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

MAIN REPORT

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WORLD METEOROLOGICAL ORGANIZATION

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UNESCO United Nations Educational, Scientific and Cultural Organization منظمة الأمم المتحدة للتربية والعلم والثقافة Cairo Office مكتب القاهرة

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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

This 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 effect 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 sub-domains; 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 this report will continue to inform regional dialogue, priority-setting and positioning on climate change in the Arab region as envisioned under this collaborative regional effort.

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ACRONYMS AND ABBREVIATIONS

abs.diff	absolute difference
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
ACL	anthroponotic cutaneous leishmaniasis
AEZ	agro-ecological zones
ALADIN	Aire Limitée Adaptation dynamique Développement InterNational
AMWC	Arab Ministerial Water Council
APCM	Arab Permanent Committee for Meteorology
Apr-Sept	April–September
ArabCOF	Arab Climate Outlook Forum
AR4/AR5	Fourth/Fifth Assessment Report (IPCC)
ARPEGE	Action de Recherche Petite Echelle Grande Echelle
ARST	active red sea trough
BCIP	Bias Correction Intercomparison Project
BMZ	German Federal Ministry for Economic Cooperation and Development
CAMRE	Council of Arab Ministers Responsible for the Environment
CDD	maximum length of dry spell
CH_4	methane
CL	cutaneous leishmaniasis
CMIP	Coupled Model Intercomparison Project
CNRM-CM5	Centre National de Recherches Météorologiques- Climate Model 5
CO_2	carbon dioxide
COP	Conference of Parties
CORDEX	Coordinated Regional Climate Downscaling Experiment
CPET	Collaborative Programme on the Euphrates and Tigris
CRU	University of East Anglia Climatic Research Unit
CWD	maximum length of wet spell
DARE	data rescue
days/yr	days per year
DBS	distribution-based scaling
DMN-MOR	Direction de la Météorologie Nationale-Morocco
DRR	disaster risk reduction
DTR	diurnal temperature range
EBM	ecosystem-based management
EC-EARTH	ECMWF-based Earth-system model
ECMWF	European Centre for Medium Range Forecasts
EGM	expert group meetings
EH	Ethiopian Highlands
ERA-Interim	ECMWF Re-Analysis Interim
ERAINT	ERA Interim-driven
ESCWA	United Nations Economic and Social Commission for Western Asia
ESM	Earth System Model
ET	evapotranspiration
ETCCDI	Expert Team on Climate Change Detection and Indices
EU	Upper Euphrates
ESDB	European Soil Database
FAO	Food and Agriculture Organization of the United Nations
FAR	First Assessment Report (IPCC)
GAP	Southeastern Anatolia Project
GCM	global climate model or general circulation model
GCOS	Global Climate Observing System
GDP	gross domestic product
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory-Earth System Model 2
GHG	greenhouse gas

GIAHS	Globally Important Agricultural Heritage Systems
GIS	Geographic Information Systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GLWD	Global Lakes and Wetlands Database
GLC	global land cover
GMIA	Global Map of Irrigation Areas
GPC	Global Precipitation Climatology Project
GPCC	Global Precipitation Climatology Centre
GRACE	Gravity Recovery and Climate Experiment
GRanD	Global Reservoir and Dam Database
GRDC	Global Runoff Data Centre
GSFC DAAC	Goddard Space Flight Center Distributed Active Archive Center
ha	hectares
hPa	hectopascals
HWSD	Harmonized World Soil Database
HIRAM	High Resolution Atmospheric Model
HIRLAM	High Resolution Limited Area Model
HEC-HMS	Hydrologic Engineering Center Hydrological Modelling System (hydrological model)
HydroSHEDS	Hydrological data and maps from Shuttle elevation derivatives at multiple scales (WWF)
HYPE	Hydrological Predictions for the Environment (hydrological model)
IM	integrated mapping
IPCC	Intergovernmental Panel on Climate Change
ITCZ	intertropical convergence zone
IWRM	Integrated Water Resources Management
JCDMS	Jordanian Climate Data System
JMD	Jordanian Meteorological Department
JR	Jordan River
km	kilometres
km^2	square kilometres
km^3	cubic kilometres
m	metres
m asl/ m bsl	metres above sea level/ metres below sea level
MD	Mediterranean Coast
MENA	Middle East North Africa
MH	Moroccan Highlands
MIRCA	monthly irrigated and rainfed crop areas
mm	millimetres
mm/day	millimetres per day
mm/mon	millimetres per month
mm/yr	millimetres per year
MNA22	25-km resolution (MENA domain 0.22 degrees)
MNA44	50-km resolution (MENA domain 0.44 degrees)
MPI-ESM-LR	Max Planck Institute for Meteorology-Earth system model
MR	Medjerda River
MSLP	mean sea level pressure
MW	megawatt
m^3/s	cubic metre per second
m^3/t	cubic metre per tonne
m^3/yr	cubic metre per year
NAO	North Atlantic oscillation
NASA	National Aeronautics and Space Administration (USA)
no.	number
NOAA	National Oceanic and Atmospheric Administration (USA)
NTD	neglected tropical disease
NWP	numerical weather prediction
N_2O	nitrous oxide
Oct-Mar	October–March
ODA	official development assistance
PMD	Palestinian Meteorological Department
ppm	parts per million

RCA3	Rossby Centre Regional Atmospheric Model 3
RCA4	Rossby Centre Regional Atmospheric Model 4
RCM	regional climate model
RCP	representative concentration pathway
REMO	Regional Model, Max Planck Institute, Hamburg, Germany
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
RVF	rift valley fever
SDII	simple daily intensity index
SDS	sand and dust storms
Sida	Swedish International Development Cooperation Agency
SMHI	Swedish Meteorological and Hydrological Institute
SPI	standardized precipitation index
SR	Senegal River Headwaters
SRTM	Shuttle Radar Topography Mission
SU	number of summer days
SU35	number of hot days
SU40	number of very hot days
Td	dew-point temperature
ton/ha	tonnes per hectare
TR	tropical nights
TRMM	Tropical Rainfall Measurement Mission
TU	Upper Tigris
UAE	United Arab Emirates
UDEL	University of Delaware Air Temperature and Precipitation data
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Office for Disaster Risk Reduction
UN Environment	United Nations Environment Programme
UDEL	University of Delaware Air Temperature and Precipitation
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
UNU-INWEH	United Nations University Institute for Water Environment and Health
US$	United States dollar
VA	vulnerability assessment
VA-WG	Vulnerability Assessment Working Group
VIC	Variable Infiltration Capacity (hydrological model)
WADI	water associated disease index
WAM	West African monsoon
WATCH	Integrated Project Water and Global Change
WCRP	World Climate Research Programme
WFDEI	WATCH Forcing Data methodology applied to ERA-Interim
WHIST	World Hydrological Input Set-up
WMO	World Meteorological Organization
WSDI	warm spell duration index
WWF	World Wildlife Fund
W/m^2	watts per square metre
ZCL	zoonotic cutaneous leishmaniasis
yr	year
°C	degree Celsius
%	per cent

OVERVIEW

BACKGROUND

REGIONAL INITIATIVE FOR THE ASSESSMENT OF CLIMATE CHANGE IMPACTS ON WATER RESOURCES AND SOCIO-ECONOMIC VULNERABILITY IN THE ARAB REGION

The Arab region with its unique and complex geopolitical and socioeconomic setting is facing major challenges affecting the ability of Arab States[1] 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. A higher frequency and intensity of floods, droughts and extreme weather events has also been experienced in many Arab States.

These disasters have affected the built environment, fragile land resources and natural ecosystems, which have aggravated the situation of already vulnerable communities, and resulted 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. Historical climate records show an increase in the global mean temperature over the last 165 years, with the year 2016 reported to be the hottest year on record by the World Meteorological Organization (WMO), which places the average temperature of the Earth today at 1.1 °C above pre-industrial levels.[2] The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[3] projects the global mean surface temperature by the end of the 21st century likely to increase as low as 1.1 °C 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 report 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 water scarce. To do so means assessing these global temperature changes through a regional lens that characterizes regional specificities, conditions and constraints. Such efforts must be firmly grounded in science that can inform policy through dialogue between Arab States and among various stakeholder groups.

To better bridge the science–policy interface, such assessments should take into consideration the impact of climate change on water resources and what this means for the vulnerability of peoples and ecosystems throughout the region. Combining impact assessment projections with vulnerability assessment also furthers efforts to identify regional vulnerability hotspots and priorities for coordinated action on climate change adaptation in the Arab region.

1 MANDATES AND PARTNERSHIPS

The Council of Arab Ministers Responsible for the Environment (CAMRE) adopted the first Arab Ministerial Declaration on Climate Change in December 2007 during its 19th session convened at the League of Arab States secretariat in Cairo, Egypt. The declaration is considered the starting point of Arab collective action on climate change, and serves as the basis for subsequent Arab action and positioning thereon. The declaration asserts that the Arab region will be among the regions most vulnerable to the potential impacts of climate change and that these impacts might have negative repercussions on Arab regional development. The extent of these potential impacts and effects were not well understood at that time, however, as the only references available were the global assessment reports issued by IPCC and a limited number of country-level reports. No comprehensive picture of climate change impacts across the Arab region was available, and thus no strategy for addressing them. The Arab declaration recognized this challenge and demonstrated an appreciable and early understanding of the importance that climate change assessment plays in informing climate action. It does so by calling for adaptation measures to be fully consistent with socioeconomic development, sustainable economic growth and poverty eradication goals, which should be based on "the development and dissemination of methodologies and tools that assess the impacts of climate change and their extent." The declaration concludes with the call to:

"Establish studies and research centres for climate change in the regions of developing countries, including the Arab region. These centres should be concerned with examining impacts and challenges facing the citizens and peoples of the developing countries as a result of climatic change."

In response to this mandate, the 25th Ministerial Session of the United Nations Economic and Social Commission for Western Asia (ESCWA) adopted Resolution 281 (XXV) in May 2008 in Sana'a, Yemen. The resolution requests ESCWA to prepare an assessment of the vulnerability of economic and social development to climate change, with particular emphasis on freshwater resources.[4] ESCWA subsequently consulted with the League of Arab States, the United Nations Environment Programme (UN Environment) and regional partners to pursue this work. The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) of the League of Arab States subsequently submitted a project brief to the Arab Economic and Social Development Summit proposing to conduct an assessment of climate change impacts on available water resources in the Arab region as one of five projects proposed to advance integrated water resources management (IWRM) for sustainable development in the region. The Arab Summit endorsed the five projects at its ministerial session in January 2009 in Kuwait, where

Sirs Al-Muqassar Reserve, State of Palestine, 2017. Source: Alaa Kanaan.

it also mandated the establishment of the Arab Ministerial Water Council as a new intergovernmental mechanism to be responsible for addressing water challenges facing the Arab region. The Kuwait Summit further assigned this new ministerial council the responsibility to follow up on the implementation of the five IWRM projects submitted by ACSAD. In tandem, work on the preparation of the Arab Framework Action Plan on Climate Change (2010–2020) was initiated under CAMRE in 2009 to formulate a collective programme of work on climate change adaptation, mitigation and cross-cutting issues across a range of socioeconomic and environmental sectors.

Inter-agency collaboration was then formalized at the United Nations–League of Arab States 9th Sectoral Meeting (Cairo, June 2009), which focused on climate change. It concluded with the agreement that the United Nations and League of Arab States and their respective specialized organizations would collaborate on the preparation of a joint assessment of vulnerabilities and impacts of climate change on land and water resources management. The Expert Group Meeting towards Assessing the Vulnerability of Water Resources to Climate Change in the Arab Region (Beirut, October 2009) was then hosted by ESCWA, the League of Arab States and UN Environment with the financial support of the Islamic Educational, Scientific and Cultural Organization and the involved Arab member States and sister United Nations and League of Arab States organisations. A joint concept note was formulated outlining four pillars of work, which was presented by ACSAD to the Arab Ministerial Water Council (AMWC) in July 2010 and endorsed. Further discussion of the four pillars was then undertaken during the United Nations–League of Arab States Expert Group Meeting on the Development of a Vulnerability Assessment for the Arab Region to Assess Climate Change Impacts on the Water Resources Sector (Beirut, November 2010) hosted by ESCWA and then welcomed by the inter-agency Regional Coordination Mechanism based on the report submitted by UN Environment as chair of the Thematic Working Group on Climate Change (Beirut, November 2010). The resulting concept note for the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region was finalized by ESCWA in December 2010. The Regional Coordination Mechanism Thematic Working Group on Climate Change mandated ESCWA to lead the coordination of the regional initiative, which is now referred to as the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR).

RICCAR is implemented through an inter-agency collaborative partnership involving 11 partner organizations, namely ACSAD, ESCWA, 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 WMO.

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).[5]

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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 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.

2 OBJECTIVES

RICCAR 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.

3 IMPLEMENTATION FRAMEWORK

The regional initiative is structured along four pillars of work (see Figure 1):

Pillar 1: Baseline review of water and climate information and the development of a regional knowledge hub to provide a common knowledge base;

Pillar 2: Preparation of an integrated assessment that combines regional climate modelling, regional hydrological modelling and vulnerability assessment tools at the Arab regional level;

Pillar 3: Institutional strengthening and capacity-building of water and meteorological organizations, as well as related ministries and expert stakeholders, in the area of data management, seasonal forecasting, regional climate modelling, hydrological modelling and vulnerability assessment;

Pillar 4: Awareness-raising activities and dissemination of information tools to facilitate access to key message, methodologies and information to targeted stakeholders.

The culmination of work to date on the second pillar is represented by the issuance of this report. However, the preparation of this report is the product of efforts conducted under all four pillars of work, under which regular consultations and exchanges with Arab States, international experts, regional organizations and local stakeholders were pursued.

As shown in Figure 2, this process included the nomination of national hydrological focal points and the formation of regionally representative working groups and task forces, including the Vulnerability Assessment Working Group, Regional Knowledge Hub Working Group, Task Force on Sensitivity and the Task Force on Adaptive Capacity. The Task Force on Regional Climate Modelling was established early on in the initiative and contributed to the vetting and establishment of the Arab Domain, which was subsequently adopted by WCRP-CORDEX as the CORDEX-MENA Domain. Consultation with international climate scientists interested in regional climate modelling in the Domain followed.

Annual expert group meetings were also conducted during the development and vetting of the integrated assessment methodology and preliminary findings, while capacity-building workshops provided training on climate data rescue, extreme climate indices, regional climate modelling, hydrological modelling and vulnerability assessment integrated mapping tools. Regional stakeholders were also invited to complete a survey to help finalize the set of indicators and indicator weights assigned to inform the integrated vulnerability assessment.

As preparation of the regional assessment outputs advanced, peer reviews were organized to ensure the validity of the applied methodology and findings.

These efforts also resulted in the efforts to establish 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

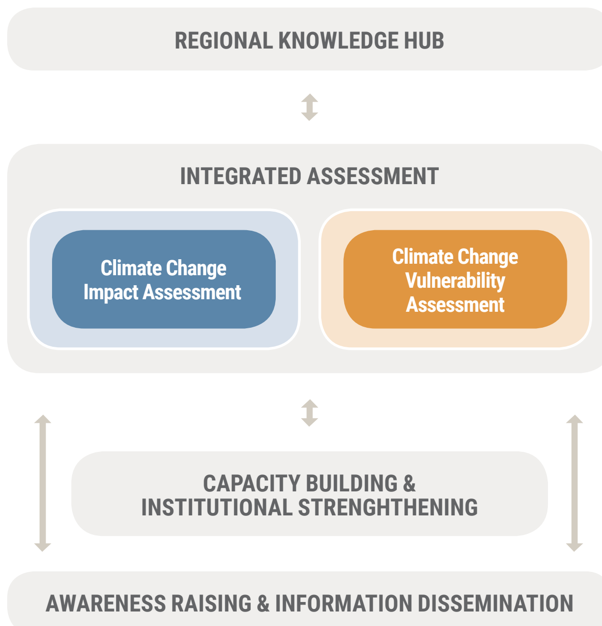
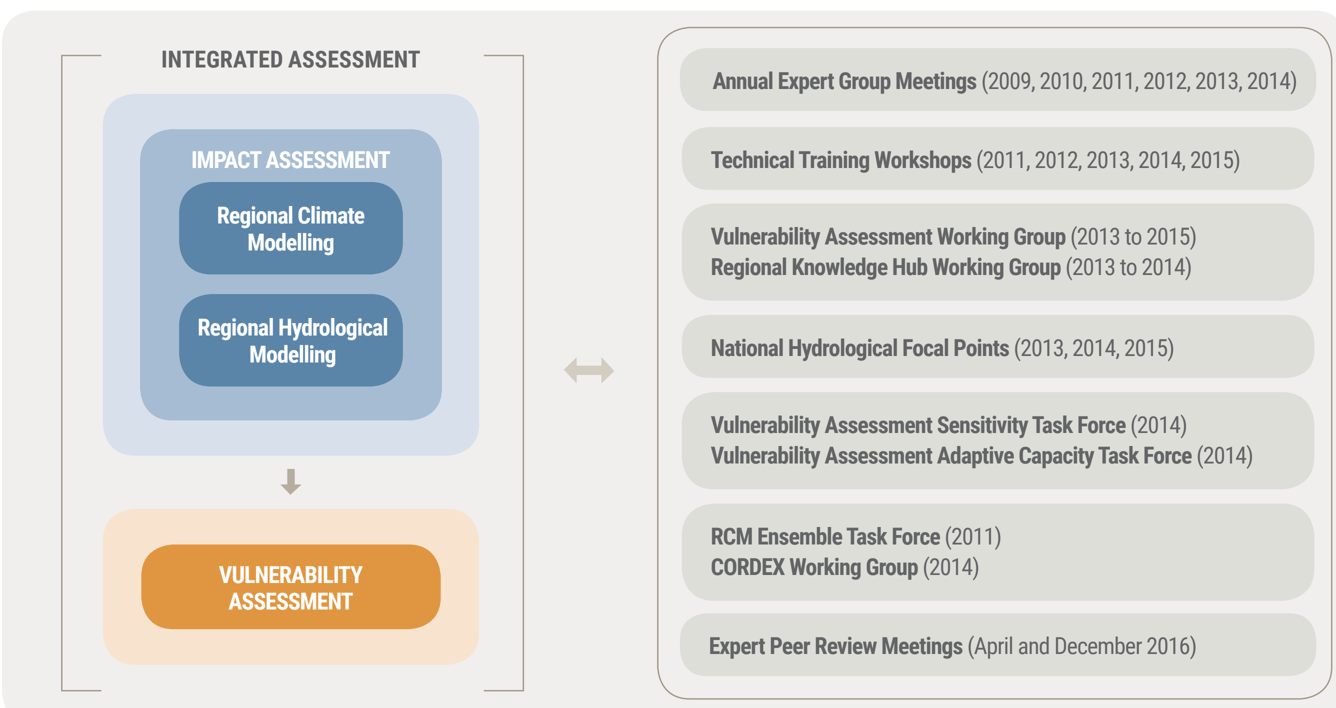


FIGURE 2: RICCAR-related consultative mechanisms informing integrated assessment



OVERVIEW

This Arab Climate Change Assessment Report (ACCAR) 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 sub-domains, including 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 sub-sectors in the Arab region, in the absence of adaptation or any mitigating measures.

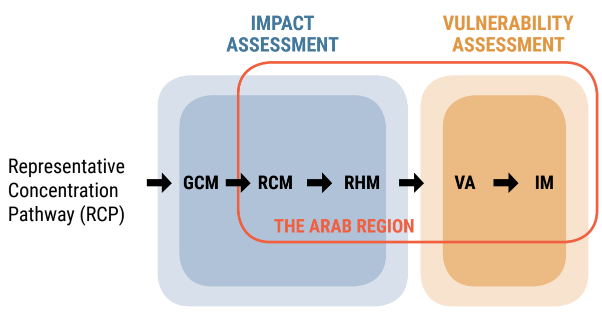
Impact assessment studies focusing on extreme climate events, the agricultural sector and human health provide additional insights on how climate change is projected to impact Arab States. In so doing, the report identifies vulnerability hotspots and vulnerable sectors across the Arab region and illustrates 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. A series of selected essential climate variables, extreme climate indices and socioeconomic and environmental parameters are used for presenting and illustrating the outcomes of the integrated assessment. Three time periods were selected for presenting results, namely the reference period (1986–2005), mid-century (2046–2065) and end-century (2081–2100) periods. The analysis is elaborated based on two representative concentration pathways, which generally describe a moderate emissions scenario (RCP 4.5) and a high emissions scenario (RCP 8.5). These time periods and scenarios were selected to facilitate comparability with other climate modelling experiments being conducted at global, regional and national levels. Regional climate modelling and hydrological modelling outputs presented in this report were generated based on a 50 km^2 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.

It is expected that this scientific report will help to inform decision-makers, advisors, researchers and stakeholders about climate change impacts as they affect the Arab region, with a view to informing policy dialogue, priority-setting, and action across the Arab region.

1 INTEGRATED ASSESSMENT METHODOLOGY

This report presents the outcomes of the RICCAR integrated assessment methodology that was developed based on the interest to combine impact assessment and vulnerability assessment approaches into a cohesive framework for assessing the impact of climate change on water resources and socioeconomic vulnerability at the Arab regional level. The methodology is grounded on the use of regional climate modelling, hydrological modelling, vulnerability assessment and integrated mapping tools. Five stages of analysis were agreed upon (see Figure 3):

FIGURE 3: RICCAR integrated assessment methodology



Step 1. Select representative concentration pathways (RCPs) to adopt and review available global climate models (GCMs). In order to be coherent with other work being pursued under CORDEX, it was determined that RICCAR would purse regional climate modelling for RCP 4.5 (moderate scenario) and RCP 8.5 (high-end scenario).

Step 2. Generate ensembles of regional climate modelling (RCM) projections over an Arab Domain. This involved defining the Arab Domain and generating dynamically downscaled RCM projections and ensembles for specific climate scenarios and resolutions, for general climate variables as well as for region-specific extreme climate indices.

Step 3. Interface regional hydrological models (RHM) with RCM outputs to analyse climate change impacts on water resources. This involved bias-correcting the RCM results to serve as inputs for the generation of RHM ensembles using two hydrological models, with specific focus on the region's shared river basins and specific sub-domains.

Step 4. Conduct a vulnerability assessment (VA) based on the impact assessment findings across the Arab region in targeted sectors and sub-sectors identified through a consultative process, and based on the classification and weighting of region specific geospatial indicators that characterize sector exposure, sensitivity and adaptive capacity with respect to climate change.

Step 5. Complete the integrated mapping (IM) of the assessment for facilitating regional policy analysis and dialogue by presenting vulnerability hotspots and climate change trends and challenges across the Arab region.

This methodological framework is elaborated in a series of publications focusing on various components of the integrated assessment.[6] The development and application of this 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, as was shown in Figure 2.

The aim of this integrated assessment methodology is to 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 across Arab States about priority issues, challenges and opportunities for collective action. The application of this methodology 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.

2 STRUCTURE OF THE REPORT

This *Arab Climate Change Assessment Report* is structured into four sections and divided among 14 chapters. It opens with an introduction followed by two parts that echo the main components of the integrated assessment methodology, namely impact assessment (Part I) and vulnerability assessment (Part II), which are followed by a conclusion.

The introduction provides background on the regional initiative, an overview of the report and a review of baseline information and sources of data used to prepare the integrated assessment. 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 regional climate modelling outputs presented in Part I.

Part I (Impact Assessment, Chapters 1–7) reviews regional climate modelling and hydrological modelling projections generated for the Arab Domain and selected subdomains, and how these results were generated. Results and findings of concern to some of the major shared surface-water basins in the Arab region are presented in Chapter 4. Impact assessment case studies of extreme events and sector-based case studies based on RCM and RHM outputs are presented in Chapters 5, 6 and 7.

Part II (integrated vulnerability assessment, Chapters 8–14) reviews VA methodology and main components of the assessment (Chapter 8), followed by the results for each of the five sectors and nine subsectors studied (Chapters 9–13), followed by a brief summary of the findings (Chaper 14).

The conclusion presents key findings and explores how this assessment report can inform regional policymaking and future work.

The main report 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 RICCAR publication series, which elaborates and complements the methodologies presented in this report. The publication series is comprised of:

Technical notes – these serve as stand-alone explanatory notes and elaborate in greater detail the applied methodologies and information sources used.

Technical reports – these serve as stand-alone publications and present detailed case studies or provide additional analysis that build upon the RICCAR modelling outputs, several of which are summarized in the main report.

Training materials – these can be used to inform training on methodologies and climate change assessment and adaptation in the Arab region, based on work being conducted under RICCAR and RICCAR-related projects and initiatives.

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.

BASELINE INFORMATION AND DATASETS

Data availability and data quality are crucial for the conduct of any assessment. The availability of observed climate and water station data across the Arab region is very limited and the distribution of quality-controlled, long-term observational sites within the Arab region is uneven. In areas where station data are recorded, access to datasets may not be publicly available or not available in digitized form to allow for use in computer-based modelling applications.

RICCAR efforts were thus focused on using national data from regional or global data sources whenever possible to ensure the use of harmonized and quality-controlled datasets that are comparable across Arab States. This limited the ability of the initiative to adopt indicators and use data that were well-elaborated in some Arab States, but not in others. Such a limitation may not be the case when integrated vulnerability assessment using the same methodology is applied at the country or local level.

The following sections review the main climate features and trends that characterize climate in the Arab region, followed by 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 presented in this report. This section also offers information on related work conducted under RICCAR to support Arab States in the area of climate data rescue (DARE) and the development of disaster-loss databases, highlighting their usefulness for climate change analysis.

1 CLIMATE CHARACTERISTICS OF THE ARAB REGION

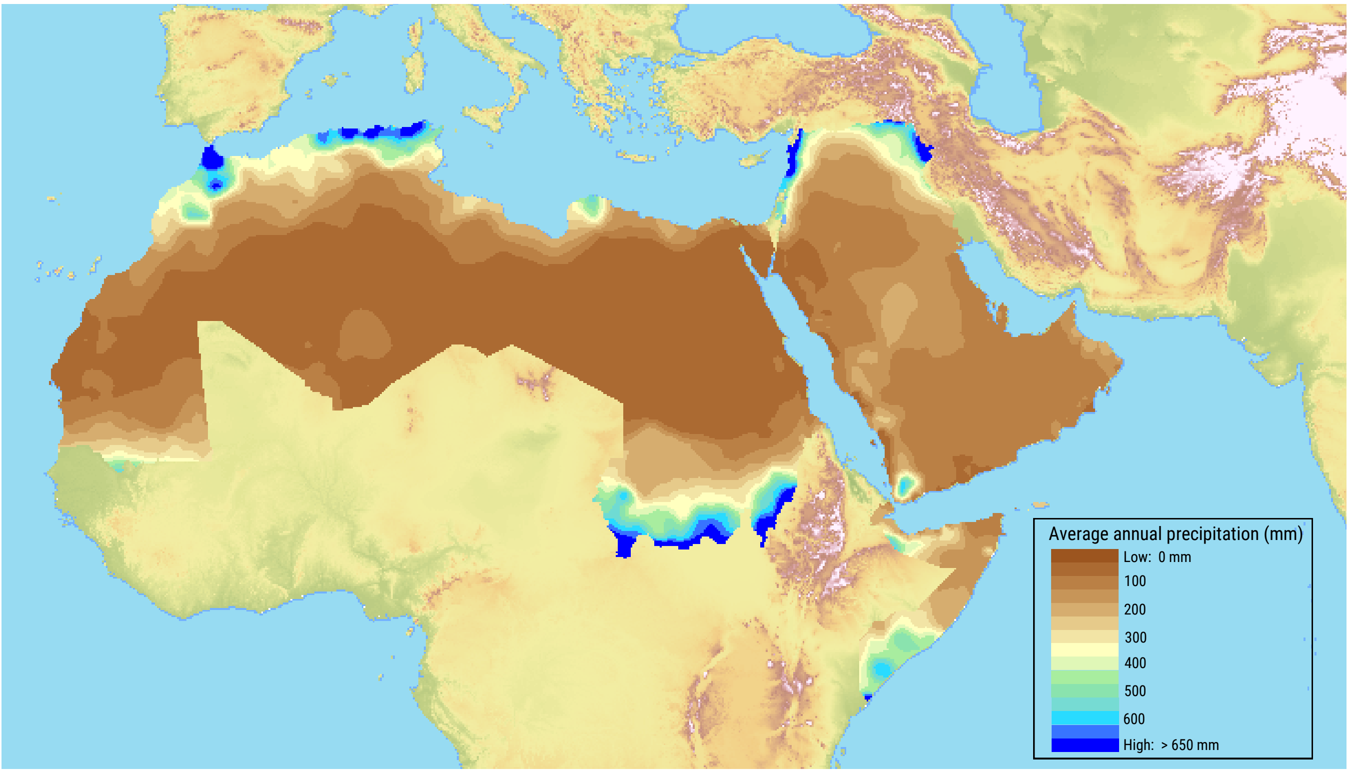
1.1 Climate zones and features

Most of the Arab region is characterized by a predominantly arid to semi-arid climate (annual rainfall distribution shown in Figure 4). The Sahara Desert constitutes most of the surface area of North Africa, covering Mauritania, southern Morocco, and extending further east into vast are of Libya, Egypt and as far as Atbara in Sudan. This desert exhibits one of the harshest climates in the world, with an annual rainfall of less than 25 mm and temperatures rising over 50 °C in the hottest months to below freezing in the winter. Located just at the south of the Sahara Desert, the Sahel has a tropical, hot steppe climate and represents an ecoclimatic zone of transition between the Sahara to the north and the Sudanian Savanna. This zone includes southern Mauritania, the extreme south of Algeria, as well as central and southern Sudan. Constant heat and little variations in temperatures characterize this area, with an average mean temperature never lower than 18 °C. The dry season in the Sahel lasts for 8 to 10 months with irregular rainfall during the short rainy period, and receives 100–600 mm of rain annually, depending on the different sub-zones (around 100–200 mm in Khartoum and 200–600 mm in Kiffa, south Mauritania).

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

Although mostly arid or semi-arid, the Arab region also encompasses temperate zones in the northern and higher elevations of the Maghreb and Mashreq. The Atlas Mountains, located in the northern parts of Morocco, Algeria and Tunisia, constitute relief from the dry desert with cooler temperatures and much higher precipitation (up to 1,500 mm/yr). These areas, which extend to the northern stretches of Libya and Egypt, exhibit a Mediterranean climate as in the western areas of Jordan, Lebanon, State of Palestine and Syrian Arab Republic with warm, dry summers and rainy, cool winters. In the highlands of Lebanon, northern Syrian Arab Republic and north-eastern Iraq, temperatures are, on average, below 10 °C in winter (January), and receive more than 1,000 mm/yr of precipitation on average, with snowfall covering mountainous areas above 1,500 m. South of the high elevations, the cold semi-arid steppe climate with cold winters occurs along a narrow stretch of Morocco, Algeria and Tunisia, as well as in Jordan, Syrian Arab Republic and Iraq in the Mashreq region. Further inland, it transforms into an arid desert climate as it reaches the Sahara Desert in North Africa and the vast Desert in Syrian Arab Republic covering more than half of the country and extending through inland Iraq and Jordan.

FIGURE 4: Mean annual precipitation distribution across the Arab region (1986-2005)



A limited portion of the Arab region exhibits an equatorial climate characterized by high year-round temperatures and heavy precipitation most of the year, such as southern Somalia and some parts of southern Sudan. The southern Somalia area, for example, receives 300–500 mm of rainfall annually; minimum temperatures are around 30 °C all year long and can be as high as 41 °C in March – the hottest month of the year.

Most of the Arabian Peninsula is characterized by a hot desert climate with less than 100 mm/yr of rainfall. Average temperatures range from 40 °C to 50 °C in summer and 5 °C –15 °C in winter, with very high daily fluctuations. Exceptions to these conditions occur in coastal zones of eastern Oman, south-western Saudi Arabia (Hijaz) and Yemen, where rainfall is higher, due to the seasonal monsoon winds and northward expansion of the Intertropical Convergence Zone (ITCZ). For instance, precipitation levels can attain 1,500 mm/yr on the south-western mountain slopes of Yemen.[7]

While annual rainfall varies between 0 mm and 650 mm on average for the region as whole (rainfall can exceed 900 mm in some areas), average evaporation rates often exceed 2,000 mm/yr. Evaporation observations along the southern and eastern shores of the Mediterranean indicate rates in the order of 1,000 mm/yr increasing to 2,000 mm/yr or more while moving further inland. The same trend is found upon moving from the North African coast towards the Sahara inland, and then decreases gradually with increase in rainfall and relative humidity as it reaches southern Sudan with evaporation rates in the order of 1,500 mm/yr. In the Arabian Peninsula, the total annual evaporation rate ranges from 2,500 mm in the coastal areas to more than 4,500 mm inland. Similar to evaporation, observations of evapotranspiration (ET) rates vary both spatially and temporally. The largest annual ET values are found in south-western Algeria, southern Egypt, Djibouti, southern Iraq, south-eastern Saudi Arabia, north-eastern Yemen, and western Oman with more than 2,200 mm/yr. Overall, the summer rate in the Arabian Peninsula is three times the potential evapotranspiration rate in wintertime.[8]

1.2 Atmospheric patterns affecting climate variability

The state of the North Atlantic Oscillation (NAO) – the principal feature affecting climate variability in the northern hemisphere – largely governs annual variations of rainfall in the Maghreb, most of the Mashreq and the northern part of the Arabian Peninsula. It consists of opposing variations between areas of low pressure centred near Iceland and high pressure zones in the south of the Azores in the Atlantic Ocean. The interaction of these two poles modifies the circulation of the westerly winds across the Atlantic into

Europe and the Mediterranean, with important effects on the winter season at mid-high latitudes. When the pressure difference is high (positive NAO phase), the westerly winds are stronger and track more to the north, leading to higher-than-normal temperatures and precipitation levels across northern Europe in winter, but causing drier conditions in the Mediterranean. In the opposite phase, the westerlies and the storms they bring track farther south, leading to cold winters in Europe, but more storms in the Mediterranean and more rain in North Africa.[9] Precipitation variability in the Arabian Peninsula is affected by the Indian seasonal monsoon winds that bring moist airmasses from the Indian Ocean, causing rainfall in the coastal zones of eastern Oman, Saudi Arabia (Hijaz region) and Yemen. Most of the precipitation occurs in May and continues until August in the uplands, but often appears as early as March. In this area, rain falls mainly as heavy showers followed by flash floods. Occasionally, these countries also experience serious consequences of tropical cyclones. The Indian monsoon system is largely controlled by the position of the ITCZ, a zone of low pressure at the Equator, where the north-east and southeast trade winds converge to form a band of increased convection, cloudiness, and precipitation, that moves seasonally south and north of the Equator.[10] The ITCZ also affects the West African Monsoon (WAM), which is the circulation pattern affecting most of the rainfall in the Sahel. It consists of a low-level moisture flow originating in the equatorial and southern tropical Atlantic Basin. When the ITCZ seasonally shifts northwards, reaching West Africa in mid-June, it interacts with the WAM which converges on to the continent bringing rains to the Sahel from July to September.[11]

1.3 Extreme events and climate related hazards

In recent years, extreme temperatures and precipitation events in the region have recurrently led to a variety of weather- and climate-related hazards, such as heatwaves, droughts, floods, cyclones and sand- and dust storms (SDS). These natural events have become more frequent and more severe, with substantial and widespread consequences on social and economic conditions in many areas. Drought is the most prevalent climate hazard; its impacts on livelihoods are severe and cause the highest human losses. Its effects include decreased water supplies, as well as loss of harvest and livestock, which, in turn, threaten food security and often cause widespread malnutrition. One example is the devastating droughts in Syrian Arab Republic of 1998–2000 and 2007–2010, which were the most severe in some 1,100 years, causing considerable economic losses and the displacement of more than one million people.[12] This is the case currently in the Greater Horn of Africa, where the prolonged drought has led to successive failed harvests and widespread livestock deaths in some areas.[13] Though usually associated with drought and desertification, the region has also recently been experiencing devastating floods and flash floods. They occur after intense and short-duration rainstorm events, causing severe damage to infrastructure and often leading to human losses. Major floods have been striking Saudi Arabia recurrently since 2009, the most recent of which – in February 2017 – caused the loss of several human lives. Other countries, such as Oman, experienced similar events with heavy flooding in early 2017, which led to four deaths and destroyed hundreds of settlements.[14]

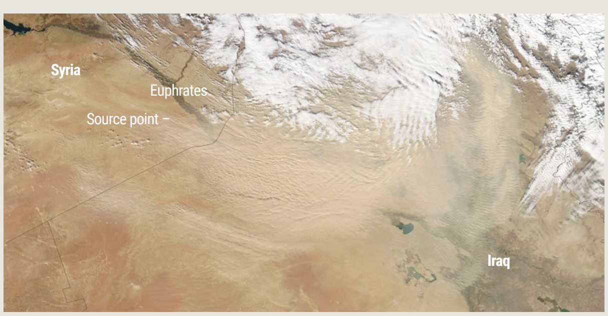
The Active Red Sea Trough (ARST) is an occasional weather phenomenon associated with extreme precipitation, flash floods, and severe societal impacts in the Middle East, as was the case with a major flood in Jeddah, Saudi Arabia, on 25 November 2009. ARST results from the interaction of a persistent stationary wave in the tropical easterlies with a superimposed amplifying Rossby wave, resulting in northward propagating moist airmasses over the Red Sea.[15]

Heavy flood conditions also often follow tropical cyclones events, which are widespread in the vicinity of the Indian Ocean and Arabian Sea, and can have long-lasting impacts on coastal settlements and natural systems. Examples include tropical cyclone Gonu, the strongest tropical cyclone on record in the Arabian Sea, which struck Oman in June 2007, leaving 49 dead and costing about US$ 4 billion in widespread damage.[16] More recently, tropical cyclone Chapala hit coastal Yemen in November 2015 and was the first hurricane-strength storm known to make landfall in Yemen, leaving hundreds of dwellings submerged by water.[17] The impacts of extreme events such as storm surges in the region also add to the vulnerability of coastal zones, which house highly populated cities as well as major centres of economic development. They expose potentially vulnerable locations to sea-level rise, particularly in low-elevation areas. An example is the Nile Delta which has been extensively documented and studied as it is an area of high risk in the case of sea-level rise, with locations susceptible to inundation encompassing major urban neighbourhoods, agricultural areas and coastal wetlands.[18] Other major natural hazards in the region are sand- and duststorms. They result from high winds associated with extreme heat, and have led, in many Arab States, to serious adverse impacts on human health and agricultural productivity, as well as traffic accidents and airline delays (see Box 1). All these extreme events, when associated with unstable conditions, such as the development of informal, unsafe settlements or limited access to transport, health, education and other basic services, become disasters rather than just hazards, given the extensive devastation they can inflict, and require risk reduction on a large-scale. In light of the increased frequency and intensity of these disaster events, an urgent need for disaster prevention and management has been identified in the region and is currently being developed through disaster loss databases, detailed in the section on disaster loss.

BOX 1: Sand and dust storms in the Arab region

Sand and dust storms (SDS) are common examples of extreme weather conditions in the Arab region. These events can last from a few hours up to several days and create long-lasting environmental impacts in the source areas (loss of surface sediments, disturbed consolidation of topsoil) but, most importantly, affect the receiving areas with severe adverse impacts. Common effects include severe air pollution and reduced visibility leading to increased traffic and aircraft accidents. In addition, severe impacts on human health are systematically reported, such as increased occurrence of respiratory diseases. These events also affect livelihoods and the economy as they exacerbate, in a cyclic way, the loss of land productivity, ecosystem integrity and biodiversity, leading to population displacement and loss of critical habitats and wetlands in the Mesopotamia area.[19] It is estimated that about US$ 13 billion of gross domestic product are lost every year to duststorms in the Middle East and North Africa.

The North African region is the largest global source of SDS (with the Sahara Desert as the most significant source of dust) followed by the West Asia region.[20] In the latter region, the major dust sources extend in a continuous band from the northern part of the Tigris-Euphrates basin to the coast of Oman.[21] Accordingly, SDS are persistent issues of concern, particularly in Iraq and the southern Arabian Peninsula, and are most prevalent during the spring and summer months owing to the strong winds characterizing the winter–spring seasonal transition. Examples include a duststorm hitting the Arabian Peninsula in late February 2015, when the low-pressure system triggered strong north-westerly winds carrying dust from as far as northern Saudi Arabia, Iraq and Kuwait to the shores of the Persian Gulf and the Arabian Sea.[22] The Mashreq region also recently widely witnessed such phenomena, with a massive duststorm in September 2015, which lasted for several days, striking the Syrian Arab Republic and Iraq and spreading through Lebanon, Egypt and Jordan.[23] The storm was unprecedented in recent Lebanese history, leading to five deaths and 750 cases of asphyxiation or shortness of breath.[24]



Dust Storm in Syria and Iraq, 2011. Source: NASA, LANCE/EOSDIS MODIS Rapid Response Team.

While the natural geological topographical and climatic features constitute key factors in determining the incidence of SDS, human interference with natural land features is an additional significant contributing factor in generating them. This includes practices such as overgrazing and overworking of farm areas, poor water use, and land clearing. This combination of driving factors is further compounded by increasing climate variability in many already fragile regions, with decreased rainfall, extended drought periods, higher temperatures and increased frequency of high-velocity wind events, all of which exacerbate the conditions that spawn SDS.[25] In line with IPCC AR5 findings, RICCAR results project warming in the region, as well as an intensification of extreme events, which implies that the region will be potentially challenged by droughts and water scarcity, compounded by heightened SDS events, in the future.

For these reasons and because of the continuum and interconnectivity of ecosystems and landscapes across the region, a coordinated and integrated approach among affected countries is essential to effectively tackle this challenge. Several steps have been taken in this regard at the regional level, such as the Ankara Ministerial Declaration on the issue of SDS, signed in 2010 by countries of West Asia, including Iraq and the Syrian Arab Republic, along with a follow-up action plan. At the national level, the Iraqi Government has made efforts to develop a national programme to combat SDS, in collaboration with UN Environment and FAO.

More recently, international resolutions have also been adopted concerning this issue. Building upon the United Nations Environment Assembly Resolution 1/7 on promoting air quality[26] and the United Nations General Assembly resolution 70/195 on combating sand and dust storms,[27] the United Nations Environment Assembly adopted a resolution on SDS (UNEP/EA.2/Res21)[28] in 2016 to promote a coordinated approach to globally combating SDS and support Member States in addressing the challenges through policy measures and actions. UN Environment is also playing an important role in raising awareness and elevating SDS as a regional and global emerging environmental issue as part of its programme of work, in particular at the West Asia office, which covers an area deeply affected by this phenomenon.[29]

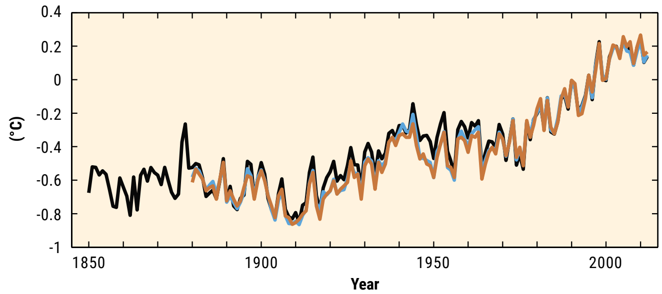
2 CLIMATE DIAGNOSTICS

2.1 Global observed climate trends

Observations of changes in the climate system are based on records from direct physical and biogeochemical measurements, ground stations, satellites and many other types of observing systems that monitor the Earth's weather and climate. Records of data from hundreds to millions of years are studied through paleoclimate reconstructions, while actual global-scale observations began in the mid-19th century. Together, they provide a comprehensive view of the variability and long-term changes in the atmosphere, the ocean, the cryosphere and the land surface.[30] According to the IPCC, scientific evidence for warming of the climate system is undeniable. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 (Figure 5).[31] The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show an increase of about 0.85 °C from 1880 to 2012 (based on multiple independently produced datasets), and about 0.72 °C from 1951 to 2012 (based on three independently-produced data sets).

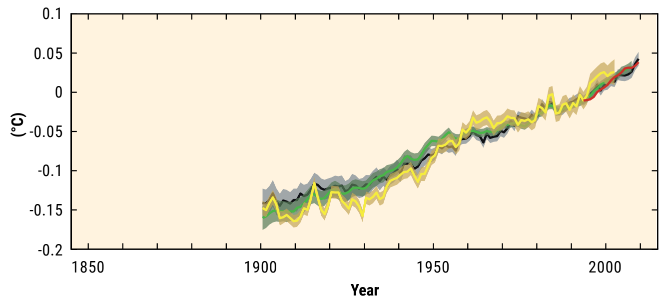
Recent observations and analysis by the US National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) have shown that, since instrumental record-keeping began in 1880, surface temperatures of the Earth were the warmest in the year 2016, making it the third year in a row to set a new record for global average surface temperatures.[32] Phenomena such as El Niño or La Niña, which warm or cool the upper tropical Pacific Ocean and cause corresponding variations in global wind and weather patterns, may contribute to short-term variations in global average temperature. A warming El Niño event occurred for most of 2015 and the first four months of 2016, and its direct warming impact in the tropical Pacific is believed to have led to an increased annual global temperature anomaly for 2016 by 0.12 °C. The oceans have absorbed a considerable part of this increased heat, and accounted for more than 90% of the energy accumulated in the climate system between 1971 and 2010 (only about 1% stored in the atmosphere) with a virtually certain warming of the upper ocean (0–700 m) during this period.[33] The current warming trend indicates that a key change is occurring in the balance of energy fluxes, with the energy influx outweighing the outflow. This is also reflected in other observed processes which are also shifting to reflect the climate system's transition towards a warmer state. For example, over the last two decades, the Greenland and Antarctic continental ice sheets have been losing mass and glaciers continued to shrink almost worldwide and contributed to sea-level rise throughout the 20th century, with a global mean sea-level rise of 0.19 m recorded over the

FIGURE 5: Observed globally averaged combined land- and ocean-surface temperature anomaly until 2012 (relative to 1986–2005)



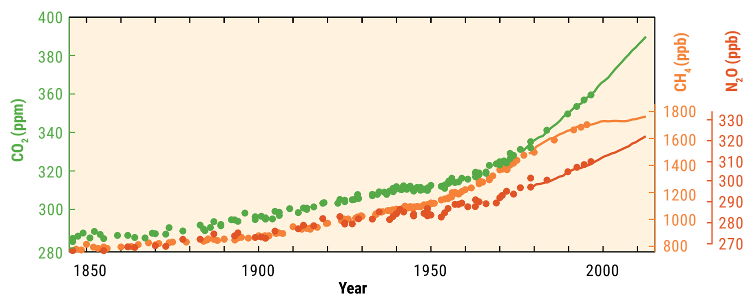
Source: IPCC, 2014

FIGURE 6: Global mean sea-level change until 2010 (relative to 1986–2005)



Source: IPCC, 2014

FIGURE 7: Globally averaged observed greenhouse gas concentrations until 2011



Source: IPCC, 2014

period 1901–2010. Moreover, it has been shown that northern hemisphere spring snow cover has continued to decrease in extent over the past five decades.[34]

The increasing amount of greenhouse gases (GHGs) in the atmosphere plays a major part in these warming trends by radiatively perturbing the Earth's energy balance. Anthropogenic GHG emissions have increased since the pre-industrial era, driven by population growth and economic developments (Figure 7). Historical emissions have driven atmospheric concentrations of carbon dioxide, methane and nitrous oxide to levels that are unparallelled in at least the last 800,000 years, leading to an uptake of energy by the climate system. Concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have all shown major increases since 1750 (40%, 150% and 20%, respectively).[35]

Calotropis procera indicating desertification, North Kordofan, Sudan, 2004. Source: Stefan Schneiderbauer.

Moreover, satellite data have confirmed that the annual CO_2 level has now exceeded 400 parts per million (ppm) as a global average, compared to around 280 ppm measured in ice cores during the pre-industrial revolution period.[36]

As for the observed precipitation trends, the IPCC AR5 reports that precipitation has likely increased since 1901 when considering the average over the mid-latitude land areas of the northern hemisphere. However, IPCC expresses low confidence in findings related to area-averaged, long-term trends in other latitudinal zones due to poor data quality, data incompleteness or disagreement among available estimates.[37] This is evidenced by observed precipitation trends along Mediterranean coastlines that have witnessed a decline in precipitation. The IPCC AR5 also assessed the literature on global and regional changes in climate extremes, indicating a very likely global trend towards fewer cold days and nights and more warm days and nights. It also expressed consensus that heavy precipitation events have likely increased in more regions than decreased. Decadal variability dominated longer-term trends in drought extremes, although regional trends were witnessed, including increasing dryness or drought in East Asia, the Mediterranean and West Africa and decreasing drought in central North America and north-western Australia.[38] Other studies have indicated that both observations and models show generally increasing trends in extreme precipitation since 1901, with the largest changes in the deep tropics. On a global scale, AR5 reports that the observational annual-maximum daily precipitation increased by an average of 5.73 mm/day over the period 1901–2010, or 8.53% in relative terms.[39] This increase was evidently not uniform across the globe. The broadness of these statements to ensure representation of global trends in high and low altitudes, from the poles to the tropics, demonstrates the importance of also conducting smaller-scale geographic assessments that can provide more regional-specific insights.

2.2 Regional climate observations

Relatively little is known about the evolution of climate over the Arab region in recent decades compared to other parts of the World. One of the first regional studies on climate trends focusing on extreme indices was conducted by Zhang et al. (2005) and examined trends in extreme temperature and precipitation for the period 1950–2003 based on national data from 52 stations in 15 countries in the eastern part of the Arab region.[40] Results have shown statistically significant warming trends in the region based on temperature indices indicating a significant increase in the frequency of warm days, in particular towards the 1990s, as well as a significant but gradual reduction in the number of cold days starting in the 1970s. On the other hand, trends in precipitation were characterized by strong interannual variability without any significant trend. More recently and to date, the most comprehensive study of extreme climate trends across the whole Arab region is the one conducted by Donat et al. (2014), which was the outcome of a workshop organized by ESCWA in 2012.[41] Daily observational data obtained from more than 100 weather stations spanning the Arab region[42] since the middle of the 20th century were collected and data from 61 stations were ultimately analysed after assessment of quality and homogeneity. Their results gave evidence of consistent and significant warming trends across the region with clear increased frequencies of warm days and warm nights, higher extreme temperature values, fewer cold days and nights and shorter cold spells since the early 1970s. On the other hand, analyses of changes in precipitation extremes were less significant and spatially inconsistent, whereby results of area-average, long-term trends since 1960 showed a tendency towards drier conditions, but with little change since the 1970s. Results, however, indicated that the western part of the region (Algeria, Morocco, Mauritania) had exhibited a consistent tendency towards wetter conditions during the past 30 years, unlike the eastern part (Egypt, Djibouti, Arabian Peninsula) which showed some consistent drying trends.

Other studies encompassing the Arab region were conducted, using globally available datasets such as Tanarhte et al. (2012), which compared different gridded datasets of temperature and precipitation across several subregions over the Mediterranean and the Middle East for the period 1961–2000.[43] Similar trends of increasing temperatures and downward trends of precipitation were found for most subregions in all datasets, however with different magnitudes and levels of significance. For instance, an overall positive temperature trend of 0.2 °C to 0.4 °C per decade was found in Saudi Arabia and the Arabian Gulf and was particularly significant during the summer months. Similar trends were also found for the northern parts of Morocco, Algeria, Tunisia, Libya and Egypt, starting in the mid 1970s. For precipitation, though showing mostly downward trends, the study indicated variable and sometimes contradicting results among datasets with overall non-significant trends, which is in line with the findings mentioned previously. Characteristics of heatwaves in the Middle East region (excluding North Africa) were also investigated, based on data from a global dataset covering the period 1973–2010. The analysis of long-term temperature data suggested an increased frequency of heat extremes since the 1970s, with increasing trends in the number of heatwaves found at all stations, although no significant change in their duration and maximum temperature were detected, implying no change in their intensity.[44]

Most of the studies investigating the evolution of climate in the Arab region have focused on analysing trends in specific subregions or individual countries.

In the Mashreq, most studies using station data are conducted at the country level. For instance, a recent analysis of 44 years of daily measurements from 58 stations in the western, populated and agricultural areas of Jordan over the period 1970–2013 showed a significant decrease in rainfall at a rate of 1.8 mm/yr.[45] In the Syrian Arab Republic, analysis of the 52-year record (1955–2006) from 30 selected synoptic stations for temperature and precipitation have revealed an overall decrease in precipitation in northern and north eastern zones of the country, while autumn precipitation significantly increased at the stations lying mostly in the northern zone of central Syrian Arab Republic.

In terms of temperature, trends have showed an extensive increase in summer temperature in all Syrian Arab Republic stations with prominent increases in coastal and western regions. The analysis of extreme events and indices for the period 1965–2006 showed significant increasing trends for several parameters, such as annual maximum and minimum daily temperatures, the number of tropical nights and the number of summer days. On the other hand, the number of cool nights and days and diurnal temperatures revealed significant decreasing trends.[46] In Iraq, temporal and spatial changes in precipitation and temperatures were assessed for the period 1980–2011, based on 28 station data distributed throughout the country. Increasing trends in minimum and maximum temperatures were observed, as well as decreasing precipitation trends (ranging from 1.3 to 6.2 mm/yr). Results also showed no differences in the geographic location throughout Iraq, implying that climatic impacts are spatially uniform in this area.[47]

Several studies have examined trends of area-specific climate and extremes in the North Africa region. One of them assessed trends based on daily precipitation data from 22 stations in Algeria, Morocco and Tunisia for the common period 1970–2002. Results have indicated strong trends towards a decrease in precipitation totals and in the duration of precipitation episodes (length of wet spells), coupled to increases in the ratio of dry days and the duration of dry spells. These results were particularly pronounced for Morocco and western Algeria. The study also pointed to a greater significance and spatial consistency for indices representing dry periods than heavy precipitation indices, indicating that droughts periods are simultaneously impacting large areas.[48] Another study focused on the Greater Horn of Africa and analysed daily observed station data for maximum and minimum temperatures and precipitation for the period 1971–2009. It showed increased frequencies of warm days and warm nights coupled to decreased frequencies of cold days and cold nights. It was also observed that extreme indices, such as the length of the maximum number of consecutive dry days (CDD) and the length of the maximum number of consecutive wet days (CWD) significantly decreased in Eritrea and Djibouti. This is likely to be associated with the sharp decline in total annual precipitation in these areas observed around 2000–2010.[49] Other work on climate trends in North Africa was conducted using globally available datasets. For instance, analysis of time evolution of air temperature and heatwaves occurrences over this area for the period 1979–2011 have shown a significant warming (1 °C–3 °C) appearing by the mid-1960s over the Sahara and Sahel. This was associated with clear, higher frequencies of warm temperatures and lower frequencies of cold temperatures, as well as longer duration and more frequent occurrences of heatwaves (mean frequency multiplied by 2 or 3 after 1997). The latter occurred mostly during the March–May dry season and tended to be preceded by an abnormal warm episode starting over Libya and propagating eastward.[50] Another study over sub-Saharan Africa (5°S–25°N) examined a combination of downscaled global datasets and station data covering the period 1979–2005. Results have shown a statistically significant increase in the annual number of warm days and nights and a corresponding decrease in cold days and nights. Moreover, increases in total annual precipitation were observed mainly in the western part of North Africa, accompanied by a significant decrease in the annual number of CDD in these regions[51], which supports the findings of Donat et al. (2014). Regional warming trends have also been reported in country-level studies of North Africa, such as at stations in Libya[52], Sudan[53] Tunisia[54] and Morocco. For instance, a study was conducted in the latter country on 20 selected stations for the period 1970–2012, mostly located in the northern part of Morocco and covering the most important agricultural zones and also the rainiest regions that are contributing most of the country's water resources. As seen in previously mentioned results, trend analysis indicated more statistically significant trends for temperature than for precipitations indices. In this study, all temperature-based indices showed increasing trends for the number of warm days and nights and a decrease for the number of cold days and nights over the past four decades. On the other hand, precipitation indices showed a tendency towards wetter conditions for a few locations in the far north of Morocco, compared to the drier conditions in the south.[55]

Climate trends have also been assessed in the eastern area of the Arab region, such as the Arabian Peninsula. Analysis of quality controlled records of temperature and precipitation data from a total of 44 stations[56] was conducted by AlSarmi and Washington (2011) for the period 1980–2008 and has shown a significant warming trend. Results indicated that annual minimum and maximum temperatures have increased by 0.55 °C and 0.32 °C per decade, respectively and over all the Arabian Peninsula, which led to significant decrease in the Diurnal Temperature Range (DTR). It was also shown that warming rates were higher in the non-monsoonal region located north of 20° N and that the highest significant warming was experienced in spring (March–April) and summer (May–September) seasons. On the other hand, declining precipitation trends were observed but were insignificant and the interannual temperature and precipitation variability indicated a marked negative association after 1998.[57] A subsequent study on climate extremes based on daily datasets indicated a general decreasing trend of cold temperature extremes and increasing trends of warm temperature extremes during the period of analysis.[58] In particular, a remarkable and highly significant increase in very warm nights has occurred in the last two decades with a rate of increase in frequency of 3.6% per decade over the period 1986–2008. On the other hand, spatial patterns have shown, in general, higher temperature

Kawkaban, Yemen, 2013. Source : Wikimedia Commons/ Rod Waddington.

trends in terms of magnitude and significance over the northern Arabian Peninsula for day-time extremes, while, for night-time extremes, the trends were higher and significant for the southern region especially during recent decades. Analysis of precipitation indices showed less robust results with no significant trends except for the annual number of days with precipitation greater than 10 mm (R10), which showed a significant decrease during 1986–2008. Moreover, the analysis of changes in the dew point temperature (Td) and mean sea-level pressure (MSLP) indicated a potential for significant dynamical control of climate change in this region. Another station-based study for the north-eastern Arabian Peninsula/Gulf area and the period 1973–2012 has also indicated an upward temperature trend of 0.8 °C on average, accompanied by a decrease in barometric pressure (1 hPa), reduction in humidity (6%), and decrease in visibility (9%).[59] These results generally support findings from country-level analyses, such as reported statistically significant decreasing rainfall trend in Saudi Arabia of as much as 47.8 mm per decade for the recent past (1994–2009), as well as significant increasing rates of temperature which were faster in the dry season of June–September (0.72 °C per decade) than the wet season of November–April (0.51 °C per decade).[60] Another study over Kuwait for 1958–2000, based on summer extreme temperatures, has indicated that the most significant observed heatwave events occurred in the last decade of the 20th century.[61]

As can be seen from these observations, the region has been subject to evident warming trends since the middle of the 20th century. Although the studies conducted give a reasonable idea of the status of the past climate and its trends to this date, it is important to note that most of the available station data in the region are limited in coverage, consistency and accessibility, which hampers accurate knowledge of climate trends over the whole Arab region. The availability of quality meteorological observation datasets and the access to long-term measurements is thus paramount in this context and would allow a more thorough and detailed analysis of the evolution of the climate with consideration of wider spatial coverage and longer time spans.

3 CLIMATE INDICES AND DATA SOURCES

3.1 Essential climate variables

For purposes of consistently reporting climatological information, the climate is described by a set of 50 essential climate variables developed under the Global Climate Observing System (GCOS),[62] which are listed in Table 1. IPCC has adopted this set of variables as a basis for understanding past, current and possible future climate variability and change.[63]

3.2 Extreme event Indices

Extreme weather events have a severe impact on many key aspects of our lives, such as health, agriculture, economy and infrastructure and it is thus necessary to predict the patterns of future extreme events with a view to building the resilience of Arab States. In this regard, observations provide a key foundation to understanding their long-term changes and the underpinning of climate model evaluation and projections. Indices for climate extremes were developed by the WMO Expert Team on Climate Change Detection and Indices (ETCCDI) with the aim of providing an easily understandable and manageable set of indices for impact studies and to make a global and multi-model comparison possible. ETCCDI suggests 27 indices (Table 2) related to either temperature or precipitation, which are commonly calculated based on daily observed precipitation data and daily minimum and maximum temperatures.[64]

A set of extreme event indices that are most representative and of concern for the region were selected for study in this report (see Chapter 1). Analysis of additional indices from the ETCCDI list can be generated from the RICCAR regional climate modelling data that will be available on a regional knowledge hub to inform further research.

