C on average. The lowest temperatures occur during December-February, with lows of around 5-10°C. While most of this zone has extremely low population densities, it contains the major ports and cities of Libya and Egypt (Tripoli, Alexandria and Cairo), which include some of the highest population densities in the world. These cities may be especially vulnerable to the high daily and night-time temperatures. There is an observed warming trend in mean, minimum and maximum temperatures over the baseline period, particularly during the summer and winter seasons.

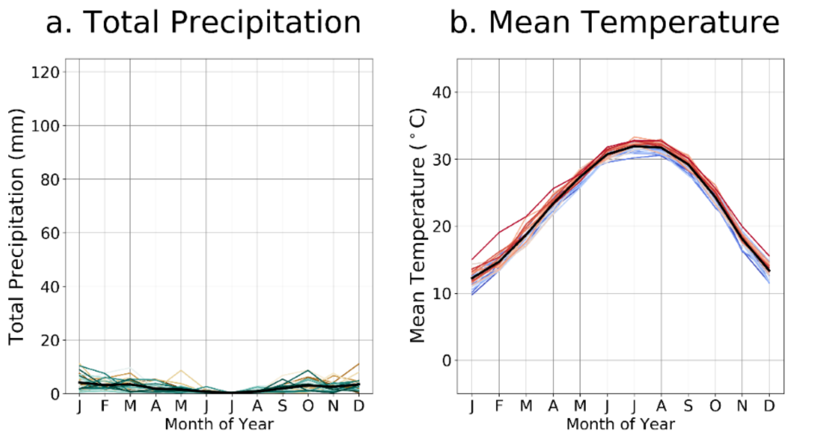



*Figure 12: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 2. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.*

This zone contains the Egyptian Nile Valley and the Nile Delta, some of the most densely populated rural areas and intensively irrigated agricultural areas on Earth. Surrounded by desert and experiencing very little rainfall, these farmlands rely entirely on transboundary water originating in Ethiopia and other sub-Saharan nations. The northern and coastal fringes of the zone are semi-arid desert, and contain important rainfed agricultural and pastoralist grazing areas, particularly along the Mediterranean coasts of Libya and Egypt, and Egypt's Red Sea coast. Within the arid interior are elevated areas where slightly higher humidity and lower temperatures support montane xeric woodlands, such as in Algeria and Egypt. These areas are internationally significant biodiversity refuges and provide grazing rangelands for nomadic pastoralist communities (Laity, 2008). Elsewhere within the desert, oases formed around springs fed by shallow aquifers support irrigated agriculture (Kendouchi et al., 2013). Many of these oases are very old, but recent decades have seen an expansion of modern agriculture into some desert areas, such as Oweinat in Egypt, relying on extensive groundwater pumping (Powell and Fensham, 2016; Almulla et al., 2020).

***Future climate projections***

The climate projections show a climate change signal for this region of increasing temperatures in all months, particularly in the hottest months when average daily maximum temperatures may exceed 40˚C. The region is expected to remain very dry; minimal change in rainfall is seen across all the models. Figure 13 shows that the models cluster around a signal for little change in annual mean precipitation, and 2-4˚C increase in annual mean temperature, compared to the baseline. The models show high consensus, giving higher confidence in the likelihood of these changes.

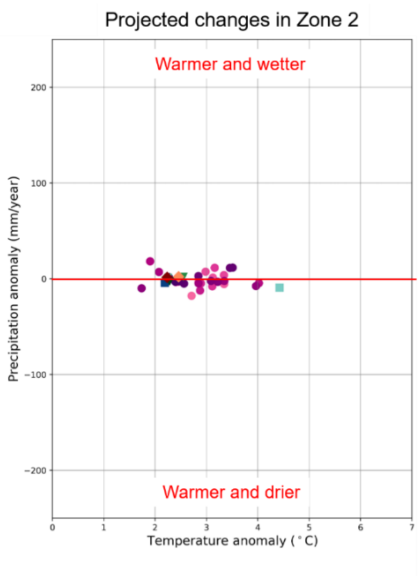



*Figure 13: Projected change in average annual precipitation and temperature in Zone 2 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red lines indicate the zero axis i.e. no change. Similar plots for projected trends in seasonal means are Appendix B.*

Temperatures are projected to increase in all months of the year, with the greatest increase seen in June-August (see Appendix B). The minimum, mean and maximum temperatures are also projected to increase. This could mean that average monthly temperatures in the 2050s may be hotter than the highest temperatures experienced in the current climate, particularly during summer months.

Parts of this zone already experience average daily maximum temperatures above 35°C during the summer. The projections show that periods where the maximum temperature is above 35°C will be more frequent, longer and hotter, and areas that currently don’t exceed 35°C may in the future. Overnight minimum temperatures during summer months are already high and will more frequently exceed 25°C (and 30°C in the hottest parts), so heatwave conditions will be more frequent and intense. Humidity is higher around coastal areas, so these are the locations of greatest concern. Given the presence of large urban areas such as Cairo, heat stress will be a growing and major issue for human and animal populations.

Climate projections show little change in rainfall, with the zone remaining very dry. This, combined with increasing temperatures, means that the amount of water available for use will reduce due to increasing evaporation rates, with no season more strongly affected than another. As rainwater is low in this region it is more likely this will affect shallow groundwater stores and aquifer recharge rates, impacting water available for irrigation (Abu-Bakr, 2020). Drought frequency, intensity and duration is expected to increase.

Very little rainfall in this zone means rivers are vital for water supply. Egypt depends heavily on the Nile. Most of the Nile's water supply comes from rainfall in the Upper Nile Basin (Ethiopia, South Sudan, Uganda). Although projections show an increase in rainfall in the Upper Nile Basin (subject to considerable uncertainty), there is also a projected increase in the frequency of hot and dry years (Coffel et al., 2019), which will result in additional evaporation of river waters, along with increased demand for water for irrigation and other livelihoods. It is therefore likely that water scarcity will increase, despite potentially higher regional rainfall in the Upper Nile Basin, which in turn will cause water stresses in the Lower Nile Basin (Egypt and Sudan). There is also a large inter-annual and inter-decadal variation in rainfall in the Nile basin, which is expected to increase in future. This may result in a greater frequency of flood and drought periods affecting water availability downstream (Coffel et al. 2019).

The Mediterranean and Red Seas are projected to see a sea level rise (SLR) of up to 0.5m between 2000 and 2100 (EEA, 2020) and an increase in sea surface temperature of as much as 1.2°C between 1980 and 2040 (IPCC, 2014) with a corresponding projected increase in the frequency of marine heat waves (MHW). MHW cause mass mortality of invertebrates that underpin the marine food chain (Lewandowska et al., 2014), potentially devastating fish stocks. They also cause coral bleaching and increase the likelihood and intensity of algal blooms. SLR will impact the Nile delta with increasing erosion rates, inundation of wetlands and other low-lying lands, increasing risk of flooding, accelerating coastal retreat, including erosion of sand dunes and coastal sand belt, breaching of coastal barriers, and damage of coastal inlets (Eldeberky, 2011). The number of extratropical cyclones in the North Atlantic basin and Mediterranean may decrease although the signal is unclear; however, the severity of storms is projected to increase. The combined effects of SLR and storm severity could increase the intensity and frequency of extreme wave events, further exacerbating coastal erosion and inundation, among other impacts.

### 3.3.3 Zone 3: Highland regions of Iran and Iraq

***Baseline climate in context***

Zone 3 includes the highlands of Iran and Northeast Iraq, much of which lies over 2000m above sea level. This zone has a continental climate and experiences a high degree of seasonality, with hot, dry summers and cold, wet winters (annual cycles of precipitation and temperature are shown in Figure 14). June-September is the hot dry season, with average maximum daily temperatures ranging from 25 to 31°C. December-February are the coolest months with sub-zero temperatures common, and overnight minima reaching below -5°C on some occasions. Maximum daytime temperatures are in the low-30s during this season. There has been an observed increase in mean, minimum and maximum temperatures over the baseline period, particularly during the summer months. Precipitation is highest in November-May (~70-80mm), which falls as snow in the coldest regions. There is large year-on-year and month-on-month variability, and no clear trend over the baseline period. This is one of the wettest zones across the MENA region.

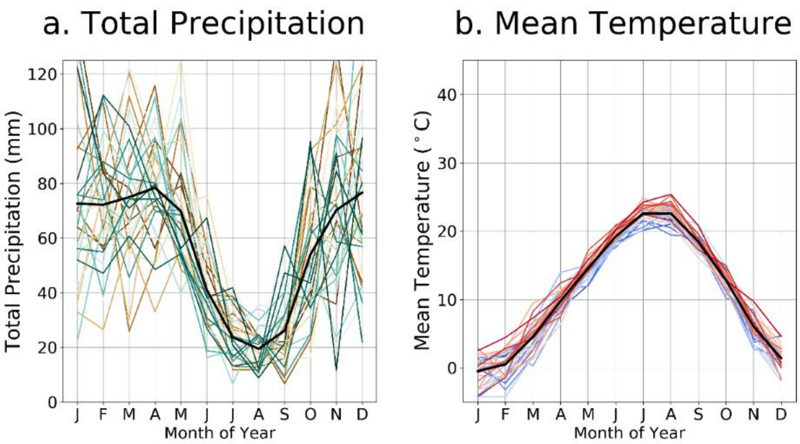



*Figure 14: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 3. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.*

Most Iraqi cities in this zone (Erbil, Kirkuk and Mosul) are at lower elevations (200-250 m), while major Iranian cities lie above 1000m (e.g., Mashhad) or 1500m (e.g., Tehran, Isfahan). Population density is highest in the north west. As well as major population centres, this zone includes areas of extreme deprivation and poverty due to poor infrastructure, remoteness from markets and government services, and the fragility of natural resource bases. Major agriculture systems comprise highland agriculture, scattered pastures and pastoralism, and there are substantial intensively irrigated areas along rivers (this zone includes the Tigris River from where it crosses the border with Turkey down to Baghdad). Major crops are wheat and/or barley, although rice is grown along the coast of the Caspian Sea. Hydrology in this zone is complex, featuring inflow from transboundary rivers (e.g., the Helmand from Afghanistan), Iranian rivers forming tributaries to the Tigris, rivers that flow to the Caspian Sea and Persian Gulf, and major rivers (e.g., the Zayande) that are endorheic. Water insecurity is a major concern across the zone: for example, over recent decades the Zayande River has regularly begun running dry before reaching Isfahan due to over-withdrawal for agriculture (Abou Zaki et al., 2020). Areas of northern Iran above 4000m are glacial, and snowmelt is an important contributor to river flows in spring and summer. The zone's ecological complexity with different habitats and climate regimes contributes to Iran's importance as a global centre of biodiversity. While the Persian Gulf coast is exposed to sea level rise and intensifying tropical cyclones, the Caspian Sea level is falling, which may pose different environmental risks on the northern coasts.

***Future climate projections***

Model projections show a warming signal with the range of annual average temperature increase projected to be 2-4°C higher than the baseline period, as shown in Figure 15. The models show a high consensus around the temperature increases. There is less model agreement on potential changes in annual precipitation totals, with a spread between increases and decreases in precipitation amounts. Overall, a large proportion of models depict a decrease in average precipitation amounts and only a small number show a slight increase.

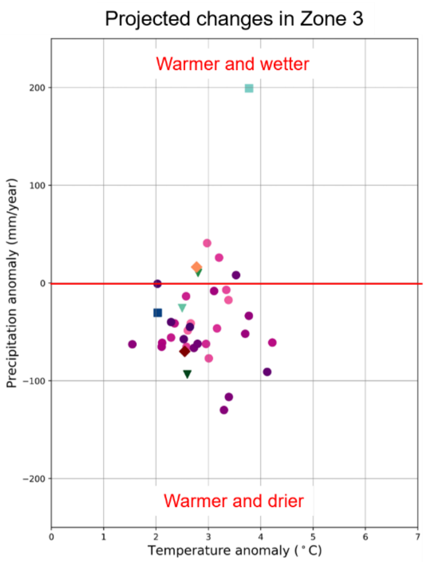



*Figure 15: Projected change in average annual precipitation and temperature in Zone 3 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e., no change. Similar plots for projected trends in seasonal means are in Appendix B.*

Rising temperatures are seen across all months, with the greatest increase from June to August, the warmest and driest period of the year (see Appendix B). This increase means that average daily temperatures (mean, maximum and minimum) in the 2041-2070 period could be as warm or warmer than the equivalent values experienced in the hottest years in the recent past. For example, it will become a common occurrence to observe maximum daily temperatures that exceed 35°C for periods in the hottest months.

The onset of the precipitation can vary by a period of a month or two in the present day, and climate models show no indication that this variability will change or lead to a more systematic shift in rainfall onset. There is some indication that the wet season will become drier, although the signal is mixed with some models showing a slight increase in precipitation. The dry season does not show much projected change in precipitation.

The level of the Caspian Sea is projected to drop by an average of 9-18m between 2020 and 2100 due to loss of winter ice and increased evapotranspiration, as well as projected decreased river inflows (Nandini-Weiss et al., 2019). As a result, the Caspian Sea surface area could shrink by 23% for a 9m drop of sea level, and by 34% for an 18m drop (Prange et al., 2020). The Iranian coastal zone of the sea is likely to see the least shrinkage compared to shallower regions to the north and east. Sea surface temperature in the Caspian Sea is projected to rise. There is some evidence for a decrease in frequency of coastal storms in the Caspian Sea, but there is low confidence in this projection.

Major rivers in this zone include the Tigris in Iraq and the Karkheh river in Iran. The Tigris is fed at source by snowmelt in the mountains of Turkey. With higher temperatures, less precipitation will fall as snow, reducing river baseflows. With a potential decrease in precipitation in this zone and increase in evaporation due to higher temperatures, the streamflow of the Tigris in this zone may decrease. Overall, (Zones 3 and 4) Iraq may see a decline in river discharge for the Tigris and Euphrates (Adamo et al., 2020). The Karkheh River in Iran is projected to see significant reduction in stream flow of up to 24% in the period 2020-2080, particularly in spring. The Karkheh River Basin may experience earlier snowmelt, which with increasing temperatures, implies rainfall becomes more important to sustaining river flows than snowpack (Abrishamchi et al., 2012). Additionally, with the potential for decreased precipitation in general and higher evaporation, baseflows are likely to be lower in the future (Nasseri et al., 2017).

### 3.3.4 Zone 4: Lowlands of Iran

***Baseline climate in context***

Zone 4 is mostly hot, arid desert and includes the lowlands of southern Iran and the central plateau, with an average elevation of 900m. The zone is hotter and drier than the rest of Iran, but similarly has a continental climate, with a high degree of seasonality (annual cycles of precipitation and temperature are shown in Figure 16). Average summer temperatures are around 25-28°C, with maxima in the mid-30s. The summer months (June-September) are also very dry. The coolest and wettest period of the year (December-February) has temperatures averaging in low single figures, and overnight minima occasionally below zero, although the frequency of overnight frosts has been decreasing over the baseline period. The amount of rainfall increases from October to a peak around March, but with noticeable variability from year to year and month to month, with some years experiencing very low levels of rainfall. There is no observable trend in rainfall amounts over the baseline period, but mean, minimum and maximum temperatures have been increasing during 1981-2010, as shown in Figure 16.

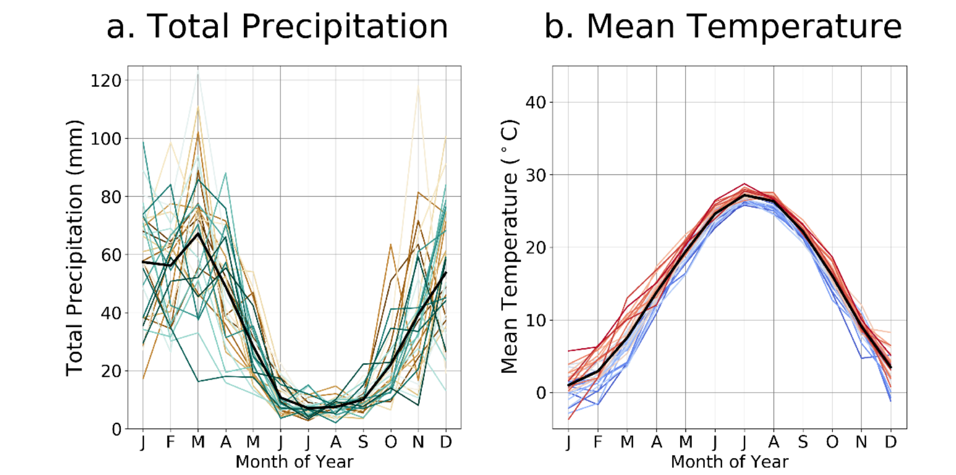



*Figure 16: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 4. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.*

Population density is very low, with some areas either entirely uninhabited or below five people per km$^2$, although there are some small cities close to the Afghan border (e.g., Saravan) and along the coast of the Gulf of Oman. Rural livelihoods in this zone are mostly confined to pastoral production from dry rangelands, although there is some localised irrigation and wheat production in the far east (Sistan and Baluchistan Province) using transboundary water sources and/or groundwater. Iran's date production is concentrated in this zone.

***Future climate projections***

Future projections for the region show a strong and consistent signal for temperatures to increase by around 2-4°C compared to the baseline period. All models agree on this rise in temperature (see Figure 17), lending high confidence to the projections. The models demonstrate a wide spread of future rainfall changes, with some predicting greater totals than current annual means and some predicting less (Figure 17). There is considerable uncertainty in future annual rainfall projections compared to those for temperature; both increases and decreases compared with 1981-2010 are plausible.

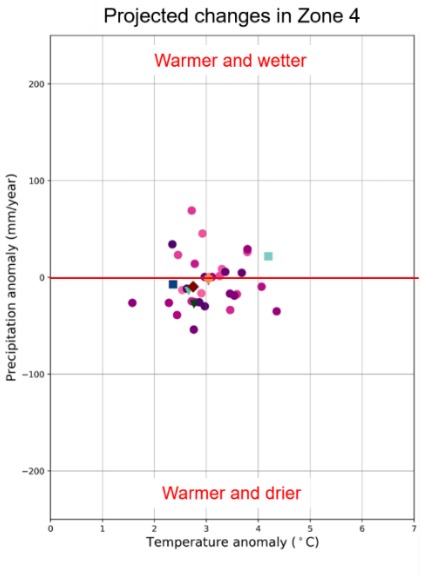



*Figure 17: Projected change in average annual precipitation and temperature in Zone 4 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e., no change. Similar plots for projected trends in seasonal means are in Appendix B.*

The greatest increases in temperature are projected to occur in the summer months, with May to September regularly observing maximum temperatures above 35°C (see Appendix B). There is even a possibility that daily mean temperatures could reach 35°C in the hottest months of July and August. As with other zones, this warming implies that in the 2050s, an average year will be as warm or warmer than the very warmest years seen in the recent past. Future minima are projected to be around 2-3°C higher than the baseline temperatures, daily average temperatures would very rarely fall below zero. Overnight frosts, which are already rare, will become very occasional and short-lived.

The onset of autumn/winter rains can vary by a month or two in the present day, and climate models show no indication that this variability will change. With warmer temperatures overall, water availability is expected to decline due to increasing evapotranspiration. This is most important in the spring when rainfall is at its peak and average daily temperatures could be reaching around 20°C. Although the average change in rainfall is uncertain, large inter-annual variability creates potential for more frequent, intense and long-lasting periods of drought, even where long-term average rainfall amounts are relatively comparable to the present day.

Sea level is projected to rise in the Persian Gulf (one study suggests an increase of up to 11cm by the end of the century (Irani et al., 2018)) with significant increases in sea surface temperature (SST). There is high confidence that the maximum SST will increase by more than 4°C. While tropical cyclones have not yet been recorded over the Persian Gulf, warmer SSTs and changes in regional atmospheric circulation due to climate change could give rise to them in the future (Lin and Emmanuel, 2016). This, combined with the rise in sea level, could increase the risk of extreme wave events and put coasts at risk of erosion, inundation and destruction of coastal infrastructure.

### 3.3.5 Zone 5: Arabian Peninsula

***Baseline climate in context***

Zone 5 is dominated by the hot, dry desert of the Arabian Peninsula, which rises to the south to become the Yemeni highlands and then falls to the Hadrumaut coastal plain bordering the Gulf of Aden and Arabian Sea. The climate in this zone is extremely hot and arid (annual cycles of precipitation and temperature are shown in Figure 18). Maximum temperatures can occasionally reach 40°C in the summer months. Although in the winter months the overnight temperatures can fall to below 5°C, in summer, overnight minima above 25°C are not uncommon. The diurnal temperature range is ~10°C. There has been an observed increase in mean, minimum and maximum temperatures over the baseline period.

