RICCAR

Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region

ARAB CLIMATE CHANGE ASSESSMENT REPORT

EXECUTIVE SUMMARY

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PREFACE

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio Economic Vulnerability in the Arab Region (RICCAR) is a joint initiative of the United Nations and the League of Arab States launched in 2010.

RICCAR is implemented through a collaborative partnership involving 11 regional and specialized organizations, namely the United Nations Economic and Social Commission for Western Asia (ESCWA), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), Food and Agriculture Organization of the United Nations (FAO), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), League of Arab States, Swedish Meteorological and Hydrological Institute (SMHI), United Nations Environment Programme (UN Environment), United Nations Educational, Scientific and Cultural Organization (UNESCO) Office in Cairo, United Nations Office for Disaster Risk Reduction (UNISDR), United Nations University Institute for Water, Environment and Health (UNU-INWEH), and World Meteorological Organization (WMO). ESCWA coordinates the regional initiative. Funding for RICCAR is provided by the Government of Sweden and the Government of the Federal Republic of Germany.

RICCAR is implemented under the auspices of the Arab Ministerial Water Council and derives its mandate from resolutions adopted by this council as well as the Council of Arab Ministers Responsible for the Environment, the Arab Permanent Committee for Meteorology and the 25th ESCWA Ministerial Session.

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FOREWORD

The Arab Climate Change Assessment Report (ACCAR) is the outcome of work conducted within the framework of the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR), which was launched jointly by the League of Arab States and United Nations organizations as a response to the first Arab Declaration on Climate Change issued in December 2007.

The report is the first regional assessment to comprehensively assess the impact of climate change on water resources in the Arab region as a single geospatial unit by generating ensembles of regional climate and hydrological modelling projections until the year 2100. It is also the first to conduct an integrated assessment of these climate change impacts as they affect the socioeconomic and environmental vulnerability of Arab States. Previous analyses of climate change across the Arab region had been drawn from global assessments that segment Arab States between the Asian and African continents or various subdomains; stand-alone modelling outputs; or country-level studies that aimed for a regionally representative picture, despite differences in assumptions, scenarios and methodologies.

The findings presented in this report fill this gap and are based on a common and uniform methodological framework applied across the Arab region, which thus allows for regional dialogue and exchange among Arab stakeholder groups, whether they are situated on the Atlantic Ocean or the Sea of Oman. This framework was developed under RICCAR through a collaborative partnership involving the League of Arab States, United Nations organizations and specialized agencies. It was realized by engaging scientists and stakeholders in an integrated assessment that considers regional-specific indicators related to geography, climate, water and vulnerability, based on scientific methods. These findings are also the outcome of the partnership forged with the Adaptation to Climate Change in the Water Sector in the MENA Region (ACCWaM) project, which contributed significantly to the development of the integrated vulnerability assessment applied in this report.

Both the preparation and the findings of this report have informed policy dialogue on climate change at the Arab regional level. It has enhanced the capacity of governments, experts and civil society to draw upon climate science to inform decision-making by regularly informing and engaging with them throughout the preparatory process via intergovernmental sessions, expert groups, consultative forums, workshops, working groups, task forces and high-level events. This has included deliberations that have taken place under the auspices of the Arab Ministerial Water Council, the Arab Permanent Committee for Meteorology and the Arab Group of climate change negotiators that reports to the Council of Arab Ministers Responsible for the Environment.

The Implementing Partners and Donors of the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region are thus pleased to present to you – our stakeholders and colleagues – this Arab Climate Change Assessment Report, 10 years after the first Arab Declaration on Climate Change was issued. It is hoped that it will continue to inform regional dialogue, priority-setting and positioning on climate change in the Arab region as envisioned under this collaborative regional effort.

ACRONYMS AND ABBREVIATIONS

ACCAR	Arab Climate Change Assessment Report
ACCWaM	Adaptation to Climate Change in the Water Sector in the MENA Region
ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands
AMWC	Arab Ministerial Water Council
APCM	Arab Permanent Committee for Meteorology
ArabCOF	Arab Climate Outlook Forum
AR4/AR5	Fourth/Fifth Assessment Report (IPCC)
CAMRE	Council of Arab Ministers Responsible for the Environment
CDD	maximum length of dry spell
CNRM-CM5	Centre National de Recherches Météorologiques-Climate Model 5
CO_2	carbon dioxide
CORDEX	Coordinated Regional Climate Downscaling Experiment
CWD	maximum length of wet spell
DARE	data rescue
DBS	distribution-based scaling
DRR	disaster risk reduction
EC-EARTH	ECMWF-based Earth-system model
EH	Ethiopian Highlands
ESCWA	United Nations Economic and Social Commission for Western Asia
ETCCDI	Expert Team on Climate Change Detection and Indices
EU	Upper Euphrates
FAO	Food and Agriculture Organization of the United Nations
GCM	global climate model or general circulation model
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory-Earth System Model 2
GIS	Geographic Information Systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
HEC-HMS	Hydrologic Engineering Center Hydrological Modelling System (hydrological model)
HYPE	Hydrological Predictions for the Environment (hydrological model)
IM	integrated mapping
IPCC	Intergovernmental Panel on Climate Change
ITCZ	intertropical convergence zone
JCDMS	Jordanian Climate Data System
JMD	Jordanian Meteorological Department
JR	Jordan River
km	kilometres
MD	Mediterranean Coast
MENA	Middle East North Africa
MH	Moroccan Highlands
mm	millimetres
MR	Medjerda River
m^3/s	cubic metre per second
NAO	North Atlantic oscillation
NTD	Neglected Tropical Disease
PMD	Palestinian Meteorological Department
RCA4	Rossby Centre Regional Atmospheric Model 4
RCM	regional climate model
RCP	representative concentration pathway
RHM	regional hydrological model
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
R10	annual number of days with precipitation greater than 10 mm
R20	annual number of days with precipitation greater than 20 mm
SDII	simple daily intensity index
Sida	Swedish International Development Cooperation Agency
SMHI	Swedish Meteorological and Hydrological Institute
SPI	standardized precipitation index
SR	Senegal River Headwaters
SU	number of summer days
SU35	number of hot days
SU40	number of very hot days
TR	tropical nights
TU	Upper Tigris
UNISDR	United Nations Office for Disaster Risk Reduction
UN Environment	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNU-INWEH	United Nations University Institute for Water Environment and Health
VA	vulnerability assessment
VIC	Variable Infiltration Capacity (hydrological model)
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
°C	degree Celsius
%	per cent

SUMMARY

SUMMARY OF MAIN FINDINGS AND CONCLUSIONS

The Arab Climate Change Assessment Report (ACCAR) presents regional climate modelling (RCM) and regional hydrological modelling (RHM) projections for the Arab region until the year 2100, based on climate scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5).

It also examines the impact of climate change on shared water resources, as well as the vulnerability of water, agriculture, ecosystems, human settlements and people to climate change in the Arab region, along with associated subsectors.

Findings of case studies examining flood frequency, droughts, crop productivity and human health are also considered, as well as research on climate and water data in the region.

The assessment report shows that the Arab region will experience rising temperatures, as well as climate change impacts on its freshwater resources over the course of this century and that these changes will have implications for socioeconomic and environmental vulnerability in Arab States, albeit to varying degrees. The following 15 conclusions summarize some of the key findings presented in the report.

1. The temperature in the Arab region is increasing and is expected to continue to increase until the end of the century.

The average mean change in temperature for RCP 4.5 shows an increase of 1.2 °C to 1.9 °C at mid-century and 1.5 °C to 2.3 °C by end-century. For RCP 8.5, temperature increases from 1.7 °C to 2.6 °C for mid-century and 3.2 °C to 4.8 °C towards end-century. Parts of the Arab region could thus witness a temperature increase of 5 °C by the end of this century compared to the reference period (1985–2005).

The highest increases in average mean temperature in the Arab region are projected in the non-coastal areas, including the Maghreb, the upper Nile River Valley, and the central and western parts of the Arabian Peninsula. The Maghreb will experience a mid-century average temperature increases of 1.4 °C to 2.5 °C under RCP 4.5 and RCP 8.5 respectively, and an end-century average temperature increase of 1.8 °C to 4.1°C under RCP 4.5 and RCP 8.5 respectively. Meanwhile, the upper Nile River Valley is projected to experience an increase in mean temperature of 1.5 °C to 2.0 °C at mid-century under RCP 4.5 and RCP 8.5 respectively, and an increase of 1.8 °C to 3.6 °C by end-century. The highest temperature increase will be felt by the end of the century in the western inland parts of the region around the Tindouf basin.

2. Precipitation trends are largely decreasing across the Arab region until the end of the century, although some limited areas are expected to exhibit an increase in the intensity and volume of precipitation.

Decreasing precipitation trends can be seen in most of the Arab region towards mid-century, with a reduction of about 90 mm in average annual precipitation for the

Woman carries water home, Darfur, Sudan, 1994. Source: Stephan Schneiderbauer.

Atlas Mountains under RCP 8.5. By the end of the century, both scenarios project a reduction of the average annual precipitation reaching 90–120 mm/year in the coastal areas. This is mainly projected around the Atlas Mountains and in the upper Euphrates and Tigris basin.

Some areas, however, show increasing precipitation trends, such as the south-eastern Arabian Peninsula and some parts of the Sahel, which can be better understood by looking at extreme climate indices and subdomain findings. For instance, results for Wadi Diqah in Oman indicate an increase in precipitation intensity and heavy precipitation days, together with an increasing number of consecutive dry days for future periods under both RCPs. Runoff and evapotranspiration across the region generally follow the same trends as precipitation, noting that evapotranspiration is limited by water-scarcity constraints in some areas.

3. Extreme climate indices and seasonal projections provide valuable insights into climate change impacts, particularly at smaller scales of analysis.

Annual mean temperature and precipitation are generally insufficient to assess the impact of climate change on the region and reference to extreme climate indices and their seasonal peaks can provide greater insight into the implications of temperature and precipitation for different subregions.This also can help to enhance understanding and action for reducing disaster risks at smaller scales of analysis. The projections show that the number of very hot days over 40 °C will increase significantly across the Arab region until the end of the century. The number of consecutive dry days is increasing to a more moderate extent, while the number of annual days when precipitation is over 20 mm is limited, due to averaging across the region. Analysis of smaller domains can provide greater insight of trends related to extreme climate events in specific areas.

4. Analysis of climate change impacts on shared water resources can benefit from regional and basin-level assessments.

The impact of climate change and climate vulnerability will further complicate the management of shared water resources. Regional hydrological models can provide general trends to inform regional understanding of climate change impacts in a transboundary context, based on smaller domains that cover parts of basins included in a regional domain. While regional models can provide annual and seasonal analysis that can inform regional cooperation, basin-level analysis allows for greater representation of watershed dynamics and the application of basin-specific models focused on issues of concern to riparian states. Complementary assessments can thus be pursued when examining the impacts of climate change on shared water resources in the region, depending on the forum and scale of analysis sought.

5. Sector case studies enhance understanding of climate change implications.

Regional climate modelling, hydrological modelling and vulnerability assessment findings can help to inform additional analysis at the sector level, such as demonstrated in the agricultural sector and human-health case studies. These case studies reveal that the impact of climate change should not be limited to examining average changes in climate trends, but should also consider the implications of maximum and minimum climate phenomena and extreme climate events, as well as changes over seasons.

The findings related to the agricultural sector clearly show how changes in temperature, precipitation and evapotranspiration are contributing to water scarcity and affecting green sectors in the Arab region. The findings related to the health case studies show that increases in temperature towards the north is creating new health challenges for the region in terms of heat, humidity and certain neglected tropical diseases.

6. Predicted vulnerability is largely moderate to high and exhibits a generally increasing gradient from north to south across the Arab region.

Throughout the Arab region and across all sectors and subsectors, the vulnerability of Arab States to climate change is moderate to high and is generally increasing over time and across both RCP scenarios.

The resultant vulnerability tends to be lowest in the Maghreb, Levant and, to some extent, the Zagros Mountains in the upper Tigris–Euphrates basin. Conversely, the southern third of the Arab region, which includes the Sahel, southern Sahara Desert, the south-western Arabian Peninsula and the Horn of Africa, exhibit the highest projected vulnerability in the region. The areas in-between generally indicate moderate vulnerability.

Euphrates River, Iraq, 2017. Source: Naji Geha.

7. Both components of potential impact are important to consider when conducting vulnerability assessments.

Exposure is based upon a selection of different indicators that can generally be classified into precipitation-based or temperature-based parameters. The vulnerability assessment results suggest a stronger correlation to change in precipitation than temperature. This assessment is reasonable, considering many subsectors are dependent upon water availability.

Sensitivity is correlated with population density, which generally confines areas of higher sensitivity to urbanized coastal areas and the lower Nile River Valley; the remaining areas, which encompass most of the Arab region, demonstrates low sensitivity. It is noted that over half of the subsectors studied have the population dimension weighted more heavily than the other two sensitivity dimensions. Other than the population density indicator, indicators within this dimension are based on national data and thus the dimension has little spatial variation at a subnational level.

Although other subsectors do not emphasize population, they highlight certain indicators that are correlated with population density, such as livestock density and flood-prone areas, which are affected by rural development and urbanization, respectively.

8. Of the three components of the integrated vulnerability assessment, adaptive capacity is most likely to influence vulnerability, suggesting that the ability of mankind to influence the future is stronger than that of climate change and environmental stressors.

While the respective contributions of potential impact (the aggregated result of exposure combined with sensitivity) and adaptive capacity to vulnerability were weighted equally in the assessment, adaptive capacity often reveals a stronger correlation with vulnerability. This is partly because sensitivity is generally low across the region and particularly in less populated areas that constitute over three-quarters of the Arab region's surface area. This, in turn, reduces the potential impact generated when combining sensitivity with exposure.

The findings also reveal that large areas situated in some of the Arab region's least developed countries are projected to witness increases in precipitation with moderate average increases in temperature relative to other parts of the region over the course of the century, but that these trends are insufficient to offset their low levels of adaptive capacity. Thus, low projected exposure to climate change is insufficient to counterbalance low adaptive capacity.

9. Areas with the highest vulnerability, which have been defined as hotspots, generally occur in the Horn of Africa, the Sahel and the south-western Arabian Peninsula, irrespective of sector, subsector or projected climate scenario.

Vulnerability hotspots have been defined by the top 10% of vulnerability aggregated values, combined with a top 20% and top 30% buffer.

All hotspots exhibit low adaptive capacity, although their exposure to climate change varies. Vulnerability hotspots generally recur in the Sahel extending northwards into the Sahara Desert, the south-western Arabian Peninsula along the Red Sea, and the Horn of Africa.For instance, most of the Horn of Africa shows low-to-moderate exposure due to increasing precipitation coupled with modest increases in temperature.

Moreover, sensitivity in this area is generally low and potential impact is thus largely low to moderate. Nevertheless, this modest potential impact is not sufficient to counterbalance the low adaptive capacity in that part of the region.

10. Despite declining precipitation, areas with the lowest vulnerability relative to the region include the western Mediterranean, coastal Maghreb, and the coastal Levant due to higher adaptive capacity in this area, as compared to other parts of the region.

Relatively large decreases in precipitation and runoff coupled with small increases in temperature results in variable exposure, ranging from low to high, depending on the sector or subsector and scenario.

Sensitivity is generally low, other than in population centres near the coast, affecting much of the coastal Levant and selected areas in the Maghreb. Adaptive capacity is moderate, compensating for areas which reveal higher potential impact. The resultant vulnerability is low to moderate.

Young boys carrying water, Jowhar, Somalia, 2013. Source: UN Photo/Tobin Jones.

11. Even though the central Mediterranean coast and Green Mountains are subject to particularly strong warming, the area is indicative of moderate vulnerability due to relatively higher adaptive capacity, as compared to other parts of the region.

Exposure is variable along the Mediterranean coast because increases in temperature are modest and precipitation is found to be unchanged or decreasing slightly; meanwhile, indices such as the number of summer days over 35 °C are expected to increase substantially.Sensitivity is also wide-ranging, but is often high immediately near the coastline, where population density is highest. Lastly, adaptive capacity in this area is generally moderate.This is in line with the findings in other parts of the region where vulnerability is strongly influenced by the adaptive capacity of areas to respond to changes in climate.

12. Despite precarious environmental, economic and social conditions within the lower Nile River Basin, the area demonstrates projected moderate vulnerability due to high adaptive capacity relative to other parts of the region.

The lower Nile River Basin towards the Mediterranean exhibits the highest population density in the Arab region, thus projecting high sensitivity. Exposure is variable, depending on the climate scenario under study and the indicators selected for each subsector. Adaptive capacity is high in some parts of the basin, which compensates for elevated potential impact.

13. Although the Euphrates and Tigris rivers face challenges due to demographic pressures, hydro-infrastructure developments and water-quality degradation, socioeconomic vulnerability to climate change is found to be moderate relative to other parts of the region.

Exposure to climate change in the Euphrates and Tigris is variable relative to the rest of the region. Precipitation is generally decreasing in the upper part of the basin and increasing in the lower part, but can vary depending on the time period and climate scenario.

Temperature increases are modest. Sensitivity is generally low, despite a high population density near Baghdad and generally high degradation of vegetative cover. Adaptive capacity is variable, but generally moderate. The net result signals moderate vulnerability in general.

14. Despite remaining among the hottest areas in the Arab region, and signalling increasing temperatures, the Arabian Gulf generally projects moderate vulnerability to climate change.

Like the entire Arab region, the central and eastern Arabian Peninsula is experiencing higher temperatures. Exposure is low to moderate as projected temperature increases are mid-range as compared to the Sahel and Sahara.

Meanwhile, projected precipitation is relatively unchanged compared to the reference period, except along the Sea of Oman and nearby mountain range.

Overall sensitivity in the central region of the Gulf is low to moderate, while adaptive capacity remains moderate. As a result, vulnerability to climate change is moderate for the central and eastern areas of the Gulf compared to the rest of the region.

15. Region-specific integrated vulnerability assessments can be drawn upon to inform regional cooperation, as well as basin-level, country-level and sector-level analysis to advance understanding and collective action on climate change.

The Arab Ministerial Water Council, the Council of Arab Ministers Responsible for the Environment, the Arab Permanent Committee for Meteorology and intergovernmental mechanisms responsible for agriculture and health have identified climate change as a challenge to consider within the context of regional and national efforts to achieve sustainable development. Arab Member States have drawn upon the RICCAR impact assessment and integrated vulnerability assessment findings to inform their work on climate change.

OVERVIEW

INTRODUCTION

The Arab region with its unique and complex geopolitical and socioeconomic setting is facing major challenges affecting the ability of Arab States to ensure the sustainable management of water resources and the delivery of water services for all. Freshwater scarcity, population growth, urbanization, conflict and changing migration patterns have increased pressures on human settlements and ecosystems and are impacting the health and welfare of women and men, children and the elderly, including vulnerable groups. This is despite regional, national and local efforts to achieve the United Nations Sustainable Development Goals in an integrated and inclusive manner.

Climate change and climate variability are imposing additional pressures, with adverse impacts being felt largely on the quantity and quality of freshwater resources and the ability of the region to ensure food security, satisfy energy demand, sustain rural livelihoods, protect human health and preserve ecosystems.

Many Arab States have also experienced a higher frequency and intensity of floods, droughts and extreme weather events. These disasters have affected the built environment, fragile land resources and natural ecosystems, which have aggravated the situation of already vulnerable communities, resulting in significant economic losses, social dislocation, environmental degradation and displacement in several parts of the region.

Studies since the early 20th century have concluded that the climate is changing. Moreover, the IPCC Fifth Assessment Report projects that the global mean surface temperature is likely to increase by at least 1.1 °C by the end of the 21st century under a moderate scenario or up to 4.8 °C under a high-end scenario relative to the 1986–2005 reference period. In tandem, the IPCC is virtually certain that there will be more frequent hot temperature extremes over most land areas as global mean surface temperature increases. The report further elaborates on the breadth and intensity of socioeconomic and environmental risks attributable to climate change as the temperature increases above the 1.5 °C and 2 °C thresholds relative to pre-industrial levels.

While these international assessments provide important insights into global processes and threats to global systems, it is crucial to understand what this means for the Arab region that is already hot, arid and where water is scarce. To do so means assessing these global temperature changes through a regional lens that characterizes regional specificities, conditions and constraints.

With these considerations and in response to joint United Nations and League of Arab States mandates, RICCAR has strived to address this issue and better bridge the science–policy interface by taking into consideration the impact of climate change on water resources and what this means for the vulnerability of peoples and ecosystems throughout the region. It has done so based on an integrated assessment methodology combining impact assessment projections with vulnerability assessment to identify regional vulnerability hotspots and priorities for coordinated action on climate change adaptation in the Arab region.

Beirut, Lebanon, 2015. Source: Carol Chouchani Cherfane.

BACKGROUND ON RICCAR

Mandates and partnerships

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) is the outcome of the first Arab Ministerial Declaration on Climate Change (2007), which recognized the potential impacts that climate change may have on development in the Arab region. The Declaration called for a comprehensive assessment of the potential impacts of climate change on the most vulnerable developing countries, including Arab States, as well as the need to identify priorities and implement climate change adaptation and mitigation programs at the national and regional levels.

A series of successive resolutions followed. This included the resolution adopted by the 25th Ministerial Session of the Economic and Social Commission for Western Asia (ESCWA) calling for the preparation of an assessment of socioeconomic vulnerability caused by the impacts of climate change on water resources (Sana'a, May 2008). The Arab Summit for Economic and Social Development also approved a project to examine the impacts of climate change on water resources in the Arab region (Kuwait, 2009).

These events led to the launching of RICCAR in 2009 and its endorsement by the Arab Ministerial Water Council as a regional initiative contributing to the implementation of the Arab Strategy for Water Security in the Arab Region to Meet the Challenges and Future Needs for Sustainable Development 2010–2030.