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 and ESCWA, in cooperation with the National Meteorological Service of Morocco (Casablanca, March 2012). The workshop initiated intensive data-collection and compilation activities using daily information 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 over the Arab region using historical observations, which are now documented in a peer-reviewed journal article.[65]

TABLE 1: Essential climate variables

ATMOSPHERIC	**Surface** - Air temperature - Air pressure - Precipitation - Radiation budget - Water vapour - Near-surface wind speed and direction	**Upper air** - Temperature - Water vapour - Wind speed and direction - Cloud properties - Earth radiation budget	**Composition** - Carbon dioxide - Methane - Other long-lived greenhouse gases - Ozone and aerosols supported by their precursors
OCEANIC	**Surface** - Sea-surface temperature - Sea-surface salinity - Sea level - Sea state - Sea Ice - Surface current - CO_2 partial pressure - Ocean colour - Ocean acidity - Phytoplankton	**Subsurface** - Temperature - Salinity - Current - Nutrients - CO_2 partial pressure - Ocean acidity - Oxygen - Tracers	
TERRESTRIAL	- River discharge - Water use - Groundwater - Lakes - Snow cover - Glaciers and ice caps - Ice sheets	- Permafrost - Albedo - Land cover (including vegetation type) - Fraction of absorbed photosynthetically active radiation (FAPAR)	- Leaf Area Index (LAI) - Above-ground biomass - Soil carbon - Soil Moisture - Fire disturbance

Source: GCOS, 2010

TABLE 2: Climate Indices (developed by the WMO Expert Team on Climate Change Detection and Indices)

Index	Description	Definition	Unit
Temperature indices			
TXn*	Min Tmax	Coldest daily maximum temperature	°C
TNn*	Min Tmin	Coldest daily minimum temperature	°C
TXx*	Max Tmax	Warmest daily maximum temperature	°C
TNx*	Max Tmin	Warmest daily minimum temperature	°C
DTR*	Diurnal temperature range	Mean difference between daily maximum and daily minimum temperature	°C
GSL	Growing season length	Annual number of days between the first occurrence of 6 consecutive days with Tmean >5 °C and first occurrence of consecutive 6 days with Tmean <5 °C.	days
CSDI	Cold spell duration index	Annual number of days with at least 6 consecutive days when Tmin <10th per centile	days
WSDI	Warm spell duration index	Annual number of days with at least 6 consecutive days when Tmax>90th per centile	days
TX10p*	Cool days	Share of days when Tmax <10th per centile	% of days
TN10p*	Cool nights	Share of days when Tmin <10th per centile	% of days
TX90p*	Warm days	Share of days when Tmax >90th per centile	% of days
TN90p*	Warm nights	Share of days when Tmin >90th per centile	% of days
FD	Frost days	Annual number of days when Tmin <0 °C	days
ID	Icing days	Annual number of days when Tmax <0 °C	days
SU	Summer days	Annual number of days when Tmax >25 °C	days
TR	Tropical nights	Annual number of days when Tmin >20 °C	days
Precipitation indices			
Rx1day*	Max 1-day precipitation	Maximum 1-day precipitation total	mm
Rx5day*	Max 5-day precipitation	Maximum 5-day precipitation total	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (when precipitation ≥1.0 mm)	mm/day
R95p	Annual contribution from very wet days	Annual sum of daily precipitation >95th per centile	mm
R99p	Annual contribution from extremely wet days	Annual sum of daily precipitation >99th per centile	mm
PRCPTOT	Annual contribution from wet days	Annual sum of daily precipitation ≥1mm	mm
CWD	Maximum length of wet spell/ consecutive wet days	Maximum annual number of consecutive days with daily precipitation ≥1.0 mm	days
CDD	Maximum length of dry spell/ consecutive dry days	Maximum annual number of consecutive days with daily precipitation <1.0 mm	days
R10 mm	Heavy precipitation days	Annual number of days when precipitation ≥10mm	days
R20 mm	Very heavy precipitation days	Annual number of days when precipitation ≥20mm	days
Rnnmm	Precipitation above a user-defined threshold	Annual number of days when precipitation ≥nn mm (nn: user-defined threshold)	days

Note: All indices are calculated annually. * denotes indices which are also calculated monthly.
Source: ETCCDI, 2009; Donat et al., 2014

3.3 Meteorological data sources

Climate datasets originate as measurements of sub-daily or daily weather variables collected over time and merged to create climate records. Point measurements taken in situ at observation stations are usually the most direct and therefore precise form of observation. For regional analysis, however, the point data may not be representative for larger regions, particularly where the terrain varies widely (e.g. mountains and coast) and the measurement itself can also be error-prone. As an example, measured precipitation observations can be lower than the actual amount due to losses from wind or evaporation. Such limitations should be kept in mind when using observed climate data. Also, observation data can be organized into gridded datasets, similar to how data are organized in climate model outputs. It is an interpolation of available observed station data from non-uniform point data to the selected grid. While an advantage of gridded data is that they can provide data at points where there are no observation stations, the quality of the gridded data is always a function of the amount of station data that they contain.

Due to the infrequency of reporting and quality assurance issues, it can be difficult and time- consuming to work directly from station data. However, international research groups have created gridded observed datasets from such station data that are suitable for climate-related studies and are freely available. These have gone through some type of quality control and further processing to improve their usability. Generating re-analysis data is a specific application that uses a numerical weather prediction (NWP) model to incorporate all available meteorological observations (from ground weather stations and satellites) into a common structure over an observed period of time, this process is referred to as data assimilation.[66] The outcome is data that are evenly spaced in the gridded structure of the NWP model, both horizontally and at various vertical levels in the atmosphere. Since, in these simulations, large amounts of surface and upper-air observations are assimilated, they provide a close representation of reality and are particularly useful for sites where there are no actual observations. Reanalysis data are seen as an important component for both testing and evaluating climate models and are also used in combination with other observations to improve gridded observed datasets. As with all climate data, however, they have some limitations. An example is precipitation data from reanalyses, which have been shown to provide good representation of the temporal precipitation distribution, but can have large biases in precipitation magnitude, which can vary, depending on location. Reanalysed temperature data, on the contrary, generally show a better agreement with observations.

Numerous historical meteorological datasets are available for the Arab region, with continuous developments, as new methods for combining in situ observations with numerical methods and remote- sensing continue to evolve. Even though measurements for a wide range of parameters exist, none of these datasets individually gives a perfect representation of the actual observations and thus a combination of different datasets has been drawn upon under RICCAR to make best use of their different characteristics. They include observed station data provided by meteorological services through ACSAD as well as the following datasets:

Snow cover over Lebanon, 2017. Source: Carol Chouchani Cherfane.

University of East Anglia Climatic Research Unit Time Series (CRU v3.21) consists of datasets comprising month-by-month variations in climate, starting in 1901 on 0.5° resolution grids. Variables include cloud cover, diurnal temperature range, frost day frequency, potential evapotranspiration, precipitation, daily mean temperature, monthly average daily maximum and minimum temperature, vapour pressure and wet day frequency. Period of data used for RICCAR was until 2012 according to data available at the time of study.[67]

Global Precipitation Climatology Project (GPCP v1.2) provides global monthly surface precipitation data at 60 arcminute (1 degree) grid resolution from 1979 onwards.[68]

Global Precipitation Climatology Centre (GPCC v6): full data reanalysis of monthly global land-surface precipitation based on the 67 200 stations worldwide. Data used at the time of analysis covered the period 1901–2010 at a spatial resolution of 0.5° x 0.5°.[69]

University of Delaware Air Temperature and Precipitation (UDEL v3.01) comprises a series of gridded temperature and precipitation datasets based on station records starting from 1900 (data used for this study covered the period 1900–2010). It provides relatively detailed global land-surface climatology of the two most essential variables in a spatial resolution of 0.5° x 0.5°.[70]

Tropical Rainfall Measurement Mission Project (TRMM 3B42-v7), published by the Goddard Space Flight Center Distributed Active Archive Center (GSFC DAAC), provides daily precipitation data from 1997 onwards at a resolution of 0.25° x 0.25°.[71]

European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim Reanalysis is a global atmospheric reanalysis product that covers the period from 1979 onwards and is continuously updated in real time. It includes a set of 3-hourly surface parameters, describing weather, as well as ocean-wave and land-surface conditions, and 6-hourly upper-air parameters covering the troposphere and stratosphere. The spatial resolution is approximately 80 km (T255 spectral) on 60 vertical levels from the surface up to 0.1 hPa.[72]

WATCH forcing data methodology applied to ERA-Interim (WFDEI) was used for setting up the hydrological models and for the bias correction of modelled precipitation. It is interpolated to a 0.5° x 0.5° grid and is a combination of observations and reanalysis model data. As mentioned previously, the re-analysis uses NWP to incorporate all available weather observations into a common structure over an observed period of time.[73] WFDEI covers the period 1979–2012 and is based on monthly observed values from the CRU dataset that are distributed to daily values, according to the temporal distribution coming from the ERA-Interim reanalysis.[74]

3.3.1 Climate data rescue

Past records of the climate system represent key information for undertaking thorough and reliable/comprehensive climate assessments. Despite the considerable amount of past climate data and recent efforts to improve data availability and accessibility, records are still spatially and temporarily limited and are often not homogeneous in terms of quality standards. Moreover, it is estimated that most climate records prior to the 1960s are not digitized and only available in hard-copy or imaged form.[75] Even raw digital climate data are frequently subject to a wide range of errors which can be further introduced into the chain of processing and data transmission. This situation makes these records unusable preventing undertaking reliable climate analysis and restricting the knowledge of past and future climate

Amman, Jordan, 2017. Source: Carol Chouchani Cherfane.

variability. The need for rescuing these climate assets and ensuring high-quality, long-term climate time series to enable a better understanding, detection and prediction of global climate variability and change is therefore of paramount importance. In this context, there has been rising awareness among international bodies and the scientific community on the key and urgent need to recover and transfer into digital format historical weather observations held in perishable media in order to enable their treatment, which led to major data rescue (DARE) initiatives. This concept refers to the process of preserving all data at risk of being lost due to deterioration of the medium and digitizing current and past data into computer-compatible form for easy access.[76] These rescued data combined with already available data enable enhanced climate model evaluation and consequently better assessments of projections of the climate into the future that can serve as input for policymakers to prepare appropriate plans in view of climate change conditions. One of the important additional benefits is that longer climate records of extended location coverage make possible a better analysis of climate extremes.[77]

A number of DARE efforts are currently underway at the global, regional, and national levels, based on guiding principles developed by WMO, which includea number of DARE initiatives aimed at improving both the availability and accessibility to long-term and high-quality climate records, as well as capacity-building through integrated bilateral and multilateral DARE projects.[78] An important resource that has been recently developed is the I-DARE portal, which consists of a web-based database providing a single point of entry for information on the status of past and present DARE projects worldwide, on data that need to be rescued and on the methods and technologies involved.[79] Moreover, as mentioned in the previous section, a set of climate-data standards and protocols has been developed and implemented at the global level (e.g.temperature and precipitation extremes) in order to maximize the utility of rescued data and newly produced datasets and overcome issues related to data standards, digitization, exchange and sharing at multi-spatial scales.

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 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. It involved participants from meteorological services in Jordan, State of Palestine, Saudi Arabia and Yemen and paved the way for collaboration opportunities and for the initiation of new climate data rescue initiatives.[80] 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). Paper records housed at JMD consisted primarily of notebooks containing daily and sub-hourly data, as well as a large number of charts.

A joint ESCWA/WMO mission was thus conducted with JMD staff to train local staff on data rescue and digitization of climate records; establish an inventory of climate data records in paper format to be recovered and digitized; ensure a safe and well organized archiving storage with the involvement of local authorities; and develop 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, the monthly registers and associated charts (temperature, humidity, rainfall, pressure, sunshine, and wind data) have been organized, stored in labelled archival boxes, with each box catalogued electronically. Approximately 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 the 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 is now completed.[81]

3.4 Water resources in the Arab region

3.4.1 Water availability

Water is a scarce and fragile resource in the Arab region, with an uneven spatial and temporal distribution both at regional level and within each country. Several factors have increased strains on this resource in terms of quantity and quality over recent decades. In a regional context, these include population growth, migration, changing consumption patterns, regional conflicts and governance. The potential implications of climate change and future climate variability are additional factors putting further pressure on its availability, which varies in terms of occurrence and extent across the region.

Water resources availability is affected by the predominant semi-arid to arid climate and the combination of high spatial and temporal rainfall variability. Only certain parts of the mountainous areas along the northern and southern boundaries of the region exhibit prevailing wet conditions that enables the occurrence of surface water. Narrow coastal plains in North Africa, the eastern Mediterranean, and the south-western corner of the Arabian Peninsula receive considerable runoff from mountain ranges as opposed to the interior deserts. In North Africa, the humid conditions in the Atlas Mountains enable the occurrence of several coastal rivers in Morocco, Algeria and Tunisia such as the Sebou River, the Chelif River and the Medjerda River respectively.

Surface water resources in the Mashreq are mainly derived from large, humid areas in the north of the Arab region that are characterized by higher and more consistent precipitation. The Taurus-Zagros Mountain range in the north captures significant precipitation from moist westerly winds and constitutes the main headwaters of the Euphrates and Tigris Rivers. Similarly, precipitation from the eastern Mediterranean mountain ranges feed the headwaters of the shared Jordan, Orontes and Nahr el Kabir Rivers, as well as smaller Lebanese and Syrian Arab Republic rivers. South of the Arab region, runoff generated in the Ethiopian and equatorial highlands constitute the headwaters of the Nile River, which is shared by Egypt and Sudan as well as nine other non-Arab riparian countries. As for the Arabian Peninsula, its scant rainfall and very high evaporation rates impede the occurrence of surface water and groundwater recharge and cannot sustain perennial river systems. The irregular but intense rainfall that occurs in the mountainous areas along the Red Sea and Arabian Sea, however, accumulates in, and infiltrates along, the extensive wadi channels (intermittent streams), often constituting important localized sources of freshwater.

Groundwater resources constitute a major source of water supply in the region. Renewable groundwater resources are limited and occur mainly in the form of shallow aquifers recharged from activities dependent on surface water, especially during large floods. Most aquifer systems are found in large geological formations that can cover hundreds of kilometres with significant volumes of stored fossil groundwater stemming mainly from past pluvial periods. These non-renewable resources are found in particular in the Sahara and the Arabian Peninsula and span several Arab States. Examples include the Nubian sandstone aquifer

(Egypt, Libya, Sudan and Chad), the north-western Sahara aquifer (Algeria, Libya and Tunisia), the eastern Arabian aquifer (Bahrain, Iraq, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates (UAE) and Yemen) and the Disi aquifer (Saudi Arabia and Jordan). Smaller aquifer systems also exist, such as those in wadi discharge areas, where several channels join and allow the accumulation of thick alluvial deposits to form wadi aquifers. They often constitute a major source of recharge to the deep underlying aquifers. In addition, coastal aquifers are common in the region especially around the Mediterranean, namely on the northern coast of Egypt, the Lebanese coastline and the Gaza Strip, as well as several coastal cities along the eastern Gulf.

In line with natural spatial water availability, some countries rely more on surface water resources (for example Egypt and Iraq), while others rely mainly on groundwater resources (for example Libya, Gulf countries), almost every Arab State depends for its water supply on rivers or aquifers that are shared with neighbouring Arab or non-Arab countries. This high dependency underpins the necessity and importance of transboundary cooperation for the efficient management of these resources and to ensure its sustainability, knowing that Arab States are among the most water-scarce countries in the world. In this regard, and based on mandates from the Arab Ministerial Water Council, particular emphasis was given to shared water resources in RICCAR by providing climate change projections and analysis for five selected shared surface water basins (See Chapter 4).

3.4.2 Water basin delineations and drainage networks

The Hydrological data and maps from Shuttle elevation derivatives at multiple scales (HydroSHEDS) dataset was used for topography, watershed delineation and drainage networks for both the impact and vulnerability assessments. It is derived from elevation data of the Shuttle Radar Topography Mission (SRTM) elevation data at 3 arcsecond resolution (GL3S). The original SRTM data have been conditioned in terms of hydrology using a sequence of automated procedures. Manual corrections were made where necessary.[82] Information on groundwater resources was used only for the vulnerability assessment, and was based on data included in the Map of Global Groundwater Vulnerability to Floods and Droughts at the scale of 1: 25,000,000 published in 2015.[83]

3.4.3 River discharge data

River discharge observations are point measurements representing the integrated sum of all runoff occurring upstream of the measurement point. They provide an important variable for analysing changing hydrological, climatological and development conditions in the upstream basin. They also provide an important variable for calibrating and testing hydrological models.

Access to observed river discharge data is, however, limited in the Arab region. International sources from outside the region proved to be the main supplier for river discharge data, and it is of limited extent. Data from the Global Runoff Data Centre (GRDC)[84] was used but many discharge stations had only short periods of record which ended in the early to mid-1980s. River discharge records were also obtained from various freely available reports and publications, such as a report published by the US Geological Survey (USGS) on the Tigris and Euphrates river basins.[85] Some records were also obtained from national hydrological focal points designated through the Arab Ministerial Water Council by Arab States. Longer records of observed river discharge would have benefited the assessment.

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

3.4.4 Lakes and reservoirs

Data sources on lakes and reservoirs used for the impact assessment are the following:

Global Lakes and Wetlands Database (GLWD) is published by the World Wildlife Fund (WWF) and the Centre for Environmental Systems Research, at the University of Kassel in Germany based on the combination of best available sources for lakes and wetlands on a global scale (1:1 to 1:3 million resolution), and the application of Geographic Information Systems (GIS) functionality. It enabled the generation of a database focused on three coordinated levels: large lakes and reservoirs, smaller water bodies, and wetlands.[86]

Global Reservoir and Dam Database (GRanD) is based on the compilation of global available reservoir and dam information with corrections and completion of missing information from new sources or statistical approaches. It initially included all reservoirs with a storage capacity of more than 0.1 km^3, but many smaller reservoirs were added depending on data availability.[87] This dataset was complemented with national data provided by ACSAD.

For the vulnerability assessment, data related to dams were based on the Aquastat 2015 database[88] complemented with data from national sources for selected countries (Oman, Saudi Arabia, Iraq, Sudan and the Syrian Arab Republic).[89]

4 TOPOGRAPHIC AND TERRESTRIAL FEATURES AND DATA SOURCES

4.1 Topographical features of the Arab region

The Arab region extends over an area of some 14,000,000 km^2 including about 30,000 km of coastline, and exhibits widely contrasting topography and distinctive landforms. It is characterized by large mountainous zones and vast deserts that cover most of the area, in which several oases create microclimates where limited agriculture can be practiced. The Sahara Desert in North Africa spans elevations that range from 30 m below sea level to peaks that exceed 3,000 m in the Ahaggar Mountains in southern Algeria and the Tibesti Mountains in southern Libya. The Atlas Mountains along the northern coast provide a shield from the desert, stretching from south-western Morocco (peaking at 4,167 m) to the eastern edge of Tunisia. Further east, the Sinai Peninsula is largely desert with mountainous topography and covers a surface area of 13,000 km^2. The Karkaar Mountains in Somalia along the Gulf of Aden, provide topographic relief to a landscape dominated by plateaus, plains and highlands in the Horn of Africa.

Western Asia is bounded by the Taurus-Zagros Mountain range in the north, which extends from southern Turkey to the Iraq-Iran border. They extend for thousands of kilometres and represent a barrier to the movement of cold airmasses from the north. Two other mountain chains run along the eastern Mediterranean shore: the Lebanon Western Mountain range with Qurnat as Sawda as its highest peak (3,090 m) and the Eastern Mountain Range (Anti-Lebanon) running parallel to it and stretching to the Golan Heights Plateau in the south, where Mount Hermon (2,814 m) on the Lebanese-Syrian Arab Republic border is the highest peak. More than half of the Syrian Arab Republic is covered by the Syrian Desert (500,000 km^2), which also extends into parts of western Iraq, Jordan and Saudi Arabia.

In the Arabian Peninsula, the Nafud Desert (65,000 km^2) spans north-western Saudi Arabia to the Dahna Desert. It joins the Rub' al Khali Desert, one of the world's largest sand deserts covering more than 650,000 km^2 in southern Saudi Arabia as well as parts of Oman, UAE and Yemen. The Arabian Peninsula also features several mountain ranges, of which the Hijaz and Asir Mountains along the length of the Red Sea coast reach elevations of 2,000 m. Further south, the Yemen Mountain range rises up to 3,666 m along the southern stretch of the Red Sea coast and then runs parallel to the Gulf of Aden as the Hadhramaut Mountain range. The fertile Najd Plateau in the centre of the Arabian Peninsula reaches elevations of up to 1,500 m as it slopes from west to east. Wadis and saltmarshes (sabkhas) are common features of the peninsula. In the south-east, the Oman Mountain range (Al-Hajar) borders the Gulf of Oman and eastern area of the UAE, peaking at more than 3,000 m at Jebel Shams. In addition to mountain ranges and highlands, the region also hosts areas well below sea level, of which the lowest exposed point on Earth at the Dead Sea (422 m bsl) and other areas of depression such as Djibouti's Lake Assal at 155 m bsl.

4.1.1 Wadis

Intermittent streams or wadis are one of the most common and important landscape elements of the region, in particular in the Arabian Peninsula, draining wide catchment areas and ranging from ten to hundreds of kilometres in length. For example, Wadi al Batin is a shared wadi with a length of 970 km crossing Iraq, Kuwait and extending south-westwards into Saudi Arabia, where it is referred to as Wadi ar Rimah. Wadis have played an important role in both the ancient and recent history of tribes zand settlements of the Peninsula such as in Yemen, Saudi Arabia and Oman, providing important supplies of water to populations for domestic and irrigation purposes. These seasonal streams are affected by the drainage system, the transport and texture of sediments, the frequency of overflows and the variability of rainfall. Upon the offset of heavy rains, the peak flood carried by a wadi can reach some thousands of cubic metres per second (m^3/s). Better management and control of wadi flows is a subject of growing interest in Arab States from a disaster risk perspective, as destructive wadi overflows are common and cause major damage to dwellings and agricultural areas). They are also, however, an important source of freshwater to exploit in view of the ever-increasing demand on water.[90] It is to be noted that there is sometimes confusion between the English and Arabic language use of the term “wadi”, which also means “valley” in Arabic.

4.1.2 Sabkhas

Sabkhas or saline flats are a distinctive geomorphologic feature of the Arab region. These are salt-crusted depressions with impermeable floors lying just above the water table, where salt brine has accumulated after being subject to periodic flooding and evaporation.[91] Sabkhas are commonly found in the eastern Arabian Peninsula (UAE, Qatar, Oman), in parts of Iraq and the Syrian Arab Republic, as well as along the shores of the Gulf of Suez and the Red Sea and the coastal lands of North Africa, where they are commonly referred to as “shotts”.[92] Outstanding examples of sabkhas include the Umm es Samim Sabkha, one of the highest salt formations in the region (100 m high) located in the east of the Rub’ al-Khali Desert in Oman. The Shott el Djerid in Tunisia is another example; it constitutes the largest saltpan of the Sahara Desert with a surface area of more than 5,000 km^2, and is part of a series of seasonal saltpans in the country fed from groundwater in the Atlas Mountains, some of which extend into Algeria.[93] Until recently, sabkhas were considered as wastelands which adversely impacted plant and vegetation cover, constituted corrosion hazards and caused damage to construction sites. They are currently being increasingly considered as important ecosystems, however, and hold considerable potential as sources of solar power generation, algae culture and hydrocarbon energy.[94]

4.1.3 Oases

Oases are isolated areas of vegetation found in deserts and represent complex and fragile agro-ecosystems. They are generally located along non-perennial rivers (wadis), shallow water tables or deep artesian groundwater, creating enough pressure for water to seep to the surface. Natural oases are sustained by occasional rainstorms feeding the underground. Management practices and agricultural techniques that have been implemented for millennia in the oases of the world reflect the remarkable skills of local populations in using their limited natural resources in a sustainable manner.

Oasis ecosystems are unique in nature and were sustained in the Arab region through a rigorous management of limited water, land and biological resources over the years in strong alliance with date-palm tree plantations. Traditionally, communities have planted strong trees, such as palms, around the perimeter of oases to minimize damage and encroachment from desert sand. The region is home to major oases such as the Al-Hasa Oasis in Saudi Arabia, which is the largest in the world, having a surface area exceeding 10,000 ha and hosting some 3 million palm trees.[95] The Tafilalet Oasis in Morocco is also one of the largest in the world. The sustainability of the latter oasis system is increasingly being threatened. A recent study indicated that the groundwater table depth has dropped 50% over the past 40 years, leading to a 50% decline in the number of date-palm trees.[96] Other major oasis systems are found in Algeria, Tunisia, Egypt, Libya and the UAE.

Shott el Djerid, Tunisia, 2012. Source: Dennis Jarvis-flickr.com

For many decades, oases in the region have played an essential role in the development of local communities and in maintaining ecological balance owing to established cultural and indigenous knowledge. They represent vital sites for trade and transportation routes in deserts and are important biodiversity and ecosystem-rich areas[97] but are increasingly vulnerable to changing environments. As such, they have received much attention in the past few years, with several being designated as Globally Important Agricultural Heritage Systems (GIAHS) by the Food and Agricultural Organization of the United Nations (FAO). These are the Oases System in the Atlas Mountains of Morocco (2011), the Gafsa Oases in Tunisia (2011), the Al Ain and Liwa Historical Date Palm Oases in UAE (2015) and, most recently, the Siwa Oasis in Egypt, which was recognized in 2016 for the preservation of the environmental and heritage ecosystem in the cultivation of dates (see Box 2).[98] Main challenges to achieving sustainable adaptive management of oases in the Arab region include shortage of information and knowledge on the status and trends of oasis ecosystem behaviour among decision-makers, as well as the lack of public awareness as a means to support the implementation of best agro-ecological and economic management practices.

BOX 2: Siwa Oasis in Egypt

Siwa Oasis is located in a depression in the northern area of Egypt's Western Desert, 80 km from the Egyptian-Libyan border and 300 km south of the Mediterranean port town of Marsa Matrouh. Much of the depression sits below sea level, reaching 133 m bsl at its deepest. The climate of Siwa exhibits extreme aridity from April to November and very low rainfall from December to March (10 mm/yr on average), and its population increased from about 8,000 in 1980 to 28,000 in 2016.

The eco-geographical isolation of Siwa from the Nile Valley and Egyptian Delta made its conditions favourable for agricultural production that depends completely on groundwater resources for irrigation. The oasis is located above two reservoirs of groundwater. The upper reservoir exhibits high salinity (1,800–7,500 ppm) and the deep Nubian sandstone reservoir exhibits salinity of the drinking-water standard (170–325 ppm).

About 97 km^2 (10% of the total depression area) are currently cultivated, comprising mainly date- palm and olive orchards that are irrigated by several hundred groundwater-fed wells. Agriculture has been, and continues to be, the most important economic activity in Siwa and is the main source of livelihood of its population. There are currently some 280,000 date-palms with an annual yield of about 25,000 tonnes of dates, which represent an important local staple food in the oasis and a pillar for local food security. Similarly, the oasis hosts a significant share of national olive production with a total annual yield of 27,500 tonnes of green olives. Livestock is also an important component of the Siwaian cropping system with a total number of about 9,000 goats and sheep and more than a thousand cattle providing manure as a source of organic fertilizer for crops.

In 2002, the Egyptian Government declared 7,800 km^2 in and around Siwa Oasis a protected area in recognition of its cultural, biological and environmental diversity. In October 2016, FAO awarded the dates production sector in the Siwa Oasis the Globally Important Agricultural Heritage Systems (GIAHS) certificate, which assigns the oasis the status of an international agricultural heritage system that preserves agro-biodivesity, traditional knowledge and livelihoods associated with the cultivation of dates.

Siwa Oasis, Egypt, 2016. Source: FAO.

4.2 Topographic and other terrestrial data sources

For climate modelling, different sources were used to obtain terrestrial data with a varying level of detail depending on the different models applied (Chapter 1). The WHIST programme (World Hydrological Input data Set-up Tool)[99] was used to prepare the baseline information for the models applied by SMHI in this study. Its function was to develop information for the hydrological models (such as the delineation of sub-basins, production of river routeing and calculation of the proportions of soil and land-use classes) based on the different source databases on topography, soil, land use and agriculture detailed in the sections below.

4.2.1 Topography

Topography data are based on the HydroSHEDS Database[100], which is also used for drainage networks and watershed delineation.

4.2.2 Soils

Soil data were based on the Harmonized World Soil Database (HWSD). Version 1.2 is a 30 arcsecond raster database with over 15,000 different soil mapping units that combine existing regional and national updates of soil information worldwide. It is based on four source -databases: the European Soil Database (ESDB), the Soil Map of China (1:1 000 000), various regional SOTER Databases (SOTWIS Database) and the FAO–UNESCO Soil Map of the World.[101]

4.2.3 Land use

For the impact assessment, the Global Land Cover (GLC 2000) dataset was used by SMHI for climate modelling. Produced by an international partnership of 30 research groups coordinated by the European Commission's Joint Research Centre, the dataset is at 1 km resolution and contains two levels of land-cover information – detailed, regionally optimized land-cover legends for each continent and a less thematically detailed global legend that harmonizes regional legends into one consistent product.[102]

For modelling using the HEC-HMS model and for the Vulnerability Assessment, land use data was based on the Global Land Cover-SHARE (GLC-SHARE). It was published by FAO in 2014 and provides a set of 11 major thematic land-cover layers resulting from a combination of best available, high-resolution national, regional and/or subnational land-cover databases. The database is produced with a resolution of 30 arcseconds. The major benefit of the GLC-SHARE product is its capacity to preserve available land-cover information at the country level obtained by spatial and multi-temporal source data.[103]

4.2.4 Agriculture

For the impact and vulnerability assessments, Version 5 of the Global Map of Irrigation Areas (GMIA), published by FAO in 2013 was used. It shows the area equipped for irrigation around the year 2005 as a percentage of the total area as a raster with a resolution of 5 arcminutes. Additional map

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

layers show the percentage of the area equipped for irrigation that was actually used for irrigation.[104] In addition, the Global Monthly Irrigated and Rainfed Crop Areas (MIRCA) dataset was used for the modelling undertaken by SMHI. It provides both irrigated and rainfed crop areas of 26 crop classes for each month of the year with a spatial resolution of 5 arcminutes.[105]

4.2.5 Forest cover

For the vulnerability assessment, a map of global forest change published by the Department of Geographical Sciences at the University of Maryland, USA, was used. It has a spatial resolution of 1 arcsecond and maps global forest loss and gain from 2000 to 2012 based on Earth observation satellite data.[106]

5 SOCIO-ECONOMIC DATA SOURCES

The main socioeconomic-related datasets used for the vulnerability assessment are listed below. Detailed information on the applied data, including metadata on data sources, how the data were developed, their spatial resolution, statistical scale etc., is provided in the individual indicator factsheet that will be made available via the regional knowledge hub.

5.1 Demographic datasets

The main data sources used for population and demographics-related estimates in the region are presented below.

Population density. Estimates were based on the LandScan Global Population Database, which comprises the geographical distribution of population at 1 km resolution. It represents census data from the period 2010–2014 and was adjusted to take refugees and internally displaced people inot account in 2015.[107]

Migrant and refugee population. Data from the Population Division of the United Nations Department of Economic and Social Affairs (UN-DESA) for the years 2010–2015 were used to provide migrant population estimates[108], while refugee population estimates were based on the United Nations High Commissioner for Refugees (UNHCR) data of 2015.[109] Estimates were given as the number of migrants/refugees per 1,000 inhabitants.

Urban extent. Version 1 of the Global Rural-Urban Mapping Project, (GRUMPv1) was used for this indicator and consists of estimates of human population for the years 1990, 1995, and 2000 at 30 arcsecond (1 km) grid resolution.[110] The urban extent grids distinguish urban and rural areas based on a combination of population counts (persons), settlement points and the presence of night-time lights.

Share of children and elderly of total population. Data for this indicator was based on data of the Population Division of UN-DESA for the year 2015.[111]

5.2 Economic datasets

Economic resources datasets included estimates on indicators such as the gross domestic product (GDP) per capita, based on the latest available data (2007–2014) published by the World Bank.[112] Additionally, the International Development Statistics (IDS) online database was used to provide information on the Official Development Assistance Index for the Arab States. It is based on the latest available data (2007–2014) and covers bilateral aid, multilateral aid, private providers' aid and other resource flows to developing countries.[113]

5.3 Technology-related datasets

The International Telecommunication Union (ITU) dataset of 2013 was used to provide information on Information and Communication Technologies (ICT) expressed as the ICT Development Index per country.[114]

5.4 Equity-related datasets

Some indicators of equity include the female to male unemployment ratio with data based on estimates by the International Labour Organization (ILO) as the latest available data (2007–2014).[115] Another example is the female to male literacy ratio across Arab States that was provided through estimations for the year 2015 from the UNESCO Institute for Statistics.[116]

6 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 to generate the necessary knowledge to inform efficient risk estimation, climate change adaptation and disaster risk reduction (DRR) processes. National disaster databases record a good number of indicators of loss of both human and economic assets, such as fatalities, injuries and evacuation, as well as damage to infrastructure and livelihood assets, such as housing, agriculture, livestock, critical services and line utilities. This information is collected locally with a relatively high degree of detail, usually up to the municipality level or even lower, depending on the size of the country.

In order to strengthen global accounting for disaster losses, UNISDR initiated 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".[117] It is the only publicly available methodology and open-source tool for building disaster databases, and permits the homogeneous capture, analysis and graphic representation of information on disaster occurrence and loss. It has been under continuous development and improvement for almost two decades, when Latin American countries began to build systematic disaster inventory databases.

Forest fire, Lebanon, 2010. Source: Carol Chouchani Cherfane.

The Sendai Framework for Disaster Risk Reduction, adopted by the international community in March 2015, was developed to guide efforts on disaster risk reduction in the period 2015–2030 and calls for countries to systematically account their disaster losses in order to measure and understand their risks in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. 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. The findings of this report are based on national disaggregated disaster-loss data customized for the 2015 Global Assessment Report on Disaster Risk Reduction (GAR, 2015)[118], and provides an overview of the national risk context of the selected countries, based on their nationally accounted disaster loss and focusing attention on frequency, mortality and economic loss indicators. The result is a historical review of disaster trends that provides the basis for well-informed decisions and effective disaster risk reduction interventions, and whose main findings are presented in the following section.

6.1 Main findings from disaster loss databases in selected Arab States

Nationally reported disaster datasets were used and customized to take into account only disasters triggered by natural hazards (weather-related or of geological origin) and therefore excludes the records that refer to man-made hazards (such as oil spills, technological disasters, etc.).[119] In addition, the records were evaluated against a set of quality criteria prior to analysis.[120] In order to compare disaster losses and damage across all six countries with national disaster-loss databases, the last available 30–40 years were considered for the regional analysis. The breakdown of loss and damage due to disasters during this period is summarized in Table 3 for the period covered in each country.

As seen in Figure 8, forest fires were the highest in frequency for the combined designated countries, followed by drought. In terms of combined economic losses by hazard type, results show that floods accounted for the highest share

TABLE 3: Summary of losses and damage for selected Arab States for the specified data periods

Country	Data period	Number of events	Number of deaths	Houses destroyed	Houses damaged	Damage to crops (ha)
Jordan	1982-2012	593	145	83	594	840
Lebanon	1980-2013	2,527	156	181	1,366	17,700
Morocco	1990-2013	713	2,165	5,109	21,915	281,807
State of Palestine	1980-2013	388	45	65	798	0
Tunisia	1982-2013	1,918	330	17,821	24,728	837,288
Yemen	1971-2013	1,637	4,126	22,392	37,311	20,234

Source: based on Data provided by UNISDR, 2017a, based on Desinventar Consolidated Database, 2015

(Figure 9), which was also often the case at the individual country level. In Yemen, for example, the vast majority of economic losses (87%) were caused by floods and flash floods. The highest human losses, by far, were reported in Yemen and Morocco (even when comparing similar time periods) and the highest combined economic losses culminated in Yemen with around US$ 3 billion, followed by Tunisia (about US$ 685 million) and Morocco (about US$ 530 million) as shown in Figure 10.

When examining the distribution of losses caused by climate-related and geological hazards through the database, data records clearly show the prevalence, with the exception of Yemen, of climate- related hazards as the source of most of the damage. In addition, climate-related hazards have 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).[121]

6.2 Using historical disaster data for climate change analysis

Disaster-loss databases can play an important role in climate change analysis by helping in the identification of “hotspot” areas, where impacts are higher or more recurrent than normal, helping prioritizing actions based on evidence and by providing strong justification for investments in climate change adaptation and disaster risk reduction. A better understanding of patterns and trends and quantitative measures of risk can contribute to improving the process of planning by making it more transparent and comprehensive and can provide the quantitative measures needed to identify and advocate for solutions with the highest possible levels of efficiency and/or effectiveness. In the case of the Arab States considered, the elevated average annual losses are incontestable imperatives to invest in disaster risk reduction and climate change adaptation: for example, losses of almost US$ 20 million per year in climate- related disasters in Morocco is a fact that can be used to justify projects using cost–benefit analyses. In Lebanon, where there is a much lower level of losses per year, database records show that 40% of all costs are associated with forest fires, probably making it a priority for climate change adaptation/disaster risk reduction plans. In Tunisia, almost 50% of all mortality due to floods is concentrated in the province of Sfax, while 70% of reported economic loss is concentrated in the province of Tozeur: regions that could obtain priority when designing actions to reduce flood risk.

Data available through these disaster loss databases also helped ACSAD generate updated flood risk maps for the Arab region, which were used to inform the vulnerability assessment and particularly the sub-sector assessment related to inland flooding.

FIGURE 9: Combined economic losses by hazard type in US$

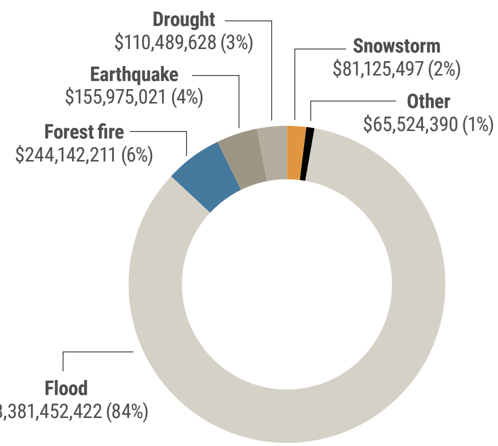
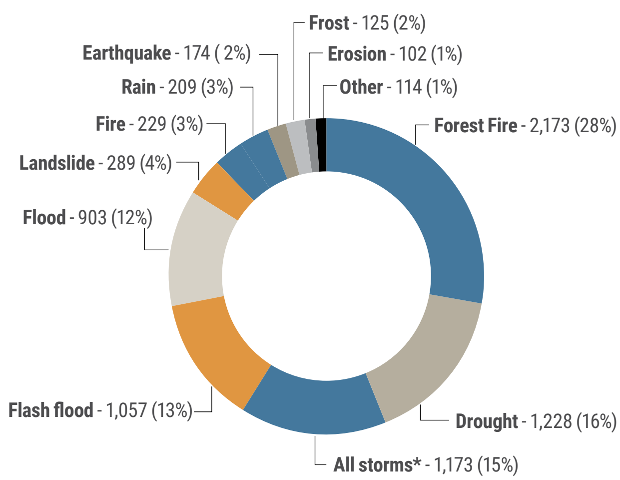
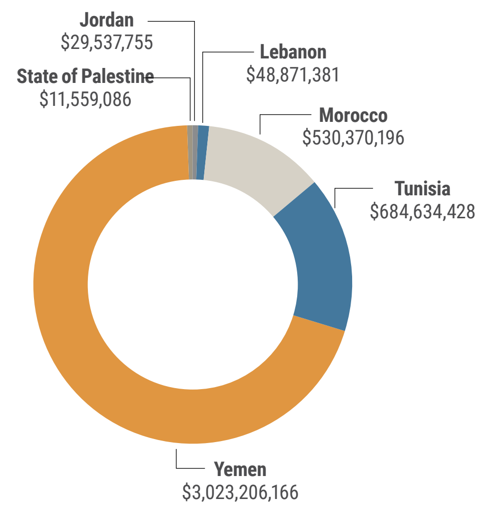


FIGURE 8: Hazard frequency by type (for the six countries combined)



* The “All storms” hazard includes, in order of descending frequency: snowstorms, electric storms, storms, hailstorms, windstorms and sandstorms.

FIGURE 10: Combined economic losses by country in US$



Note: Figures 8,9 and 10 are based on Data provided by UNISDR, 2017a, based on Desinventar Consolidated Database, 2015

ENDNOTES

1. There are 22 Arab States, namely Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, State of Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates and Yemen.
2. WMO, 2017
3. IPCC, 2014
4. ESCWA, 2008
5. WCRP is co-sponsored by WMO, the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission of UNESCO.
6. ESCWA, 2011; ACSAD et al., 2017; SMHI, 2017; ESCWA et al., 2017
7. Shahin, 2007; WWF, 2011; UNEP, 2013
8. Based on Shahin, 2007; Odhiambo, 2016; Terink et al., 2013
9. Brandimarte et al., 2011; Hurrell et al., 2013
10. Krishnamurti et al., 2013
11. Cornforth, 2012 ; Roehrig et al., 2013
12. Kelley et al., 2015; Flohr et al., 2017
13. UNISDR, 2017c
14. Khan, 2013; Express News, 2017; The National, 2017
15. Vries et al., 2013
16. Fritz et al., 2010
17. AccessScience, 2015; WHO, 2015
18. Hereher, 2010; Hasan et al., 2015; Shaltout et al., 2015
19. De Longueville et al., 2010; Almazroui, 2013; Giannadaki et al., 2014
20. UNEP et al., 2016
21. WMO and UNEP, 2013
22. NASA, 2015
23. UNISDR, 2015b; Jasim, 2016
24. The Daily Star Lebanon, 2015
25. UNEP et al., 2016
26. UNEA, 2014
27. Resolution A/RES/70/195 of 2015 (UNGA, 2015)
28. UNEA, 2016
29. WMO and UNEP, 2013
30. Stocker et al., 2013
31. IPCC, 2014
32. NASA, 2017a
33. IPCC, 2014
34. IPCC, 2014
35. IPCC, 2014
36. NASA, 2017b
37. IPCC, 2013
38. IPCC, 2013
39. Asadieh and Krakauer, 2015
40. Study by Zhang et al., 2005 covering the Mashreq and Arabian Peninsula.
41. The Regional Workshop on Climate Change Prediction/ Projection and Extreme Events Indices in the Arab Region, 13–16 March 2012, Casablanca, Morocco (ESCWA, 2012)
42. Data stations comprised the following countries: Algeria, Bahrain, Djibouti, Egypt, Jordan, Kuwait, Libya, Mauritania, Morocco, Saudi Arabia, Sudan, Syrian Arab Republic, Tunisia and United Arab Emirates.
43. Tanarhte et al., 2012
44. Tanarhte et al., 2015
45. Rahman et al., 2015
46. MSEA and UNDP, 2010
47. Agha and Şarlak, 2016
48. Tramblay et al., 2013
49. Omondi et al., 2014
50. Fontaine et al., 2013
51. Chaney et al., 2014
52. El-Fadli, 2012
53. Elagib, 2010
54. Dahech and Beltrando, 2012
55. Filahi et al., 2016
56. Bahrain (1 station), Kuwait (1 station), Oman (24 stations), Qatar (1 station), Saudi Arabia (11 stations), United Arab Emirates (4 stations) and Yemen (2 stations).
57. AlSarmi and Washington, 2011
58. AlSarmi and Washington, 2014
59. Senafi and Anis, 2015
60. Almazroui et al., 2012a; Almazroui et al., 2012b
61. Nasrallah et al., 2004
62. GCOS was founded in 1992 by WMO, the Intergovernmental Oceanographic Commission of UNESCO, UN Environment and the International Council for Science.
63. Bojinski et al., 2014; GCOS, 2010
64. The full list of extreme events indices can be found at ETCCDI, 2009

65. Donat et al., 2014. The full reference is 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.
66. Uppala et al., 2005
67. CRU, 2013
68. Adler et al., 2003
69. Schneider et al., 2011
70. NCAR, 2014
71. TRMM, 2015
72. Dee et al., 2011
73. Uppala et al., 2005
74. Weedon et al., 2014
75. Brunet et al., 2014
76. WMO, 2016
77. McGregor, 2015
78. WMO, 2015
79. WMO and GFCS, 2016b. The portal is maintained by WMO with the assistance of the Royal Netherlands Meteorological Institute and the WMO Commission of Climatology Expert Team on Data Rescue.
80. ESCWA, 2013
81. ESCWA, 2014; WMO and GFCS, 2016a
82. Lehner et al., 2008
83. BGR and UNESCO, 2015b. Data on groundwater resources basins in this map is based on the Groundwater Resources Map of the World 1:25 000 000 published by BGR/UNESCO in 2008 and complemented by additional types of aquifers which were added in 2015 (BGR and UNESCO, 2015a).
84. GRDC, 2012
85. USGS, 2012
86. Lehner and Döll, 2004; WWF and CESR, 2004
87. GWSP, 2015; Lehner et al., 2011
88. FAO, 2015
89. Information from the Aquastat database was from the year 2010 data and that from national sources from 2013 data. Refer to the factsheet "Areas served by Dams" for detailed information on the datasets used for the vulnerability assessment.
90. Based on Edgell, 2006; Şen, 2008; Shahin, 2007
91. West, 2013
92. Al-Farraj, 2005; Ghazanfar, 2006; Ashour, 2013; El-Omla and Aboulela, 2012
93. IUCN, 2015
94. Gulf News Environment, 2015; The Gulf Today, 2015
95. Aldakheel, 2011
96. Khoumsi et al., 2014; Euronews, 2016
97. Hassan, 2003; Battesti, 2005; Mekki et al., 2013
98. FAO, 2017; Egyptian Desert Research Center, 2016; FAO, 2016
99. SMHI, 2014
100. Lehner et al., 2008
101. Fischer et al., 2008; Batjes, 2012
102. Arino et al., 2008; JRC, 2000
103. Latham et al., 2014
104. FAO, 2013 ; Siebert et al., 2005
105. Portmann et al., 2010
106. Hansen et al., 2013
107. University of Tennessee Battelle, 2015
108. UN-DESA, 2016a
109. UNHCR, 2016
110. CIESIN, 2014
111. UN-DESA, 2016b
112. The World Bank, 2015
113. OECD, 2015
114. ITU, 2016
115. ILO, 2015
116. UNESCO Institute for Statistics, 2015
117. DesInventar, 2016. DesInventar is an open-source data tool which helps to compile a detailed disaster loss and damage inventory. It offers several functions for the analysis of information gathered based on assessments following pre-defined but adaptable indicators through a very simple and user-friendly interface.
118. UNISDR, 2015a
119. GAR can be accessed at: www.desinventar.net
120. More information on the methodology and subsequent datasets is available in the technical report Disaster Loss Data and Linkage to Climate Change Impacts for the Arab Region (2017), which was prepared by the UNISDR Regional Office for Arab States as part of RICCAR publication series (UNISDR, 2017).
121. Extensive disaster risk events refer to low-severity, high-frequency disasters, while intensive events have a high level of intensity with mid to low frequencies.

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PART I

IMPACT ASSESSMENT

CHAPTER 1

PURSUING REGIONAL CLIMATE MODELLING AND HYDROLOGICAL MODELLING IN THE ARAB REGION

This chapter provides background information on climate modelling processes and presents the region-specific methodology that was developed and applied under the climate change impact assessment component in RICCAR. The methodology is grounded on the use of regional climate modelling and regional hydrological modelling to generate climate projections over a defined Arab Domain and selected subdomains. It involved selecting a set of climate and hydrological variables that were analysed considering different emission scenarios, resolutions and time periods to facilitate comparability with other climate modelling experiments being conducted at the global, regional and national levels.

1.1 GLOBAL CLIMATE MODELLING

Climate change projections are generated using global climate models (also referred to as general circulation models (GCMs)). These are numerical models that combine physical processes on the land surface and in the ocean, atmosphere and cryosphere to simulate the response of the global climate system to increasing greenhouse-gas concentrations. GCMs are used to study a variety of climate attributes, such as surface temperature, atmospheric temperature profiles, rainfall, atmospheric circulation, ocean circulation, wind patterns, snow and ice distributions and many other variables that are part of the global climate system. More than 100 parameters are available at the global scale to describe the climate observed in the atmosphere, ocean, land or sea ice, or their interaction (e.g. radiative forcing fields).

In these models, the Earth is divided into a three-dimensional grid-like pattern, whereby the values of selected parameters are calculated for each grid point over time to give predictions of their future values and thus provide information on the expected climate for specified conditions and time frame. Each model is characterized by a specific spatial resolution which represents the vertical and the horizontal size of the grid cells (usually expressed in degrees of latitude and longitude or in kilometres) and a temporal resolution or computational "time steps"[1] that establish the temporal sampling rate at which the model-output fields are calculated for each grid box. The interval between each computation depends on the model resolution and the computing capacity.[2]

Global climate models, in conjunction with nested regional climate models, represent the most advanced tools available to provide geographically and physically consistent estimates of regional climate change. GCMs are continuously being improved as scientific understanding of the climate develops and computational power increases. Over the years, several coupled model intercomparison projects (CMIPs) have produced vast ensembles of GCM results that can be used to assess possible future climate changes: the fifth phase of collaboration (CMIP5) supported the preparation of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC).[3] The typical resolution of CMIP5 models ranges from 100 km to 200 km. Some global models run in horizontal resolutions of about 70 km, however. This represents a significant advancement, since the GCMs developed in the 1990s, which were used in the IPCC First Assessment Report (FAR), had an average model grid-cell resolution of around 500 km.[4] GCM components have also evolved over the years with the state-of-the-art Earth System Models (ESMs) incorporating additional aspects of the climate system, such as sophisticated land-surface models, models of ocean and sea ice, biogeochemical processes and the carbon cycle and, more recently, computationally expensive submodels of atmospheric chemistry and land ice.[5]

Al Hajir, Oman, 2016. Source: Khajag Nazarian.

1.1.1 Reference and projection periods

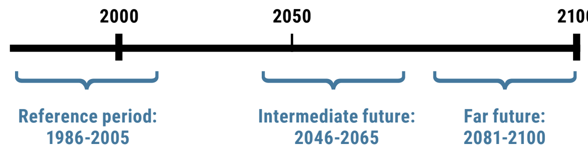
When creating future climate projections, climate models begin with a period of observed historical climate that is used as a reference period ("control period") that helps to validate the ability of the model to represent the past, as well as to provide a reference point against which climate change projections into the future can be compared. Biases in climate models refer to the differences between the observed long-term mean for a region and the modelled long-term mean results from the control period over the same region. Regional climate modelling outputs are also compared with global outputs and such comparison thus requires uniformity across the compared time periods.

The IPCC and other regional climate modelling experiments generally run climate simulations based on two to three future time periods that are compared with a historical reference period.[6] The following 20-year time periods are generally used: 1986–2005 (reference period), 2016–2035 (near future), 2046–2065 (intermediate future) and 2081–2100 (far future). This report presents climate change analysis with respect to reference period, intermediate future (mid-century time period) and far future (end-century time period), as illustrated in Figure 11. The near-future period is excluded as this 20-year period may be the subject of climate variability rather than climate change, which generally requires a longer time horizon to identify trends emerging from climate projections.

1.1.2 Representative concentration pathways

Different approaches to future scenarios in climate research have been used over time, varying from representations of

FIGURE 11: Time periods considered for analysis



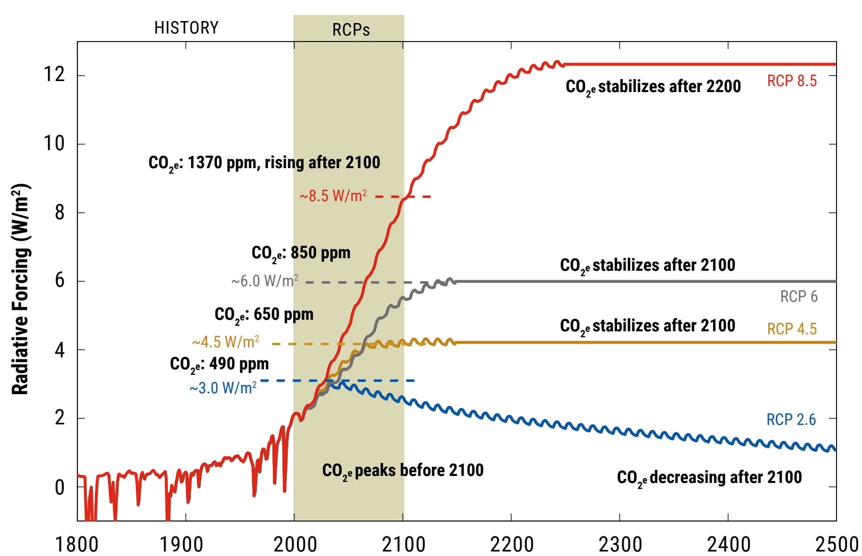
annual increases in global average concentrations of GHGs to advanced representations of emissions of many gases and particles affecting climate and derived from detailed socio-economic and technology assumptions.

Climate change projections conducted within the framework of RICCAR are based on two of the four representative concentration pathways (RCPs) developed by IPCC for informing global and regional climate modelling work presented in its AR5, which shifted from the former approach based on Special Report on Emissions Scenarios (SRES) used in previous IPCC Assessment Reports.

As shown in Figure 12, there are four RCP scenarios named in accordance with their expected radiative forcing expressed in watts per square metre (W/m²), namely RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Each represents a trajectory of GHG concentrations over time to reach a particular radiative forcing in the year 2100. As such, RCPs make no assumptions as to policy changes that may affect the climate; instead they only delimit the range of possible forcings that might occur. Policy analysts and researchers can work back from these trajectories to investigate what may cause them. In this approach, each RCP could result from different combinations of economic, technological, demographic, policy and institutional futures.

FIGURE 12: Representative concentration pathways

	Radiative forcing	CO_2 equivalent concentration in 2010	Rate of change in radiative forcing
RCP 8.5 High Emissions	8.5 W/m²	1370 ppm	Rising
RCP 6.0 Intermediate Emissions	6.0 W/m²	850 ppm	Stabilizing
RCP 4.5 Intermediate Emissions	4.5 W/m²	650 ppm	Stabilizing
RCP 2.6 Low Emissions	2.6 W/m²	490 ppm	Declining



Source: Adapted from Meinshausen et al., 2011

The climate projections studied in RICCAR are based on RCP 4.5 (moderate-case scenario) and RCP 8.5 ("business as usual" – worst-case scenario). RCP 2.6 was examined to a lesser extent, where global GHG emissions peaks by 2020 and then decline thereafter, but are not presented in this report.

To put these scenarios into context, Figure 13 illustrates the corresponding global surface temperature changes projected with respect to these four RCPs that were used to generate climate modelling outputs for IPCC AR5. The figure shows that the mean global surface temperature, with respect to the 1986–2005 reference period, is projected to increase by the end of this century by 1 °C under the optimistic RCP 2.6 scenario, nearly 2 °C under the moderate RCP 4.5, to potentially over 4 °C under the pessimistic RCP 8.5 scenario.

IPCC AR5 reports that global climate risks increase as temperatures rise beyond the 2 °C temperature change, with a high likelihood that extreme weather events become more frequent and intense beyond this threshold.[7]

IPCC has been mandated by the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) under the Paris Agreement to provide it with a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global GHG emission pathways in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty.

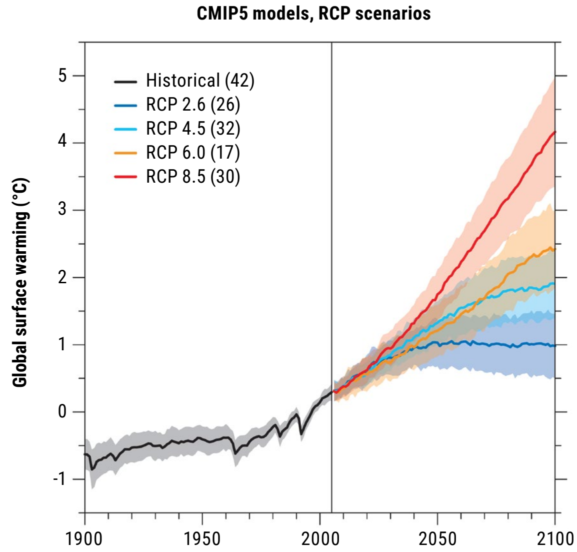
1.2 REGIONAL CLIMATE MODELLING

Despite the rapid progress and development of GCMs, important gaps remain in generating outputs on a smaller scale grid. In order to better understand these smaller-scale processes, climate scientists downscale their models to describe limited areas of the world, which are referred to as domains, through the use of regional climate models (RCMs). A core activity of RICCAR was to produce regionally downscaled future climate projections for the Arab region, which involved setting up a domain. The domain sets the limiting boundaries within which a regional climate model is nested in a GCM. An RCM can then provide a higher-resolution view and an understanding of regional climate conditions by focusing on a specific area (domain) and using the driving forces provided by a GCM as input, as shown in Figure 14. This avoids developing and running a climate model at the global scale when analysis is sought for a specific region.

In this context, there is considerable worldwide cooperation and exchange to promote the advancement of climate science at the global and regional levels. An initiative designed to enhance this cooperation is the Coordinated Regional Climate Downscaling Experiment (CORDEX) organized under the World Climate Research Programme (WCRP).[8] Through establishing a standardized approach, CORDEX aims to evaluate and improve regional climate downscaling models and techniques and produce coordinated sets of regional downscaled projections worldwide.

An integral part of this approach is establishing common regional modelling domains to be used by all participating modelling groups.

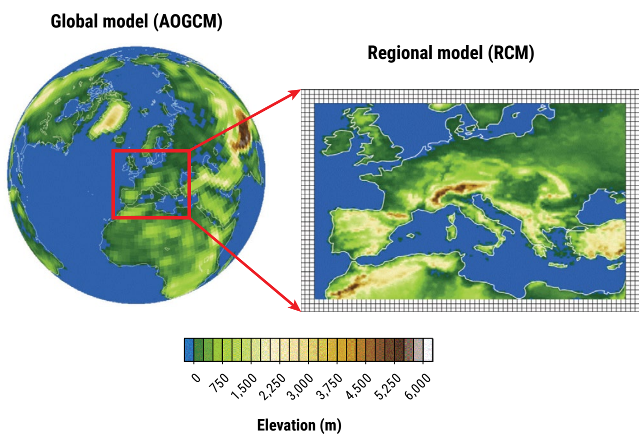
FIGURE 13: Global temperature change projections for RCP scenarios under CMIP5



Note: Mean global temperature change relative to 1986–2005 is shown as a colored line and one standard deviation is shown with colored shading. The number of model runs is given in parentheses.

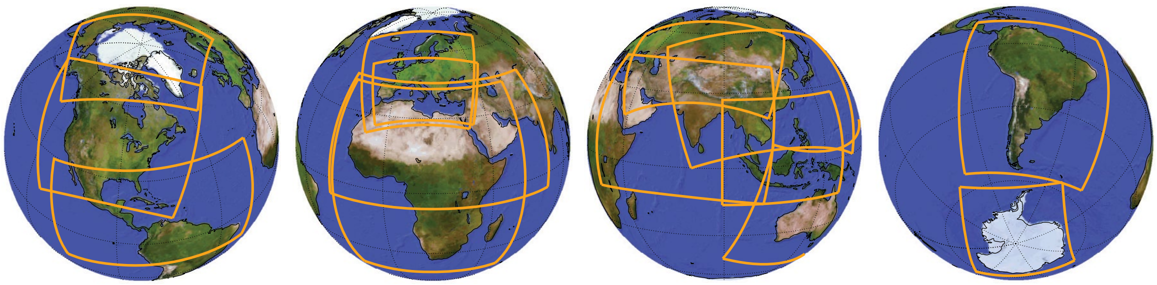
Source: Knutti and Sedláček, 2013

FIGURE 14: Schematic depiction of the one-way RCM nesting technique



Source: Giorgi and Gutowski, 2015.