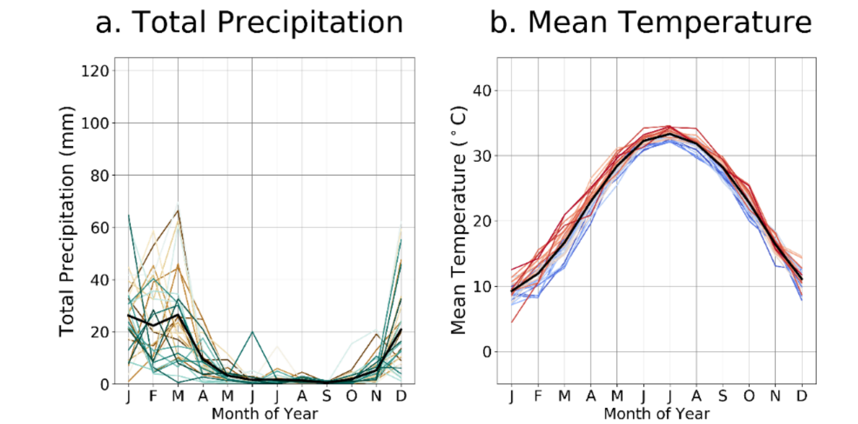



*Figure 18: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 5. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.*

Although the region is largely desert, there are some localised climate exceptions. In the summer, the Arabian Sea coastline receives air from the cold surrounding waters, which can lead to microclimates of cooler, humid conditions in small pockets along the coast. Dust and sandstorms are a feature across this zone throughout the year.

Much of the zone is desert, and there is little to no rainfall through the year. Any rain that does fall in this zone tends to be in isolated heavy downpour events over a period of hours (Almazroui et al., 2012), mainly occurring in the north associated with frontal systems on the subtropical jet. There is significant variability in rainfall amounts from year to year, with no observable trend over the baseline period. Yemen's higher topography means that there is more rainfall in this region of the zone and temperatures are cooler, although the climate is still predominantly hot and dry, with a large diurnal range.

Areas of intensely irrigated agriculture lie along the Tigris and Euphrates rivers and in the centre of Saudi Arabia (e.g., Buraydah) where they are fed by groundwater from non-renewable aquifers, making agriculture in Saudi Arabia unsustainable. Sparse rangelands in the west of Saudi, Yemen and areas of Oman support pastoralism, while Yemen's highlands also support highland agriculture, some rainfed agriculture, and there are limited but important areas of irrigation. Date production is important in the Gulf coastal area. Aside from the Tigris-Euphrates river system, most surface water in the zone is seasonal or irregular, with wadis filling rapidly after rainfall and then drying again. Groundwater is critical in this region but has been unsustainably mined for agriculture, particularly in Yemen and Saudi Arabia (World Bank, 2018; FAO and OECD, 2018). This zone contains several major cities, notably: Baghdad, Basra, Riyadh, Jeddah, Sana'a, Dubai, Mecca, Medina, and Kuwait City, all with populations over one million. Jeddah and Aden are vulnerable to sea level rise, while Kuwait City, the cities of the UAE, Bahrain, Doha and Dammam are also vulnerable to intensifying tropical cyclones in the Persian Gulf.

The Tigris-Euphrates river system is the most important in this zone. A heavily engineered watershed (> 60 main dams) that is shared by Turkey, Iran, Syria, Saudi Arabia, Jordan and Iraq, it is one of the largest river basins in the Middle East covering an area of 879,790km$^2$ (Daggupati et al., 2017).

Precipitation in the form of snow is the major source of streamflow and most of this originates in the high mountains of eastern Turkey (Balov and Altunkaynak, 2020). The stream flows of the Tigris and the Euphrates Rivers are associated with the North Atlantic Oscillation (NAO) which governs the path of Atlantic mid-latitude storm track and precipitation in the eastern Mediterranean (Cullen and deMonocal, 2000).

***Future climate projections***

There is a strong signal and good agreement between climate models for an increase in average daily temperatures (Figure 19). Temperatures are projected to increase by around 2-4°C on average compared to the baseline period. Many of the climate models project relatively little change in rainfall across the region, although some models indicate the possibility of increases in total annual rainfall amounts (Figure 19).

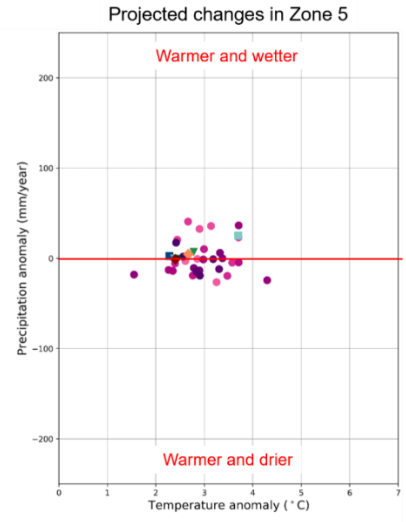



*Figure 19: Projected change in average annual precipitation and temperature in Zone 5 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e. no change. Similar plots for projected trends in seasonal means are in Appendix B.*

Increases are projected in both maximum and minimum temperatures, by up to 2-5°C in the hottest June-November period (see Appendix B). Maximum temperatures in June-August could exceed 40°C in most years and mean temperatures in these summer months may often exceed 35°C. This could be quite substantial in the summer months with average temperatures, which are already hot (30-35°C), increasing by up to 5°C. The warmest period of the year will get longer, with daily maximum temperatures exceeding 35°C, starting earlier in the spring and extending into the autumn. Minimum daily temperatures may consistently reach or exceed 25°C. These changes raise issues around the future habitability of much of the region without adaptive measures; many areas within already have either a very hostile climate or are uninhabitable.

Any possible increase in rainfall is unlikely to translate into greater water availability, both because of the nature of rainfall in this zone (heavy, short downpours with flashy runoff and little infiltration), and because increasing temperatures will increase the rate of evaporation.

Increases in evaporation will also affect the river systems in this zone. Combined with a potential drop in snowmelt contributions in the mountains where the rivers originate, the average annual Euphrates-Tigris river discharge may decline by as much as 9.5% between 2040 and 2069, with the greatest decline in Turkey (12%), and the smallest decline in Iraq (4%) (Adamo et al., 2020).

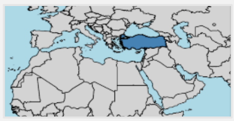
Some microclimates are projected to remain. The Arabian Sea coast will still have cooler, moister pockets as these are largely driven by cold upwelling of ocean waters in the summer, which will be slower to respond to warming.

Changes in climate over Yemen are more difficult to evaluate because of extreme contrasts in topography over short distances. In general, the climate is projected to be warmer, particularly in the summer. Little can be derived from the models on direction or degree of change in rainfall. Irrespective of precipitation uncertainty, water stress will increase as temperatures warm.

The coast of Zone 5 incorporates the eastern Red Sea coast, the Yemen and Oman coasts on the Gulf of Aden and the Arabian Sea, and the Persian Gulf. Sea level is projected to rise along all coasts in this zone, with significant increases in sea surface temperature (SST). The IPCC reports very high confidence in average temperatures for semi-enclosed seas increasing over the period 2010-2039, with the greatest increases projected for the surface waters of the Persian Gulf (4.26°C) and the Red Sea (3.45°C)[5]. There is high confidence that the maximum SST will increase by more than 4°C in the Persian Gulf (IPCC, 2019). The Gulf of Aden and the Arabian Sea are projected to see an increase in SST, a rise in sea level and an increase in frequency and severity of storms and tropical cyclones. Therefore, the coasts of Yemen and Oman are likely to experience more storm-related impacts – high winds, flooding, coastal inundation, and erosion – with associated risks to infrastructure, water supply and livelihoods (Bell et al., 2020).

The Gulf of Oman is projected to see increased SST and SLR. It currently contains the world’s largest ‘dead zone’, which is an area completely lacking in marine life due to lack of oxygen caused by pollution (Queste et al., 2018). Algal blooms and dead zone areas are likely to grow as increases in temperature lead to increased stratification of oxygenated water and concentrate pollutants.

### 3.3.6 Zone 6: Turkey



***Baseline climate in context***

Zone 6 covers Turkey and has a Mediterranean climate. Temperate and sub-humid agriculture in the west develops into highland agriculture in the eastern mountains, with patches of dry rangelands supporting pastoralism in the southern-central area. This zone has a warm to hot summer climate with mild to cool winters (annual cycles of precipitation and temperature are shown in Figure 20). Away from the Black Sea coast, maximum temperatures in the hottest months of the year regularly reach 35°C. In the winter, temperatures inland are often sub-zero, although coastal regions are warmer, still with some cool to cold days, but not nearly so harsh. There has been an observed increase in mean, minimum and maximum temperatures over the baseline period.

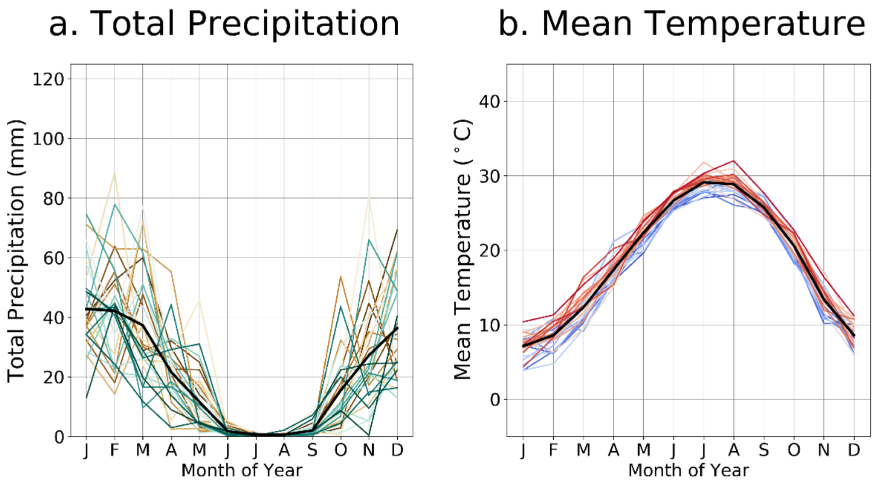



*Figure 20: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 6. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.*

The summer months (June-September) are dry, with most of the annual rain falling from September and peaking in December to March. Annual rainfall totals are relatively low in most areas. There is some diversity in the climate in this zone, with the Black Sea coast being cooler and wetter than the rest of the country and receiving rainfall throughout the year. Rainfall amounts are highly variable from year to year and there is no observable trend over the baseline period.

Population densities are highest along the western (Aegean) and southern (Adana) coasts, and the area around Istanbul. Ankara with a population of 5 million sits at an elevation of 1000m, while Istanbul with a population of 14 million, Izmir with a population of 3 million and Bursa with a population of 2 million, are all coastal. Turkey is a major producer of wheat, sugar beet, cotton, fruit and vegetables, and is the world's largest producer of apricots and hazelnuts. Stone fruit, barley and winter wheat require periods of cold temperatures to induce flowering, without which yields may be lower and stone fruit trees may not fruit. Rainfed agriculture is relied on for barley, rye and winter wheat production, while many other cash crops, such as cotton and peanuts, are grown in spring and summer in irrigated systems.

As in other zones, most surface waters have been mobilised through dams and support extensive irrigation, particularly on the southern Mediterranean coast (Adana) and the river valleys of the eastern highlands (e.g., Şanlıurfa Province). The Taurus Mountains provide major tributaries for transboundary water in the Tigris and Euphrates rivers, as well as domestic rivers flowing west and south. Winter temperatures and melting regimes are very important in this region, as snowmelt during the spring and summer constitutes around 60-70% of total baseflow in some rivers, such as the Upper Euphrates (Uysal, Sensoy & Sorman, 2016).

***Future climate projections***

There is a strong signal and good agreement between climate models for an increase in temperatures by around 2-4°C for most of the year (Figure 21), lending high confidence. Climate projections for this region show some spread in the range of changes in rainfall, but most models show an overall reduction in total annual rainfall (Figure 21), lending medium confidence to projections.

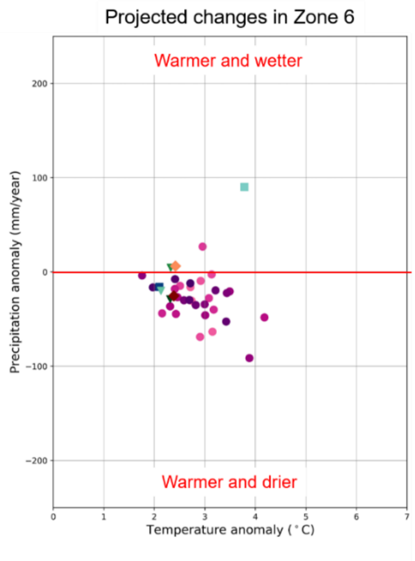



*Figure 21: Projected change in average annual precipitation and temperature in Zone 6 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e., no change. Similar plots for projected trends in seasonal means are in Appendix B.*

The greatest warming is expected in the hottest months (June-August), where annual average temperatures are expected to be 2-5°C warmer than the recent past. There will be an increase in the frequency and duration of periods where the daily maximum temperature is above 35˚C; temperatures during these periods will be hotter, often exceeding maximum recorded temperatures to date. Projections show increased interannual variability in temperature, but the warmest months are expected to be consistently warmer than past climate, such that the coolest years in the future are warmer than the warmest years of the recent past.

Increases in both the minimum and maximum temperatures will affect production of peaches, apricots, and dates. While temperatures are increasing, there is not expected to be a change in the diurnal range. This is because daily minimum and maximum temperatures are increasing by approximately the same amount. Warming over all seasons and all times implies crops will experience additional heat stress, and decreasing cumulative cold hours required for vernalisation. Mean daily temperatures during winter (December-February) are projected to increase by between 1 and 4˚C, which may impact production of peaches, apricots and to a lesser extent dates, barley and winter wheat.

Climate projections for this region show relatively good agreement for an overall reduction in total annual rainfall. Most of this reduction is projected to occur in the wettest months of the year (December-May). Reductions in average rainfall, combined with increasing temperatures and evapotranspiration rates, implies less water may be available for crop production, particularly impacting rainfed crops. There is some evidence that rainfall events will be more intense in a future climate (IPCC, 2013), which could cause flash flooding events and can severely damage crops.

Higher temperatures will lead to a shortening of the period in which precipitation falls as snow, reducing snowpacks. Combined with an overall decrease in precipitation in this zone, this means that sustained snowmelt will reduce. The spring snowmelt is also likely to occur earlier in the year. These factors, combined with increasing temperatures, are likely to lead to pronounced drops in river baseflows. The Tigris and Euphrates river system is mainly fed by snowmelt from the eastern mountains of Turkey. The average annual Euphrates-Tigris discharge in Turkey is projected to decline (Adamo et al., 2020).

Increasing temperatures will increase evapotranspiration. Evaporative reservoir and lake losses can be significant in hot, arid areas; these losses are likely to be magnified due to climate change. They can also impact irrigation systems. Evaporative losses could be quite substantial in the summer months with average temperatures – which are already hot at over 30°C in the hottest years – increasing by up to 4 or 5°C.

Sea levels in the Mediterranean and Black Seas are projected to rise by up to 0.5m over the course of the 21st century and sea surface temperature may increase by as much as 1.2°C between 1980 and 2040, with corresponding increases in the frequency of marine heat waves (MHW). MHW cause mass mortality of invertebrates that underpin the marine food chain (Lewandowska et al., 2014), potentially devastating fish stocks. They also cause coral bleaching and increase the likelihood and intensity of algal blooms. In the Black Sea, the IPCC estimates an upper limit of 0.82m sea level rise for the period 2081-2100 (Allenbach, 2015) and an SST increase of 2°C between 2000 and 2100. Both the Mediterranean and Black Sea are projected to see an increase in intensity of storms with associated erosion and inundation (IPCC 2019).

### 3.3.7 Zone 7: The Levant

***Baseline climate in context***

Zone 7 includes Jordan, Syria, the Occupied Palestinian Territories (OPTs), Lebanon and Israel. On a broad scale, this zone is characterised by a series of north-south highlands (1000m+) that separate Mediterranean coastal plains from arid interiors. The climate is mostly hot and arid but does have some variation, with the western Mediterranean coastal regions being slightly cooler, wetter and more humid. The annual cycles of precipitation and temperature are shown in Figure 22. During the summer months, the mean daily temperature consistently exceeds 35°C from June to September, with daily maxima exceeding 45°C at times and overnight minima around 30°C. The winter months (November-February) are cooler, but daily maxima still exceed 25°C, falling to not much below 10°C on cooler nights. There has been an increase in mean, minimum and maximum temperatures over the baseline period.

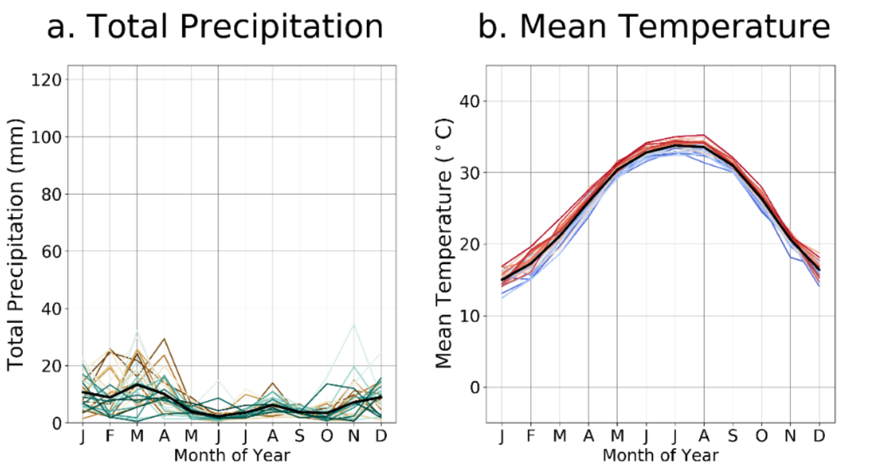



*Figure 22: Observations of a. total monthly precipitation and b. average daily mean temperature over the baseline period (1981-2010) for Zone 7. Each line is one individual year. Colours show the ordering of years from brown-blue (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack, of a trend over the baseline period. The bold black line indicates the average of the 30-year period.*

This is a dry zone, with the small amount of rainfall that does occur happening throughout the year, but mainly between November and April. Rainfall amounts vary from year to year, and there is some evidence of a drying trend during February-May over the baseline period (Figure 22). This will have had a detrimental effect on annual precipitation totals over this period.

The coastal plains and highlands are dominated by mixed rainfed agriculture, the interior regions by dry rangelands, and irrigated agriculture along some large and many small rivers (e.g., the Euphrates, Jordan, Yarmouk, Litani and Orontes). Irrigated agriculture supported by groundwater is also present in the coastal plains, and in some interior areas; this is nearly always unsustainably exploited (World Bank, 2018; FAO and OECD, 2018). In the Lebanese highlands, which reach the greatest elevation, highland agriculture is practised; snowmelt is also an important contributor to water sources originating in the Lebanese mountains.

The distribution of water is highly uneven; away from the rivers, water is mostly available on the coastal plains. For the most part, population densities correlate with water distribution, particularly the cities of Lebanon, and the siting of Aleppo, Hama and Homs next to major rivers. However, without access to major water sources, Damascus (Syria) relies on two springs, creating significant problems for water supplies particularly during droughts (Arraf, 2019), while Amman (Jordan) relies on inter-basin transfers (Shumilova et al., 2017). While the Palestinian West Bank has greater water endowments than Jordan, chronic water insecurity results from issues related to the politics and governance of occupation (Mason, Zeitoun and Mimi, 2012; Giglioli, 2013). Gaza struggles with water supplies and is reliant on transfers. Barley and wheat are the major cereal crops. Fruit trees and olives occupy large areas of agricultural land and vegetable production is also important, particularly for smallholders. Sheep and goat production is particularly important in the arid interiors, either as part of mixed-dryland agricultural systems, or as the basis of pastoral systems.

***Future climate projections***

There is a strong signal and good agreement between climate models for an increase in temperatures by around 2-4°C for most of the year (Figure 23), lending high confidence. There is less agreement on the direction and amount of projected change in rainfall, but most models are projecting little change (Figure 23), lending medium confidence.