RICCAR is implemented through an inter-agency collaborative partnership involving 11 partner organizations, namely ESCWA, the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), the Food and Agriculture Organization of the United Nations (FAO), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, the League of Arab States Secretariat, the Swedish Meteorological and Hydrological Institute (SMHI), the United Nations Educational, Scientific and Cultural Organization (UNESCO) Cairo Office, UN Environment, the United Nations Office for Disaster Risk Reduction (UNISDR), the United Nations University Institute for Water, Environment and Health (UNU-INWEH) and the World Meteorological Organization (WMO).

In addition to the resources provided by the partner agencies, funding is provided by the Swedish International Development Cooperation Agency (Sida) and the German Federal Ministry for Economic Cooperation and Development (BMZ), which financially support RICCAR

Liwa Desert, Abu Dhabi, 2012. Source: Khajag Nazarian.

through the Adaptation to Climate Change in the Water Sector in the MENA Region (ACCWaM) project.
Three climate research centres were consulted under the regional climate modelling component of the initiative, namely the Center of Excellence for Climate Change Research at King Abdulaziz University (Saudi Arabia), King Abdullah University of Science and Technology (Saudi Arabia) and the Climate Service Center (Germany). The Cyprus Institute (Cyprus) and the International Center for Biosaline Agriculture (United Arab Emirates) were also consulted during the technical review of the RICCAR Arab Domain, which was subsequently adopted as the Middle East North Africa (MENA) Domain by the Coordinated Regional Climate Modelling Experiment (CORDEX) of the World Climate Research Programme (WCRP).

Commitment and support for the initiative have been further articulated by Arab States through follow-up resolutions adopted by the Arab Ministerial Water Council (AMWC), Arab Permanent Committee for Meteorology (APCM) and the Council of Arab Ministers Responsible for the Environment (CAMRE). The ACSAD Board of Directors, comprised of Arab ministers of agriculture and the ESCWA Committee on Water Resources, have also continued to mandate the work being conducted under RICCAR. The regional initiative is also referenced in the *Arab Strategy for Water Security in the Arab Region to Meet the Challenges and Future Needs for Sustainable Development 2010–2030* and its Action Plan, the *Arab Framework Action Plan on Climate Change*, and the *Arab Strategy for Disaster Risk Reduction 2020* and its Implementation Plan.

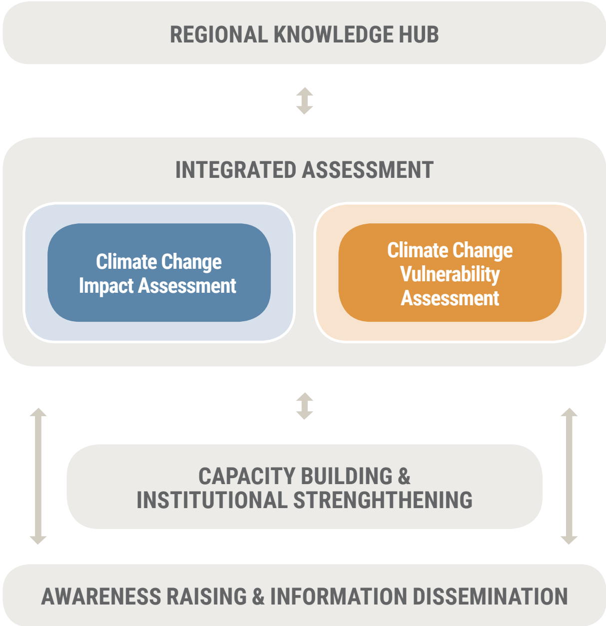
Objectives and implementation framework

The regional initiative aims to assess the impacts of climate change on freshwater resources in the Arab region and to examine the implications of these impacts for socioeconomic and environmental vulnerability based on regional specificities. It does so through the application of scientific methods and consultative processes that are firmly grounded in enhancing access to knowledge, building capacity and strengthening institutions for climate change assessment in the Arab region. In so doing, RICCAR provides a common platform for assessing, addressing and identifying regional climate change challenges, which, in turn, inform dialogue, priority setting, policy formulation and responses to climate change at the Arab regional level.

The implementation framework of RICCAR is structured around four pillars of work (Figure 1) consisting of: a baseline review and set-up of a regional knowledge hub; an integrated assessment consisting of impact assessment and vulnerability assessment components; awareness-raising and information dissemination; and capacity-building and institutional strengthening. ESCWA served as coordinator of the regional initiative, and provides regular reporting to AMWC and APCM on RICCAR-related activities.

The initiative has also contributed to the establishment of an Arab Climate Outlook Forum (ArabCOF) and a regional knowledge hub, which will continue to support and deliver on RICCAR's four pillars of work.

FIGURE 1: RICCAR implementation framework



INTEGRATED ASSESSMENT METHODOLOGY

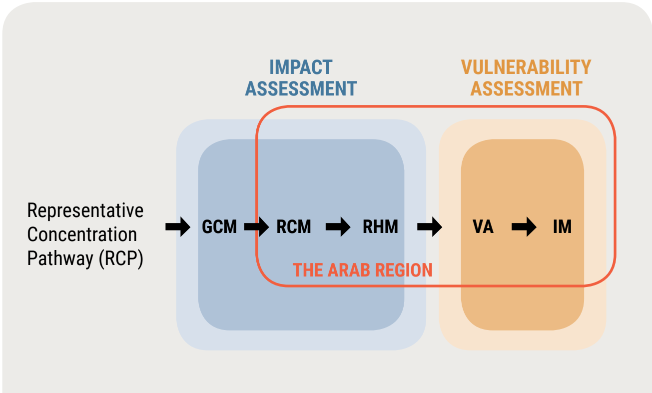
The Arab Climate Change Assessment Report presents a comprehensive picture of the impact that climate change is expected to have on freshwater resources in the Arab region and how this will affect the vulnerability of water resources, agriculture, natural ecosystems, human settlements and people until the end of the century.

The results are based on the outcome of a region-specific integrated assessment that generates regional climate modelling and hydrological modelling projections for the Arab region and for selected subdomains, including some of the region's major shared surface water basins.

These outputs are then used to inform an integrated vulnerability assessment that considers how exposure to climate change over time will affect the vulnerability of five key sectors and nine subsectors in the Arab region, in the absence of adaptation or any mitigating measures.

The development and application of the RICCAR methodological framework were pursued through iterative consultations with Arab States and international experts, the designation of national hydrological focal points and regional consultations organized through expert groups, workshops, working groups and task forces. Five stages of analysis were agreed upon as shown in Figure 2.

FIGURE 2: RICCAR integrated assessment methodology



Step 1. Select RCPs to adopt and review available global climate models (GCMs).

Step 2. Generate ensembles of regional climate modelling (RCM) projections over a defined Arab Domain.

Step 3. Interface regional hydrological models (RHM) with RCM outputs to analyse climate change impacts on water resources.

Step 4. Conduct a vulnerability assessment (VA) based on the impact assessment findings across the Arab region in targeted sectors and sub-sectors

Step 5. Complete the integrated mapping (IM) of the assessment for facilitating regional policy analysis and dialogue

In addition, impact assessment studies focusing on extreme climate events, the agricultural sector and human health provide additional insights on how climate change is projected to impact Arab States. In so doing, the report identifies vulnerability hotspots and vulnerable sectors across the Arab region and illustrates how the relative resilience of Arab communities and strategic sectors will be affected unless collective, coherent and coordinated action is taken to address the root causes of vulnerability and adapt to climate change.

Considering the limited availability of long-term quality-controlled climate and water data in the Arab region, RICCAR efforts were focused on using observed national station data, when available, coupled with data from regional or global sources to ensure the use of harmonized and reliable datasets that are comparable across Arab States.

A description of the meteorological data, water resources related data, topography and other terrestrial data, in addition to the socioeconomic related datasets used to inform the climate, hydrological and vulnerability assessments are provided in detail in the main report.

A series of selected essential climate variables, extreme climate indices and socioeconomic and environmental parameters were used for presenting the outcomes of the integrated assessment. Three time periods were selected for presenting results, namely:

- Reference period (1986–2005)
- Mid-century period (2046–2065)
- End-century period (2081–2100).

The analysis is elaborated based on two representative concentration pathways (RCPs):

- RCP 4.5 – generally describe a moderate-emissions scenario
- RCP 8.5 – generally describes a high-emissions or “business as usual” scenario.

Regional climate modelling and hydrological modelling outputs presented in the report were generated based on a 50 km x 50 km grid, while other scales of analysis were applied when conducting some of the impact assessment case studies and during the preparation of the integrated vulnerability assessment.

The Arab Climate Change Assessment Report and its technical annex serve as a reference document which extensively describes methods, outputs and conclusions generated from the assessment. The methodological framework is also further elaborated in a series of publications focusing on various components of the integrated assessment.

It is expected that this scientific report will provide a regional, science-based assessment of climate change impacts and vulnerability based on uniform and harmonized datasets and assumptions, which can inform further climate change research and foster dialogue among Arab States about priority issues, challenges and opportunities for collective action. Ultimately, it also provides a regional baseline, regional datasets and assessment outputs that can, in turn, be used to inform and prepare smaller-scale assessments at the sub-regional, national and local levels.

BOX 1: Contributions of RICCAR to improving climate data availability for effective climate analysis in the Arab region

Along with the central objective of pursuing an integrated and comprehensive climate assessment for the region, considerable work was conducted under RICCAR to support Arab States in the area of climate data collection, climate data rescue (DARE) and the development of disaster loss databases to support climate change analysis.

Extreme events data compilation

The interest of Arab meteorologists in improving regional analysis of extreme climate indices was evident at the RICCAR Regional Workshop on Climate Change Prediction/Projection and Extreme Events Indices in the Arab Region, organized by WMO, ESCWA and the National Meteorological Service of Morocco (Casablanca, 2012). The workshop collected and quality-controlled daily climate data from a large number of weather stations in the region. The results allowed for the identification of annual maximum daily precipitation trends and provided new information on extreme events in the Arab region using historical observations, which are documented in a peer-reviewed article in the *International Journal of Climatology* co-authored by WMO experts and representatives of Arab meteorological services.

*Article full reference: Donat, M.G., Peterson, T.C., Brunet, M., King, A.D., et al. 2014.Changes in Extreme Temperature and Precipitation in the Arab Region: Long-term Trends and Variability Related to ENSO and NAO. *International Journal of Climatology*, 34(3): p. 581-592.

Climate data rescue

Past records of the climate system represent key information for undertaking thorough and reliable climate assessments and a large part of past climate records is often spatially and temporarily limited with a lack of homogeneity in terms of quality standards. The key and urgent need to recover historical weather observations held in perishable media has created rising awareness among international bodies and the scientific community, which led to major DARE initiatives.

As part of RICCAR meetings, and further to recommendations from participants for follow-up actions on climate data exchange between meteorological offices in the region and data rescue, ESCWA organized a Subregional Training Workshop on Climate Data Rescue and Digitization in 2013 under the auspices of RICCAR. It aimed to provide training on theoretical and practical aspects of DARE and digitization of climate records, including discussion of methods of transferring source medium, converting to digital records, required metadata, storage and back-up practices, quality-control of data and homogenization. The meeting involved participants from meteorological services in the region and paved the way for collaboration opportunities and for the initiation of new climate DARE initiatives.

One of the outcomes was the development of a climate data rescue implementation plan for the Jordanian Meteorological Department (JMD) and the Palestinian Meteorological Department (PMD) through a joint ESCWA/WMO project. It involved JMD staff training in DARE and digitization of climate records; establishing an inventory of climate data records in paper format to be recovered and digitized; ensuring a safe and well organized archival storage with the involvement of local authorities; and developing an implementation plan for the recovery and digitization of all inventoried archives, including estimated time steps for each element of the plan. As a result, about 98% of the JMD paper notebook data have been inventoried, quality-controlled and keyed into the Jordanian Climate Data System (JCDMS).

A mission between JMD and PMD to rescue the climate data of West Bank stations at JMD was also established and a joint project to rescue climate data of 10 gauging stations from the 1950s to the 1960s with the support of ESCWA and Sida has now been completed.

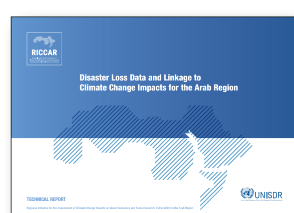
Disaster loss databases
The development of national disaster databases represents a low-cost, high-impact strategy to systematically account for disaster losses. It is the crucial first step in generating the necessary knowledge to inform efficient risk estimation, climate change adaptation and disaster risk reduction (DRR) processes.

In order to strengthen global accounting for disaster losses, UNISDR launched the Global Disaster Loss Collection Initiative that is designed to assist in the establishment of national disaster-loss databases in all regions of the world following a methodology established under “Desinventar”.

Damages in Muscat after the passage of Cyclone Gonu, Oman, 2007.
Source: Wikimedia Commons.

Recognizing the importance of having sound disaster loss and damage databases to use as information for efficient risk reduction and development, Arab States have recently expressed interest in establishing such databases. RICCAR supported the population of disaster loss databases in six Arab States, namely Jordan, Lebanon, Morocco, the State of Palestine, Tunisia and Yemen, based on the methodology and tools developed by UNISDR. The outcome was a comprehensive analysis of weather-related and geological disasters together with their socioeconomic and environmental impacts over a 30-year period. Based on collected data records, the findings of this report clearly show the prevalence of climate-related hazards as the source of most of the damage as compared to geological hazards. In addition, climate-related hazards have shown very defined increasing trends in the region. Frequency, mortality and economic losses are on the rise, especially regarding small- and medium-scale events (extensive events).

Developing disaster-loss databases thus helps identify “hotspot” areas and accordingly prioritize actions based on evidence, and provides strong justification for investing in climate change adaptation and disaster risk reduction. In the case of the Arab States under consideration, the elevated average annual losses highlighted in the report’s findings are incontestable imperatives to invest in disaster risk reduction and climate change adaptation.



Detailed information and findings on this study is available in the RICCAR technical report *Disaster Loss Data and Linkage to Climate Change Impacts for the Arab Region (2017).*

STRUCTURE OF THE REPORT

In line with the structure of the Arab Climate Change Assessment Report, the Executive Summary is organized in four sections.

It opens with a general overview followed by two parts that echo the main components of the integrated assessment methodology, namely impact assessment (Part I) and vulnerability assessment (Part II). Each part starts with a summary of the corresponding methodology applied and a short section providing details on the presentation of results in this report. Main results, findings and conclusions are then summarized for each.

Part I (impact assessment) reviews RCM and RHM projections generated for the Arab Domain and selected subdomains, with reference to some of the major shared surface water basins in the Arab region, as well as impact assessment case studies of extreme events and sector-based case studies based on RCM and RHM outputs.

Part II (integrated vulnerability assessment) reviews outputs from the integrated vulnerability assessment, presenting a summary of results for each of the five sectors and nine subsectors studied, followed by the main findings and conclusions for this component.

All the integrated assessment outputs and case studies presented are original work generated within the framework of the regional initiative and build upon the dynamically downscaled RCM outputs presented in Part I.

The closing part (**next steps**) explores how this assessment report can inform regional policymaking and future work, as well as envisioned next steps and additional resources stemming from RICCAR.

Full details on outputs generated from the assessment are extensively described in the Arab Climate Change Assessment Report and its accompanying technical annex. The methodological framework is also further elaborated in a series of publications focusing on various components of the integrated assessment.

Reference to a corresponding RICCAR publication of the series (technical report, technical note or training material) is mentioned in the relevant section throughout this Executive Summary when deemed useful to provide further elaboration on specific findings.

Well in Sana'a, Yemen, 2014. Source: Julien Harneis.

PART I

IMPACT ASSESSMENT

METHODOLOGY OVERVIEW

The impact assessment methodology is grounded on the use of regional climate modelling and regional hydrological modelling to generate climate projections.

The RCM approach was applied to dynamically downscale global climate modelling results to regional scales. An Arab Domain (Figure 3) was thus established for framing the application of RCMs in accordance with guidelines put forth by the Coordinated Regional Climate Downscaling Experiment (CORDEX) of the World Climate Research Programme.

Regional climate modelling outputs were generated by SMHI using the Rossby Centre Regional Atmospheric Model (RCA4), forced at its boundaries by three state of- the-art global climate models (GCMs), namely EC-Earth, CNRM-CM5 and GFDL- ESM2M. An average of the three-model output ("ensemble") was derived for RCP 4.5 and RCP 8.5 for the various climate variables up to the end of the 21st century at a horizontal resolution of 50 x 50 km.

Comparisons with results of 25 km resolution for the RCP 8.5 projections were made, noting that at this resolution only two projections were available and were thus not combined as an ensemble. Analysis for them consisted primarily of comparisons against the respective 50-km projections driven by the same GCM (EC-Earth, GFDL-ESM2M).

All RCM simulations results were bias-corrected using the distribution-based scaling (DBS) method to avoid typical biases originating from either the driving GCM model or the RCM used for downscaling.

Concerning results, it is worth noting that larger uncertainties are involved for precipitation than for temperature outputs, whereby the precipitation change signal is more sensitive to the driving GCM rather than the emission scenario.

Regional hydrological modelling was carried out through two main hydrological models using DBS-corrected precipitation and temperature results as inputs. The Hydrological Predictions for the Environment (HYPE) and Variable Infiltration Capacity (VIC) models were used to produce RHM results over the entire Arab region. The Hydrologic Engineering Center Hydrological Modelling System (HEC-HMS) model was used only to investigate hydrological impacts from changes in extremes at selected local scales.

The limited quantity of hydrological observation data generates uncertainties regarding the accuracy of the hydrological modelling outputs. For instance, as runoff projections are based on precipitation outputs, they demonstrate high uncertainties for both the HYPE and VIC models.

FIGURE 3: CORDEX-MENA DOMAIN

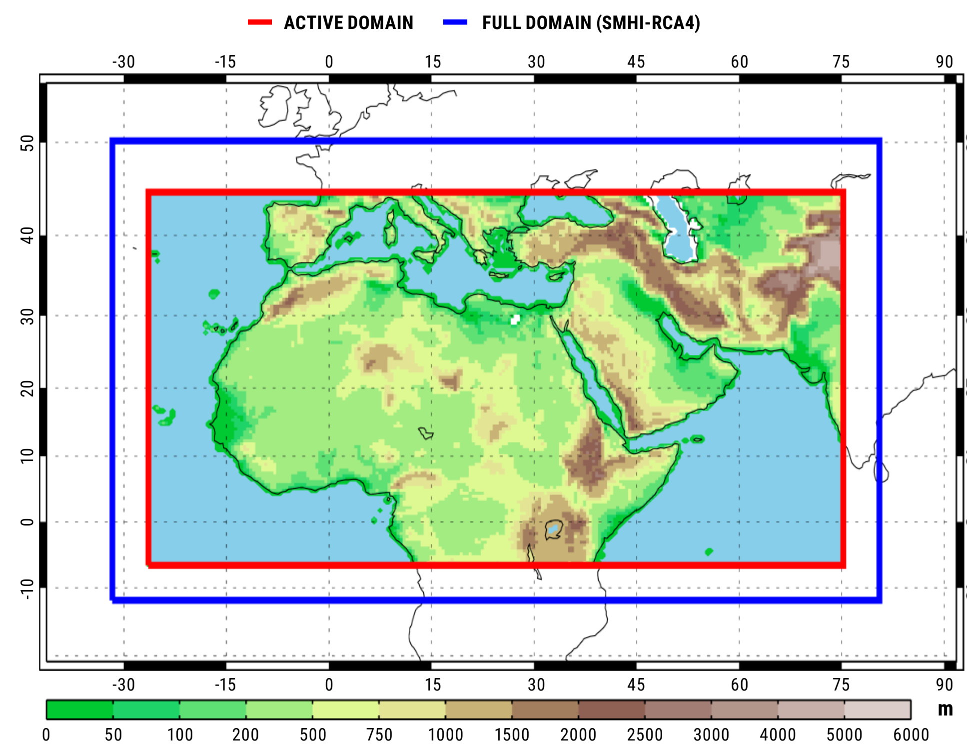


TABLE 1: RCM and RHM output variables

Modelling source	Output variables	Absolute/difference unit
Regional climate modelling	Temperature (Tmean, Tmax, Tmin)	°Celsius
	Precipitation	mm
Regional hydrological modelling	Runoff	mm
Related to the Arab region, the Mediterranean Coast and the Moroccan Highlands findings	Evapotranspiration	mm
Regional hydrological modelling	Runoff	mm
Related to presentation of shared surface basins findings	River discharge (only HYPE) - Mean discharge - High flow - Low flow	 m^3/s m^3/s m^3/s or number of days

It is also worth pointing out that the higher the human influence on the river system (water-regulation infrastructure, irrigation, etc.) compared to the size of the river, the higher the uncertainties will be in the results. These factors should be taken into consideration when interpreting and analysing discharge-related results.

It is thus important to note that the RHM approach does not replace the need to carry out local studies that address water resources management in more detail but it does help to identify key areas that would potentially benefit from more detailed studies.

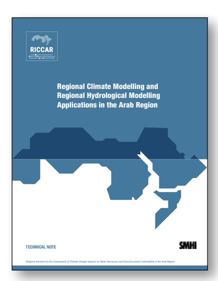
Additional information on bias correction, as well as model calibration, validation and performance of the applied HYPE and VIC models, is available in the corresponding RICCAR technical note. Further information on HEC-HMS application is available in the RICCAR technical report *Impact of Climate Change on Extreme Events in Selected Basins in the Arab Region (2017)*.

The list of specific variables studied from each modelling source are presented in Table 1 and results are expressed in terms of changes from the reference period.

Although mean changes in the future climate are of interest for many applications, changes in extreme weather events are sometimes even more important, as they can have severe impacts on human health, built infrastructure, the natural environment, the transport sector and the economy at large.