FIGURE 15: CORDEX domains



Source: WCRP, 2015a.

A common domain, together with a common list of standard model outputs, provides a framework for comparing model performance and future climate projections over these regions and thus fosters better communication and exchange of regional climate information. Regional climate models are especially suitable to assess changes expected in terms of extreme weather events, which are of great importance to develop adaptation strategies as they better represent the local processes related to weather/climate extremes with respect to GCMs.[9] It was decided at the onset of RICCAR that following the CORDEX approach would enhance the outcomes of the study and provide a productive means for continued development beyond the project's lifetime. At the time of writing, there were 14 established CORDEX regions around the globe (Figure 15). There was no unifying domain covering the Arab region prior to its set-up under RICCAR.

1.2.1 The Arab Domain

The RCM approach was applied to dynamically downscale GCM results to regional scales. This is usually done by first identifying the specific region of the globe in focus for the downscaling. In the case of RICCAR, the region of interest covers all Arab States and their water resources. As the majority of water resources in Arab States originates from outside the region, it was necessary to set up the boundaries of a domain that includes all the headwaters of shared surface-water resources flowing into the region. This encompasses a wider geographic area than those covered by the land areas of Arab States, as it requires extending the area of study to cover the headwaters of the Tigris and Euphrates Rivers in the north, as well as the headwaters of the Nile River in the south.

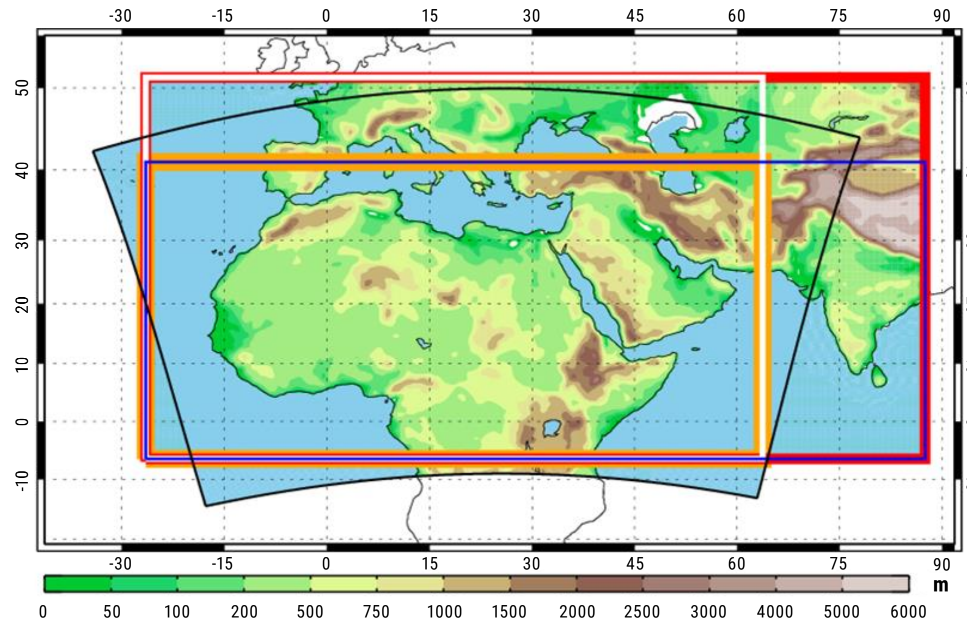
Defining an appropriate regional domain is not a trivial task and a number of tests were required to determine the ability of different domain configurations to appropriately represent the regional climate. Regional consultation in this regard was organized within the framework of the RICCAR RCM Ensemble Task Force, which was led by SMHI. Testing various domain sizes revealed that it was important to extend the domain sufficiently to the east to be able to appropriately represent the prevailing circulation patterns originating from the Indian Ocean. This concern had to be balanced, however, as a larger domain also requires larger computing needs and disk storage for the output. It was thus desirable to agree on setting up a domain that provides satisfactory results without placing undue demands on computing resources. Five configurations were tested and evaluated, together with regional climate experts, as shown in Figure 16. Focus was on comparing circulation, precipitation and temperature results from the different configurations.

The final CORDEX-MENA Domain (Figure 17) is a hybrid of the tested domain configurations presented in Figure 16. It is based on the minimum domain shown in orange, extended further eastwards and northwards. Nevertheless, it should be noted that CORDEX-MENA is an extended domain that requires substantial computing resources for completing century-long simulations. It is also noted that the Comoros, while an Arab State, is not included in the Arab Domain given its geographic location. The Comoros can be studied, drawing on high-resolution GCMs or RCM outputs covering the CORDEX-AFRICA Domain.

With these considerations, the CORDEX "Region 13: Middle East North Africa (MENA)" regional domain or CORDEX-MENA regional domain (27W–76E, 7S–45N) was established under CORDEX within the WCRP[10] as shown in Figure 17. This is synonymous with the Arab Domain as referred to in this report.

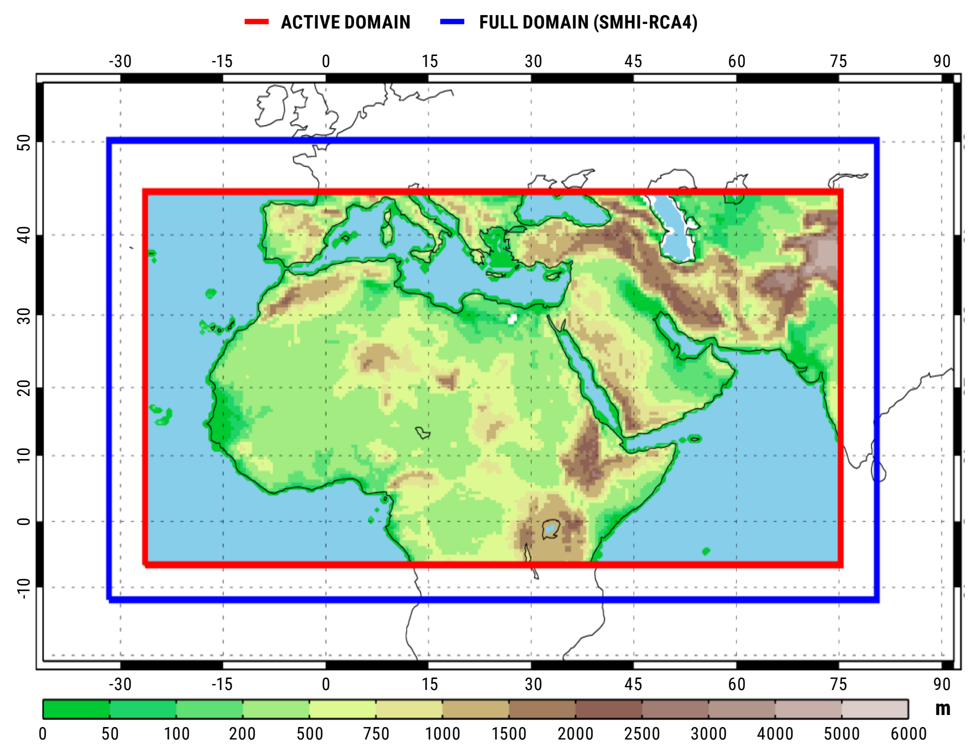
This is a result of the tests conducted together with recommendations from climate scientists in the region that had conducted independent tests with other RCMs. According to the tests made, this choice provides a robust representation of circulation, precipitation and temperature. It thus fulfils both the spatial and performance criteria set forth, while limiting the extent.

FIGURE 16: Different domain configurations tested for the CORDEX-MENA Domain (Arab Domain)



Note: The boundary in orange represents the minimum domain configuration that would satisfy spatial criteria and served as the starting reference for comparison. The boundary in blue represents the eastward extension and the one in white the northward extension. The one in red represents extensions both east and north. The black boundary represents the domain used for previous studies supported by UNESCO.

FIGURE 17: CORDEX-MENA Domain



Note: The Active domain (red) contains the area where RCM results are considered usable. The Full domain (blue) indicates the actual area needed for the RCM (RCA4 in this case) to perform properly within the active domain. The area between Active and Full domain is a transition zone between the GCM driving boundaries and the RCM: using results from this zone should be avoided.

1.2.2 Regional climate modelling projections

The list of the available RCM simulations over the CORDEX-MENA domain that were used for the purposes of generating the findings presented in this report are shown in Table 4. The fourth version of the Rossby Centre Regional Atmospheric Model (RCA4) developed at SMHI was the only RCM available for analysis for future simulations in RICCAR. It is built upon its predecessor RCA3 with substantial physical and technical improvements[11] and is developed from the NWP High Resolution Limited Area Model (HIRLAM). There are three types of simulations identified from the table – evaluation, historical and scenario:

- The *evaluation (or hindcast) simulation* is used to assess how well an RCM can represent recent climate over the domain. It was created using ERA-Interim[12] as the driving GCM data at the boundaries and is considered equivalent to driving the RCM with observations.

- The *historical simulation* uses observed emissions data for the period that should statistically represent the historical period from 1950 to 2005.

- For the *scenario simulation* runs performed under RICCAR, downscaled simulations by RCA4 were driven by lateral boundary conditions from three different CMIP5 GCMs, namely EC-EARTH[13], CNRM-CM5[14] and GFDL-ESM2M[15]. As previously outlined, this report focuses on results for RCP 4.5 and RCP 8.5 scenario projections, which began in 2006. The projection under the RCP 2.6 pathway has not been analysed in detail, but is available for use in future research as needed.

A total of nine RCA4 projections are listed in Table 4. Seven of these are at 50-km resolution and two are at 25-km resolution. Six of the 50-km projections based on RCP 4.5 and RCP 8.5 scenarios have been used to create three-member ensemble analyses in RICCAR. The two projections at 25-km resolution were conducted for RCP 8.5 to gain insights as to whether smaller-scale regional climate modelling experiments could generate clearer climate signals under this more pronounced climate scenario. The conclusions relating to the 50-km ensemble outputs are presented in this report, along with a comparison with projections generated at 25-km resolution, as appropriate.

A number of other climate model efforts have also been pursued since the set-up of the CORDEX-MENA Domain for similar or the same domain by other climate modelling centres, such as the Cyprus Institute (Cyprus), Climate Services Center (Germany), Direction de la Météorologie Nationale (Morocco) and the Center of Excellence for Climate Change Research (CECCR) at King Abdulaziz University (Saudi Arabia). These were initiated during or after the impact assessment phase of the RICCAR integrated assessment was completed, however, and thus could not be incorporated into the ensemble analysis used to prepare the integrated vulnerability assessment. Nevertheless, most of them have gone through an early testing stage (setting and optimizing regional models for the Arab Domain, performing hindcast evaluation runs driven by reanalysis data, etc.). Continued work on the domain is expected under the coordination of the CORDEX-MENA Working Group hosted by the Cyprus Institute.

TABLE 4: RCM simulations conducted over the CORDEX-MENA Domain by the Rossby Centre at SMHI under RICCAR

RCM	Driving GCM/ Reanalysis	Evaluation 1979-2010	Historical 1950-2005	RCP 2.6 2006-2100	RCP 4.5 2006-2100	RCP 8.5 2006-2100	RESOLUTION (km)
RCA4	ERA-INTERIM	X					50
RCA4	EC-Earth		X	X	X	X	50
RCA4	EC-Earth		X			X	25
RCA4	CNRM-CM5		X		X	X	50
RCA4	GFDL-ESM2M		X		X	X	50
RCA4	GFDL-ESM2M		X			X	25
HIRAM	GFDL-ESM2M		X				25
REMO	MPI-ESM-LR		X				50

The ability for RCA4 to represent the climate was evaluated by comparing the outputs of the model for the reference period with observed datasets. The higher the coherence between the modelling outputs and the observed datasets, the higher the confidence that the regional model can be used to project climate into the future.

The results of these simulations showed a common tendency for a cold bias in temperature that is more pronounced in winter than in summer for both the RCMs and the GCMs that were used. An exception is the warm bias during summer in the south-eastern part of the Arabian Peninsula, which includes parts of Oman. The GCMs exhibit the same pattern of bias, which indicates that the bias is carried over from the GCMs to the RCMs. This is supported by the fact that RCA4 driven by reanalysis shows more accurate temperature results (ERA-Interim) but the warm bias for the Arabian Peninsula is also apparent with this simulation. It is worth noting that the largest differences between the two observational datasets (CRU and UDEL) also occur for the Arabian Peninsula, so uncertainties in the observational datasets may be in play.

In terms of precipitation, the results show that most of the RCM simulations exhibit a dry bias over Central Africa during summer, but that this appears more pronounced for RCA4. During winter, the dry bias also appears further north in the Atlas Mountains and in the headwaters of the Tigris and Euphrates rivers. This is apparent for the GCM ensemble as well.

It is noted that as model grid-box outputs in general represent area averages, differences compared to station observations result not only from model errors, but also from the scale gap between grid box and point scale.[16] The latter discrepancy, which is not a model error, is known as the representativeness problem.[17] Gridded observations may therefore be considered more appropriate for validating the skill of the RCM to represent the climate.

Further information on these observation dataset comparisons is provided in the RICCAR technical note *Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region (2017)* prepared by SMHI.[18]

1.3 REGIONAL HYDROLOGICAL MODELLING

Although climate models include some representation of hydrological processes, they generally do not resolve the hydrological cycle at a level of detail suitable for hydrological applications. Hydrological models are thus used to further assess the impact of climate change on hydrological processes. The aim within RICCAR was to provide a large-scale overview of hydrological effects over the entire Arab region. Hydrological modelling was carried out at this regional scale, which is referred to as Regional Hydrological Modelling (RHM) in this report. Producing perfect representation of river flows at local scales cannot be expected from such model applications. Efforts were made to produce a reasonable representation of hydrological processes over regional scales, given the sparse data available. The value of these modelling outputs is that they provide a consistent approach for generating information on runoff, evapotranspiration, discharge and other variables with a similar level of detail over the entire region. By providing a regional overview in this way, the regional patterns of projected hydrological change can be seen and trends and areas that would be affected can be identified. 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.

Flood waters, Lebanon, 2014. Source: Carol Chouchani Cherfane.

1.3.1 Bias correction for hydrological modelling

Even though they are based on physical principles, information generated by GCMs consist of numerical approximations which may lead in some cases to biases resulting in deviation of the simulated climate from that observed.[19] It is thus nowadays widely recognized that climate model results cannot be used directly as inputs to other more specialized impact models and an adjustment (bias correction) towards the observed climatology is necessary. In particular, there are typically biases in the RCM statistics of key hydrometeorological variables, such as precipitation and temperature.[20] Many of these biases originate from either the driving GCM model or the RCM used for downscaling. Since hydrological models are very sensitive to anomalies in rainfall amounts, direct use of RCM outputs in impact studies is therefore usually not appropriate and the hydrologically important variables precipitation and temperature need first to be adjusted before use in impact studies.[21] While several bias-correction methods exist, all the RCM projections in RICCAR were adjusted using the distribution-based scaling (DBS) method developed by Yang et al. (2010).[22] More detailed information on different bias-correction methods is provided in Nikulin et al. (2015).[23] The following steps were performed within the DBS approach:

- Correction factors were derived by comparing the RCM output with observed climate variables for a similar control period;
- Correction factors were then applied to RCM outputs for the future climate period. This was done for precipitation and temperature for the entire regional domain;
- The WFDEI dataset was used as observed climate to define the DBS parameters for each RCM projection for the control reference period 1980–2009;
- The DBS-corrected precipitation and temperature values were then used as inputs to drive the hydrological models and also in the analysis of extreme events.

The original DBS approach was developed for applications over a wide range of climates in both Europe and Africa. It has been well-tested for areas that usually exhibit a positive bias in precipitation. For the RICCAR region, the climate projections showed tendencies for negative precipitation biases for many areas.[24] Additional focus was thus needed to further develop the DBS techniques to better account for negative precipitation biases. No additional development was needed for the temperature bias-correction technique.
It is important to note that this approach assumes that the biases being corrected are systematic in nature and of similar magnitude for both present and future climate. Although bias correction is essential, it can to some extent also modify the climate change signal. It is also worth noting that applying bias adjustment to climate-model simulations introduces a level of uncertainty in impact modelling. Care should thus be taken with respect to bias-correction assumptions and unavoidable limitations in its application, as also outlined in IPCC (2015). In this context, a Bias Correction Intercomparison Project (BCIP) has recently been established to: address the level of uncertainties that bias adjustment introduces to the flow of climate information; advance the bias-adjustment technique; and provide best practice on use of bias-adjusted climate simulations.[25]

1.3.2 Hydrological models applied

Three different hydrological models (Table 5) were applied within RICCAR. The Hydrological Predictions for the Environment (HYPE) and Variable Infiltration Capacity (VIC) models were used to produce RHM results over the entire Arab region and the HEC-HMS model was used to investigate hydrological impacts from changes in extremes at selected local scales. They all model rainfall runoff processes with primary focus on surface waters.

Both HYPE and VIC are freely available, open-source models. They were chosen as both have been designed for use in large-scale applications and have been successfully used in various regions around the world. Both have been applied to assess hydrological change using future climate projections and can easily accommodate large datasets spanning timescales exceeding 100 years. HEC-HMS is also freely available and is a rainfall-runoff model that has been widely used for a variety of applications. It is not, however, specifically known for large-scale applications. The three models are briefly described hereafter.

TABLE 5: Hydrological models applied under RICCAR

Hydrological model	Application	Set-up
HYPE	Regional approach	Runoff basins
VIC	Regional approach	Grid boxes, 50 km resolution
HEC-HMS	Local extremes	Runoff basins

1.3.2.1 Hydrological Predictions for the Environment (HYPE) model

The HYPE model was developed at SMHI to better address environmental problems affecting hydrological systems, including nutrient transport and the effects of a changing climate.[26] HYPE is based on the widely applied Hydrologiska Byråns Vattenbalansavdelning (HBV) model concept and works on the basis of establishing sub-basins according to topographical data and then assigning different classes within each sub-basin to further represent heterogeneity. These classes – or hydrological response units – are based on land use, soil type and elevation.


Taking river measurements in Penjwen, Iraq, 2014. Source: Sadeq Oleiwi Sulaiman.

The water balance for each class is calculated individually before being combined to generate the overall water balance in each sub-basin. The HYPE model structure was designed to accommodate the large quantities of data needed for modelling large areas and for long time periods, such as with climate change projections. It has been successfully applied in large- and small-scale applications and serves both as a research tool and as an operational forecast model.[27] Input data for this model include forcing data (precipitation, temperature) as well as static data (land cover, soil type, lakes and reservoirs).

1.3.2.2 Variable Infiltration Capacity (VIC) model

The VIC Model is a large-scale, semi-distributed hydrological model that was originally developed as a macroscale hydrological model.[28] As such, it is typically applied on continental or subcontinental scales using a rectangular grid structure ranging from 0.125° to 2.0°, although finer-scale applications have been made in recent years. Within each grid box, multiple land covers can be represented and variable topography is included through the use of elevation bands. VIC allows for two modes of calculation, either water-balance mode with a 24-hour time step or energy balance mode that allows for sub-daily time steps. The water-balance mode was used for this application. Each VIC grid cell is modelled independently to resolve different components of the water balance.[29] Represented processes include infiltration, percolation, evapotranspiration, snow accumulation and snowmelt (not represented are lakes, irrigation, subsurface/groundwater flow and channel losses, including seepage and evaporation). Representation of lateral flows between grid boxes can be done in a separate step for routeing flows, but this was not included in this study. Input data for VIC include daily precipitation, temperature and wind speed in 0.5° resolution from the WFDI dataset, as well as global VIC parameters comprising pre-processed soil and land-cover data.[30]

1.3.2.3 Hydrologic Engineering Center Hydrological Modelling System (HEC-HMS) model

The HEC-HMS model is a modelling package that is designed to accommodate varying hydrological applications over a range of geographical areas.[31] Depending on how it is set up, it can be used for both large river basin applications, as well as urban conditions. It is often used in combination with other modelling tools for a number of water resources management applications. It supersedes the HEC-1 hydrological model from which it is based by offering a number of advancements and modelling options, including different ways to simulate the key variables of precipitation, evapotranspiration and infiltration.

This model was used by ACSAD in RICCAR in order to study hydrological impacts from changes in extremes at the local scale for three different basins, namely Wadi Diqah (Oman), Medjerda River (Tunisia/Algeria), and Nahr el Kabir (Lebanon/ Syrian Arab Republic). For this purpose, the GIS extension HEC-GeoHMS was additionally used. This extension provides the user with a set of procedures, tools and utilities to prepare GIS data for import into HEC-HMS and generation of GIS data from HMS output. It allows visualization of spatial information and watershed characteristics, performs spatial analysis, delineates sub-basins and streams, constructs inputs to hydrological models and assists with report preparation.

Additional information on bias correction, as well as model calibration, validation and performance of the applied HYPE and VIC models, is available in the RICCAR technical note *Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region (2017)*.[32] Additional 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)*.[33]

1.4 EXPLANATION OF ANALYSIS AND PRESENTATION OF RESULTS

1.4.1 Ensemble analysis

To derive the best possible estimate of the results from the different climate models, the ensemble method was used, whereby all model simulations based on the same emissions scenario and resolution are grouped and presented as mean values: an ensemble mean. As an ensemble should consist of at least three members – preferably more – the two 25-km resolution projections were 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) as shown in Table 6. Such analyses show if and where the use of higher resolution would add value.

1.4.2 Regional climate modelling outputs

The different climate models applied under RICCAR provide results of projections for specific variables and are expressed in terms of changes from the reference period. The main variables analysed stem from the application of RCMs, which are most commonly drawn upon to generate projections related to temperature and precipitation (Table 7).

An important consideration concerning the precipitation variable is that, in many studies worldwide, changes in precipitation are often expressed as a percentage change from a base reference period, which provides an easy basis for comparison. Using percentage change can be problematic in regions that have extremely low precipitation, however. Given the small amounts of precipitation for the reference period in such areas, large percentage changes can result even if changes in magnitude are relatively small. The Arab region contains large climatic variations, particularly with regard to precipitation, which is extremely low over large areas. Projected changes in precipitation are thus primarily presented in terms of magnitude (mm) but also expressed as relative terms (%) in the narrative. 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.

TABLE 6: Description of the RCA4 ensembles

Scenario/resolution	Global model forcing
RCP 4.5, 50 km	EC-Earth, CNRM-CM5, GFDL-ESM2M
RCP 8.5, 50 km	EC-Earth, CNRM-CM5, GFDL-ESM2M

1.4.3 Regional hydrological modelling outputs

The bias-corrected RCM outputs provide needed inputs to run RHMs. The key parameter studied in RHMs is runoff. Complementary variables include evapotranspiration, soil moisture and river discharge, as well as two discharge-derived parameters, namely high-flow and low-flow discharge values (Table 7).[34] These were simulated based on bias-corrected results for temperature and precipitation generated by the RCMs. To ensure consistency across the integrated assessment components represented in this report, all results are based on the bias-corrected RCM outputs, unless otherwise noted.

When examining the projected changes of runoff, consideration should be given to the fact that these are based on precipitation outputs, which exhibit high uncertainties as mentioned in previous chapters. Runoff output projections also thus demonstrate high uncertainties for both the HYPE and VIC models.

For some rivers and streams pertaining to specific subdomains, no observation datasets on discharge were available against which the model could be verified.
It is 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. Moreover, concerning results for discharge and related outputs, it will be recalled that as the VIC model used in this assessment does not take into consideration the lag effects of storage and evaporation from natural lakes or dam features, discharge-related outputs were only completed through the HYPE Model.

Findings related to groundwater recharge and soil moisture are not included in this report as they require further examination based on small-scale analysis.
Groundwater recharge is of interest for the region given the significant amount of fossil groundwater resources

TABLE 7: 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

available and is better assessed in tandem with hydrological modelling. The hydrological models selected for regional application do not directly represent groundwater, however. Change in runoff could be used as a proxy for indicating change in groundwater recharge by interested researchers, while specialized groundwater models at a smaller scale of analysis could be applied, drawing upon the bias-corrected datasets made available for the Arab region.

The interpretation of soil moisture from RHMs should also be made with caution. Preliminary analysis shows that the soil moisture in the VIC model simulations was not at equilibrium for all areas at model initialization and for dry areas in particular. Soil-moisture content in such areas increased over the simulation time until it reached equilibrium state in the model. This means that comparing future soil-moisture states to reference period states does not give an accurate picture of how soil moisture will change in the future for these areas. Addressing this issue would require running the VIC model for an extended time using present climate data to first reach a better soil-moisture equilibrium, often referred to as “model spin-up” and then re-run all the VIC simulations. Model spin-up was considered for VIC, but was apparently not sufficient to respond to conditions in the dry areas of the Arab Domain. Given these issues, HYPE results give a more accurate assessment of change in soil moisture and can be made available upon request.

Examination of future change in soil moisture was conducted to derive a “low soil moisture” indicator based on the HYPE model results for the Arab Domain, which is defined as the mean of the lowest soil moisture occurring every year during the reference period (1986–2005). When comparing future climate to the reference period, the change is identified as the mean number of additional days per year for each future period. The results show an increasing number of days over time. For these two indicators, due to the high uncertainties in value changes in soil moisture, results can be presented as a scale of “high” or “low” change to provide a general idea of these changes without giving exact values and thus avoid misinterpretation. These results are not included in the report.

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

1.4.4 Extreme event indices

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 transportation sector and the economy at large. It is therefore necessary to study these events in order to provide the information needed to inform policy- and decision-making on climate change adaptation and measures to enhance resilience across the Arab region. The list of 27 indices developed by ETCCDI provides metrics for extreme events and is presented in the overview chapter.[35] The present chapter presents analyses of seven indicators from the ETCCDI list and two additional regional-specific indicators that were deemed to be more relevant for examining temperature thresholds in the already hot Arab region, namely summer days over 35 °C (SU35) and summer days over 40 °C (SU40). The nine indices are listed in Table 8. An analysis of additional extreme events indices can be generated from the projections.

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

TABLE 8: Extreme events indices studied

Index	Long name	Definition
EXTREME TEMPERATURE INDICES		
SU	Number of summer days	Annual number of days when daily maximum temperature > 25ºC
SU35	Number of hot days	Annual number of days when daily maximum temperature > 35ºC
SU40	Number of very hot days	Annual number of days when daily maximum temperature > 40ºC
TR	Number of tropical nights	Annual number of days when daily minimum temperature > 20ºC
EXTREME PRECIPITATION INDICES		
CDD	Maximum length of dry spell	Maximum number of consecutive days when daily precipitation < 1mm
CWD	Maximum length of wet spell	Maximum 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)

BOX 3: Comparing RICCAR reference period data with observed data in the Arabian Peninsula

Climate scientists can draw upon the regional modelling outputs generated using RCA4 under RICCAR and compare them with simulations generated by applying other RCMs as a means to help review their work and gain insights into climate phenomenon being witnessed across the Arab region or in parts of the region.

As an example, the findings below provide a comparison between the RCA4 simulations for the reference period (1986–2005) and a set of observed records of temperature and precipitation in the Arabian Peninsula for the period 1980–2008. The station data provided by National Meteorological Services comprised the following countries: Bahrain (1 station), Kuwait (1 station), Oman (24 stations), Qatar (1 station), Saudi Arabia (11 stations), UAE (4 stations) and Yemen (2 stations).

Comparisons reveal that RICCAR simulations of the recent past are overall in good agreement with the Arabian Peninsula station data, especially regarding temperature variables, as shown in Table 9. As for extreme temperature indices, comparisons between datasets for SU40 (number of summer days above 40 °C) and TR (number of tropical nights) show better concordance for the latter index. Discrepancies between RICCAR simulations and observed data for SU40 are evident in the tables below. Possible reasons for these discrepancies could be the difference in data periods considered in RCM outputs and station data or different averaging methods of datasets. The coarse RCM resolution (50 km) could also explain these discrepancies.

As for precipitation variables, a noticeable underestimation of the annual values was observed over the high-altitude stations such as the Saiq in Oman, Khamis Mushait in Saudi Arabia and Sana'a station in Yemen, which needs to be taken into consideration when examining results for those countries. Close means are however reported for other countries as shown in Table 10, and were also evident for extreme indices such as CDD, CWD, R10 and R20.

TABLE 9: Comparison of temperature and SU40 indicator results for the RICCAR reference period (1986–2005) and observed station data (1980–2008)

	Temperature (°C)				SU40 (days)			
	Kuwait	Oman	Qatar	UAE	Kuwait	Oman	Qatar	Bahrain
RICCAR RCMs	27.5	25.6	27.7	27.3	130.1	2.8	113.0	136.9
Station Data	26.3	22.5	27.3	27.6	139.4	29.6	90.7	30.0

TABLE 10: Comparison of precipitation results between RICCAR RCMs (1986–2005) and station data (1980-2008)

	Precipitation (mm/month)		
	Kuwait	Oman	Qatar
RICCAR RCMs	8.6	7.5	8.0
Station Data	10.0	9.9	6.4

Source: Said AlSarmi, based on comparative assessment of RICCAR reference period and observed data, as presented in AlSarmi and Washington, 2014.

1.4.5 Seasonal outputs

Although change in annual mean values can be sufficient for some impact applications, it is often important to also see how future changes will likely occur over different seasons. As water is a key focus for this study, evaluating differences between "wet" and "dry" seasons is of considerable interest, and results were thus presented for two seasonal periods; namely April–September and October–March to assess how climate in the Arab region varies between them.

This broadly represents dry and wet periods over the entire domain, although which period is wet and which is dry varies in different subregions.

Two seasons were chosen as robust time periods that could be applied over the entire domain to avoid more complicated analysis of how the length of seasons may change in different subregions in the future.

In addition, some results were generated in terms of three boreal summer months (June, July, August) and three boreal winter months (December, January, February).

This study of projected changes over time at the seasonal level was applied for most of the variables, except for the extreme events indices. Analysis of seasonal and interseasonal variability can also be examined.

1.4.6 Subdomains

The RICCAR Assessment Report provides results presented as both maps and plotted time-series. The maps generally show the entire Arab Domain. On the other hand, the time-series presented are area means summarized over specified subdomains. Selected subdomains have been chosen to give an overview of different areas of special interest over the region (Figure 18 and Table 11).

It should be noted that the Mediterranean Coast (MD) subdomain comprises five small rivers and the Moroccan Highlands (MH) sub-domain includes three rivers (Moulouya, Oum-er-Rbia and Sebou).

Two additional subdomains were identified as areas of interest by Arab States and studied by SMHI, namely the Sana'a River and the Wadi Diqah. The small size of the surface water systems in the Sana'a Basin increased the uncertainty of the results, while the changing situation on the ground complicated efforts to undertake groundwater recharge analysis as initially envisioned. As for Oman, climate projections relating to Wadi Diqah were instead studied by ACSAD within the context of conducting an analysis of extreme climate events using HEC-HMS, and is presented in Chapter 5. Results for the subdomains based on the regional hydrological modelling projections are, however, available for informing further analysis upon request.

FIGURE 18: Location of subdomains identified for analysis

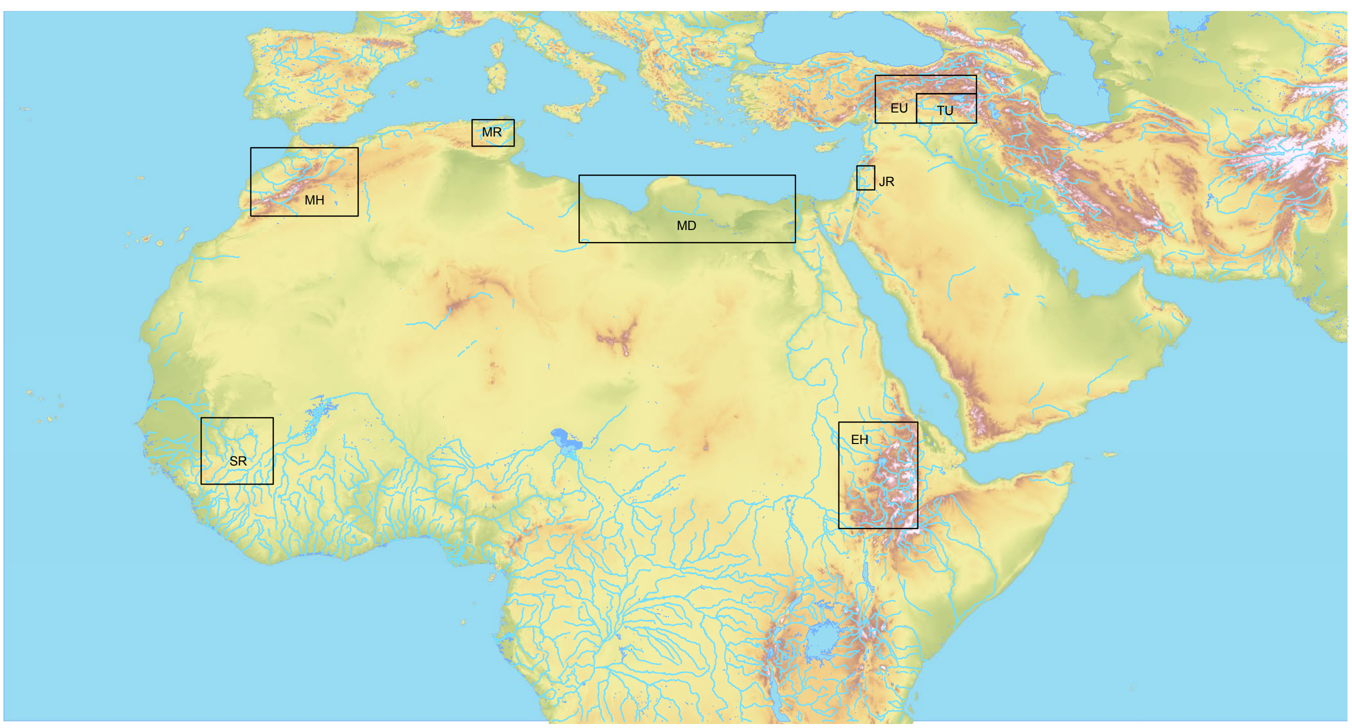


TABLE 11: List of sub-domains considered for analysis

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

ENDNOTES

1 Representing time increments at which equations in the model are resolved.

2 ESCWA, 2011; Flato et al., 2013

3 Taylor et al., 2012

4 Miao et al., 2014

5 Heavens et al., 2013; Flato et al., 2013

6 IPCC, 2013; IPCC, 2014

7 IPCC, 2014

8 Giorgi et al., 2009; WCRP, 2015a

9 Rummukainen, 2010

10 WCRP, 2015b

11 Kjellström et al., 2016; Samuelsson et al., 2011; Strandberg et al., 2014

12 Dee et al., 2011

13 Hazeleger et al., 2010

14 Voldoire et al., 2012

15 Dunne et al., 2012

16 Maraun et al., 2015

17 Klein Tank et al., 2009

18 SMHI, 2017

19 IPCC, 2015

20 For example, Kotlarski et al., 2005; Kay et al., 2006

21 For example, Graham et al., 2007; Lenderink et al., 2007

22 See Yang et al., 2010

23 See Nikulin et al., 2015

24 Bosshard et al., 2014

25 Nikulin et al., 2015. More detailed information on bias-correction methodology can be found in the sources mentioned in this section. Access to bias-corrected datasets as they become available is provided by CORDEX at: http://www.cordex.org

26 Lindström et al., 2010

27 SMHI, 2015

28 Liang et al., 1994

29 Gao, 2010 ; Devia et al., 2015

30 SMHI, 2016

31 US Army Corps of Engineers, 2000

32 SMHI, 2017

33 ESCWA et al., 2017

34 The river discharge is the arithmetic mean discharge value. The high-flow value represents the value with the 100-year return time (probability of 1% to occur or to be exceeded in any given year). The low-flow value represents the arithmetic mean value for all days with values less than the 20th percentile (if expressed in m^3/s) or the number of days with a value less than the 20th percentile in the reference period (if expressed in number of days), noting that it is equal to 73 days in the reference period.

35 Peterson, 2005; Peterson and Manton, 2008

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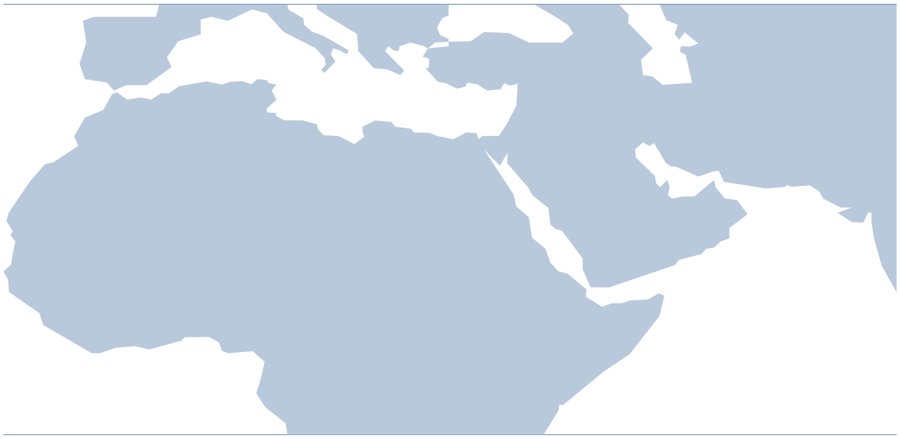
REGIONAL CLIMATE MODELLING: ARAB DOMAIN



CHAPTER 2

REGIONAL CLIMATE MODELLING RESULTS FOR THE ARAB DOMAIN AND SELECTED SUBDOMAINS

The bias-corrected RCM output presented in this chapter includes temperature, precipitation and selected extreme events indices expressed in terms of change from the reference period. Most results are for the entire Arab Domain or as plotted time-series showing area means summarized over two representative subdomains of special interest, namely the Moroccan Highlands and the Mediterranean Coast. The selection of specific subdomains (presented in Chapter 1) aimed to provide more distinct indicative information over certain areas of interest, including shared river basins. RCM results pertaining to shared river basins are presented alongside their regional hydrological modelling outputs in Chapter 4.

Regional climate modelling outputs were generated by SMHI using the RCA4 model, forced at its boundaries by three state-of-the-art GCMs, namely EC-Earth, CNRM and GFDL-ESM. 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. Due to limited space, selected outputs are presented in this report. Additional results are available in the Technical Annex and online through the regional knowledge hub. As discussed in Chapter 1, the results for temperature are more certain than those for precipitation because the precipitation change signals are correlated more with the driving GCM rather than the emission scenario.

2.1 PROJECTED CHANGE IN CLIMATE ACROSS THE ARAB DOMAIN

2.1.1 Change in temperature

Maps of projected temperature changes (compared to the reference period 1985–2005) over the Arab Domain for the different time periods and the two RCP scenarios are presented in Figure 19. As can be seen, all projections show that temperatures will rise over the Arab region during this century. The general change in temperature for RCP 4.5 shows an 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 range of these values represents the variation in results according to different areas in the region. The higher increase at mid-century is shown in the non-coastal areas, with the greatest changes projected in the Sahara Desert. By the end of the century, the increasing change in temperature becomes much more evident throughout the Arab domain. The areas showing higher increases are the broader Sahara region and East Africa, including Morocco and Mauritania. For this period, the increasing temperature signals along the western shores of Yemen and Saudi Arabia under RCP 8.5 are also stronger than under RCP 4.5 in comparison with the rest of the Arabian Peninsula.

Al Ramaa Mountain, Yemen, 2005. Source: Ihab Jnad.

When focusing on seasonal changes, results show no evident tendency for temperature to increase more during one particular season of the year (not shown). 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) which are presented in detail in Chapter 4. However, it seems apparent that for most countries along the Mediterranean, the increase during summer will be larger than during winter.

FIGURE 19: 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

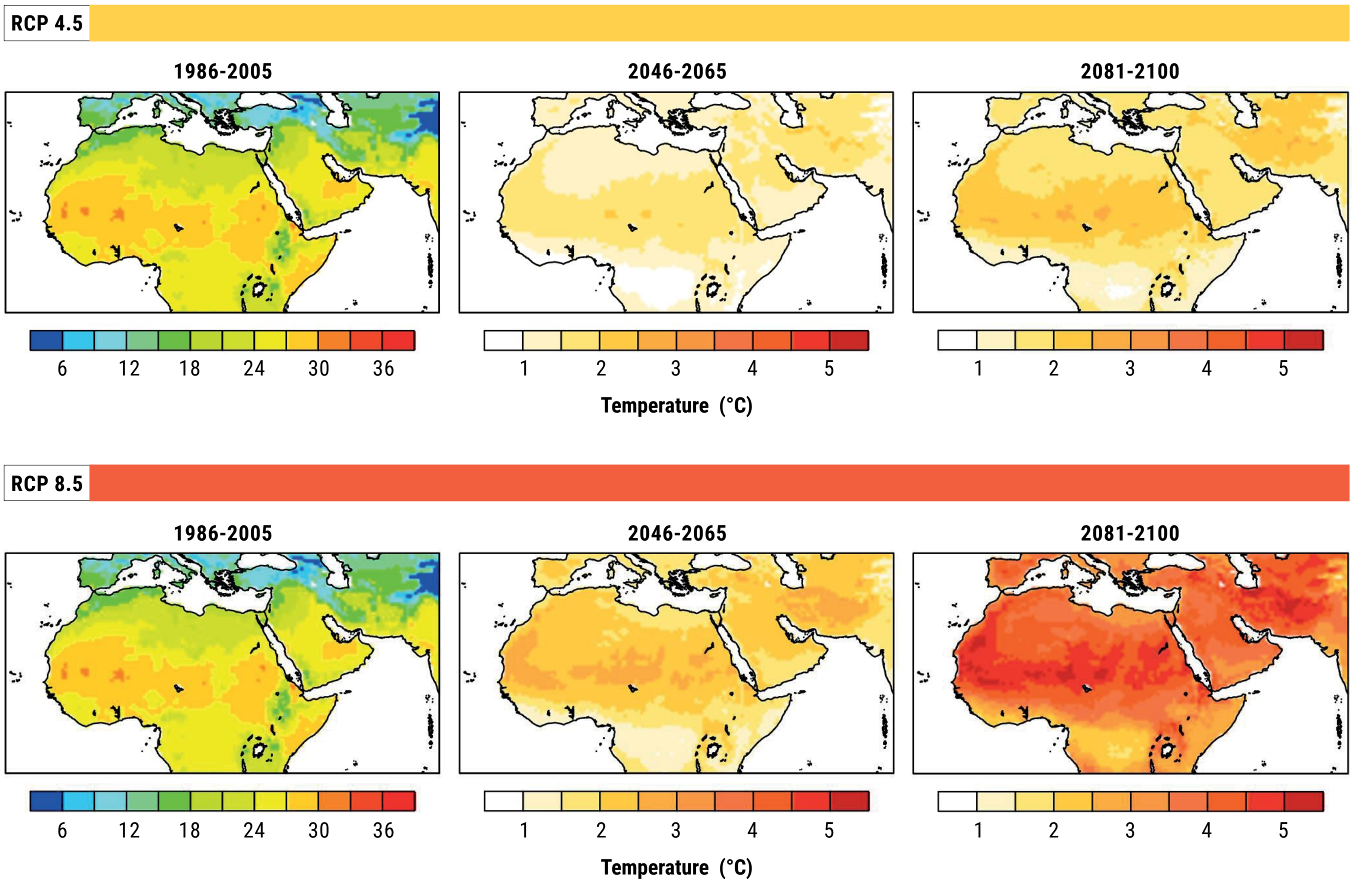
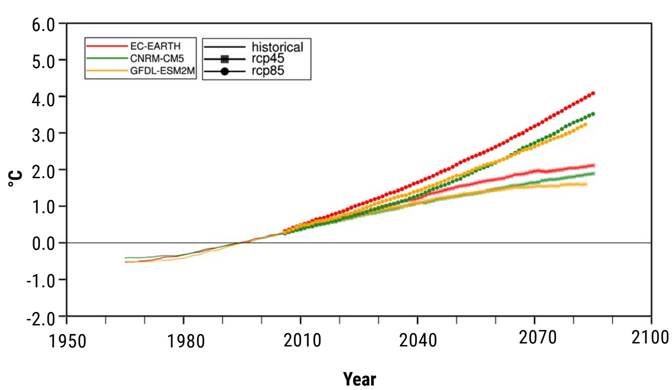


Figure 20 depicts the projected temperature change over the 21st century, averaged over the Arab Domain based on the reference period 1986–2005 and as a 30-year moving average. In agreement with the global and other regional simulations, the different paths of the two RCP emission scenarios start diverging around mid-century. The projected change in temperatures starts becoming discernible for the two scenarios after 2030–2040. As can be seen, all projections are in agreement that temperatures will rise over the Arab region during the next century.

FIGURE 20: Change in mean temperature (°C) over time for the Arab Domain as a 30-year moving average for six individual climate projections



2.1.2 Change in precipitation

As precipitation is much more variable over the domain, there is little benefit to present the area mean time series over the entire Arab Domain in the same way that was done for temperature. This type of figure is more useful when rainfall is averaged over smaller subregions. Such time-series plots are presented in more detail in the following sections of the report.

The maps in Figure 21 show the spatial extent of projected precipitation change over the Arab region averaged for the three-member ensemble, for the mid- and end-21st century sub-periods, considering the two RCP emissions scenarios. Precipitation changes vary considerably across the Arab Domain with no universal trend for annual results as well as at the seasonal level. Decreasing trends can be seen in most of the Arab region at mid-century. By the end of the century, both scenarios suggest a reduction of the average monthly precipitation reaching 8–10 mm in the coastal areas of the Arab Domain, mainly around the Atlas Mountains in the west and upper Euphrates and Tigris rivers in the east. Some areas, however, show increasing precipitation trends, such as the south-eastern Arabian Peninsula and some parts of the Sahel. This pattern is potentially due to the displacement of the ITCZ bringing precipitation and which, according to several studies tends to move further northwards in response to warming.[1] As increasing temperatures are projected in these areas, this projected precipitation trend concords with this hypothesis.

At the seasonal level (Figure 22 and Figure 23), the stronger precipitation changes for countries along the Mediterranean coast are projected for the winter months and will be negative, as much as –40% in the worst case for the Moroccan Highlands. For this area, a number studies have confirmed the strong influence of the North Atlantic Oscillation (NAO) on precipitation variability in Morocco, and these results are in line with the fact that a positive NAO is associated with reduced rainfall in Morocco in the boreal winter season (December–February).[2] Further south, rainfall changes are more pronounced during the summer months, while the sign of change varies from west to east.

Erosion of river banks in Morocco,2015. Source: Heribert Rustige.

FIGURE 21: 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

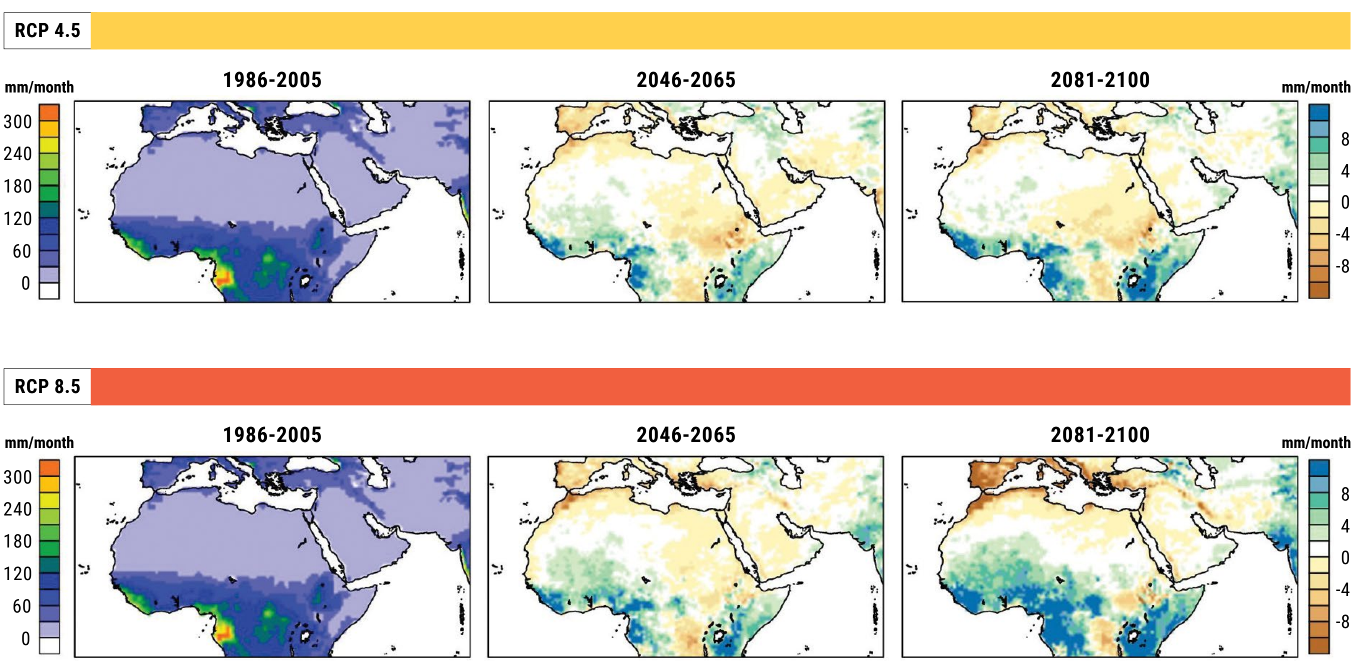


FIGURE 22: Mean change in seasonal precipitation for mid- and end-century for ensemble of three RCP 4.5 projections compared to the reference period

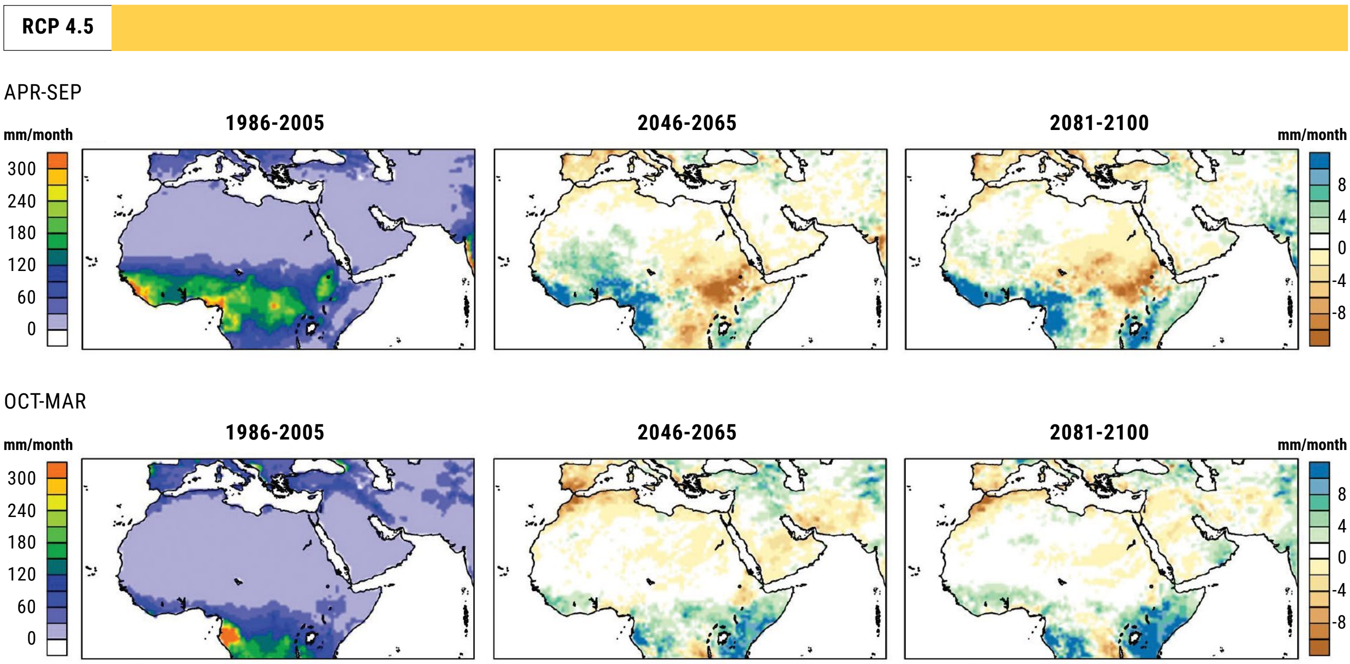


FIGURE 23: Mean change in seasonal precipitation for mid- and end-century for ensemble of three RCP 8.5 projections compared to the reference period

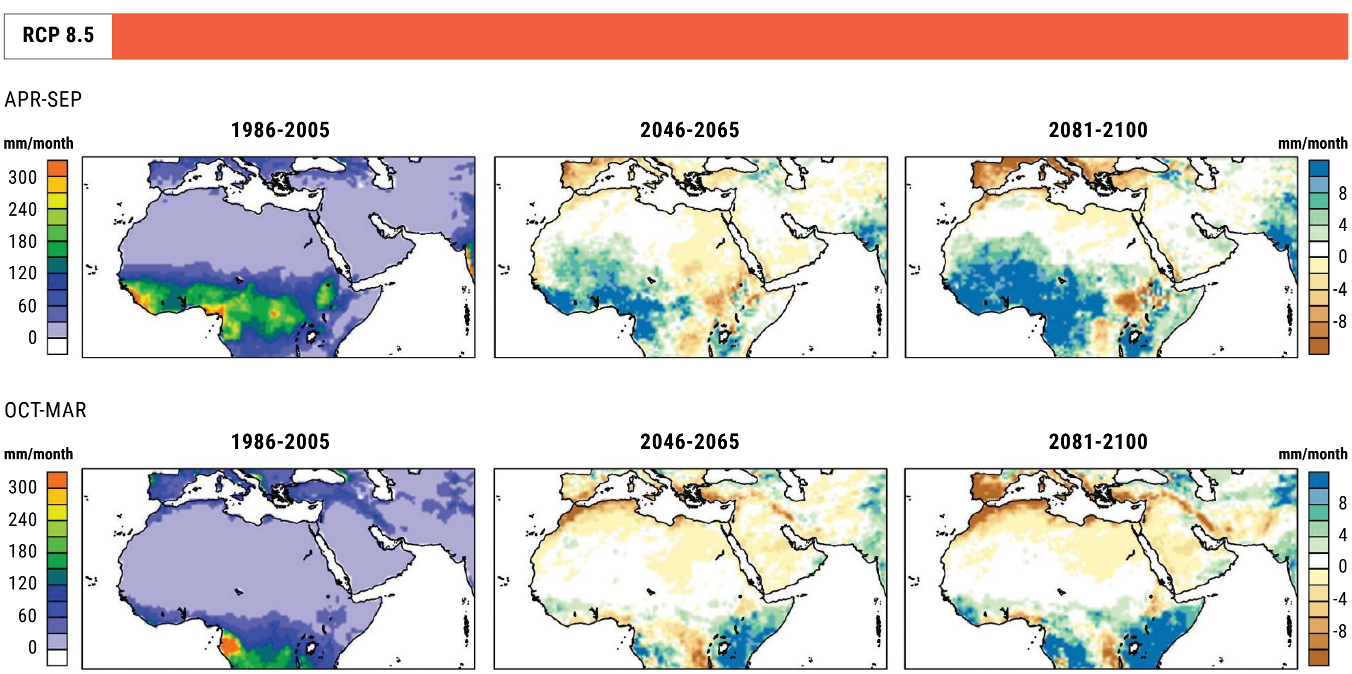
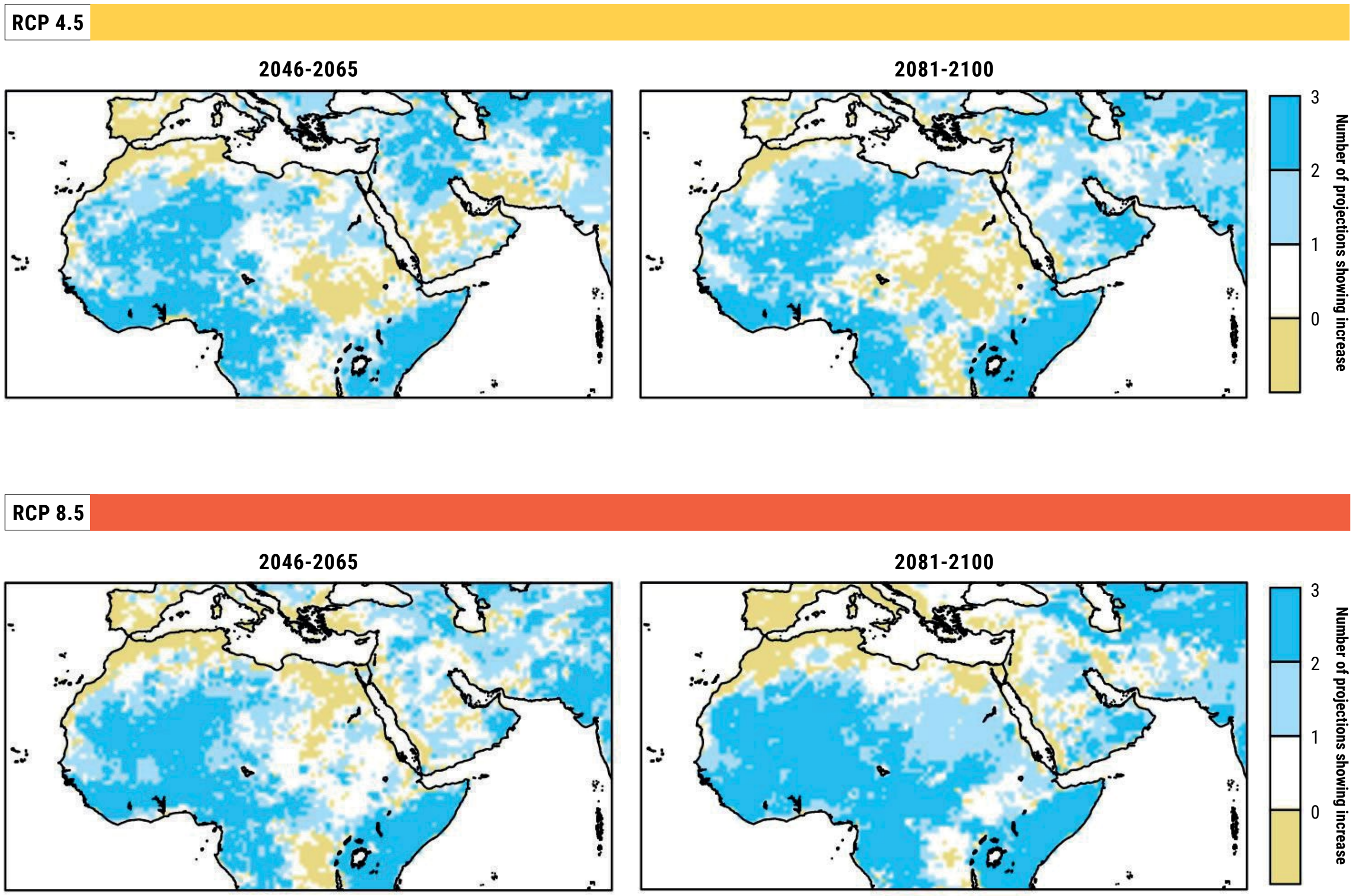


FIGURE 24: Agreement on mean change in annual precipitation from the reference period between the ensemble of three RCP 4.5 and three RCP 8.5 projections for mid- and end-century



Note: Brown indicates where all ensemble projections agree on a decrease in precipitation, dark blue indicates where all agree on an increase in precipitation, white indicates where two of three projections show a decrease and light blue indicates where two out of three projections show an increase.

Figure 24 indicates where the three ensemble members are in agreement regarding positive or negative change in annual precipitation. This inter-model agreement (disagreement) can be used as a measure of high (low) robustness for the climate change signal.

As can be seen, projections agree on a decrease of rainfall 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 and for the coastal areas of the Arabian Peninsula along the Red Sea.

Agreement on the projected increases of precipitation appears in various patterns in the Arabian Peninsula across time periods and scenarios such as in the south-eastern Arabian Peninsula and the Sahel.