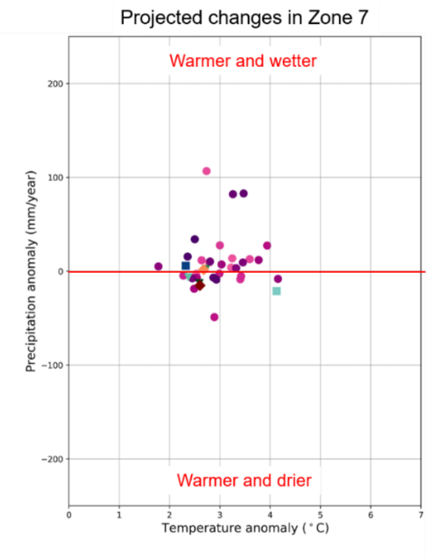



*Figure 23: Projected change in average annual precipitation and temperature in Zone 7 from a selection of climate models. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. The red line indicates the zero axis i.e., no change. Similar plots for projected trends in seasonal means are in Appendix B.*

There is a strong signal and good agreement between climate models for a mean daily temperature rise, with the greatest increase in the hottest months of the year. This includes increases to the maximum and minimum temperatures. As with the other regions, what would be a very hot year in the present climate, will be representative of the coolest year expected in the 2050s. The frequency and duration of periods where the daily maximum temperature is above 40°C may increase, and mean temperatures during these periods will be hotter, often exceeding maximum recorded temperatures to date. Daily and maximum temperatures will exceed 35°C for longer, from earlier in the spring and longer into autumn, which may negatively impact crop production due to heat stress during the flowering period. Warming over all seasons means that periods of cold temperatures will decrease, which may impact production of crops and fruits. These crops require periods of cold to induce flowering, especially stone fruits such as apricots and dates, which will not fruit otherwise.

While little change is projected in total future rainfall amounts, there is some evidence that rainfall will occur less frequently, but rainfall events will be more intense (IPCC, 2013). Increasing temperatures mean that evapotranspiration will also increase. This could be quite substantial in the summer months with average temperatures, which are already hot, increasing by up to 3 or 4°C, implying that less water will be available for crops.

Sea level in the Mediterranean is projected to rise (IPCC 2019), affecting the coasts of Syria, Lebanon and the OPTs, with more frequent inundations and erosion. The frequency of storms in the Mediterranean may decrease, although confidence in this signal is low. When storms do occur, they are expected to be more severe, exacerbating extreme wave events. Sea surface temperature (SST) is projected to increase, and the frequency of marine heat waves (MHW) will increase (Darmaraki et al., 2019). MHW cause mass mortality of invertebrates that underpin the marine food chain (Lewandowska et al., 2014), potentially devastating fish stocks. They also cause coral bleaching and can increase the occurrence of algal blooms.

The major rivers in zone 7 are the Euphrates in Syria, the Orontes in Syria and Lebanon, and the River Jordan in Jordan and the OPTs, providing water for human consumption, as well as agriculture and other industries.

The stream flow of the Euphrates is projected to decrease by as much as 12% due to decreased snow melt in the mountains of Turkey, combined with decreased precipitation and increased evaporation. The Orontes will see similar effects. Research into streamflow in the upper Jordan River has concluded that even a small decrease in annual precipitation amount will lead to a significant drop in streamflow: a decrease of precipitation by 20% could lead to a decrease of streamflow of more than 40% (Givati et al., 2019). For the period 2070-2099 the total runoff is projected to decrease by as much as 23%, with a significant decrease of the groundwater recharge (Smiatek et al., 2011).

# 4 Climate change risks and interpretation for the MENA region

This section examines some of the key climate risks identified in this analysis relevant to development themes. The themes analysed include water resources (4.1), food security (4.2), human health (4.3), cities and infrastructure (4.3) and coastal areas (4.4).

## 4.1 Water resources

### 4.1.1 Overview of relevant socioeconomic trends

The MENA region does not have enough freshwater to supply current demand sustainably. Nine of the world's ten most water-stressed countries are located within the region (WRI, 2019). Growing populations, urbanisation, rising living standards and economic diversification are increasing demand for water (UNDP, 2018). Of the region's population, 65% experience 'high' or 'very high' surface water stress, compared to a global average of 35% (World Bank, 2018). Non-renewable groundwater supplies are being overexploited to meet rising demand, such as the expansion of agricultural production. In Saudi Arabia, it is estimated that the extraction of groundwater for irrigation saw water levels in some aquifers fall more than 200m (UNDP, 2018). While there has been significant progress in improving access to fresh drinking water and sanitation, this progress has been unequal (UNDP, 2018). Overexploitation and pollution also affect water quality and contribute to the degradation of critical ecosystems such as wetlands and springs (UNDP, 2018; World Bank, 2018). For example, the quality of groundwater supplies is undermined by agricultural pollution and saltwater intrusion within coastal aquifers (UNDP, 2018).

Water, food, and energy securities are strongly linked across the MENA region (Allan, Keurletz, and Woertz, 2015; Hoff et al, 2019). Agriculture is the region's largest consumer of water resources, accounting for 80% of national water demand on average, and leaving little water for drinking, industrial and service sector use (World Bank, 2018). In Saudi Arabia, Yemen, Iran and Oman, this figure rises to over 90% (World Bank, 2018). Agriculture is also a significant consumer of energy, largely for pumping irrigation water. Linkages between energy and water are bidirectional: energy generation consumes water, and pumping and desalinating water consume energy (UNDP, 2018; Hameed et al., 2019). Energy demand from desalination is set to grow in the future, as there are few conventional water sources available to meet growing water demand (UNDP, 2018). Much of this growth is expected to take place in Gulf countries (UNDP, 2018) and scenarios forecast by the International Energy Agency (IEA, 2019) suggest that desalination could account for 15% of the region's energy use by 2040. Desalination plants are vulnerable to marine pollution such as oil spills, which can reduce water quality and cease production. They have also been targeted during conflict (Mogieliniki, 2020). This presents risks in terms of water supply, especially as in the event of emergencies some countries may only have limited supplies stored (Tahir et al., 2019). Water is not evenly distributed around the region; some countries enjoy relatively high endowments compared to nations such as Yemen, Kuwait and Libya (WRI, 2019). In countries such as Egypt, Syria, Iraq and Jordan, reliance on international rivers means that the availability of local water resources is shaped by the population and development dynamics in upstream countries (Mazzoni et al., 2018). Of the region's surface water, 60% is shared transboundary, with unequal levels of dependency among states (FAO and World Bank, 2018; Hameed et al., 2019).

The region is water scarce, but the region's water insecurity results largely from weak governance and failures to exploit opportunities and manage risks effectively (World Bank, 2018). In the past, policy and investment were geared towards increasing supply rather than managing use effectively (FAO and World Bank, 2017). The region also continues to heavily subsidise water for both human consumption and agriculture. Subsidising water occurs both directly, and indirectly through the subsidising of fuel used in water pumping. Consequently, water users and investors have few incentives for conserving water or investing in improved water management (World Bank, 2018). 'Unaccounted for' water also undermines efficient water use in the region. The amount of water lost within distribution networks as a result of illegal usage, leaks and inaccurate monitoring, is estimated to range from 15-60% (UNDP, 2018). Water resources are also not allocated evenly, reflecting socioeconomic inequalities within societies (UNDP, 2018). Although laws related to the allocation of water rights exist, these are rarely underpinned by effective institutions for enforcement (FAO and World Bank, 2017). Water allocations often favour politically connected landowners engaged in commercial agriculture, who have a vested interest in obstructing reforms in water policy and management, leaving the rural poor behind (Zeitoun et al., 2012).

Those living in conflict-affected regions suffer from poor access to water. In Iraq and Syria, conflict has led to direct physical damage of water infrastructure and the erosion of social capital linked to the management of national water services (FAO and World Bank, 2017). These conflicts have also witnessed the 'weaponisation' of water by conflicting parties in Iraq and Syria, with attacks on and armed conflict over control of critical water infrastructure, negatively affecting local communities (Schillinger et al., 2020).

Population displacement also raises challenges for managing water resources. Not only do new arrivals place additional pressure on water and sanitation services, but they also pose logistical challenges in terms of ensuring access (FAO and World Bank, 2017). Displacement dynamics are not uniform, with some living in camps and others among local communities, including urban zones. Those living outside official camps often lack access to basic services, while at the same time being difficult to monitor and target (Diep et al., 2017).

### 4.1.2 Summary of relevant climate projections

The climate projections indicate increases in temperature across the entire MENA region. In non-desert areas, such as the Mediterranean coast, Iran/Iraq highlands, Turkey, Syria, and Lebanon (zones 1, 3, 6 and 7), this is combined with decreases in precipitation. In the dry desert regions of North Africa, Iran, and the Arabian Peninsula (zones 2, 4 and 5), climate projections indicate little change to an already very low amount of precipitation. These projected decreases are for annual average precipitation and there is evidence for an average reduction in rainfall amounts throughout the wettest seasons in these areas. Although the trend is for decreasing precipitation, this does not correspond to a reduction in heavy rainfall events; rather, these events are projected to be more intense in the future as more of the rain that does fall, does so in isolated intense downpours (IPCC, 2013; Tabari 2020).

Changes in monthly and daily precipitation are relevant to waterlogging of soils and flooding. In areas of high slopes (e.g., Atlas (zone 1), highlands of Yemen, Iran, Levant (zone 7) and Turkey) intense rainfall leads to dangerous flash flooding. In areas with low slopes, repeated heavy rainfall events within a certain period leads to waterlogged soils and crop losses. Many river systems in the area, notably the Tigris-Euphrates watershed (TEW), rely on spring snowmelt to maintain streamflow. Decreasing overall precipitation will reduce all sources of river recharge, while increasing temperatures will increase evaporation from rivers and result in a lower proportion of precipitation falling as snow. This will reduce volume of snowmelt, specifically impacting rivers which rely on this source of water. Snowmelt will also occur earlier in the year, compounding the impact on river recharge rates. These factors will affect the countries in the TEW: Turkey, Iran, Syria, Jordan, Saudi Arabia, and Iraq, but also other areas such as Morocco, Algeria, Eastern Iran where rivers are fed by glaciers (zone 3), and the Lebanese highlands.

Surface water availability and non-fossil ground water recharge are also significant factors affecting water resources across the MENA region. Surface water availability is important in all zones, and the projected decrease in precipitation in non-desert areas will have significant impacts. In the lowlands of Iran, Turkey, and the Levant (zones 4, 6 and 7), groundwater recharge is of particular importance as abstraction is increasing rapidly, especially in areas without surface water; this is making water availability an increasingly fraught issue.

Potential evapotranspiration (PET) variations are used as a proxy for potential changes in crop water deficit and indicate where evaporative losses from surface water are increasing (see Glossary for evapotranspiration definition): for example, if more water is lost in dam storage in Lake Nasser, and in the TEW through PET. Decreasing or static annual rainfall and increasing temperatures across the MENA region indicate that PET will, in general, increase. Across the Arabian Peninsula and Turkey (zones 5 and 6), a substantial increase in average temperatures in the summer months are expected, raising already hot temperatures by up to 5°C. It should be noted though that high variability in thresholds and sensitivities may mean local, small scale variability in changes to PET across the highland regions of Iran and Iraq (zone 3).

### 4.1.3 Implications for water security in the MENA region – Key risks

#### *4.1.3.1 Increasing agricultural water demand driving water deficits*

Expansion of irrigation and increasing agricultural water demand has been the main driver of unsustainable water exploitation in the region (Molle and Berkhoff, 2009; Sowers, Vengosh and Weinthal, 2011).

As a result, several countries use more than a sustainable supply of water each year, including Jordan (114%), Egypt (117%), Yemen (126%), Libya (711%) and Kuwait (2,200%) (World Bank, 2007). While desalination and water recycling are increasingly important, most deficits have been met by withdrawing groundwater reserves, some of which are renewable, and others are not. For instance, in several parts of Jordan, groundwater tables are falling more than 5m per year, increasing to over 10m per year in Mafraq since 2012 (MWI and BGR, 2019). Comparably, groundwater levels in Morocco's Saiss basin fell by 90m between 1980 and 2012 (Ameur et al. 2017). Such withdrawals cannot be sustained in the long term, and in some areas of Jordan, Yemen, Morocco and other countries there are concerns about aquifers being degraded beyond use. For example, some studies suggest that all groundwater reserves in the Arabian Peninsula could be depleted within a century (Mazzoni, Heggy and Scabia, 2018).

Climate projections indicate increasing temperature, potential evapotranspiration (PET), more variable and declining precipitation, and higher drought frequency, all of which will reduce the amount of surface water available to meet demand from agriculture. At the same time, higher temperatures themselves also increase water demand from agriculture. Water quality is also highly likely to be negatively impacted by higher temperatures, with pollutants concentrated in reduced supplies. This in turn can create negative feedback loops by which supplies are further compromised.

Increasing water demand from agriculture and an overall decline in the availability of water supplies will further increase water stress. In the short to medium term, this is likely to accelerate current patterns of over-withdrawal from, and degradation of, freshwater systems, particularly aquifers (Sowers, Vengosh and Weinthal, 2011; Lezzaik, Milewski and Mullen, 2018). The impacts of climate change over the coming decades on groundwater recharge are unclear; aquifer recharge rates are determined by transmissivity and storage capacities, aquifer depth and geologies of confining layers. Some studies indicate that shallow groundwater recharge in MENA is likely to decline due to reductions in precipitation and more surface runoff during intense rain events; however, the evidence is ambiguous, and recharge may increase under some conditions (Döll, 2009; Pulido-Velázquez et al., 2015).

#### 4.1.3.2 *Increasing economic competition and governance stresses over water allocations*

Further diversification of the region's low- and middle-income economies beyond agriculture will be key to growth, job creation and the affordability of imported food (Antonelli and Allan, 2015; United Nations World Water Assessment Programme, 2016). However, with agriculture accounting for over 80% of the MENA region's national water withdrawals on average, limited supplies are left available for other uses (Figure 24). Insufficient and interrupted domestic water supply is common in major cities of low- and middle-income countries such as Lebanon, Jordan, Yemen and the OPTs, with sometimes significant social costs (Zawahri, Sowers, and Weinthal, 2011). Similarly, in 2015 businesses leaders ranked water insecurity the most significant risk to firms and economies in the region (World Economic Forum, 2016). However, the importance of agriculture and agricultural water supply for national food security, rural jobs and for landed elites makes water sector institutional reforms and reallocations politically challenging (Sowers, Vengosh, and Weinthal, 2011; Allan, 2012).

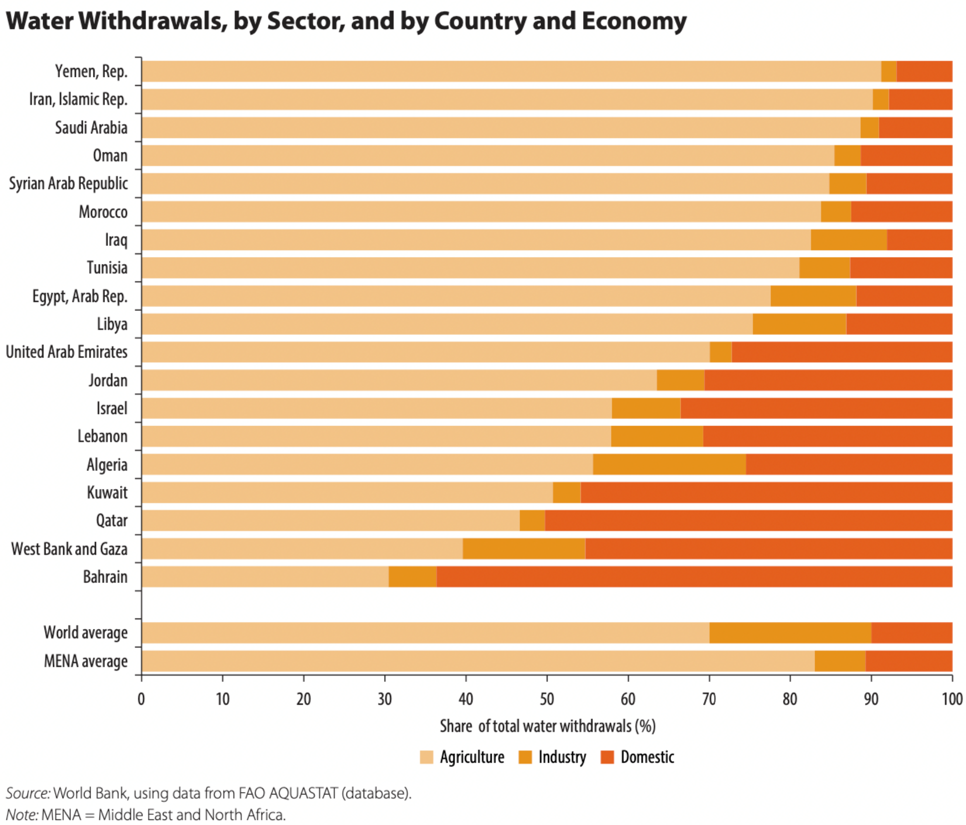



*Figure 24: Water withdrawals, by Sector, and by Country and Economy. Source: World Bank, 2018*

As water supply-demand deficits widen in the changing climate, competition over available water supplies between users and uses will be exacerbated. Competition between agriculture and other sectors is likely to be prominent, given agriculture is already the region's largest consumer of water and is likely to experience large increases in water demand from climate change.

Agriculture is a relatively minor contributor to employment and GDP in high-income countries, and these countries experience lower barriers accessing investment capital for desalination and other non-conventional sources of water. However, low- and middle-income countries with high or extremely high water stress and large agricultural sectors will be much more vulnerable and face more severe water governance challenges. These include Lebanon, Iran, Jordan, Yemen, Morocco, Algeria, Tunisia, Syria, West Bank and Gaza, Turkey and Egypt (Gilmont, 2015; WRU, 2019; World Bank, 2020).

Intensifying competition for water implies lost productivity and burdens on middle-income countries struggling to grow their economies and generate jobs. Economic losses from climate-related water scarcity in the MENA region have been projected at between 4 to 10% of GDP (Taheripour et al., 2020), the largest in the world (World Bank, 2016). These impacts will not be distributed evenly. Qatar, Israel, Lebanon, Iran, Jordan, Libya, Kuwait, Saudi Arabia, the UAE, Bahrain and Oman are all classified as 'extremely high' in terms of their baseline water stress, which measures the ratio of total water withdrawals to available renewable water supplies (WRI, 2019).

Generating jobs and economic growth in sectors less water-intensive than agriculture may alleviate some of this competition (Allan, 2012; Gilmont, 2015; Antonelli and Allan, 2015). Nevertheless, agricultural is, and likely will remain, the largest source of employment for the rural poor (Allan, 2012). As competition for water increases, already stressed governance systems are likely to face more political challenges around water allocations and rights. For example, allocations may favour large agricultural producers or state-owned industries, while small farmers may receive lower prioritisation. As competition for water intensifies, governance systems for agreeing and enforcing water rights and allocations, which have so far under-delivered on sustainable water management, are likely to come under increasing stress (Rached and Brooks, 2010).

#### *4.1.3.3 Conflict and water*

'Water wars' are a prevalent theme of water and climate discourse in the region. Examples of rivers and sources of transboundary tensions include: the Nile (zone 2), Tigris-Euphrates (zones 6, 7, 3 and 5), and Jordan (zone 7) rivers (Swain, 2001). All of these are transboundary rivers in which riparian states have engaged in combinations of sabre-rattling, diplomacy and institutional agreements over water-sharing. However, although tensions escalate over such transboundary water sources, there is little evidence that countries are willing to engage in armed conflict over transboundary water (Katz, 2011). Comparably, there are reports of intracommunal violence and tensions over water, particularly in rural areas of Yemen and Iraq, and water is known to have been used as a weapon of war in Syria and Iraq (King, 2015; Gleick, 2019). These examples are usually highly localised and context-dependent: for example, already hostile relationships may turn violent over water conflicts rather than water being the primary cause.