Seven selected indicators were thus examined under RICCAR, stemming from the list of 27 indices developed by the WMO Expert Team on Climate Change Detection and Indices (ETCCDI). Two additional regional-specific indicators that were deemed to be more relevant for examining temperature thresholds in the already hot Arab region were also studied, namely the annual number of days with daily maximum temperature over 35 °C (SU35) and over 40 °C (SU40), as seen in Table 2.

In addition to providing impact assessment results for the Arab Domain, a selection of specific subdomains was also made aiming to provide more distinct indicative information over certain areas of interest, including shared river basins (Figure 4).

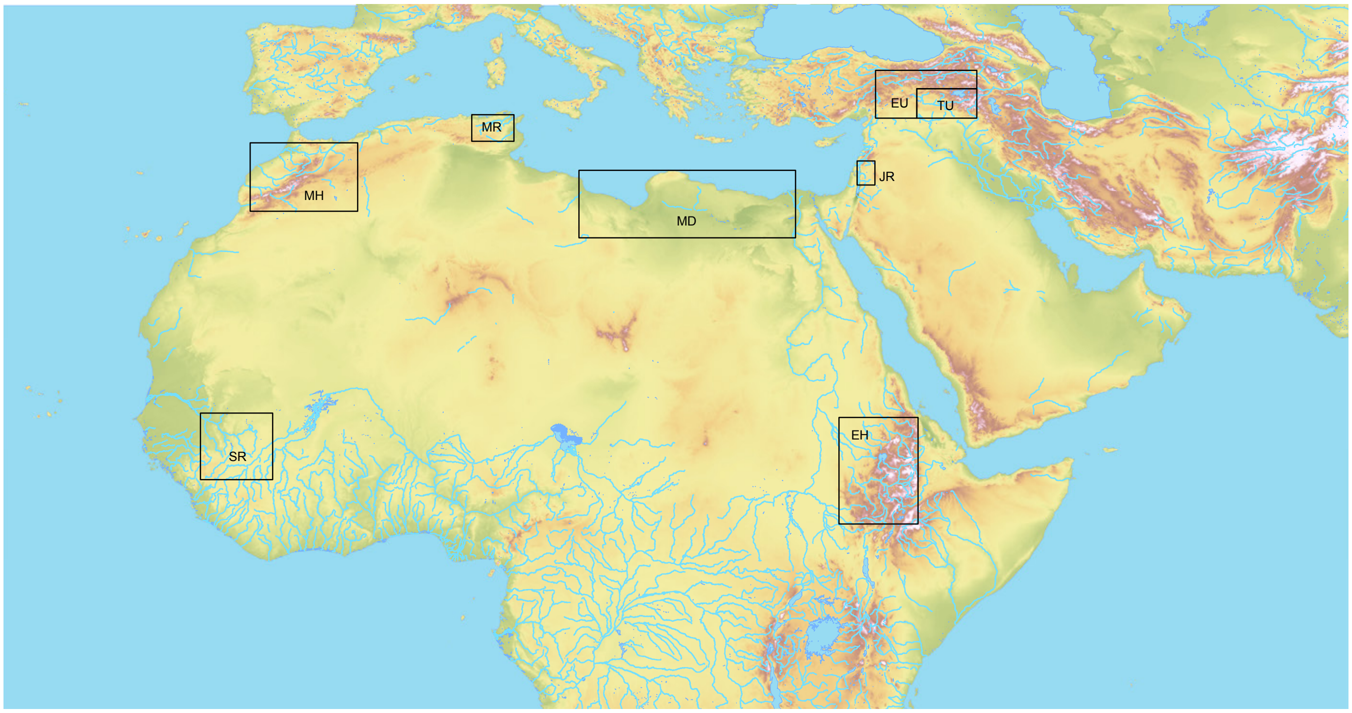


Further information on the methodology applied for the impact assessment component is available in the RICCAR technical note *Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region (2017)*.

TABLE 2: Extreme events indices studied

Index	Long name	Definition
EXTREME TEMPERATURE INDICES		
SU	Number of summer days	Annual number of days when daily maximum temperature > 25°C
SU35	Number of hot days	Annual number of days when daily maximum temperature > 35°C
SU40	Number of very hot days	Annual number of days when daily maximum temperature > 40°C
TR	Number of tropical nights	Annual number of days when daily minimum temperature > 20°C
EXTREME PRECIPITATION INDICES		
CDD	Maximum length of dry spell	Maximum annual number of consecutive days when daily precipitation < 1mm
CWD	Maximum length of wet spell	Maximum annual number of consecutive days when daily precipitation ≥ 1mm
R10	Annual count of 10mm precipitation days	Annual number of days when daily precipitation ≥ 10mm
R20	Annual count of 20mm precipitation days	Annual number of days when daily precipitation ≥ 20mm
SDII	Simple precipitation intensity index	The ratio of annual total precipitation to the number of wet days (≥ 1mm)

FIGURE 4: LOCATION OF SUBDOMAINS IDENTIFIED FOR ANALYSIS



Subdomains	Identifier	Subdomain Name	Coordinates
Selected Subdomains	MH	Moroccan Highlands	9W 1W 30N 35N
	MD	Mediterranean Coast	15E 31E 28N 33N
Shared River Basins	EH	Ethiopian Highlands (Blue Nile Headwaters)	34E 40E 7N 15N
	TU	Upper Tigris (Tigris River Headwaters)	40E 44E 37N 39N
	EU	Upper Euphrates (Euphrates River Headwaters)	37E 44E 39N 40N
	MR	Medjerda River	15E 31E 28N 33N
	JR	Jordan River	35E 37E 32N 34N
	SR	Senegal River Headwaters	12W 7W 10N 15N

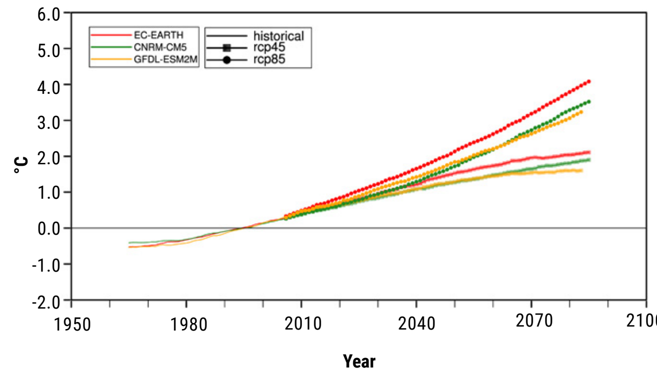
MAIN RESULTS AND FINDINGS

Main findings and results stemming from the impact assessment are presented in the following sections.

The maps show the spatial extent of projected change over the Arab region averaged for the three-member ensemble, for mid-century and/or end-century compared to the reference period, considering different RCP emission scenarios (RCP 4.5 and/or RCP 8.5).

1. The temperature in the Arab region is increasing and is expected to continue to increase until the end of the century.

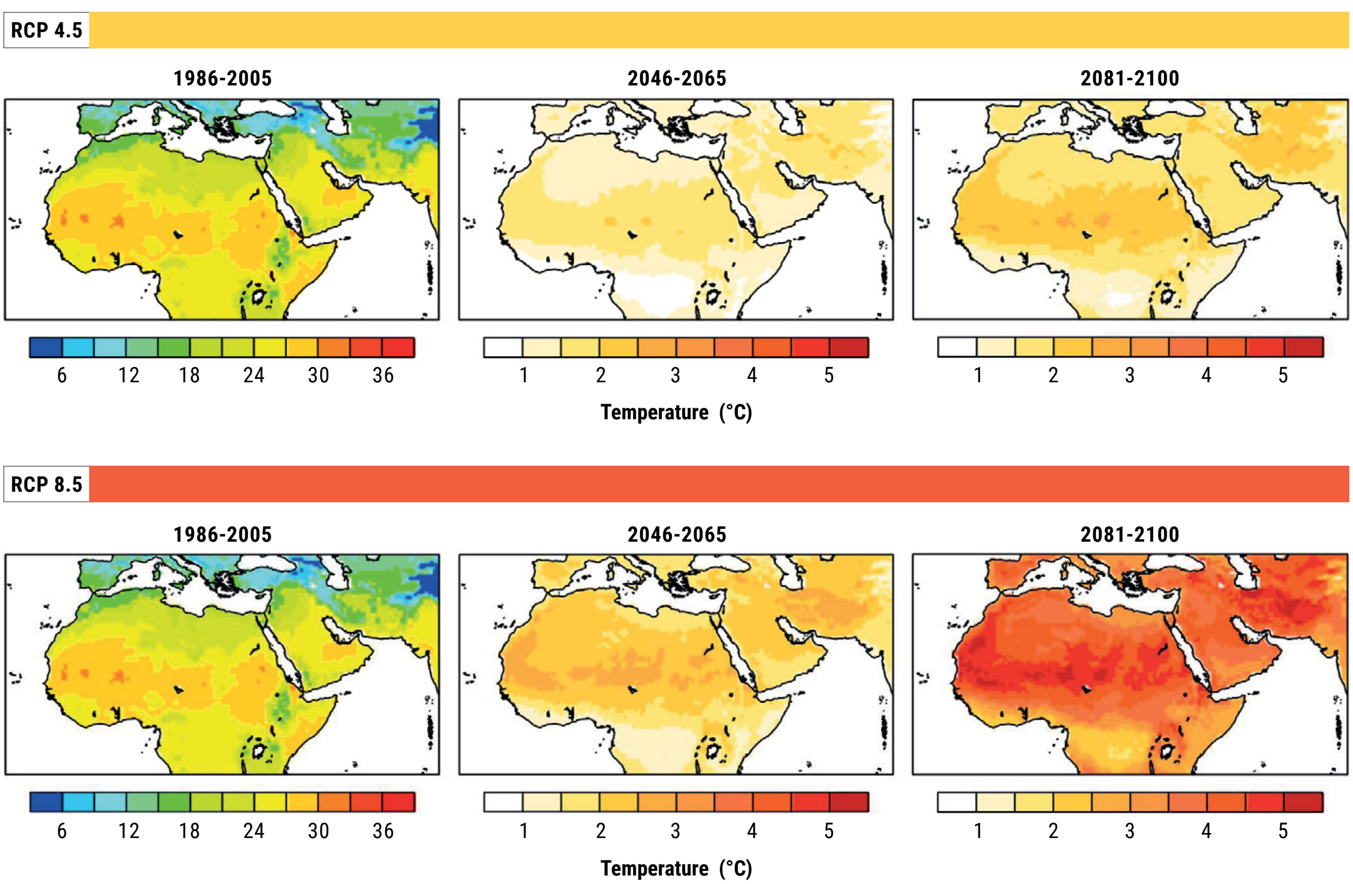
FIGURE 5: Change in mean temperature (°C) over time for the Arab Domain as a 30-year moving average for six individual climate projections



All projections indicate that temperatures will rise over the Arab region during this century (Figure 5 and Figure 6). The average mean change in temperature for RCP 4.5 shows a projected increase of 1.2 °C–1.9 °C at mid-century and 1.5 °C– 2.3 °C by end-century.

For RCP 8.5, temperatures increase to 1.7 °C–2.6 °C for mid-century and 3.2 °C–4.8 °C towards end-century. The higher increase at mid-century is shown in inland areas, with the most marked changes projected in the Sahara Desert.

FIGURE 6: Mean change in annual temperature (°C) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period



By the end of the century, the increasing change in temperature becomes much more evident throughout the Arab domain, with parts of the Arab region that could witness a temperature increase of 5 °C compared to the reference period.

Overall, the highest increases in average mean temperature in the Arab region are projected in the non-coastal areas, including the Maghreb, the upper Nile River Valley, the Tigris and Euphrates headwaters, and the central and western parts of the Arabian Peninsula.

The range of temperature change varies according to the different subdomains, but all exhibit increasing ranges towards the end of the century which are more intense for RCP 8.5 compared to RCP 4.5.

For instance, the Moroccan Highlands will experience mid-century average temperature increases of 1.4 °C to 2.2 °C under RCP 4.5 and RCP 8.5 respectively, and an end-century average temperature increase of 1.8 °C to 4.1 °C under RCP 4.5 and RCP 8.5, respectively.

Meanwhile, the upper Nile River Valley is projected to experience an increase in mean temperature of 1.5 °C to 2.0 °C at mid-century under RCP 4.5 and RCP 8.5, respectively, and an increase of 1.8 °C to 3.6 °C by end-century.

The change in mean temperature for the Tigris and the Euphrates headwaters is also notable with a projected increasing trend towards end-century, whereby mean temperature changes for the worst-case scenario are projected to reach an increase of 4.5 °C and 4.8 °C for the Tigris headwaters and the Euphrates headwaters, respectively.

As for seasonal changes, results have shown no evident tendency for temperature to increase more during one particular season of the year. The warming is more or less evenly distributed over all seasons. For some areas, there is a larger projected increase in the winter season (e.g. Senegal river headwaters) and for others the summer season sees larger increases (e.g. Tigris river headwaters). However, it seems apparent that for most countries bordering the Mediterranean, the increase during summer will be larger than during winter.

Atlas Mountains, Morocco, 2015. Source: Heribert Rustige.

2. Precipitation trends are largely decreasing across the Arab region until the end of the century, although some limited areas are expected to exhibit an increase in the intensity and volume of precipitation.

Projected precipitation changes vary considerably across the Arab Domain with no universal trend for annual or seasonal results. Decreasing precipitation trends can be seen in most of the Arab region towards mid-century (Figure 7). In particular, a reduction of about 90 mm in average annual precipitation for the Atlas Mountains is projected under RCP 8.5. By the end of the century, both scenarios project a reduction of the average annual precipitation reaching 90–120 mm/year in coastal areas. This is mainly projected around the Atlas Mountains and in the upper Euphrates and Tigris basins.

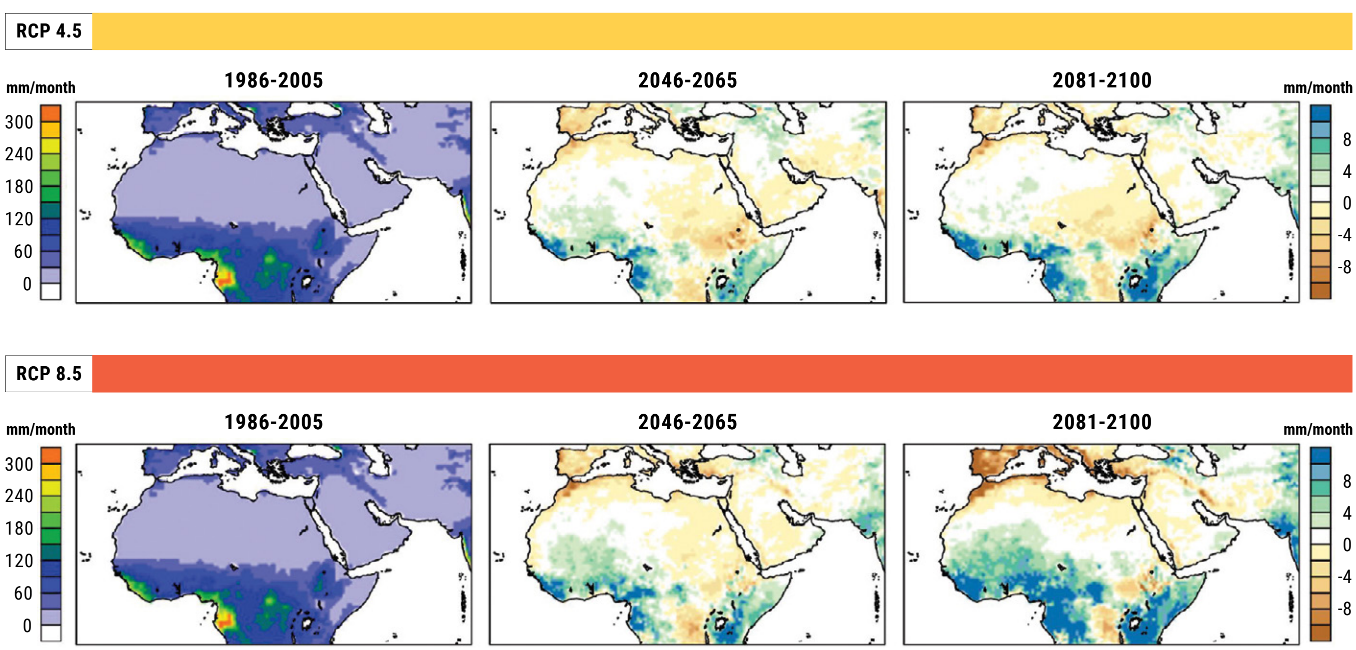
There is an evident agreement between model projections on a decrease in precipitation projections in the Atlas Mountains region, mostly accentuated at mid-century (for both scenarios) and for RCP 8.5 at end-century.

For the latter period and scenario, an agreement on a decrease in precipitation is evident for the coastal Mashreq area as well as for the coastal areas of the Arabian Peninsula along the Red Sea.

For some areas, however, results show an inter-model agreement on increasing precipitation trends, such as the south-eastern Arabian Peninsula and some parts of the Sahel, which is a pattern potentially resulting from the northward displacement of the Intertropical Convergence Zone (ITCZ), bringing precipitation.

King Talal Dam, Jordan, 2017. Source: Carol Chouchani Cherfane.

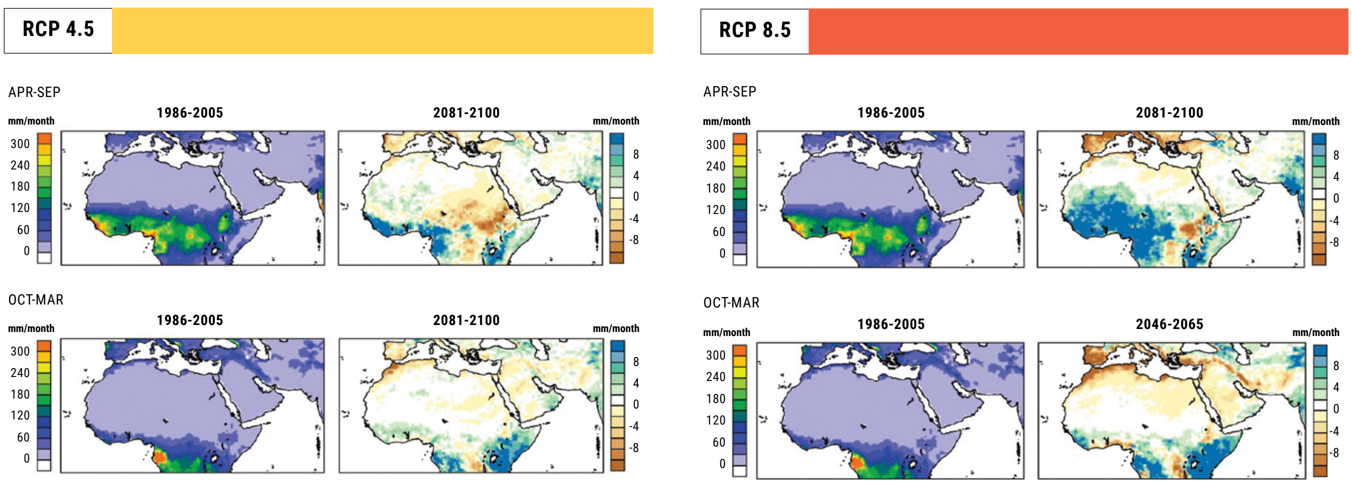
FIGURE 7: Mean change in annual precipitation (mm/month) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period



The trends can be better understood by looking at extreme climate indices and subdomain findings. For instance, results for Wadi Diqah in Oman indicate an increase in precipitation intensity and heavy precipitation days (annual number of days when precipitation ≥ 10mm), together with an increasing number of consecutive dry days (CDD) for future periods under both RCPs.

At the seasonal level (Figure 8), the stronger precipitation changes for countries bordering the Mediterranean are projected for the winter months and will be negative, with a reduction of as much as 40% in the worst case for the Moroccan Highlands, projected at end-century under RCP 8.5. In this regard, a number of studies have confirmed the strong influence of the North Atlantic Oscillation (NAO) on precipitation variability in Morocco. On the other hand, the Senegal River headwaters exhibit a projected increase in precipitation in the winter season at end-century for the worst-case scenario, while the headwaters of the Blue Nile in the Ethiopian Highlands show a decrease of -7% for the same case. Both the Tigris and Euphrates headwaters show a decrease of precipitation during winter and an increase during summer. For RCP 4.5, however, an increase in these basins is projected even for the winter.

FIGURE 8: Mean change in seasonal precipitation (mm/month) for end-century for ensemble of three RCP 4.5 projections compared to the reference period



BOX 2: Projected runoff and evapotranspiration changes over the Arab region

Concerning hydrological variables, results for changes in runoff and evapotranspiration assessed from both the HYPE and VIC models across the region generally follow the same trends as precipitation.

The Moroccan Highlands with considerable decrease in precipitation also show considerable decrease in runoff. Although there are some differences in the magnitude of change across the region, results for runoff from the three-member hydrological ensemble are generally in agreement between the two hydrological models used.

Evapotranspiration was shown to decrease generally over time as there is less water available to evaporate or transpire in the arid Arab region where water quantity is often a limiting factor. The pattern of change for evapotranspiration thus largely follows the pattern of change for runoff. For basins where there is relatively sufficient water, evapotranspiration increases over time, which is a contributing factor to the decrease in runoff in those areas. An example is the headwaters of both the Tigris and Euphrates during the winter season.

Tigris River, Iraq, 2015. Source: Ihab Jnad.

3. Extreme climate indices and seasonal projections provide valuable insights into climate change impacts, particularly at smaller scales of analysis.