Sharjah, United Arab Emirates, 2013. Source: Khajag Nazarian.

2.1.3 Changes in extreme temperature indices

Overall, looking at the extremes for temperature, all of the indices relating to hot days show increasing trends as expected. Changes in both the number of hot days (SU35) and the number of very hot days (SU40) show generally larger increases than the number of summer days (SU). The latter finding is not surprising as the number of summer days for present climate is already high over most of the region.

For these indices, the RCP 8.5 scenario at the end of the century stands out as a particularly harsh change for living conditions. This holds for the number of tropical nights (TR) as well, which indicates dwindling chances that there will be a cooler evening after a hot day. The hot days (SU35) indicator shows a particularly strong warming along the Mediterranean coast for eastern Libya and Egypt.

The results towards the end of the century for SU35 (Figure 26) show significant warming trends for both scenarios reaching an increase of up to 80 days in the southern Arabian Peninsula and on the western coast of Africa for the RCP 8.5 emission scenario. Changes for the SU40 indicator (Figure 27) show strong projected warming in the Sahara and central Arabian Peninsula areas for RCP 8.5, indicating 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 baseline period, the TR indicator exhibits significant warming trends over time with a projected increase mainly in central Africa and southern Arabian Peninsula regions, particularly for RCP 8.5. According to the literature, there are indications that night-time temperature extremes in the Arabian Peninsula are potentially affected by the Indian Ocean sea-surface temperatures.[3]

This index has considerable implications with regards 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).

FIGURE 25: Mean change in the number of summer days (SU) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

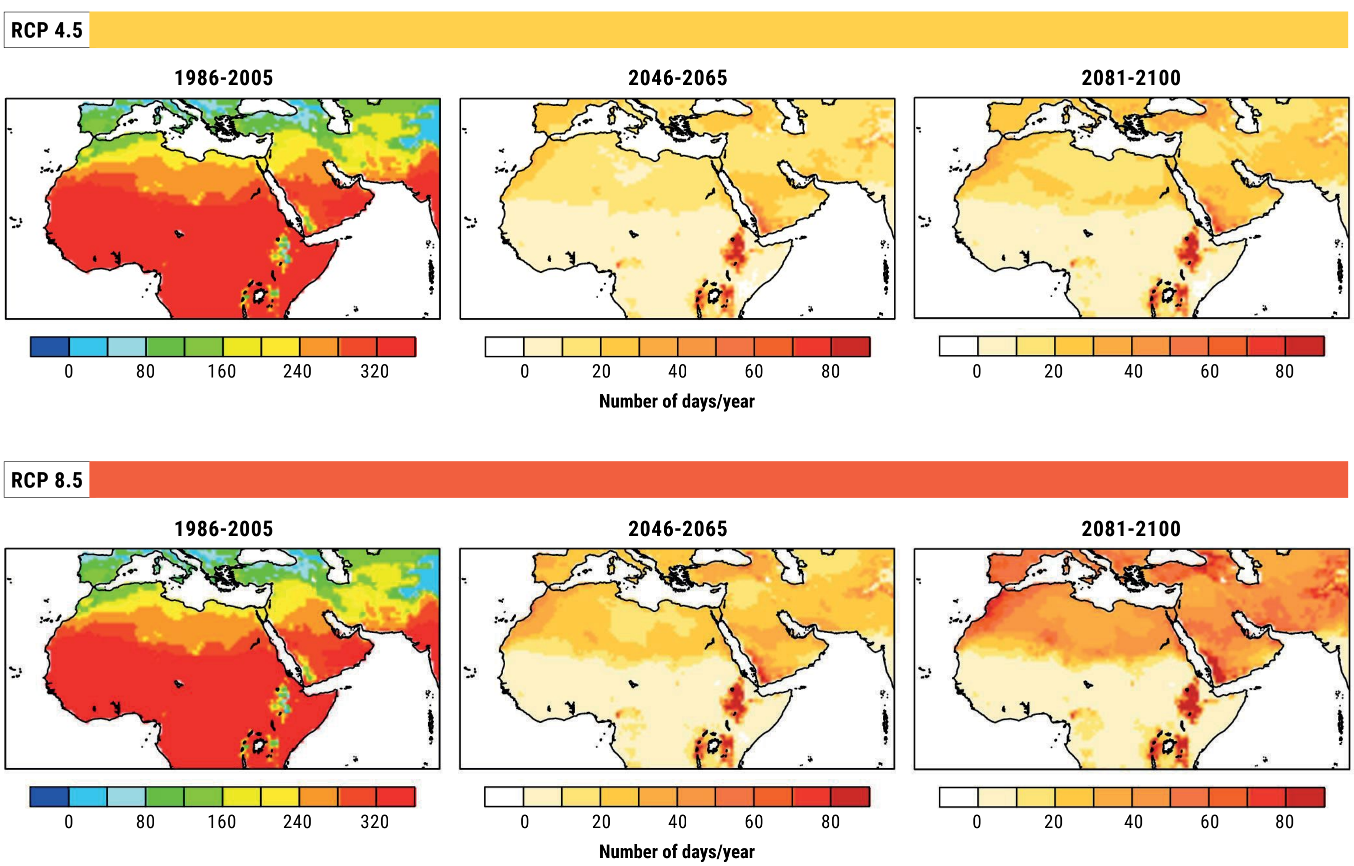


FIGURE 26: Mean change in the number of hot days (SU35) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

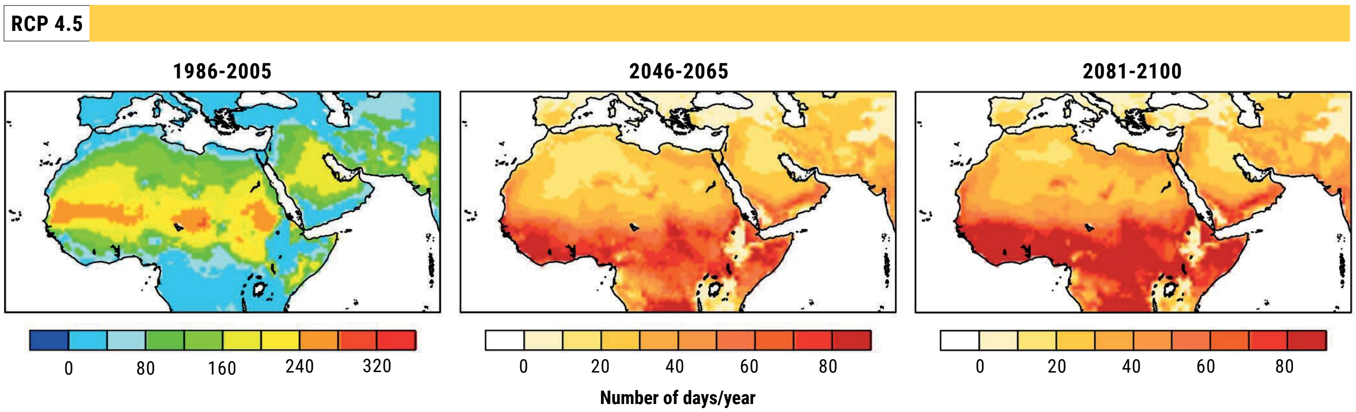


FIGURE 27: Mean change in the number of very hot days (SU40) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

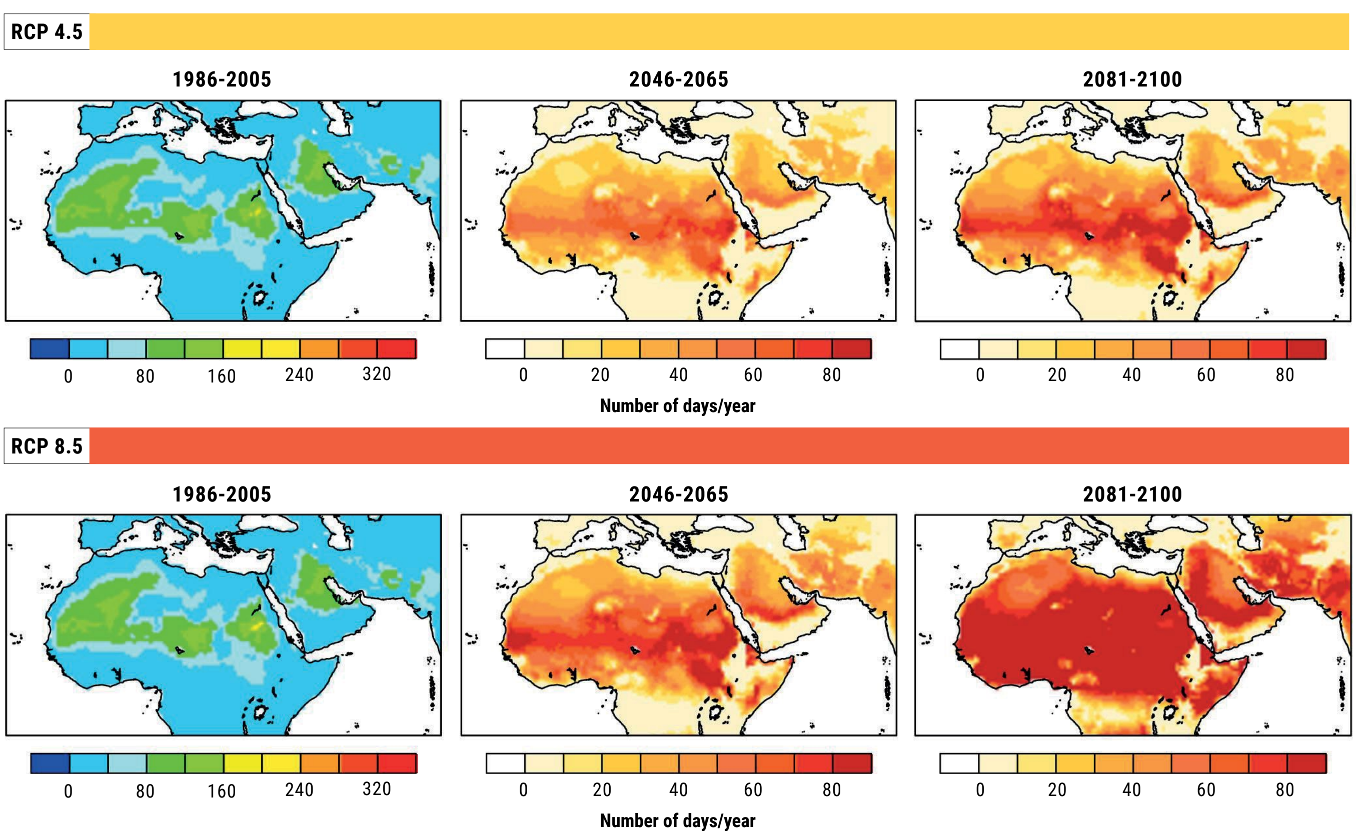
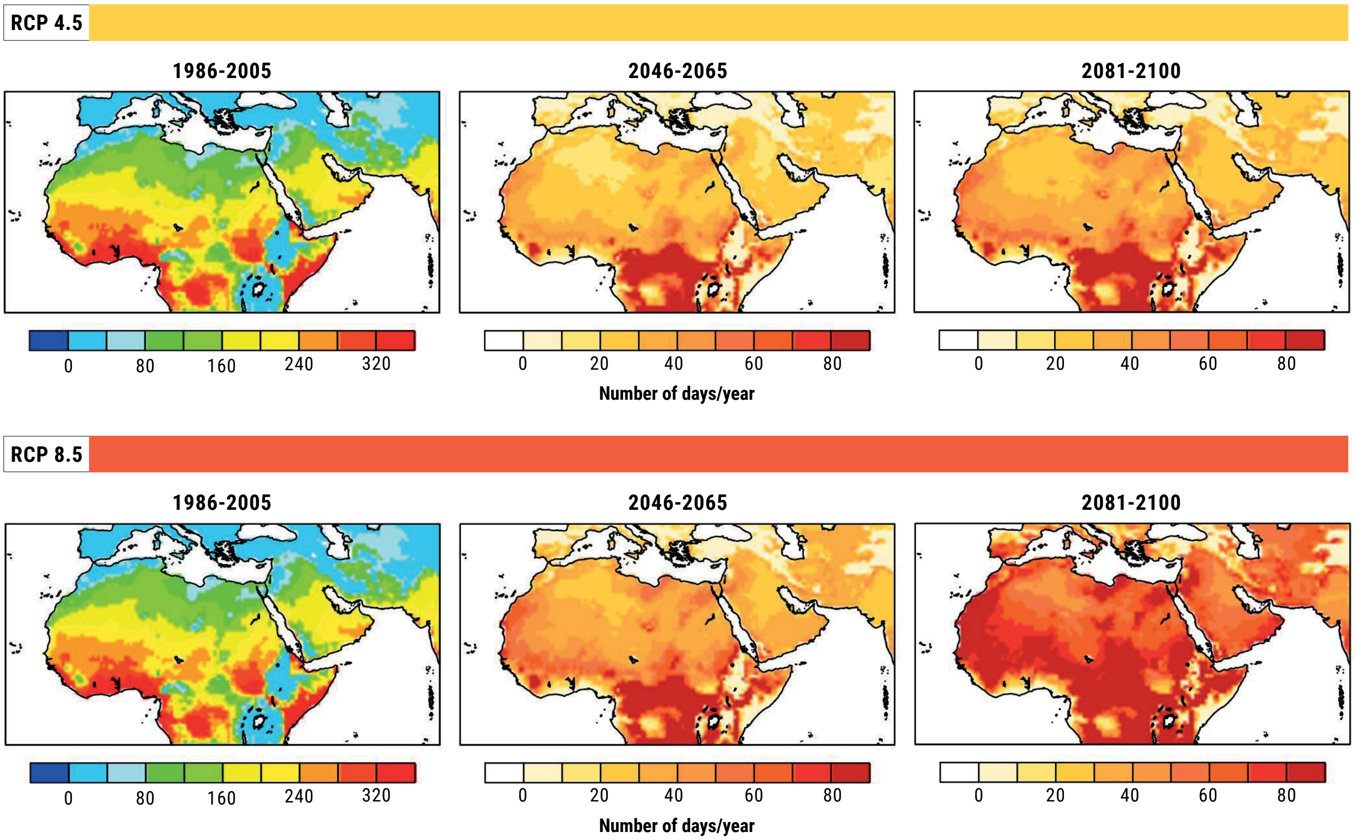


FIGURE 28: Mean change in the number of tropical nights (TR) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period



2.1.4 Changes in extreme precipitation indices

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 with an increase in the number of consecutive dry days specifically for the Mediterranean, as well as the western and northern parts of the Arabian Peninsula by the end of the century (Figure 29). Changes in the length of dry spells are expected to be more significant under the RCP 8.5 scenario and towards the end of the century. The increases in CDD 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 part of North Africa 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.

Changes in the annual number of 10 mm precipitation days (R10) indicate decreasing trends over time compared to the baseline period (Figure 31). Similarly, results for the annual number of 20 mm precipitation days (R20) (Figure 32) for the end of the century are similar to the R10 index, suggesting a projected overall reduction in rainy days with these intensities over the region.

The simple precipitation intensity index (SDII) in Figure 33 shows increasing trends across the majority of the region for all the climate projections, except for the Moroccan Highlands, which stands out as the only one where all projections showed a decreasing trend.

Storm in Beirut, Lebanon, 2014. Source: Carol Chouchani Cherfane.

FIGURE 29: 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

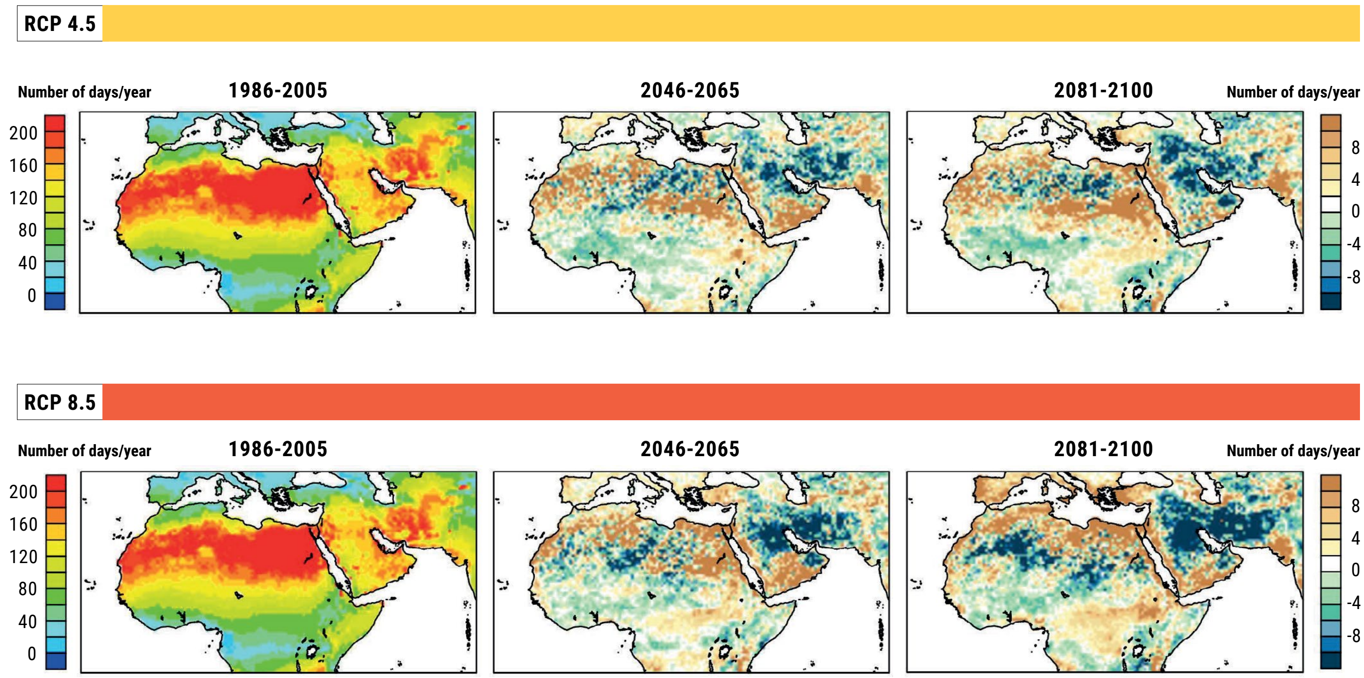


FIGURE 30: Mean change in the maximum length of wet spell (CWD) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

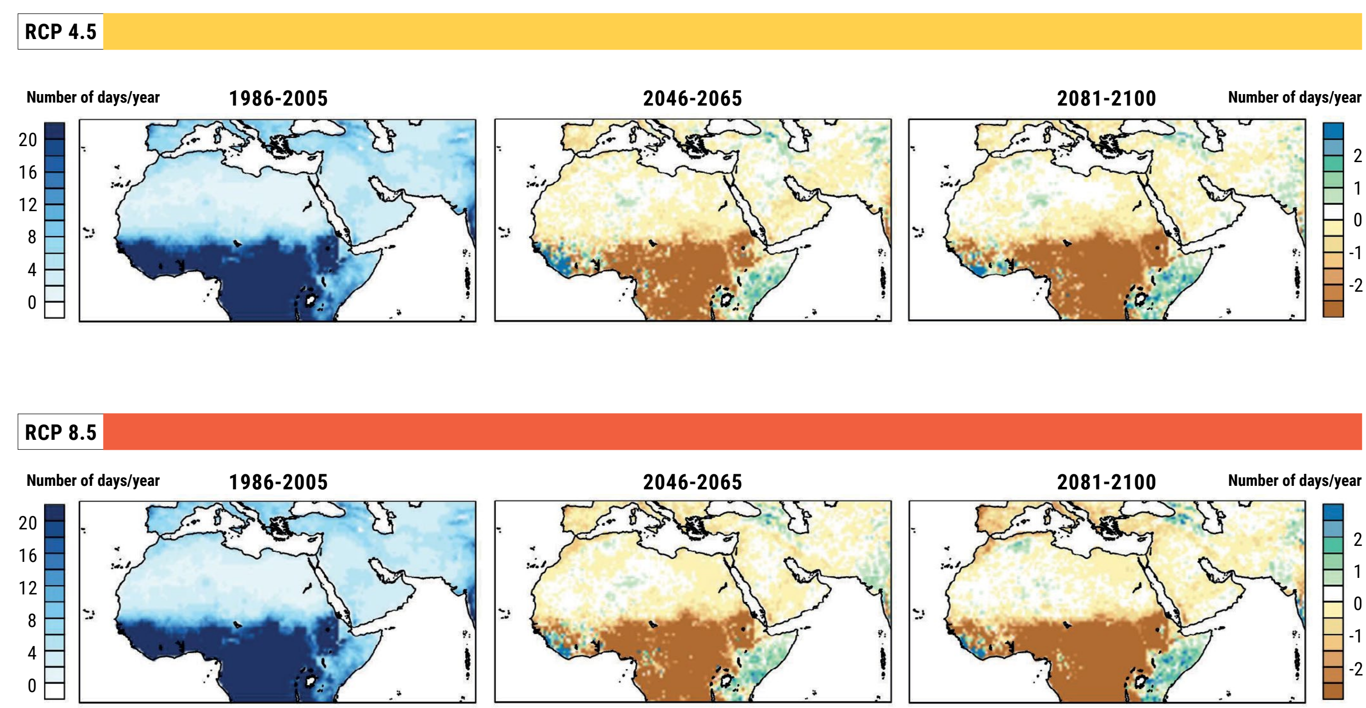


FIGURE 31: Mean change in the number of 10 mm precipitation days (R10) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

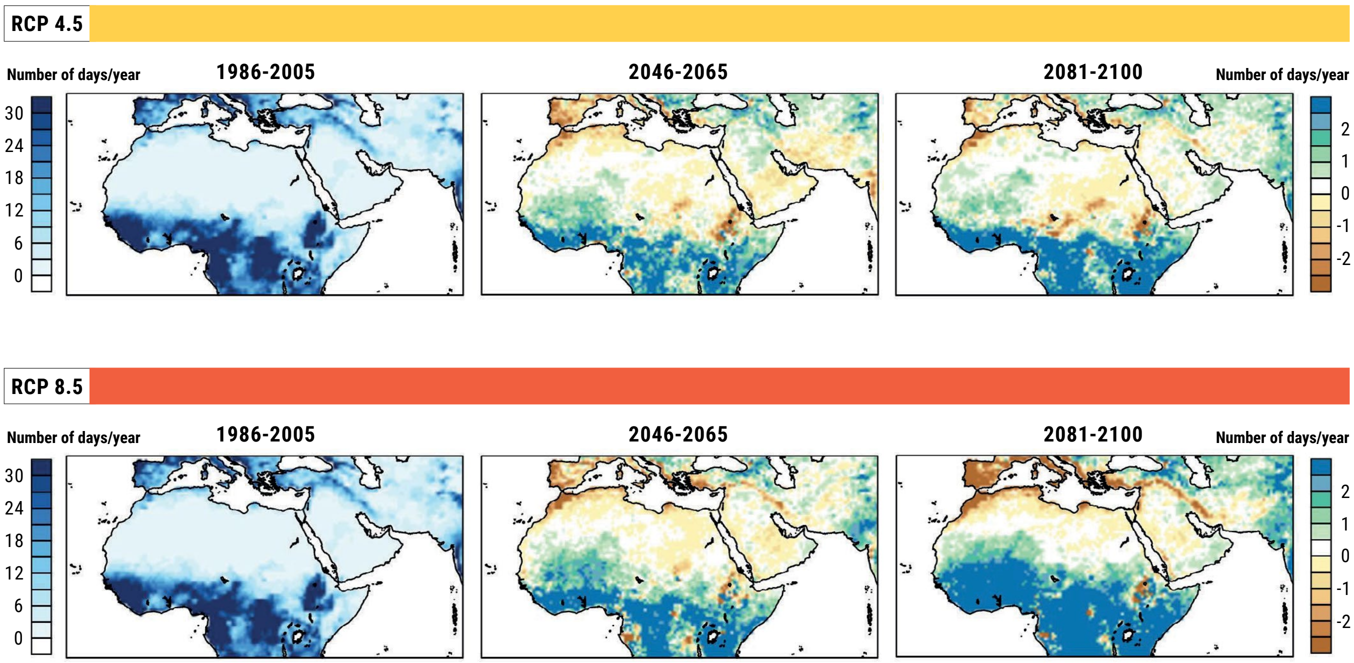


FIGURE 32: Mean change in the number of 20 mm precipitation days (R20) (days/yr) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period

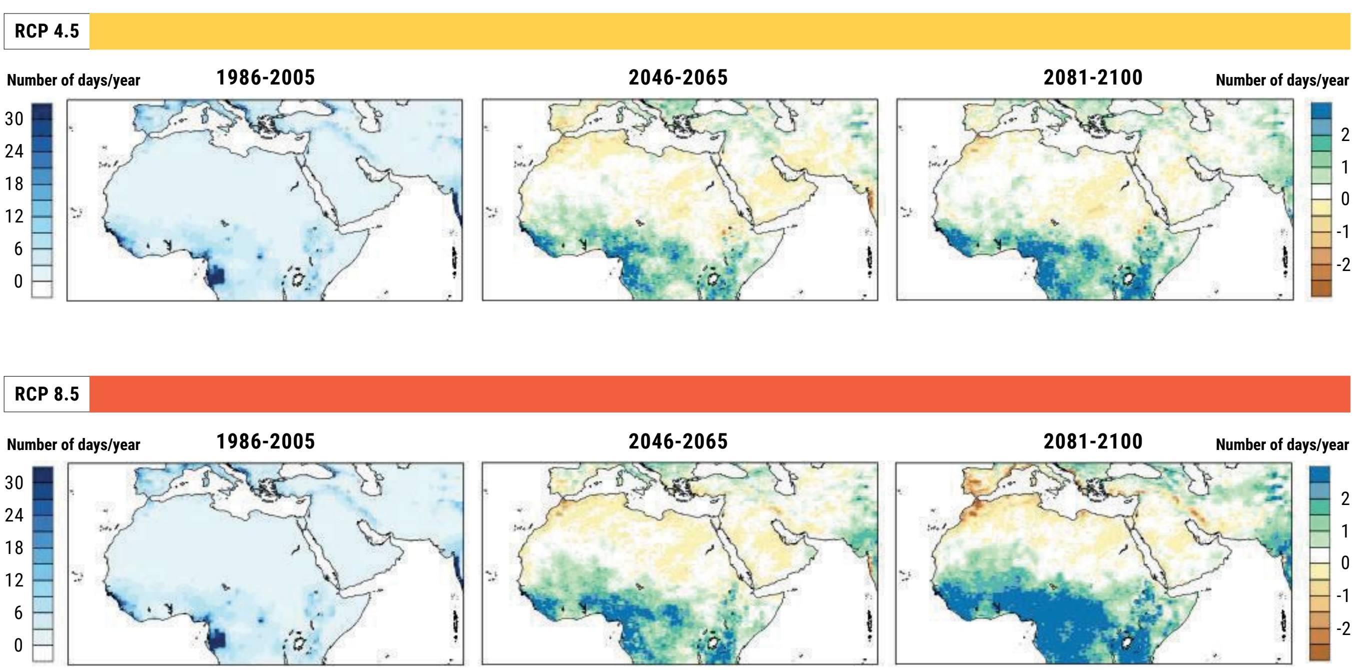
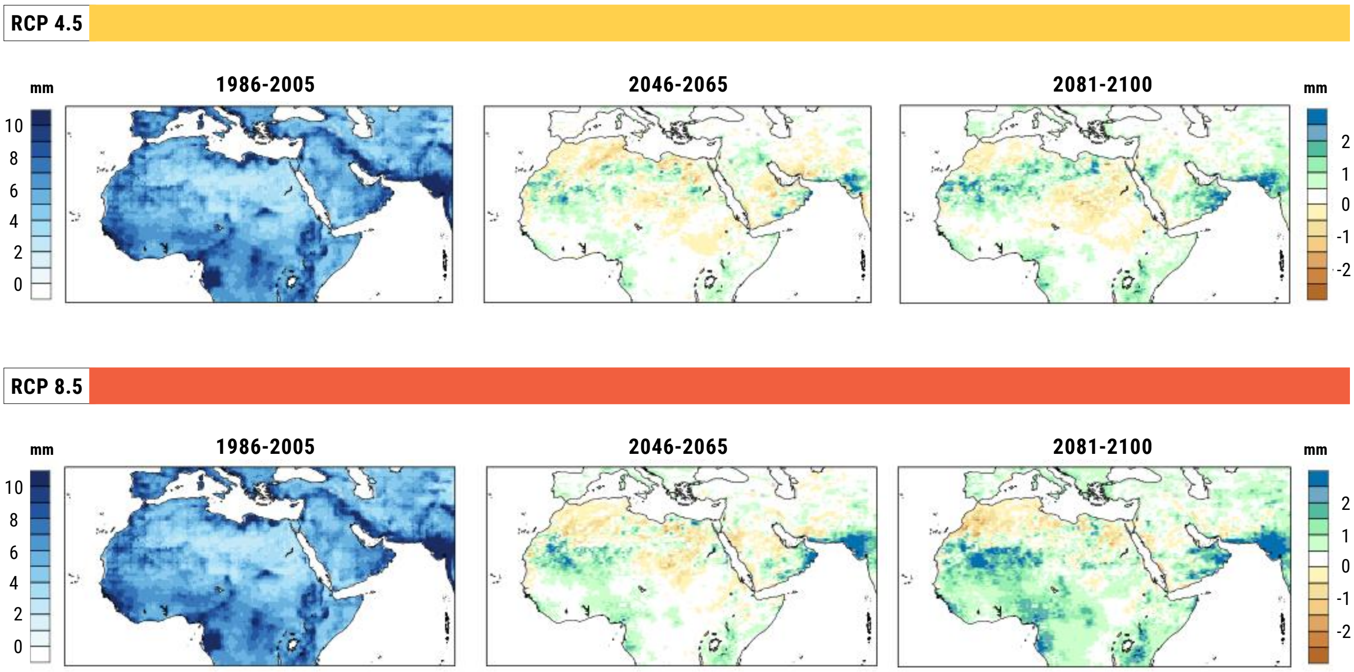


FIGURE 33: Change in the Simple Precipitation Intensity Index (SDII) (mm) for mid- and end-century for ensemble of three RCP 4.5 and RCP 8.5 projections compared to the baseline period



2.2 COMPARATIVE ANALYSIS WITH OTHER REGIONAL CLIMATE MODELLING ASSESSMENTS

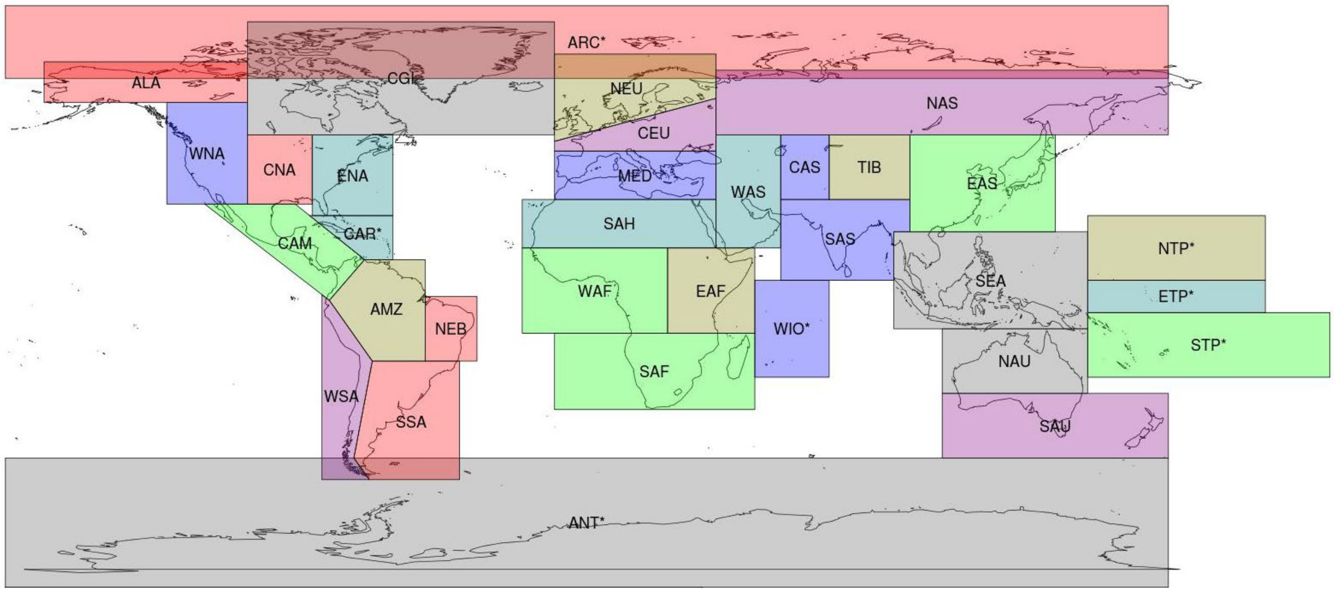
2.2.1 IPCC AR5 findings relating to Arab States

Temperature and precipitation projections from the IPCC AR5 are based on a global synthesis output from around 40 GCMs CMIP5 simulations, most of them performed by independent modelling groups. In addition to the focus and discussion mainly of global results (which was the case for the previous reports), IPCC adopted a more systematic regional assessment that was presented in the Atlas of Global and Regional Climate Projections (annex in AR5).[4] This regionalized climate change assessment effort was based purely on the output of global models and no statistical or dynamical downscaling methods were considered.
The corresponding Arab region as defined in RICCAR is encompassed in five of these subregions as shown in Figure 34, namely: South Europe/Mediterranean (MED), Sahara (SAH), West Africa (WAF), East Africa (EAF) and West Asia (WAS). Model projections reveal warming in all seasons in the different subregions under consideration, while precipitation projections are more variable and show some distinct subregional and seasonally dependent changes. The summary of outputs for the different scenarios and time periods presented hereafter are based on the 50th per centile (median) of the CMIP5 ensemble distribution.

In terms of temperature, projections for RCP 4.5 at mid-century suggest an increase of about 2 °C for most of the Arab region, except for the areas of southern Algeria and the central part of the Arabian Peninsula which, according to this scenario, will experience an increase of 3 °C. The projected warming is stronger at end-century compared to the baseline period (overall increase of 3 °C), with the exception of the southern coastal fringe of the Arabian Peninsula (2 °C warming). Projections for RCP 8.5 at mid-century are spatially similar to the RCP 4.5 scenario at the same time period, but with an additional 1 °C temperature increase overall. By end-century, the warming clearly intensifies with a 5 °C increase in temperature in North Africa compared to the reference period, 7 °C in Algeria and Morocco, 5 °C in the Mashreq area and Arabian Peninsula and reaching 7 °C in Iraq and Saudi Arabia.[5]

According to the IPCC, confidence levels for temperature projections for these subregions indicate that it is very likely that all of Africa will continue to warm during the 21st century. The overall quality of the CMIP5 models implies that the Sahara region, which is already hyper-arid, is likely to remain under this regime. There is, however, lower confidence in projection statements about the drying of West Africa.

FIGURE 34: Spatial boundaries of the geographical regions used in the IPCC 5th Assessment Report



Source: IPCC, 2015

Model agreement for West Asia and for the Mediterranean subregions indicate the likelihood that temperatures will continue to increase throughout the 21st century. Moreover, the length, frequency and/or intensity of warm spells or heatwaves were assessed as being likely to increase throughout the whole Mediterranean region.[6]

Results are much more spatially and temporally variable in terms of precipitation. Projections for the RCP 4.5 scenario at mid-century exhibit decreases in precipitation of about 10% over the Mediterranean, Sahara, Mashreq region and most of the Arabian Peninsula, with a more pronounced reduction (up to 20%) in areas of Morocco, Algeria and Mauritania. This projected decline of up to 20% also spreads over all North Africa at the end of the 21st century. On the other hand, increases in precipitation of up to 10% are projected for mid-century in Sudan, Somalia, north-eastern Saudi Arabia and the southern part of the Arabian Peninsula. According to the CMIP5 models, this increase will likely become widespread over most of the Arabian Peninsula by end-century. Under the business-as-usual RCP 8.5 scenario, the northern African coast, Mauritania and Mashreq will likely experience more dramatic decreases in precipitation compared to the baseline period (up to 20% for mid-century and 30%–40% for end-century), while increases are projected in central Africa for mid-century and intensify when moving south (up to 20% increase) and towards end-century (up to 40%). The major part of the Arabian Peninsula also exhibits increases in precipitation at mid-century (10%) which intensifies at end-century in central and southern parts, but shows decreases of up to 10% in the northern part over this sub-period.[7]

Interestingly, in the AR5 Regional Atlas and over subregions of Africa, the overall confidence in the projected precipitation changes is characterized, in the best case, as only medium, due to the overall limited ability of models to adequately represent the important local phenomena that have a strong influence on African climates. At the seasonal level, African subregions are projected to receive unaltered precipitation by 2081–2100 in the boreal winter half of the year (October to March), although somewhat elevated in RCP 8.5, and little change is projected in the six-month summer season. As for the West Asia subregion, there is medium confidence in projected changes showing an overall reduction in precipitation. At the seasonal level, precipitation in general is projected to decrease in both winter and summer. However, the various interacting dynamical influences on precipitation of the region (that models have varying success in capturing in the current climate) results in uncertainty in both the patterns and magnitude of future precipitation change. Most of the Mediterranean subregion exhibits a likely and notable decrease in summer mean precipitation, while no change or moderate reduction is projected in the winter half of the year.[8]

2.2.2 Findings from other corresponding climate projections

Other climate modelling projections have been undertaken for the CORDEX MENA region as part of a study by Lelieveld et al., 2016, using an ensemble of 26 CMIP5 model output for RCP 4.5 and RCP 8.5 comparing similar mid- and end-century time slices based on the baseline period 1986–2005.

A robustness check to evaluate the level of model agreement indicated that the models consistently project strong temperature changes, whereas precipitation results are much less consistent. In accordance with RICCAR results, model projections suggest that there is a clear projected warming with more marked increases for RCP 8.5 and that climate warming in the region is much stronger in summer than winter. Regarding temperature extremes, the indices studied were different than those selected in RICCAR but exhibit the same warming trends with increasing trends in heat extremes, in particular for the number of warm days and nights. It was shown that, on average, the maximum temperature during the hottest days in the recent past was about 43 °C, which could increase to about 46 °–47 °C by mid-century and would reach nearly 50 °C by the end of century for scenario RCP 8.5. The warm spell duration index (WSDI), which is an indication of present-day heatwaves, is projected to increase steeply from about 16 days in the reference period to 83–118 days by mid-century to more than 200 days by the end of the century for RCP 8.5. Additionally, while the coldest nights (TNn) in the reference period can be below frost point, temperatures turn positive in the first half of the century, increasing further to more than 4 °C by the end of the century for RCP 8.5. Based on these projections, there is an increasing risk that part of the region may become inhabitable for some species, including humans, at least for the warmer months of the year.[9]

The Atmospheric and Climate Modelling group of the Cyprus Institute has recently produced regional climate simulations for the Arab region using a climate version of the Weather Research and Forecasting (WRF) model forced by a bias-corrected version of NCAR's global Community Earth System Model (CESM1).[10] Projected changes of temperature suggest a general warming throughout the Domain. As expected from the climate scenarios used, this temperature increase is higher towards the end of the 21st century and under the business-as-usual RCP 8.5. For the reference period (1986–2005), all local temperature patterns were found to be consistent in both CYI-WRF and RICCAR-RCA4 simulation experiments, which was also evident for the projected changes with comparable results for the warming magnitude range and general spatial patterns. Locally, some discrepancies were apparent, particularly in the location of the hotspots of temperature climate change which are found to have slightly shifted northwards for the WRF simulations over North Africa. Such discrepancies are expected, however, due to the fact that the two regional models have substantial differences, while they are also forced by different global models. Projected rainfall changes have shown that reference period precipitation was in general agreement with the RCA4 simulations of RICCAR. Although not relevant for this study, WRF over parts of the Tropics is wetter than RCA4. Nevertheless, rainfall regimes over the arid and semi-arid parts of the Arab Domain were consistent between the two modelling experiments. Since precipitation is a more challenging variable to be modelled, local discrepancies between the RICCAR and CYI simulations were found. For example, the wetter conditions projected by RCA4 for the northern part of the Domain (more evident for mid-century and RCP 4.5 scenario) were not in agreement with WRF. RCA4 also indicates a slight precipitation increase over the southern Arabian Peninsula of the winter half of the year which was not evident in the WRF simulations. Nevertheless, the global models are also found to disagree on the sign of change over the particular region.[11]

As for other corresponding domains which overlap with the CORDEX-MENA Domain, a number of climate projection studies have been performed on related CORDEX domains such as CORDEX-AFRICA[12] (see following section), EURO-CORDEX[13] and Central Asia[14]. Most of the published East Asia and MEDCORDEX domain studies are, at the time of writing, dedicated to model optimization, evaluation and sensitivity experiments.

Apart from studies focusing on different CORDEX domains that encompass parts of the Arab region, model simulations have also been carried out on areas coinciding with the Arab Domain and are overall consistent with RICCAR projections (see Box 4).

2.2.3 Findings from CORDEX MENA compared to CORDEX AFRICA

Results obtained from CORDEX-MENA were compared to CORDEX-AFRICA simulations, that have a partially overlapping domain (25W–60E, 7S–42N). Because CORDEX-AFRICA data are not bias-corrected, only the RCM outputs from both datasets were analysed. An ensemble for end-century was obtained for CORDEX-AFRICA based on nine differing GCMs at 50-km resolution.

CORDEX-AFRICA outputs were subtracted from CORDEX-MENA outputs and show that, throughout the region, the change in temperature is generally higher for the CORDEX-AFRICA ensemble with an increase up to 1.1 °C noted in North Africa and the Arabian Peninsula. Differences generally decrease from the coastline towards the inland parts of North Africa (Figure 35). This is somehow expected, as parts of the common domain that exhibit the larger discrepancies between the two sets of simulations are located near the edges of one of the two CORDEX domains (e.g. the Tropics or Mediterranean Coast of Africa) and are thus strongly affected by the regional models' buffer zone. The range of the RICCAR CORDEX-MENA simulations is determined by obtaining the minimum and maximum values between the three ensemble members. For most of the extent of the common domain, one to six of the nine CORDEX-Africa models are within range of the CORDEX-MENA ensemble (Figure 36). Areas with low differences in temperature have better agreement, such as the Atlantic coast and Sahara Desert, where nearly all CORDEX-AFRICA models are within range. Conversely, areas with large differences in temperature have no agreement for range, for example the Tigris-Euphrates basin for RCP 8.5. Worthy of note is that areas where the CORDEX-AFRICA projections are out of the range of the CORDEX-MENA ones are of very limited extent, highlighting the confidence in the RCA4 projections used in this report.

FIGURE 35: Comparison between CORDEX MENA and CORDEX AFRICA outputs for temperature change at end-century

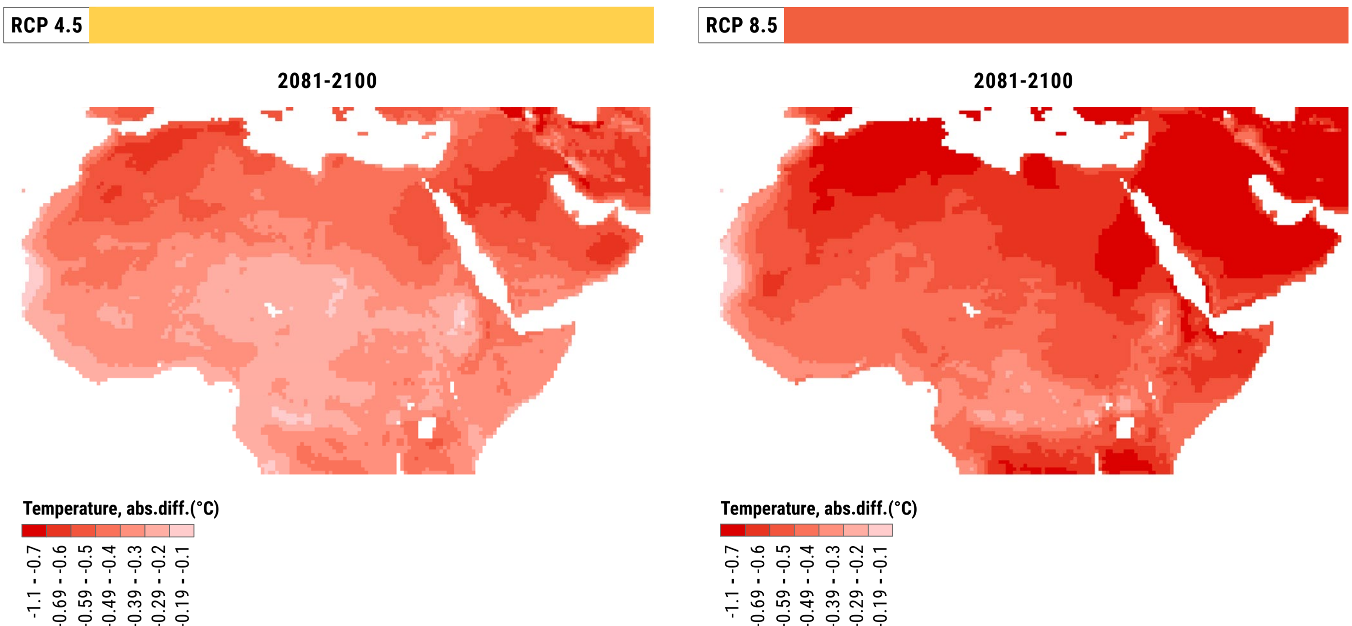
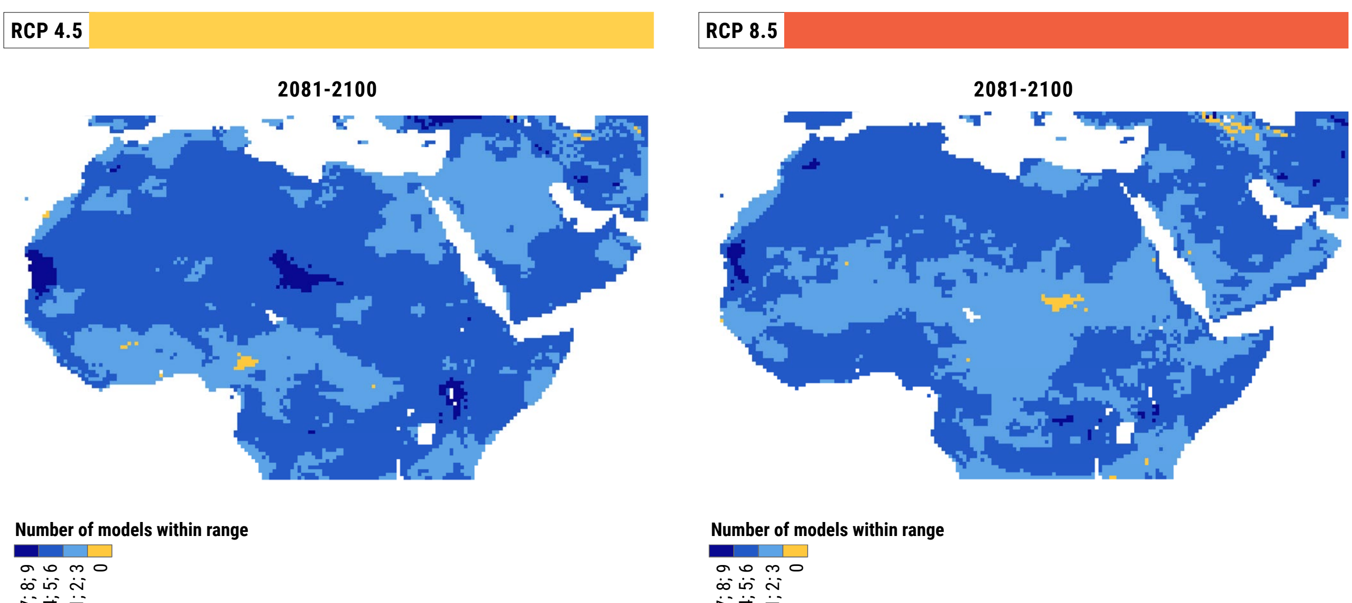


FIGURE 36: Number of CORDEX AFRICA models within the range of CORDEX MENA models for temperature at end-century



Similar to temperature, differences in precipitation values are determined by subtracting CORDEX- AFRICA from CORDEX-MENA. However, for both ensembles, the data are first normalized by the reference period. Precipitation values tend to be greater for the south-western Arabian Peninsula and sub-Saharan Africa. On the other hand, CORDEX-MENA values tend to be greater in the south-eastern Arabian Peninsula and the Sahara Desert (Figure 37). Nevertheless, these regions are characterized by very low precipitation amounts.

The range of results obtained from the CORDEX-MENA ensemble was also compared to CORDEX AFRICA and the range was determined by the minimum and maximum value obtained from the CORDEX MENA ensemble. Values were normalized by the reference period. Results show that, overall, one to six of the nine models were in agreement. As with temperature, limited areas, spread throughout the common domain are found with low or no agreement (Figure 38).

FIGURE 37: Comparison between CORDEX MENA and CORDEX AFRICA outputs for precipitation change at end-century

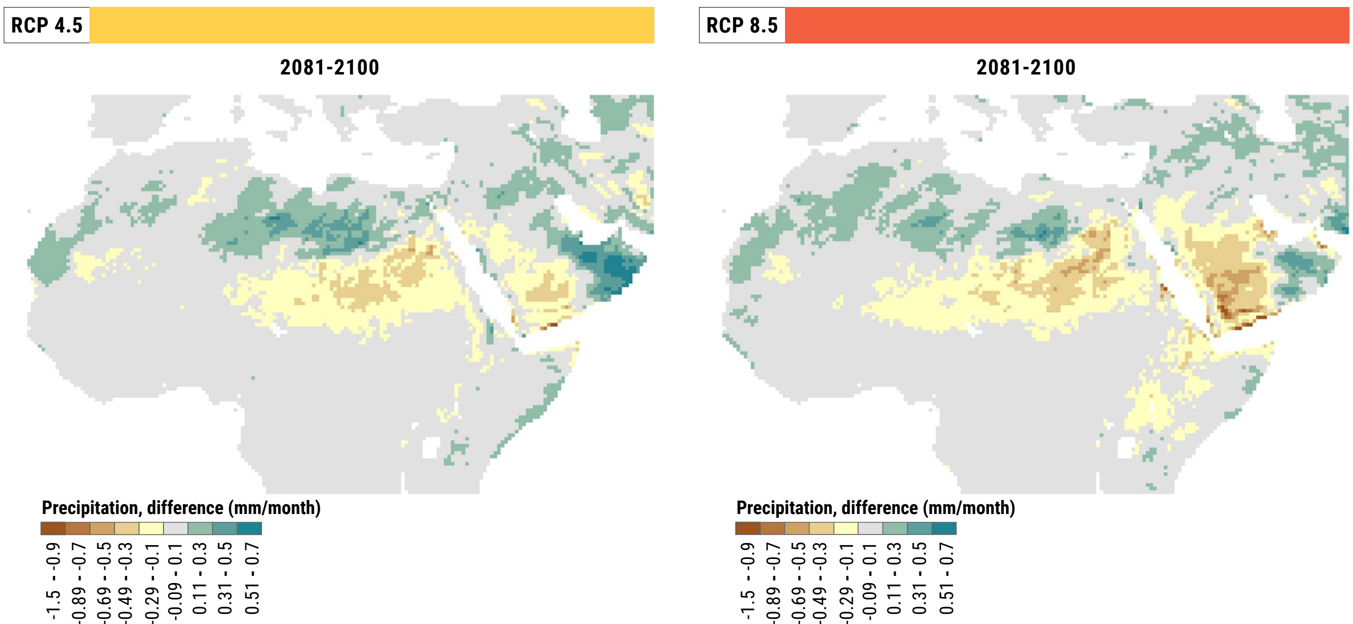
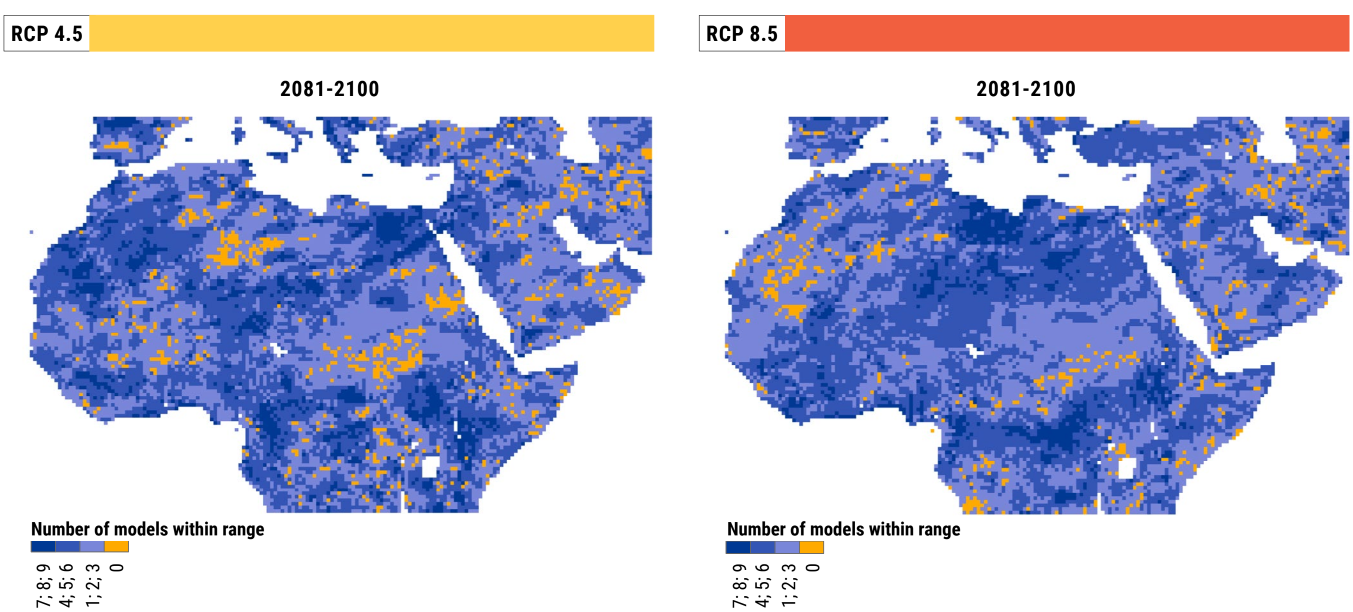


FIGURE 38: Number of CORDEX Africa models within the range of CORDEX MENA models for precipitation at end-century



Although this evaluation considered end-century only, it is assumed that similar trends will emerge for mid-century. Because a comparison was conducted using RCM output, it is also assumed that differences in values will be greatly reduced if DBS ensemble output is compared.

BOX 4: ALADIN-Climate projections for the Arab region

A set of climate simulations conducted by Direction de la Météorologie Nationale of Morocco (DMNMOR) assess future climate change over the Arab region using the climate version of the Aire Limitée Adaptation dynamique Développement InterNational (ALADIN) or ALADIN-Climate Model, at a horizontal resolution of 50 km.[15] This dynamic regional climate model follows the same physical characteristics as the general circulation model ARPEGE–Climate[16] used in the CMIP5 exercise (an atmospheric model of CNRM-CM5). It is a bi-spectral RCM with a semi-implicit, semi-lagrangian advection scheme and its configuration includes an 11-point wide bi-periodization zone in addition to the more classical 8-point relaxation zone. ALADIN comprises the Fouquart and Morcrette radiation scheme (FMR15)[17] based on the European Centre for Medium Range Forecasts (ECMWF) model, incorporating effects of greenhouse gases (CO_2, CH_4, N_2O and CFC) and direct effects of aerosols, as well as the first indirect effect of sulphate aerosols. The vertical discretization of this RCM is 31 levels mostly located in the troposphere with a time step of 15 minutes.

Version 5 of ALADIN-Climate was used in this work, as was the case within the framework of MedCORDEX. Version 4 of the RCM was used for the European ENSEMBLES project where it was inter-compared with several European RCMs at 50-km and 25-km resolution,[18] and was also used for the assessment of future climate changes over Morocco.[19]

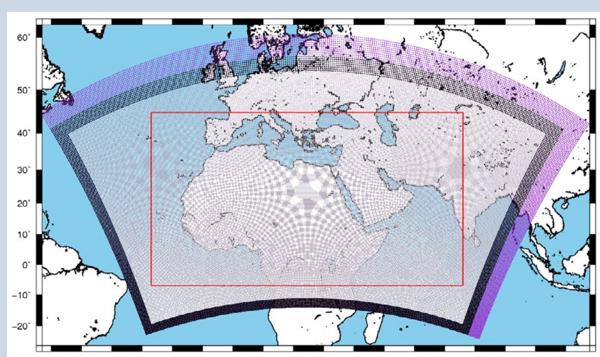
TABLE 12: Description of simulations

Institute	Model	Resolution	Driving model	Driving experiment	Period
DMN-MOR	ALADIN	0.44°	CNRM-CM5	CNRM-CM5	1971–2005
DMN-MOR	ALADIN	0.44°	CNRM-CM5	RCP 4.5	2006–2100
DMN-MOR	ALADIN	0.44°	CNRM-CM5	RCP 8.5	2006–2100

Three simulations have been carried out by ALADIN-Climate with a horizontal resolution of 50 km driven by CNRM-CM5 (see Table 12).[20] The historical simulation covers the period 1971–2005. The other two were run under the two emission scenarios RCP 4.5 and RCP 8.5 over the period 2006–2100. The full spatial domain (including the Davies relaxation zone) for the RCM is illustrated in Figure 39, noting that the area considered for analysis (red rectangle) coincides with the CORDEX-MENA Domain.

Future changes in the Arab region climate have been assessed by calculating a set of climate change indices covering both mean and extreme aspects, namely the annual mean temperature, the heatwave duration index[21], the annual total rainfall amount and the annual maximum number of consecutive dry days.[22] Figure 40 and Figure 41 show the future changes stemming from ALADIN-Climate for the different variables under RCP 4.5 and RCP 8.5, respectively. The changes are calculated for the future period 2036–2065 compared to the reference period 1971–2000.

FIGURE 39: Spatial extent of the Domain considered using ALADIN-Climate



Note: the area within the red rectangle includes the entire Arab region and was considered for analysis.