Globally, many river-sharing agreements are not designed to deal with increasingly variable precipitation, higher temperatures and evaporation (World Bank 2010). As climate change exacerbates supply shortages, quality and increasing demand, growing tensions over transboundary resources are likely, particularly where the upstream country is building or has built dams, such as in Turkey on the Euphrates and Tigris rivers. Increasing variability will also challenge the design assumptions of major infrastructure such as the Grand Ethiopian Renaissance Dam on the River Nile, and strategies for filling and releasing water (Conway 2017). Such issues are likely to be particularly problematic during drought years: For example, during the drought of 2014, Turkey stopped releasing water down the Euphrates, compounding drought impacts in Syria (Jaafar and Woertz 2016). Nevertheless, increased chances of armed conflict as a result are not a foregone conclusion.

Local water shortages and competition for water are likely to increase in a hotter climate with more variable or decreasing precipitation. Such conditions can lead to local conflict that are usually rooted in wider and deeper social or political grievances spanning beyond increased water competition amidst diminishing supplies (Ide et al. 2020). However, the potential for these to turn violent should not be exaggerated.

***Focus box 4: Compound risks: governance, drought, and conflict in Syria***

Climate risks are not isolated; how they interact with and compound other sources of risk can be difficult to disentangle. Despite some claims to the contrary, drought and climate change clearly did not cause the uprising and eventual conflict in Syria (Selby et al., 2017). The Syrian civil war emerged out of social, economic and political grievances resulting from decades of poor governance. A *subset* of grievances in rural areas stemmed from inept public responses to a humanitarian crisis resulting from drought, the impacts of which were greatly exacerbated by long-term mismanagement and degradation of natural resources (Barnes, 2009; de Châtel, 2014).

By contrast, drought impacts in parts of Syria during 2014 and 2018 clearly impacted both on the humanitarian situation and on crisis interventions. Crop failures and water shortages led to higher prices for people living in poverty, and greater demands on humanitarian responses, compounding and compounded by impacts of the ongoing conflict (Humanitarian Country Team, 2014; USAID, 2018).

#### *4.1.3.4 Environmental degradation*

Rapid urbanisation, unsustainable water abstraction, pollution and land reclamation have significantly degraded aquatic ecosystems across the MENA region in recent decades (Scott, 1995; Darwall, 2014). As rivers are dammed and waters diverted for human use, the reduced amount of water for natural ecosystems reduces their extent, ecosystem function and biodiversity. Low environmental flows of water have also contributed to increasing concentrations of water pollution, associated with impacts on human health in several countries including Egypt and Lebanon (e.g., Megahed et al., 2015; el-Fadel et al, 2003).

Future climate stresses such as decreasing precipitation, increasing evapotranspiration and increased heat stress will further degrade natural water stores and ecosystems, exacerbating the stresses of direct human impacts (Leberger et al., 2021). As well as impacts mediated through water resources, the MENA region's coastal wetlands will also be exposed to impacts from sea level rise (see section 4.4) (Blankespoor, Dasgupta, and Laplante, 2012).

Climate change impacts will exacerbate existing drivers of ecosystem degradation, threatening the loss of biodiversity and ecosystem services such as fishing grounds in aquatic ecosystems across the region. Particularly vulnerable areas are likely to include the Litani (Lebanon and Syria), Jordan (Jordan, Israel, OPTs), and Oum er Rbia (Morocco) rivers (Darwall, 2014), as well as wetlands and lakes such as: the lakes of Egypt's north coast (El-Shazly et al., 2017), Lake Urmia in Iran (Schmidt, Gonda and Transiskus, 2020), the marshes of southern Iraq (Priestley, 2020), and wetlands of Tunisia, Algeria and Morocco (Flower, 2001).

Freshwater quality is another issue of particular concern, especially where there are current concentrations of water pollution. While intense rainfall events may increase the flushing of pollutants in some cases, lower average flows in streams and rivers imply increasing concentrations of pollutants in freshwater environments (Whitehead et al, 2009). The increase in pollutant levels can also lead to algal blooms which are harmful to fresh water and marine life, often creating 'dead zones' and making the water unfit for human consumption.

## 4.2 Food security

### 4.2.1 Overview of relevant socioeconomic trends

Agriculture plays a relatively small and declining role in the region's economies, yet remains socially significant, especially for the rural poor. On average, agriculture contributes 13% to the GDP of MENA countries (Pratt et al., 2018). This ranges from low single figures in Gulf countries to contributions of 14% in countries such as Morocco and Egypt (Woertz, 2020). Agriculture contributes 26% to employment on average, but in low and lower-middle income countries this rises to an average of 50% (Pratt et al., 2020). Furthermore, given that up to 70% of the region's poor live in rural areas, average contributions to GDP obscure the importance agriculture plays in terms of alleviating rural poverty and food insecurity (Pratt et al., 2020; Jobbins and Henley, 2015).

The region contains some of the world's most productive agriculture areas, especially along major river basins such as the Nile and the Euphrates. However, as a whole, MENA is commonly described as a region where agricultural productivity is constrained by limited water and soil resources, extreme heat and aridity, and drought risk. Since the period of European colonisation and until relatively recently, agricultural development was largely framed in terms of 'overcoming geography' through expanding irrigation coverage (Davis and Burke, 2011; Borgomeo and Santos, 2019). While this had impressive successes in boosting yields, there have also been costs. Growing demand for irrigation water is the key factor driving unsustainable consumption of water resources across the region. Land use changes through agricultural modernisation have also degraded land and water resources and accelerated desertification processes in some areas. Increasing water stress (quality and quantity) and growing competition for water from other uses implies there is little scope for further irrigation expansion in the future, and that in some areas, irrigation coverage may decline in the future.

Other constraints on agriculture include land fragmentation, low levels of diversification and job creation in the off-farm rural economy. Smallholders make up most of the region's farmers, but government policy is predominately orientated towards larger agribusinesses (Dixon et al., 2001; FAO and OECD, 2018). Compared to larger farms, small scale producers are often excluded from public support or private financial resources, constraining their options for investing in productivity and climate change adaptation. Overall, the region's agricultural sectors and rural economies are hampered by poor productivity and weak growth, resulting in poor job creation, which in turn drives rural to urban migration (Pratt et al., 2018).

Food production continues to play a significant role in the region's political life. Although the economic importance of agriculture differs between countries, the 'rural social contracts' between central governments and rural communities are generated through the allocation of land and water resources, particularly to rural elites (Houdret and Amichi, 2020). The issue of food security is especially politically sensitive, with the key issue lying in food prices, rather than food availability *per se* (Jobbins and Henley, 2015). On average, households in the region are said to spend 44% of their income on food compared to 6.4% in USA, 8.2% in the UK, 46.7% in Kenya and 56.7% in Nigeria. Food price inflation and volatility also have socio-political impacts (FAO and OECD, 2018). In 2011, food prices were explicitly referenced in the popular slogan of the Arab Spring, 'bread, freedom, and social justice', demonstrating the nexus of social grievances around living standards, corruption and failing social contract (Woertz, 2020). Historically, governments have tried to offset food price increases through subsidies. As the examples of Kuwait and Egypt show, under fiscal pressure governments are more likely to make cuts to other forms of subsidies such as fuel, rather than food (Woertz, 2020).

International trade has a key role in meeting the food needs of the MENA region's people, particularly for staple cereals. Cereals such as wheat have high water requirements and cover around 65% of the region's arable land (FAO & OECD, 2018; Woertz, 2020), yet cereals are also relatively cheap on international markets.

Importing cereals – and the embedded 'virtual water' used to produce them – allows the region's countries to reallocate water from cereal production to essential social needs and higher-value economic activities, such as tourism and export-oriented agriculture (Allan, 2012). The MENA region's countries import 50% of their cereal demand on average, rising to over 85% in Saudi Arabia and Yemen (Jobbins & Henley, 2015). However, these high levels of food import dependence create other socio-political vulnerabilities through exposure to food price volatility in global markets, supply chain disruptions and geopolitical threats of weaponising food (Woertz, 2013; Koch, 2021).

Food import dependency is likely to increase as the region's population grows. While population growth is expected to slow, this will be uneven and the region's population is still set to grow by 130 million by 2050 (Waha et al., 2017). The majority of this growth will take place in urban areas, which may increase demand for more processed foods that include higher quantities of fats and sugar; this implies increasing dietary-related health burdens (Hwalla et al., 2016; FAO and OECD, 2018; Woertz, 2020). A growing urban population will place additional pressures on food demand and distribution, while at the same time offering opportunities in terms of more efficient market coordination and distribution. This in turn could lower prices for urban consumers (Jobbins and Henley, 2015).

#### 4.2.2 Summary of relevant climate projections

Across the MENA region, there is a strong signal for warming over all seasons, with increases seen in mean, minimum and maximum temperatures. During spring and summer, the number of days reaching temperatures above 35˚C is projected to increase, which is likely to cause heat stress in fruit crops during the flowering period. Other crops have different maximum temperature and precipitation sensitivities at various life stages which impact crop yields (see Dreccer et al. 2018). This will affect the entire region including rainfed and dryland systems as well as pastoral systems, where a shortage of available forage results in overgrazing. Higher temperatures could leave livestock vulnerable to negative health impacts such as heat stress, which would result in a decline in animal productivity. Higher temperatures are likely to impact the development of all crop types, as more energy is devoted to managing heat stress rather than growth. This will be especially acute in areas already experiencing high temperatures. Increasing temperatures and little change in rainfall means that evapotranspiration will increase across the region, further reducing water availability for crops.

Increasingly high spring and summer temperatures may also put additional stress on cropping calendars, even where systems are already adapted around hot dry summers, such as in the Arabian Peninsula (zone 5). Vernalising temperatures, where periods of cold during the autumn and winter seasons are required to induce flowering, will be affected by rising minimum temperatures, presenting challenges for multiple crops across all the climatic zones. However, as both minimum and maximum temperatures are projected to increase by approximately the same amount, crops such as citrus are unlikely to experience stress associated with greater diurnal temperature ranges.

There is no signal for a change in the timing of the onset of rains, meaning there is no anticipated delay to the start of normal growing seasons across the region due to precipitation. However, the timing and duration of traditional growing seasons may be affected by higher temperatures across all seasons. For much of the region (for example in the Iran lowlands of zone 4) there is considerable variability from year to year in the timing of the onset of rains; climate model simulations indicate little change in inter-annual variability in the future. Comparably, there is no signal for the changes in the onset of winter rains, however climate models have difficulty replicating the nature of localised rainfall events in these zones, implying lower confidence in these seasonal projections.

There is high confidence that the intensity of extreme precipitation events is projected to increase with warming (IPCC, 2013, Tabari 2020). This means that despite indications that overall rainfall totals may reduce in some areas, more of the rain that falls could fall as intense, shorter duration events. This could increase risks of flooding and waterlogging of soils, potentially contributing to crop losses and soil degradation.

Increasing minimum temperatures combined with a reduction in precipitation totals in some zones, with no distinct change in precipitation in already arid locations, indicates that drought frequency and intensity is expected to increase compared to the present day. This presents particular risks for rainfed, dryland and pastoral systems, as well as increasing the demand for irrigation water.

### 4.2.3 Implications for food production in the MENA region – Key risks

#### *4.2.3.1 Systemic vulnerabilities in agriculture*

Agricultural livelihoods and production systems across the MENA region are complex and diverse, adapted to specific local conditions: seasonal water availability, temperature regimes and soil fertility (Dixon et al, 2001). Most of these agricultural systems depend not on the continued productivity of a single crop, but of several different crops, all responding in slightly different ways to climate variables at different points in the year. Production systems are also accompanied by complex infrastructural, social and economic systems, such as food supply chains.

Collectively, these agricultural and food systems experience multiple stresses, such as the degradation of natural resource bases and persistent poverty, that constrain their adaptive capacity and undermine resilience (Dixon et al., 2001; Jobbins and Henley, 2015; Waha et al., 2017). Therefore, the risks that climate change poses to food and agriculture need to be understood in a systemic way, considering multiple factors beyond the impacts of shifts in single climate variables on single crops (Fischer, Shah, and van Velthuize, 2002; Urruty, Tailliex-Lefebvre and Huyghe, 2016).

The most prominent risks to agriculture from climate change are apparent in crop production. Increasing maximum and minimum spring and summer temperatures and increasing drought risk are likely to result in depressed yields and raised risk of harvest losses, particularly in non-irrigated systems. Our analysis suggests that yields of rainfed cereals such as barley, are likely to decline due to higher summer temperatures, shortening viable growing seasons, and higher rates of evapotranspiration increasing crop demands for water. Likewise, summer crops and some cash crops such as horticultural crops, may become less tenable in locations where higher temperatures, increases in evapotranspiration, and constraints on water availability limit yields.

Warmer winter temperatures, with rising minimum temperatures across the region, also imply declining yields of stone fruits such as olives, dates, apricots and peaches. Conversely, in some areas, warmer winter temperatures may result in opportunities for the production of new crops unable to tolerate current cold snaps experienced in highlands, or able to benefit from higher levels of photosynthesis during the winter.

Declining agricultural productivity will increase compound risks through lower rural incomes, reduced rural job creation and lower national food production, particularly where cereal production is reduced. This may also impact economically important crops such as fruit and vegetables, which are key agricultural exports for several countries. For example, dates account for 65% of Tunisia's total agricultural exports (Pratt et al., 2018). Overall, horticultural crops account for an estimated 40% of the total value of MENA agricultural production (FAO and OECD, 2018).

#### *4.2.3.2 Livelihood groups and production systems*

The impact of climate change will be unequal across different livelihood groups and production systems, with some key farming livelihood groups at greater risk of being disproportionally affected in comparison to others (see Appendix C). For example, pastoral and highland areas are particularly vulnerable due to the fragility of natural resource bases such as soil and water, while such locations are already home to some of the region's poorest communities (Dixon et al., 2001; Waha et al., 2017). In a region where half of all land and a quarter of all arable land is degraded, higher temperatures and aridity will exacerbate processes of desertification, erosion, and environmental degradation (World Bank, 2019).

Our analysis suggests that pastoral and mixed dryland agriculture areas are likely to become more marginal due to greater heat stress, increased variability in rains, seasonal shifts, and aridification. These findings concur with those of others who suggest that some areas of_dryland agriculture are likely to revert to pastoral rangelands as cereal farming becomes unviable (Verner, 2012; World Bank, 2019). Dryland and pastoral producers across the region increasingly rely on supplementary feed and transported water to manage drought risk and compensate for declining rangeland and cereal productivity, (Hazell, 2003; Mohamed and Squires, 2018), trends climate change is likely to accelerate. Our analysis also suggests highland farming systems, such as those in Iran, Morocco and Yemen, could become more marginal due to changes in temperature and water regimes, which in turn increase the risk of soil erosion. By contrast, production in irrigated systems, such as along the Nile and Euphrates rivers, is likely to be more resilient than in areas relying on declining or more variable rainfall. Higher temperatures will see crop water requirements increase; however, irrigated agriculture will place additional stress on supplies from rivers and groundwater. The region's remote and marginal highlands, drylands and pastoral rangelands are currently areas of extensive rural poverty (Dixon et al., 2001). Our analysis suggests that these areas also host the agricultural and livelihood systems most vulnerable to climate impacts. This implies the risk that the region's highlands, dryland and rangeland areas become trapped in cycles of lower agricultural productivity, resource degradation and worsening poverty.

Climate projections indicate higher temperatures, declining and variable rainfall, and higher aridity across the region. These trends also indicate increasing crop water requirements in agriculture. While conversion of rainfed to irrigated agriculture will be a climate adaptation option in other parts of the world (Rosa et al, 2020), constrained water supplies mean irrigation expansion will not be widely possible in the Middle East and North Africa. These factors imply increasing competition over water between agriculture and other sectors, and that areas without access to sufficient water for irrigation will be most affected.

***Focus box 5: Gender and social vulnerability to climate change***

Markers of social difference, such as disability, significantly shape vulnerability to climate impacts. Gender is a particularly prevalent and powerful source of differential climate vulnerability. Unequal access to resources, economic opportunity and participation in decision-making mean that men and women have different exposure to, and differing capacities to respond and adapt to, climate risks. In rural areas of the MENA region, three key gender-differentiated climate vulnerabilities relate to women's roles as primary caregivers, the extent of unpaid women's labour in agriculture, and male outmigration contributing to the prevalence of female headed households (Verner, 2012). These three issues all increase the burdens on rural women and limit their ability to respond and adapt to changing climate risks.

#### ***4.2.3.3 Drought risk management***

Drought presents one of the greatest climatic hazards in the MENA region in the present day, yet drought management is largely based in crisis responses rather than proactive risk management (Jedd et al., 2020). Reactive responses to crisis have high costs compared to proactive risk management measures, and are also less effective at addressing the agricultural, economic and social impacts of drought (WMO and GWP, 2017). The lack of effective risk management institutions also encourages individual farmers to take unsustainable risks and use water and land resources unsustainably (Hazell, 2009).

Climate projections show increased maximum temperatures in the summer, higher evapotranspiration, increasing winter minimum temperatures and more variable rainfall under climate change, all of which increase exposure to drought and risk of harvest failure. Higher evapotranspiration rates will also increase losses from standing bodies of water, such as irrigation systems, dams and lakes; for example, Egypt's Ministry of Water and Irrigation estimates that by 2100 losses from the High Dam Lake will increase by up to 10% (Elba et al, 2017).

Drought impacts can contribute to harvest failures, lost income for farmers, higher costs for food consumers, and other economic and social costs such as unplanned migration and unemployment (De Chatel, 2014; Opitz-Stapleton et al., 2017). Droughts can also contribute to rural poverty traps, undermining development gains made during good yield years. This could manifest into more frequent, more widespread, and deeper social and economic drought impacts such as rising food prices and unemployment which could in turn contribute to political instability (Woertz, 2017).

#### *4.2.3.4 Food import dependence*

MENA countries are heavily dependent on food imports, particularly for staple cereals such as wheat, and this dependency is increasing. The key food security issue for governments is ensuring the availability of sufficient amounts of safe food at affordable prices. The continued reliance on food imports leaves MENA countries highly exposed to price shocks and volatility in global markets, as seen during the food price crisis of 2008. Food prices are highly political, and in contexts such as Egypt, have contributed to social and political unrest (Korotayev and Zinkina, 2011; Al-Shammari and Willoughby, 2019).

Our analysis suggests a series of future endogenous risks to agricultural productivity across the MENA region, with yields of important food staples, including wheat and barley, likely to decrease. These risks imply that the current trend towards increasing reliance on food exports will accelerate further.

Increasing reliance on food imports means greater exposure to exogenous risks, such as climate impacts on agriculture production in global breadbaskets and price volatility in international food markets (Benzie and John, 2015; Porter et al., 2014). Globally significant crop export production sites, such as Canada, China and Russia, will also be impacted by climate change. For example, the IPCC projects that the global production of wheat will significantly reduce with each degree Celsius of global temperature increase (Hoegh-Guldbergy et al., 2018). Such impacts will not be uniform; some areas may see increasing productivity whilst others will see a reduction (Hoegh-Guldbergy et al., 2018). Greater risks of harvest failure in major breadbaskets also imply greater food price volatility in global markets, increasing the risks of food price shocks in MENA countries with heavy reliance on food imports (FAO and OECD, 2018).

Impacts of food import dependence will be experienced differently in different countries across the MENA region. Richer states within the region, such as Saudi Arabia, are likely to have the financial means to absorb rising food costs, including those linked to food imports and foreign markets (Jobbins and Henley, 2015). Countries such as Egypt and Morocco may be able to boost domestic food production slightly while growing other economic sectors to offset food price volatility risks. In countries like Jordan, and especially Yemen, poor fiscal performance and high levels of import dependency make them highly vulnerable to such risks (Jobbins and Henley, 2015). Households across the MENA region already spend a high proportion of their incomes on food and are highly exposed to food price inflation (Woertz, 2017). Poor populations living in countries affected by conflict, where economies are stagnant and where poverty is increasing, are likely to be particularly affected.