Annual mean temperature and precipitation are generally insufficient to assess the impact of climate change on the region and reference to extreme climate indices and their seasonal peaks can provide greater insight into the implications of temperature and precipitation for different subregions. This also can help to enhance understanding and action for reducing disaster risks at smaller scales of analysis.

Overall, looking at the extremes for temperature, all the indices relating to hot days show increasing trends over time. For these indices, the RCP 8.5 scenario at the end of the century stands out as a particularly harsh change for living conditions.

For instance, changes in the number of very hot days (SU40) show significant projected warming throughout the region, in particular over the Sahara and central Arabian Peninsula areas for RCP 8.5 (Figure 9). This indicates that the increase in the extreme temperature on coastal areas would be lower than the inland areas of the region for both scenarios.

As compared to the reference period, the indicator related to the number of tropical nights (TR) also exhibits significant warming trends over time with a projected increase mainly in central Africa and southern Arabian Peninsula regions, particularly for RCP 8.5 (Figure 10). This indicator has considerable implications with regard to cropping systems, as some crops require a substantial difference in temperature between day and night. Furthermore, increased night-time temperatures can also affect human and animal health conditions since it is more difficult for their organisms to recover after a very hot day or a spell of warm days (e.g. heatwave events).

Regarding precipitation extremes, there is considerable variation over the region. The projections for the maximum length of dry spell (CDD) suggest trends towards drier conditions specifically for the Mediterranean, as well as the western and northern parts of the Arabian Peninsula by the end of the century (Figure 11).

The increases in CDD are expected to be more significant under the RCP 8.5 scenario and towards the end of the century, and can be an indication that the dry summer season is likely to be extended in length, especially in the aforementioned regions. Some areas in the central and eastern parts of North Africa, however, show a decline in CDD. In all cases, results for this indicator ought to be complemented with additional information, since an indication of a shorter dry period does not rule out an increase in drought frequency occurring at the same time.

Results for the annual number of 20 mm precipitation days or "very heavy precipitation days" (R20) for the end of the century (Figure 12) are similar to the R10 indicator, both suggesting a projected overall reduction in rainy days with these intensities over the region. When examining changes at the basin level, the R20 indicator showed little change over time, except for the Euphrates headwaters and the Senegal River, where all projections showed increasing trends. Analysis of smaller domains can thus provide greater insight into trends related to extreme climate events in specific areas.

Floods in Gaza after thunderstorm Alexa, State of Palestine, 2011. Source: Alhasan Sweirju/Oxfam-flickr.com

FIGURE 9: Mean change in the number of very hot days (SU40) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

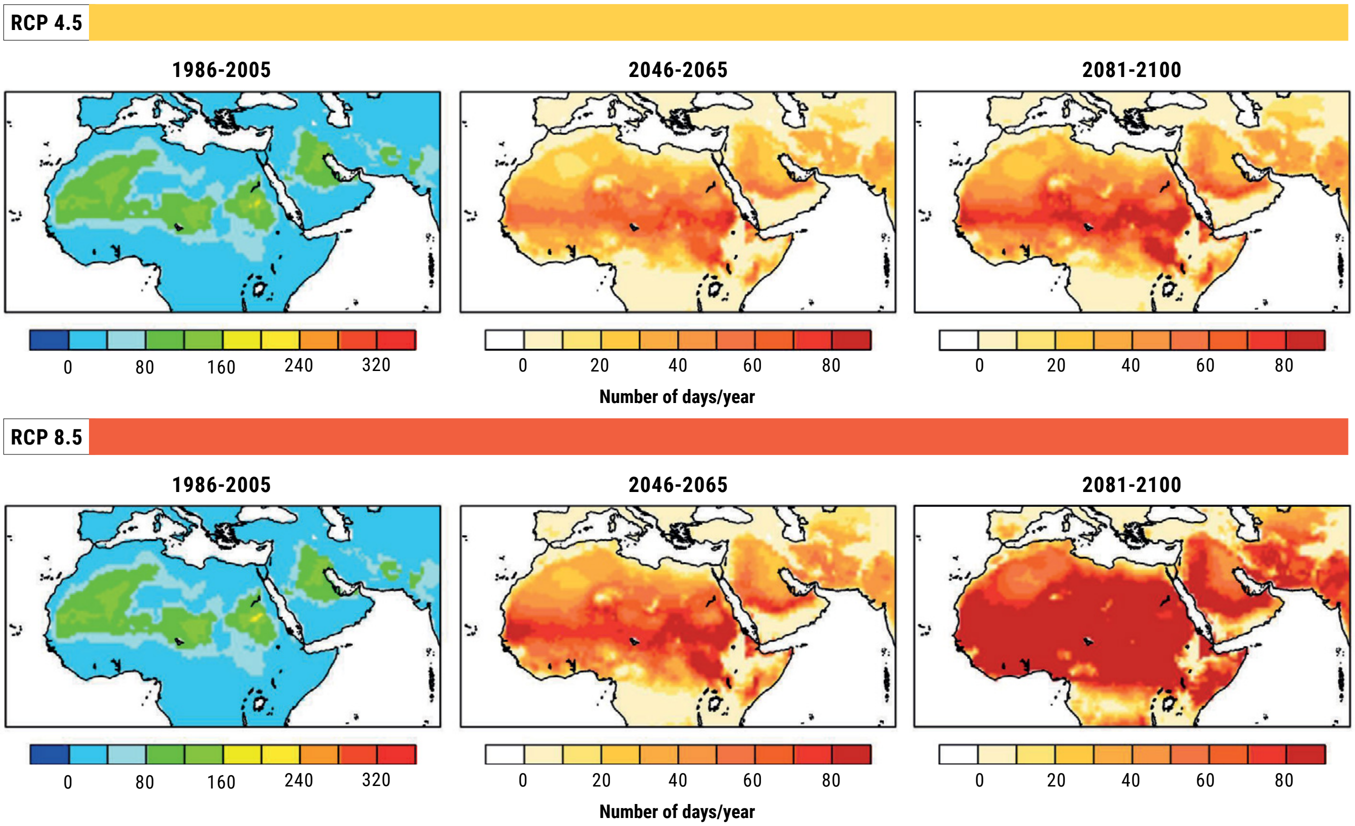


FIGURE 10: Mean change in the number of tropical nights (TR) (days/yr) for mid-and end-century for ensemble of three RCP 4.5 and 8.5 projections compared to the reference period

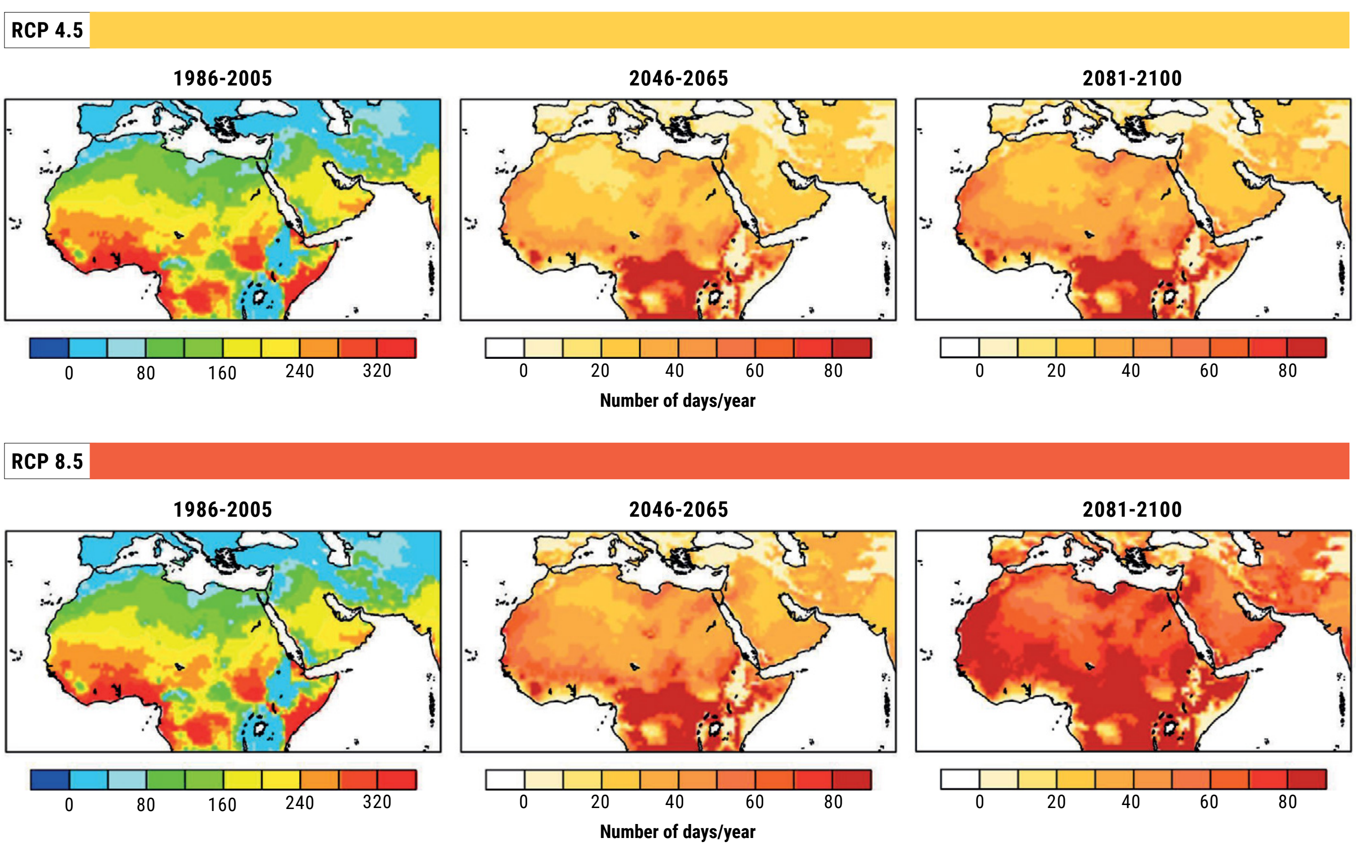


FIGURE 11: Mean change in the maximum length of dry spell (CDD) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

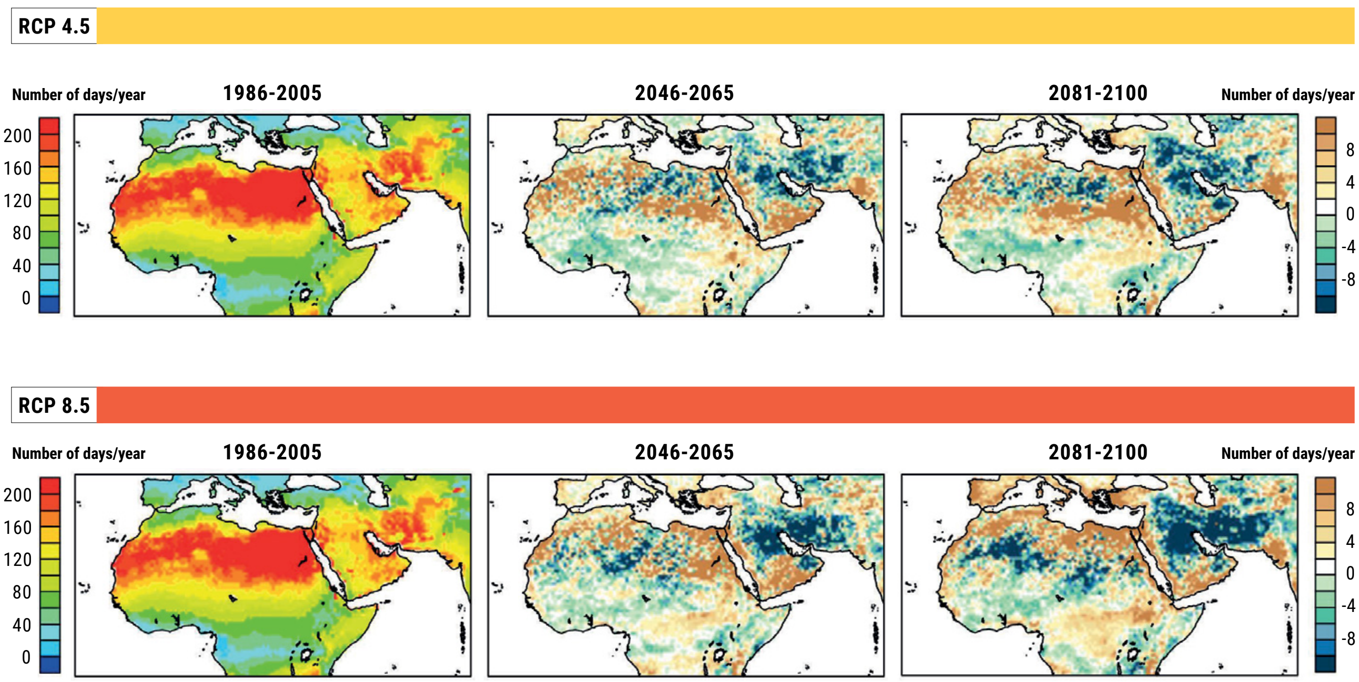
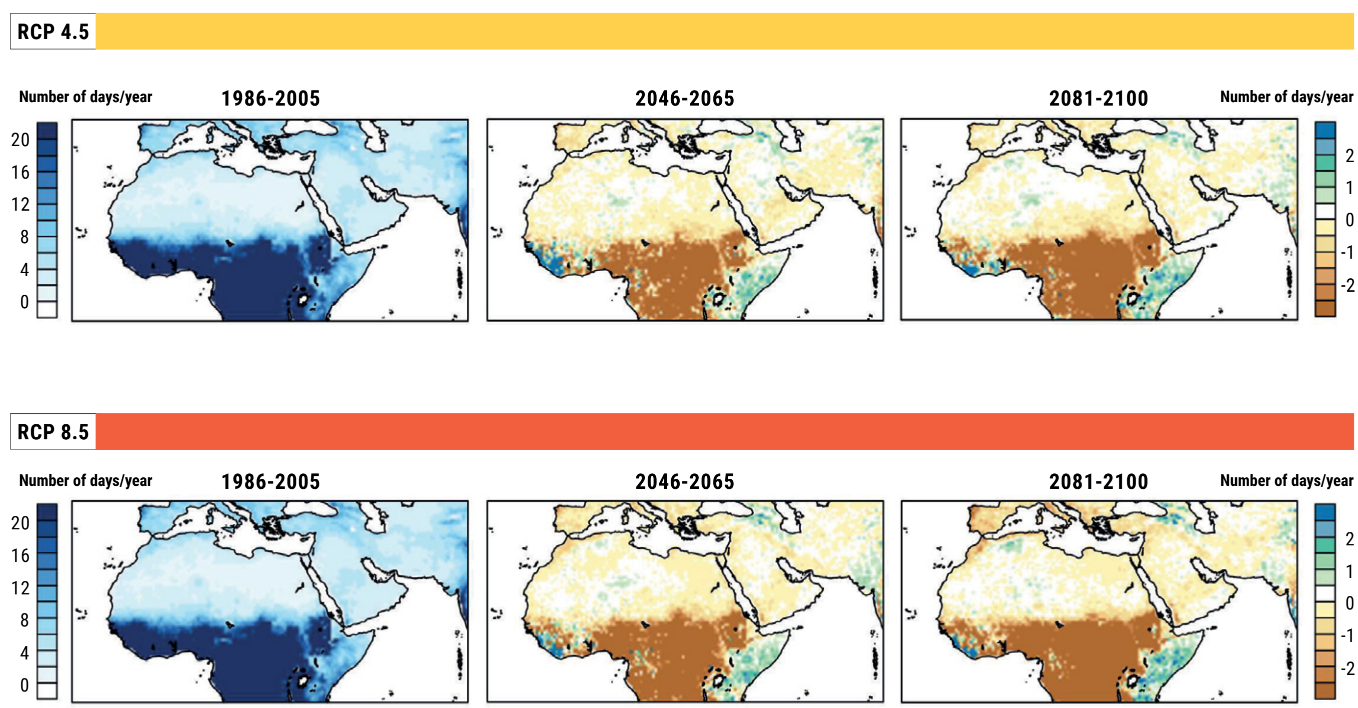


FIGURE 12: Mean change in the number of 20 mm precipitation days (R20) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period



BOX 3: Extreme events impact assessment for selected river basins

A case study examined the impacts of climate change in terms of extreme events in three river basins in the Arab region, namely the Nahr el Kabir River basin shared between Lebanon and Syrian Arab Republic; the Wadi Diqah River basin in Oman; and the Medjerda River basin shared between Algeria and Tunisia.

For each basin, changes in the following indicators were analysed: extreme temperature and precipitation indices; extreme drought events (based on the Standardized Precipitation Index – SPI method); and extreme flood events.

Results have shown that all three basins are projected to experience increases in heat extremes by the end of the century and for both emission scenarios.

Precipitation extremes projections are more variable, with a general increasing trend in CDD for the selected basins in most cases, coupled to an increasing trend in R20 by the end of the century for all basins except for the Medjerda River.

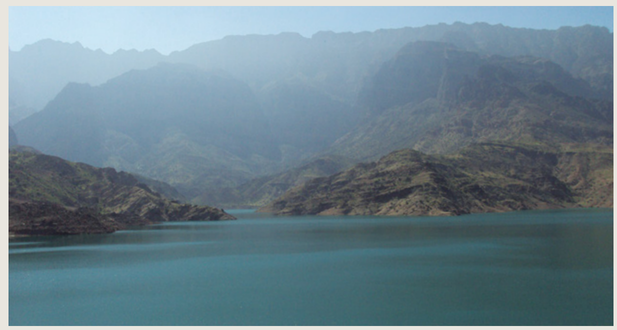
Concerning drought and flood events, the following results have been reported:

For the **Nahr el Kabir basin**, a tendency towards drier conditions is projected by end-century with an increase in the occurrence of moderate drought in particular for RCP 8.5, but with no severe or extreme droughts events projected to occur. The basin is likely to experience an increase in the magnitude of peak flow and flood frequencies over the 21st century.

For the **Wadi Diqah basin**, in accordance with the reference period, there is no indication of projected severe or extreme droughts over the 21st century, while moderate drought conditions are still projected to occur with generally few changes compared to the reference period. The magnitude of peak flow events is likely to increase in the basin by the end of the century, and projections show a decreasing number of extreme flood days at mid-century, followed by an increase at end-century.

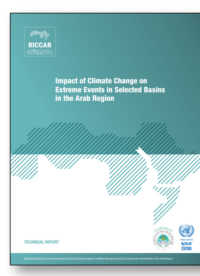
For the **Medjerda basin**, there is a tendency towards significantly drier conditions with projected episodes of severe and extreme droughts over time, in addition to moderate drought which is projected for both time periods and emission scenarios. For the moderate emission scenario, the basin is likely to experience an increase in the magnitude of peak flows together with a decreasing number of extreme flood events. For the high-emission scenario, however, the mean magnitude of peak flow is projected to decrease over time.

Nahr el Kabir River, Syrian Arab Republic, 2007. Source: Ihab Jnad.



Wadi Diqah Dam reservoir, Oman, 2011. Source: Ihab Jnad.

Sidi Salem dam, Medjerda River, Tunisia, 2015. Source: Elarbi Alaeddin.



Full details of the methodology, as well as additional results and analysis are available in the RICCAR technical report *Impact of Climate Change on Extreme Events in Selected Basins in the Arab Region (2017).*

4. Analysis of climate change impacts on shared water resources can benefit from regional and basin-level assessments.

The high dependency on shared surface and groundwater resources in the region makes them of strategic importance for achieving sustainable development, especially since some river systems extend across the borders of non-Arab countries.

Policy efforts aiming at national policy integration across water-dependent sectors are thus complicated by the interdependency of the water resources shared by riparian countries, each seeking to achieve its own development goals. The impacts of climate change and climate variability are expected to further complicate the management of shared water resources.

Regional hydrological models can provide general trends to inform regional understanding of climate change impacts in a transboundary context, based on smaller domains that cover parts of basins included in a regional domain.

Selected shared river basins were examined through specific subdomains which included mainly headwater areas of the Nile, the Tigris and Euphrates, the Medjerda, the Jordan and the Senegal Rivers. A set of variables was studied, of which results for runoff and discharge generated from the HYPE model for each subdomain are presented in Figure 13.

The value of these modelling outputs is that they provide a consistent approach for generating information on hydrology-related variables with a similar level of detail over the entire region.

Regional results from the three-member hydrological ensemble are generally in agreement between the two hydrological models used, although there are some differences in the magnitude of change.

The headwaters of the Blue Nile in the Ethiopian Highlands show wide variation between the individual ensemble members, but the mean changes show decreased runoff over time.

The Tigris and Euphrates headwaters, however, show small increases in winter runoff, even when precipitation changes are negative. This is likely due to less snow storage during the warmer winters over time compared to the reference period, and thus increased runoff during this season. This is followed by reduced runoff during the summer months because of reduced snowmelt, which is seen in the summer pattern of runoff for these basins.