FIGURE 40: Future changes in different variables from ALADIN-Climate projections for RCP 4.5 for the future period 2036–2065 compared to the reference period 1971–2000

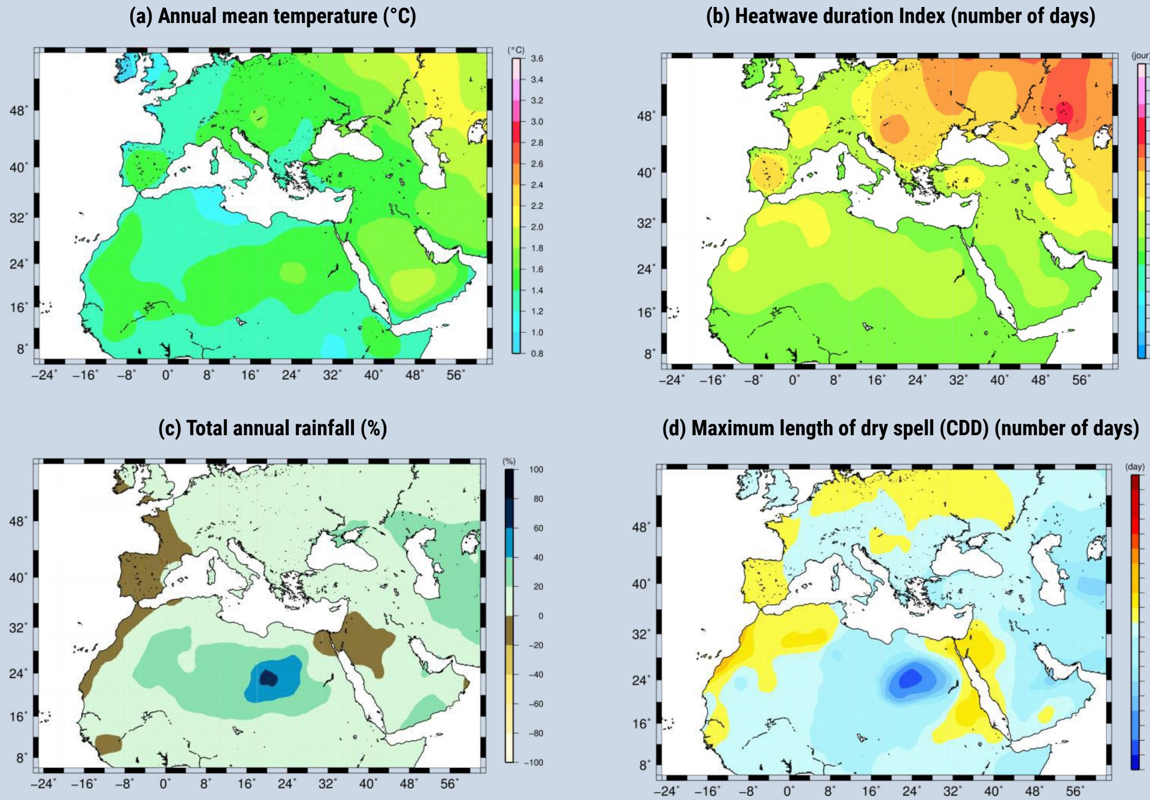
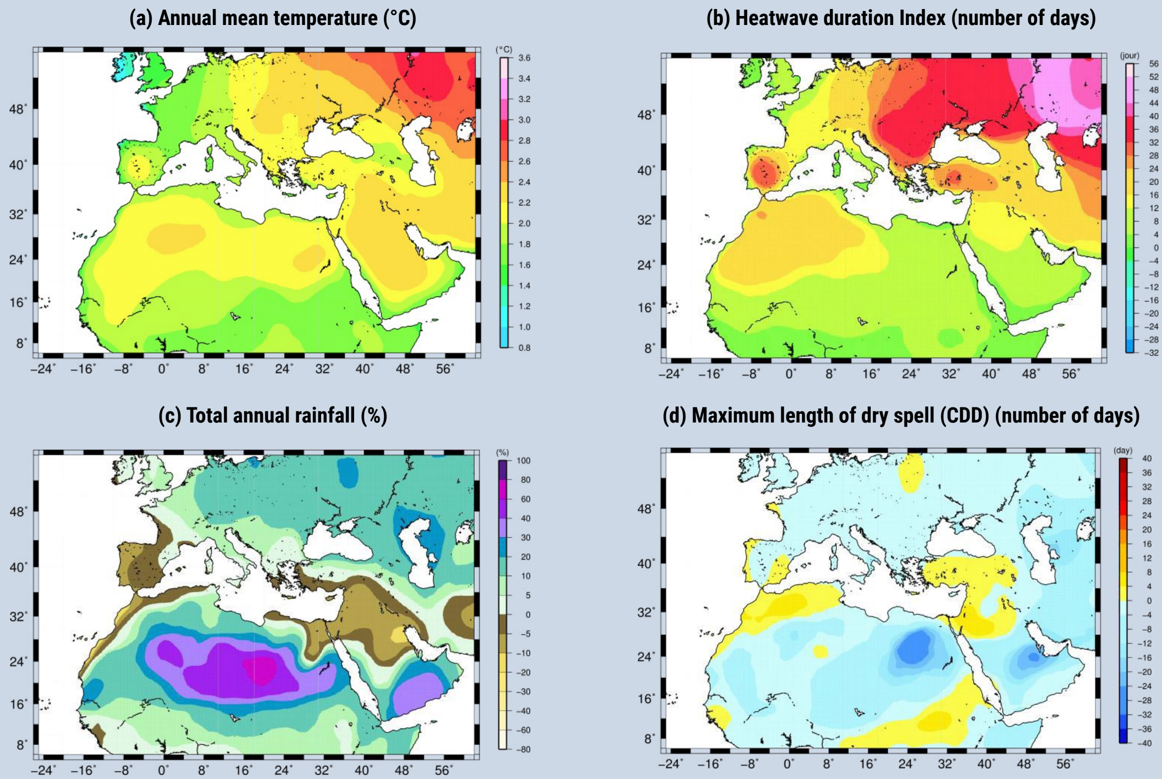


FIGURE 41: Future changes in different variables from ALADIN-Climate projections for RCP 8.5 for the future period 2036–2065 compared to the reference period 1971–2000



As potentially expected, results show a projected generalized warming for the whole region in the future. This temperature rise generally ranges between 1 °C and 1.2 °C for the emissions scenario RCP 4.5, reaching 2.2 °C to 2.4 °C under RCP 8.5 in the Arabian Peninsula.

Extreme heat events are also projected to increase, with heatwaves longer by about 4–16 days under RCP 4.5 with the highest values located in the western part (Morocco and Algeria) as shown in Figure 40b. The increase in temporal persistence of heatwaves is even higher with RCP 8.5 and reaches 16–20 days over Morocco, Algeria and western Libya (Figure 41b).

In contrast to temperature, precipitation changes show less consistency through the region. For RCP 4.5, a decrease in precipitation of up to 20% is projected in the western part (Morocco) and in the northern part of the Arabian Peninsula. The remaining zones show an increase that can reach 20–40% or even more such as in the southern regions of Algeria, Libya, Egypt and the Arabian Peninsula which are desert regions that register very little precipitation in the current climate (Figure 40c). These projected increases represent not more than 30 mm of total rainfall per year in most cases. Trends under RCP 8.5 are similar in terms of spatial distribution, with more intense changes and an extension of the drying area from Morocco to northern Algeria and over the Arabian Peninsula (Figure 41c).

A seasonal analysis of changes under the RCP 8.5 scenario showed a trend towards less total rainfall amounts in winter generalized to nearly the entire region. The contrasted changes of precipitation across the region have already been reported in previous studies, even when using GCMs with lower resolutions than the one used in this study.[23] In this context, it is important to point out that, although the Arab region displays important climate similarities, there are a number of differences between subregions associated with differing atmospheric circulation and rainfall patterns characterizing the area.[24]

Changes in the maximum length of dry spell (CDD) which represents extreme droughts are generally consistent with the projected future evolution of rainfall amounts (Figures 40d and 41d); with more persistent severe drought over the western part (Morocco), the northern half of Algeria and around the Red Sea. This type of projected evolution is consistent with previous results like those found by Sillmann et al., 2013.

Overall, projected changes in climate for the period 2036–2065 from ALADIN-Climate thus exhibit the following:

- A generalized warming over the entire region, varying from 1 °C to 2.4 °C, depending on the scenario and subregions, which is projected to appear also in terms of increase in heatwave duration;
- A projected decrease in annual total rainfall amounts in the western part of the Domain (mainly in Morocco) and in the northern Arabian Peninsula;
- More persistent extreme droughts in the north-western part of the region (Morocco and Algeria).

Source: Fatima Driouech and Khalid El Rhaz, National Climate Centre, Direction de la Météorologie Nationale, Morocco

Acknowledgements: The authors are grateful to the National Meteorological Service of Morocco (Direction de la Météorologie Nationale) for having provided the necessary computing resources and staff needed for conducting this work.

2.3 PROJECTED CHANGE IN CLIMATE IN THE MOROCCAN HIGHLANDS

Projected changes in temperature, precipitation and extreme events indices for the Moroccan Highlands subdomain are presented in Figure 42.

For scenario RCP 4.5, the change in mean temperature shows an increase of 1.4 °C by mid-century and of 1.8 °C towards the end of the 21st century. Under RCP 8.5, temperature increases are accentuated with a mean of 2.2 °C change for mid-century and 4.1 °C by end-century.

With regard to precipitation, model simulations indicate a reduction over time compared to the baseline period, which is more severe for RCP 8.5. This change is of about –9% for RCP 4.5 at mid-century and –11% at end-century. For RCP 8.5, mean precipitation change is –13% for mid-century and –23% by end-century. This subdomain also stands out in terms of precipitation extremes such as the SDII indicator, whose projections all showed a decreasing trend, unlike the other subdomains which exhibited either an increase or no change in the SDII indicator over time. Looking at seasonal changes, the greatest precipitation changes are projected for the winter months with a reduction of as much as 40% at the end- century sub-period for RCP 8.5. As mentioned in a previous section, this can potentially be explained by the strong influence of the NAO, particularly in winter precipitation. In general, during positive NAO phases, winter rainfall in Morocco tends to be lower than normal.[25] Besides the uncertainties in accurately simulating NAO, future climate models suggest an increasing trend of positive winter NAO for the 21st century.[26]

2.4 PROJECTED CHANGE IN CLIMATE ALONG THE MEDITERRANEAN COAST

Results showing projected changes in temperature, precipitation and extreme events indices for the Mediterranean Coast until the end of the century are presented in Figure 43.

Positive changes in temperature are projected over time. Mean change in temperature for RCP 4.5 is 1.2 °C at mid-century and 1.6 °C at end-century. Changes are stronger for RCP 8.5, with an increase of 1.8° C for mid-century and 3.4 °C for end-century. Regarding precipitation, trends are variable with no change for RCP 4.5 at mid-century and an increase of 4% at end-century. Projected results for RCP 8.5 show decreases (–8% and 16% for mid- and end-century, respectively). Changes in extreme temperature and precipitation generally follow these trends.

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

FIGURE 42: Mean change in temperature, precipitation and selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Moroccan Highlands

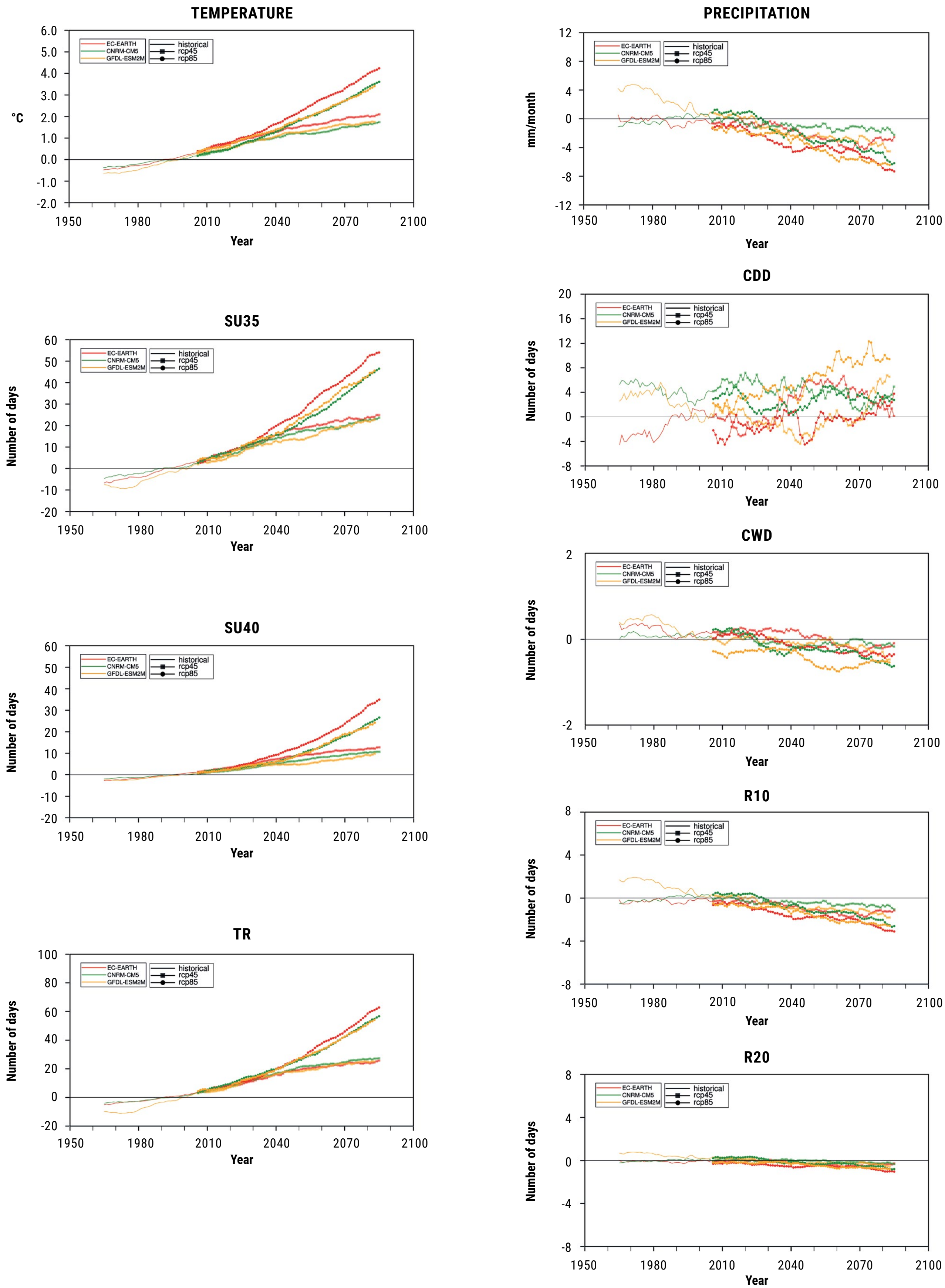
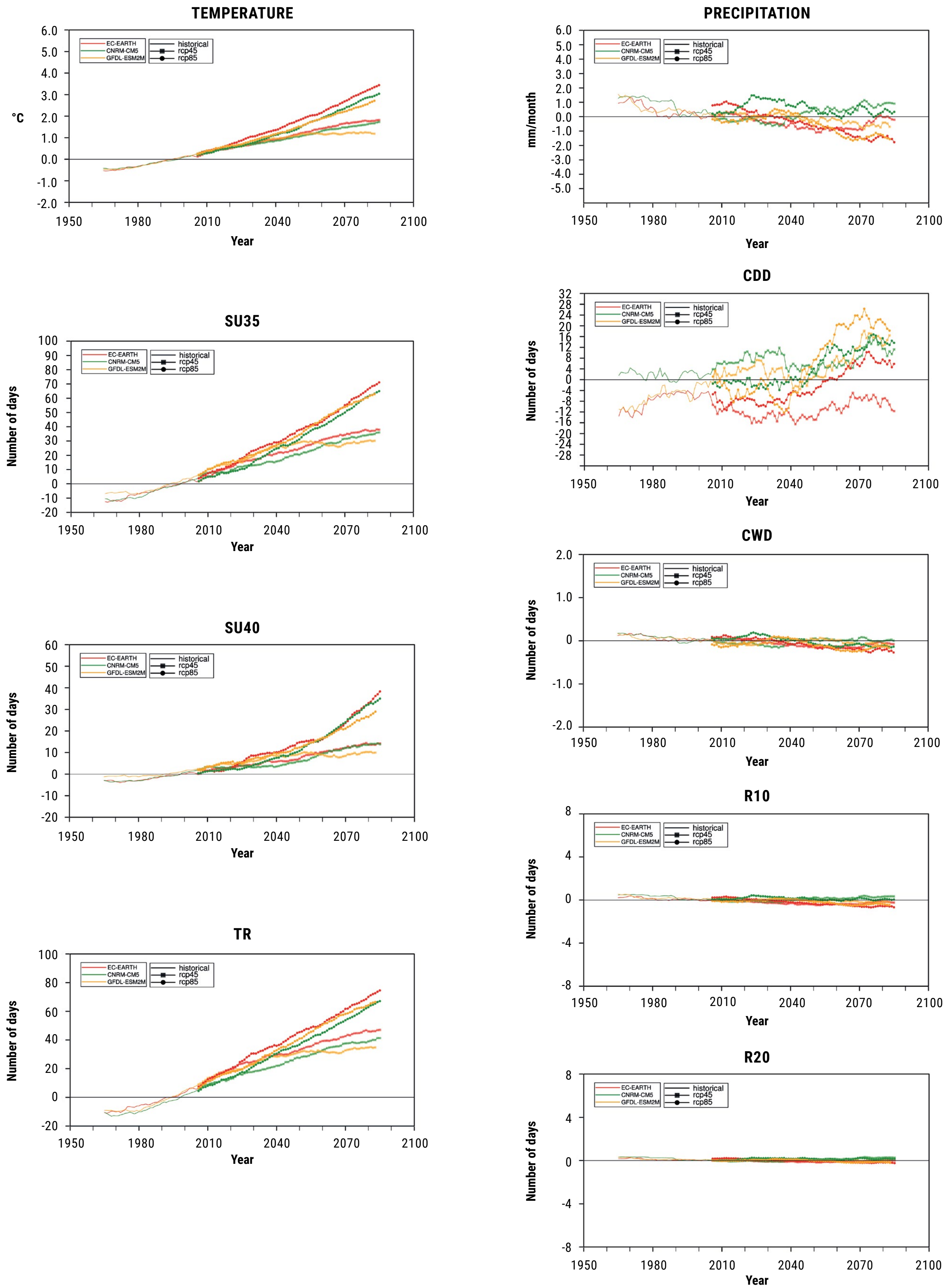


FIGURE 43: Mean change in temperature, precipitation and selected extreme event indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Mediterranean Coast



ENDNOTES

1. McGee et al., 2014; Schneider et al., 2014
2. Marchane et al., 2016
3. AlSarmi and Washington, 2014
4. IPCC, 2013a
5. IPCC, 2013a; IPCC, 2013b; IPCC, 2013c
6. Christensen et al., 2013
7. IPCC, 2013a; IPCC, 2013b; IPCC, 2013c
8. Christensen et al., 2013
9. Pal and Eltahir, 2016
10. Monaghan et al., 2014
11. IPCC, 2013a
12. For example, Laprise et al., 2013; Dosio and Panitz, 2016
13. For example,. Jacob et al., 2014
14. For example, Ozturk et al., 2017
15. Radu et al., 2008; Déqué and Somot, 2008; Farda et al., 2010; Colin et al., 2010; Nabat et al., 2015
16. Voldoire et al., 2012
17. Morcrette, 1990
18. Christensen et al., 2008; Sanchez-Gomez et al., 2009; Christensen et al., 2010
19. Driouech et al., 2009; Driouech et al., 2010
20. Salas y Mélia D. et al., 2005; Voldoire et al., 2012
21. The heatwave duration index is percentile-based and corresponds to the maximum number of consecutive days per period where maximum temperature is above its corresponding 90th percentile (Goodess, 2005).
22. Commonly known as maximum length of dry spell (CDD) based on ETCCDI, 2009.
23. i.e Sillmann et al., 2013
24. Donat et al., 2014
25. Marchane et al., 2016
26. For example, Gillett et al., 2003

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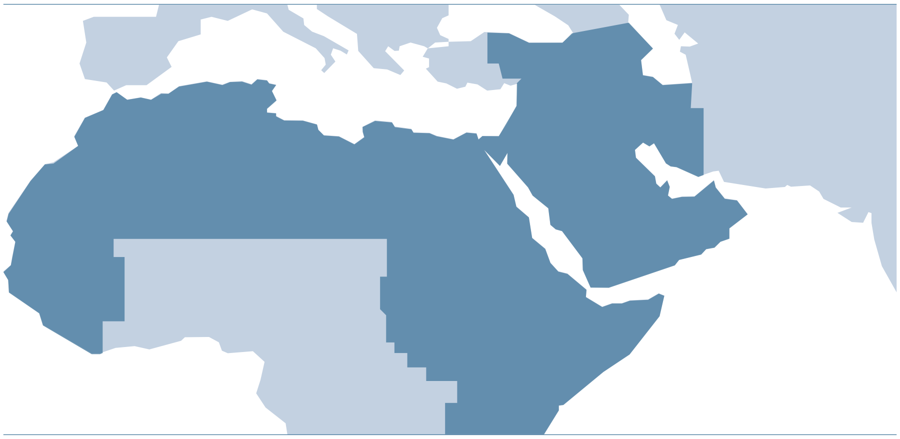
REGIONAL HYDROLOGICAL MODELLING: ARAB REGION



CHAPTER 3

REGIONAL HYDROLOGICAL MODELLING RESULTS FOR THE ARAB REGION AND SELECTED SUBDOMAINS

The regional hydrological modelling (RHMs) variables generated using the VIC and HYPE hydrological models include runoff, evapotranspiration, mean discharge (with related high-flow value and low-flow value), groundwater discharge, soil moisture and low soil moisture,[1] with selected findings reported in this chapter. These were generated for mid- and end-century considering RCP 4.5 and RCP 8.5 emission scenarios at a 50-km resolution. Comparisons with results of 25-km resolution are available for changes in runoff and discharge for the RCP 8.5 projections, noting that only two projections were available at this resolution and were thus not combined as an ensemble. Additional outputs are available in the Technical Annex.

As explained in the overview chapter, 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. Moreover, for some river and streams pertaining to specific subdomains, no observation datasets on discharge were available to verify the model. This was the case for the Moroccan Highlands (MH) and Mediterranean Coast (MD) subdomains, for which discharge-related outputs (mean discharge, high-flow value, low-flow value) will not be presented in the report due to this uncertainty. It is also worth pointing out at the increasing uncertainties in the results the higher the human influence on the river system compared to the size of the river. This is particularly true for small rivers such as the Jordan River and this issue should be taken into consideration when interpreting and analysing discharge-related outputs. Discharge-related outputs were only completed through the HYPE model but the runoff calculated from the VIC model that contributes to river discharge is included and compared to the HYPE model results.

3.1 PROJECTED CHANGES IN WATER AVAILABILITY DUE TO CLIMATE CHANGE IN THE ARAB REGION

3.1.1 Changes in runoff

Changes in area runoff over the Arab region are shown in Figure 44. Each plot summarizes the three member ensemble results from both the HYPE and VIC models. Although there are differences in some subregions, outcomes from the two hydrological models generally show similar trends of runoff change. The largest discrepancies appear to be at the upper reaches of the White Nile. Changes in runoff largely follow the same pattern of change as for precipitation change. 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 seen in Figure 45.

3.1.2 Changes in evapotranspiration

Changes in evapotranspiration over the Arab region are presented in Figure 46. Each plot summarizes the three member ensemble results from both the HYPE and VIC models. Intuitively, one would expect evapotranspiration to increase with rising temperature and this is most likely the case in places where water is not scarce. For the arid Arab region, however, water quantity is often a limiting factor and evapotranspiration thus decreases over time as there is less water available to evaporate or transpire. The pattern of change for evapotranspiration thus largely follows the pattern of change for runoff. For basins where there is 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 rivers during the winter season. Overall, projected changes in evapotranspiration are in line with the ensemble projection agreement presented in Figure 47.

FIGURE 44: Mean change in annual runoff (mm/month) for mid- and end-century for the ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period using two hydrological models

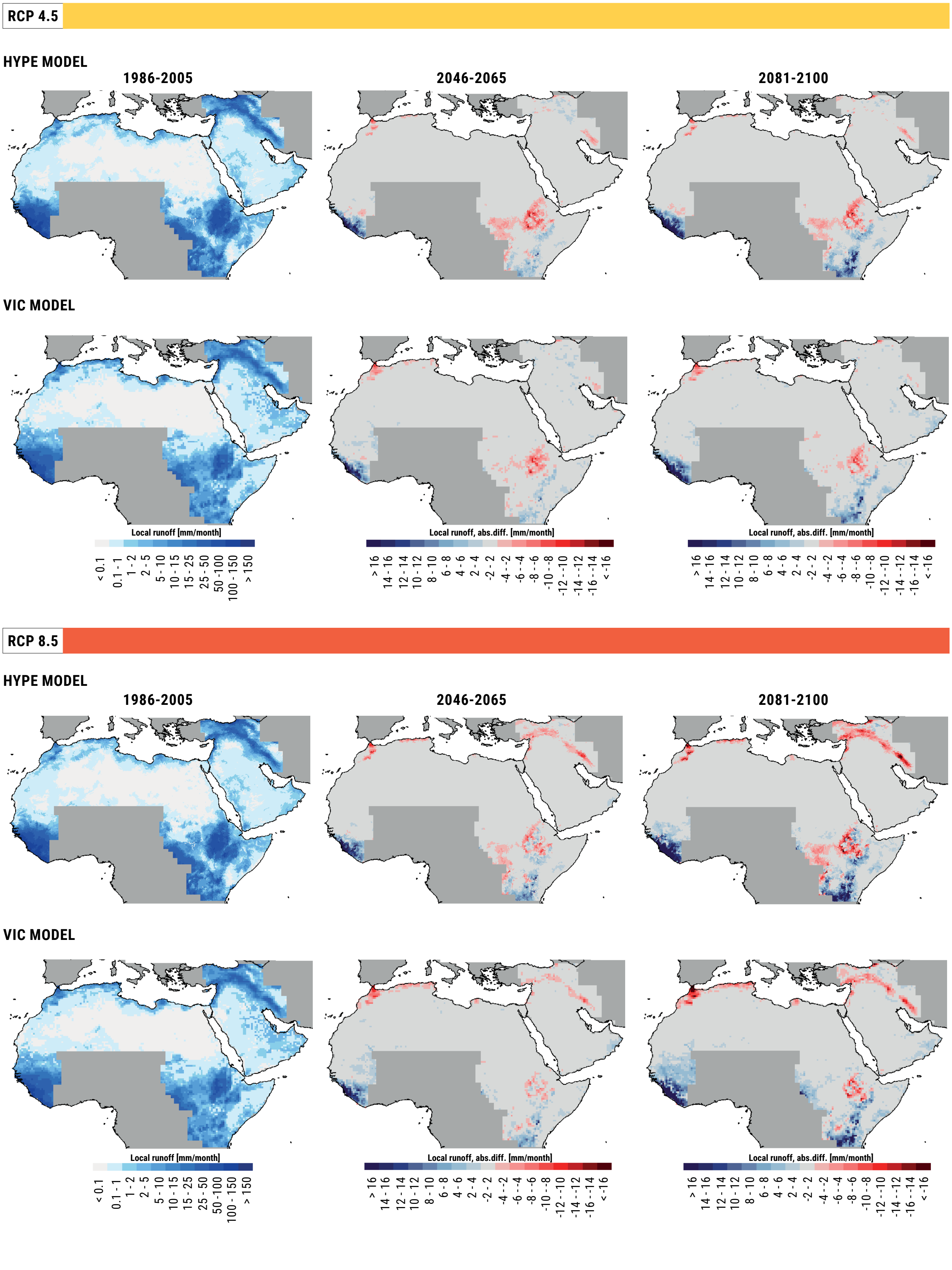
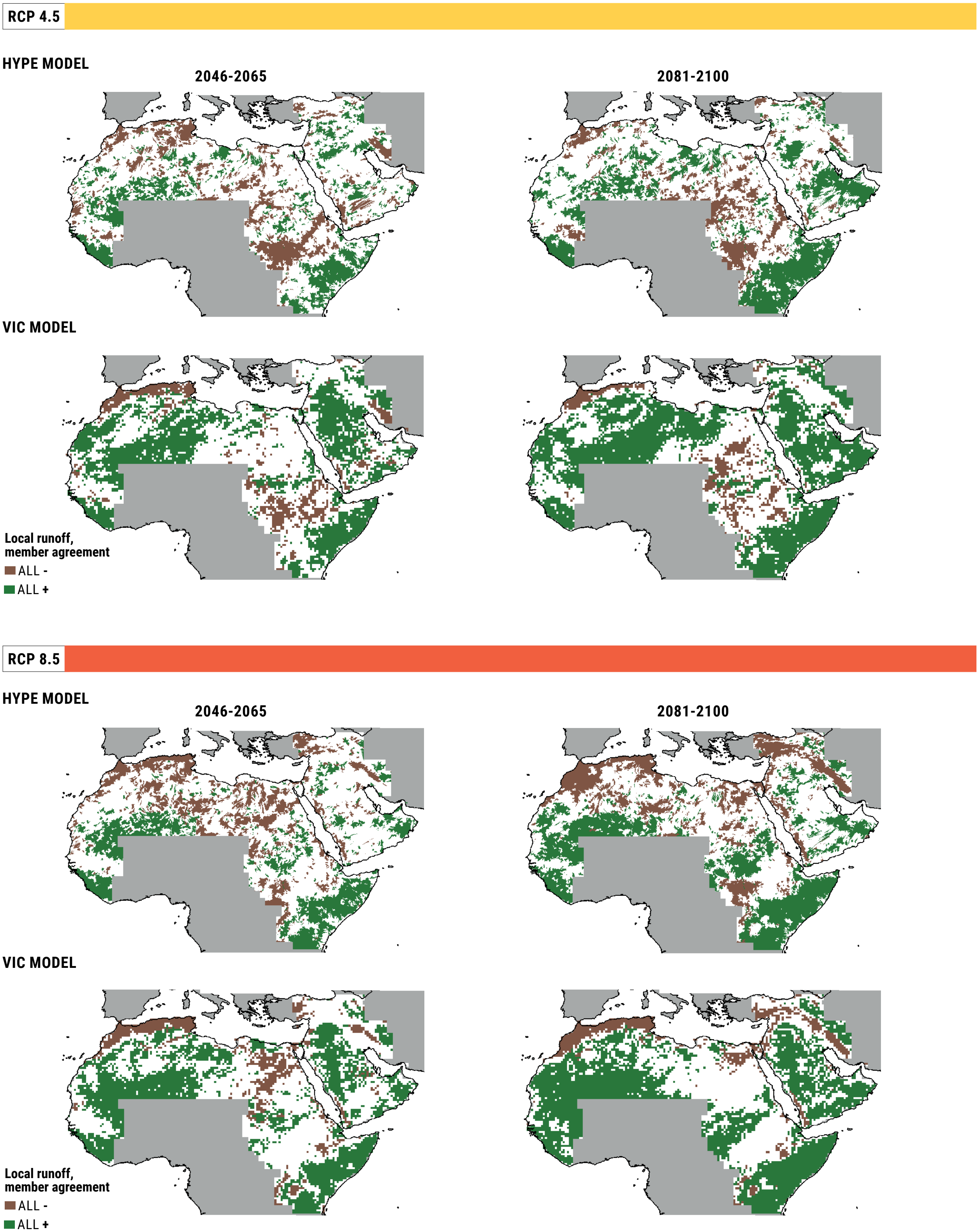


FIGURE 45: Agreement on mean change in annual runoff for mid- and end-century between the ensemble of three RCP 4.5 and RCP 8.5 projections from the reference period



Note: Brown indicates where all ensemble projections agree on a decrease (**-**) in runoff, and green indicates where all agree on an increase (**+**) in runoff

FIGURE 46: Mean change in annual evapotranspiration (mm/month) for mid- and end-century for the ensemble of three RCP 4.5 and RCP 8.5 projections compared to the reference period using two hydrological models

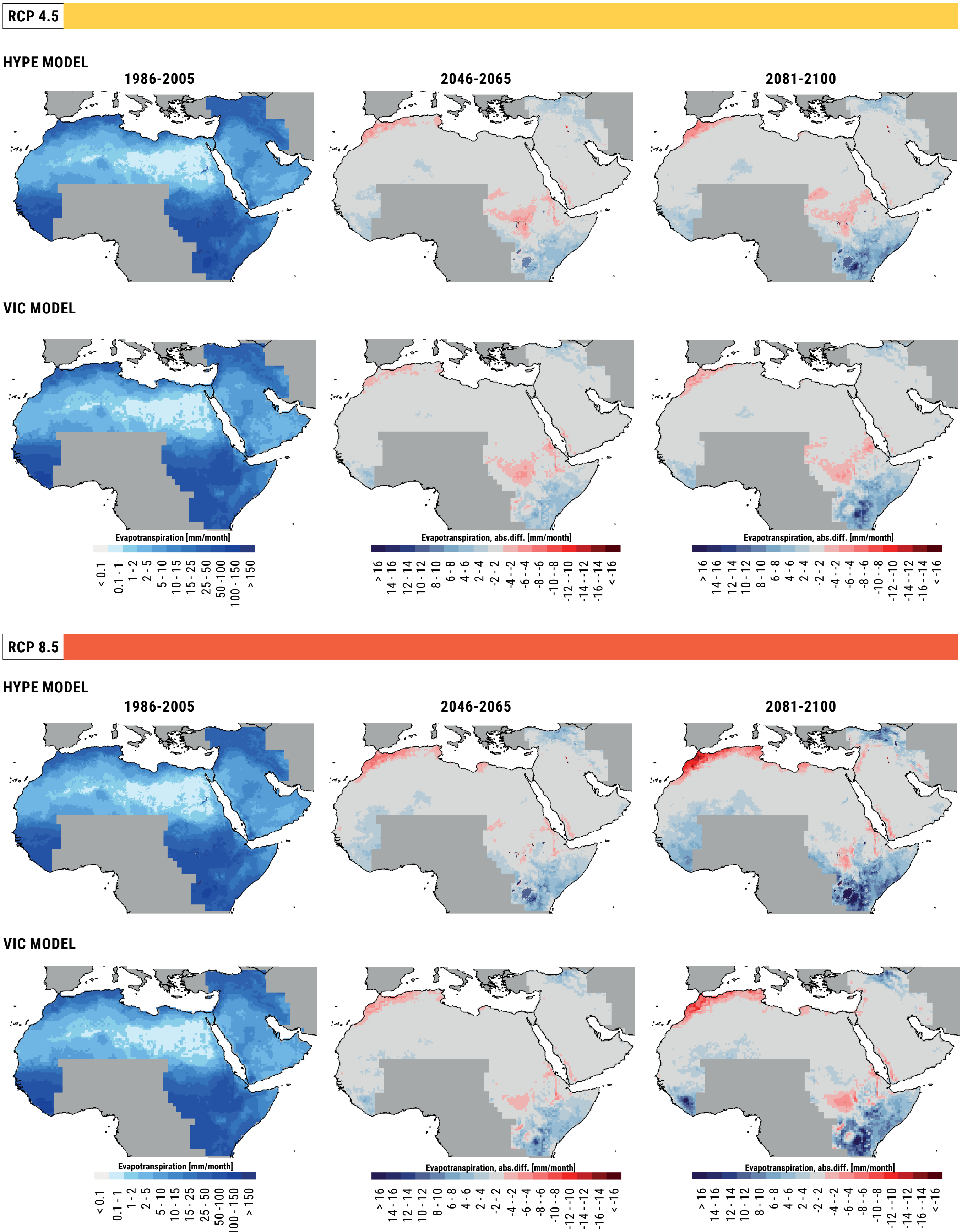
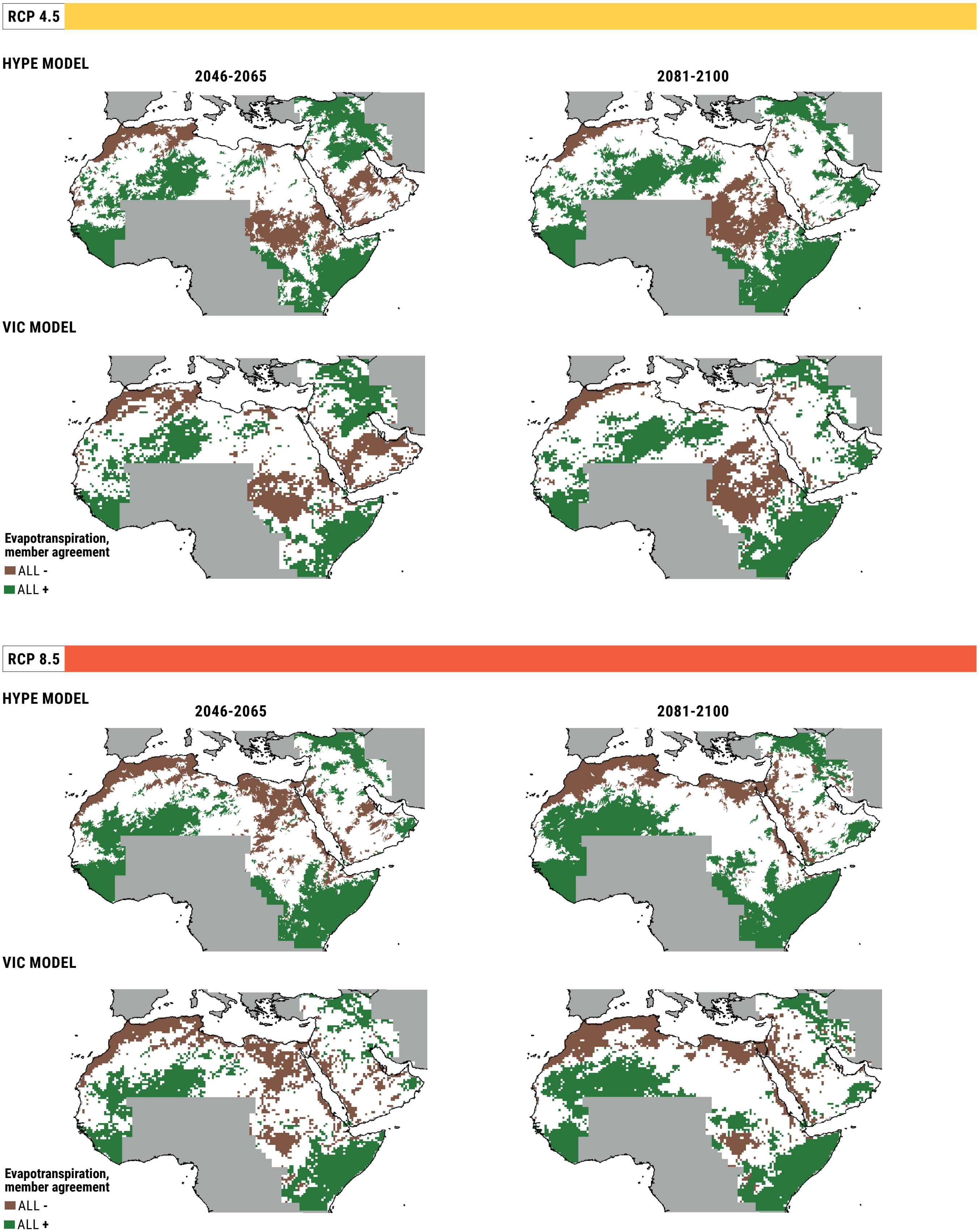


FIGURE 47: Agreement on mean change in annual evapotranspiration for mid- and end-century between the ensemble of three RCP 4.5 and RCP 8.5 projections from the reference period



Note: Brown indicates where all ensemble projections agree on a decrease (**-**) in evapotranspiration, and green indicates where all agree on an increase (**+**) in evapotranspiration

3.2 MOROCCAN HIGHLANDS

Regional hydrological modelling results for the Moroccan Highlands are presented in Figure 48. This subdomain displays a considerable projected decrease in precipitation. Runoff changes for the Moroccan Highlands appear to follow a marked decrease, in particular for RCP 8.5, representing up to a 32%–40% decrease at mid-century and 48%–59% decrease by end-century, depending on the model. The same pattern is exhibited for changes in evapotranspiration for both models with decreases projected throughout the years reaching a reduction of 10%–11% at end-century for RCP 4.5 and 22%–26% for RCP 8.5.

Similar decreasing trends in runoff are evident whether the HYPE model is applied to generate projections as the 50-km resolution or smaller scale resolution of 25 km, for the RCP 8.5 scenario.

FIGURE 48: Mean change in runoff and evapotranspiration (using HYPE and VIC) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Moroccan Highlands

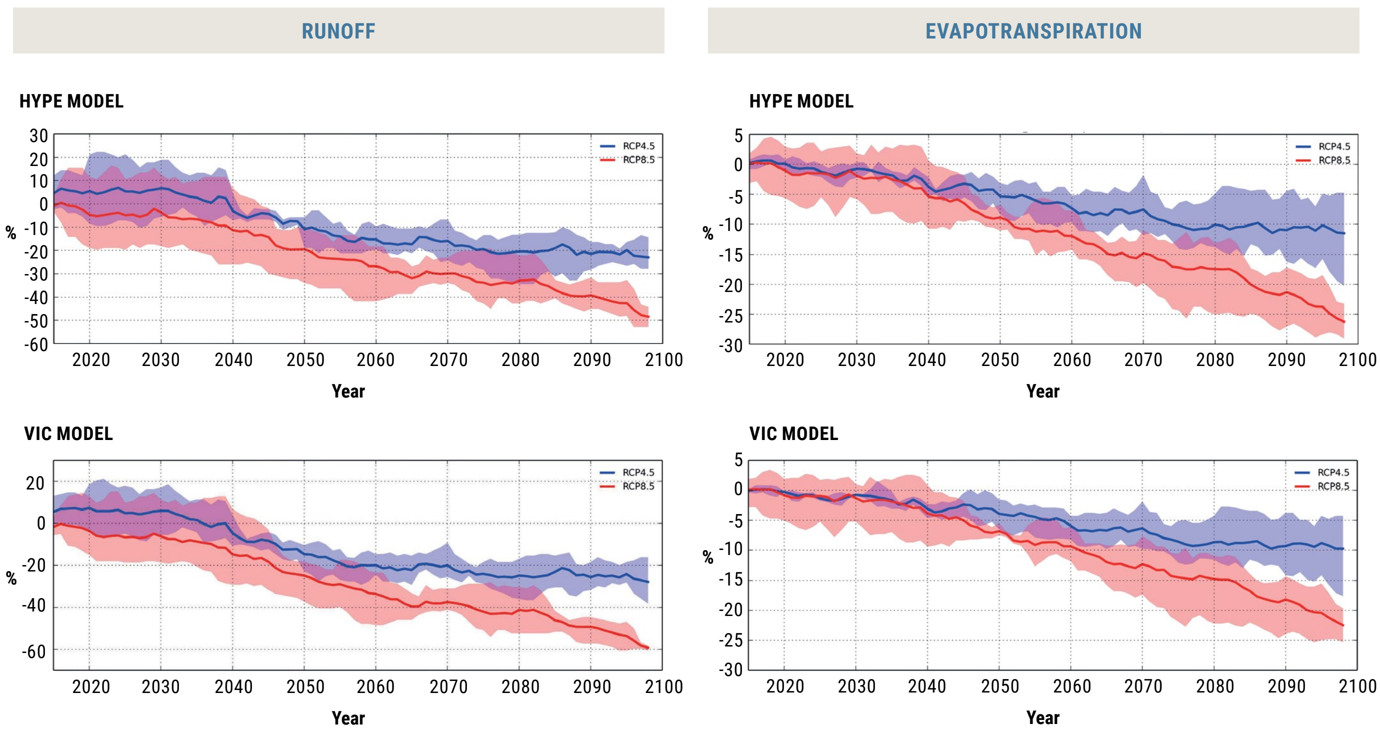
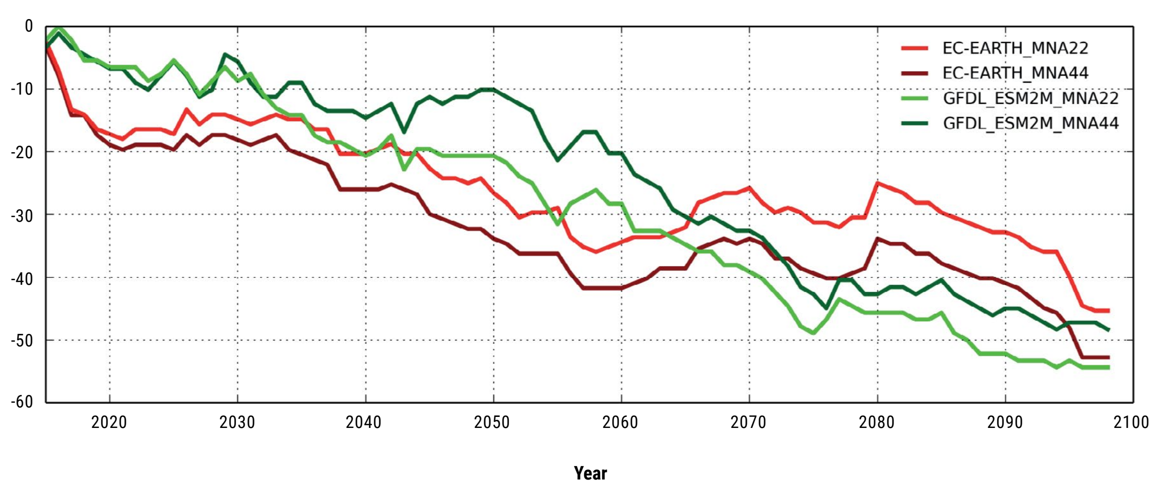


FIGURE 49: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff (using HYPE) over time for two RCP 8.5 projections for the Moroccan Highlands



3.3 MEDITERRANEAN COAST

Changes in runoff and evapotranspiration for the Mediterranean Coast subdomain are displayed in Figure 50. Projections of changes in runoff comprise a wide range of values for both models and thus no clear trend in projections can be concluded. Concerning evapotranspiration, the VIC model results show a mean decrease of 14% at end-century for RCP 8.5, which is also apparent in the winter and summer season for this emission scenario and time period. While results for mid-century and from the HYPE model also show an overall reduction in evapotranspiration, the wide range of values does not allow providing a conclusive trend for these conditions. The mixed climate signals for runoff in the near term along the Mediterranean coast may be attributable to climate variability and the intermittent nature of shallow surface waters in the region. The longer-term trends for runoff in the subdomain, however, demonstrate slightly more consensus on the decline in runoff under the pessimistic RCP 8.5 projection towards end of the century.

FIGURE 50: Mean change in runoff and evapotranspiration (using HYPE and VIC) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Mediterranean Coast

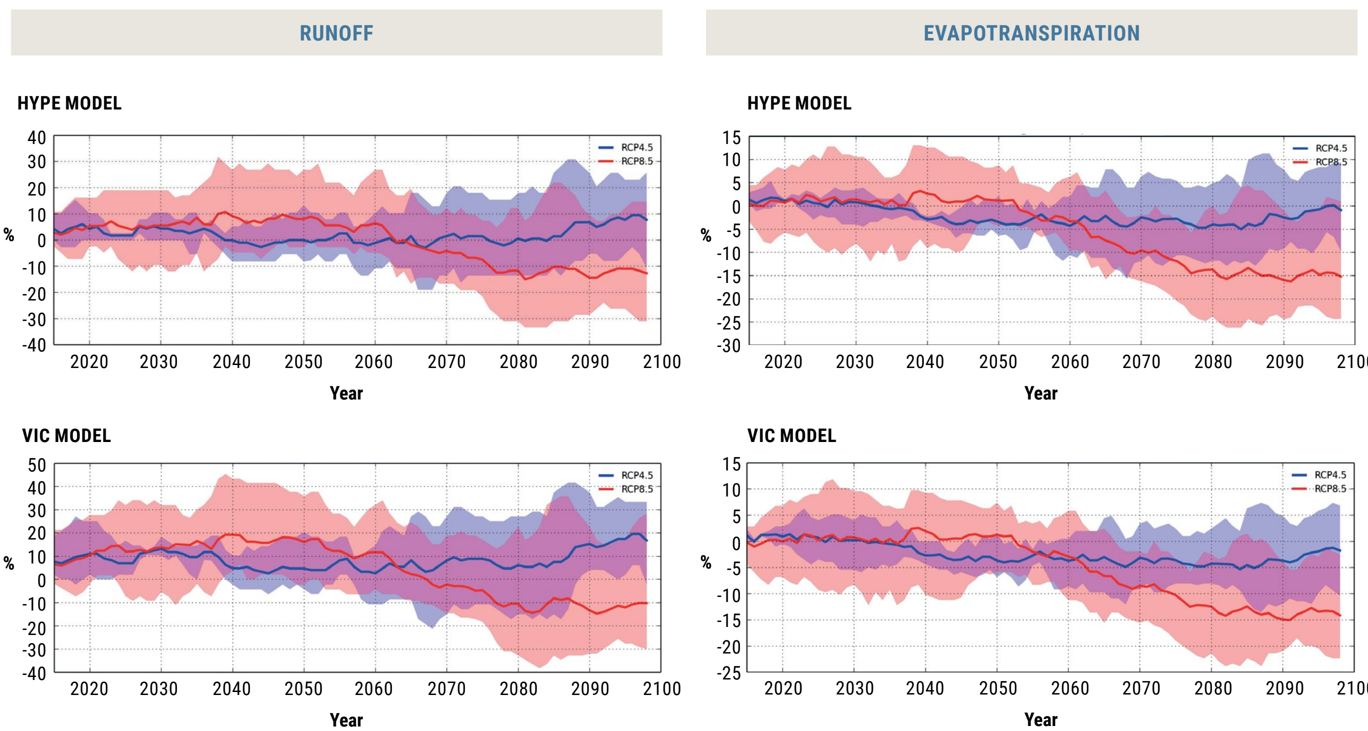
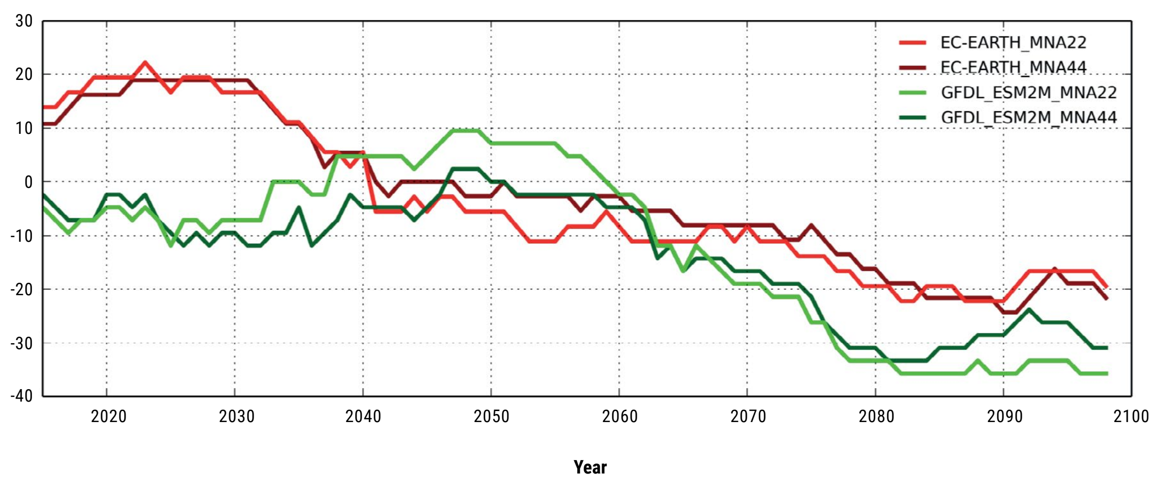


FIGURE 51: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff (using HYPE) over time for two RCP 8.5 projections for the Mediterranean Coast



ENDNOTES

1. Groundwater discharge was also considered but, as data were limited, only simple analysis using a hydrological model was conducted, as noted in Chapter 2. Soil moisture was also analysed, but is not included in this report.

REFERENCES

AlSarmi, S. H. and Washington, R. 2014. Changes in Climate Extremes in the Arabian Peninsula: Analysis of Daily Data. *International Journal of Climatology*, 34: p.1329-1345.

CHAPTER 4

FINDINGS FOR SELECTED SHARED WATER BASINS IN THE ARAB REGION

Shared water resources are of considerable importance in the Arab region, with over 66% of freshwater resources in Arab States originating from outside national borders[1] and 14 out of 22 Arab States sharing a surface-water body. All Arab States, with the exception of Comoros, share a transboundary groundwater resource. 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 their own development goals. The impacts of climate change and climate variability projected over the coming years are expected to further complicate shared water resources management efforts. Regional climate and hydrological modelling outputs can thus help to create a common starting point to assist neighbouring States discuss shared water resources management under changing climate conditions.

Given the importance of these shared resources for the region, Arab States laid particular emphasis on the necessity of considering shared basins within RICCAR's scope of work and to include climate change projections and analysis of extreme events on selected shared water basins in the Arab region in the assessment report. This was requested during the RICCAR Fifth Expert Group Meeting in 2013[2] and the tenth session of the Arab Ministerial Water Council Technical Scientific Advisory Committee (Doha, May 2014).[3]

This chapter thus includes selected essential climate variables and extreme climate indices produced from the regional climate modelling projections and regional hydrological modelling outputs for five shared surface water basins in the region: the Nile, the Tigris and Euphrates, the Medjerda, the Jordan River Basin and the Senegal River Basin.

For each of these, a brief overview of general basin characteristics is provided, including a review of selected sectors deemed to be vulnerable to climate change. This is followed by results from regional climate modelling and regional hydrological modelling simulation outputs for a specific subdomain within each basin.

The location of these subdomains (overview map in Chapter 1) was strategically identified, based on the basin's characteristics and the availability of reliable data. For most basins, subdomain delineation mainly included headwaters areas, as further downstream, water flow is often heavily influenced by human interventions such as water regulation structures. In a context of future projections, providing a better future representation of changes in the entire river basin would require an assessment of changes in water management systems (agricultural practices, energy system changes, etc.) as well as population projections in conjunction with climate change projections, which goes beyond the scope of the study. Projections of changes at the river basin headwaters serves as a starting point to assess overall impacts on available water within the basin.

In addition to the considerations reviewed in Chapter 3, it is noted that a broad set of variables were studied (runoff, evapotranspiration, soil moisture, mean discharge, high-flow value and low-flow value) for each subdomain, but only runoff and mean discharge are presented in this chapter.

The projection changes for each variable were generated through the end of the century (and at the seasonal level) for RCP 4.5 and RCP 8.5 emission scenarios at 50-km resolution. Comparisons with results from 25-km resolution are available for changes in runoff and discharge for the RCP 8.5 projections, noting that at this resolution only two projections were available and were thus not combined as an ensemble. Additional outputs are included in the Technical Annex.

4.1 NILE RIVER BASIN

4.1.1 Overview and subdomain selection

The Nile River (Figure 52) is one of the world's major rivers and an important freshwater reservoir. It is 6,695 km long with a basin area of 3,180,000 km^2 shared among the following 11 riparian countries: Burundi, Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, United Republic of Tanzania and Uganda. The basin is home to 370 million inhabitants with Egypt having the largest population (80.4 million).[4] The two main tributaries of the Nile River are the White Nile, with sources on the Equatorial Plateau, and the Blue Nile originating in the Ethiopian Highlands. The major lakes in the Nile basin system are Lake Victoria, Lake Kyoga, Lake Albert, Lake Tana, Lake Edward and Lake Nasser.[5]

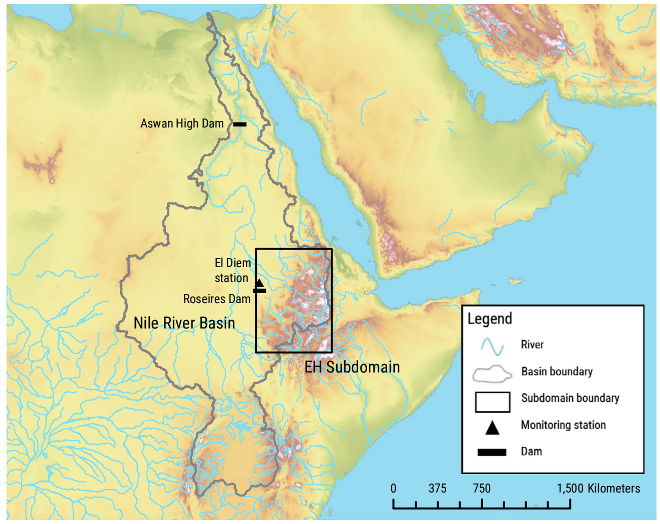
The Nile River basin is characterized by high climatic diversity and variability. The mean annual rainfall is around 630 mm/yr but is spatially very different. About 28 % of the basin receives less than 100 mm annually and a substantial area (34%) exhibits sub-humid conditions with rainfall ranges of 700–1,300 mm. Rainfall is negligible from northern Sudan across Egypt (less than 50 mm/yr) and precipitation in excess of 1,000 mm is restricted to two areas: the equatorial region from south-western Sudan to most of the Lake Victoria basin (1,200-1,350 mm/yr) and the Ethiopian Highlands (around 1,300 mm/yr at the Roseires Dam station).[6] Evapotranspiration losses account for more than 70% of the water balance in the wettest areas of the Nile Basin, such as the Blue Nile and the equatorial lakes sub-basins and even a higher percentage in drier areas.[7]

Historically, the Nile River has shown significant fluctuations in flow, with most of it coming from the tributaries. The Blue Nile contributes more than 60% of the total flow of the Nile (measured at Aswan Dam) and the other major river systems, namely the Sobat and the Atbara, contribute slightly less than 15% each. The White Nile contributes about 18%.[8] The Blue Nile is characterized by a marked seasonal regime following the rainfall pattern at the headwaters, with most of the flow generated during the rainy season from June to September. The long-term (1912–2010) mean annual discharge of the Blue Nile at the Ethiopia-Sudan border (Roseires Dam/ El Diem station) is 49.3 billion m^3/yr.[9] The long-term mean annual flow of the Nile at Aswan is 85 billion m^3.[10]

4.1.2 Vulnerable sectors

The size and complexity of the Nile River basin display a range of vulnerabilities that vary from one riparian country to another. There are numerous areas in the basin which, through the combination of precarious environmental, economic and social conditions, become vulnerable to additional threats. The key sectors with potential vulnerabilities to climate change impacts in this basin are summarized below.

FIGURE 52: Map of the Nile River basin and extent of subdomain



Agriculture, food security and livelihoods
Most of the water use in the Nile basin countries is directed towards agriculture, accounting for more than 80% of all water uses. In the arid and semi-arid downstream regions, the Nile constitutes the sole source of water for agriculture. In Egypt and Sudan for instance (representing some 80% and 17% of total basin wide abstraction for irrigation, respectively), the amount of water used for irrigation is almost as much as the total annual renewable water resources.[11] The irrigation potential of the other countries is also extensive, with agriculture contributing to one third of the overall gross domestic product (GDP) in the basin and providing more than 75% of the total labour force.[12] Already high levels of poverty and underdevelopment in the region put rural communities particularly at risk, as they are also dependent on rainfed agriculture (particularly Ethiopia, Sudan and the upper basin around Lake Victoria). The overdependence on rainfall leaves the countries extremely vulnerable to droughts, floods and extreme weather conditions. In the past, this has led to massive agricultural losses and food insecurity and is now eliciting a move towards urgent investment in water-storage capacity to counteract the uncertainty caused by the climate. Ethiopia, for example, has prioritized investments in large-scale hydrological infrastructure for electricity and storage.