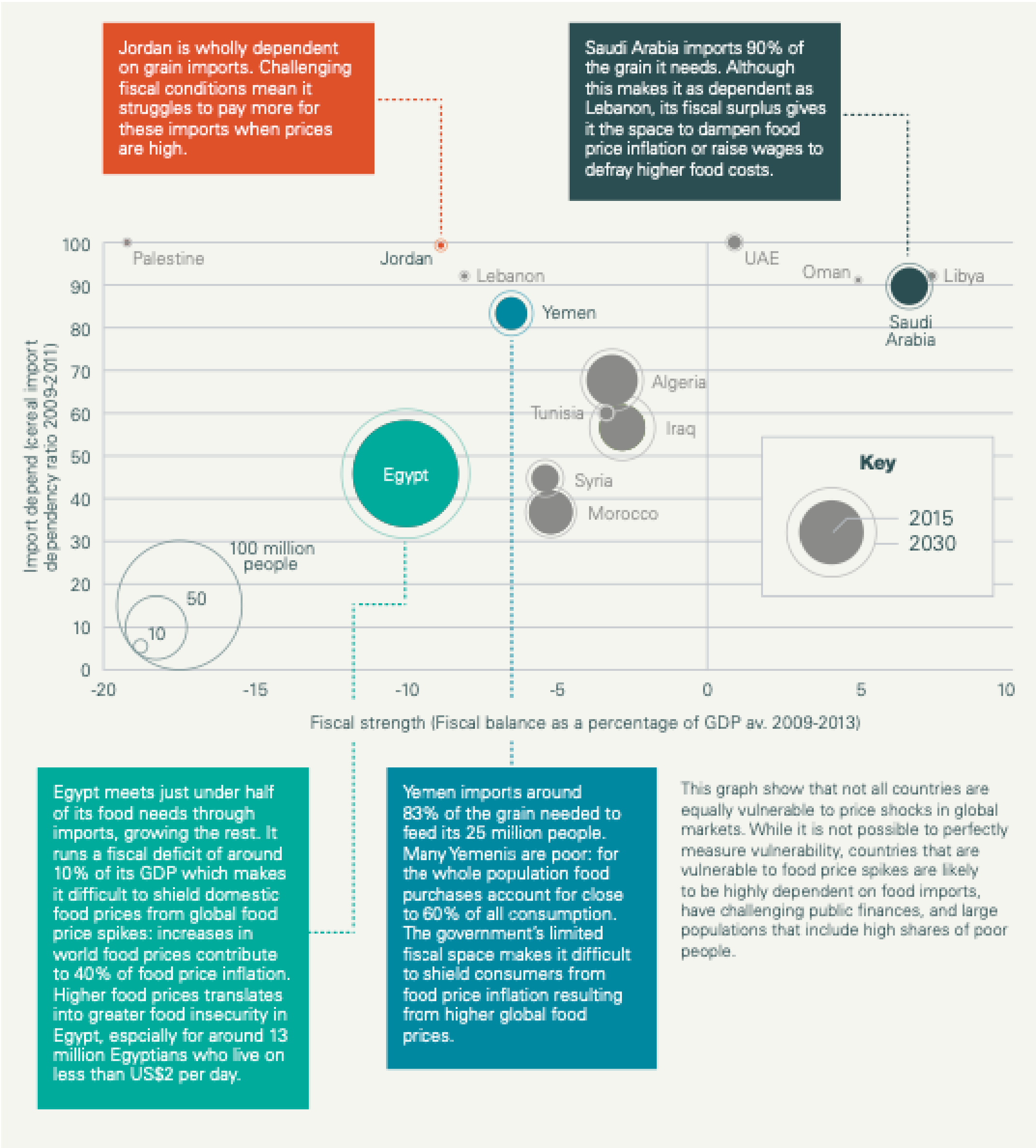



*Figure 25: Countries are most vulnerable to food price shocks when neither citizens nor governments can defray the higher costs. Source: Jobbins and Henley, 2015. Copyright © World Food Programme 2015*

## 4.3 Human health, cities and infrastructure

### 4.3.1 Overview of relevant socioeconomic trends

With the decline in rural economies and the availability of economic opportunities within cities, the region's urban centres will continue to attract new arrivals (major cities in the MENA region are shown in Figure 26). By 2050, it is projected that the region's urban areas will account for 70% of the population (UN Habitat, 2020a). The main drivers include economic migrants from overseas, rural-urban migration and those displaced by conflict (UN Habitat, 2020a; IOM, 2015). The rate of growth is however not uniform, with urbanisation rates varying across the region (IOM, 2015; UNESCWA, 2016). In response to urbanisation, due to the limited scope for expanding mega cities, governments in countries such as Algeria, Tunisia and Egypt have adopted policies to encourage the movement of economic activity and populations towards second tier cities (UN Habitat, 2012).

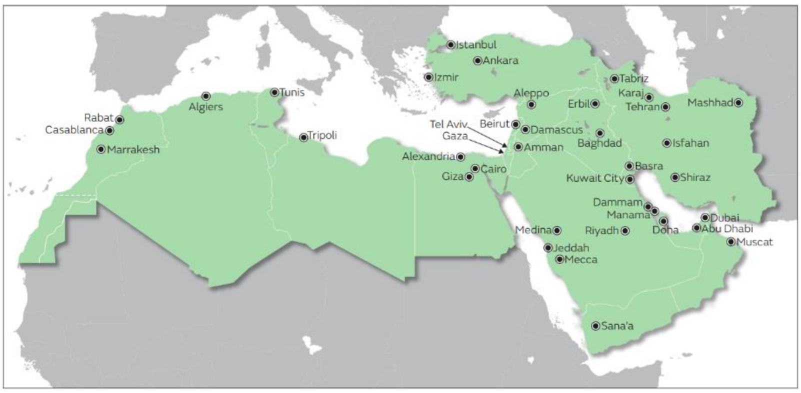



*Figure 26: Cities in the MENA region with population over 1.5 million.*

The growth in the region's urban areas has not always been matched in terms of the availability of services or affordable housing. For example, in Gulf states there is a disparity between the earnings of migrant workers and higher earning residents, with migrants often living in temporary housing on construction sites or within informal settlements (UN Habitat, 2012). Growing informal settlements in the region are an evident sign of increasing urban inequalities. While some informal settlements have access to basic services, others do not (UN Habitat, 2012; UN Habitat, 2020a). The dense nature of their construction often makes retrofitting services difficult (UN Habitat, 2020). These sites are often poorly built and located in hazard prone areas, exposing those who live there to both manmade and natural hazards (World Bank, 2011; Peters et al., 2019).

Rates of urbanisation coupled with increasing populations are only adding to the issue of generating enough jobs. In both mega and second tier cities, the inability for their economies to absorb growing populations is said to be fuelling issues of unemployment, underemployment and poverty (Monshipouri, 2020). Excluding the agricultural sector, it is estimated that 45% of the region's employment is linked to the informal economy (UN Habitat, 2020b). This form of work is marked by job insecurity, low pay, poor workers' rights and reduced job growth (UN Habitat, 2020; Kabbani, 2019). In Palestine, Egypt and Jordan, young people account for 80% of those working within the informal sector (Kabbani, 2019). Youth unemployment remains an issue in the region, with a figure of 30% youth unemployment placing the MENA region above the global average of 13% (Kabbani, 2019).

Analysts suggest that the concentration of conflict within urban areas is likely to continue to define our 'conflict environment' (Kilcullen, 2012). The impact of conflict on the region's urban areas is only adding to the difficulties some cities are facing, both in terms of physical and non-physical damage (FAO and World Bank, 2017). Essential services such as water, sanitation and healthcare are undermined not only due to physical damage, but also the loss of individuals critical for their operation (ICRC, 2015; FAO and World Bank, 2017).

The region has seen improvements in healthcare services in recent years. In key areas such as life expectancy, there has been a decline in mortality rates and a reduction in communicable diseases (SHOPS Plus, 2018; Asbu et al., 2017). Although government spending on healthcare shows signs of increasing among MENA countries, it is still low compared to global averages (SHOPS Plus, 2018; Asbu et al., 2017) and access to healthcare is characterised by individuals spending their own income to access healthcare services (Asbu et al., 2017).

The rise in non-communicable diseases such as diabetes, presents a challenge for the region. Regional averages suggest a higher than global average in rates of obesity among men and women (Asbu et al., 2017). This has been linked to diets and urban lifestyles characterised by a lack of exercise (Wiggins and Keats, 2014; Mabry, 2018). Urbanisation is expected to see a rise in demand for processed foods containing high quantities of fats and sugars (FAO and OECD, 2018). Poor air quality is also linked to pulmonary and cardiac health risks (WHO, n.d.) In cities such as Cairo, poor air quality as a result of ambient particles and nitrogen dioxide, has been linked to an estimated 8-11% of deaths in those aged over 30 (Wheida, et al., 2018). Estimates for the region suggest that 6.8% of deaths in 2013 were the result of diseases linked to air pollution (World Bank and IHM, 2016).

The success in bringing down mortality rate coupled with a drop in fertility rates, could see the rise in the number of people aged over 65 (UNESCWA, 2017). The projected average of 11% hides variations within the region. Several countries are likely to see an increase to 15%, and highs of 20% and 23% in Lebanon and Tunisia respectively (UNESCWA, 2017). To give a sense of this increase, in 2015 Tunisia had the largest proportion of people aged over 65 at 8% (UNESCWA, 2017). Ageing populations are likely to place an increased pressure on state services including healthcare, especially in urban areas where social support networks are not as strong as their rural counterparts (Mckee et al., 2017).

### 4.3.2 Summary of relevant climate projections

High temperatures are already a significant issue in many of the cities in this region, particularly during the summer months. Climate projections show a strong and consistent signal for further warming, with the greatest temperature increases during the hottest periods of the year. Given the physiological limits of humans to withstand extreme heat, heat stress and even the basic habitability of some regions are a factor (Raymond et al., 2020). While high temperatures and heat stress are a risk throughout the region, in urban areas the impacts are exacerbated by the urban setting itself. High daytime maximums affect the amount of time that can be spent in productive work, but overnight minimums are important for the body’s ability to cool down, and so also have a critical relationship with overall mortality and morbidity. In urban areas, the large thermal mass of buildings reduces the diurnal range by trapping daytime heat and releasing it slowly overnight. This urban heat island effect means that cities are often 2-3˚C warmer than the surrounding area.

In coastal cities, higher humidity, associated with proximity to the sea rather than climate change, is an important climatic factor. Additionally, sea level rise and coastal erosion are both projected to increase with climate change, with consequences for coastal city sea defences.

Future changes to rainfall are more uncertain than the projected increases in temperature and show differences across the region. However, combined with increases in temperature, water availability and quality is another consistent risk across urban areas.

Although models are very broad scale and so too coarse to adequately resolve local, convective rainfall events, the dynamics of the hydrological system mean that in a warmer world more of the rain that falls is likely to fall in high intensity events (IPCC, 2013; Tabari, 2020). In the MENA region, where often rain mainly falls in short-lived downpours, this will mean an increase in intensity, if not the frequency of extreme rainfall events (de Vries, et al., 2018). Areas currently prone to flooding could expect to experience more severe flooding events in a future, changed climate.

Another feature of the region's climate that is important for cities are dust storm events. There is little direct evidence on these events, particularly as little is known about how winds may change in the future. However, as with extreme rainfall, there is good indirect evidence to indicate that dust storms could be more frequent in the future. Although rainfall projections are varied, the more intense evapotranspiration that will occur as temperatures rise, and the increased frequency and intensity of droughts, will increase the occurrence of dust sources that cause dust storm events, contributing to the poor air quality in many of the cities in the MENA region.

### 4.3.3 Implications for urban areas and human health in the MENA region – Key risks

#### *4.3.3.1 Human health*

Some of the most significant impacts of climate change, particularly in the urban context, are potentially associated with human health. In this region, impacts associated with thermal stress, already a high impact area, will become substantially worse with climate change. Temperatures in the region, which are already on the limits of human habitability in many areas in some parts of the year, will increase substantially. For coastal cities, the problems of heat stress are likely to be greater, not because the temperature increase will be greater along the coast, but as a result of higher humidity in these areas causing greater thermal stress on the body.

A more complex health impact, but one also related to climate change, is air pollution. Again, this is already a problem in many cities across the region. Climate change will contribute to exacerbating air pollution through a potential increase in dust events associated with drier conditions and more frequent drought events increasing dust source areas.

Both thermal stress and air pollution will particularly affect megacities in the region, but a number of smaller cities often house more people overall and may have fewer resources to manage climate-related heat crises. The most vulnerable groups are the elderly, infants, the disabled, and pregnant women – those most sensitive to heat and pollution – but also refugees and manual workers who may be less able to manage their exposure to dangerous climate conditions. The region has a high proportion of workers, particularly migrant workers, linked to the informal economy, and the aging population is a particular concern.

Two other areas of health that may be affected by climate change, but for which it is more difficult to draw firm conclusions about changes in risk, are shifts in vector-borne and zoonotic disease dynamics and dietary related health problems. For both themes, links to climate are extremely complex and even where climate is a contributing factor, health outcomes are dominated by socio-economic conditions (Campbell-Lendrum, et. al, 2015; Medek et. al., 2017).

***Focus box 6: Limits to adaptation***

The rate and magnitude of climate change in the coming decades may exceed the limits to adaptation of some socio-ecological systems (Adger, et al., 2009). The limits to climate adaptation are a complex set of thresholds that can be physical or social. In a social context the limit to adaptation comes when no adaptation actions are available or sufficient to manage risks to a level considered tolerable to achievement of objectives (Dow, et. al., 2013). From a physical perspective, a limit to adaptation is more straightforward in the exceedance of the absolute physical limit of survivability of the climate, so that no adjustment in exposure or vulnerability can compensate. For the MENA region, where the climate is already extremely harsh, climate change, even at relatively low levels, has the potential to exceed limits to adaptation in some regions at some periods of the year. The main example of this is associated with thermal stress. A wet-bulb temperature (air temperature measure by a saturated thermometer) of 35°C marks the upper survivable physiological limit for humans, although much lower values have serious health and productivity consequences. The Gulf Coast is one of the regions that has already been observed to have exceeded this threshold in the recent past. Climate model projections indicate that this threshold will be exceeded routinely in this area by the 2050s, and occasionally across a wider area, mainly along coastal regions of the Middle East (Raymond, et al., 2020).

#### *4.3.3.2 Urban water availability and sanitation*

As urban areas grow, often in an informal way, demand for water will increase and sanitation services will come under increasing pressure. The climate signal for rainfall is mixed, but with increasing temperatures leading to greater evapotranspiration, water stress will become an increasingly serious issue. This is combined with the greater demand for water from agriculture that will result from higher temperatures, placing urban basic services under further pressure just as urban demand for water also increases.

For some urban areas the absolute availability of water will be a factor, but for most this will be a more complex question of quality water availability, demand management and infrastructure service provision. In some cities, like Amman and Tripoli in Lebanon for example, people have taps but no consistent water provision, and networked sanitation systems struggle to work effectively as there is not enough water to flush them. Higher temperatures may also negatively affect water availability through impacts to infrastructure such as distribution and pumping systems.

The impact of reduced water availability and increasing demand is a risk to urban water security and sanitation across the region, but is particularly severe in the driest countries, and those countries in or post conflict situations (see section 4.1 for water stress).

#### *4.3.3.3 Resilient urban food systems*

Urban food systems are exposed to climate risk through rising and fluctuating food prices, related to climate impacts on agricultural production, both domestically and internationally. Water scarcity, heat stress and increases in floods and drought all contribute to both reducing average crop yields and greater variability in production and therefore more volatile food prices. This is true globally, but for the MENA region where the climate is already very dry and hot in many areas, crops are often grown close to their physiological limits, and options for adaptations to more drought-tolerant or water-efficient crops is limited.

The impact of increasing food prices and price fluctuations contributes to exacerbating urban poverty, particularly in countries with exposed agricultural sectors and high food costs, such as Egypt and Jordan. There are also risks for political insecurity, especially associated with stresses on production of culturally important crops, such as wheat.

In addition to the total availability and affordability of staple crops, their safety and nutritional value is also critical. The relationship between climate and crop quality is less well studied, but in urban areas where there is a dependence on market access to food, food choices for many of the urban poor could be limited by affordability as climate exerts increasing pressure on food systems (see section 4.2 for food security).

#### *4.3.3.4 Infrastructure*

The climate-related risks to infrastructure include the issues of food and water system functions already highlighted, but also issues related to energy, transport and communications, and risks associated with climate-related disasters in urban areas.

Increases in temperature, particularly in the summer months, can result in both an increase in energy demand for cooling, and a decrease in production and transmission capacity. Power stations struggle with cooling and overheat lines and cables become less efficient, presenting an increasing strain on power, generation, and transmission during extreme heat events.

Another factor to consider in terms of urban water management and sanitation infrastructure is the increased risk of flooding events, as more of the rain that falls does so in heavy downpour events. Coastal flooding, associated with storm incursion and salination of groundwater as a result of sea level rise, and coastal erosion are both important risks for sea defence infrastructure.

For cities, the key factor is not only the increase in climate hazard intensities and frequencies, but also the rapidly growing population and the difficulties in some cities to keep up with the resultant increasing demands on infrastructure. These issues are likely to impact on cities across the region, especially in the context of growing informal settlements, but pose particular risk for low- and middle-income economies without sufficient capacity and capital for investment.

#### *4.3.3.5 Inclusive economies*

Although perhaps not a direct risk, climate change, via the mechanism highlighted above, has the potential to put a brake on economic growth, through the multiple compound risks that cities, particularly those with low levels of investment and controlled and planned growth, already face.

Low- and middle-income countries such as Morocco, Egypt, Tunisia, Lebanon, Jordan, Iraq, Iran, Syria and Yemen are most at risk from the impact of climate projections on socioeconomic factors, and the economic functioning of cities which are often already failing to create jobs and meet the needs and aspirations of youth, particularly as urban areas continue to grow (see Focus box 7).

***Focus box 7: Jobs and employment***

Generating employment is a political priority in MENA countries facing large youth bulges. Climate change poses risks to employment in current sectors such as agriculture and tourism. It may also limit options for economic diversification and employment in new sectors, especially where those sectors are temperature-sensitive or water-intensive. Another climatic risk to jobs is from heat extremes, which are likely to reduce labour productivity in summer months, particularly in working environments without access to artificial cooling. There are also likely to be opportunities to create jobs in the green economy as part of responses to climate change, particularly in new industries generating renewable energy. The challenge is to identify new, labour-intensive economic opportunities with low carbon and water input requirements.

Investment in the green economy offers opportunities for generating new employment, although there are no reliable estimates for the number of potential green jobs in the MENA region. Renewable energy generation tends to create more employment per MWh than oil or coal generation. Creating well-paid employment in high-tech sectors is politically attractive, although the total numbers of jobs in renewable energy will be relatively modest and offer little to semi-skilled workers (Cote, 2019). There is greater scope for semi-skilled job creation in labour-intensive sustainable agriculture and off-farm value addition to agriculture.

## 4.4 Coastal areas

### 4.4.1 Overview of relevant socioeconomic trends

MENA coastal areas contain a microcosm of the region's economic activity. These areas are home to new economic sectors related to industry, trade and tourism, while also supporting traditional livelihoods such as fishing and agriculture (Waha et al., 2017). Given that these areas are both economically productive and offer a more hospitable climate compared with inland areas, the region's coastal areas will continue to prove attractive, with populations within coastal cities expected to reach 100 million by 2030 (Waha et al., 2017).

Urban development in coastal areas has occurred against the backdrop of poor urban planning. Old, densely populated cities along the north African coastline are characterised by poor infrastructure and housing, placing individuals at risk of natural hazards (World Bank, 2011). Urban growth in these cities has also been underpinned by the building of informal settlements in low lying areas and natural flood plains (World Bank, 2011).

Some countries have tried to control the growth of urban coastal areas by investing in second cities further inland. Morocco, Algeria and Tunisia have all overseen attempts to attract economic activity and populations away from crowded coastal areas to the country's hinterlands (UN Habitat, 2012). In contrast, along the Gulf coast, countries such as Bahrain, Qatar and UAE continue to undertake large land reclamation projects and the development of artificial islands to support growing populations (Hamza and Munawar, 2009; Naser, 2014).

The centrality of coastal areas to economic life in the MENA region means that we see a competition for space between different sectors. The growth linked to the energy sectors in the Gulf provided the impetus for economic development along the Gulf coast (Hamza and Munawar, 2009; Naser, 2014). The MENA region's coastal areas have also become popular tourist destinations, attracting investment, and providing local employment. Although the growth of new sectors offers opportunities in terms of diversification of national economies, it also brings competition to more traditional livelihoods. For example, agriculture in coastal areas has come under increased pressure due to urbanisation and tourism (Dixon et al., 2001). Similarly, Egyptian mariculture is also competing with urbanisation and tourism along the country's Mediterranean and Red Sea coasts (Adeleke, 2020).