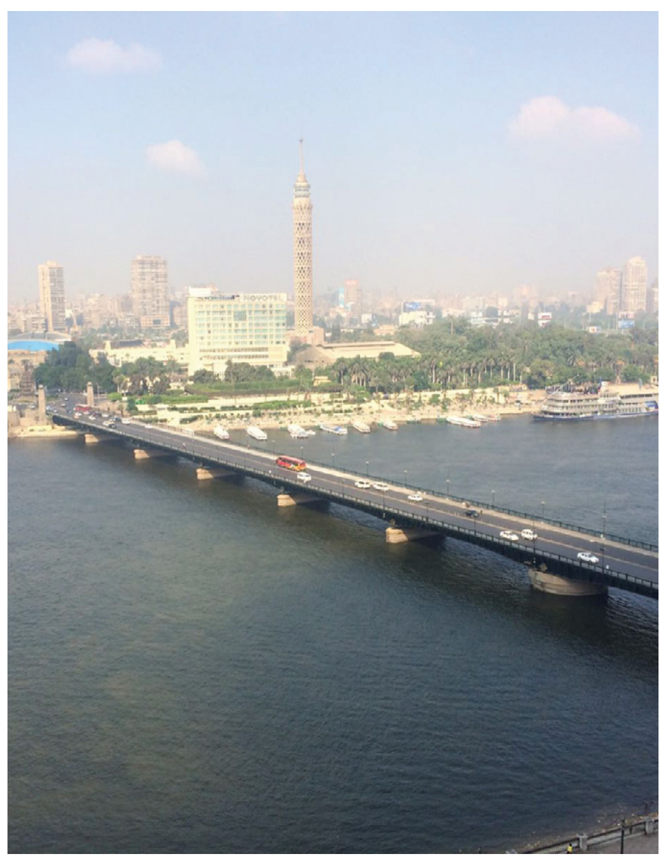
The Medjerda River basin shows results similar to those of the Moroccan Highlands in terms of mean runoff change with a decrease over time, but not as severe.

No definite trend in runoff can be observed for the Jordan River basin due to the wide range of values.

The Senegal River headwaters, which otherwise show runoff increases, show a slight decrease of runoff at the end of the century for RCP 4.5, even though precipitation shows an increase. A likely explanation for this is that the increase in precipitation is offset by increases in evapotranspiration.

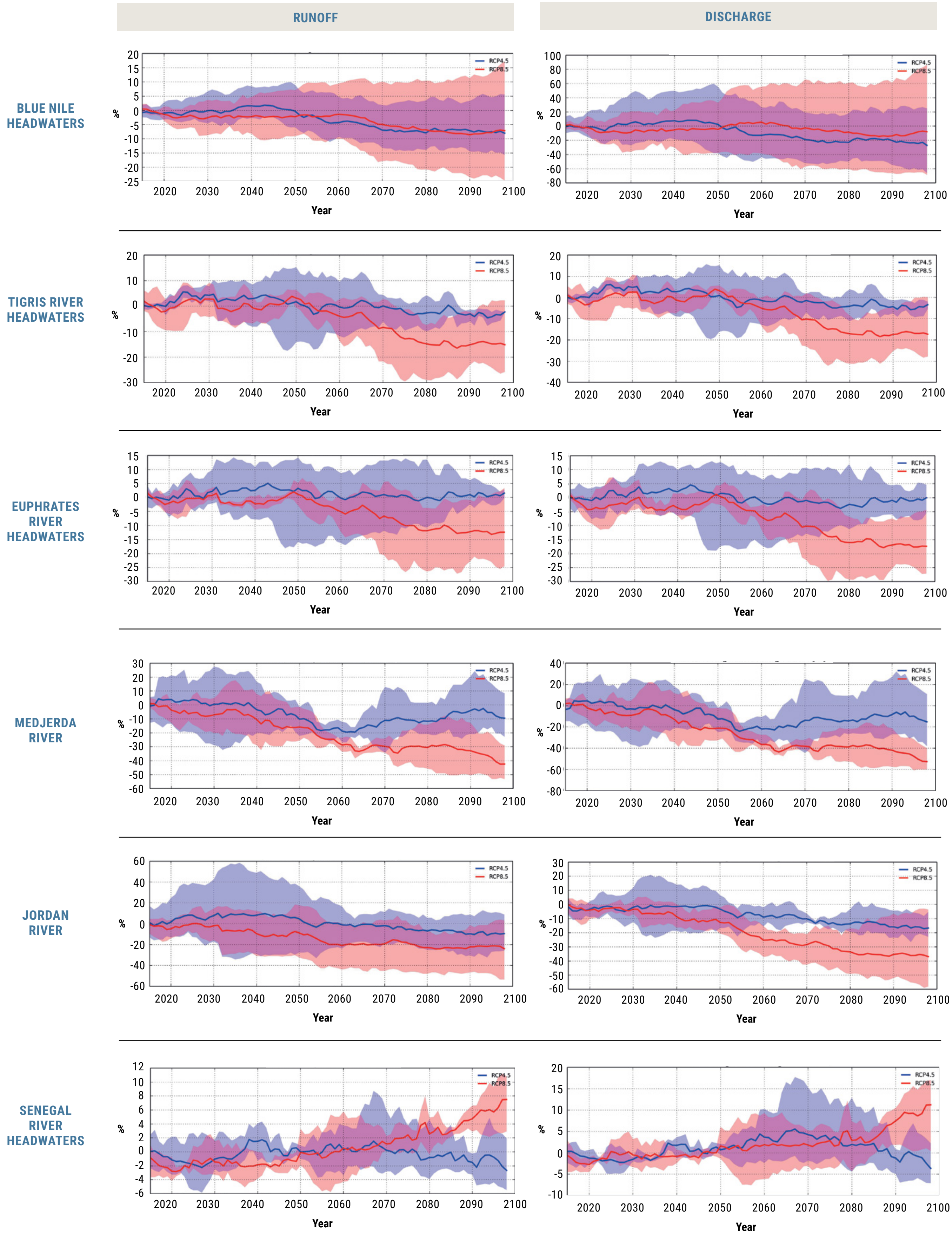
As can be seen, the wide range of values around the mean often cannot allow the conclusion of definitive trends at the watershed level. Thus, while regional models can provide annual and seasonal analysis that can inform regional cooperation, basin-level analysis is necessary to allow for greater representation of watershed dynamics and the application of basin-specific models focused on issues of concern to riparian states.

Complementary assessments can thus be pursued when examining the impacts of climate change on shared water resources in the region, depending on the form and scale of analysis sought.



Nile River, Egypt, 2015. Source: Carol Chouchani Cherfane.

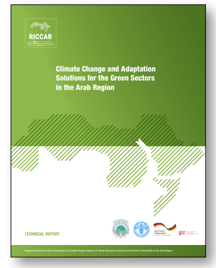
FIGURE 13: Mean change in runoff and discharge (using HYPE model)[1] over time for ensemble of three RCP 4.5 and 8.5 projections for the studied shared rivers



[1]Runoff changes were also studied using the VIC model (available in the Arab Climate Change Assessment Report - Main Report and its technical annex)

5. Sector case studies enhance understanding of climate change implications.

Regional climate modelling, hydrological modelling and vulnerability assessment findings can help to inform additional analysis at the sector level.Based on RICCAR climate projections, climate change impacts were assessed with regard to major green sectors in the region and the findings clearly highlight how the resulting increase in water scarcity is one of the major impacts of climate change on these sectors, with more marked vulnerabilities towards end-century and for RCP 8.5.



Full details of the methodology, as well as additional results and analysis are available in the RICCAR technical report *Climate Change and Adaptation Solutions for the Green Sectors in the Arab Region (2017).*

It was shown that over 50% of the surface area of the Arab region's major cropland systems (including wheat, maize, sorghum, potatoes, vegetables and olives) belong to the two highest vulnerability classes, with the highest vulnerability occurring in the Nile Valley, the Tigris–Euphrates basin, the south-western Arab Peninsula and the western parts of North Africa. Moreover, the impact of CO_2 on different crops varied according to their photosynthetic pathway. For instance, irrigated wheat and cotton (C3 crops) appeared to benefit from projected elevated atmospheric CO_2 concentrations in non-limited water conditions. Efficient water management is thus an essential adaptation measure to exploit the potential of this type of crops in converting the higher CO_2 concentration into higher yields.

The main impacting factor for livestock is also the potentially limited water resources in the future as well as the projected decline of the food resource base due to recurrent droughts, degradation of rangelands and desertification. These factors render livestock raised under a grassland production system more prone to climate vulnerability than those raised under mixed systems. Most vulnerable livestock areas were shown to be located along the Nile Valley, the Horn of Africa and south-western Arabian Peninsula, followed by areas of the Fertile Crescent and North Africa, with cattle being the most affected.

For the already vulnerable forestry sector due to the region's aridity and high deforestation rates, the major impacts will also result from projected water stress (dry and hot years), inducing defoliation, accelerated ageing, reduction in regeneration capacity and increased sensitivity to pest attacks. Overall, a reduction in forest productivity and possible shifts in the composition of species are potentially expected, in addition to exacerbated vulnerabilities due to human activities.

On the other hand, the fishery and aquaculture sector was shown to be particularly affected by increasing temperatures, in addition to droughts and floods. Coupled with human over-exploitation, climate change conditions may induce the collapse of certain stocks.

Irrigated cotton field, Deir el Zor, Syrian Arab Republic, 2007. Source: Ihab Jnad.

Climate change in the Arab region also has the potential to threaten human health and well-being. Heat stress, for instance, can induce adverse impacts on human health due to high humidity coupled with extreme temperatures, and often constitutes a significant cause of mortality. A study of vulnerabilities to heat stress in the region have indicated that the African Atlantic coastline and the central Arabian Gulf are among the most susceptible areas to heat stress.

Acting through direct and indirect pathways, climate change is also expected to change patterns of communicable and non-communicable disease incidence in the region. In this regard, RICCAR examined the impact of climate change on the transmission of leishmaniasis and schistosomiasis in selected areas in North Africa. These two important neglected tropical diseases (NTDs) are endemic to the Arab region and sensitive to changing climate conditions.

In the case of leishmaniasis, results for western North Africa indicated that projected warmer temperatures during winter months could extend the period of suitability for disease transmission.

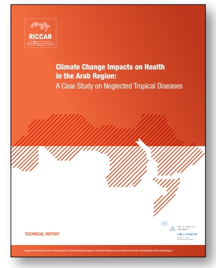
For schistosomiasis, results for Egypt have shown that while transmission has historically been limited during colder months, increasing temperatures will create conditions that intensify the risk of infection during winter months. These changes in exposure are projected to occur in some areas where populations experience higher levels of susceptibility and lack of adaptive capacity.

In particular, leishmaniasis presents a greater threat to the health and socioeconomic status of women who work in agriculture and animal care as they may be exposed to sandfly bites, while also having restrained coping capacity such as limited access to financial resources for healthcare.

This can also result in negative impacts on psychological well-being and quality of life due to social stigmatization associated with disfiguring scars. Impacts of water-related diseases such as schistosomiasis are also characterized by gender-based vulnerability in regions where women and children bear the burden of water-related household tasks.

Understanding these vulnerabilities is critical for public health decision-makers in order to target marginalized groups and reduce disproportionate climate change impacts on the burden of disease.

The findings generated from the agricultural sector and human health case studies thus show that projected climate change impacts create new challenges for the region that are worth considering for developing efficient strategies to cope with those impacts.



Full details on the study are provided in the RICCAR technical report *Climate Change Impacts on Health in the Arab Region: A Case Study on Neglected Tropical Diseases (2017)*.

Most importantly, they also reveal that the impact of climate change should not be limited to examining average changes in climate trends, but should also consider the implications of maximum and minimum climate phenomena and extreme climate events, as well as changes over seasons.

Casablanca coast, Morocco, 2005. Source: carloszgz-flickr.com

PART II

INTEGRATED VULNERABILITY ASSESSMENT

METHODOLOGY OVERVIEW

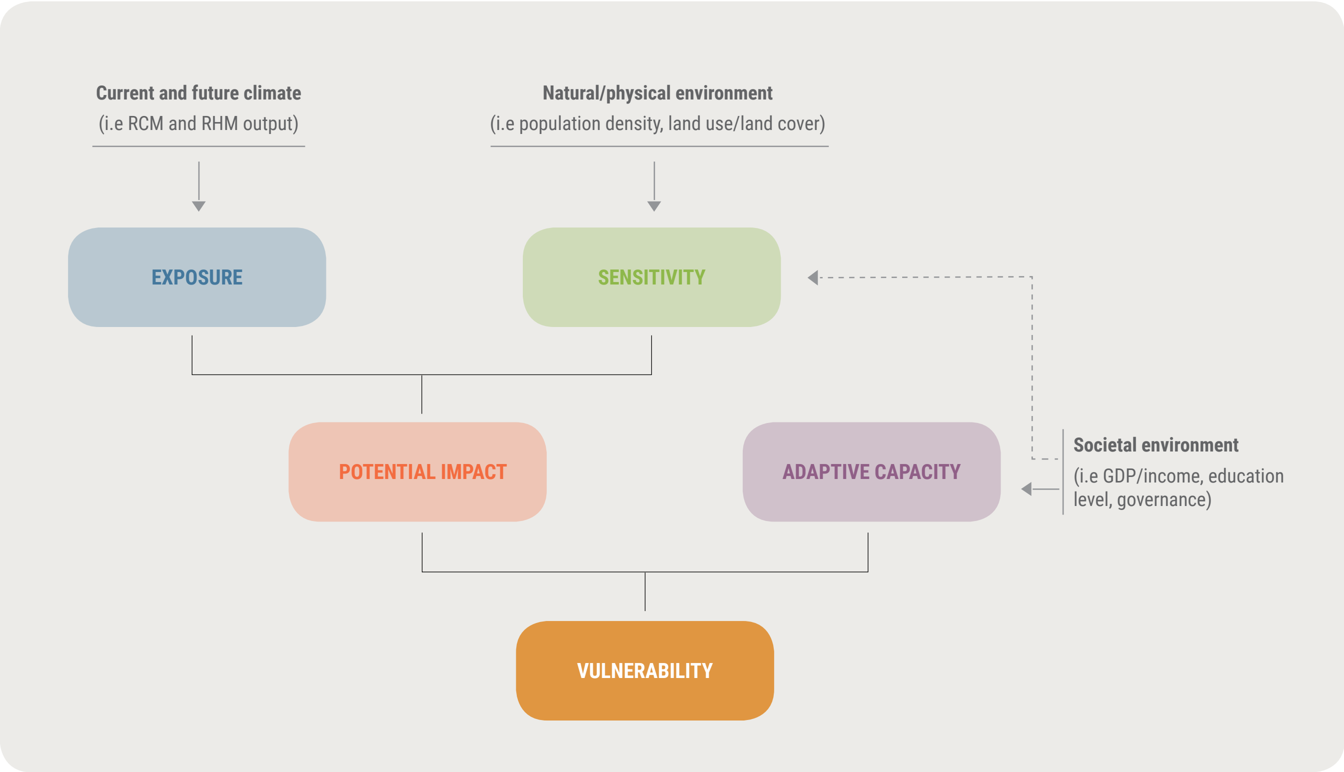
The integrated vulnerability assessment methodology applied in RICCAR is based on an understanding of vulnerability as a function of a system's climate change exposure, sensitivity and adaptive capacity to cope with climate change effects, consistent with the approach put forward by IPCC in its Fourth Assessment Report (AR4) and as illustrated in Figure 14. It was developed through a consultative and participatory process with experts from the Arab region.

With the aim of attaining a comprehensive assessment that can serve as a basis for dialogue and consultation on climate change issues across the Arab region and among its Member States, the integrated vulnerability assessment combines a series of individual vulnerability assessments for several water-related climate change impacts on different sectors in the region. This type of assessment provides an integrated and cross-sectoral understanding of the region's vulnerability to potential climate change impacts. As such, the overall Arab region's vulnerability comprises the different sectoral vulnerabilities towards the various key climate change impacts identified, which are comprised of one or more subsectors.

Based on the outcomes of consultations conducted as part of RICCAR, five key sectors were selected for examination along with associated subsectors (Figure 15). They consist of: (1) Water, focused on water availability; (2) Biodiversity and ecosystems, including (a) Forests, and (b) Wetlands; (3) Agriculture, including (a) Water available for crops, and (b) Water available for livestock; (4) Infrastructure and human settlements, focused on inland flooding; and (5) People, including (a) Water available for drinking, (b) Health conditions due to heat stress, and (c) Employment rate for the agricultural sector.

The integrated mapping methodology combines indicators that contribute to the characterization of the sensitivity, exposure, potential impact and adaptive capacity components and dimensions of vulnerability with respect to climate change as represented in an impact chain (Figure 14). It draws upon regionally appropriate and available indicators and applies weights to each indicator (derived from statistical analysis, existing literature, stakeholder information, expert opinion) as developed by regional consultations and expert opinions. These weighted dimensions are then reflected in a geometric aggregation method used to combine these components to determine climate change vulnerability.

FIGURE 14: Components of vulnerability and impact chain structure



This process was carried out using the ArcGIS software, enabling the production of vulnerability maps that display current and potential future vulnerabilities to climate change through a multi-step process (Figure 16).

Exposure indicators were derived from the regional climate modelling and regional hydrological modelling outputs (using VIC hydrological model results for the latter) and are the sole dynamic datasets applied in the assessment. They were developed for three different time periods (reference period, future mid-century, future end-century) and two climate scenarios (RCP 4.5, RCP 8.5) each. Sensitivity and adaptive capacity indicators were retrieved from available statistical databases or synthesized from multiple datasets derived from one or more sources.

Vulnerability assessment results were ultimately presented as maps describing precise locations where people, the environment or natural resources are at high risk. It is important to note that rather than reveal results obtained for the entire region, maps highlight solely the specific area of interest for a given sector or subsector. Areas of interest were based on one or more indicators. For example, maps for all climate change impacts studied under the People sector showed populated areas only. This approach helps to focus discussions on the area of interest and allows for a cohesive presentation of the Arab region. Areas outside the specific area of interest, but part of the Arab region, are shaded in light grey.

It is also essential to point out that due to data limitations, many of the same adaptive capacity indicators have been used for all climate change impacts. Results are therefore largely similar. Higher adaptive capacity is generally found in the northern Maghreb and the Levant, while lower adaptive capacity is revealed in the southern Maghreb and areas near the Gulf of Aden. Other areas suggest moderate adaptive capacity. Although the indicators themselves are not necessarily applicable for a given climate change impact, they can be considered as proxies for the dimensions they represent.

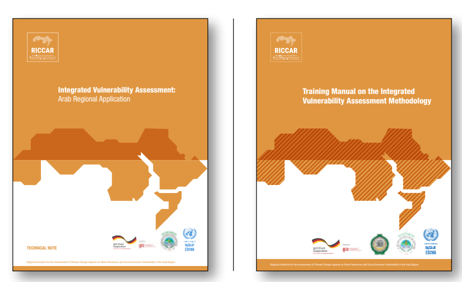
The vulnerability assessment outputs have also identified hotspots which represent areas with the highest projected vulnerability. For RICCAR, they have been defined as areas with the highest 10% of aggregated vulnerability values combined with the top 20% and 30% as hotspot buffered areas. Although they have been defined for all sectors and subsectors for all projected climate scenarios, the resultant hotspots are often indistinct when presented on a regional map. Hotspots at the sector level for RCP 8.5 end-century were, however, discernible at a regional scale, and have thus been presented in the report. This approach serves the purpose of a regional vulnerability assessment designed to highlight shared challenges from climate change. Such an assessment, however, does not provide a suitable basis for the concrete planning of adaptation measures on the local level. We recommend taking the hotspots identified on the regional level as an entry point to conduct further and more in-depth studies on a national or subnational level in order to identify locations for adaptation interventions. Such applications are already being carried out.

FIGURE 15: Sectors and subsectors selected for the Arab region vulnerability assessment

SECTORS	SUBSECTORS
Water	Water availability
Biodiversity and Ecosystems	Area covered by forests Area covered by wetlands
Agriculture	Water available for crops Water available for livestock
Infrastructure and Human Settlements	Inland flooding area
People	Water available for drinking Health conditions due to heat stress Employment rate for the agricultural sector

FIGURE 16: Integrated vulnerability assessment methodology steps

Step 1. Developing impact chains
Step 2. Identifying and selecting indicators
Step 3. Data acquisition
Step 4. Normalization and classification of indicator data
Step 5. Weighing and aggregation of indicators
Step 6. Aggregation of vulnerability components
Step 7. Presenting outcomes as vulnerability maps



Detailed guidance on the methodology applied for this component with precisions on each step is presented in the RICCAR technical note *Integrated Vulnerability Assessment: Arab Regional Application (2017)*.

Additional information is also provided in the *Training Manual on the Integrated Vulnerability Assessment Methodology (2017)* prepared within the framework of the ACCWaM programme support to RICCAR.

MAIN RESULTS AND FINDINGS

Outputs generated from the integrated vulnerability assessment are dense and characterized by a long set of findings pertaining to each sector, subsector and vulnerability component, each available for different time periods and emission scenarios.

Accordingly, results presented in this report are first summarized for each sector, including overall vulnerability for each time period and climate scenario, as well as identified hotspots for that sector. Overall findings of the vulnerability assessment are then synthesized in a list of 10 conclusions summarizing key issues arising from the assessment.

It is worthy to note that projected vulnerability varies among the different sectors and subsectors, depending upon the selected indicators therein. Nevertheless, some common trends have emerged between the vulnerability components (exposure, sensitivity, adaptive capacity) at a regional level. Moreover, the degree of vulnerability is generally constant in certain areas for a given climate scenario, independent of the sector or subsector.

It is also important to consider that, although some of the areas may project lower vulnerability than others, these results are relative to the Arab region alone and vulnerability may be considerably higher if compared globally.

For example, all areas within the region project an increase in temperature, and an increase in the number of very hot days (SU40) is forecast for at least 94% of the region. These changes induce the likelihood of heat stress and other temperature-related risks. Similarly, declining precipitation and runoff are valid concerns for a region that already suffers from water scarcity. These changes in climate are exacerbated by elevated natural and physical stressors, which are inhibited by the limited ability to adapt.

SUMMARY OF RESULTS BY SECTOR

Overall vulnerability results pertaining to each sector are summarized in the following pages. Outputs for specific subsectors, time periods and emission scenarios are available in the main report and technical annex.