Energy sector and hydropower
The Nile River is an important source of hydropower generation. Several dams have been constructed for this purpose, notably in Egypt and Sudan, and also at the Owen

Falls in Lake Victoria. Hydropower plays an increasing role in water management in the basin's development with, for instance, the 6,000 MW Renaissance Dam on the Blue Nile underway in Ethiopia and the 80 MW Regional Rusumo Falls Hydroelectric Project being developed in Rwanda. Changing climatic conditions have the potential to impact the operation regimes of dams built along the river, with effects on hydropower generation and flow volumes to downstream countries.[13]

Sensitivity to extreme events
The climate of the Nile basin varies considerably over both space and time, resulting in recurrent fluctuations in river flows. Research on the Nile basin has shown that the river's natural flow is particularly sensitive to precipitation that falls on the Ethiopian Highlands. Several events of extreme-flow conditions, including floods and droughts, occurred in the Blue Nile Basin, with the example of a devastating drought in the Ethiopian Highlands in the 1980s due to long dry spells within the rainy season. Another example is the severe flooding experienced in Sudan in 1988 resulting from heavy rainfalls over Khartoum and Atbara. Possibly shifting temperature and precipitation patterns due to climate change will have an impact on the recurrence of extreme conditions, as well as contributing to changes in the river's flow regime.[14]

Groundwater resources
Groundwater resources within the basin are highly variable, both in terms of their recharge and their extent. Groundwater is used increasingly to irrigate during the dry season: in the most arid zones, groundwater may be the only supply source for all types of farm activities. Groundwater resources are under pressure from increased water demand due to rapid population growth and surface pollution, with unsustainable abstractions in many areas, posing a threat in climate change conditions.[15]

Public health-related issues
The population of the Nile basin has long been vulnerable to waterborne diseases associated with interannual fluctuations in rainfall and temperature. Moreover, despite water development projects being vital for increasing agricultural productivity and improving the socio-economic status of rural communities, it has been shown that these projects also have the potential to modify hydrological processes in a way that increases the risk of water-associated diseases.[16] There is also growing evidence that these infrastructure projects can facilitate the transmission of water-associated diseases by providing favourable environments for vectors, hosts and pathogens, such as cholera, schistosomiasis and malaria, all prevalent water-associated diseases within the Nile basin. Published data on cholera case numbers and incidence all suggest that the countries of the Nile basin form a geographic hotspot for cholera in Africa.[17]

Transportation sector
The Nile River is a critical waterway for the transportation of people and goods, as well as for the tourism sector. The river and its tributaries are seasonally navigable and people living along the river have always used it as a vital mode of transporting both goods and people. River steamers represent an important means of transport during the flood season upstream, when transport is not possible by road. Most major cities and towns in Egypt and Sudan are situated on or near the riverbanks. Potentially declining Nile flows due to climate change could increase the vulnerability of the sector.[18]

Highly urbanized areas
Rapidly growing cities in the Nile Basin and the concentration of services in densely populated areas are often located in the zones most sensitive to climate variability. One example is the Nile Delta region which accounts for 30%-40% of Egypt's agricultural production and for most of its tourism and industrial base. As this coastal zone lies in a low elevation area, it would be considerably affected by sea-level rise, saltwater intrusion and other potential social and economic impacts of climate change.[19]

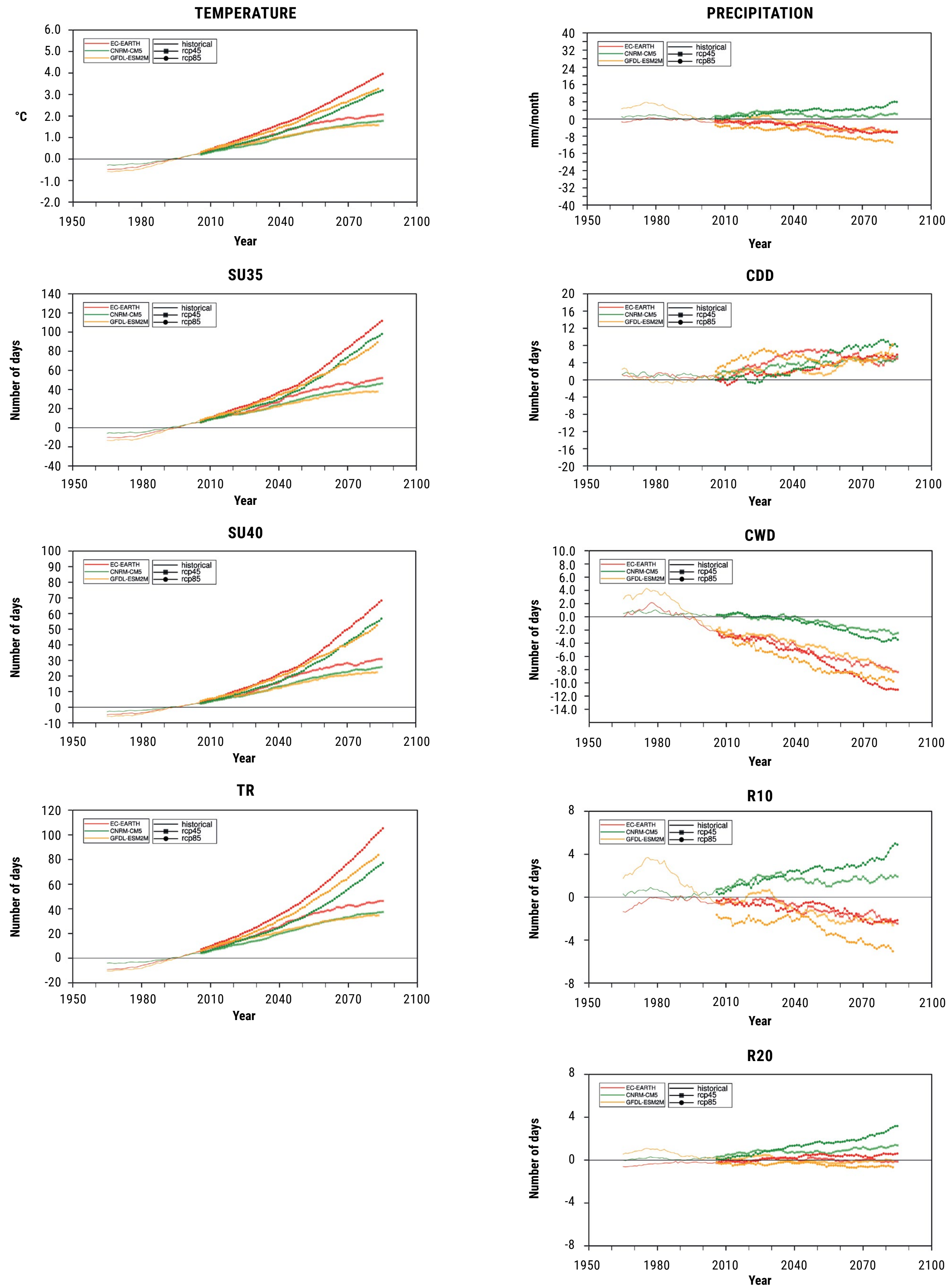
In addition to the key sectors mentioned above, several potential vulnerabilities require consideration and further analysis in the context of climate change. These include population dynamics and projections in the basin, including migration patterns, and their links with future changes in water supply and demand. In this context, poverty, which is widespread in the region as well as gender aspects, ought to be taken into account especially with regard to implications in a shifting climate and availability of water resources. Moreover, attention should be given to transboundary impacts of changing rainfall and temperature patterns in terms of hydrology and socio-economic implications, as they relate to the effects of upstream developments on downstream conditions.

Finally, given the current hydropolitical transboundary configurations in the basin, institutional and cooperative structures play a pivotal role of either alleviating or exacerbating the vulnerabilities due to a changing climate in their consideration and implementations of plans, policies, and projects addressing climate change issues.

4.1.3 Regional climate modelling findings

Changes projected for temperature, precipitation and related extreme events until the end of the century are presented in Figure 53 for the Blue Nile Headwaters. Results show an overall projected increase in temperatures and decrease in precipitation.

FIGURE 53: Mean change in temperature, precipitation and selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Blue Nile Headwaters



The change in mean temperature for RCP 4.5 shows an increase of 1.5 °C at mid-century and 1.8 °C at end-century. For RCP 8.5, temperatures increase to 2 °C for mid-century and 3.6 °C at end-century. At the seasonal level, the highest increase in temperature is shown to occur in winter with an increase of as much as 3.9 °C by the end of the century for RCP 8.5. As for precipitation, results for RCP 4.5 show a close projected change of −6% and −5% at mid- and end-century respectively. For RCP 8.5, precipitation change is −3% for mid-century and −5% by end-century, reaching the highest reduction in winter with a 7% decrease.

4.1.4 Regional hydrological modelling findings

The headwaters of the Blue Nile in the Ethiopian Highlands show wide variation between the individual ensemble members for runoff for both models (Figure 54) and no conclusive trend can be perceived. The mean values from discharge changes show a decrease over time but, given the high-value ranges in this case too, this trend cannot be considered conclusive. For instance, the change in mean discharge for end-century is −8% for RCP 8.5, but values range from −68% to 86%.

FIGURE 54: Mean change in runoff (using HYPE and VIC) and discharge (using HYPE) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Blue Nile Headwaters

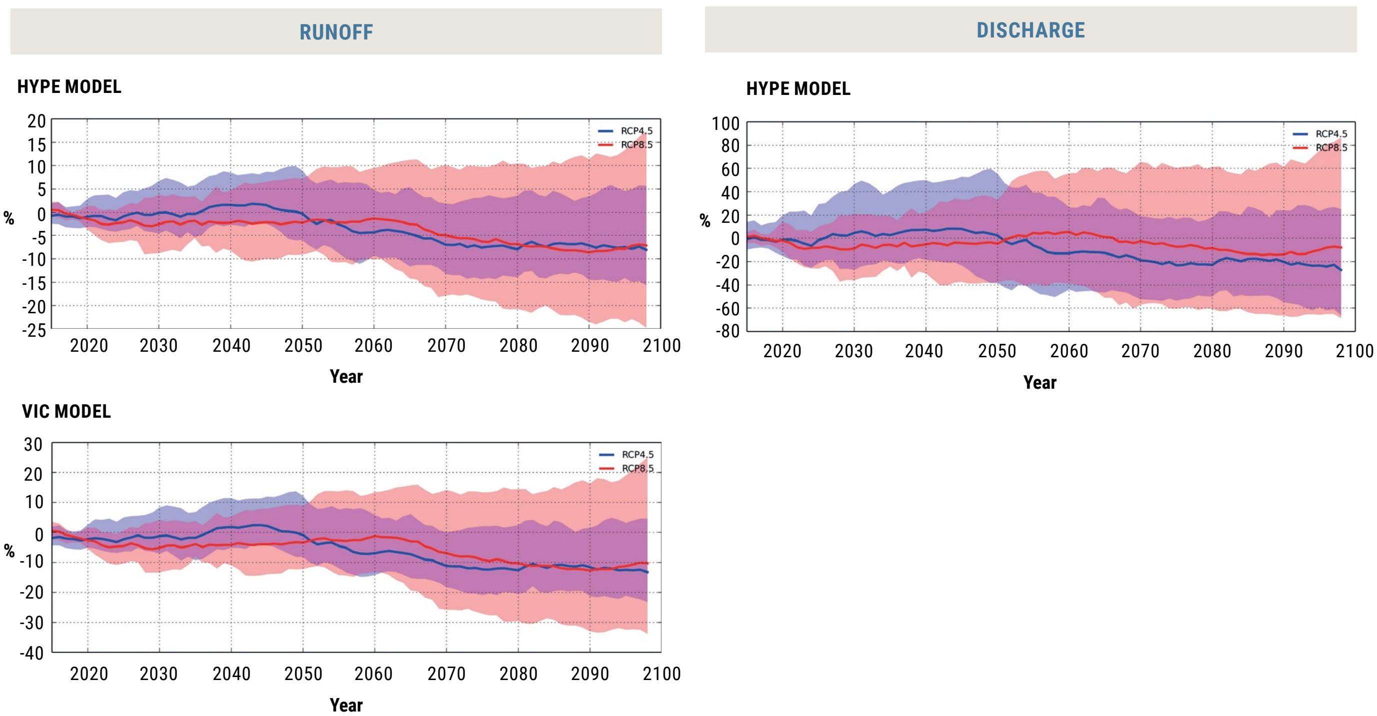
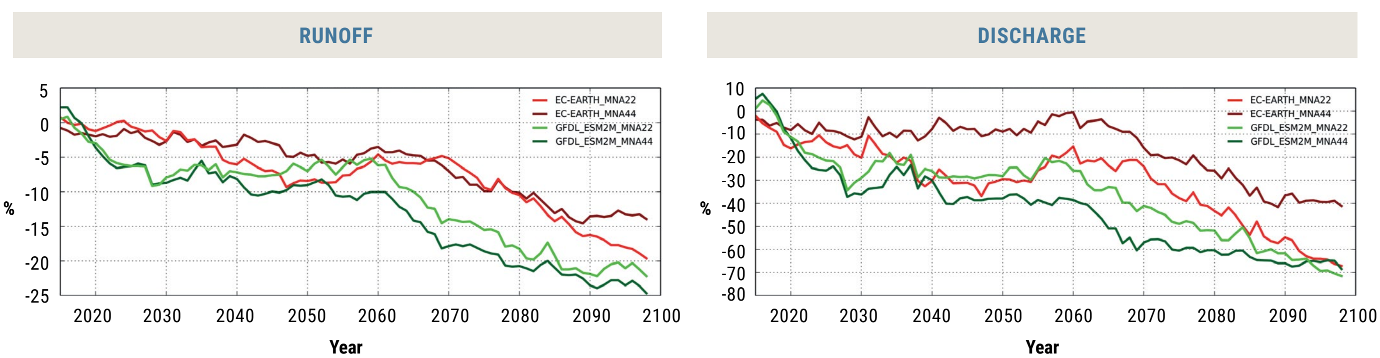


FIGURE 55: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff and discharge (using HYPE) over time for two RCP 8.5 projections for the Blue Nile Headwaters



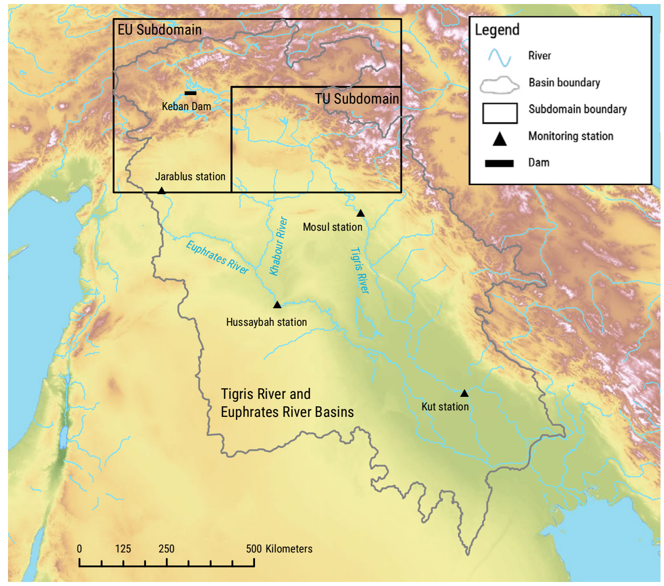
4.2 TIGRIS RIVER AND EUPHRATES RIVER BASINS

4.2.1 Overview and subdomain selection

The Euphrates River (Figure 56) originates in the mountains of eastern Turkey and reaches a length of 2,786 km as it flows through the Syrian Arab Republic and Iraq. It is joined by three tributaries in the Syrian Arab Republic: the Sajur, the Balikh and the Khabour rivers. The 1,800 km long Tigris River has four basin riparian countries: the Islamic Republic of Iran, Iraq, Syrian Arab Republic and Turkey. It originates in the Armenian Highlands in Turkey, flows south and merges with the Euphrates River in southern Iraq. The Tigris has a number of tributaries that make significant contributions to runoff along its course, most of which are shared by Iraq and Turkey or the Islamic Republic of Iran and Iraq. The Tigris and Euphrates merge to feed the Mesopotamian marshlands in southern Iraq. The combined catchment area of the Euphrates and Tigris river basins, including its outlet Shatt al Arab, is around 90,000 km^2, with the overall basin home to more than 50 million people in the Islamic Republic of Iran, Iraq, the Syrian Arab Republic and Turkey.[20] The basin climate is considered similar to a Mediterranean climate, with snowfall in winter in the mountainous Turkish headwater area, and an increasingly hot and dry (arid) climate as the rivers approach the sea. Mean annual precipitation in the basin ranges from approximately 1,000 mm in the Turkish headwaters in the north to 150 mm in the Syrian Arab Republic and just 75 mm in southern Iraq. Mean precipitation in the Tigris basin area is significantly higher than in the Euphrates Basin, owing to the high precipitation rates in the Zagros Mountains in the east of the Tigris basin, which contribute to Tigris streamflow. Most of the precipitation in the Tigris and Euphrates basin falls as snow and remains in the snowpack until the spring snowmelt.[21]

Most of the Euphrates streamflow originates from precipitation in the Armenian Highlands, with Turkey providing about 89% of the total Euphrates flow. While the three Euphrates tributaries used to make up around 8% of the annual Euphrates flow, their contribution has dropped today to 5% or less, due to decreased flow of the Khabour. In Iraq, there are no major surface-water contributions to the Euphrates, except for rare runoff events generated by heavy storms. Before 1973, the mean annual flow of the Euphrates at Jarablus was around 30 billion m^3, but this figure dropped to 25.1 billion m^3 after 1974 and fell to 22.8 billion m^3 after 1990. This is most likely due to climate variability and more frequent periods of drought and the construction of large dams in Turkey as part of the Southeastern Anatolia Project (GAP). Compared to the long-term mean discharge over the period of record from 1937 to 2010, the Euphrates records have shown below-average discharge at Jarablus and Hussaybah since 1999, possibly reflecting a combination of drier weather conditions and the effects of extensive dam-building. With the construction of large water-engineering structures in upstream Turkey and Syrian Arab Republic such as the Keban Dam in 1974 and the Tabqa Dam in 1975, the Euphrates flow regime has shifted towards less pronounced seasonal flow variation starting in the mid-1970s compared to the near-natural flow regime (1937 until the 1970s). The Tigris River exhibits mean annual flows of 20 billion m^3 at Mosul (1931–2011) and 25.7 billion m^3 at Kut station further downstream (1931–2005). Flow contribution to the mean annual flow volume of the Tigris from tributaries located between Mosul and Kut amount to an estimated 25 billion m^3.[22] The construction of several dams in Iraq may have led to a significant reduction in flow volumes in the course of the river, especially after Mosul, reflected in the changes in flow volumes at Kut since 1973 with a mean annual flow volume from 32 billion m^3 before 1973 to 16.7 billion m^3 for the period 1974–2005.[23] Compared to the Euphrates flow regime, the Tigris high-flow season is much longer and more pronounced due to higher winter precipitation over a much greater basin area. Its flow regime can be considered natural before the 1970s, with limited water regulation in the runoff generation area in Turkey, Islamic Republic of Iran and Iraq upstream of Mosul. Because of the extremely high seasonal and annual flow fluctuations in the Euphrates and Tigris rivers, storage facilities are a key concern for water resources management for the riparian countries in both basins.

FIGURE 56: Map of the Tigris and Euphrates river basins and subdomain extent



4.2.2 Vulnerable sectors

The Euphrates and Tigris river basins are faced with increasing challenges in terms of demographic pressures, hydro-infrastructure developments and water-quality concerns. These factors, in addition to changes in climate patterns and recent conflict situations, are set to deeply affect future water availability and associated socio-economic impacts in the basins yet further. The key vulnerable sectors to climate change in the Tigris–Euphrates basin are presented below.

Agriculture, food security and livelihoods

Agricultural development and food production in the Euphrates and Tigris riparian countries rely heavily on the availability of water in the basin. The droughts that were experienced in the 2000s convey important messages about what could happen in this area in the future if drought intensification occurs. Other extreme events such as dust storms (see next section), which have become more and more common over recent years, are also intrinsically linked to agricultural productivity in the basin. In Iraq, drought and land degradation are major factors jeopardizing food production, with the north depending on rainfall and the central and southern parts relying on irrigation. The extreme droughts of 2007–2009 that affected the country damaged almost 40% of the cropland, with higher intensity in the northern governorates and reaching over 50% in Ninawa and Erbil governorates. The situation caused 20,000 rural inhabitants to move in search of more sustainable access to drinking water and livelihoods. Crops for which Iraq was famous, such as dates, rice and grain, could no longer be grown because the Euphrates River was flowing well below its usual level. Syrian Arab Republic also experienced similar effects due to severe droughts: hundreds of thousands of Syrians lost their livelihoods and had migrated to cities by 2009. It was reported that around 160 villages in northern Syria were abandoned during this period due to reduced water availability. Several studies even connect the Syrian uprising and subsequent outbreak of civil war due to the drought and its consequences. Agriculture has long been a cornerstone of the Syrian economy and this sector is highly vulnerable to changes in climate patterns.[24]

Sensitivity to extreme events

Major impacts of extreme events have been observed in the basin in the last few years. In 2012, Baghdad suffered its worst recorded floods in 30 years; in May 2013, nearly 600 families were displaced by severe flooding and more than 30,350 ha of crops were damaged or destroyed by floodwaters in Missan, Qadissiya and Wassit governorates. Syrian Arab Republic was also affected by a series of floods and extreme weather, such as the snowstorms in Damascus in December 2013, as well as during the winter of 2014/2015 with torrential rain and flooding throughout the country putting a halt to all activities. Other common extreme event phenomena in the basin are dust- and sandstorms. The Euphrates and Tigris basin has been identified as a significant source area for dust storms in Iraq and across the region, with fallow agricultural lands considered the main hotspots of dust generation. These storms have had severely negative socio-economic impacts such as budgetary losses, reduced visibility, which significantly disrupted transport, and increases in surface heat. It also further aggravated drought effects, damaged crops and soil and affected the public health sector with acute and chronic respiratory affections. Potential future changes in climate patterns in terms of extreme weather events are aspects of major importance to consider in the basin.[25]

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

Groundwater resources

It has been reported that, apart from pressures on surface-water availability, heavy exploitation of groundwater poses serious concerns for resource sustainability. A study published in 2013 with the use of NASA images from Gravity Recovery and Climate Experiment (GRACE) satellites revealed a dramatic increase in the dryness of the soil and depletion of below-ground water levels between January 2003 and December 2009. It indicated that the Euphrates and Tigris basins registered the second fastest rate of regional groundwater storage loss in the world after India. As strong interlinkages exist between surface- and groundwater in the Euphrates and Tigris river basins, groundwater depletion is thus also an issue of concern in the context of a changing climate.[26]

Water quality and ecosystems

Pollution from agricultural and domestic sources seriously affects water quality in the basin, with both rivers suffering from severe salinity which increases along the course of the river in Iraq. Moreover, in the Tigris basin region, the Mesopotamian marshes have suffered severe damage as a result of upstream damming projects in the 20th century, reducing the marshes to 14% of their original size. Water quality and ecosystems are thus also important aspects to consider in a context of changing climate and upstream water-regulation developments.[27]

Hydropower sector

The hydropower sector, including micro-hydrological installations, presents opportunities to improve access to electricity in Syrian Arab Republic, Lebanon, Tunisia and other parts of the region. In Iraq, hydropower represents 9.22% of the electricity supply. Temperature and precipitation effects from climate change and upstream developments could alter future hydrological conditions in these countries and, as a result, future hydropower generation.

A study by Pilesjo and Al-Juboori (2016) has shown that a reduction in rainfall by 10% in Iraq has the potential to cause a 25%–50% loss in hydropower generation. As a result of temperature increases of a few degrees, the impact of higher evapotranspiration on hydropower might result in a substantial decrease in generated electricity and thus in lower energy security.[28]

Geopolitical context

In addition to the role that hydrological conditions and water availability play in contributing to economic disruptions, the unrest that erupted in Syrian Arab Republic and Iraq have had severe impacts on urban water-distribution systems, including intentional attacks owing to their strategic value. Armed groups took control of many of the water-storing and regulating structures on the Euphrates in both Syrian Arab Republic and Iraq during the past few years, such as the Tabqah Dam in Syrian Arab Republic in early 2013, which put the water intake for the Aleppo governorate and parts of the Raqqah governorate out of service, depriving more than 5 million Syrians of access to safe water.

Another example is the control of the Mosul Dam in Iraq with major concerns over a cut in water supply, but most importantly a risk of dam collapse which is threatening the life 1.5 million inhabitants in the surroundings areas. This context of political instability is placing additional pressures on the resource and its management in Syrian Arab Republic and Iraq, especially in a context of potential reduced water availability due to climate impacts.[29]

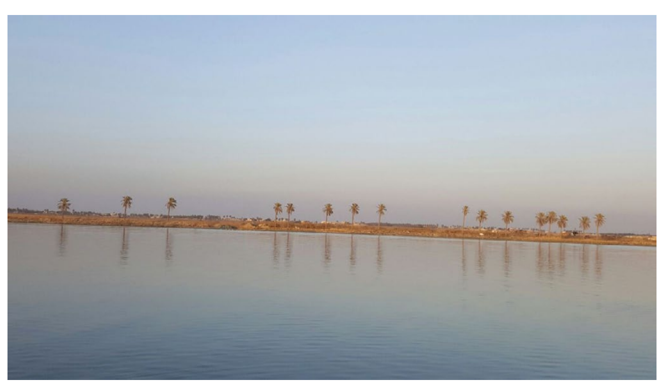
These issues constitute the key current sector with potential severe implications in terms of climatic impacts; several other vulnerabilities also exist such as future changes in water demand and supply due to population and demographic patterns, as well as impacts of upstream developments.[30] Institutional frameworks for transboundary cooperation are also crucial components to take into account in view of future climate variability to ensure effective formulation and implementation of policies and strategies to address future climate variability and its potential impacts on the sectors mentioned above.

4.2.3 Regional climate modelling findings

Projected changes in temperature, precipitation and extreme events indices are presented in Figure 57 and Figure 58 for the Tigris and Euphrates headwaters, respectively.

The change in mean temperature for the Tigris headwaters show an overall increase towards end-century and more marked for RCP 8.5. At mid-century, the projected increase for RCP 4.5 is 1.8 °C and 2.2 °C at end-century. For RCP 8.5, the change is 2.5 °C for mid-century and up to 4.5 °C by end-century. Temperature in the summer season sees larger increases than the winter for this subdomain. Annual projected patterns of precipitation are variable for the Tigris headwaters with increases for RCP 4.5 (4% at mid-century and 1% at end-century). For RCP 8.5, precipitation change is negative with a reduction in 3% for mid-century and 4% for end-century. At the seasonal level, 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. In general, precipitation changes are milder for RCP 4.5 than for RC 8.5.

Changes in mean temperature of the Euphrates headwaters follow the same trends as the Tigris headwaters in terms of increases towards end-century, with projected increases of 1.9 °C for RCP 4.5 at mid-century and of 2.3 °C at end-century. More marked changes are exhibited for RCP 8.5, with a temperature increase of 2.6 °C for mid-century and 4.8 °C for end-century. As for precipitation, increases are projected for RCP 4.5 (4% at mid-century and 3% at end-century). For RCP 8.5, no significant precipitation change is projected for either time period. Concerning precipitation extremes, in particular for the SDII indicator (not shown), four out of six projections displayed an increasing trend for the Tigris headwaters, while all projections showed increases for the Euphrates headwaters. The Euphrates headwaters subdomain, along with the Senegal River, were the only ones displaying increasing trends for the R20 index in all its projections, compared to the other subdomains where little change was projected.



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

FIGURE 57: Mean change in temperature, precipitation and selected extreme event indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Tigris River Headwaters

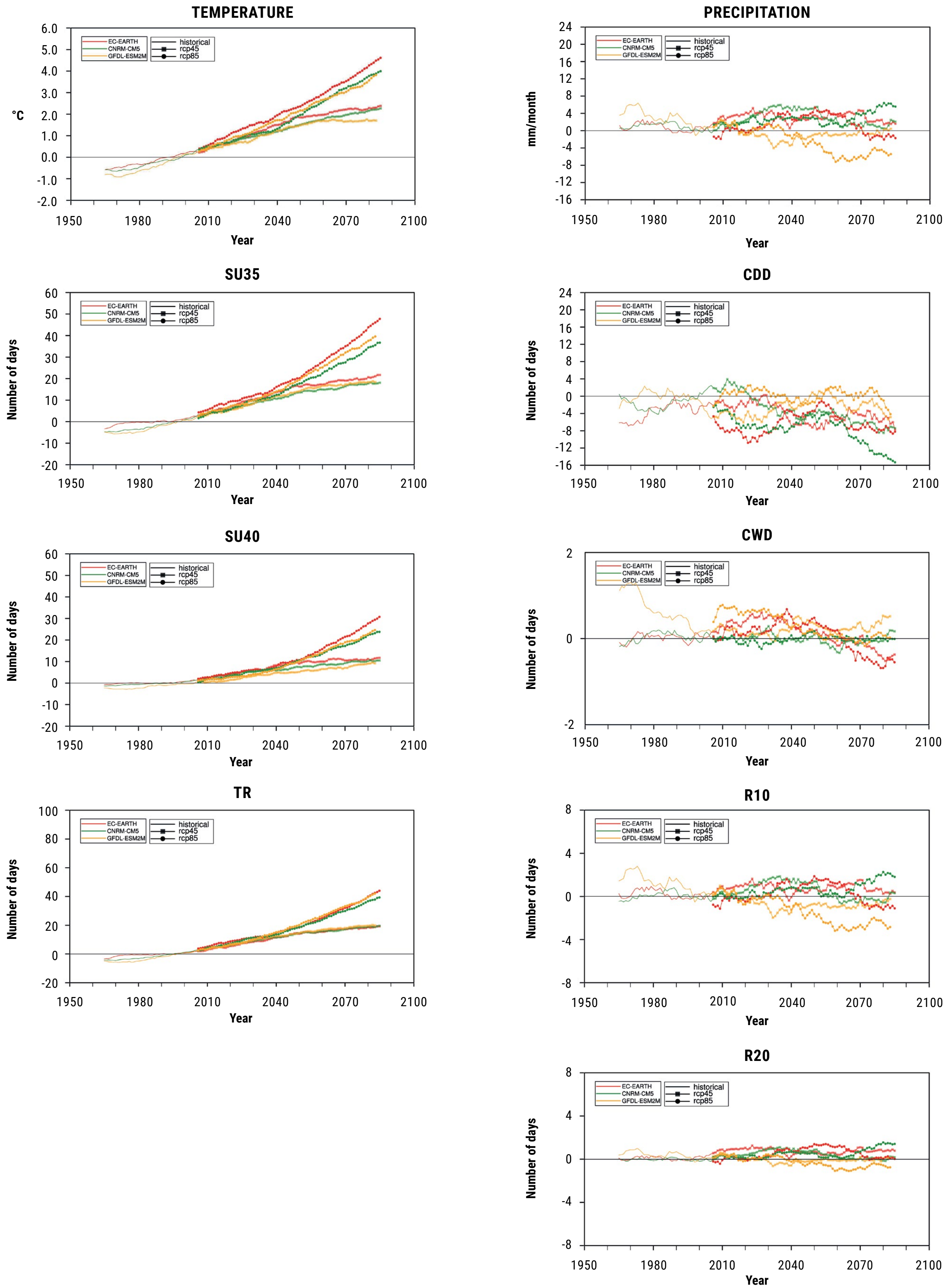
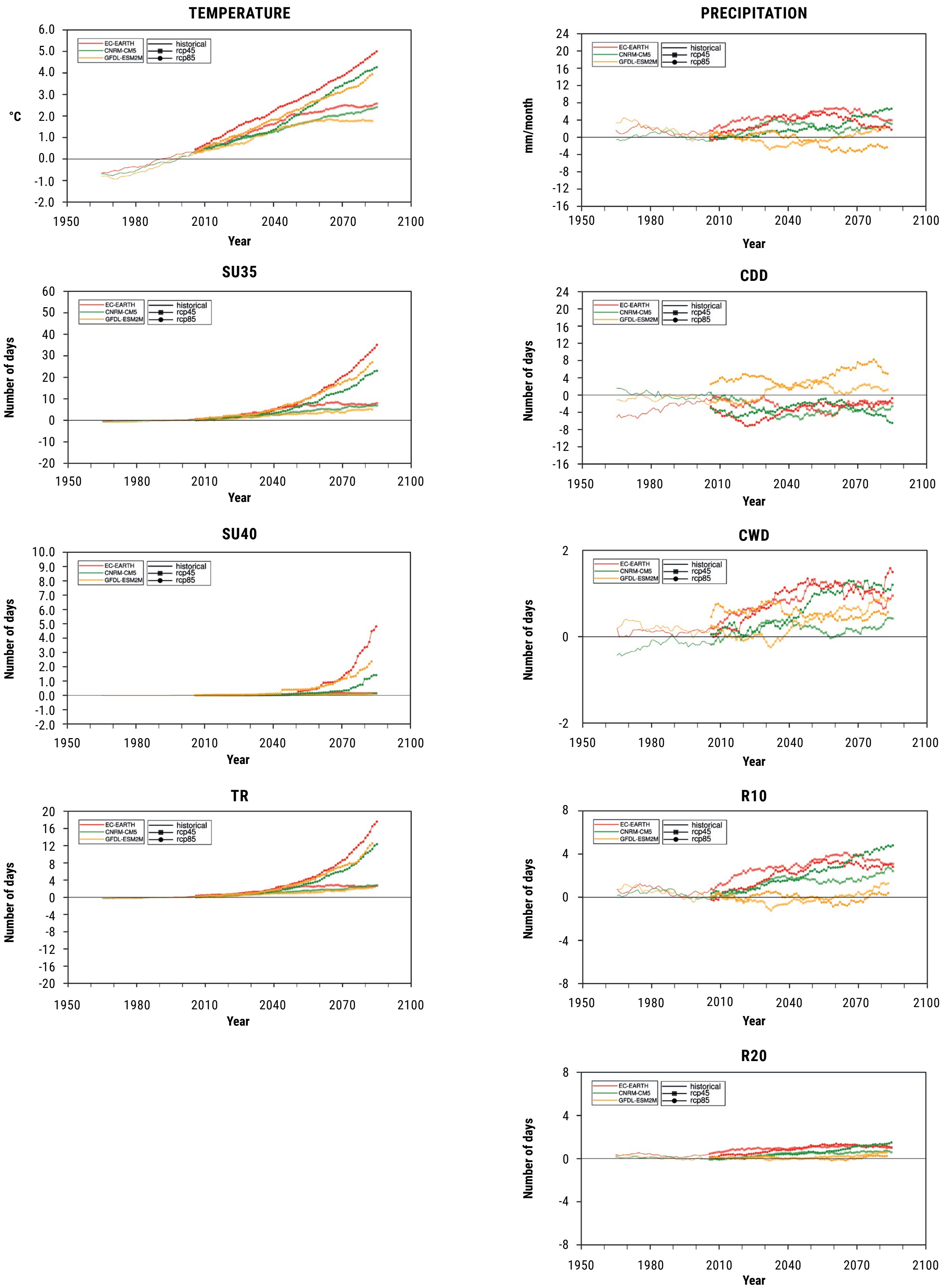


FIGURE 58: Mean change in temperature, precipitation and selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Euphrates River Headwaters



4.2.4 Regional hydrological modelling findings

The Tigris and Euphrates headwaters show small increases in winter runoff (Figure 59 and Figure 61) even when precipitation changes are negative. This is likely due to less snow storage compared to the reference period and thus increased runoff during winter followed by reduced runoff during the summer months, as there is reduced snowmelt, which is seen in the summer pattern of runoff for these basins.

For the Euphrates headwaters, both models project increases at the end of the century for RCP 4.5 (2%–6%, depending on the model), as well as increases in the winter season for these conditions (12%–14%, depending on the model). Moreover, a decrease in mean runoff is projected by the HYPE model in the summer season at the end of the century for RCP 4.5 (−5%) and RCP 8.5 (−22%). This decrease in runoff in the summer season is also projected for the Tigris headwaters, with both models showing a reduction at the end of century for both emission scenarios ranging from 6% to 9% for RCP 4.5 and from 15% to 22% for RCP 8.5, depending on the model.

Concerning change in discharge, no definite trend can be observed for mid-century for the Tigris and Euphrates headwaters due to the wide value ranges. At the end of the century, however, there is a projected decrease of 3% in mean discharge for the Tigris headwaters for RCP 4.5 (values varying from −5% and −2%) and −17% for RCP 8.5, though the latter range is from −28% change to no change.
A signal of projected decrease in mean discharge for the summer period is also apparent (−18%) at end-century at RCP 8.5 with the range of values all indicating a decrease (−27% to−6%).

Projections for the Euphrates headwaters for the end of century exhibit a decrease of 17% in mean discharge (varying from −27% and −4%) for RCP 8.5. Mean discharge values are also projected to decrease in the summer season for the mid- and end-century time periods for RCP 8.5. The choice of GCM appears to have more influence on the discharge results for the Tigris and Euphrates than the resolution applied for the analysis, as observed in the figures below presenting the RCP 8.5 results for the 50-km and 25-km resolutions, although both signal a decline compared to the reference period by the end of the century.

It is worthy to note that projections for the change in the high flow value (100-year flow value) in the Euphrates show a decrease of 26% for RCP 8.5. A decrease is also reflected in the summer at both time periods and in the winter at end-century for this emission scenario. On the other hand, the Tigris headwaters exhibit a possible projected increase ranging from 6% to 11% in the high-flow value for RCP 4.5 for the end-century period.

FIGURE 59: Mean change in runoff (using HYPE and VIC) and discharge (using HYPE) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Tigris River Headwaters

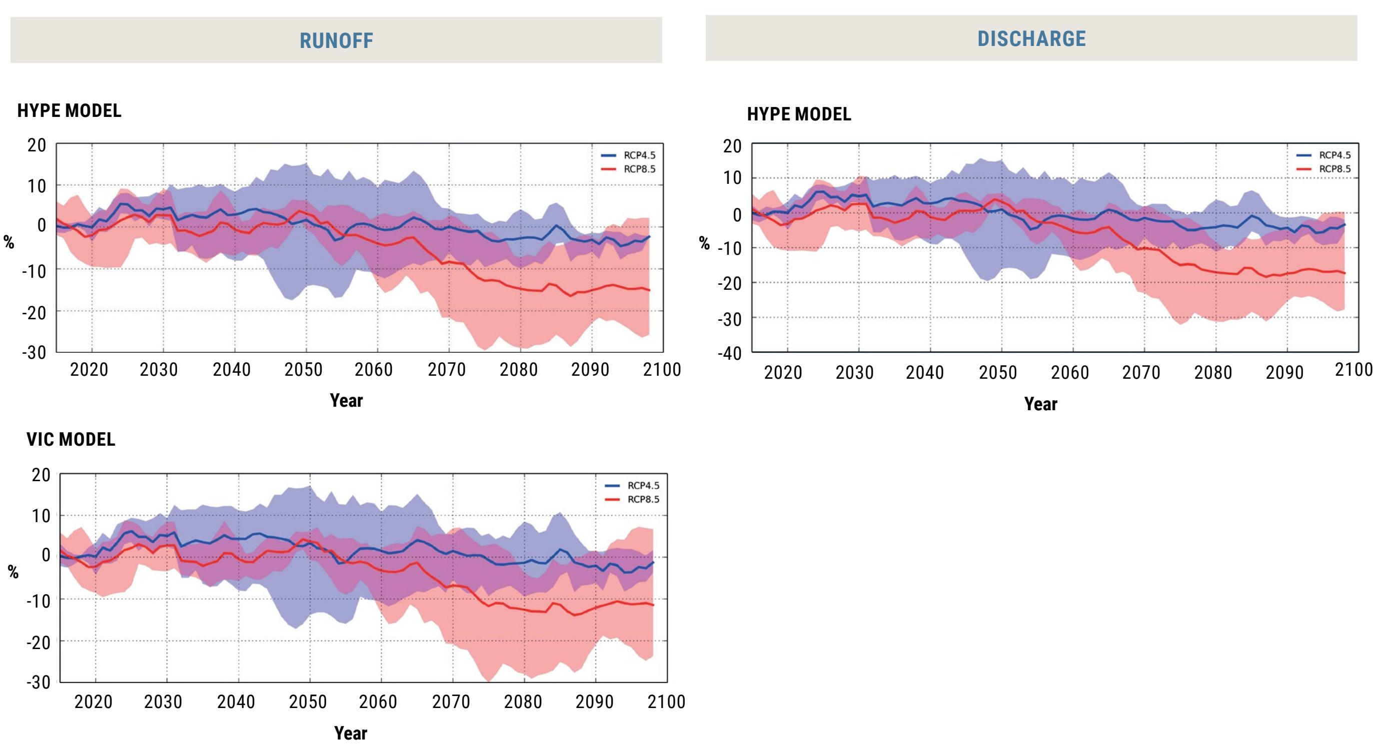
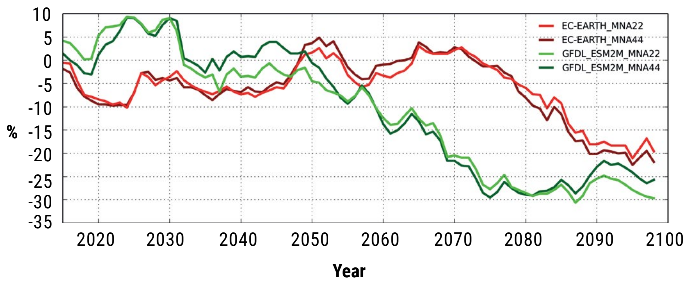


FIGURE 60: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff and discharge (using HYPE) over time for two RCP 8.5 projections for the Tigris River Headwaters

RUNOFF



DISCHARGE

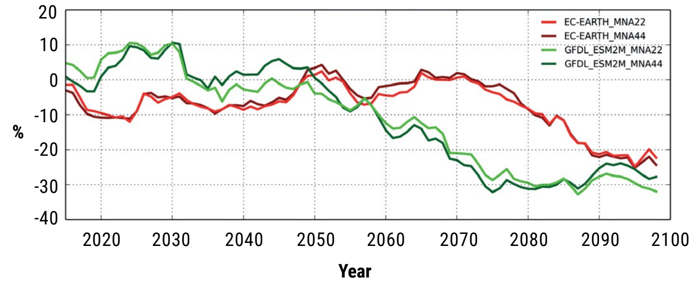
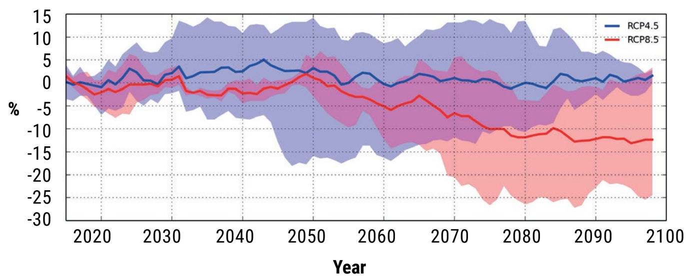


FIGURE 61: Mean change in runoff (using HYPE and VIC) and discharge (using HYPE) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Euphrates River Headwaters

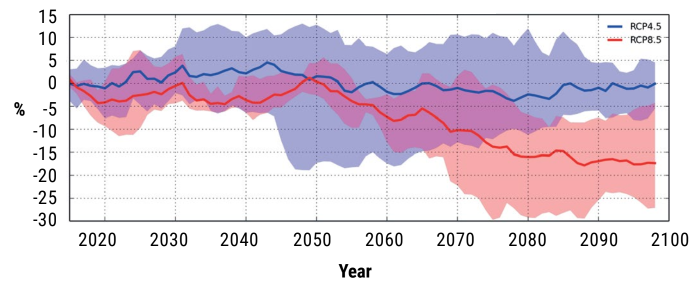
RUNOFF

DISCHARGE

HYPE MODEL



HYPE MODEL



VIC MODEL

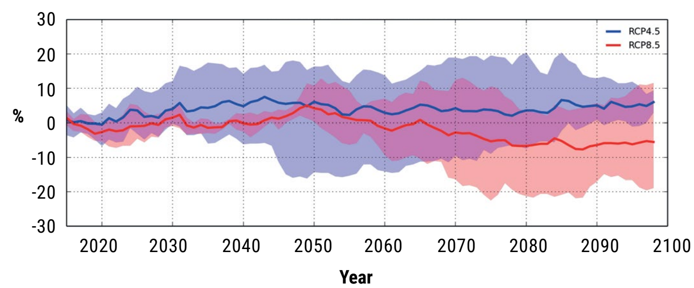
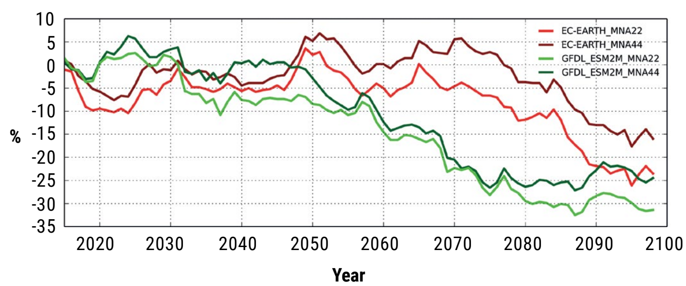
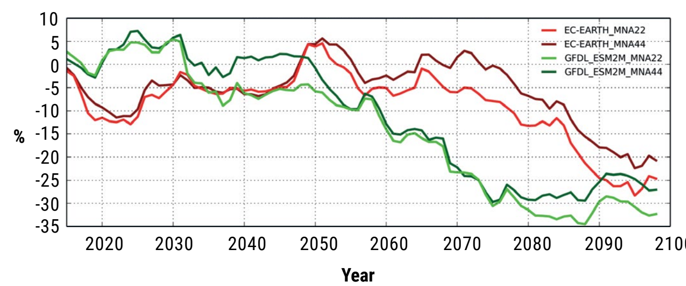


FIGURE 62: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff and discharge (using HYPE) over time for two RCP 8.5 projections for the Euphrates River Headwaters

RUNOFF



DISCHARGE



4.3 MEDJERDA RIVER BASIN

4.3.1 Overview and subdomain selection

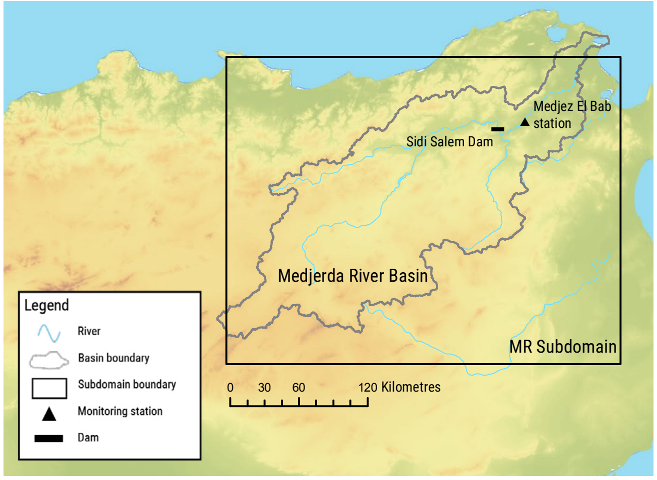
The 484-km long Medjerda River originates in north-eastern Algeria, flows eastwards to Tunisia, and then discharges to the Gulf of Utica in the Mediterranean Sea (Figure 63). It is the longest river in Tunisia and the most important for this country in terms of water supply, providing around 37% of its surface water and 22% of its renewable water resources. Some 32% and 68% of the basin area (22,070 km²) are located in Algeria and Tunisia, respectively. In 2010, the total population in the basin was estimated to be 2.2 million.[31]

The Medjerda River basin climate can be classified as Mediterranean sub-humid to semi-arid with hot, dry summers and a winter rainy season. The source areas of the northern tributaries are the humid Kroumir Mountains (Souk Ahras area in Algeria), where summits exceed 1,400 m asl and annual precipitation ranges between 600 mm and 800 mm. The catchment area reaches over to the Dorsal Mountain range in the south, where semi-arid conditions prevail with precipitation not exceeding 400 mm/yr. Although situated near the Kroumir Mountains, the presence of a topographically induced rain shadow in the mid-Medjerda valley renders it a relatively dry region. The rainy season extends from September to May, with erratic rainfall and frequent high-magnitude flood events resulting in vast inundations of the floodplains. The annual average precipitation in the basin ranges from 350 mm/yr to 600 mm/yr.[32]

Even though the river is perennial, its hydrological regime is irregular, characterized by low flows with a regular appearance of extreme floods often exceeding 980 m³/s. In 1973, the discharge reached 3,500 m³/s at Medjez El Bab station (downstream of Sidi Salem Dam). These overflows threaten towns and rural populations living along the river, as well as important infrastructure such as irrigation systems and bridges in the lower valley and the Medjerda Delta. On average, the river's mean daily discharge is 30 m³/s and thus constitutes up to 1 billion m³/yr. A total of 11 dams are in operation in the river basin providing 59% (1,200 million m³) of the total resources mobilized by dams in northern Tunisia. Another seven dams are planned or are under construction (300 million m³).

It is widely reported that the dams have modified the river's flow regime since the implementation of these infrastructure development projects and, more precisely, after the construction of the largest Sidi Salem Dam in 1982, with the downstream channel progressively narrowing.[33]

FIGURE 63: Map of the Medjerda River Basin and subdomain extent



4.3.2 Vulnerable sectors

The Medjerda River is Tunisia's principal watercourse and constitutes, totally or partially, the water supply for more than half the Tunisian population, with some 2 million inhabitants living along the river and its tributaries and approximately 4 million additional inhabitants in the north-east and the centre-east of the country who are also supplied by water transfers from the basin. The vulnerable key sectors to climate change identified during the research are presented below.

Agriculture, food security and livelihoods
Agriculture is the primary economic activity in the basin and constitutes the bulk of production and employment with more than 87,000 people employed by this sector. The river occupies an essential place in the national strategy for food security as agricultural production in the basin contributes about half the total food production in Tunisia. The food security of the entire country is thus dependent on water supply from the river, knowing that it is used to irrigate about 90,000 ha, to which an additional 18,000 ha are partially irrigated with water transfers through the Larousia Dam. Given the river's importance for the rural livelihoods (63% of the basin population being rural), pluri-annual droughts are an issue of concern. Despite the presence of dams and water-transportation infrastructure, the risk of water deficit due to potential climate change impacts still exists, threatening the livelihoods of small-income farmers and their vulnerability to face supplementary investments as a result of droughts.[34]

Sensitivity to extreme events and dam siltation
An important characteristic of the Medjerda's River's hydrological regime is the regular appearance of extreme floods in the past (1969, 1973) as well as in recent years (2000, 2003, 2004, 2005, 2009 and 2012).

These floods have been devastating on both sides of the river, submerging villages and causing considerable loss of life. The flood of January 2003 in northern and central Tunisia was fatal to eight people and resulted in the displacement of 27,000 others.

The floods were exacerbated by the effect of the storage dams that are subject to significant siltation and have modified the river's flow regime. In particular, the construction of the Sidi Salem Dam in 1982 has caused the downstream channel to narrow down progressively. The purpose of the dam was to control and level off the interannual variable inflows to secure adequate domestic and agricultural irrigation water supply for the northern and central parts of the country, especially in Tunis. Water from the dam is also used to cool several power plants. Although it has contributed greatly to the development of the northern regions of Tunisia, it has also had significant adverse implications due to the silting of its reservoir, not only diminishing basin yield, but also impacting hydropower potential.

Some studies indicate that the dams that have been subject to siltation due to erosion and thus to reduced storage capacity, are expected to have even more storage reduction in the order of 30%-40% by the year 2030 as a result of the potential effects of climate change. During the flood of January 2003, the Sidi Salem and Mellegue Dams required releases of flood volumes of up to 1,300 m^3/s, causing an overflow of the riverbed, which was followed by the transport of large volumes of sediment. This contributed to increased flooding, as well as increases in the delta formation of the river mouth (equivalent to 6.2 km^2 during the 20th century time frame) and thus also affecting biodiversity. These overflows threaten towns and rural populations living along the river, as well as important infrastructures such as irrigation schemes and bridges in the lower valley and the Medjerda Delta. Moreover, as a densely populated area, the Medjerda River basin is at considerable risk if flooding events are to be more frequent in the future with potentially severe impacts on infrastructure, human security and economic development.[35]

Water quality and public health issues
The Medjerda River basin is characterized by many sources of pollution that are of considerable concern. During large floods, releases to agricultural plains downstream of dams cause the accumulation of sediments along the wadi beds, turning the coastal areas into "delta-like" structures, which also affects biodiversity. In addition, the basin is subject to deep waterlogging and salinization due to stagnation of saline runoff water resulting in land degradation of up to 60% of the land. Runoff and drainage waters enriched with soluble elements flow towards the lower parts of watersheds where salts migrate to the particular detriment of drinking-water quality and agricultural productivity.

In addition to natural conditions, water quality in the basin is largely affected by pollution from anthropogenic sources. These include industrial pollution due mainly to the food industry, such as the manufacture of dairy products, with industrial discharges estimated at 221 m^3/day. In addition, urban domestic pollution occurs due mainly to discharge of untreated domestic wastewater estimated at 1.27 million m^3/yr, as well as treated sewage discharge from 19 wastewater treatment plants estimated at 12 million m^3/yr that carry high pollutant loads of nitrogen and phosphorus. These loads are responsible for eutrophication observed in the reservoirs of the Sidi Salem and Siliana Dams.

Urban pollution also arises from the dumping of solid waste, estimated at 149,000 t/yr for the four northwest governorates of the Medjerda basin. This figure is tripled when all six governorates within the river basin are taken into account. Water quality and public health issues thus constitute an important sector to consider for further analysis in conditions of climate change due to their strong interlinkages with river hydrology and climate variability.[36]

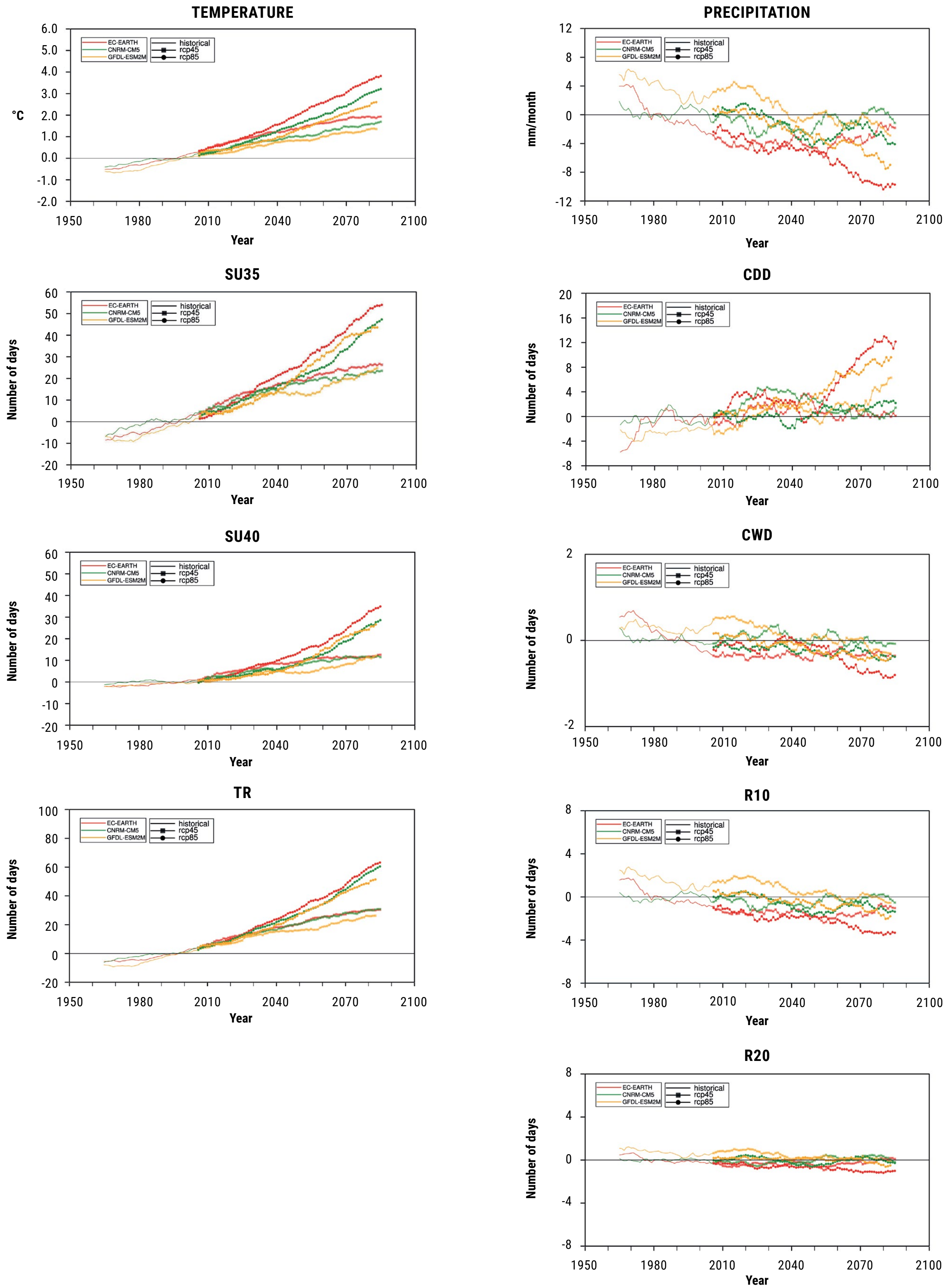
Energy sector and hydropower
Hydropower capacity in the basin is expected to be further developed by both countries over the coming years. This is to be taken into account in view of potential changes in climate and climate variability, particularly in terms of water supply, to ensure the successful development of this sector.

4.3.3 Regional climate modelling findings

Figure 66 shows projected changes in temperature, precipitation and extreme events indices for the Medjerda River until the end of the century. All projected changes in temperatures indicate an increase over time as compared to the reference period, with the most marked for RCP 8.5, reaching a change of 3.5 °C by the end of the century. The highest change is projected in the summer season for these conditions, with an increase of 4.1 °C. For the emission scenario RCP 4.5, increases are 1.2 °C and 1.6 °C at mid- and end-century, respectively.

Changes in precipitation indicate an overall reduction, with considerable differences between both emission scenarios, in particular at end-century. Projected change for RCP 4.5 is –6% at mid-century and –4% at end-century. On the other hand, for RCP 8.5, precipitation change is –9% for mid-century and –19% for end-century. These differences are especially apparent in the projected change for the winter season, where the change is –8% in mid- and end-century for RC4.5, while the change is –13% at mid-century and –21% at end-century for RCP 8.5.

FIGURE 64: Mean change in temperature, precipitation and selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Medjerda River basin



4.3.4 Regional hydrological modelling findings

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 (Figure 65). Both models project a decrease at mid-century for both emission scenarios, with 15%–16% reduction at RCP 4.5 and 31%–32% at RCP 8.5, depending on the model. A 41%–42% reduction in runoff is also projected at end-century for the RCP 8.5 emission scenario.

The same patterns appear at the seasonal level with no difference between the winter and the summer seasons.

Changes in mean discharge projections hold a wide range of values for RCP 4.5 and thus no trend can be concluded. For the RCP 8.5 emission scenario, projections for both time periods show a marked decrease, with −42% change at mid-century (ranging from −47% to −37%) and −53% at end-century (ranging from −60% to −40%).

It is worth noting that decreases are projected in the high-flow value compared to the reference period for RCP 8.5 at mid-century. On the other hand, projections show a mean increase of 60% at end-century for RCP 4.5, however the range of values (−54% to 170%) cannot allow this increase to be confirmed.