The economic development of coastal areas is altering coastal ecosystems, which have both impacts for human and natural systems. The IPCC (2014) warn that the primary drivers of coastal ecosystem degradation - such as wetlands, coastal aquifers, mangroves, coral reefs – have been the result of human activities. These ecosystems act not only as important natural habitats but also important flood and seas defences. For example, in Morocco the building of informal settlements around wetlands outside the city of Casablanca is said to contribute to flooding within the city itself (World Bank, 2011). Factors such as industrial and household pollution, and dredging to support land reclamation, is leading to the decline of marine environments. Degradation of marine environments not only undermines natural habitats, but also livelihood systems that depend on it (Hamza and Munawar, 2009; Naser, 2014). Along the regions Mediterranean coast, along with overfishing, pollution is placing pressure on small scale and subsistence fisheries. Although fishing is not a major contributor to the MENA economy, it does however provide and important source of livelihood and food security to coastal communities (FAO, 2019).

### 4.4.2 Summary of relevant climate projections

#### *4.4.2.1 Semi-enclosed Seas (SES)*

All zones in the MENA region include coasts on Semi-Enclosed Seas (SES), such as the Mediterranean, the Black and Red Seas, and the Persian Gulf. Due to their small volume, and land-locked nature, SES will respond to climate change more rapidly than other larger ocean areas and are highly vulnerable to global temperature changes. They are projected to see an increase in sea surface temperature (SST), a positive sea level rise (SLR) and an increase in frequency and intensity of storms (IPCC, 2014).

Average temperatures in the SES are projected to increase by around 4˚C by the end of the 21st century, with the greatest increases projected for the surface waters of the Persian Gulf (zones 5 and 6) and the Red Sea (zones 2 and 5; IPCC, 2019). The

Mediterranean (zones 1,2,5,6) SST is projected to increase by as much as 1.2°C between 1980 and 2040 (IPCC, 2019), with associated increases in the frequency of marine heat waves (MHWs). Such changes in SSTs, particularly when combined with toxic algal blooms fed through polluted runoff, will affect fisheries because of the negative impact on marine ecosystems (Poloczanska et al., 2016). Fish stocks in the Persian Gulf are already stressed and increased SSTs may threaten the fishing industries and the livelihoods of small scale and subsistence fishers. The Mediterranean Sea level may rise by up to 0.5m over the course of the 21st century (EEA, 2020).

Changing rainfall and temperatures can strongly influence physical and chemical conditions within SES, increasing the risk of reduced oxygen levels through water strata. This can decimate fisheries through triggering massive die-offs of marine life and fish stocks. Algal blumes and eutrophication are already significant problems in many MENA coastal regions. Increased water temperatures lead to stratification of ocean layers, in turn reducing nutrient supply to upper levels and eutrophication at depth. SES are also highly vulnerable to other anthropogenic impacts such as pollution and overfishing, which, in combination with climate change will exacerbate the risks to these areas (IPCC, 2014).

The frequency of MHWs is projected to increase under climate change. These events are known to result in mass mortality of invertebrates that underpin the marine food chain (Lewandowska et al., 2014), and therefore have potential devastating impacts on fish stocks. Such heat waves also pose a risk to the coral reefs of the Persian Gulf and the Red Sea, as temperatures increase above established thresholds for mass coral bleaching and mortality, damaging critical marine ecosystems (Hoegh-Guldberg, 1999).

#### *4.4.2.2 Other marine regions*

The MENA area also includes coastlines along the Atlantic Ocean in Morocco and Western Sahara (zones 1 and 2); the Caspian Sea (zone 3); the Gulf of Aden (zone 5); the coast of Oman which meets the Arabian Sea (zone 5); and the Gulf of Oman which lies between Iran and Oman (zones 4 and 5).

As SSTs increase, the frequency, severity, duration and tracks of storms and tropical cyclones are also projected to change in some basins, though much also depends on abilities of storm formation to overcome wind shear. This could affect the coasts of Yemen and Oman, which are exposed to tropical cyclones, and Western Sahara in particular; while extra-tropical cyclone formation, intensification, and storm tracks over the Mediterranean Basin under climate change and the risks of these to Morocco, are less clear. Impacts of high winds, flooding, coastal inundation, and erosion will increase, with associated risks to infrastructure, water supply and livelihoods (Bell et al., 2020).

In contrast to the larger oceans and SES in the MENA region, the inland Caspian Sea is projected to experience a drop in sea level associated with continental drying. The current trend is for a decrease of 6-7cm/year (Wang et al., 2018), and is projected to drop by a further 9-18m between 2020 and 2100 (Nandini-Weiss et al 2019). This will cause the Caspian shelf, the Turkmen shelf, and all coastal areas in the middle and southern Caspian Sea to emerge from under the sea surface. In addition, the Kara-Bogaz-Gol Bay on the eastern margin will be completely desiccated. Overall, the Caspian Sea's surface area would shrink by 23% under a 9m drop and by 34% under an 18m drop in sea level (Prange et al., 2020).

### 4.4.3 Implications for coastal areas within the MENA region – Key risks

#### *4.4.3.1 Exposure of economically important assets*

Compared to other regions, MENA's cities, populations, and infrastructure are highly concentrated in coastal areas (Dasgupta, 2009). Low-lying economically important assets include ports, such as Dubai, Suez and the associated canal, major cities such as Alexandria and Beirut, and tourism areas such Egypt's Red Sea coast and northern Tunisia.

SLR across most coastal areas of the MENA region, combined with more intense coastal storms, presents prominent climate risks to economically important coastal assets. The combination of SLR and coastal storms will increase the frequency of coastal flooding due to higher sea levels and increased coastal inundation associated with storm surges. Combined with high winds, these changes pose further risk to coastal assets through the impacts of flooding, coastal erosion, saltwater corrosion and wind damage.

Our analysis shows that while slow onset SLR poses risks to the long-term viability of installations, more intense coastal storms may present more immediate risks by disrupting productivity and increasing both operations and maintenance costs. Critical infrastructure, such as port systems, may require considerable investment in adaptation to remain operational. Increased costs for maintaining industrial, port and transportation, energy and other infrastructure may place further burdens on public and private expenditure and undermine economic growth and employment. Alexandria, Beirut, Istanbul, Izmir, Algiers, and Benghazi have all been identified among the twenty global cities most vulnerable to SLR, in terms of average annual economic losses (Hallegatte et al., 2013).

The Nile Delta highlights these risks. Despite its relatively small land area, it is estimated that 41% of Egypt's population live in the Delta (World Bank, 2017; Gebremichael et al., 2020). The Nile Delta is home to several of Egypt's cities, including the major city of Alexandria and the port cities of Said and Damietta (Gebremichael et al., 2020). It also contains industrial sites such as the production of natural gas and supports both agriculture and aquaculture (ibid). The Nile Delta plays an important role in Egypt's food production, containing 63% of the country's arable land, and the Delta's coastal lakes contribute 40% of Egypt's harvested fish (Kafrawy et al., 2018; Gebremichael, 2020). Some projections suggest that that a combination of changes to the surrounding land and SLR, could affect 5.7 million jobs by 2100 (Gebremichael, 2020).

#### *4.4.3.2 The costs of migration decisions*

MENA's coastal populations will continue to grow. Those living in large cities are more likely to be afforded protection from SLR through adaptation and coastal defence works. However, protecting people in smaller towns and rural areas is likely to be more challenging and less cost effective. This implies that governments may face increasingly difficult trade-offs and decisions over the costs of adaptation versus the costs of inaction.

Low-lying residential areas and sites of employment exposed to SLR and coastal storm surges face inundation risks. Secondary impacts of SLR such as soil salinisation, aquifer salination and rising groundwater levels may result in impacts on residential and agricultural areas before direct inundation (Kouzana, Mammou and Fefoul, 2009; Waha et al. 2017). The weight of urban construction and the overexploitation of coastal aquifer systems is contributing to land subsidence in the Nile Delta, which in some areas is as high as 20mm/yr. (Rateb and Abotalib, 2020).

Areas in which adaptation investments are either ineffective or unaffordable are likely to see increasing out-migration as people leave inundated areas. A key question is whether governments plan for and support this out-migration as part of coherent adaptation responses, or whether households are left to bear the costs of either unplanned migration or remaining trapped in unviable areas.

Our analysis suggests that rising inequality is likely as the rural poor in marginal areas such as artisanal fishing and farming communities may not have the political support or financial means to adopt necessary adaptation measures. Even where communities may lie behind coastal protection, they may not have access to investment and capital to remediate secondary impacts of SLR, such as saltwater intrusion and rising groundwater levels. For example, in Abu Qir, in the west of Egypt's Nile Delta, the Mohamed Ali Sea Wall of 1830 prevents inundation from the sea. However, rising groundwater levels due to increased seaward hydrostatic pressure acting on aquifers, has turned residential areas into marshes and damaged the foundations of residential buildings. Such impacts of slumping property values also contribute to cycles of urban poverty (Kouzana et al., 2009; Yachieli et al, 2010; Kerrou et al., 2010).

Some studies have projected large population movements as a result of SLR (Hauer et al., 2020). While people move in response to fast onset disaster events, caution must be taken with projections of population movements as a response to long-term changes such as SLR in which layered impacts are likely to unfold over multidecadal to centuries time scales. Current evidence highlights that such movements must be viewed as part of a decision-making process influenced by social, economic, and political factors, rather than a single response to environmental change (McMichael et al., 2020; Hauer et al., 2020). However, current forms of rural-urban migration and displacement due to conflict include those moving to informal settlements, often built-in low-lying areas exposed to hazards such as flooding or lacking access to basic services (World Bank, 2011; UN Habitat, 2020).

Furthermore, consideration also needs to be given to the risks faced by those that remain – or 'trapped populations' – due to economic or social constraints (Hauer et al., 2020). There may also be costs, particularly gendered costs, associated with the fragmentation of households, with men seeking employment while leaving the rest of the family behind, as seen by current rural-urban migration trends in the region (Verner, 2012) (see Focus box 5 on climate risks and gender issues).

This is a particular risk in low-lying rural areas of Egypt, Tunisia, Algeria, Iraq and Lebanon where coastal homes and livelihoods are exposed to increasing coastal storm intensities and saltwater intrusion into groundwater, making some areas unviable for habitation (Gebremicheal et al., 2018). In particular, 70-80% of the population in Lebanon and Gaza live within a few kilometres of the coast. Some protection from SLR effects is provided by the steep elevation profile on the Mediterranean coast, however they are vulnerable to damage from storms. Furthermore, SLR will compound existing salination and pollution problems with coastal aquifers.

#### *4.4.3.3 Loss of ecosystems and ecosystem services*

As coastal areas in the region have developed, natural coastal habitats such as dunes and wetlands have been degraded or removed to make way for the economic development of coastlines. The region's marine environments have also come under threat. Fisheries are over-exploited across the region, and coral and mangrove ecosystems have been degraded because of fishing, construction, and marine pollution. The region's ecosystems are highly sensitive to further impacts that not only have ecological impacts but also important implications for human systems as well. They offer both coastal protection and support livelihoods, not only in traditional sectors such as small scale and subsistence fishing, but also in growing sectors such as tourism.

Our analysis highlights that coastal ecosystems across the MENA region will be increasingly threatened by SLR, the increasing intensity of coastal storms, flooding, and saltwater intrusion, combined with increasing SSTs. Coral reefs are vulnerable to increasing SST which, combined with changes to precipitation patterns, will affect water circulation, especially in SES (IPCC, 2014; IPCC, 2019). This can lead to stratification and reduction in nutrient supply in water columns, causing the development of new dead zones, or the expansion of existing ones, and exacerbate toxic algal blooms. The areas likely to be most severely affected are coral reefs and mangroves in the Red Sea and Gulf, dune systems and wetlands in the Mediterranean coasts of North Africa, Lebanon, and Turkey, as well as the wetlands along the coasts of Iraq and Iran (IPCC, 2014).

Furthermore, wetlands, dunes, mangroves, and coral reefs provide natural sea defences that protect from extreme waves, so the degradation of these ecosystems exacerbates flood risk. However, there may be opportunities to restore these habitats and deliver co-benefits to coastal protection, biodiversity conservation and tourism value (Aitali et al., 2020; Karanga and Saito, 2018; Keestra et al., 2018; Debpietri and McPhearson, 2017).

High SSTs are of particular concern in coral reef systems, as corals are highly temperature sensitive: wide scale bleaching events have occurred in response to MHWs elsewhere in the world. Coral reefs have high economic value to tourism in Egypt, and the Red Sea is an internationally important area of coral reef biodiversity, presenting a particular climate risk for this area (Hilmi, Safa and Renaud, 2012). Increasing SST will also add stress to fish stocks through impacts on physiology, habitat and ecology (Tzanatos et al., 2014; Cramer et al., 2018; Wabnitz et al., 2018).

# 5 Summary

This report considers the exposure and vulnerability to climate and climate change within the Middle East and North Africa (MENA) region. It sets out a broad range of climate-related risks for the region, to support development planning.

The climate of the MENA region is predominantly hot and arid, although there are small, more clement zones along some coasts and high-altitude areas, where winter precipitation is common. Climate change projections for the 2050s show with high confidence a substantial warming trend. There is less confidence around rainfall amounts, but modelling suggests either little change in rainfall, or for many regions, some indication of overall drying. Warmer temperatures contribute to increased evapotranspiration, so the overall signal is for increased aridity across the region. This combination of increasing temperatures and aridity in an already hot and arid region, together with exposure of the large coastline to sea level rise and storms, means that climate change will increase stress on existing vulnerable populations in the next few decades.

Some of the key risks identified in this report include food and water security, risks to human health and to cities and infrastructure, as well as specific risks associated with coastal zones. However, climate presents just one element of risks and multiple stresses across the region. Climate change will undoubtedly test human and agricultural systems, yet not all problems across the region will be driven by climate change. Climate risks are not isolated threats; how they interact with, and compound other sources of risk can be difficult to disentangle. For example, conflict and migration across the region are more complex issues caused by a multitude of factors spanning beyond climate change. It is important to consider the climate risks presented within this report in the context of development objectives and the wide range of intersectional risks that include socio-economic stresses and other drivers of change.

Nevertheless, long-term climate risks themselves will present considerable challenges, both in terms of average climate conditions which require adaptation to new ways of living, and through climate extremes and shocks such as droughts, that exacerbate pre-existing and complex compounding risks. Development that accounts for climate risks includes no-regrets investments in adaptation and resilience aligned to development goals, such as governance, social protection, health and education, all of which have co-benefits for climate risk and the wider development of the region. This kind of incremental adaption develops climate resilience within systems to support the continuation of existing activities, despite the changing climate. However, in some areas of the MENA region food, water and urban systems are already functioning at the very limits of climate tolerance, and the impacts and limitations of heat and water stress are strongly felt in the present day. As climate change pushes systems beyond these limits, transformational adaptation is required to develop entirely new activities, such as new businesses and land uses, where existing ways of life become no longer viable.

The climate risks identified in this report demonstrate that climate change already does and will continue to present considerable challenges to development in the region. The MENA region contains fragile and vulnerable states, in which climate risks can amplify pre-existing issues, particularly around food and water stress; these compounds the problems facing development such as poverty, health, employment and gender equality. If the climate risks outlined in this report are considered within the context of the wider intersectional issues the region faces, it is possible to ensure that such risks can be effectively managed in development planning, and development goals can still be achieved despite the considerable challenges of a changing climate.

# 6 References

Abdelmohsen, K., Sultan, M., Ahmed, M., Save, H.,.. and Abdelmalik, K. (2019) Response of deep aquifers to climate variability. *Science of the Total Environment* 677: 530-544, https://doi.org/10.1016/j.scitotenv.2019.04.316

Abotalib, A., Sultan, M. and Elkadiri, R. (2016) Groundwater processes in Saharan Africa: Implications for landscape evolution in arid environments. *Earth-Science Reviews* 156: 108-136, http://dx.doi.org/10.1016/j.earscirev.2016.03.004

Abou Zaki, N., Torabi Haghighi, A., Rossi, P.M., Tourian, M.J., Bakhshaee, A. and Kløve, B., 2020. Evaluating Impacts of Irrigation and Drought on River, Groundwater and a Terminal Wetland in the Zayanderud Basin, Iran. *Water*, *12*(5), p.1302.

Abououn, E., and El Taraboulsi – McCarthy, S. (2021) "International Aid Prioritizes Pandemic over Peace. But at What Cost?" Washington DC: United States Institute of Peace (https://www.usip.org/publications/2021/01/international-aid-prioritizes-pandemic-over-peace-what-cost)

Abu-Bakr, H. A. (2020) Groundwater vulnerability assessment in different types of aquifers. Agricultural Water Management, Volume 240, 106275, ISSN 0378-3774, https://doi.org/10.1016/j.agwat.2020.106275.

Abrishamchi, A., Jamali, S., Madani, K., Hadian, S. (2012) Climate Change and Hydropower in Iran's Karkheh River Basin. Proceedings of World Environmental And Water Resources Congress 2012, DOI: 10.1061/9780784412312.336

Adamo, Nasrat, Al-Ansari, Nadhir, Sissakian, Varoujan K. (2020) Global Climate Change Impacts on Tigris-Euphrates Rivers Basins, Journal of Earth Sciences and Geotechnical Engineering, ISSN 1792-9040, E-ISSN 1792-9660, 10(1) pp. 49-98

Adeleke, B., Robertson-Anderson, D., Moodley, G., and Taylor, S. (2020) 'Aquaculture in Africa: a comparative review of Egypt, Nigeria and Uganda vis-a vis South Africa' Fisheries Science and Aquaculture

Aitali, R; Snoussi, M; Kasmi, S. (2020) 'Coastal development and risks of flooding in Morocco: the cases of Tahaddart and Saidia coasts' Journal of African Earth Sciences, 164: 103771, DOI: 10.1016/j.jafrearsci.2020.103771

Al-Shammari, N. and Willoughby, J. (2019) Determinants of political instability across Arab Spring countries. Mediterranean Politics, 24(2), pp.196-217. Vancouver

Allan, T. (2012) The Middle East water question: Hydropolitics and the global economy. Bloomsbury Publishing.

Allan, T., Keulertz, M., and Woertz, E. (2015) 'The water-food-energy nexus: an introduction to nexus concepts and some conceptual and operational problems' Int. J. Water Res. Dev. 31: 301-311 doi: 10.1080/07900627.2015.1029118

Allenbach, K., Garonna, I., Herold, C., Monioudi, I., Giuliani, G., Lehmann, A., Velegrakis, A.F. (2015) Black Sea beaches vulnerability to sea level rise, Environmental Science & Policy, Volume 46, Pages 95-109, ISSN 1462-9011, https://doi.org/10.1016/j.envsci.2014.07.014.

Almazroui, M. Nazrul Islam, M., Jones, P. D., Athar, H., Ashfaqur Rahman, M. (2012) Recent climate change in the Arabian Peninsula: Seasonal rainfall and temperature climatology of Saudi Arabia for 1979–2009, Atmospheric Research, Volume 111, Pages 29-45, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2012.02.013.

Almulla, Y., Ramirez, C., Pegios, K., Korkovelos, A., Strasser, L.D., Lipponen, A. and Howells, M., 2020. A GIS-based approach to inform agriculture-water-energy nexus planning in the North Western Sahara Aquifer System (NWSAS). *Sustainability*, *12*(17), p.7043.

Ameur, F., Kuper, M., Lejars, C., Dugue, P. (2017) Prosper, survive or exit: Contrasted fortunes of farmers in the groundwater economy in the Saiss plain (Morocco). Agriculture Water Management. 191, 207-217.

Antonelli, M. and Tamea, S. (2015) Food-water security and virtual water trade in the Middle East and North Africa. International Journal of Water Resources Development, 31(3), 326-342.

Arraf, F., 2019. Causes of Decreasing Water Balances in the Barada Awaj (Damascus) Drainage Basin until the Uprising in Syria. *Open Journal of Modern Hydrology*, *9*(4), pp.143-160.

Asbu, E.Z., Masri, M.D. and Kaissi, A. (2017) 'Health status and health systems financing in the MENA region: roadmap to universal health coverage' Global Health Research and Policy, (2017): 2-25

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018) Present and future köppen-geiger climate classification maps at 1-km resolution. Scientific Data, 5, 1–12. https://doi.org/10.1038/sdata.2018.214

Bell, S. S., Chand, S. S., Tory, K. J., Ye, H., Turville, C. (2020) North Indian Ocean tropical cyclone activity in CMIP5 experiments: Future projections using a model-independent detection and tracking scheme. Int. J. Clim., 40, 15 6492-6505 DOI: 10.1002/joc.6594

Benzie, M., and A. John (2015) Reducing vulnerability to food price shocks in a changing climate. Stockholm: SEI

Blankespoor, B., Dasgupta, S. and Laplante, B. (2012) Sea-level rise and coastal wetlands: impacts and costs. The World Bank.