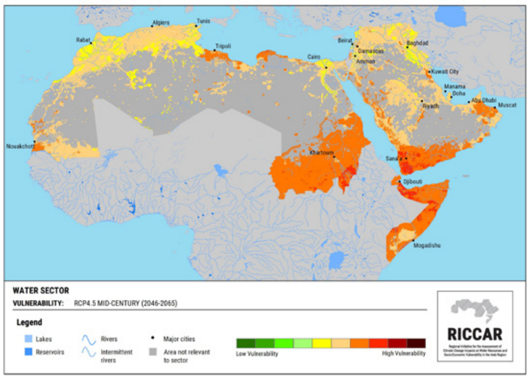
Jebel Akhdar, Libya, 2009. Source: Ihab Jnad.

WATER SECTOR

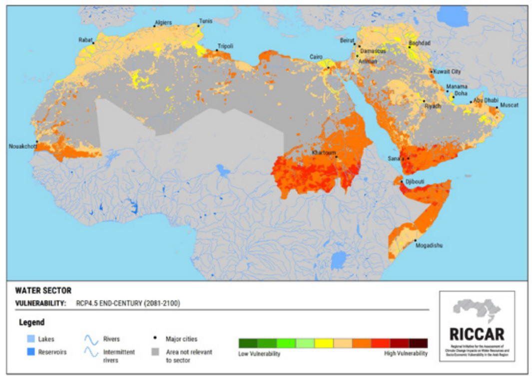
OVERALL VULNERABILITY

RCP 4.5

2046-2065

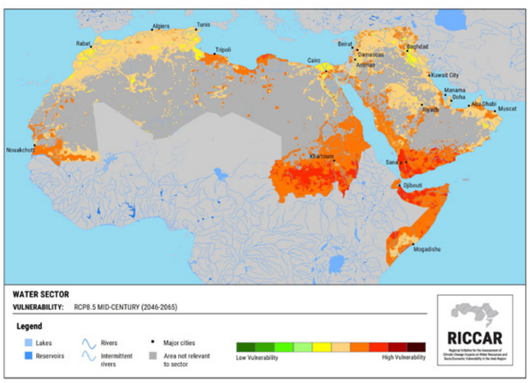


2081-2100



RCP 8.5

2046-2065



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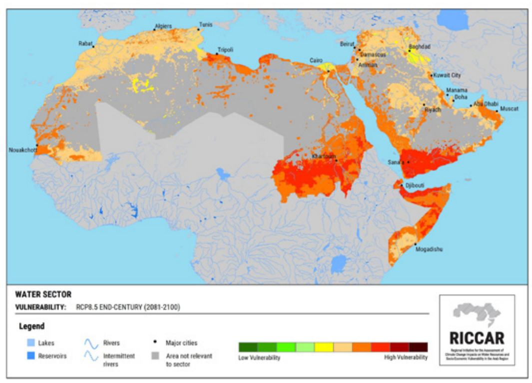


SUMMARY

Sector and subsector	Scenario		% of study area experiencing vulnerability			Study area % of Arab region	Defined study area
			Low	**Moderate**	**High**		
WATER Water availability	Mid-Century	RCP 4.5	0%	57%	43%	**49%**	• Forest areas • Wetland areas • Rainfed areas • Irrigated areas • Livestock areas › 10 heads/km² • Population density › 2 inhabitants/km²
		RCP 8.5	0%	48%	52%		
	End-Century	RCP 4.5	0%	52%	48%		
		RCP 8.5	0%	43%	57%		

Projected overall vulnerability

Vulnerability for both mid- and end-century is nearly equally divided between areas of moderate and high vulnerability, with a slight increase in areas of high vulnerability by end-century. Such highly vulnerable areas include the upper Nile Valley, the south-western Arabian Peninsula and the northern Horn of Africa, due to low adaptive capacity. Areas with relatively low vulnerability include the Tigris–Euphrates basin and the lower Nile Valley, including the Nile Delta.

Trend analysis indicates the largest increases in vulnerability along the coast in the Red Hamada basin and the eastern Murzuk basin from mid- to end-century, due partly to a surge in maximum length of dry spell. Conversely, the largest decreases are located in the Horn of Africa, due partly to rising precipitation and runoff. The most vulnerable water users are projected as pastoralists and livestock, similar to the reference period case.

Hotspots

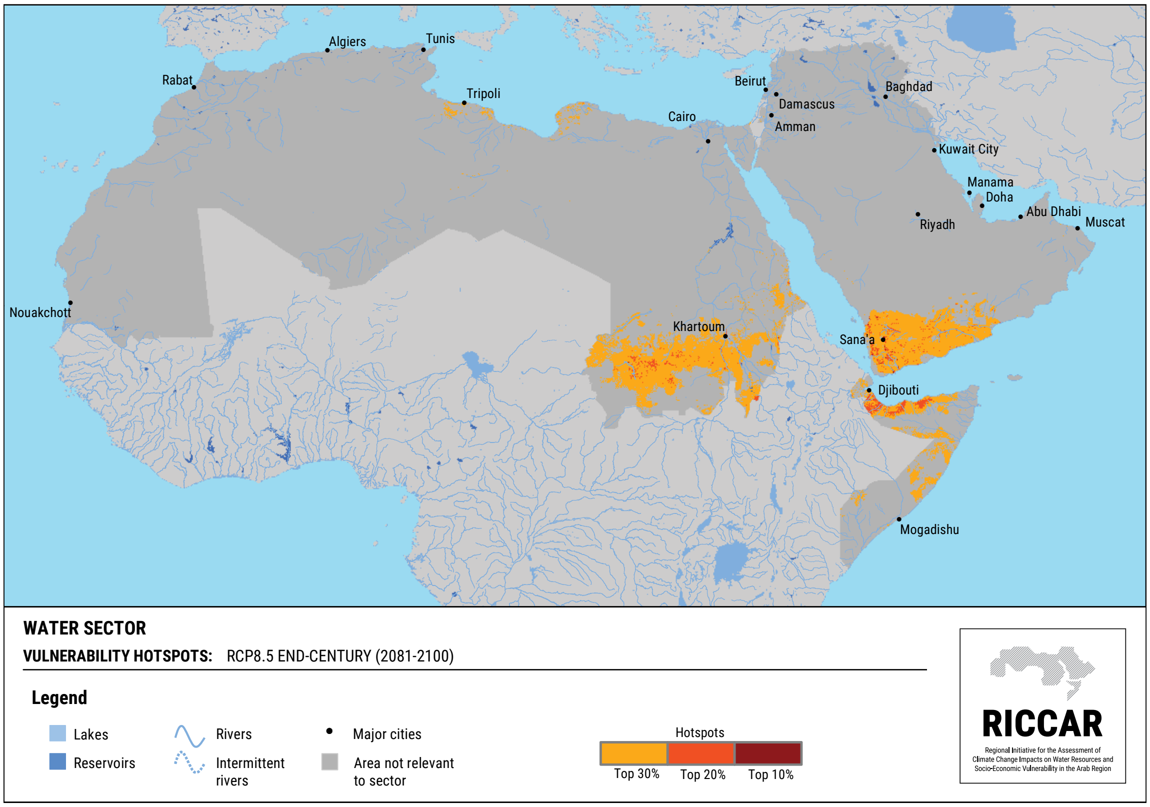
Hotspots represent up to 14% of the study area for this sector and include selected areas south of the Jebel Abyad Plateau and the Nubian Desert, the south-western Arabian Peninsula and the northern Horn of Africa. These areas are primarily influenced by low adaptive capacity as projected potential impact is low to moderate. An exception is the Dhamar Montane Plains area, located in the south-western Arabian Peninsula, which indicates relatively high potential impact, partly due to high population density and low total available renewable water resources.

All the hotspots are located in areas which reveal a livestock population. A moderately high cattle population is located near the White Nile and Blue Nile rivers south of Khartoum. A dense goat population is also indicated south of Khartoum and at certain locations within the Dhamar Montane Plains area. Lastly, the camel population is relatively high in the Horn of Africa. A fairly low incidence of sheep is revealed in all hotspot areas.

Most of the hotspot areas within areas south of the Jebel Abyad Plateau and the Nubian Desert and the Dhamar Montane Plains area include croplands. Most areas are rainfed and sorghum, cereals and other crops are cultivated. Irrigated areas are also reflected in hotspots to a limited extent. Drought and rainfall variability will reduce crop yields, impacting food security, already known to affect these areas.

The vulnerability hotspot map developed for this sector and representing the worst-case scenario for end-century is presented in Figure 17.

FIGURE 17: Water sector – Vulnerability hotspots – End-century RCP 8.5

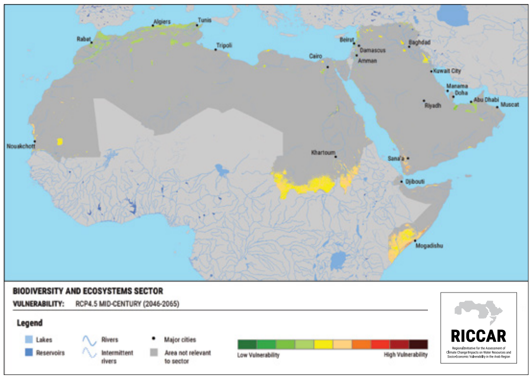


BIODIVERSITY AND ECOSYSTEMS SECTOR

OVERALL VULNERABILITY

RCP 4.5

2046-2065



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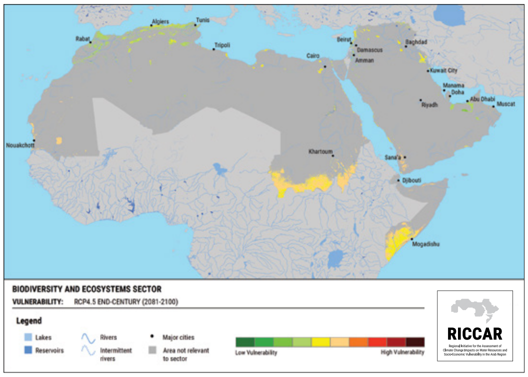
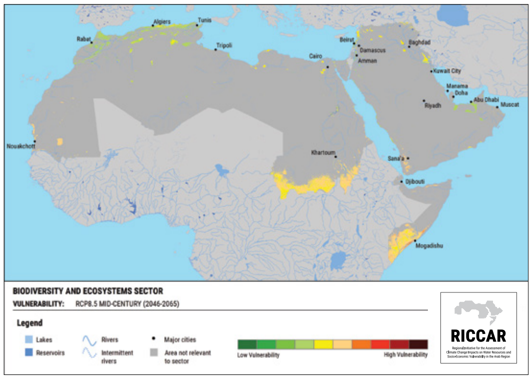


RCP 8.5

2046-2065



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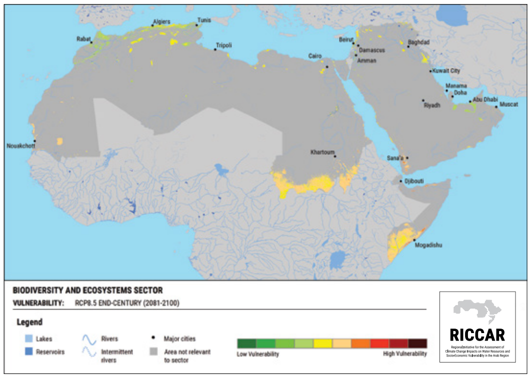


SUMMARY

Sector and subsector	Scenario		% of study area experiencing vulnerability			Study area % of Arab region	Defined study area
			Low	Moderate	High		
BIODIVERSITY AND ECOSYSTEMS	Mid-Century	RCP 4.5	1%	98%	1%	**7%**	• Forested areas • Wetland areas
		RCP 8.5	0%	99%	1%		
	End-Century	RCP 4.5	1%	99%	0%		
		RCP 8.5	0%	98%	2%		
Area covered by forests	Mid-Century	RCP 4.5	0%	59%	41%	**5%**	• Forested areas
		RCP 8.5	0%	42%	58%		
	End-Century	RCP 4.5	0%	50%	50%		
		RCP 8.5	0%	36%	64%		
Area covered by wetlands	Mid-Century	RCP 4.5	5%	94%	1%	**2%**	• Wetland areas
		RCP 8.5	1%	97%	2%		
	End-Century	RCP 4.5	6%	93%	1%		
		RCP 8.5	1%	97%	2%		

Projected overall vulnerability

Ecosystems are at risk of terrestrial change or extinction due to climate change impacts. Nearly the entire region (at least 98%) projects moderate vulnerability for both mid- and end-century for the two climate scenarios. Nevertheless, like the trends revealed for the subsectors *Area covered by forests* and *Area covered by wetlands*, most ecosystems within the study area exhibit a constant-to-increasing vulnerability under RCP 4.5 from mid- to end-century. Exceptions are the south-western corner of the Arabian Peninsula and the southern Horn of Africa, which suggests a constant-to-decreasing vulnerability.

Similar trends are revealed for RCP 8.5, although some areas within the eastern Sahel indicate constant-to-decreasing vulnerability and some areas, such as the Shabelle–Jubba Delta, project constant-to-increasing vulnerability.

Like the reference period, the future scenarios have a strong correlation with the subsector *Area covered by forests*.

Improvements in reforestation/afforestation efforts are expected to increase biodiversity and ecosystems in the region as a whole.

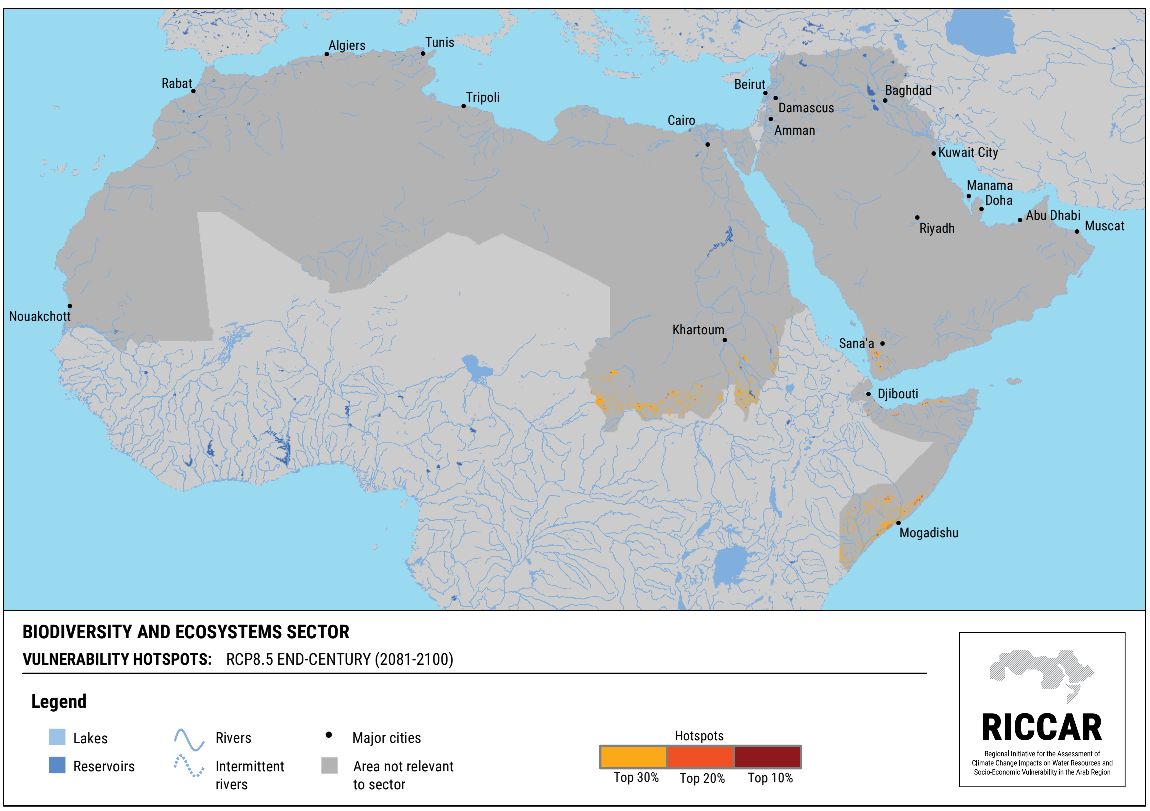
Hotspots

Identified hotspots represent the most vulnerable forests and wetlands in the Arab region and comprise 2% of the study area, including forest and wetland ecosystems in sub- Saharan Africa and the south-western Arabian Peninsula.

In particular, the Ta'izz wetlands, tidal wetlands along the southern Gulf of Aden coastline, forests of the Golis Mountains and selected freshwater marshes in the Jubba and Shabelle riparian areas exhibit the absolute highest vulnerability in the region.

Figure 18 presents vulnerability hotspots for this sector at end-century for RCP 8.5.

FIGURE 18: Biodiversity and ecosystems sector – Vulnerability hotspots – End-century RCP 8.5

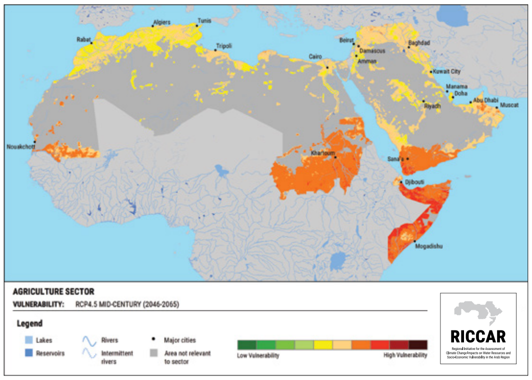


AGRICULTURE SECTOR

OVERALL VULNERABILITY

RCP 4.5

2046-2065



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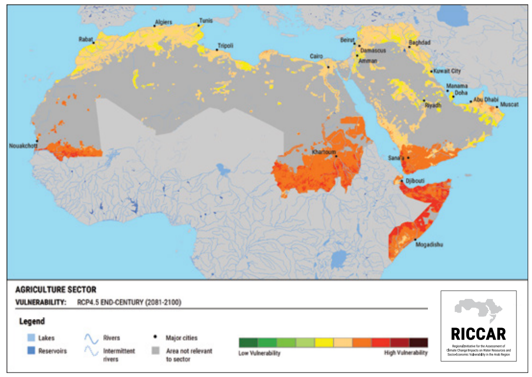
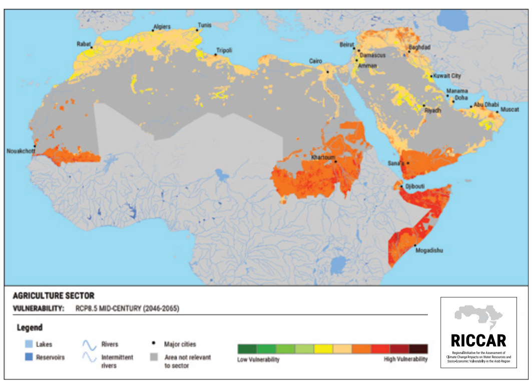


RCP 8.5

2046-2065



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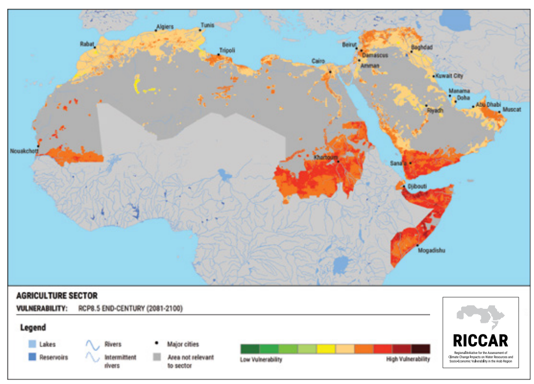


SUMMARY

Sector and subsector	Scenario		% of study area experiencing vulnerability			Study area % of Arab region	Defined study area
			Low	Moderate	High		
AGRICULTURE	Mid-Century	RCP 4.5	0%	57%	43%	**37%**	• Rainfed areas • Irrigated areas • Livestock areas > 10 heads/km^2
		RCP 8.5	0%	51%	49%		
	End-Century	RCP 4.5	0%	54%	46%		
		RCP 8.5	0%	42%	58%		
Water available for crops	Mid-Century	RCP 4.5	0%	50%	50%	**22%**	• Rainfed areas • Irrigated areas
		RCP 8.5	0%	33%	67%		
	End-Century	RCP 4.5	0%	43%	57%		
		RCP 8.5	0%	16%	84%		
Water available for livestock	Mid-Century	RCP 4.5	0%	67%	33%	**33%**	• Livestock areas > 10 heads/km^2
		RCP 8.5	0%	55%	45%		
	End-Century	RCP 4.5	0%	58%	42%		
		RCP 8.5	0%	46%	54%		

Projected overall vulnerability

Similar to the reference period, future vulnerability is fairly evenly divided between moderate and high vulnerability. For mid-century, 43% (RCP 4.5) to 49% (RCP 8.5) of the study area will experience high vulnerability and this will increase slightly to 46% (RCP 4.5) to 58% (RCP 8.5) of the study area at end-century. No part of the study area denotes low vulnerability. Areas with relatively lower vulnerability include coastal areas of the Maghreb, agricultural areas in the Grand Erg Occidental Region, the central Arabian Desert, areas east of the Dead Sea and the lower Tigris–Euphrates basin.

Although vulnerability trends from mid- to end-century area are somewhat constant, some areas reveal differences. For RCP 4.5, increasing vulnerability is more evident in the Maghreb due to decreasing rainfall and runoff and in the western Sahel due to an increasing number of hot days and very hot days. Decreasing vulnerability is indicated for the Al Hajar Mountains.