FIGURE 65: Mean change in runoff (using HYPE and VIC) and discharge (using HYPE) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Medjerda River

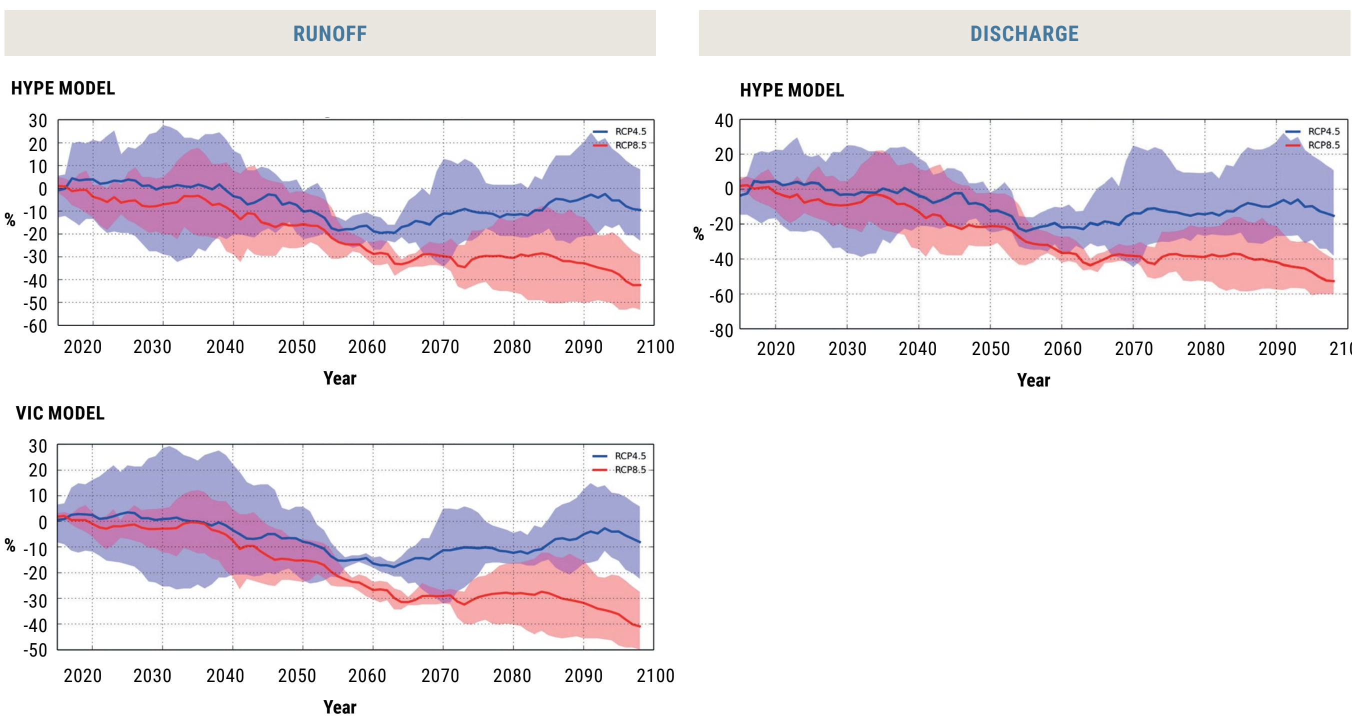
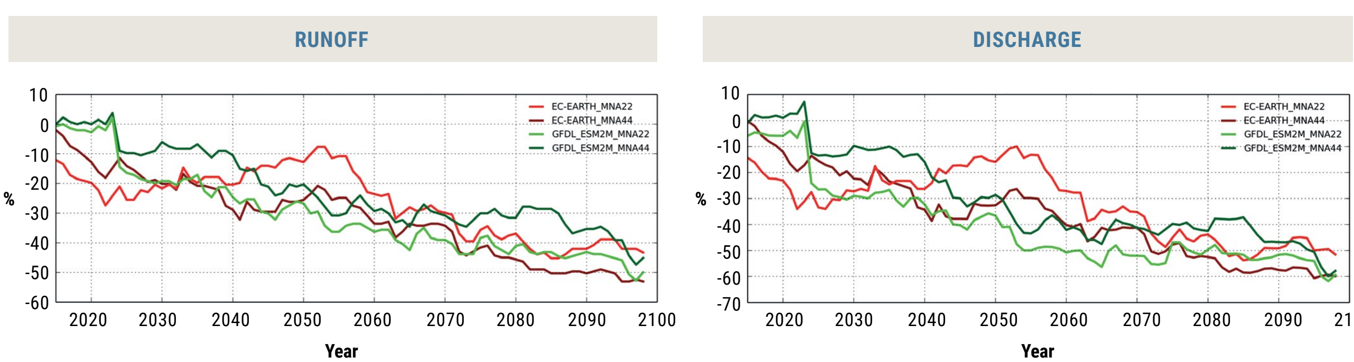


FIGURE 66: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff and discharge (using HYPE) over time for two RCP 8.5 projections for the Medjerda River



4.4 JORDAN RIVER BASIN

4.4.1 Overview and subdomain selection

The Jordan River (Figure 67) originates in the Anti-Lebanon and Jabal el Sheikh mountain ranges and covers a distance of 223 km from the confluence of the headwaters to the point of discharge into the Dead Sea. Its basin area is estimated at 18,285 km^2 (excluding the Dead Sea), distributed among several riparian countries.[37] Tributaries of the river include the Hasbani, the Liddan, and Banias rivers, which converge and flow into Lake Tiberias. As the flow leaves Lake Tiberias, it receives the waters of the Yarmouk River, which is the longest tributary in the basin and contributes significantly to it. The river is further joined by the Zarqa River in Jordan as well as several eastern and western side wadis in its lower course.

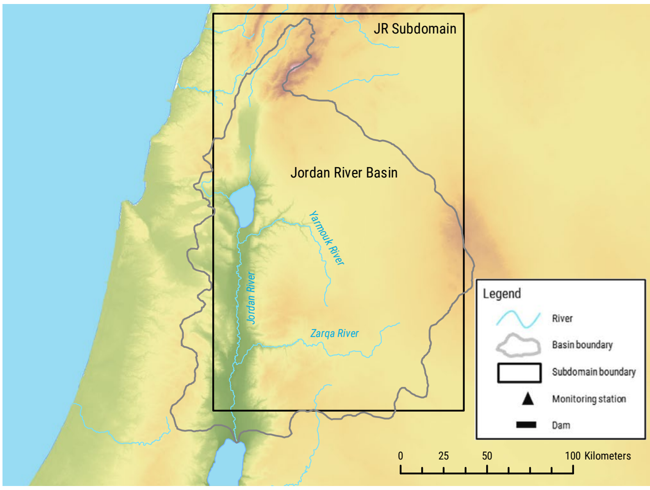
The Jordan River basin displays broad climatic variations within a relatively small area due to the rapidly changing topography which creates different microclimates. A small area in the northern part of the basin consists of mountains in Lebanon and Syrian Arab Republic, while the slopes of the north-eastern mountain ridges and parts of the east bank of the Jordan River are characterized by a dry, temperate Mediterranean climate.

The hillsides of the West Bank and the Jordan Valley have a steppe climate with low precipitation and mean annual temperatures above 18 °C. Parts of the Syrian plateaus and most of the Jordanian Highlands have an arid climate. Precipitation rates in the basin vary from 1,600 mm to 2,400 mm on the eastern slopes of Jabal el Sheikh in the north to less than 200 mm/yr in the lower West Bank and less than 100 mm/yr on the Dead Sea coast. Rainfall declines from north to south and from west to east. The basin has pronounced seasonal climate variability, with strong fluctuations in rainfall from year to year.[38] At its outlet at the Dead Sea, the river had a historic average annual discharge of some 1,300 million m^3 in the 1950s but this value has dropped dramatically to 20–200 million m^3 at present due to high levels of water abstraction through regulation and diversion structures over its course.[39]

4.4.2 Vulnerable sectors

The Jordan River basin is the focus of long-standing water disputes and territorial conflicts; the management of water resources in the basin is thus intimately linked to the regional geopolitical situation. Numerous attempts at cooperation between riparian countries in the basin have been pursued since the early 20th century, but with limited success,

FIGURE 67: Map of the Jordan River Basin and subdomain extent



which adds to the difficulty of responding to climate change challenges on scarce water resources and water-dependent sectors. The key vulnerable sectors to consider in this context are presented below.

Agriculture, food security and livelihoods

Given its large consumption of water and importance as the key source of rural livelihoods, agriculture is the sector most sensitive to climate variability and change in the West Bank. The bulk of the cultivated land is located in the Jordan River Valley, which is considered "the food basket" in the State of Palestine. This sensitivity is heightened by a reliance on rainfed agriculture (94 % of the agricultural area in the West Bank). Agricultural livelihoods, particularly within rural rainfed farming communities, are always directly affected by rainfall and drought incidence. Rainfall reduction and variability are the most important climate risk to rural livelihoods and can lead to severe negative effects on agricultural yields: completely altering a growing season if a reduced or delayed rainfall event occurs, for example.

This situation has taken place in several regions of the West Bank, where the northern governorate of Tubas is economically dependent on agriculture and has experienced repeated droughts contributing to reduced spring flow, limiting the time farmers have for irrigation and producing second or third harvests. Dry years also result in freshwater cuts by the Mekorot water utility to residents in the Jordan River Valley (as was the case during the dry year of 2008), thereby limiting the number of harvests. In Jordan, agricultural production is concentrated in two main regions, namely the western highlands where rainfall is relatively high, and the Jordan Valley. While the Jordan Valley is a much smaller area of land compared to highlands, this is where the bulk of the country's agricultural production occurs and thus where most of Jordan's surface water resources are directed.

Water pumped from the Yarmouk River and nearby wells into the King Abdallah Canal has served as the major water supplier for agriculture in the Jordan Valley, thus representing the backbone of irrigated agriculture. Even though other sources of supply are increasingly being used for this sector, such as treated wastewater, changes in climate patterns coupled to the natural water scarcity still have the potential to severely harm agricultural productivity in this region.[40]

Sensitivity to extreme events

Abnormally low rainfall in the basin has recurrently triggered drought events, resulting in economic losses, lowered agriculture productivity and threats to social and economic growth. This was witnessed in the State of Palestine, for instance, in particular between 2003 and 2010, which was characterized by below-average rainfall and several episodes of agricultural drought.

One example of extreme impacts is the case of Al-Auja village, a rural community located in the West Bank Jordan Valley which was once famous for its agricultural trade. The rich water and soil resources in the area enabled the village to be one of the few that could cultivate several crops and its agricultural productivity was completely dependent on the Auja Spring as the sole irrigation source.

Pressured water resources, drought and decreased precipitation rates ultimately resulted in a significant decline in water availability and the drying-out of the spring. This has had a destructive impact on the Palestinian agricultural economy with thousands of square kilometres lying dry or abandoned today due to lack of access to water and declining rates of precipitation (projected decline of up to 3.8 mm/month on average for RCP 8.5, end-century).

As outlined previously, risks of drought also severely impact livelihoods, particularly with the lack of access to water in situations of scarcity. Restrictions on movement and access to land resources and markets jeopardize the watering and seasonal migration of herds, reduce grazing land and, in many cases, prevent access to closer filling points. This has forced herders to purchase water from more distant (but accessible) filling points, incurring higher transportation costs. Impacts of droughts were also severe in Syrian Arab Repuglic and Jordan.[41]

Energy sector and hydropower

The direct energy consequences of climate change impacts are most likely insignificant in relation to bulk power supply priorities in the State of Palestine. There is continuing growth in energy demand across all sectors and a heavy reliance on energy imports.

Expected vulnerabilities from climatic changes relate to increased energy demands to cope with more temperature extremes at the household level, and to mitigate effects on human health and the agriculture sector. Jordan does not have indigenous energy sources, which makes the country fully dependent on imported fossil fuel.

However, some recent developments and water infrastructure plans should be taken into consideration within a context of climate change, since the water and energy sectors are closely interrelated. For instance, the proposed Red Sea–Dead Sea Canal Project involves pumping seawater from sea level at Aqaba, up 230 m in order to cross over the mountains in its path and then down to 420 metres below sea level to the Dead Sea.

The downward flow of water would be used to generate hydropower, which would partially or wholly provide the energy to desalinate the seawater for consumption in Amman and surrounding population centres. The Disi-Amman water-conveyance project also involves pumping requirements reported to be 50 MW or 2% of Jordan's annual energy consumption. The interlinkages between water resources and energy production/consumption should thus be considered and further investigated in climate change conditions with possible impacts on water and energy supply in the Jordanian part of the basin.[42]

Groundwater

Groundwater is by far the main source of water for the West Bank. With groundwater being extracted beyond sustainable limits in this area, potentials of precipitation decline and warming would exacerbate stresses on water quantity and quality. The western and southern governorates of the West Bank constitute recharge zones for groundwater, which is dependent on precipitation and evapotranspiration rates, and thus affects water availability in the east which fall within the Jordan River basin delineation.

A case of potential decline in rainfall in the coming years could also pose a significant problem for Jordan as precipitation is the only source of recharge for aquifers. Moreover, an overall increase in local and regional irrigation demand has serious implications in the country since further stress, including increased salinity, will be put on the groundwater resource which contributes about 50% to the total freshwater supply in the Lower Jordan River Basin.

The overexploitation of groundwater in the highlands also negatively affects spring discharges and base-flow runoff in rivers that constitute the major sources of water for irrigated agriculture in the Jordan Valley.

This hydrological connection between rainfall, surface- and groundwater is of major importance in terms of vulnerabilities under conditions of climate change.[43]

Water quality and public health issues
Water quality is a serious issue in the basin with the river's quality rapidly deteriorating along its course, displaying extremely high saliniy and pollution rates, particularly in its lower portion. These water-quality issues could be exacerbated and should be taken into consideration in a context of climate change. Issues of public health are also of concern. For instance, Palestinians living in the Jordan Valley area are set to face increased public health issues related to the lack of water, such as dehydration, diarrheal diseases and cholera. A major issue is the growing populations and distribution of mosquitos which are expensive to treat. The risk of parasitic disease should be taken into account in a context of climate change as changes in annual and seasonal climate variability, elevated mean temperature and extreme weather events may allow the spread of existing vectors and the establishment of new, invasive ones.[44]

Geopolitical context
Civil unrest has affected, and continues to affect, water resources management in the basin. In Lebanon, governmental plans to develop and make full use of the water resources of the Hasbani River and Wazzani springs has been the subject of recurrent tensions. In the West Bank, the occupation and restrictions on access to agricultural lands is compounded by climate-induced pressures on water resources and places health and livelihoods at risk.

Jordan has been subjected to additional water stress due to the influx of displaced peoples from neighbouring States. Since 2011, Jordan has received approximately 657,000 Syrian refugees,[45] who are situated in urban settlements throughout the country and are placing additional pressures on Jordan's scarce water resources. There have also been indications of risks of pollution of the main aquifer lying beneath the Zaatari camp due to wastewater leakages. Additionally, overpumping of the Amman-Zarqa aquifer is another source risk facing water resources in this region.[46]

In addition to the above-mentioned issues, further vulnerabilities in conditions of climate change are also of importance, such as demographic development and the vast urban expansion which leads to considerable increases in water demand.

Potential decreases in precipitation could worsen the existing water scarcity problems in the lower Jordan River basin, for instance, where more than 80% of Jordan's water resources and population are concentrated. Moreover, institutional frameworks and transboundary cooperation aspects are crucial sectors to consider in order to ensure the development of policies to counteract the potential negative effects of a changing climate, noting that the prolonged conflict in the basin region directly affects the prospects of joint water management.[47]

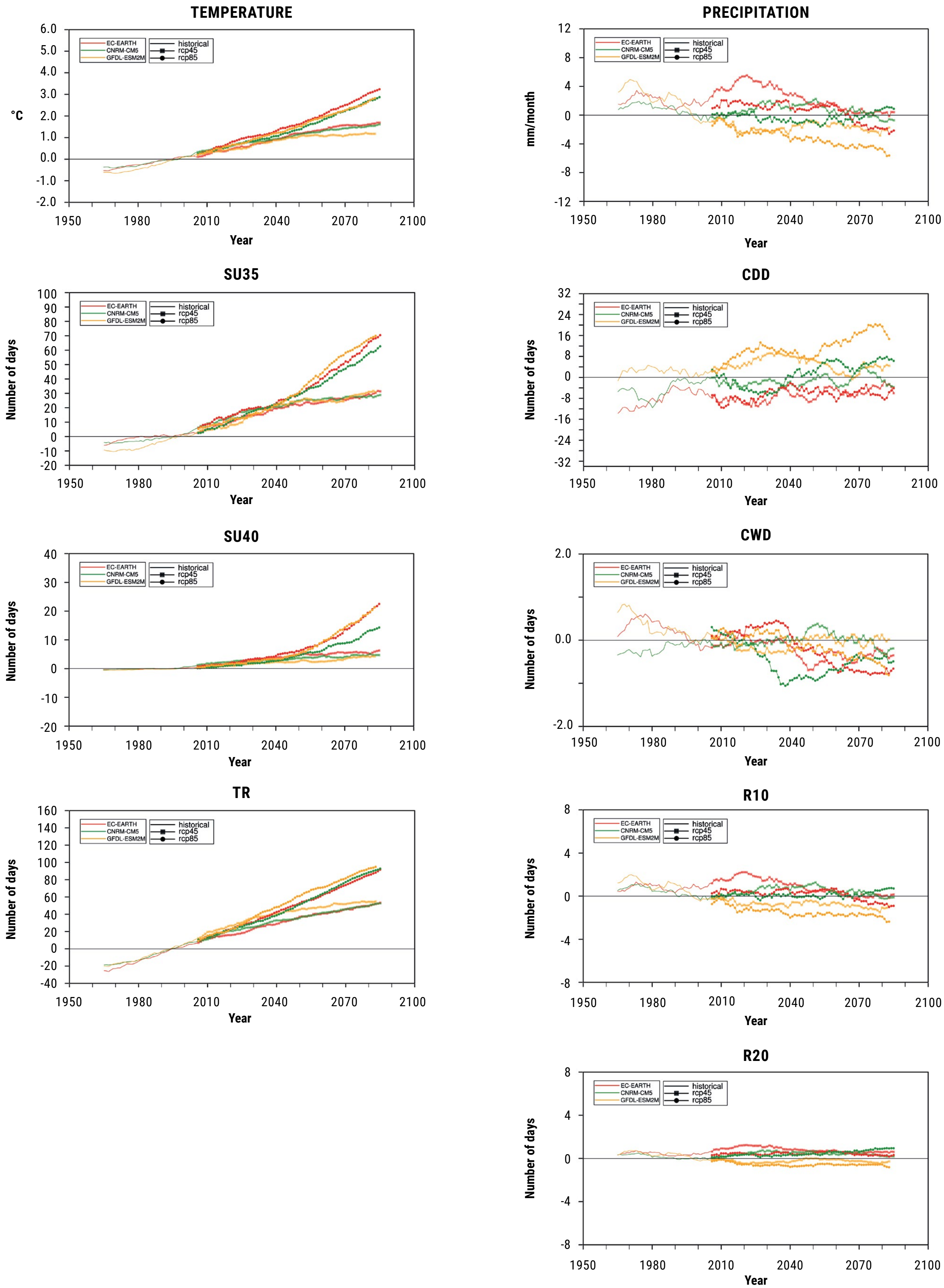
King Talal Dam, Jordan, 2017. Source: Carol Chouchani Cherfane.

4.4.3 Regional climate modelling findings

Changes in temperature, precipitation and extreme events indices until end-century for the Jordan River are presented in the plotted time series in Figure 68. Increases in mean temperatures are projected over time, with changes of 1.2 °C at mid-century and 1.5 °C at end-century for RCP 4.5. For RCP 8.5, temperatures projections show increases of 1.7 °C at mid-century and 3.2 °C by end-century.

Precipitation is projected to decrease and become more marked at end-century for RCP 8.5. For this emission scenario, projected precipitation change is –7% for mid-century and –13% by the end of the century, as compared to RCP 4.5, which exhibits a change of –7% at end-century. A decrease in precipitation of 22% is projected in the summer for RCP 8.5 at end-century. As for precipitation extremes, four out of six projections showed an increasing trend for the SDII indicator (not shown) indicating higher precipitation intensity.

FIGURE 68: Mean change in temperature, precipitation and selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Jordan River Basin



4.4.4 Regional hydrological modelling findings

Overall projections for runoff using both models exhibit a wide range of values and thus no confirmed trend can be concluded, as shown in Figure 69. The only consistent range of values is exhibited by projections from the model HYPE in the summer season for RCP 8.5, with a projected mean decrease in runoff of 21% at mid-century and 23% at end-century. Projections for change in mean discharge show an overall decrease at mid-century for RCP 8.5, as well as for both RCPs at end-century. Given the wide value range, however, no trend can be concluded as to the extent of the reduction in discharge. For instance, the decrease in mean discharge for RCP 8.5 at end-century is 37% but values range between −58% and −4%. As previously mentioned, high uncertainties remain with regard to discharge results for this subdomain, as human influence is not accounted for and can have significant effects on the hydrology, especially considering the size of the river basin.

FIGURE 69: Mean change in runoff (using HYPE and VIC) and discharge (using HYPE) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Jordan River

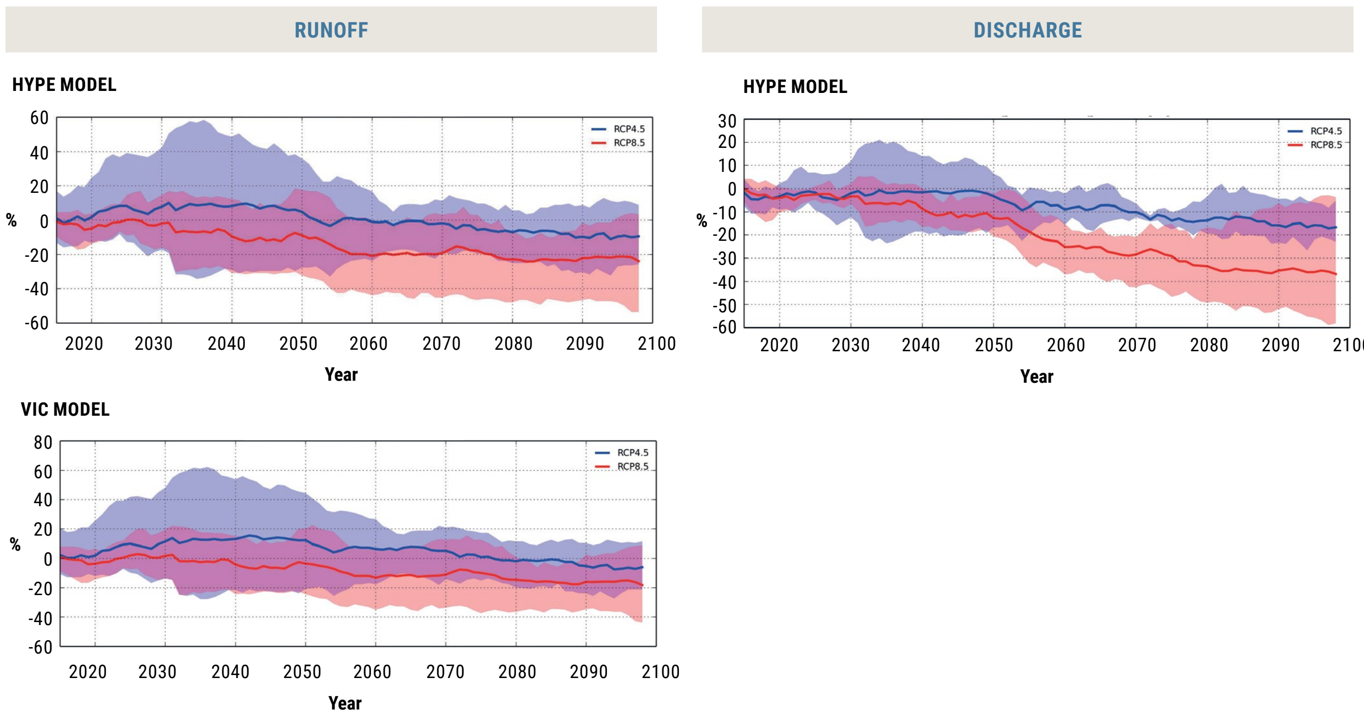
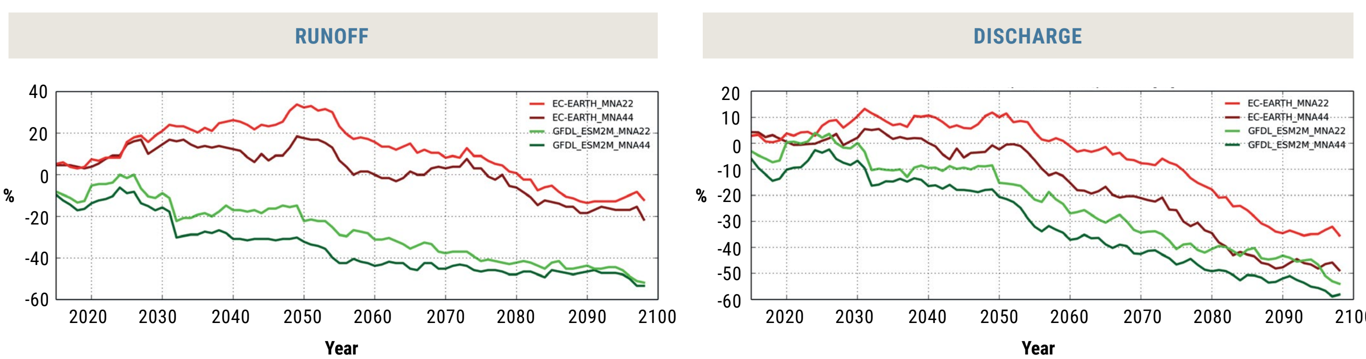


FIGURE 70: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff and discharge (using HYPE) over time for two RCP 8.5 projections for the Jordan River



4.5 SENEGAL RIVER BASIN

4.5.1 Overview and subdomain selection

With a length of 1,800 km, the Senegal River is the second-largest river in western Africa. It originates in Guinea, flows through western Mali and then forms the border between Mauritania and Senegal on its way to the Atlantic Ocean (Figure 71). The basin covers a surface area of some 300,000 km^2 mostly in Mali (53%), followed by Mauritania (26%), Guinea (11%) and Senegal (10%).[48] The river's main tributaries are the Bafing, Bakoye and Faleme and all have their source in the Fouta Djallon mountains in Guinea and contribute 80% of the river's flow.[49] The population of the basin is estimated at around 6 million[50], with nearly 85% living along the river and its tributaries.[51]

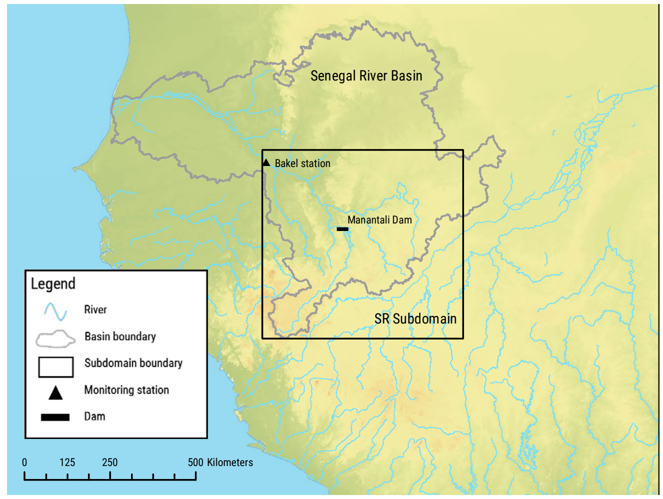
Most of the Senegal River basin has a sub-Saharan desert climate and is characterized by a contrast in rainfall across different regions. The average annual rainfall is 550 mm/yr, with a varying north-south precipitation gradient from 200–250 mm/yr in the northernmost part to more than 1, 800 mm/yr in the Guinean part of the basin in the south. The predominantly natural vegetation of the region follows this gradient, with a semi-arid savannah in the north to sub-humid forest in the south.[52] The contrasting climate between the upper basin and lower valley is also accompanied by a high interseasonal and interannual variability. The basin underwent a long-lasting period of drought starting in the 1970s that lasted more than 30 years, with sharp drops in rainfall causing the region to suffer a succession of chronic annual deficits.[53]

The river's average flow at Bakel (generally considered a reference station due to its location below the confluence with the last major tributary, Faleme) is estimated at around 690 m^3/s, (about 22 billion m^3/yr). This figure decreased from 1,374 m^3/s during 1903–1950, to 840 m^3/s in 1950–1972 and 419 m^3/s in the period 1973–2002.[54]

Since the late 1980s, the valley region has become progressively more artificially regulated with the creation of embankments, free-flow canals and irrigation ditches. These were developed in direct connection with the construction of two larger hydraulic structures, namely the Manantali Dam, located on the Bafing tributary, and the Diama Dam, located near the mouth of the river in Senegal.

The latter (0.25 billion m^3 storage) has functioned since 1986 with the purpose of blocking seawater intrusion and raising the level of the upstream water body (confined by dykes along both shores) to facilitate irrigation, navigation and the filling of lakes in Senegal and Mauritania.

FIGURE 71: Map of the Senegal River Basin and subdomain extent



The Manantali Dam (12 billion m^3 storage) has regulated the flow of the Bafing River since 1988 with the purpose of attenuating extreme floods, generating hydropower and storing water in the wet season to augment dry-season flows for irrigation and navigation purposes.

The installation of the dams has allowed year-round availability of freshwater in sufficient quantities and thus the development of irrigated agriculture in the valley, as well as access to drinking-water installations for populations living near the dams.

4.5.2 Vulnerable sectors

It has been widely reported that two major factors have exerted pressure on the basin's water resources in recent years: variability in the climate and rainfall patterns, as well as dam construction. The major vulnerable sectors in conditions of climate change are directly or indirectly related to these factors and are presented below.

Agriculture, food security and livelihoods
A major part of water use in the basin is directed towards agriculture (around 85% of water withdrawals), a sector which employs more than 50% of the labour force in all riparian countries. The upper basin has remained largely an area of subsistence agriculture, based on shifting cultivation. In the downstream valley and delta, traditional production systems (flood-recession cropping, livestock-farming, fishing) and the practice of modern irrigation with water pumped from the river exist side by side.

In its natural regime, the Senegal River's main channel overflowed during high waters in the rainy season and flooded the wide depression of the middle and lower valley for hundreds of hectares in low-flood years and more than 500,000 ha in wetter years. In these conditions and in the absence of drought, flood-recession farming substantially contributed to achieving self-sufficiency for 50% in the upper valley (the Bakel area) and for 68% in the middle valley (Podor area).

Over the last decades, this farming system was profoundly affected first by drought and chronic water deficits, as well as by the dams, particularly the Manantali Dam, which regulated the river's flow. The other important agricultural activities throughout the basin are livestock-farming and fishing, which were both also affected by the dam construction to varying degrees. For example, there were noted changes in terms of fish stocks with a 50%–70% decline in stocks downstream of Diama; increases in the Diama reservoir and the Lac de Guiers; and substantial decreases in the middle valley (particularly following disturbances in the flood cycle of the alluvial plain, which is a preferred area for fish reproduction).

The agricultural sector and all its related activities is thus a field of particular concern to consider in terms of vulnerability to climate change, as this sector is strongly linked to socioeconomic development and the preservation of livelihoods in the basin.[55]

Land degradation and desertification

Land degradation and desertification are issues of great concern in the basin. Inappropriate land use in various areas of the Fouta Djallon and the Manding plateau have caused soil erosion, land degradation and loss of soil fertility, leading to the creation of vast denuded areas. The spread of deforestation throughout the basin in combination with the overexploitation of natural resources has also modified the basin dynamics in terms of human-settlement patterns.

In addition, phenomena such as decreases in rainfall, increase in the frequency of severe droughts, the occurrence of the harmattan dust-bowl, sand-dune movements and the associated loss of arable land and livestock were precursors to an increase in land degradation and desertification over the years, which progressed toward the south of the basin. The delta has been most affected by land degradation caused by salinization. All these observed phenomena could be intensified in conditions of climate change, leading to decreased land productivity and loss of biodiversity but, most importantly, jeopardizing food security and standards of living for basin communities.[56]

Water quality, ecosystems and public health issues

The dams and associated dykes have brought about major ecological changes in the floodplain on both the Mauritanian and Senegalese sides of the river. The Diama Dam has created a permanent freshwater body whose shores have been subject to the invasion of aquatic plants (*Typha australis*, *Pistia startioles* and *Salvinia molesta*).

Senegal River, Mauritania, 2010. Source: Ihab Jnad.

This proliferation has considerably affected agricultural activities by colonizing irrigated areas and blocking irrigation canals, as well as fishing, by obstructing fishermen's mobility and constituting inaccessible refuges for fish.

These conditions have also contributed to the spread of prevalent waterborne diseases such as malaria and schistosomiasis with the invasive aquatic plants and stagnant water offering ideal conditions for the development of mosquito and snail populations. Schistosomiasis has become a major public health problem in the delta, in particular among children. The rapid increase in intestinal schistosomiasis three years after the dams started operating clearly demonstrates the causal link between the development of this disease and modification in the river regime. Similarly, before the opening of the dams, transmission of malaria primarily occurred during the rainy season but is currently being observed in the off-season (December and May).

The basin is still important for migratory birds, notably water birds, which arrive in large numbers during the European winter to wetlands in the Senegal Valley and Delta. Important delta wetlands have been preserved at four Ramsar Convention sites, including the Diawling (Mauritania) and Djoudj (Senegal) national parks.

The considerations listed above, combined with alteration of the river regime and degradation of natural habitats, put the basin's biological diversity in danger. Water quality, ecosystems and public health issues thus constitute an important sector to consider for further analysis in conditions of climate change due to their strong interlinkages with river hydrology and climate variability.[57]

Sensitivity to extreme events

A severe drought occurred in the basin in the 1970s and lasted for over three decades, with sharp drops in rainfall. The impact of the drought on water resources of the basin has been very marked, namely through the downward trend in annual flow volumes causing the region to suffer a succession of chronic annual deficits.

Also, even though the climate variability in the basin makes it prone to floods that cover large parts of the valley for several days or weeks during August to September, a very severe flood event occurred in August 1999 and lasted until mid-October in many areas. This led to the destruction of several villages and irrigation infrastructure, people abandoning their houses and vast rice-crop losses.

Further downstream, the city of Saint-Louis, located near the mouth of the river, experienced great damage due to inundation of areas built up during the drier years in the 1980s. There have also been indications of changes in local sea level in this low-lying area, which should be taken into consideration in a context of changing climate.[58]

In addition to the issues presented above, the extreme poverty which characterizes the area makes the population very vulnerable to changes in climate. The severe drought encountered in the 1960s and 1970s has pushed the riparian countries to search for ways in which they could cooperate to lessen its impacts.

This situation is unique in the region: drivers for cooperation among riparian countries were the severe drought and consequent vulnerability of the population rather than conflict over river resources.

These pressures on water resources, added to those linked to fast demographic growth and various production activities, have recently had repercussions on the basin's natural environment and its ecological diversity, which might be further threatened by the effects of climate change.

4.5.3 Regional climate modelling findings

Changes projected for temperature, precipitation and related extreme events until the end of the century for the Senegal River headwaters are presented in Figure 72.

Both results of projected temperature and precipitation changes follow an increasing trend. The positive change in mean temperature for RCP 4.5 is 1.6 °C at mid-century and 2.1 °C at end-century. For RCP 8.5, temperatures increase of 2.3 °C for mid-century and 4.3 °C by end-century compared to the reference period. A larger increase in temperatures is projected in the winter season.

Precipitation changes also show increases of 1% at mid-century and 2% at end-century for RCP 4.5. For RCP 8.5, precipitation change is more accentuated with 3% at mid-century and 9% by end-century. In terms of precipitation extremes, outputs based on the SDII indicator (not shown) indicate an increasing trend for all projections. Along with the Euphrates headwaters subdomain, projected change in the R20 indicator for the Senegal River represent an exception: all the projections showed increasing trends (compared to little change for the other subdomains).

4.5.4 Regional hydrological modelling findings

The Senegal River basin, which otherwise shows runoff increases in particular at end-century for RCP 8.5 (mean increase of 8%–18%, depending on the model), exhibits a slight decrease of runoff at end- century for RCP 4.5 (of 2%–3%, depending on the model) even though precipitation shows an increase (Figure 73). A likely explanation for this is that the increase in precipitation is offset by increases in evapotranspiration.

Concerning mean discharge change, no definite trend can be observed due to the wide value ranges. At the seasonal level, there are however, signals of an increase of 13% for the winter season at end-century for RCP 8.5 with the range of values all showing an increase (2%–26% range). When examining projected changes in high-flow value, the range of values show that an increase of 15% is projected for mid-century RCP 4.5 and 25% at end-century RCP 8.5. These projected changes are concordant with the changes exhibited in the summer season. For the winter season, increases are projected at end-century.

FIGURE 72: Mean change in temperature, precipitation and selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Senegal River Headwaters

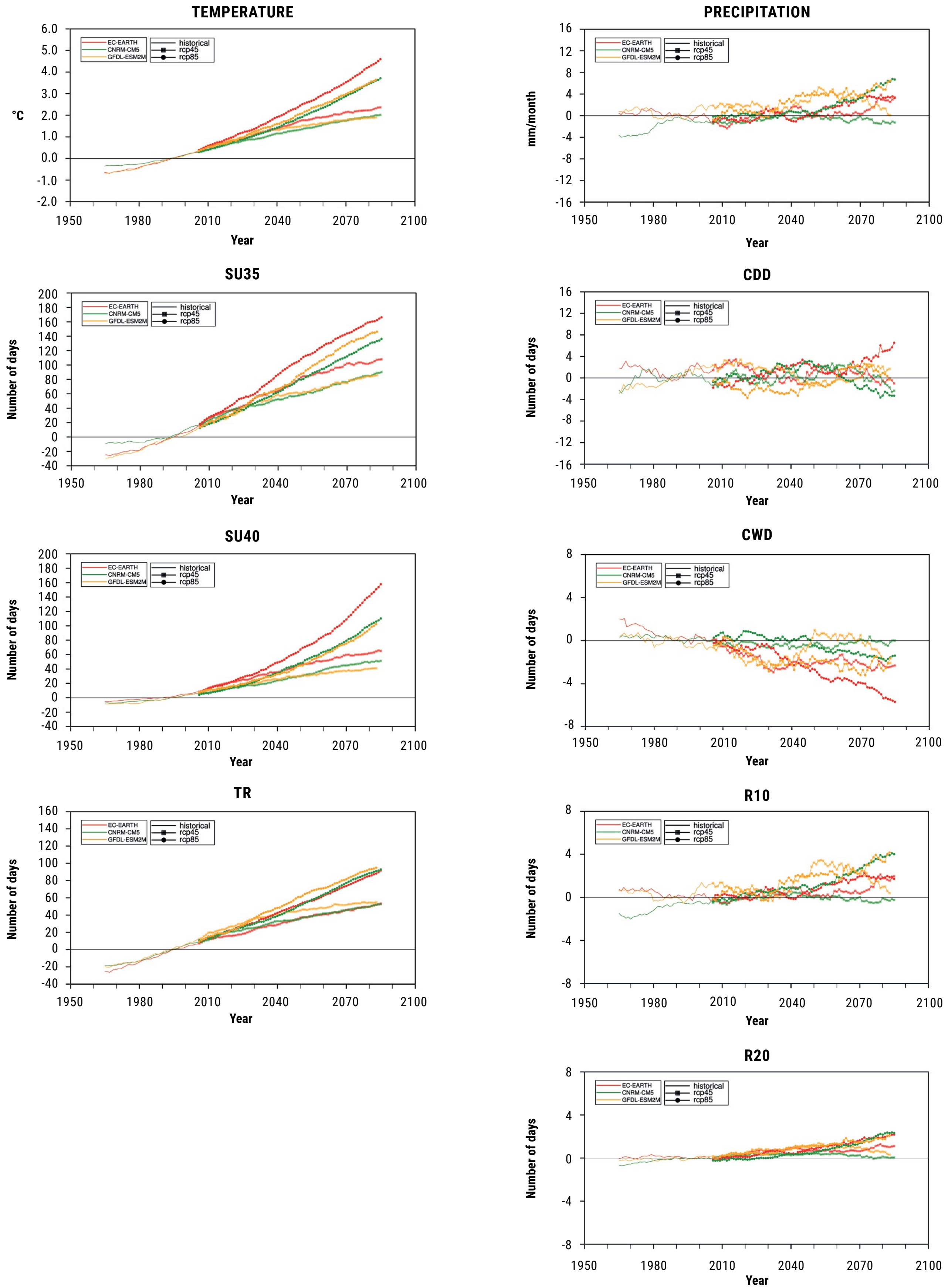


FIGURE 73: Mean change in runoff (using HYPE and VIC) and discharge (using HYPE) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Senegal River Headwaters

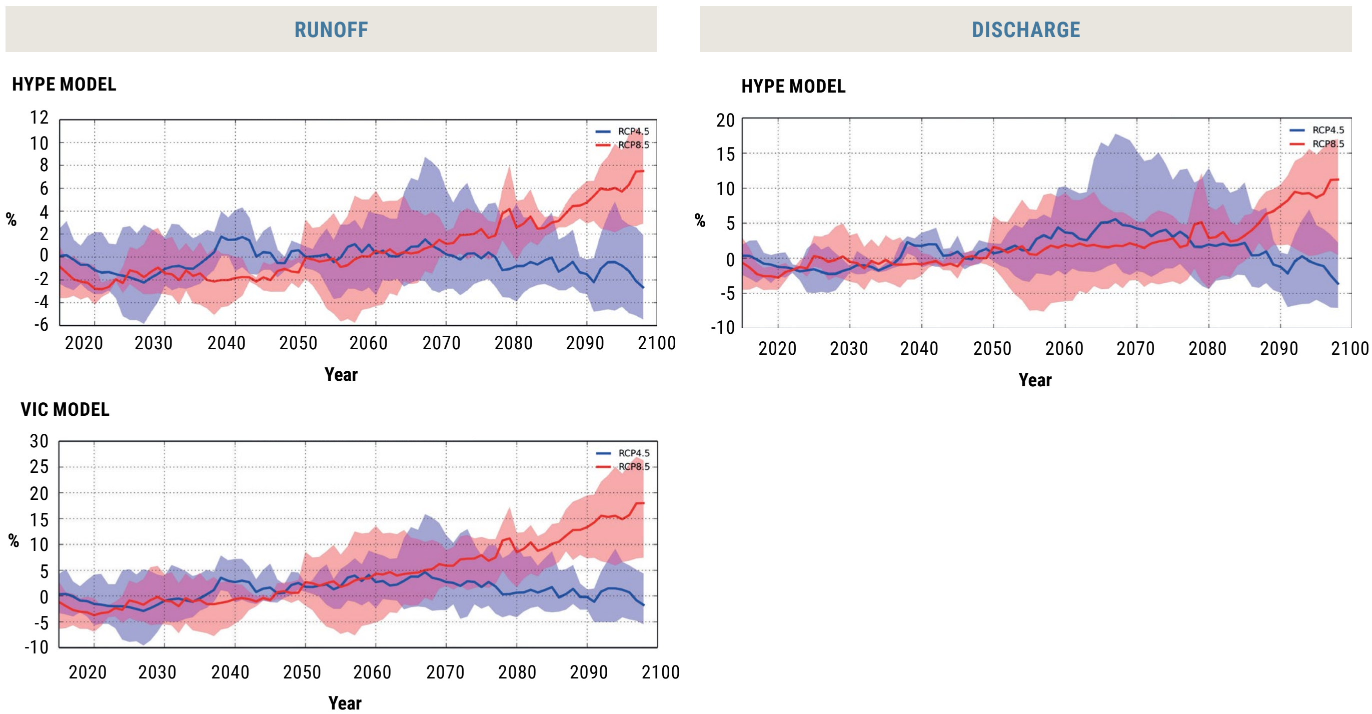
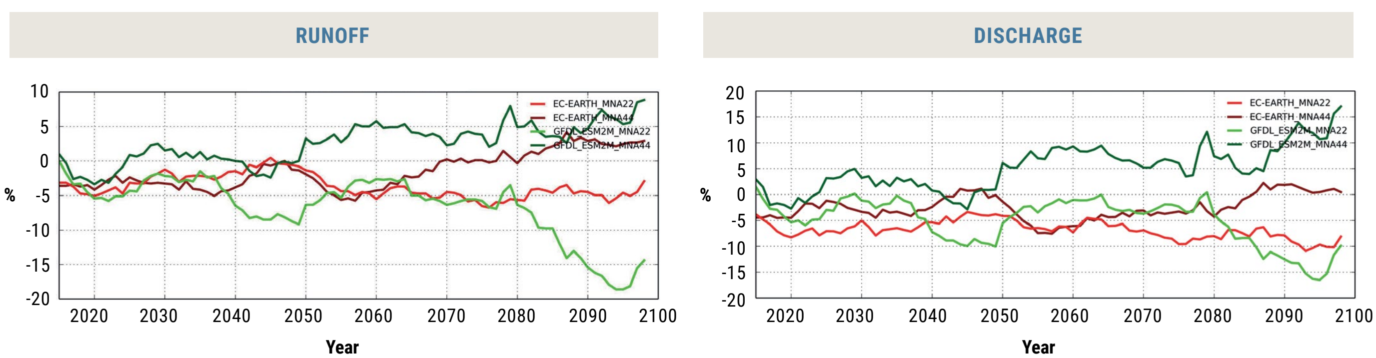


FIGURE 74: Comparison between 25 km (MNA22) and 50 km (MNA44) resolutions for mean change in runoff and discharge (using HYPE) over time for two RCP 8.5 projections for the Senegal River Headwaters



Source: SMHI (2017)

BOX 5: Using RICCAR outputs to inform further basin research

In line with one of its pillars to serve knowledge dissemination and inform further research on climate assessments in the Arab region, RICCAR's 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 (CPET) which aims to improve dialogue and cooperation among the basin countries through increased access to information and knowledge transfer 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, and the output data projections are expected to be further used within this project for simulation of river behaviour under various management options in a changing future climate.

The CPET project is implemented in collaboration with the International Centre for Biosaline Agriculture (ICBA); the Swedish Meteorological and Hydrological Institute (SMHI), the Stockholm International Water Institute (SIWI) and is funded by the Swedish International Development Cooperation Agency (Sida).

ENDNOTES

1. AMWC, 2012
2. Fifth Expert Group Meeting on the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region (Amman, 11-12 December 2013)
3. Ninth session of the Arab Ministerial Water Council Technical Scientific Advisory Committee (Cairo, 26-28 January 2014)
4. NBI, 2012; Allam et al., 2016
5. Melesse et al., 2014
6. Camberlin, 2009; Senay et al., 2014
7. NBI, 2014
8. Sutcliffe and Parks, 1999; Allam et al., 2016
9. Ali, 2014
10. Melesse et al., 2014
11. NBI, 2016
12. Karimi et al., 2012
13. Kitaw and Yitayew, 2014; Jeuland 2010; Whittington et al., 2014
14. Taye et al., 2015; Awadallah, 2014
15. Senay et al., 2014; Sherif and Singh, 1999
16. Kibret et al., 2015
17. Melesse et al., 2014; Wimberly and Midekisa, 2014
18. NBI, 2008; UNEP, 2013
19. Frihy and El-Sayed, 2013; Hassaan and Abdrabo, 2013
20. UN-ESCWA and BGR, 2013
21. Isaev and Mikhailova, 2009; Daggupati et al., 2017
22. USGS, 2012
23. ESCWA and BGR, 2013
24. Sumer, 2014; UN-Iraq, 2013b; Janabi, 2013; Kucukmehmetoglu and Geymen, 2014
25. UN-Iraq, 2013a; Middleton and Sternberg, 2013
26. Voss et al., 2013
27. Stevens, 2012; Awadh and Ahmed, 2013; Varol et al., 2011
28. Pilesjo and Al-Juboori, 2016
29. Milillo et al., 2016; Wall Street Journal, 2016
30. Bozkurt and Sen, 2013; Issa et al., 2014; Shamout and Lahn, 2015
31. Djebbi, 2012; SWIM, 2012; ACSAD, 2015
32. Moldenhauer et al., 2007; Zahar et al., 2008; Hermassi et al., 2014
33. Zahar et al., 2008; Jelassi et al., 2015; Hermassi et al., 2014
34. Hermassi et al., 2014; Chabchoub, 2011; Wiebelt et al., 2014
35. Bargaoui et al., 2014; Gharbi et al., 2016; Louati et al., 2015; Khoualdia et al., 2014
36. Arif, 2012; Abidi et al., 2015; Etteieb et al., 2015
37. UN-ESCWA and BGR, 2013
38. Zeitoun et al., 2012
39. UN-ESCWA and BGR, 2013. Courcier et al., 2005 estimates about 275 million m^3 for the year 2000 and FoEME, 2011, reports 20–30 million m^3 in 2009.
40. Wolff et al., 2007; Dobricic, 2013;Mason and Mimi, 2014; Al-Bakri et al., 2013; Lund, 2014
41. Shatanawi et al., 2013; Shadeed, 2013; WFP, 2014; Törnros and Menzel, 2014
42. Jaber, 2012; Ismail et al., 2013
43. Froukh, 2010; Mizyed, 2009;; Hashemite Kingdom of Jordan, 2010; Altz-Stamm, 2012
44. Mason and Mimi, 2009; FoEME, 2010; Mason et al., 2010
45. Reporting as of March 2017, as per UNHCR, 2017
46. Ministry of Environment, 2013; Farishta, 2014; Müller et al., 2016
47. Haering et al., 2010; Earle et al., 2015; Quba'a et al., 2017
48. OMVS, 2014c
49. FAO, 2007; OMVS, 2014a
50. This estimate is based on the assumption that 16% of the total population for the four riparian countries are living in the basin
51. OMVS, 2014b
52. Stisena et al., 2008
53. Oyebande and Odunuga, 2010; OMVS, 2014b
54. Mbaye et al., 2015
55. Varis and Fraboulet-Jussila, 2002; WFP, 2013; Djaman et al., 2016
56. OMVS, 2014c; UNEP, 2009
57. OMVS, 2014c; Mbaye et al., 2016; Manikowski and Strapasson, 2016
58. Dia, 2007; Osorio and Galiano, 2012; Yacoub and Tayfur, 2017
59. Dione, 2004; Mbengue, 2014

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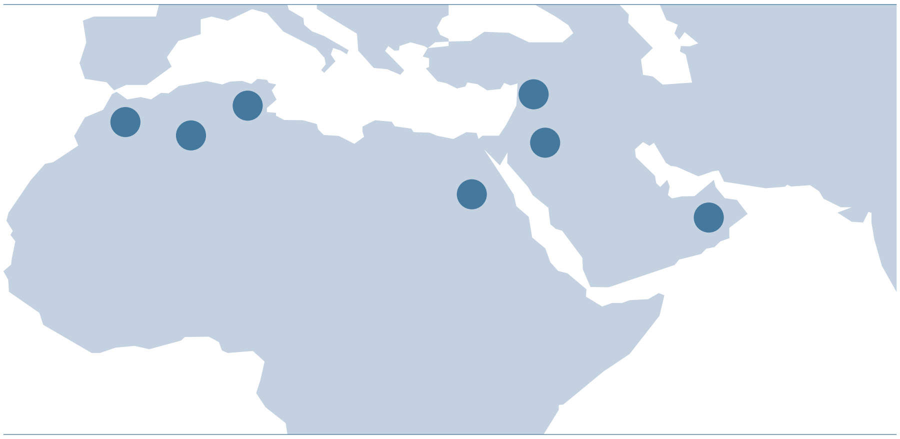
IMPACT ASSESSMENT
CASE STUDIES



CHAPTER 5

EXTREME EVENTS IMPACT ASSESSMENT FOR SELECTED BASINS

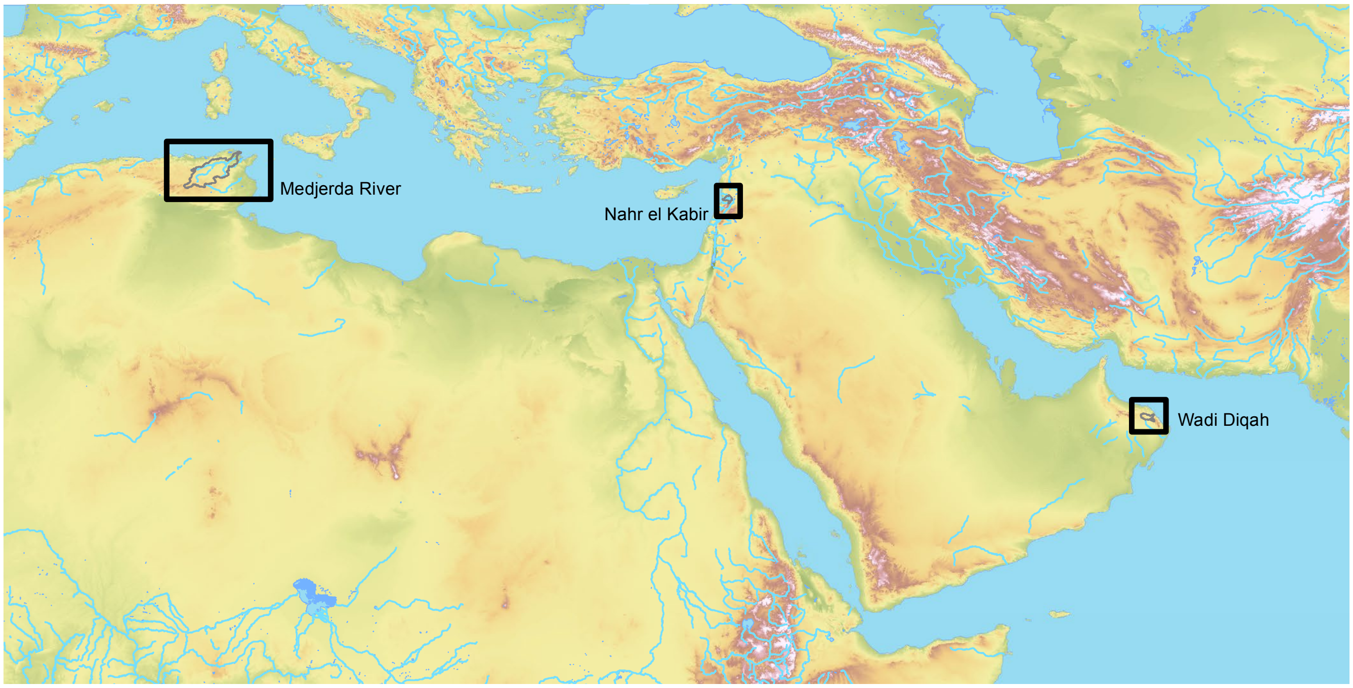
This chapter presents the impacts of climate change in terms of extreme events in three river basins in the Arab region, namely the Nahr el Kabir River basin shared between Lebanon and Syrian Arab Republic[1]; the Wadi Diqah River basin in Oman; and the Medjerda River basin shared between Algeria and Tunisia (Figure 75). For each basin, changes in the following indicators were analysed: extreme temperature and precipitation indices, extreme drought events and extreme flood events. Full details on 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) prepared by ACSAD.[2]

The Nahr el Kabir River is 56 km long and flows along the northern Lebanese border with Syrian Arab Republic and has a total watershed area of some 990 km^2. The river collects its water from tributaries on both sides, flows from east to west and discharges into the Mediterranean Sea at its outlet in Arida, Lebanon. The river basin has been characterized by recurrent floods.

The Wadi Diqah is located 60 km southeast of Muscat and is one of the few wadis continuously flowing throughout the year in Oman. The watercourse is 70 km long and the watershed covers a surface area of some 1,870 km^2. Rainfall varies seasonally and geographically over the study area with an annual average precipitation of about 148 mm/yr (about 276 million m^3).

A detailed description of the Medjerda River is available in Chapter 4, along with a basin map (see Figure 63). The river flows eastwards from north-eastern Algeria to Tunisia and then discharges to the Gulf of Utica in the Mediterranean Sea. Its total watershed area is about 22,700 km^2 and is characterized by a sub-humid to semi-arid climate with a mean annual rainfall of 480 mm/yr with irregular patterns in time and in space.

FIGURE 75: Extreme events case studies: study area



5.1 INDICATORS AND EVENTS SELECTED FOR ANALYSIS

5.1.1 Extreme temperature and precipitation

Projected trends in extreme temperature and precipitation indices were studied for each of the three basins. These were based on RCM daily temperature (Tmax; Tmin) and precipitation projections generated under RICCAR until the end of the century and for both emission scenarios RCP 4.5 and RCP 8.5.

Datasets were quality-controlled and processed into indices of climate extremes using the RClimDex package.[3] The variables analysed were based on the set of extreme climate indices developed by ETCCDI, and those presented in this chapter are listed in Table 13. Additional indices are presented in the related RICCAR technical report.[4]

5.1.2 Drought events

Projected changes in drought events in the three basins were analysed using precipitation projection datasets generated under RICCAR for both emission scenarios until the end of the century. The drought assessment was based on the Standardized Precipitation Index (SPI) according to the method developed by McKee et al.,1993, which measures drought based on the degree to which precipitation in a given time period diverges from the historical median.[5]

SPI indices are timescale-specific and compare precipitation totals for a specific period over all previous years of available data for the same period. Two timescales were selected for this study. The first is the six-month SPI (November to end of April for Nahr el Kabir and Medjerda rivers; May to end of October for Wadi Diqah), which is also referred to as agricultural drought and gives an important indication of rainfall patterns during the agricultural season in the basins.

The other timescale considered is the 12-month SPI (starting November) or hydrological drought, which reflects long-term precipitation. The SPI values were calculated according to a gamma distribution using Microsoft Excel.

It is important to note that the α and β parameters of the γ probability density function were computed for the reference period (1986–2005) then were fixed when SPI was calculated for projected climate data (2006–2100) As defined by McKee et al.,1993, SPI values are classified into different drought categories with SPI < –1.0 indicating a moderate drought, SPI < –1.5 a severe drought, and SPI < –2.0 reflecting an extreme drought.

TABLE 13: Indicators presented

Indicator	unit
Extreme temperatures	
TR (tropical nights)	No. of days/yr
SU35 (hot days)	No. of days/yr
SU40 (very hot days)	No. of days/yr
Extreme Precipitation	
CDD (maximum length of dry spell)	No. of days/yr
CWD (maximum length of wet spell)	No. of days/yr
R10 (10 mm precipitation days)	No. of days/yr
R20 (20 mm precipitation days)	No. of days/yr
SDII (Simple Precipitation Intensity Index)	mm/day
Drought events	
SPI (Standardized Precipitation Index)	-
Flood events	
90th percentile high flow	No. of days
100-yr flood	m^3/s

5.1.3 Extreme flood events

The assessment of the impact of climate change on extreme flow was carried out using the HEC HMS model and the Arc GIS extension HEC-GeoHMS.[6] The Soil Moisture Accounting (SMA) method was selected within HEC-HMS for this analysis. Data sources used to perform the hydrological simulations for each selected basin included observed climate and river discharge data for at least two stations in each basin, as well as topographic, land use and soil data pertaining to each basin. River discharge data were used for model calibration and validation for the three basins. In addition, downscaled RCM daily temperature and precipitation projections generated under RICCAR over the Arab Domain were used as inputs to the hydrological model as the climate data for different time periods and emission scenarios. Potential evapotranspiration was also used as an input and computed within the HEC-HMS model using the Priestley-Taylor method. Hydrological model runs were then performed separately on individual RCM ensemble member simulations (RCA4_EC EARTH, RCA4_CNRM-CM5, and RCA4_GFDL-ESM) covering the period 1970–2100 for RCP 4.5 and RCP 8.5. A total of six runs were thus applied for each basin. For each RCP, the ensemble mean streamflow value from the three model runs was then calculated and used as a result for the analysis. Based on the outputs, two sets of analyses were used to detect projected changes in the frequency and magnitude of extreme streamflow events until the end of the century in the selected basins. The first aimed at identifying changes in the frequency of extreme peak flow discharges: the number of days exceeding the 90th percentile values of the maximum daily streamflow value. The second analysis investigated changes in the 100-year flood value, which refers to extreme flow events with return periods equal to, or larger than, 100 years. The Gumbel frequency distribution was used for flood-frequency analyses, with the variables estimated using the maximum likelihood method.

5.2 NAHR EL KABIR RIVER BASIN – LEBANON/SYRIAN ARAB REPUBLIC

5.2.1 Extreme temperature and precipitation

All temperature indicators indicate trends towards drier conditions in the basin, apparent from projected increases in warm temperature indicators and decrease in cold spells (Figure 76). For instance, SU35 is projected to increase from 60 days to 88 and 98 days at mid- and end-century, respectively, for RCP 4.5 and up to 93 and 124 days for RCP 8.5 (Table 14).

The trend of increased temperature indicators is more pronounced under RCP 8.5. As for precipitation indicators, results are variable.

For instance, there is a significant amount of variability for the CDD indicator with no obvious temporal pattern: for RCP 4.5, an increase by three days is apparent at mid-century, followed by a decrease of three days at end-century.

On the other hand, less heavy rain (R10) is projected over time, even though very heavy rain is projected to increase (R20). Increases in rain intensity are projected for both scenarios over time as exhibited by the changes in the SDII indicator.

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

FIGURE 76: Mean change in selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Nahr el Kabir River basin

TABLE 14: Extreme event indices values for different emission scenarios and time periods for Nahr el Kabir River basin

Index	Emission scenario	1986-2005	2046-2065	2081-2100
Extreme temperature indices				
TR (days/yr)	RCP 4.5	52	81	93
	RCP 8.5		89	119
SU35 (days/yr)	RCP 4.5	60	88	98
	RCP 8.5		93	124
SU40 (days/yr)	RCP 4.5	5	15	18
	RCP 8.5		16	36
Extreme precipitation indices				
CDD (days/yr)	RCP 4.5	113	116	110
	RCP 8.5		113	112
CWD (days/yr)	RCP 4.5	7.1	7.0	6.9
	RCP 8.5		6.9	6.6
R10 (days/yr)	RCP 4.5	13.0	12.9	12.3
	RCP 8.5		12.0	12.1
R20 (days/yr)	RCP 4.5	2.6	3.0	2.9
	RCP 8.5		2.7	3.1
SDII (mm/day)	RCP 4.5	5.8	6.0	5.9
	RCP 8.5		5.9	6.1

5.2.2 Drought events

When evaluating the six-month SPI (Figure 77), results show that moderate drought occurs 55% of the time (percentage in terms of months) for the reference time period. For RCP 4.5, it changes to 45% and 65% of the time at mid- and end-century, respectively, and becomes more intense for RCP 8.5 with moderate drought occurring 75% and 90% of the time at mid- and end-century, respectively.