Borgomeo, E. & Santos, N. (2019) Towards a new generation of policies and investments in agricultural water in the Arab region: fertile ground for innovation. Rome, Italy: FAO; Colombo, Sri Lanka: International Water Management Institute (IWMI). 124p. doi: 10.5337/2019.207

Cardona, O. D., van Aalst, M. K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R. S., Schipper, E. L. F., Sinh, B. T. (2012) Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA: 65-108

Conway, D. (2017) Water resources: future Nile river flows. Nature Climate Change, 7 (5). pp. 319-320. ISSN 1758-678X

Cote, S. (2019) Renewable Energy and Employment: The Experience of Egypt, Jordan and Morocco. Riyadh: The King Abdullah Petroleum Studies and Research Center.

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.P., Iglesias, A., Lange, M.A., Lionello, P., Llasat, M.C., Paz, S. and Peñuelas, J. (2018) 'Climate change and interconnected risks to sustainable development in the Mediterranean' Nature Climate Change, 8(11): 972-980

Cullen, H. M. & deMonocal (2000) North Atlantic influence on Tigris-Euphrates streamflow. International Journal of Climatology, 20 (8), 853-863. https://doi.org/10.1002/1097-0088(20000630)20:8<853::AID-JOC497>3.0.CO;2-M

Daggupati, P., Srinivasan, R., Ahmadi, M. and Verma, D. (2017) Spatial and temporal patterns of precipitation and stream flow variations in Tigris-Euphrates river basin. *Environmental monitoring and assessment*, *189*(2), p.50

Darmaraki, S., Somot, S., Sevault, F. et al. (2019) Future evolution of Marine Heatwaves in the Mediterranean Sea. Clim Dyn 53, 1371–1392. https://doi.org/10.1007/s00382-019-04661-z.

Darwall, W., Carrizo, S., Numa, C., Barrios, V., Freyhof, J. and Smith, K. (2014) Freshwater Key Biodiversity Areas in the Mediterranean Basin Hotspot: Informing species conservation and development planning in freshwater ecosystems. Cambridge, UK and Malaga, Spain: IUCN. x + 86pp.

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. and Yan, J. (2009) 'The impact of sea level rise on developing countries: a comparative analysis' Climatic change, 93(3): 379-388

Davis, D. K. and Burke, E., (2011) (Eds) Environmental imaginaries of the Middle East and North Africa, Athens, Ohio, USA: Ohio University Press.

De Chatal, F. (2014) 'The role of drought and climate change in the Syrian uprising: untangling the triggers of the revolution' Middle Eastern Studies, (50)4: 521-535 de Vries, A. J., Ouwersloot, H. G., Feldstein, S. B., Riemer, M., El Kenawy, A. M., McCabe, M. F., & Lelieveld, J. (2018) Identification of tropical-extratropical interactions and extreme precipitation events in the Middle East based on potential vorticity and moisture transport. Journal of Geophysical Research: Atmospheres, 123, 861– 881. https://doi.org/10.1002/2017JD027587

Delaimy, W. (2020) 'Vulnerable Populations and Regions: The Middle East as a Case Study' Health of People, Health of Planet and Our Responsibility.

Depietri, Y and McPhearson, T. (2017) Integrating the Grey, Green, and Blue in Cities: Nature-Based Solutions for Climate Change Adaptation and Risk Reduction, nature-based solutions to climate change adaptation in urban areas: linkages between science, policy and practice, Edited by: Kabisch, N; Korn, H; Stadler, J; Bonn, A, Book Series: Theory and Practice of Urban Sustainability Transitions, Pages: 91-109 (DOI: 10.1007/978-3-319-56091-5_6)

Di Baldassarre, G., Wanders, N., AghaKouchak, A., Kuil, L., Rangecroft, S., Veldkamp, T.I., Garcia, M., van Oel, P.R., Breinl, K. and Van Loon, A.F. (2018) 'Water shortages worsened by reservoir effects', 1(11): 617-622.

Diep, L., Hayward, T., Walnycki, A., Husseiki, M. and Karlsson, L. (2017) Water, crises and conflict in MENA: how can water service providers improve their resilience? London: IIED (https://pubs.iied.org/10846IIED?a=L%20Diep)

Dixon, J. A., Gibbon, D. P., Gulliver, A. (2001) Chapter 3 in Farming systems and poverty: improving farmers' livelihoods in a changing world. Food & Agriculture Organisation of the United Nations: Rome.

Dogar and Sato (2018). Analysis of climate trends and leading modes of climate variability for MENA region. JGR Atmospheres, 123, 23.

Döll, P. (2009) Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment. Environmental Research Letters, 4(3), 035006.

Dreccer, M., Fainges, J., Whish, J., Ogbonnaya, F., Sadras, V. (2018) 'Comparison of sensitive stages of wheat, barley, canola, chickpea and field pea to temperature and water stress across Australia.' Agricultural and Forest Meteorology. 248, 274-294.

Droogers, P., Immerzeel, W. W., Terink, W., Hoogeveen, J., Bierkens, M. F. P., van Beek, L. P. H., and Debele, B. (2012) Water resources trends in Middle East and North Africatowards 2050. Hydrol. Earth Syst. Sci., 16, 1–14. www.hydrol-earth-syst-sci.net/16/1/2012/ doi:10.5194/hess-16-1-2012

Eaton, T., Renad M., Lina K., C, Cheng., Yazigi, J. and Salisbury, P. (2019) Conflict Economies in the Middle East and North Africa. London: Chatham House. (https://www.chathamhouse.org/2019/06/conflict-economies-middle-east-and-north-africa)

EEA (2020), Global and European sea level rise assessment, version dated 11 Dec 2020, 03:50 PM, accessed March 2021 https://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-7/assessment

El-Fadel, M., Maroun, R., Semerjian, L. and Harajli, H. (2003) A health-based socio-economic assessment of drinking water quality: the case of Lebanon. Management of Environmental Quality: An International Journal.

El-Shazly, M. M., Omar, W. A., Edmardash, Y. A., Ibrahim, M. S., Elzayat, E. I., El-Sebeay, I. I., Abdel Rahman, K. M. and Soliman, M. M. (2017) Area reduction and trace element pollution in Nile Delta wetland ecosystems. African journal of ecology, 55(4), 391-401.

Elba, E., Urban, B., Ettmer, B. and Farghaly, D. (2017) Mitigating the Impact of Climate Change by Reducing Evaporation Losses: Sediment Removal from the High Aswan Dam Reservoir. American Journal of Climate Change, 6, 230-246. doi: 10.4236/ajcc.2017.62012.

Eldeberky, Y. (2011) Coastal adaptation to sea level rise along the Nile delta, Egypt. WIT Transactions on Ecology and the Environment, Vol 149, doi:10.2495/CP111

Eriksen, S.H., Nightingale, A.J. and Eakin, H. (2015) 'Reframing adaptation: the political nature of climate change adaptation' Global Environmental Change 35(2015): 523-533

ESCWA & FAO (2017) Arab Horizon 2030: Prospects for Enhancing Food Security in the Arab Region. United Nations Economic and Social Commission for Western Asia and the Food and Agriculture Organisation of the United Nations, Beruit. FAO and OECD (2018)

FAO and World Bank (2017) Water management in fragile systems: building resilience to shocks and protracted crises in the Middle East and North Africa. Rome: FAO (http://www.fao.org/emergencies/resources/documents/resources-detail/en/c/1151116/)

FAO and OECD (2018) The Middle East and North Africa: prospects and challenges. FAO: Rome (https://www.oecd-ilibrary.org/docserver/agr_outlook-2018-5-en.pdf?expires=1616598791&id=id&accname=guest&checksum=F53682C5D3863A2A5B2FCA216B990215)

FAO (2019) Social protection for small-scale fisheries in the Mediterranean region. Rome: FAO

Fischer, G., Shah, M. M., & van Velthuizen, H. T. (2002) Climate Change and Agricultural Vulnerability. IIASA, Laxenburg, Austria

Gebremicheal, E., Sultan, M., Becker, R., El Bastawesy, M., Cherif, O. and Emil, M. (2018) 'Assessing land deformation and sea encroachment in the Nile Delta: a radar interometric and inundation modelling approach' Journal of Geophysical Research: Solid Earth, 123: 3208 – 3224 https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2017JB015084

Giglioli, I. (2013) Water politics in the West Bank. Chapter 9 *in* Sultana & Loftus (eds) *The Right to Water: Politics, Governance and Social Struggles*. Earthscan: Abingdon, UK.

Gilmont, M. (2015) Water resource decoupling in the MENA through food trade as a mechanism for circumventing national water scarcity. Food Security, 7(6), pp.1113-1131.

Giorgi, F., and Gutowski, W. J. (2015) Regional Dynamical Downscaling and the CORDEX Initiative. Annual Review of Environment and Resources, 40(1), 467–490. https://doi.org/10.1146/annurev-environ-102014-021217

Givati, A., Thirel, G., Rosenfeld, D., Paz, D. (2019) Climate change impacts on streamflow at the upper Jordan River based on an ensemble of regional climate models, Journal of Hydrology: Regional Studies, Volume 21, Pages 92-109, ISSN 2214-5818, https://doi.org/10.1016/j.ejrh.2018.12.004.

Gleick, P. H. (2019) Water as a weapon and casualty of armed conflict: A review of recent water-related violence in Iraq, Syria, and Yemen. Wiley Interdisciplinary Reviews: Water, 6(4), p.e1351.

Gleixner, S., Demissie, T. and Diro, G. T. (2020). Did ERA5 Improve Temperature and Precipitation Reanalysis over East Africa? Atmosphere, 11(9), 996

Hallegatte, S., Green, C., Nicholls, R.J. and Corfee-Morlot, J. (2013) 'Future flood losses in major coastal cities' Nature climate change, 3(9): 802-806

Hameed, M., Noradkhani, H., Ahmadalipour, A., Moftakhari, H., Abbaszadeh, P. and Alipour, A. (2019) 'A review of the 21st century challenges in the Food-Energy-water security in the Middle East' Water, 11(4): 682

Hamza, W., and Munawar, M. (2009) 'Protecting and managing the Arabian Gulf: past, present and future' Aquatic Ecosystem Health and Management, 12: 429-439

Hansen, J., Hellin, J., Rosenstock, T., Fisher, E., Cairns, J., Stirling, C., Lamanna, C., van Etten, J., Rose, A. and Campbell, B. (2019) 'Climate risk management and rural poverty reduction' Agricultural Systems, 172: 28-46

Hauer et al. (2020) 'Sea-level rise and human migration' Nature Reviews Earth & Environment, 1: 28-39

Hazell, P., Oram, P. and Chaherli, N. (2003) Managing livestock in drought-prone areas of the Middle East and North Africa: Policy issues. In Food, agriculture, and economic policy in the Middle East and North Africa. Emerald Group Publishing Limited.

Hazell, P. (2018) Chapter Fifteen. Managing Drought Risks in the Low-Rainfall Areas of the Middle East and North Africa (7-5). In Case Studies in Food Policy for Developing Countries (pp. 185-194). Cornell University Press. Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., et al. (2020). The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), 1999–2049. https://doi.org/10.1002/qj.3803

Hilmi, N., Safa, A. and Reynaud, S. (2012) 'Coral reefs and tourism in Egypt's red sea' Topics in Middle Eastern and North African Economies, 14

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., … Thépaut, J. N. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, *146*(730), 1999–2049. https://doi.org/10.1002/qj.3803

Hoegh-Guldberg, O., D. Jacob, M. Taylor, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante, K.L. Ebi, F. Engelbrecht, J.Guiot, Y. Hijioka, S. Mehrotra, A. Payne, S.I. Seneviratne, A. Thomas, R. Warren, and G. Zhou, (2018) 'Impacts of 1.5ºC Global Warming on Natural and Human Systems.' In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I.Gomis, E. Lonnoy, T.Maycock, M.Tignor, and T. Waterfield (eds.)]. In Press.

Hoegh-Guldberg, O. (1999) Climate change, coral bleaching and the future of the world's coral reefs, Mar. Freshwater Res., 50, 839-66

Hoff, H., Alrahaife, S.A., El Hajj, R., Lohr, K., Mengoub, F.E., Farajalla, N., Fritzsche, K., Jobbins, G., Özerol, G., Schultz, R. and Ulrich, A. (2019) 'A nexus approach for the MENA region—from concept to knowledge to action' Frontiers in Environmental Science, 7: p.48

Houdret, A. and Amichi, H. (2020) 'The rural social contract in Morocco and Algeria: reshaping through economic liberalisation and new rules and practices' The Journal of North African Studies

Hwalla, N., Weaver, C.M., Mekary, R.A. and El Labban, S. (2016) Public health nutrition in the Middle East. Frontiers in public health, 4, p.33.

ICRC (2015) Urban services during protracted armed conflict: a call for better approach to assisting affected people. Geneva: ICRC (https://www.icrc.org/sites/default/files/topic/file_plus_list/4249_urban_services_during_protracted_armed_conflict.pdf)

IEA (2019) Desalinated water affects the energy equation in the Middle East. Paris: IEA. (https://www.iea.org/commentaries/desalinated-water-affects-the-energy-equation-in-the-middle-east)

IOM (2015) World migration report 2015: urban migration trends in the Middle East and North Africa region and the challenge of conflict-induced displacement. Grand-Sacconnex: International Organisation for Migration. (https://www.iom.int/sites/default/files/our_work/ICP/MPR/WMR-2015-Background-Paper-MSerageldin-FVigier-MLarsen.pdf)

IPCC (2001) Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change

[Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 582 pp.

IPCC (2013) AR5 Technical Summary IPCC. (2013T). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovern-mental Panel on Climate Change. [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC (2018) Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

IPCC (2019) IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Ide, T., Lopez, M., Frohlich, C., Scheffran, J. (2020) Pathways to water conflict dueing drought in the MENA region. Journal of Peace Research. 1-15.

Irani, M., Bavani., A. M., Bohluly, A., Lahijani, H. A. K. (2018) Sea Level Rise in Persian Gulf and Oman Sea Due to Climate Change in the Future Periods. Physical Geography Research Quarterly. **49,** (4), 603-614. Doi: 10.22059/jphgr.2018.221101.1006966

Jaafar, H., Woertz, E. (2016) Agriculture as a funding source of ISIS: A GIS and remote sensing analysis. Food Policy. 64, 14-25.

Jedd, T., Fragaszy, S. R., Knutson, C., Hayes, M. J., Fraj, M. B., Wall, N., Svoboda, M. and McDonnell, R. (2020) Drought Management Norms: Is the Middle East and North Africa Region Managing Risks or Crises? The Journal of Environment & Development, p.1070496520960204. Jobbins and Henley (2015)

Jobbins, G., Kalpakian, J., Chriyaa, A., Legrouri, A. and El Mzouri, E. H. (2015) To what end? Drip irrigation and the water–energy–food nexus in Morocco. International Journal of Water Resources

Kabbani, N. (2019) Youth employment in the Middle East and North Africa: revisiting and reframing the challenge. Doha: Brookings Doha Center (https://www.brookings.edu/research/youth-employment-in-the-middle-east-and-north-africa-revisiting-and-reframing-the-challenge/)

Kafrawy, S.B., Abdelrhman, M.A.B.  AND Negm, A.M. (2018) An overview of the Egyptian northern Coastal Lakes in A. M. Negm et al. (eds.), Egyptian Coastal Lakes and Wetlands: Part I - Characteristics and Hydrodynamics, Hdb Env Chem, DOI 10.1007/698_2018_275

Karanja, JM & Saito, O. (2018) 'Cost-benefit analysis of mangrove ecosystems in flood risk reduction: a case study of the Tana Delta, Kenya' Sustainability Science 13(2): 503-516 (DOI: 10.1007/s11625-017-0427-3)

Katz, D. (2011) Hydro-political hyperbole: Examining incentives for overemphasizing the risks of water wars. Global Environmental Politics, 11(1), pp.12-35.

Keesstra, S; Nunes, J; Novara, A; Finger, D; Avelar, D; Kalantari, Z; Cerda, A. (2018) 'The superior effect of nature based solutions in land management for enhancing ecosystem services' Science of the Total Environment, 610: 997-1009 (DOI: 10.1016/j.scitotenv.2017.08.077)

Kendouci, M.A., Bendida, A., Khelfaoui, R. and Kharroubi, B. (2013) The impact of traditional irrigation (Foggara) and modern (drip, pivot) on the resource non-renewable groundwater in the Algerian Sahara. *Energy Procedia*, *36*, pp.154-162.

Kerrou, L., Renard, P., Tarhouni, J. (2010) 'Status of the Korba groundwater resources (Tunisia): observations and three-dimensional modelling of seawater intrusion' Hydrogeology Journal, 18: 1173-1190

Kilcullen, D. (2012) 'The city as a system: future conflict and urban resilience', The Fletcher Forum of World Affairs 36(2): 19-39

King, M.D. (2015) The weaponization of water in Syria and Iraq. The Washington Quarterly, 38(4), 153-169.

Khouri, R. (2019) How Poverty and Inequality are Devastating the Middle East. New York: Carnegie Corporation of New York. (https://www.carnegie.org/topics/topic-articles/arab-region-transitions/why-mass-poverty-so-dangerous-middle-east/)

Knutson, T. R., Chung, M. V., Vecchi, G., Sun, J., Hsieh T.-L., Smith, A. J. P. (2021) Climate change is probably increasing the intensity of tropical cyclones. https://news.sciencebrief.org/cyclones-mar2021/ accessed 06/05/2021

Koch, N. (2021). Food as a weapon? The geopolitics of food and the Qatar–Gulf rift. *Security Dialogue*, *52*(2), 118-134.

Korotayev, A. and Zinkina, J. (2011) 'Egyptian revolution: a demographic structural analysis' Entelequia. Revista Interdisciplinar, 13(2011): 139-169

Kouzana, L., Mammou, A.B. and Felfoul, M.S. (2009) ‘Seawater intrusion and associated processes: case of the Korba aquifer (Cap-Bon, Tunisia)’ Comptes Rendus Geoscience, 341(1): 21-35

Laity, J.J. (2008) *Deserts and desert environments*. John Wiley & Sons: Oxford.

Lewandowska, A.M., Boyce, D.G., Hofmann, M., Matthiessen, B., Sommer, U., Worm, B. (2014) Effects of sea surface warming on marine plankton. Ecol Lett. 17(5):614-23. doi: 10.1111/ele.12265. Epub 2014 Feb 28. PMID: 24575918.

Lezzaik, K., Milewski, A. and Mullen, J. (2018) The groundwater risk index: Development and application in the Middle East and North Africa region. Science of the Total Environment, 628, 1149-1164.

Lin, N., Emanuel, K. Grey swan tropical cyclones. *Nature Clim Change* **6,** 106–111 (2016) https://doi.org/10.1038/nclimate2777

Mabry, R. (2018) Urbanisation and Physical activity in the GCC: a case study of Oman. London: LSE (http://eprints.lse.ac.uk/86875/)

MacDonald, A. M., Calow, R. C., MacDonald, D. M. J., Darling, W. G., Dochartaigh, B. É. Ó. (2009) What impact will climate change have on rural groundwater supplies in Africa? Hydrological Sciences Journal, 54:4, 690-703, DOI: 10.1623/hysj.54.4.690

Martinez, J. and Eng, B. (2018) ‘Stifling stateness: the Assad regimes campaign against rebel governance’ Security Dialogue 49(4): 2018

Mason, M., Zeitoun, M. and Mimi, Z. (2012) Compounding vulnerability: impacts of climate change on Palestinians in Gaza and the West Bank. *Journal of Palestine Studies*, *41*(3), pp.38-53.

Mazzoni, A., Heggy, E. and Scabbia, G. (2018) Forecasting water budget deficits and groundwater depletion in the main fossil aquifer systems in North Africa and the Arabian Peninsula. Global Environmental Change, 53, pp.157-173.