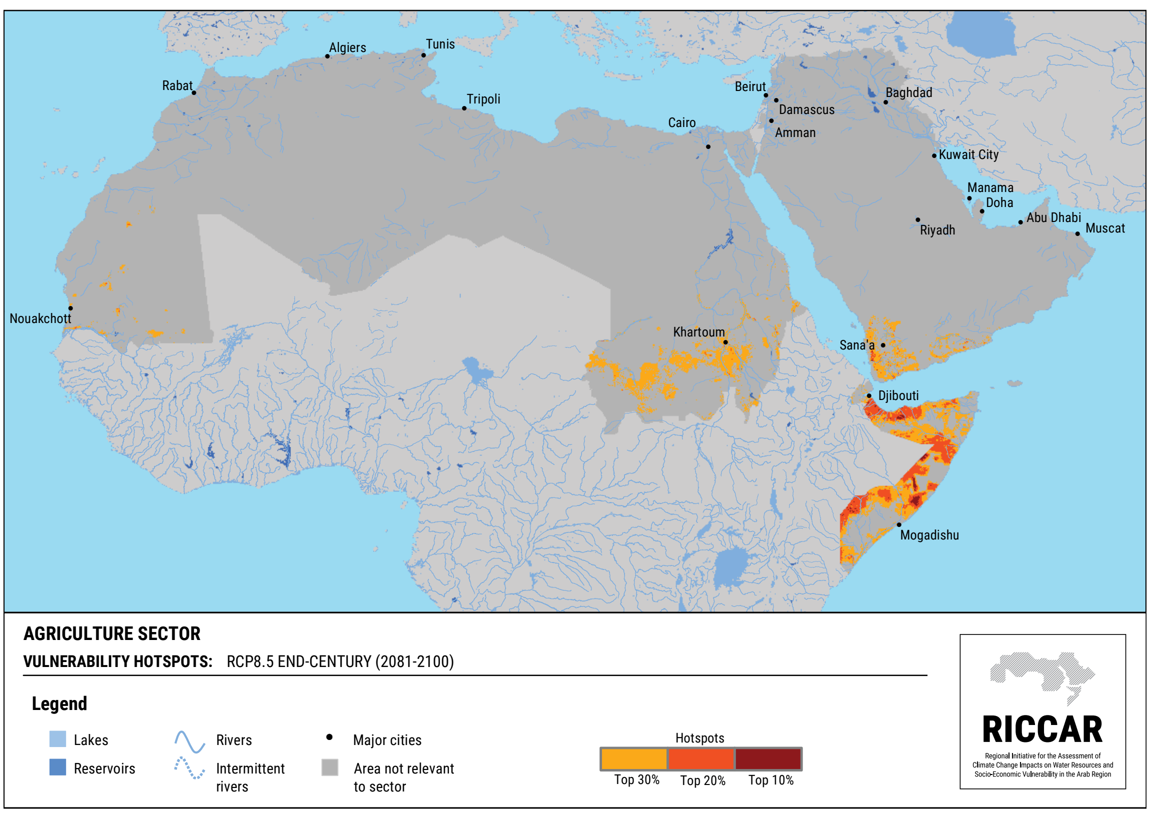
The Maghreb also exhibits increasing vulnerability under RCP 8.5 but to a lesser extent. However, a reverse trend is noted for both the western Sahel and the Al Hajar Mountains under RCP 8.5. Lastly, agricultural areas in the upper eastern Sahel, central Sahara Desert and south-western Arabian Peninsula reveal a generally increasing vulnerability under RCP 8.5.

Hotspots

Hotspots represent those agricultural areas that are most likely to exhibit high vulnerability stemming from water availability for the sector and represent up to 9% of the study area. Hotspots are dispersed throughout the Tindouf basin, eastern sub-Saharan Africa, and the south-western Arabian Peninsula. These areas indicate an estimated 94% of available water used for agriculture. Very high vulnerability with regard to agricultural water availability could mean the collapse of the sector unless strong adaptive capacity measures are taken for its survival.

The vulnerability hotspots map for the agriculture sector at end-century for the worst-case scenario is presented in Figure 19.

FIGURE 19: Agriculture sector – Vulnerability hotspots – End-century RCP 8.5

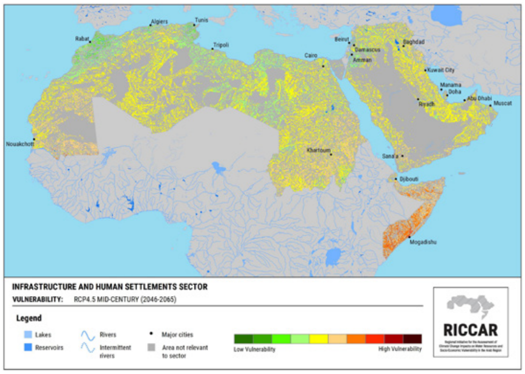


INFRASTRUCTURE AND HUMAN SETTLEMENTS SECTOR

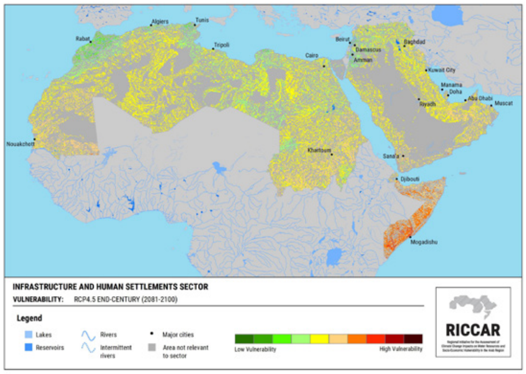
OVERALL VULNERABILITY

RCP 4.5

2046-2065

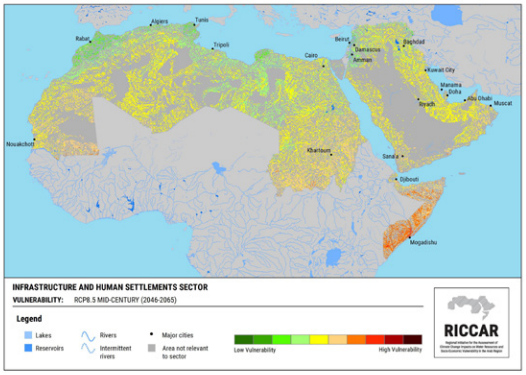


2081-2100

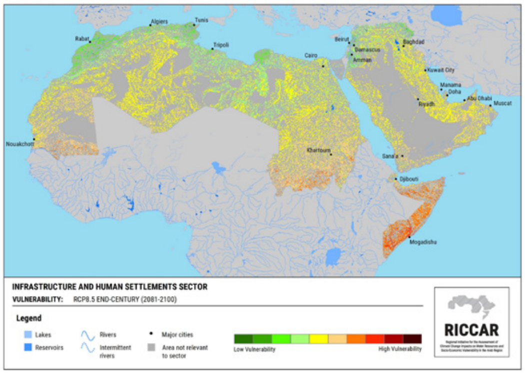


RCP 8.5

2046-2065



2081-2100



SUMMARY

Sector and subsector	Scenario		% of study area experiencing vulnerability			Study area % of Arab region	Defined study area
			Low	Moderate	High		
INFRASTRUCTURE AND HUMAN SETTLEMENTS	Mid-Century	RCP 4.5	2%	94%	4%	**32%**	• Low or greater floodprone potential
		RCP 8.5	3%	93%	4%		
Inland flooding area	End-Century	RCP 4.5	2%	94%	4%		
		RCP 8.5	4%	89%	7%		

Projected overall vulnerability

Vulnerability is expected to increase in the region, particularly in urban areas, if there is little improvement in poverty reduction, disaster preparedness and building standards. Assuming there are no changes in sensitivity or adaptive capacity, most of the study area suggests moderate vulnerability for all scenarios. Remaining areas are divided between low and high vulnerability.

Vulnerability exhibits a generally increasing gradient from north to south, whereas coastal areas indicate a relatively low vulnerability and sub-Saharan Africa reveals a generally higher vulnerability.

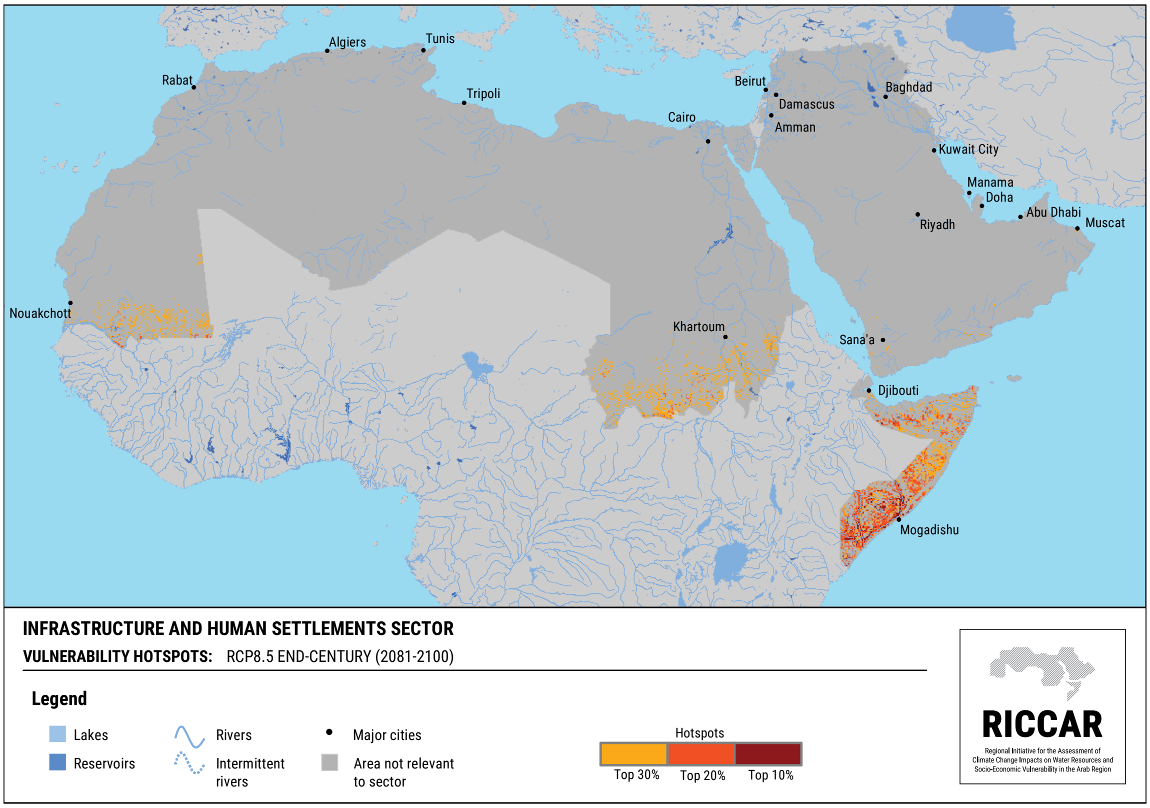
Vulnerability trends from mid- to end-century suggest limited change for RCP 4.5. For RCP 8.5, changes are also minimal, although a slight increase in vulnerability is indicated in sub-Saharan Africa and the eastern Arabian Desert. Slight decreases in vulnerability are noted towards the Mediterranean coast and the Zagros Mountains.

Hotspots

Hotspots represent up to 8% of the inland flooding study area. They are found in both the eastern and western Sahel, the Horn of Africa (particularly the Jubba and Shabelle River floodplains) and isolated areas in the southern Arabian Peninsula. Figure 20 presents vulnerability hotspots for this sector at end-century for RCP 8.5.

Flooding in the western Sahel in 2013 devastated crops and livestock in agricultural areas, damaged infrastructure and tainted the water supply in urban areas, including Nouakchott. Inland flooding in the eastern Sahel is common, particularly near the confluence of the White Nile and Blue Nile; residents have built floodwalls which separate agricultural areas from the rivers. The Jubba and Shabelle River floodplains have also been subject to recurrent floods (April 2010, April and May 2013). Steps to reduce vulnerability in this area include the development of a Flood Risk and Response Management Information System to promote flood preparedness and contingency planning.

FIGURE 20: Infrastructure and human settlements sector – Vulnerability hotspots – End-century RCP 8.5

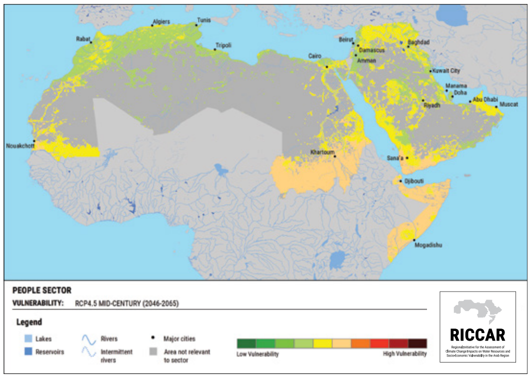


PEOPLE SECTOR

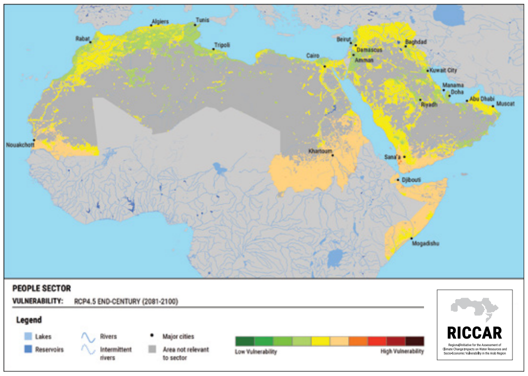
OVERALL VULNERABILITY

RCP 4.5

2046-2065

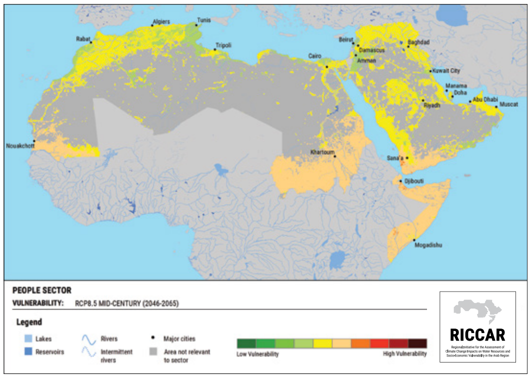


2081-2100

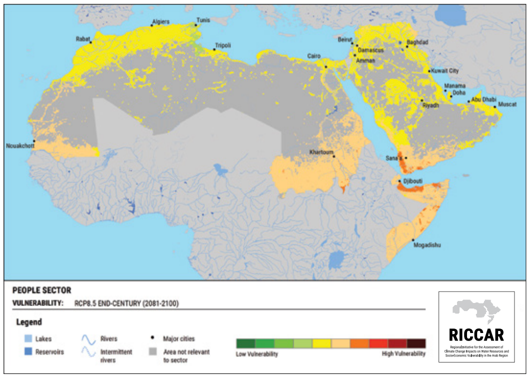


RCP 8.5

2046-2065



2081-2100



SUMMARY

Sector and subsector	Scenario		% of study area experiencing vulnerability			Study area % of Arab region	Defined study area
			Low	Moderate	High		
PEOPLE	Mid-Century	RCP 4.5	0%	100%	0%	**44%**	• Population density > 2 inhabitants/km^2
		RCP 8.5	0%	100%	0%		
	End-Century	RCP 4.5	0%	100%	0%		
		RCP 8.5	0%	98%	2%		
Water available for drinking	Mid-Century	RCP 4.5	0%	100%	0%	**44%**	• Population density > 2 inhabitants/km^2
		RCP 8.5	0%	99%	1%		
	End-Century	RCP 4.5	0%	99%	1%		
		RCP 8.5	0%	98%	2%		
Health conditions due to heat stress	Mid-Century	RCP 4.5	45%	55%	0%	**44%**	• Population density > 2 inhabitants/km^2
		RCP 8.5	30%	70%	0%		
	End-Century	RCP 4.5	37%	63%	0%		
		RCP 8.5	4%	95%	1%		
Employment rate for the agricultural sector	Mid-Century	RCP 4.5	0%	39%	61%	**44%**	• Population density > 2 inhabitants/km^2
		RCP 8.5	0%	28%	72%		
	End-Century	RCP 4.5	0%	35%	65%		
		RCP 8.5	0%	2%	77%		

Projected overall vulnerability

Similar to the reference period, projected vulnerability is largely moderate, reflecting the entire region for all scenarios except for RCP 8.5 end-century. This scenario reflects moderate vulnerability for 98% of the study area and high vulnerability for remaining areas.

Vulnerability generally indicates a lower-to-higher gradient from north to south. Areas of lowest vulnerability are located in the eastern Tell Atlas region and the Levant. Trend analysis from mid- to end-century reveals generally static to increasing vulnerability for both scenarios. For RCP 4.5, areas of increasing vulnerability are the Sahara Desert and the Atlas Mountains.

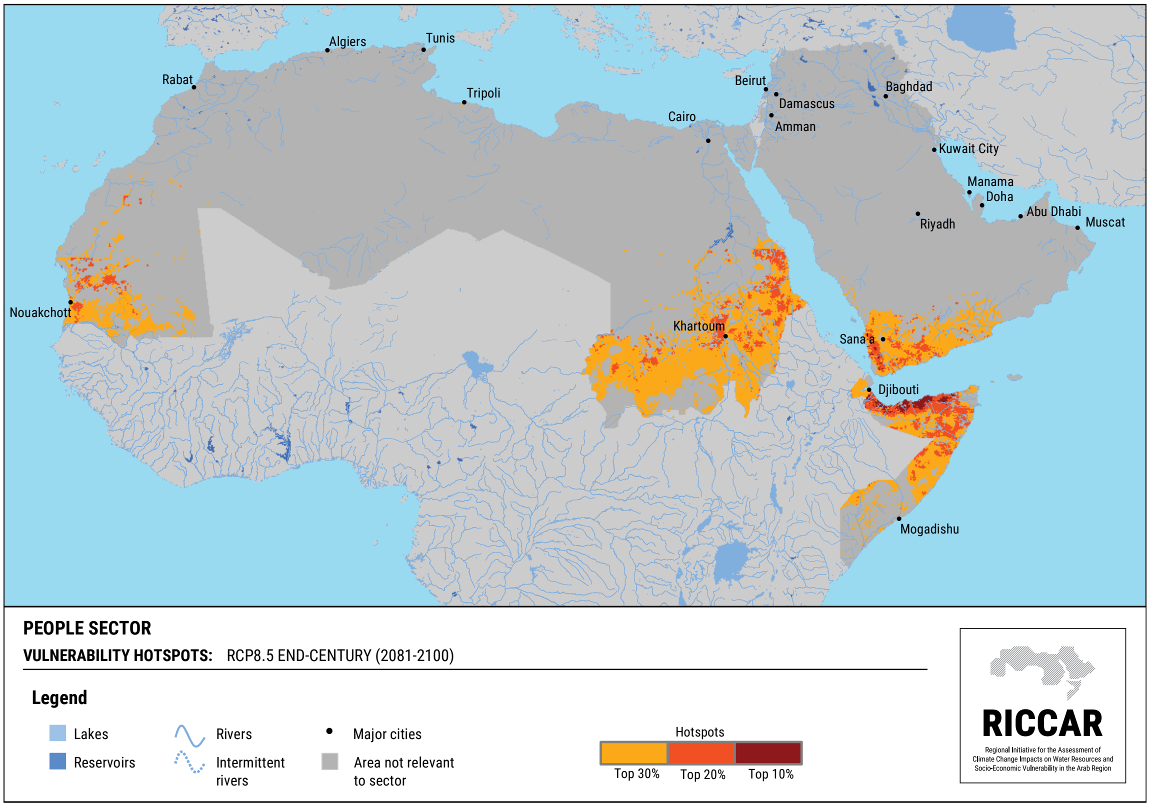
The southern Horn of Africa suggests static-to to-declining vulnerability, however. For RCP 8.5, many coastal areas indicate increasing vulnerability, such as the coastal Atlas Plains, the southern Red Sea and the southern coast of the Gulf of Aden.

Hotspots

Hotspots project the most vulnerable areas for the People sector and reflect up to 3% of the study area. Hotspots include locations in the southern Sahara and the Sahel, the south-western Arabian Peninsula, and the Horn of Africa and affect up to 28 million people (based on 2014 estimates).

The vulnerability hotspot map pertaining to this sector at end century is presented in Figure 21 and represents the worst-case scenario.

FIGURE 21: People sector – Vulnerability hotspots – End-century RCP 8.5



OVERALL FINDINGS OF THE INTEGRATED VULNERABILITY ASSESSMENT

Based on all outputs generated from the integrated vulnerability assessment, the following conclusions can be made. They follow chronologically the first 5 findings reported on in the impact assessment component.

6. Predicted vulnerability is largely moderate to high and exhibits a generally increasing gradient from north to south across the Arab region.

Throughout the Arab region and across all sectors and subsectors, the vulnerability of Arab States to climate change is moderate to high and is generally increasing over time and across both RCP scenarios.

Predicted vulnerability is largely moderate to high and exhibits a generally increasing gradient from north to south (an exception is the subsector *Health conditions due to heat stress*, due to lower exposure stemming from solely temperature-based indicators).

The resultant vulnerability tends to be lowest in the Maghreb, Levant and, to some extent, the Zagros Mountains in the upper Tigris–Euphrates basin.

Conversely, the southern third of the Arab region, which includes the Sahel, southern Sahara Desert, south-western Arabian Peninsula and the Horn of Africa, exhibit the highest projected vulnerability in the region. The areas in-between generally indicate moderate vulnerability.

7. Both components of potential impact are important to consider when conducting vulnerability assessments.

Exposure is based upon a selection of different indicators that can generally be classified into precipitation-based or temperature-based parameters.

The precipitation-based indicators, which include runoff and evapotranspiration, predict areas of increasing precipitation in some areas and decreasing precipitation in others. Areas of decreasing precipitation signal higher exposure for most subsectors (for the subsector *Inland flooding area*, the case is reversed). Conversely, areas of increasing precipitation suggest lower exposure; unchanged precipitation points toward moderate exposure. Temperature, however, is projected to increase throughout the Arab region. Although any increase in temperature is significant, increases are more pronounced for RCP 8.5 end-century compared to the other scenarios. Thus, temperature-based exposure is generally low, except for RCP 8.5 end-century.

Because precipitation signals higher variability both spatially and temporally, the vulnerability assessment results thus suggest a stronger correlation with change in precipitation than temperature. This assessment is reasonable, considering that many subsectors are dependent upon water availability.

Sensitivity is correlated with population density, which generally confines areas of higher sensitivity to urbanized coastal areas and the lower Nile River Valley; the remaining areas, which encompass most of the Arab region, demonstrates low sensitivity. It is noted that more than half the subsectors studied have the population dimension weighted more heavily than the other two sensitivity dimensions. Other than the population density indicator, indicators within this dimension are based on national data and thus the dimension has little spatial variation at a subnational level.

Although other subsectors do not emphasize population, they highlight certain indicators that are correlated with population density, such as livestock density and flood-prone areas, which are affected by rural development and urbanization, respectively.

8. Of the three components of the integrated vulnerability assessment, adaptive capacity is most likely to influence vulnerability, suggesting that the ability of mankind to influence the future is stronger than that of climate change and environmental stressors.

While the respective contributions of potential impact (the aggregated result of exposure combined with sensitivity) and adaptive capacity to vulnerability were weighted equally in the assessment, adaptive capacity often reveals a stronger correlation with vulnerability.

This is partly because sensitivity is generally low across the region and particularly in less populated areas, that constitute over three-quarters of the Arab region's surface area. This, in turn, reduces the potential impact generated when combining sensitivity with exposure.

The findings also reveal that large areas situated in some of the Arab region's least developed countries are projected to witness increases in precipitation with moderate average increases in temperature relative to other parts of the region over the course of the century, but that these trends are insufficient to offset their low levels of adaptive capacity. Thus, low projected exposure to climate change is insufficient to counterbalance low adaptive capacity.

Comparisons between adaptive capacity and vulnerability maps (end-century, RCP 8.5) across the Arab region for all sectors/subsectors are presented in Figure 22.

9. Areas with the highest vulnerability, which have been defined as hotspots, generally occur in the Horn of Africa, the Sahel and the south-western Arabian Peninsula, irrespective of sector, subsector or projected climate scenario.

Vulnerability hotspots have been defined by the top 10% of vulnerability aggregated values, combined with a top 20% and top 30% buffer. All hotspots exhibit low adaptive capacity, although their exposure to climate change varies. Vulnerability hotspots generally recur in the Sahel extending northwards into the Sahara Desert, the south-western Arabian Peninsula along the Red Sea, and the Horn of Africa.

For instance, much of the Horn of Africa (other than near the Gulf of Aden coast) shows low-to moderate exposure due to increasing precipitation coupled with modest increases in temperature. Moreover, sensitivity in this area is generally low and potential impact is thus largely low to moderate. Nevertheless, this modest potential impact is not sufficient to counterbalance the low adaptive capacity in that part of the region.

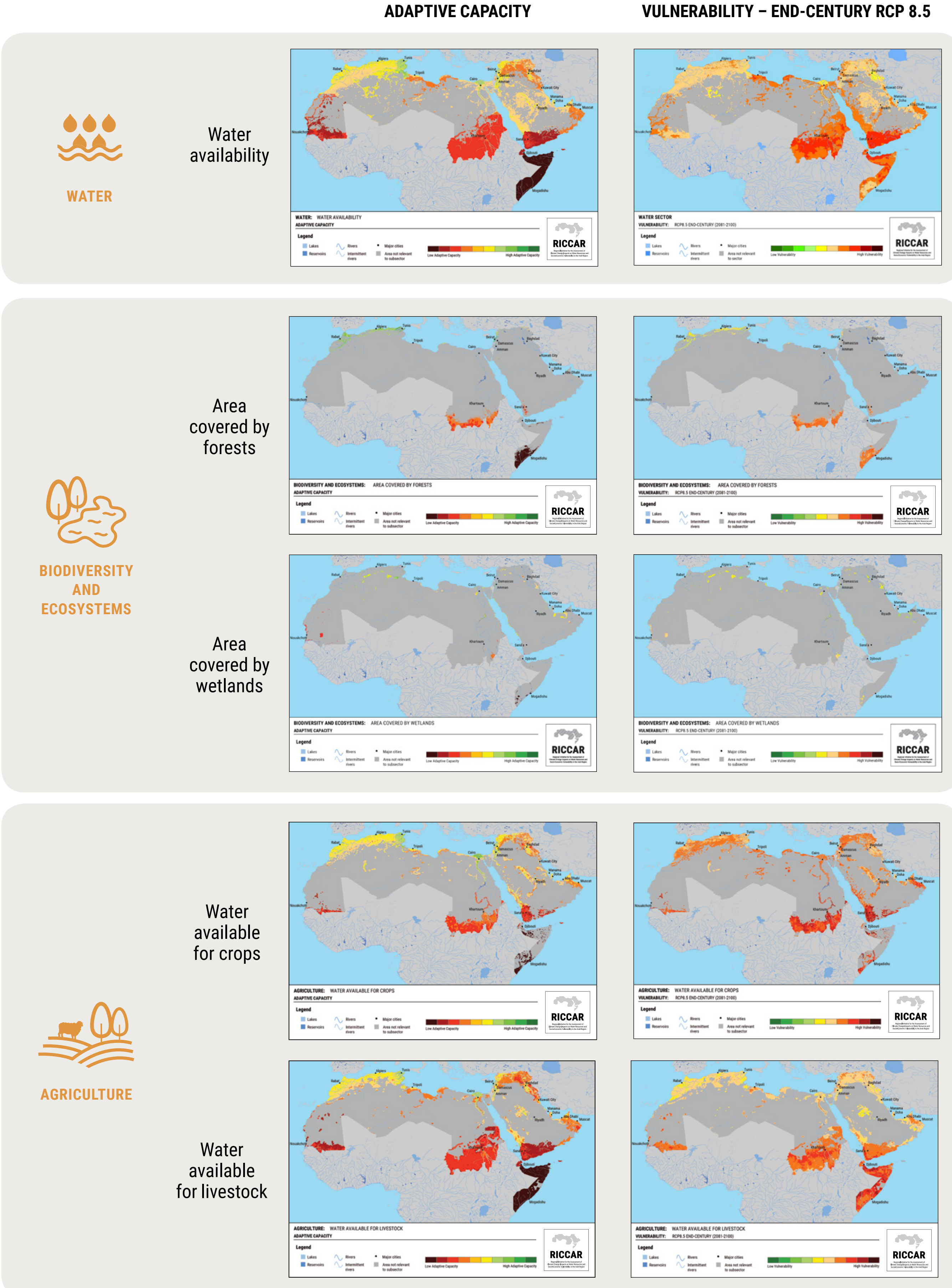
10. Despite declining precipitation, areas with the lowest vulnerability relative to the region include the western Mediterranean, coastal Maghreb, and the coastal Levant due to higher adaptive capacity in this area, as compared to other parts of the region.

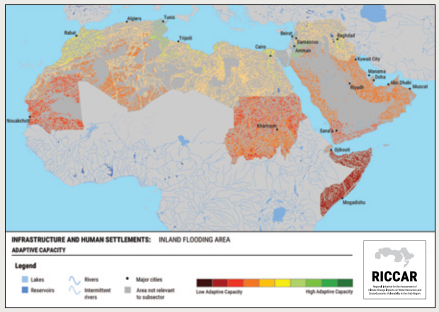
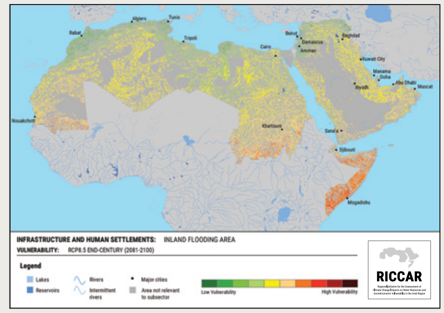
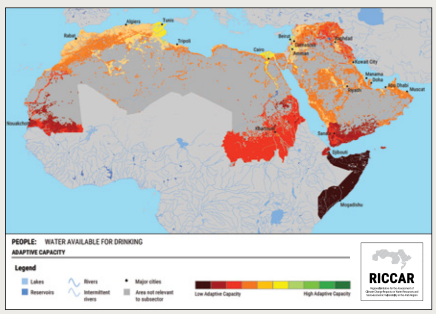
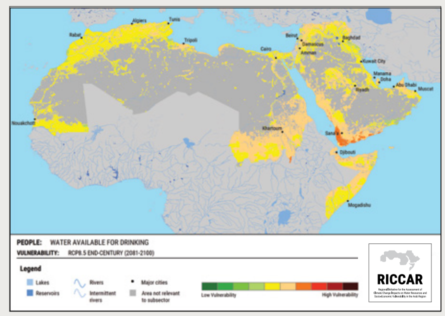
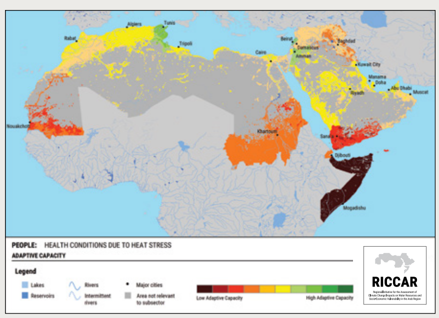
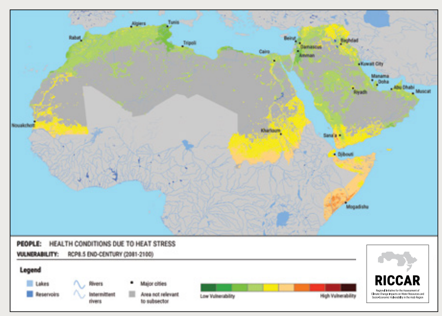
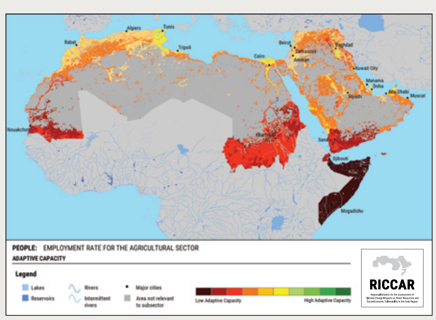
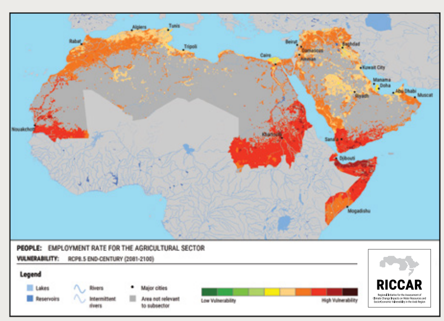
Relatively large decreases in precipitation and runoff coupled with small increases in temperature result in variable exposure, ranging from low to high, depending on the sector or subsector and scenario.

Sensitivity is generally low, other than in population centres near the coast, affecting much of the coastal Levant and selected areas in the Maghreb. Adaptive capacity is moderate, compensating for areas which reveal higher potential impact. The resultant vulnerability is low to moderate.

Nyala region, Sudan, 2006. Source: UN Photo/Fred Noy.

FIGURE 22: Adaptive capacity and vulnerability of different sectors/subsectors across the Arab region



		ADAPTIVE CAPACITY	VULNERABILITY – END-CENTURY RCP 8.5
INFRASTRUCTURE AND HUMAN SETTLEMENTS SECTOR	Inland flooding area		
PEOPLE SECTOR	Water available for drinking		
	Health conditions due to heat stress		
	Employment rate for the agricultural sector		

11. Even though the central Mediterranean coast and Green Mountains are subject to particularly strong warming, the area is indicative of moderate vulnerability due to relatively higher adaptive capacity, as compared to other parts of the region.

Exposure is variable along the Mediterranean coast because increases in temperature are modest and precipitation is found to be unchanged or decreasing slightly; meanwhile, indices such as the number of summer days over 35 °C are expected to increase substantially.Sensitivity is also wide-ranging, but is often high immediately near the coastline, where population density is highest. Lastly, adaptive capacity in this area is generally moderate.

This is in line with the findings in other parts of the region where vulnerability is strongly influenced by the adaptive capacity of areas to respond to changes in climate.

12. Despite precarious environmental, economic and social conditions within the lower Nile River Basin, the area demonstrates projected moderate vulnerability due to high adaptive capacity relative to other parts of the region.

The lower Nile River Basin towards the Mediterranean exhibits the highest population density in the Arab region, thus projecting high sensitivity. Exposure is variable, depending on the climate scenario under study and the indicators selected for each subsector.

Adaptive capacity is high in some parts of the basin, which compensates for elevated potential impact.

13. Although the Euphrates and Tigris rivers face challenges due to demographic pressures, hydro-infrastructure developments and water-quality degradation, socioeconomic vulnerability to climate change is found to be moderate relative to other parts of the region.

Exposure to climate change in the Euphrates and Tigris is variable relative to the rest of the region. Precipitation is generally decreasing in the upper part of the basin near the Zagros Mountains and slightly increasing in the lower part, but can vary depending on the time period and climate scenario. Temperature increases are modest. Sensitivity is generally low, despite a high population density near Baghdad and a generally high degradation trend in vegetative cover. Adaptive capacity is variable and largely moderate, but relatively higher near Baghdad compared to elsewhere in the subregion. The net result signals moderate vulnerability in general.

14. Despite remaining among the hottest areas in the Arab region, and signalling increasing temperatures, the Arabian Gulf generally projects moderate vulnerability to climate change.

Like the entire Arab region, the central and eastern Arabian Peninsula is experiencing higher temperatures. Exposure is low to moderate as projected temperature increases are mid-range as compared to the Sahel and Sahara.

Meanwhile, projected precipitation is relatively unchanged compared to the reference period, except along the Sea of Oman and nearby mountain range.

Overall sensitivity in the central region of the Gulf is low to moderate, while adaptive capacity remains moderate. As a result, vulnerability to climate change is moderate for the central and eastern areas of the Gulf compared to the rest of the region.

Palm trees in Marrakesh, Morocco, 2016. Source: Carol Chouchani Cherfane.

15. Region-specific integrated vulnerability assessments can be drawn upon to inform regional cooperation, as well as basin-level, country-level and sector-level analysis to advance understanding and collective action on climate change.

The Arab Ministerial Water Council, the Council of Arab Ministers Responsible for the Environment, the Arab Permanent Committee for Meteorology and intergovernmental mechanisms responsible for agriculture and health have identified climate change as a challenge to consider within the context of regional and national efforts to achieve sustainable development.

Arab Member States have drawn upon the RICCAR impact assessment and integrated vulnerability assessment findings to inform their work on climate change.

Livestock in Barakna State, Mauritania, 2010. Source: Ihab Jnad.

BOX 4: Using RICCAR outputs to inform further basin research and country-level applications

In line with one of its pillars to serve knowledge dissemination and inform further research on climate assessments in the Arab region, RICCAR-generated outputs are being used in ongoing projects related to water resources assessments in the region.

One example is the Collaborative Programme on the Euphrates and Tigris, conducted by the International Centre for Biosaline Agriculture (ICBA), SMHI and the Stockholm International Water Institute (SIWI) which aims to improve dialogue and cooperation among the basin countries regarding water management in the Euphrates and Tigris region. Building on RICCAR outcomes as it relates to hydrological climate modelling, the HYPE model schematization was used as a basis for an improved hydrological model set-up at the basin level, as well as climate projections for simulation of river behaviour under various management options in a changing future climate.

Lebanon's Third National Communication, submitted in November 2016 by the Ministry of Environment as part of the national reporting framework under the United Nations Framework Convention on Climate Change, also includes RICCAR outputs. Results on projected future changes in temperature and precipitation in Lebanon, as well as selected extreme indices were used as part of the chapter related to the country's vulnerability to climate change.

ACSAD is also working with the Government of Lebanon on an integrated vulnerability assessment of the agricultural sector at the country level with the support of the ACCWaM project. The results will inform action on climate change and is informing consultative processes aimed at formulating policies, positions and future projects.

Agricultural workers in Debel, Lebanon, 2006. Source: Carol Chouchani Cherfane.

NEXT STEPS

NEXT STEPS

Continued support will be provided by RICCAR partners to assist regional stakeholders to access and draw upon the regional assessment and associated case studies, which will inform further work on climate change impact assessment and vulnerability in the Arab region, particularly with respect to water resources.

This includes building capacity for further analysis and providing technical assistance to Arab Member States and regional stakeholders.

Access to the assessment findings and associated datasets is being made available on the RICCAR Regional Knowledge Hub. Efforts will also be made to encourage the preparation of internationally peer-reviewed journal articles based on the assessment input and outputs for reference in future reports of the IPCC.

In tandem, smaller-scale analysis drawing upon the RICCAR knowledge base will be encouraged to support further understanding of the effects of climate change at the basin, country and sector levels.

Broader assessments may also be advanced to better clarify how the Arab region fares in comparison with the rest of the world in terms of climate change vulnerability.

Such analysis is already being pursued and will support greater understanding and action on climate change in the Arab region, based on regional climate modelling, hydrological modelling and integrated vulnerability assessment tools developed and applied under the initiative through regional partnerships and collaborative frameworks fostered by RICCAR.

ADDITIONAL RESOURCES

RICCAR publication series

This report summarizes information and findings included in the *Arab Climate Change Assessment Report: Main Report*. It is complemented by a *Technical Annex* that presents more than 400 maps and figures that provide further information on the indicators and outputs generated during the regional application of the integrated assessment.

The report is part of a series of publications as shown on the following page, namely technical reports elaborating the case studies summarized in the main assessment report, as well as technical notes detailing the methodology applied during the regional climate modeling, regional hydrological modeling and vulnerability assessment phases of the integrated assessment.Training materials have also been issued and can be used to inform training in methodologies and climate change assessment and adaptation in the Arab region, based on work being conducted under RICCAR and RICCAR-related projects and activities.

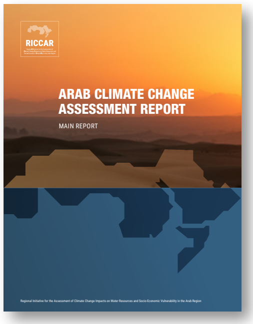
Website and Regional Knowledge Hub

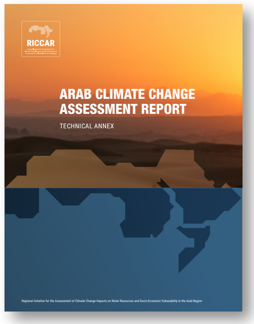
All information related to RICCAR, including meetings, workshops and related materials can be consulted on the dedicated website **www.riccar.org.**

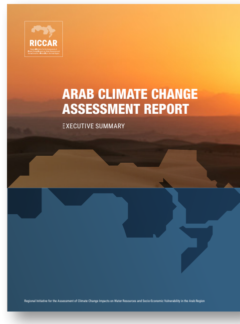
Datasets and files used to produce the modelling outputs and integrated mapping assessment results are made available online or upon request through the Regional Knowledge Hub, which includes an interactive portal for accessing maps, data files and fact sheets. This online platform complements, and builds upon, the findings already presented in the main report and its technical annex, as well as the series of publications that elaborate further on the work being pursued collectively under RICCAR.

Habbaniyah Lake, Anbar, Iraq, 2011. Source: Sadeq Oleiwi Sulaiman.

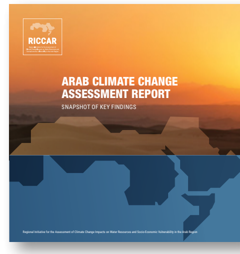
Main Report



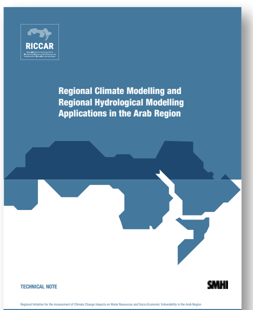


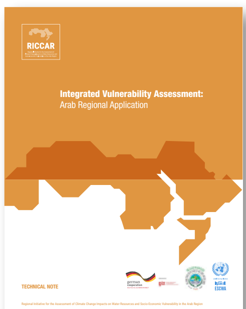


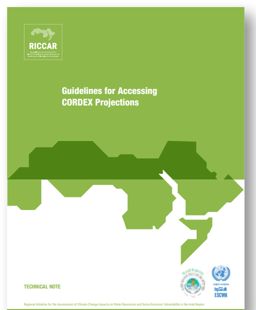
Booklet

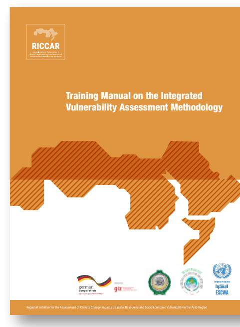


Technical Notes & Manuals

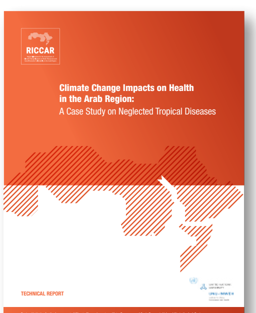


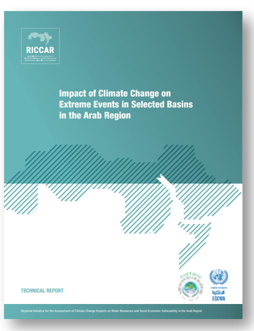


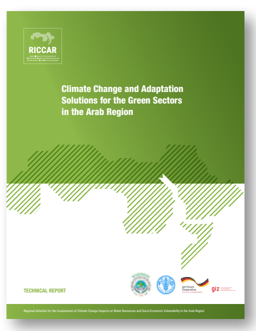


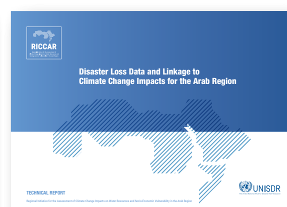


Technical Reports









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