Mckee, M., Keulertz, M., Habibi, N., Mulligan, M. and Woertz, E. (2017) Middle East and North Africa Regional Architecture: demographic and economic material factors in the MENA region. Roma: Instituto Affari Internazionali (https://www.iai.it/en/pubblicazioni/demographic-and-economic-material-factors-mena-region)

McMichael, C., Dasgupta, S., Ayeb-Karlsson, S. and Kelman, I. (2020) ‘A review of estimating population exposure to sea-level rise and the relevance for migration’ Environmental Research Letters 15:(2020) (https://iopscience.iop.org/article/10.1088/1748-9326/abb398)

Megahed, A.M., Dahshan, H., Abd-El-Kader, M.A., Abd-Elall, A.M.M., Elbana, M.H., Nabawy, E. and Mahmoud, H.A. (2015) Polychlorinated biphenyls water pollution along the River Nile, Egypt. The Scientific World Journal, 2015.

Mogielnicki, R. (2020) Water Worries: The Future of Desalination in the UAE. Washington DC: Arab Gulf States Institute in Washington

Mohamed, A.H. and Squires, V.R. (2018) Drylands of the Mediterranean Basin: challenges, problems and prospects. In Climate Variability Impacts on Land Use and Livelihoods in Drylands (pp. 223-239). Springer, Cham.

Molle, F. and Berkoff, J. (2009) Cities vs. agriculture: A review of intersectoral water re-allocation. In Natural Resources Forum Vol. 33, No. 1, pp. 6-18

Monshipouri, M. (2020) 'The middle east post-petroleum: averting the storm' Middle East Policy 26(3): 77-91

MWI and BGR (Ministry of Water and Irrigation; Bundesanstalt für Geowissenschaften und Rohstoffe) (2019). Groundwater Resource Assessment of Jordan 2017. Amman, Jordan.

Nandini-Weiss, S. D., Prange, M., Arpe, K., Merkel, U., Schulz, M. (2019) Past and future impact of the winter North Atlantic Oscillation in the Caspian Sea catchment area, Int J Clim 40, 5, 2717-2731. https://doi.org/10.1002/joc.6362

Natteri, M., Zahraie, B., Forouhar, L. (2017) A comparison between direct and indirect frameworks to evaluate impacts of climate change on streamflows: case study of Karkheh River basin in Iran. Journal of Water and Climate Change, 8 (4): 652-674.

Ntoumos, A., Hadjinicolaou, P., Zittis, G. and Lelieveld, J. (2020). Updated Assessment of Temperature Extremes over the Middle East–North Africa (MENA) Region from Observational and CMIP5 Data. Atmosphere, 11, 813. https://doi.org/10.3390/atmos11080813

Nuri Balov, M., Altunkaynak, A. (2020) Spatio-temporal evaluation of various global circulation models in terms of projection of different meteorological drought indices. Environ Earth Sci 79, 126. https://doi.org/10.1007/s12665-020-8881-0

Opitz-Stapleton, S., Nadin, R., Kellett, J., Calderone, M., Quevedo, A., Peters, K. and Mayhew, L. (2019) Risk-informed development: from crisis to resilience. Overseas Development Institute: London

Opitz-Stapleton, S., Nadin, R., Watson, C. and Kellett, J. (2017) Climate change, migration and displacement: the need for a risk-informed and coherent approach. ODI: London

Oppenheimer, M., Glavovic, B. C., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R. M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., Sebesvari, Z. (2019) Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M.

Ozturk, T., Tufan Turp, M., Türkeş, M., Levent Kurnaz, M. (2018). Future projections of temperature and precipitation climatology for CORDEX-MENA domain using RegCM4.4. Atmospheric Research, 206, 87-107, https://doi.org/10.1016/j.atmosres.2018.02.009

Peters, K., Eltinay, N. and Holloway, K. (2019) Disaster risk reduction, urban informality and a 'fragile peace'. London: ODI (https://odi.org/en/publications/disaster-risk-reduction-urban-informality-and-a-fragile-peace-the-case-of-lebanon/)

Poloczanska, E. S., Burrows, M. T., Brown, C. J., Garcia Molinos, J., Halpern, B. S., Hoegh-Guldberg, O., Kappel, C. V., Moore, P. J., Richardson, A. J., Schoeman, D. S. & Sydeman, W. J. (2016) Responses of Marine Organisms to Climate Change across Oceans, Front. Mar. Sci. https://doi.org/10.3389/fmars.2016.00062

Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso (2014) 'Food security and food production systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects'. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533

Powell, O. and Fensham, R. (2016) The history and fate of the Nubian Sandstone Aquifer springs in the oasis depressions of the Western Desert, Egypt. *Hydrogeology journal*, *24*(2), pp.395-406.

Pratt, A.N., El-Enbaby, H., Figueroa, J.L., Eldidi, H. and Breisinger, C. (2018) Agriculture and economic transformation in the Middle East and North Africa. Rome: FAO (https://www.ifpri.org/publication/agriculture-and-economic-transformation-middle-east-and-north-africa-review-past-lessons)

Prange, M., Wilke, T. & Wesselingh, F.P. (2020) The other side of sea level change. Commun Earth Environ 1, 69. https://doi.org/10.1038/s43247-020-00075-6

Priestley, C. (2020) '"We Won't Survive in a City. The Marshes are Our Life": An Analysis of Ecologically Induced Genocide in the Iraqi Marshes' Journal of Genocide Research, pp.1-23.

Pulido-Velazquez, D., García-Aróstegui, J.L., Molina, J.L. and Pulido-Velazquez, M. (2015) 'Assessment of future groundwater recharge in semi-arid regions under climate change scenarios (Serral-Salinas aquifer, SE Spain. Could increased rainfall variability increase the recharge rate?' Hydrological processes, 29(6): 828-844

Queste, B. Y., Vic, C., Heywood, K. J.,Piontkovski, S. A. (2018) Physical controls on oxygen distribution and denitrification potential in the north west Arabian Sea. Geophysical Research Letters, 45, 4143-4152. https://doi.org/10.1029/2017GL076666

Rached, E. and Brooks, D.B. (2010) 'Water governance in the Middle East and North Africa: An unfinished agenda' International Journal of Water resources development, 26(2): 141-155

Raymond, C., Matthews, T. and Horton, R. M. (2020) The emergence of heat and humidity too severe for human tolerance. Science Advances, 26(19)

Rosa, L., Chiarelli, D.D., Sangiorgio, M., Beltran-Peña, A.A., Rulli, M.C., D'Odorico, P. and Fung, I. (2020) 'Potential for sustainable irrigation expansion in a 3° C warmer climate' Proceedings of the National Academy of Sciences, 117(47): 29526-29534

Rateb, A. and Atotalib, A.Z. (2020) 'Inferencing the land subsidence in the Nile Delta using Sentinel-1 satallites and GPS between 2015 and 2019' Science of the Total Environment 729: 138868

Sachs, J., McArthur, J.W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M. and McCord, G. (2004) 'Ending Africa's poverty trap' Brookings papers on economic activity 2004(1): 117-240

Schillinger, J., Ozerol, G., Guven-Griemert, S., Heldeweg, M. (2020) 'Water in war: understanding the impacts of armed conflict on water resources and their management' WIREs Water 2020(7): e1480

Schipper, L. and Pelling, M. (2006) 'Disaster risk, climate change and international development: scope for, and challenges to, integration', Disasters 30(1): 19-38

Schmidt, M., Gonda, R. and Transiskus, S. (2020) 'Environmental degradation at Lake Urmia (Iran): exploring the causes and their impacts on rural livelihoods' GeoJournal, (https://doi.org/10.1007/s10708-020-10180-w)

Scott, D.A. ed. (1995) A directory of wetlands in the Middle East. IUCN: Gland, Switzerland

SHOPS Plus (2018) Health trends in the Middle East and North Africa: a regional overview of Health Financing and the private health sector. Rockville, MD: Abt Associates Inc. (https://www.hfgproject.org/health-trends-in-the-middle-east-and-north-africa/)

Shumilova, O., Tockner, K., Thieme, M., Koska, A. and Zarfl, C. (2018) Global water transfer megaprojects: a potential solution for the water-food-energy nexus?. *Frontiers in Environmental Science*, *6*, p.150.

Smiatek, G., Kunstmann, H., Heckl, A. (2011) High-resolution climate change simulations for the Jordan River area. Journal of Geophysical Research: Atmospheres, Volume 116, Issue D16 Climate and Dynamics https://doi.org/10.1029/2010JD015313

Sowers, J., Vengosh, A. and Weinthal, E. (2011) 'Climate change, water resources, and the politics of adaptation in the Middle East and North Africa' Climatic Change, 104(3): 599-627

Sun, C. Li, J. Ding, R, and Jin, Z. (2017) Cold season Africa-Asia multidecadal teleconnection pattern and its relation to the Atlantic multidecadal variability. Climate Dynamics, 48, 3903-3918

Swain, A. (2001) Water wars: fact or fiction?. Futures, 33(8-9), pp.769-781.

Syed, F.S., Latif, M., Al-Maashi, A. and Ghulam, A. (2019). Regional climate model RCA4 simulations of temperature and precipitation over the Arabian Peninsula: sensitivity to CORDEX domain and lateral boundary conditions. Climate Dynamics, 53, 7045–7064 (2019). https://doi.org/10.1007/s00382-019-04974-z

Tabari, H. Climate change impact on flood and extreme precipitation increases with water availability. Sci Rep 10, 13768 (2020) https://doi.org/10.1038/s41598-020-70816-2

Tahir, F., Baloch, A.A.B. and Ali, H. (2019) Resilience of desalination plants for sustainable water supply in the Middle East in P.A. Kaiter and M.G.Erechtchoukova Sustainability Perspectives: Science, Policy and Practice. New York: Springer Publishing

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012) An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society, 93(4), 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1

Tramblay Y, Jarlan L, Hanich L, Somot S (2018) Future scenarios of surface water resources availability in North African dams. Sustain Water Resour Manag 32:1291–1306. https://doi.org/10.1007/s11269-017-1870-8

Tzanatos, E., Raitsos, D.E., Triantafyllou, G., Somarakis, S. and Tsonis, A.A. (2014) 'Indications of a climate effect on Mediterranean fisheries' Climatic Change, 122(1): 41-54

UNDP (2018) Water governance in the Arab Region: managing scarcity and securing the future. New York: UNDP

UNESCWA (2016) Demographic profile of the Arab region: realising the demographic dividend. Beirut: Economic and Social Commission for Western Asia (https://www.unescwa.org/sites/www.unescwa.org/files/publications/files/demographic-profile-arab-region-2015-english.pdf)

UN Habitat (2012) The State of Arab Cities 2012: challenges of urban transitions. Nairobi: UN Habitat

UN Habitat (2020a) UN Habitat (2020) Informal settlements in the Arab region. Nairobi: UN Habitat

UN Habitat (2020b) World cities report 2020: the value of sustainable urbanisation. Nairobi: UN Habitat (https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf)

United Nations World Water Assessment Programme (2016) The United Nations World Water Development Report 2016: Water and Jobs. Paris: UNESCO

Urruty, N., Tailliez-Lefebvre, D. and Huyghe, C. (2016) 'Stability, robustness, vulnerability and resilience of agricultural systems. A review' Agronomy for sustainable development, 36(1): 15

Uysal, G., Şensoy, A. and Şorman, A. A. (2016) Improving daily streamflow forecasts in mountainous Upper Euphrates basin by multi-layer perceptron model with satellite snow products. *Journal of Hydrology*, *543*, pp.630-650.

Verner, D. ed. (2012) Adaptation to a changing climate in the Arab countries: a case for adaptation governance and leadership in building climate resilience. Washington D.C: The World Bank

Wabnitz, C.C., Lam, V.W., Reygondeau, G., Teh, L.C., Al-Abdulrazzak, D., Khalfallah, M., Pauly, D., Palomares, M.L.D., Zeller, D. and Cheung, W.W. (2018) 'Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf' PloS one, 13(5): p.e0194537.

Waha, K., Krummenauer, L., Adams, S., Aich, V., Baarsch, Coumou, D., Fader, M., Hoff., Jobbins, Guy., Marcus, R., Mengel, M., Otto, I.M., Perette, M., Rocha, M., Robinson, A. and Schleussner, C.F. (2017) 'Climate change impacts in the Middle East and Northern Africa (MENA) region and their implications for vulnerable populations groups' Regional Environmental Change, 17 (2017): 1623-1838

Weinthal, E. and Sowers, J. (2020) 'The water-energy nexus in the Middle East: Infrastructure, development, and conflict' Wiley Interdisciplinary Reviews: Water, 7(4): p.e1437.

Wheida, A., Nasser, A., El Nazer, M., Borbon, A., El Ata, G.A.A., Wahab, M.A. and Alfaro, S.C. (2018) 'Tackling the mortality form long-term exposure to outdoor air pollution in megacities: lessons from the Greater Cairo case study' Environmental Research 160: 223-231

Whitehead, P.G., Wilby, R.L., Battarbee, R.W., Kernan, M. and Wade, A.J. (2009) A review of the potential impacts of climate change on surface water quality. Hydrological sciences journal, 54(1), pp.101-123.

WHO (n.d.) 'Ambient Air Pollution'. Webpage. World Helath Organisation. (https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/ambient-air-pollution)

Wiggins, S. and Keats, S. (2014) Future diets: under and over-nutrition in developing countries. Commonwealth Health Online. (https://www.commonwealthhealth.org/wp-content/uploads/2014/05/6-Future-diets-Wiggins-.pdf)

Wisner, B., Blaikie, P., Cannon, T. and Davis, I. (2003) At Risk: natural hazards, people's vulnerability and disasters (2nd Ed.) New York, NY, Routledge, 464 pp.

Woertz, E. (2013). Oil for food: The global food crisis and the Middle East. OUP Oxford.

Woertz, E. (2017) 'Agriculture and Development in the Wake of the Arab Spring' in G. Luciani (ed.) Combining Economic and Political Development: The Experience of MENA, International Development Policy series 7 (Geneva: Graduate Institute Publications, Boston: Brill-Nijhoff), pp. 144–169

Woertz, E. (2020) Wither the self-sufficiency illusion? Food security in Arab Gulf States and the impact of COVID-19. Food Security, 12(4), pp.757-760.

World Bank (2007) Making the most of scarcity: Accountability for better water management in the Middle East and North Africa. The World Bank.

World Bank (2010) De Stefano, Lucia; Duncan, James; Dinar, Shlomi; Stahl, Kerstin; Strzepek, Kenneth; Wolf, Aaron T. 2010. Mapping the Resilience of International River Basins to Future Climate Change-Induced Water Variability, Volume 1. Main Report. Water Sector Board discussion paper series;no. 15. World Bank, Washington, DC.

World Bank (2011) North African Coastal Cities: Address Natural Disasters and Climate Change - Summary of the Regional Study. Washington D.C: The World Bank

World Bank (2019) Sustainable Land Management and Restoration in the Middle East and North Africa Region—Issues, Challenges, and Recommendations. World Banks: Washington, DC

World Bank (2016) High and Dry: Climate Change, Water, and the Economy. Washington, DC: World Bank. World Bank (2018)

World Bank (2018) Beyond Scarcity: water Security in the Middle East and North Africa. MENA Development Report. Washington, DC: World Bank. (https://openknowledge.worldbank.org/handle/10986/27659)

World Bank (2019) Sustainable Land Management and Restoration in the Middle East and North Africa Region—Issues, Challenges, and Recommendations. Washington, DC. ()

World Bank (2020) Taheripour, Farzad, Wallace E. Tyner, Ehsanreza Sajedinia, Angel Aguiar, Maksym Chepeliev, Erwin Corong, Cicero Z. de Lima, and Iman Haqiqi. (2020). “Water in the Balance: The Economic Impacts of Climate Change and Water Scarcity in the Middle East—Technical Report.” World Bank, Washington, DC.

World Bank and IHM (2016) The Cost of Air Pollution: Strengthening the Economic Case for Action. Washington DC: World Bank.

World Economic Forum (2016) The Global Risks Report 2016, 11th Edition. Geneva: World Economic Forum.

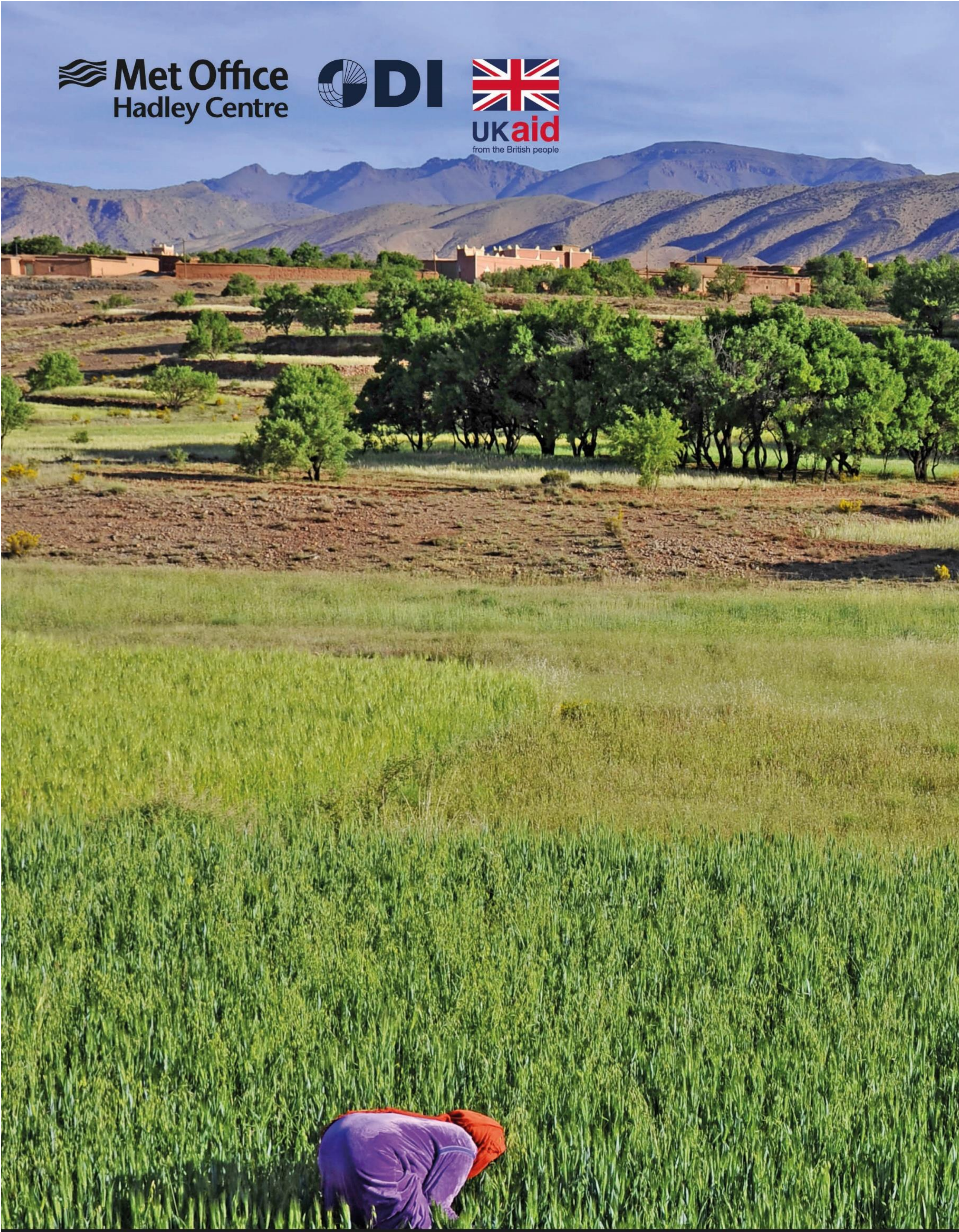
World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2017). Benefits of action and costs of inaction: Drought mitigation and preparedness – a literature review (N. Gerber and A. Mirzabaev). Integrated Drought Management Programme (IDMP) Working Paper 1. WMO, Geneva, Switzerland and GWP, Stockholm, Sweden. WRI (2019) https://www.wri.org/aqueduct/

WRI (2019) Identify and evaluate water risks around the world. Webpage, WRI. (https://www.wri.org/aqueduct/)

Yachieli, Y., Shalev, E., Stuart, W., Kiro, Y., Kafri, U. (2010) ‘Response of the Mediterranean and Dead Sea coastal aquifers to sea level variation’ Water Resources Research 46(12)

Zawahri, N., Sowers, J. and Weinthal, E. (2011) The politics of assessment: water and sanitation MDGs in the Middle East. Development and change, 42(5), pp.1153-1178.

Zeitoun, M., Allan, T., Al Aulaq, N., Jabarin, A. and Laamranis, H. (2012) ‘Water demand management in Yemen and Jordan: addressing power and interests’ The Geographical Journal 178(1): 54-66





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