When evaluating the 12-month SPI (Figure 78), results show that moderate drought occurs 60% of the time for the reference period and is projected at 55% for mid-century and 65% at end-century for RCP 4.5. A strong increase is projected at RCP 8.5, with occurrences of 75% and 80% at mid- and end-century, respectively. In summary, when comparing future projections, results show that a strong increase in the percentage of time with moderate drought conditions is expected towards end-century. There are no projected severe or extreme droughts in the six- or 12-month SPI in the basin.

FIGURE 77: Projected six-month SPI trends over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Nahr el Kabir River basin

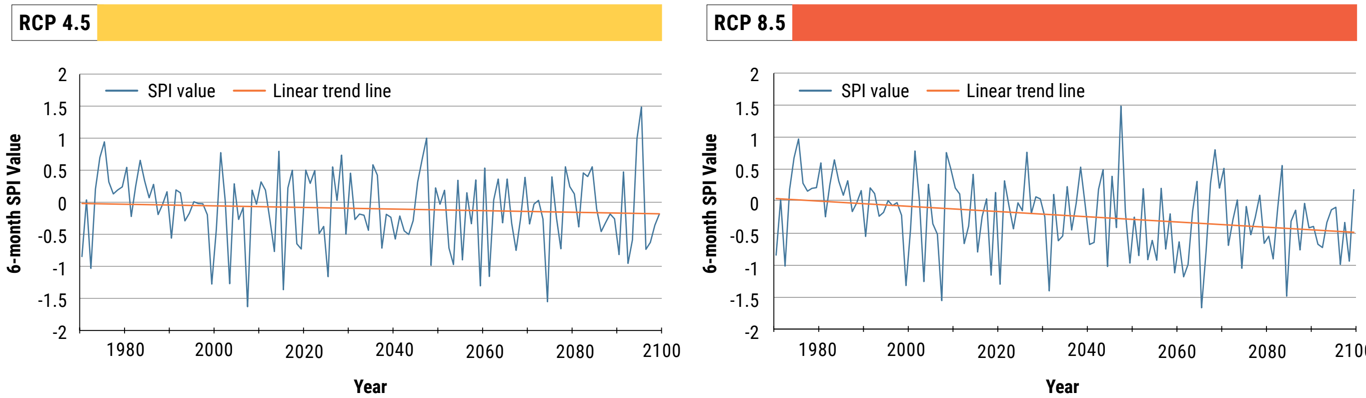
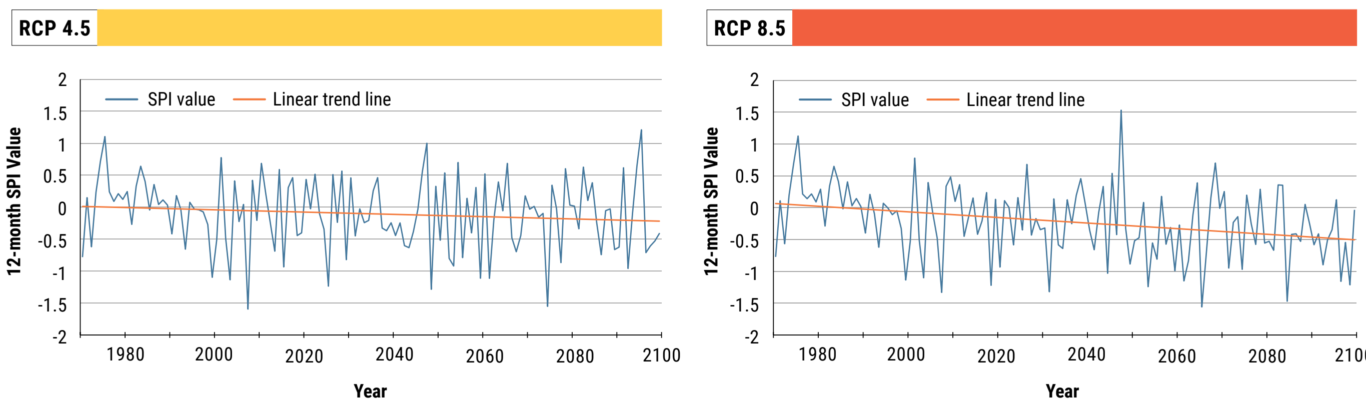


FIGURE 78: Projected 12-month SPI trends over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Nahr el Kabir River basin



5.2.3 Extreme flood events

Results show that the 90th per centile high flow days are projected to increase for both emissions scenarios in this basin (Figure 79). Moreover, trends for the 100-year flood values (Figure 80) are projected to rise strongly in particular for RCP 8.5. Results for RCP 8.5 show changes in value from 126 m^3/s at the reference period to 131 m^3/s and 149 m^3/s at mid- and end-century, respectively (Table 15).

FIGURE 79: Mean number of 90th percentile high-flow days for different emission scenarios and time periods for the Nahr el Kabir River basin

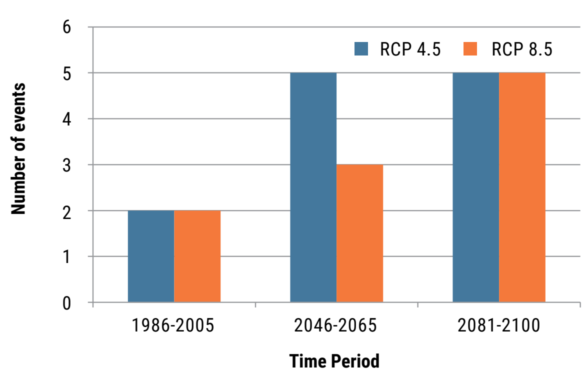


FIGURE 80: Mean change in the 100-year flood value (m^3/s) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Nahr el Kabir River basin

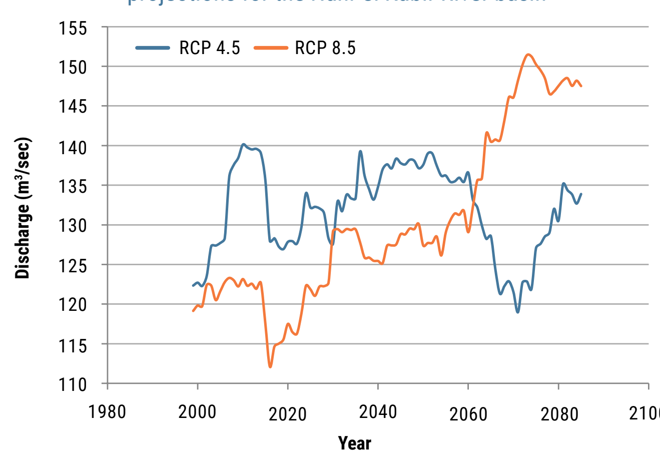


TABLE 15: Mean ensemble 100-year flood values (m^3/s) for different emission scenarios and time periods for the Nahr el Kabir River basin

Emission scenario	1986–2005	2046–2065	2081–2100
RCP 4.5	126	136	128
RCP 8.5	126	131	149

5.3 WADI DIQAH RIVER BASIN

5.3.1 Extreme temperature and precipitation

Results for extreme temperature and precipitation for the Wadi Diqah River basin are presented in Figure 81 and Table 16. All temperature indicators show a trend towards drier conditions in the Wadi Diqah basin. SU35 is projected to increase from 40 days in the reference period to 77 days and 89 days at mid- and end-century, respectively for scenario RCP 4.5. The trends for RCP 8.5 are more pronounced with increases to 88 days and 130 days, respectively, at mid- and end-century. Projections for precipitation indicators indicated a clear increasing trend for CDD in concordance with decreasing trends in CWD. On the other hand, both R10 and R20 show increases towards the end of the century and projected changes in SDII indicate that more intense precipitation events are projected for both emission scenarios.

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

FIGURE 81: Mean change in selected extreme events indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Wadi Diqah River basin

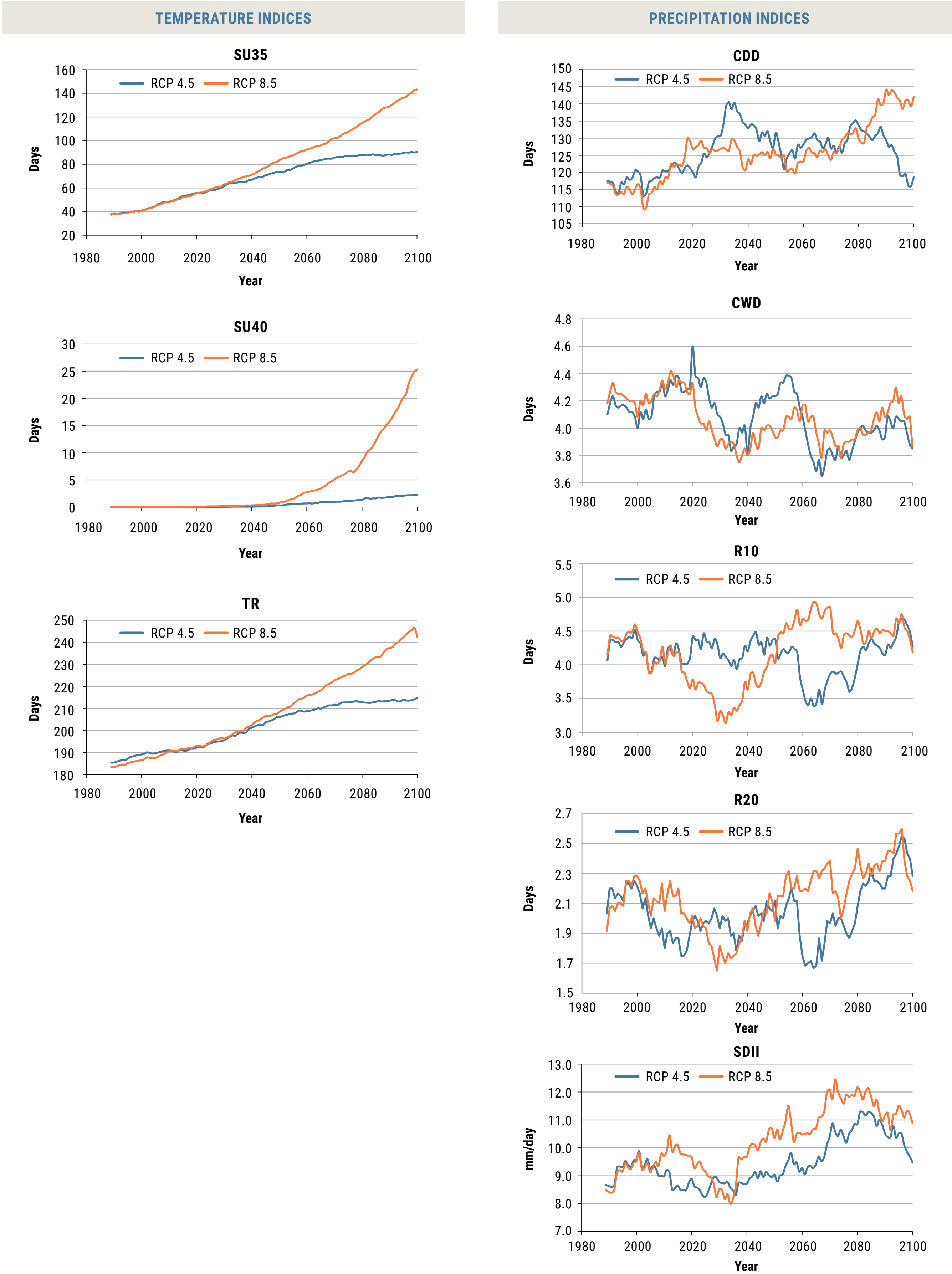


TABLE 16: Extreme event indices values for different emission scenarios and time periods for the Wadi Diqah River basin

Index	Emission scenario	1986-2005	2046-2065	2081-2100
Extreme temperature indices				
TR (days/yr)	RCP 4.5	187	207	213
	RCP 8.5		212	238
SU35 (days/yr)	RCP 4.5	40	77	89
	RCP 8.5		88	130
SU40 (days/yr)	RCP 4.5	0	0.5	1.9
	RCP 8.5		1.8	16.8
Extreme precipitation indices				
CDD (days/yr)	RCP 4.5	115	128	126
	RCP 8.5		124	139
CWD (days/yr)	RCP 4.5	4.1	4.2	4.0
	RCP 8.5		4.0	4.1
R10 (days/yr)	RCP 4.5	4.3	4.0	4.4
	RCP 8.5		4.5	4.5
R20 (days/yr)	RCP 4.5	2.1	2.0	2.3
	RCP 8.5		2.2	2.4
SDII (mm/day)	RCP 4.5	9.1	9.2	10.6
	RCP 8.5		10.6	11.4

5.3.2 Drought events

As shown in Figure 82 and Figure 83, a positive SPI trend is projected for both emission scenarios over the years, though this change in trend is not significant according to the Mann-Kendall test (α=0.05). Evaluation of results in terms of percentage of occurrence shows an overall decrease in the occurrence of moderate drought for the six-month SPI as opposed to an increase for the 12-month SPI. Values for the six-month SPI vary from 60% of the time in the reference period to 50% both at mid- and end-century for RCP 4.5. No change from the reference period is apparent for RCP 8.5 at mid-century (50%) but a decrease to 40% is projected at end-century. As for the 12-month SPI, an increase in moderate drought occurrence is projected for RCP 4.5 compared to the reference period which exhibits an occurrence of 50% (values of 65% and 60% for mid- and end-century, respectively), as well as an increase for RCP 8.5 at mid-century, with the occurrence changing from 50% (reference period) to 55% (mid-century). No severe or extreme droughts are detected in this basin.

FIGURE 82: Projected six-month SPI trends over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Wadi Diqah River basin

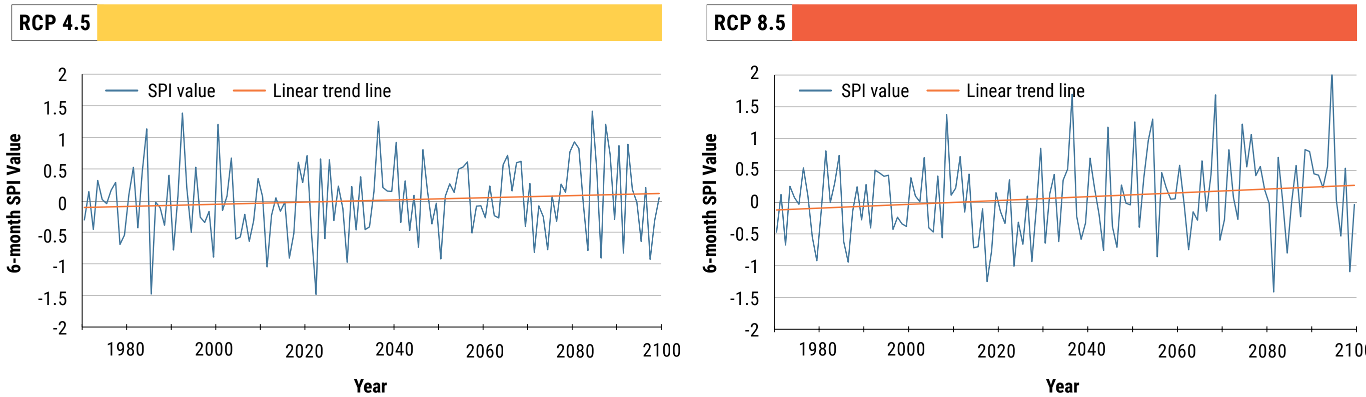
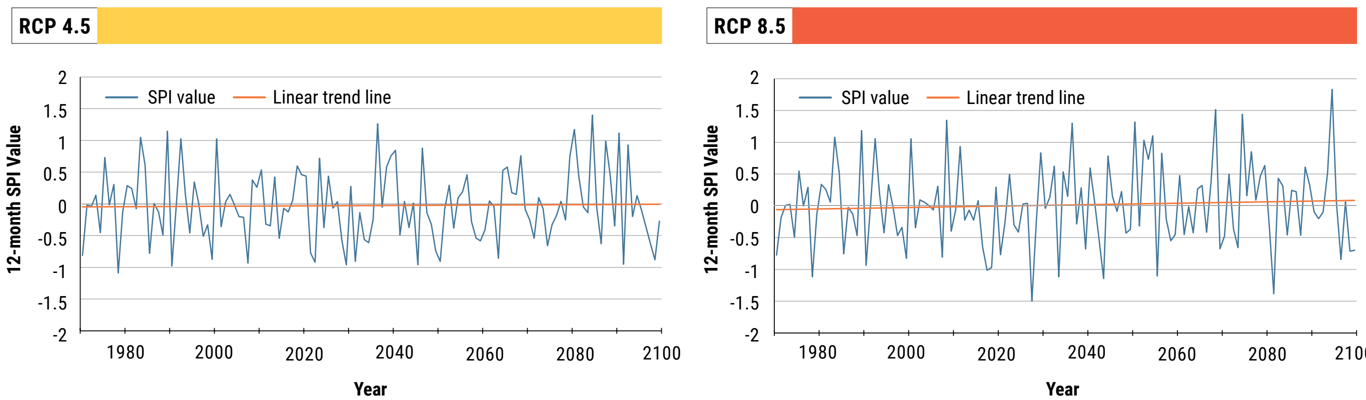


FIGURE 83: Projected 12-month SPI trends over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Wadi Diqah River basin



5.3.3 Extreme flood events

As shown in Figure 84, results for the 90th percentile high-flow days for Wadi Diqah reveal a decrease at mid-century compared to the reference period followed by an increase at end-century for both emissions scenarios. The 100-year flood value is projected to rise for both RCPs at the end of the century after a decrease at mid-century (Figure 85 and Table 17).

FIGURE 84: Mean number of 90th percentile high-flow days for different emission scenarios and time periods for the Wadi Diqah River basin

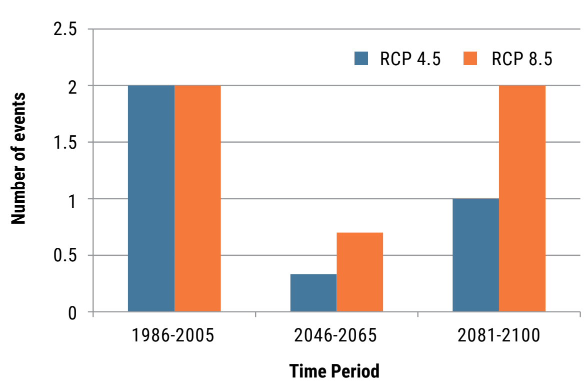


FIGURE 85: Mean change in the 100-year flood value (m^3/s) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Wadi Diqah River basin

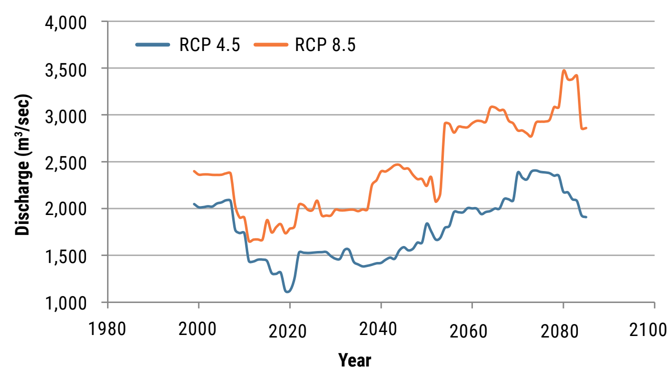


TABLE 17: Mean ensemble 100-year flood values (m^3/s) for different emission scenarios and time periods for the Wadi Diqah River basin

Emission scenario	1986–2005	2046–2065	2081–2100
RCP 4.5	2,200	1,836	2,275
RCP 8.5	2,100	2,667	3,043

5.4 MEDJERDA RIVER BASIN

5.4.1 Extreme temperature and precipitation

As shown in Figure 86 and Table 18, changes in extreme temperature indices in the basin indicate consistent trends towards drier conditions, in particular for RCP 8.5. For example, for the emission scenario RCP 4.5, the indicator SU35 is projected to increase from 45 days in the reference period to 65 days and 74 days at mid and end-century, respectively. These change to 71 and 97 days for RCP 8.5. Results for precipitation extremes are more variable. For instance, CDD show decreases at mid-century and increase at end-century. Both R10 and R20 have consistent decreasing trends at the end of the century, while precipitation intensity is projected to increase at the end of the century (SDII).

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

FIGURE 86: Mean change in selected extreme event indices over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Medjerda River basin

TEMPERATURE INDICES | **PRECIPITATION INDICES**

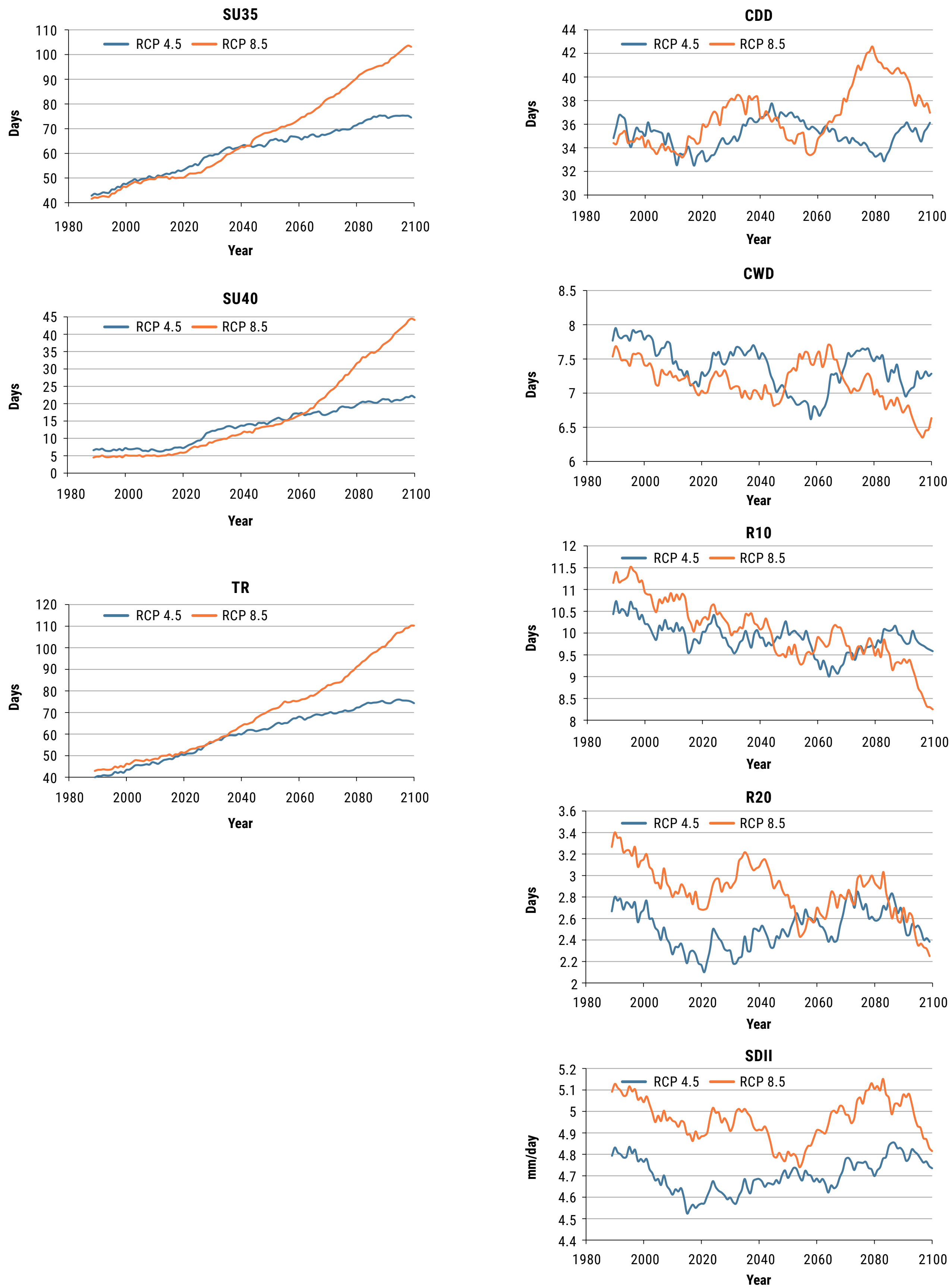


TABLE 18: Extreme event indices values for different emission scenarios and time periods for the Medjerda River basin

Index	Emission scenario	1986-2005	2046-2065	2081-2100
Extreme temperature indices				
TR (days/yr)	RCP 4.5	43	65	75
	RCP 8.5		73	102
SU35 (days/yr)	RCP 4.5	45	65	74
	RCP 8.5		71	97
SU40 (days/yr)	RCP 4.5	6	16	21
	RCP 8.5		15	38
Extreme precipitation indices				
CDD (days/yr)	RCP 4.5	35	36	35
	RCP 8.5		35	40
CWD (days/yr)	RCP 4.5	7.7	6.9	7.3
	RCP 8.5		7.3	6.7
R10 (days/yr)	RCP 4.5	10.9	9.7	9.9
	RCP 8.5		9.6	9.1
R20 (days/yr)	RCP 4.5	3.0	2.5	2.6
	RCP 8.5		2.7	2.6
SDII (mm/day)	RCP 4.5	4.9	4.7	4.8
	RCP 8.5		4.8	5.0

5.4.2 Drought events

Figure 87 and Figure 88 show that SPI values exhibit projected significant negative trends over the years (according to Mann-Kendall test with α=0.05). Unlike the other basins, the Medjerda River exhibits projected episodes of severe and extreme drought in addition to moderate drought for both RCPs over time (Table 19).

Results show a slight increase in the percentage of time with moderate drought for both SPI values and emission scenarios. Furthermore, it can be seen that severe drought conditions are expected to occur much more often by the end of the century. Lastly, extreme drought is projected to occur at the end of the century for the emission scenario RCP 8.5 only.

FIGURE 87: Projected six-month SPI trends over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Medjerda River basin

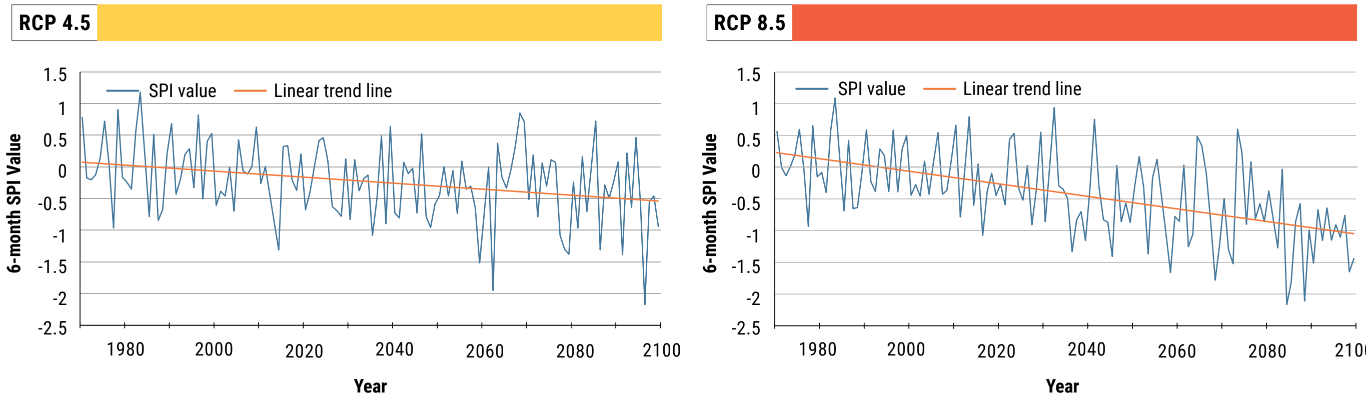


FIGURE 88: Projected 12-month SPI trends over time for ensemble of three RCP 4.5 projections for the Medjerda River basin

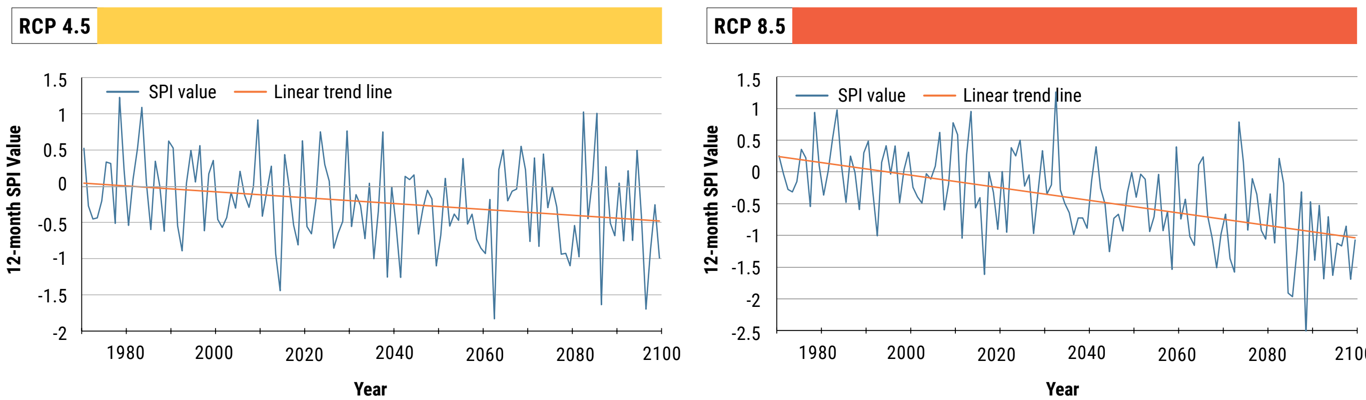


TABLE 19: Projected percentage of time with moderate, severe and extreme drought conditions until the end of the century for the six-month SPI value and the 12-month SPI value in the Medjerda River basin

Drought conditions	Drought occurence (%)				
	Reference period (1986-2005)	Mid-century (2046-2065)		End-century (2081-2100)	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Six-month SPI value					
Moderate	60	70	70	70	75
Severe	0	10	5	0	15
Extreme	0	0	0	5	10
TOTAL	**60**	**80**	**75**	**75**	**100**
12-month SPI value					
Moderate	50	75	85	50	65
Severe	0	5	5	10	25
Extreme	0	0	0	0	5
TOTAL	**50**	**80**	**90**	**60**	**95**

5.4.3 Extreme flood events

Projected changes in the 90th percentile high-flow days are highly variable for the Medjerda basin. As seen in Figure 89, decreases are projected towards end-century for RCP 4.5. On the other hand, results for RCP 8.5 exhibit increases at mid-century and decreases at end-century. Even though the latter indicator exhibits decreases for RCP 4.5, results for the 100-year flood value project increases from 790 m³/s (reference period) to 8,436 m³/s at mid-century and a further increase to 9,031 m³/s at end-century for this emission scenario. For RCP 8.5, values remain in the same range with 7,533 m³/s and 7,627 m³/s at mid century and end-century, respectively (Figure 90 and Table 20).

FIGURE 89: Mean number of 90th percentile high-flow days for different emission scenarios and time periods for the Medjerda River basin

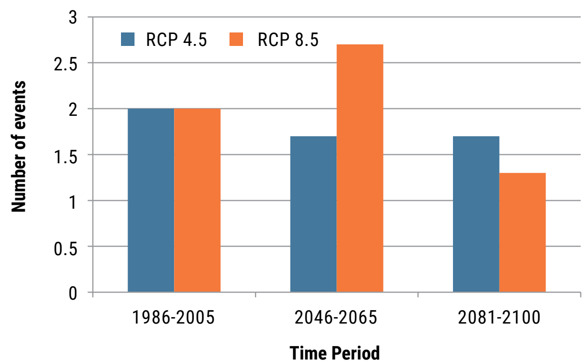


FIGURE 90: Mean change in the 100-year flood value (m³/s) over time for ensemble of three RCP 4.5 and RCP 8.5 projections for the Medjerda River basin

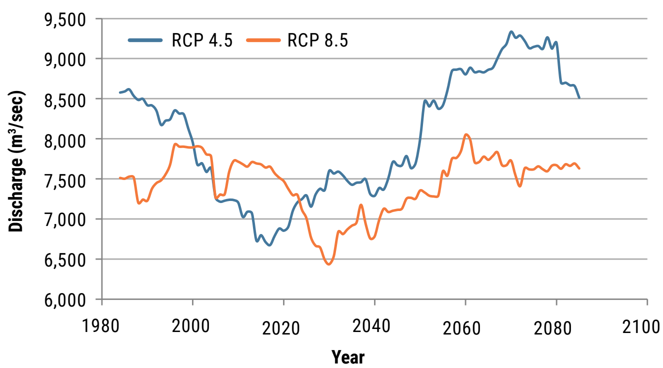


TABLE 20: Mean ensemble 100-year flood values (m³/s) for different emission scenarios and time periods for the Medjerda River basin

Emission scenario	1986–2005	2046–2065	2081–2100
RCP 4.5	7,890	8,436	9,031
RCP 8.5	7,890	7,535	7,627

5.5 SUMMARY OF KEY FINDINGS

For the Nahr el Kabir basin, by the end of the century and for both emission scenarios:

- There is a notable projected increase in heat extremes such as warm-spell duration, number of hot days, number of very hot days, and tropical nights over time;
- Results indicate an increase in precipitation intensity and very heavy precipitation days, together with an increasing number of consecutive dry days;
- There is a projected tendency towards drier conditions with an increase in the occurrence of moderate drought, 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:

- There is a projected increase in heat extremes such as warm-spell duration, number of hot days, number of very hot days and tropical nights over time and for both emission scenarios;
- Results indicate an increase of precipitation intensity and heavy precipitation days, together with increasing consecutive dry days for future periods under both RCPs;
- 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 few changes compared to the reference period;
- The basin is likely to experience a progressive general increase in the magnitude of peak flow over time for both emission scenarios, together with a decreasing number of extreme flood days at mid-century followed by an increase at end-century.

For the Medjerda basin:

- An increase in all heat extremes is projected, such as warm-spell duration, number of hot days, number of very hot days, and tropical nights by the end of the century for both RCPs;
- There is a projected overall decrease in heavy precipitation days, together with an increase in consecutive dry days over time and for both emission scenarios;
- There is a tendency towards drier conditions with projected episodes of severe and extreme droughts in addition to moderate drought over time and for both emission scenarios;
- The Medjerda basin is likely to experience an increase in the magnitude of peak flows for the moderate emission scenario, together with a decreasing number of extreme flood events. For the high-emission scenario, however, the magnitude of peak flow is projected to decrease.

ENDNOTES

1. Also referred to as Nahr el Kabir Al-Janoubi (the great southern river), not to be confused with the Nahr el Kabir Al Shamali (the great northern river), a river in the Syrian Arab Republic that is not shared.
2. ACSAD and ESCWA, 2017
3. RClimDex was developed by, and is maintained at, the Climate Research Branch of the Meteorological Service of Canada. It provides a graphical user interface to compute the 27 core indices and perform quality control on the input daily data (ETCCDI, 2017).
4. See ACSAD and ESCWA, 2017
5. McKee et al., 1993
6. The Hydrologic Engineering Center Hydrological Modelling System (US Army Corps of Engineers, 2000). Refer to Chapter 1 for more details on this model.

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ACSAD and ESCWA (Arab Center for the Studies of Arid Zones and Dry Lands; United Nations Economic and Social Commission for Western Asia). 2017. Impact of Climate Change on Extreme Events in Selected Basins in the Arab Region. *RICCAR Technical Report*. Published by United Nations Economic and Social Commission for Western Asia (ESCWA). Beirut. E/ESCWA/SDPD/2017/RICCAR/TechnicalReport.5.

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McKee, T. B., Doesken, N. J. and Kleist, J. 1993. The Relationship of Drought Frequency and Duration to Time Scales. *Proceedings of the 8th Conference on Applied Climatology*, 17(22): p. 179-183.

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CHAPTER 6

IMPACT OF CLIMATE CHANGE ON THE AGRICULTURAL SECTOR

The Arab region has the lowest per capita availability of water and arable land in the world. Renewable water resources are currently estimated at about 600 m^3 per person per year, corresponding to 10% of the world average, while arable land is about 0.15 ha per person, corresponding to 20% of the world average. Home to about 5% of the global population, the region has the highest percentage of total renewable water resources withdrawal in the world, with irrigated agriculture representing the lion's share (beyond 80%). In the Mashreq countries, the proportion of irrigated land represents 43% of the total cropland, while the Maghreb countries are much less dependent on irrigation (7%–18%), whereas Egypt is nearly 100% irrigated. Furthermore, the Arabian Peninsula and parts of northern Africa are significantly overexploiting their water resources with a significant over-reliance on fossil non-renewable groundwater. Essentially, the water situation is not sustainable and further challenged by being about 60% transboundary.

Notwithstanding efforts to increase agricultural yield, the region is not self-sufficient in food production and relies mainly on imports: about 50% of its wheat and barley, 40% of its rice and 70% of its maize. Some Gulf countries indeed import all their cereal calories. Moreover, the reliance on food imports is expected to increase by 64% between 2010 and 2030.[1] Such reliance on imports exposes Arab States to supply and price risks, as seen during the 2007/2008 and 2010/2011 global food crises. An additional strain on food and water demand is exerted by a strong population growth (almost 2% per year – about twice the world average), which is expected to double by 2050. In addition to rising population, higher living standards, urbanization and further development in general will all exercise an increasing pressure on the already scarce water resources, in turn deeply interwoven with food-security challenges.

Food security and water scarcity remain critical challenges in the Arab region with strong implications for national security, with additional strains caused by climate change impacts. Within RICCAR and through ACCWaM, this section reports on the climate change impact assessment for given time horizons, carried out on major green sectors, specifically, crop systems, livestock, fishery and aquaculture and forestry. 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).[2]

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

6.1 IMPACT ON CROPPING SYSTEMS

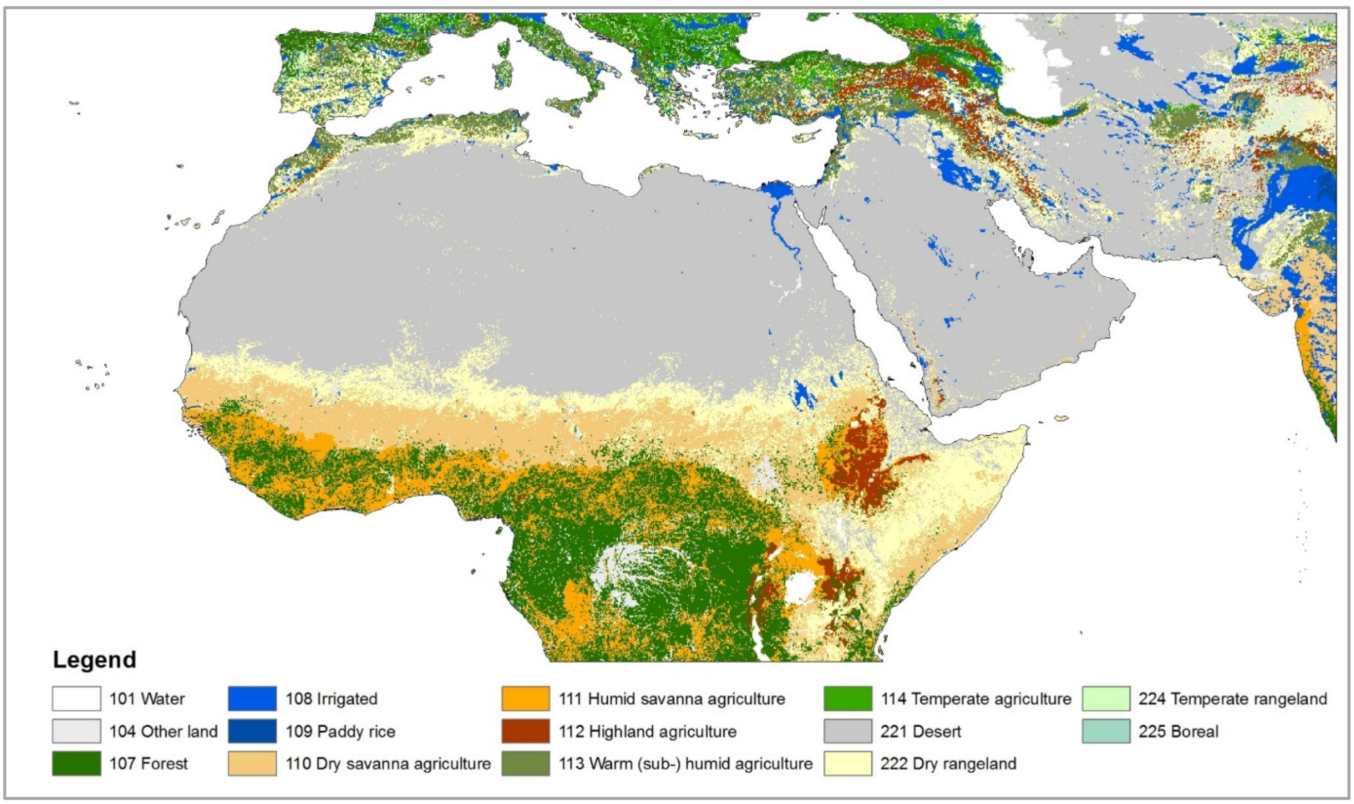
A point of departure for analysing the impact of climate change on crop systems was the identification of the existing farming systems in the region (Figure 91). This map was then superimposed on the vulnerability assessment (VA) maps.

The RICCAR VA maps show that most of the cropped area in the Arab region lies within the highest three vulnerability classes (Figure 92 and Figure 93). The areas with highest vulnerability are the Nile Valley (especially the northern parts: this is in addition to the impact of seawater-level rise on the Delta which is expected to impact negatively about 30% of the Delta land surface within this century), the Tigris–Euphrates basin, the south-western Arabian Peninsula and the western parts of North Africa on the Atlas Mountains. The analysis of the green sectors study area shows that evapotranspiration will increase and runoff will decline, resulting in increased intensity of water scarcity, as confirmed by the crop hotspots characterized by global water scarcity classes. The biophysical characterization of the crop hotspots by global farming systems revealed that the most productive systems of the region, namely irrigated and dry savanna agriculture, are those more prone to climate change: 85%–90% of their combined areas are located under the highest two vulnerability classes.

Consistent results are obtained by overlapping the hotspots with global agro-ecological zones (AEZ), where the most productive (irrigated, good soils and moderate soils) are more vulnerable to climate change under the two scenarios (RCP 4.5 and RCP 8.5) with vulnerability increasing when moving to the worst-case scenario and towards the end of the century. Consequently, the most important crops in the region, particularly wheat and sorghum, are all highly vulnerable to climate change as the majority of their areas are located within the two classes of highest vulnerability.

Sorghum crop, UAE, 2010. Source: Wikimedia commons/Priyag.

FIGURE 91: Major farming systems in the Arab region



Source: FAO, 2011

Figure 94 and Figure 95 illustrate the distribution of the harvested areas of six crops analysed by vulnerability class under the four climate change scenarios. The most affected crops are wheat and sorghum.

The latter is grown mostly in areas with the highest vulnerability (range 5.9–7.5) while the former is mostly located in the areas with second highest vulnerability (range 5.1–5.8).

It is also evident that the vulnerability of all crops increases when moving from RCP 4.5 to RCP 8.5 and when moving from mid- to end-century scenarios. This is clear in Figure 96 where, for example, the percentage of wheat area falling under the highest two classes of vulnerability increases from 57% under RCP 4.5 mid-century to exceed 65% under RCP 8.5 end-century. Similar trends apply to all the other crops even for olive – the least affected crop with the lowest percentage in the highest vulnerable areas.

FIGURE 92: Distribution (%) of major farming systems in the vulnerability classes (mid-century)

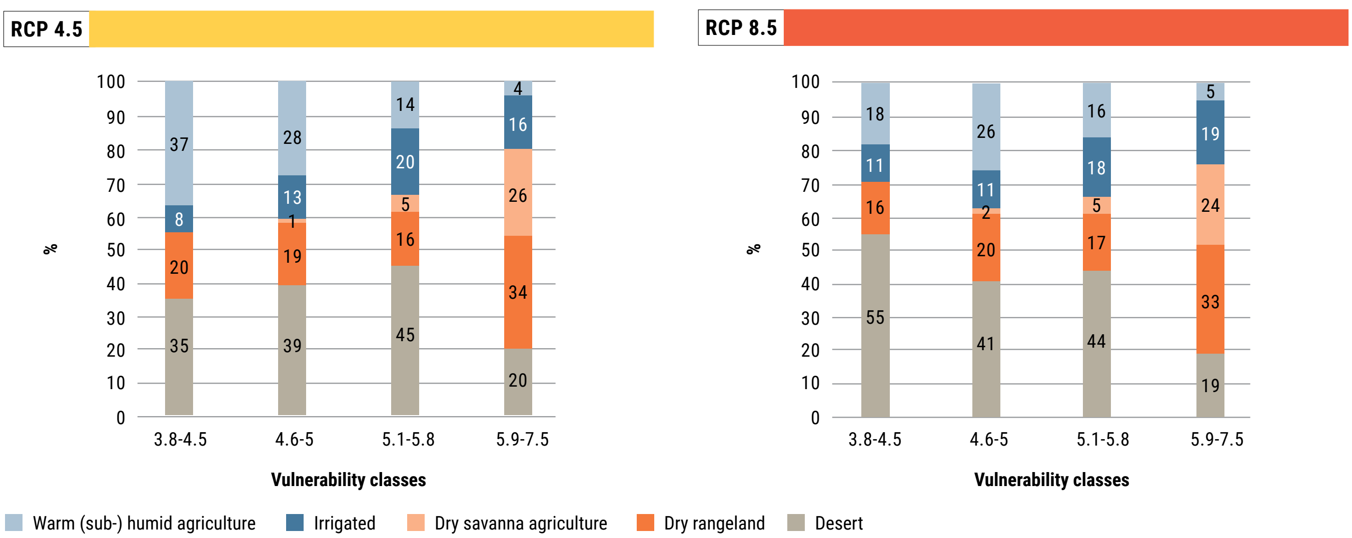


FIGURE 93: Distribution (%) of major farming systems in the vulnerability classes (end-century)

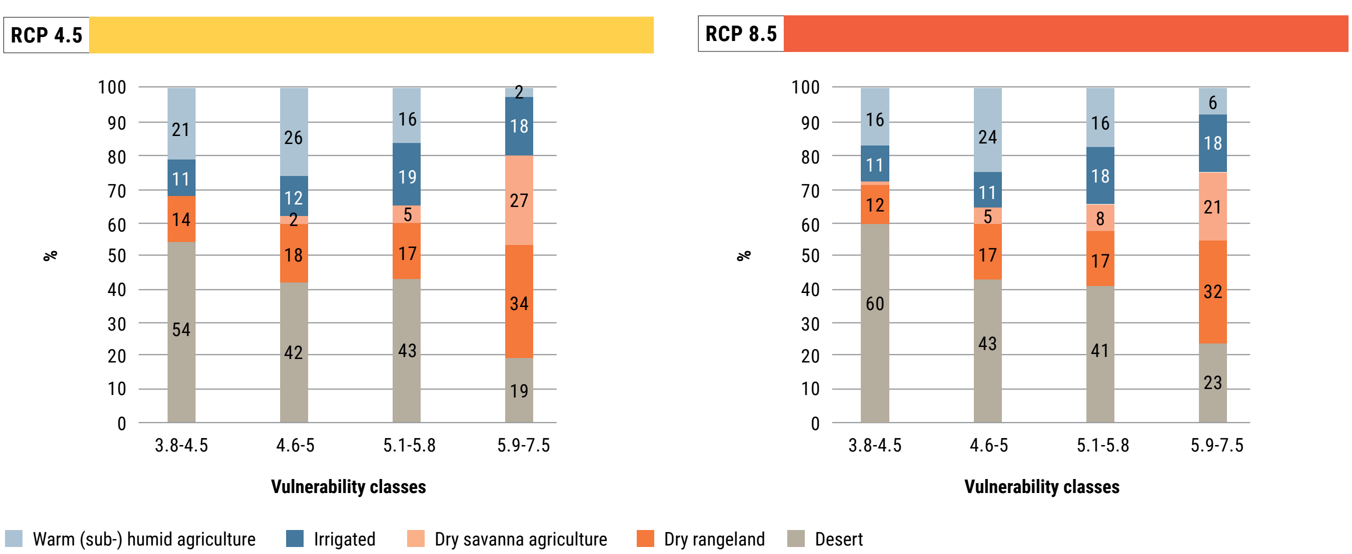


FIGURE 94: Crop area distribution in the vulnerability classes (mid-century)

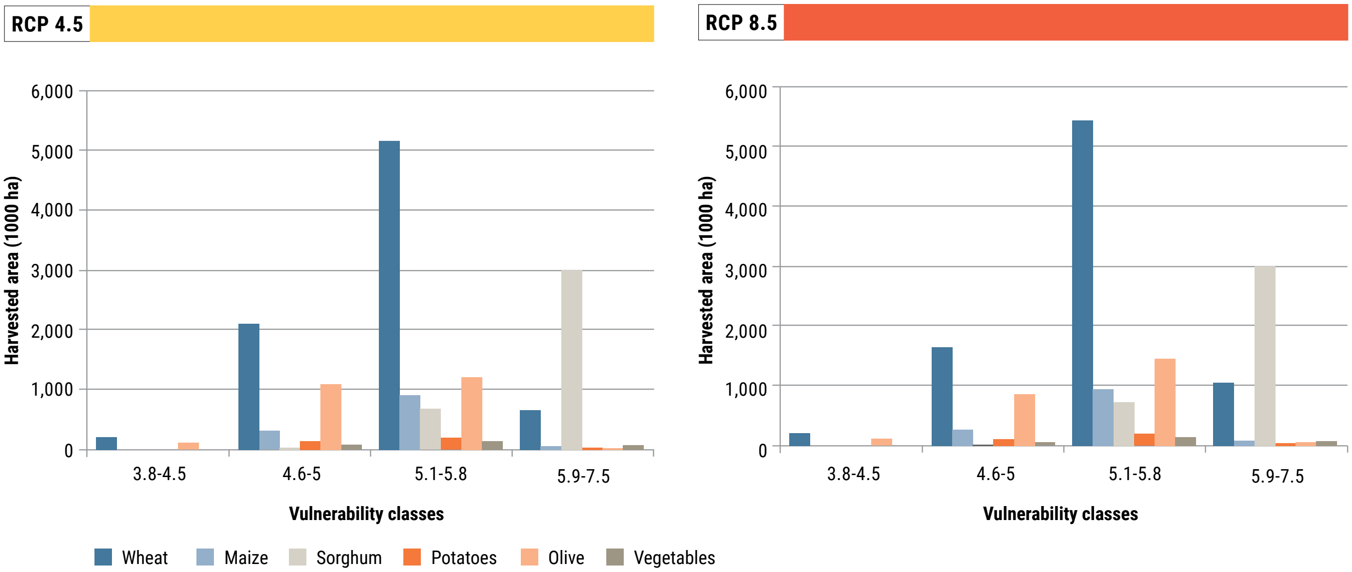


FIGURE 95: Crop area distribution in the vulnerability classes (end-century)

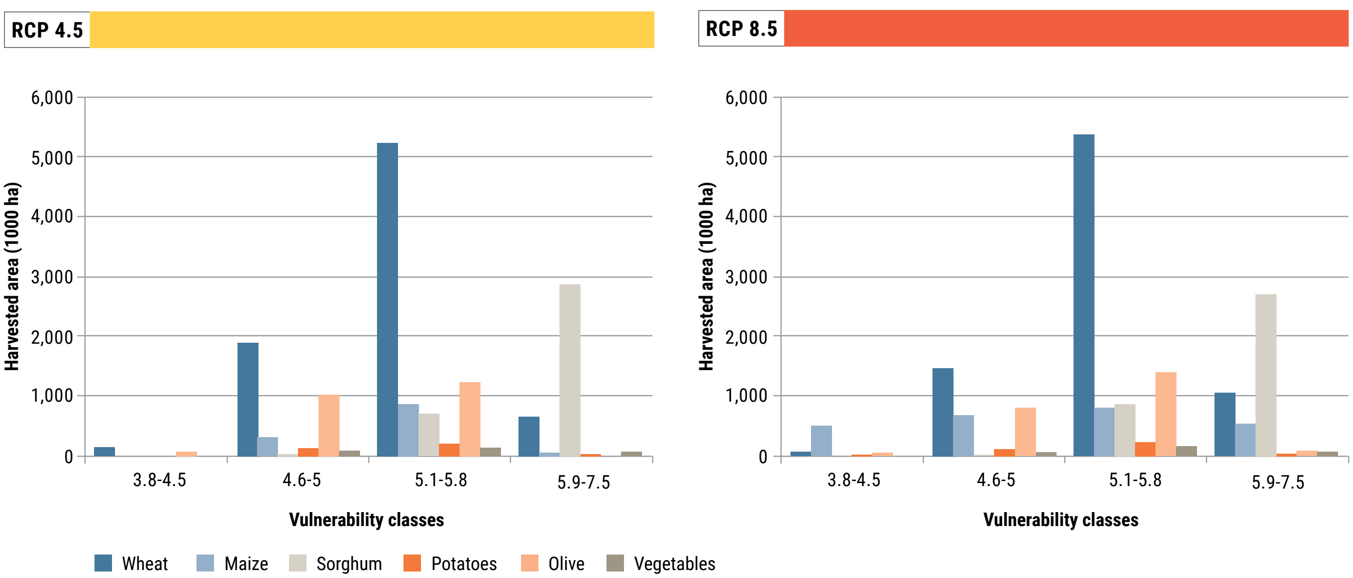
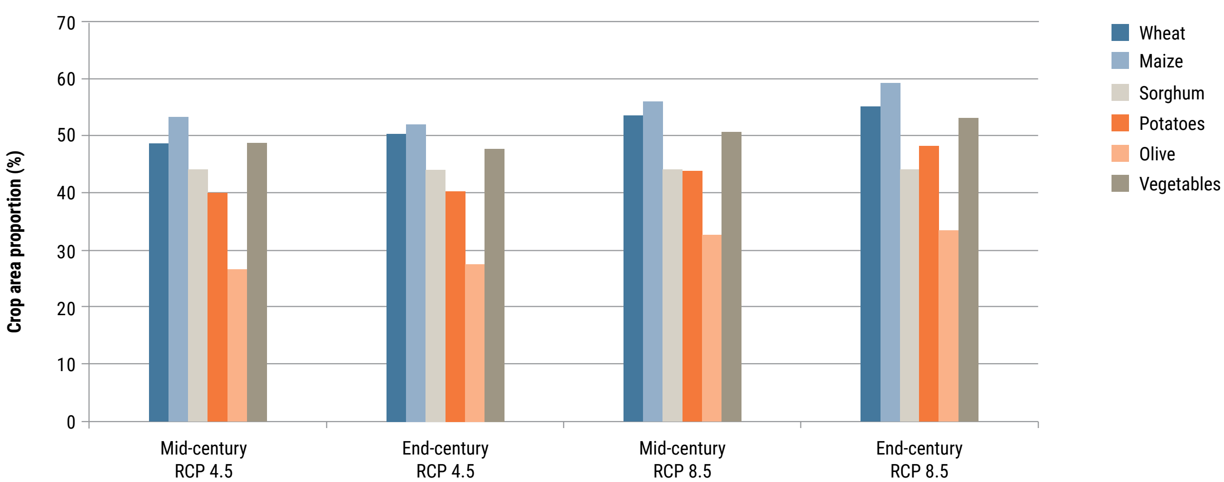


FIGURE 96: Proportion of irrigated crops areas exposed to the highest two classes of vulnerability



Although some GCMs predict yield increases for some climate scenarios, these increases will occur mostly in areas less important for the relevant crops, while the areas where the crops are concentrated will be negatively affected under all climate scenarios (both moderate and worst-case scenario). For example, irrigated maize is predicted to realize some yield increases within the second and third vulnerability classes. Sorghum, however, which is grown mostly in the highest vulnerable areas, will experience yield declines under all climate change scenarios. Wheat yield is projected to decline under all scenarios, with the largest decline expected in areas with high wheat concentrations. Maize is the least vulnerable cereal and it is expected that reduction in yield will be slight, despite it being located mostly within highly vulnerable areas. Trends for potatoes are similar to those for maize and for olive, which is the only tree crop examined: it was found to be the most vulnerable to climate change, with substantial yield reduction under all scenarios and all GCMs.

6.2 IMPACT ON LIVESTOCK SYSTEMS

The livestock sector in the region contributes to food security, poverty alleviation, employment and economic development and shares 30%–50% of the agricultural output. The vulnerability hotspot map for livestock (see Chapter 11) was produced solely on the basis of water availability without considering the impact on feed production. Adding to that the predicted change in temperature, the results of the hotspots show that the potential impacts of climate change on livestock is related to a dwindling water- and feed-resource base due to recurrent droughts, degradation of rangelands and desertification. Most vulnerable areas are located along the Nile Valley, the Horn of Africa and the south-western Arabian Peninsula, followed by areas of the Fertile Crescent and North Africa, though to a lesser extent. The vulnerability maps showed that the potential impacts of climate change on livestock are slight, compared to their impacts on crops. However, these impacts become significantly negative by the end of century with worst climate scenario. Focusing on sheep, goats, cattle and camels, the majority of these livestock are found in areas with very high vulnerability classes. Excluding camels, which have the lowest density, cattle are the most affected by climate change, followed by goats and sheep, respectively. No noticeable difference in vulnerability is observed between production systems for goats and camels but cattle and sheep – the most important animals in terms of value and number, respectively – raised on grassland production systems will be more prone to climate vulnerability than those raised under mixed systems. The latter is especially true for sheep, whose vulnerability increases dramatically with a grassland system compared to a mixed system under worst-case climate scenario.

Aquaculture near the Orontes river, Lebanon, 2011. Source: Joelle Comair.

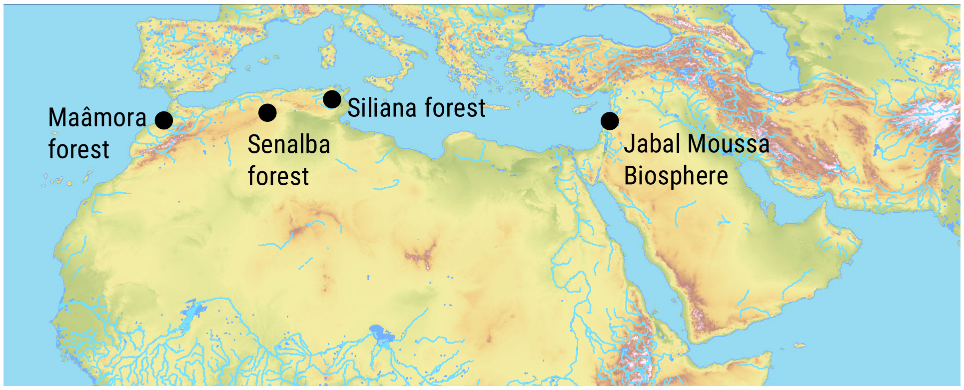
6.3 IMPACT ON FISHERIES AND AQUACULTURE

Marine fisheries in the region – and to some extent aquaculture – contribute to food security, poverty alleviation, employment and economic development and share about 25% of agricultural output. In 2011, for example, while the self-sufficiency of cereal in the region reached 45%, the self-sufficiency of fish reached about 75%. Moreover, aquaculture fish production is expected to increase in the coming years, further reducing the gap between domestic supply and demand. However, freshwater aquaculture of many countries in the region is likely to be affected by climate change and may be affected by flooding, drought or high temperatures. It should be noted that the pressure exerted on biodiversity by the pressure of fishing activities has a greater impact on stocks and ecosystems than climate change. Because many fishery resources are heavily overexploited, a change in climate is likely to cause the final collapse of some stocks if fishery management does not reduce exploitation.

6.4 IMPACT ON FORESTRY

In the Arab region, rising atmospheric CO_2 concentrations, higher temperatures, changes in annual and seasonal precipitation patterns and the frequency of extreme events, such as droughts and forest fires, are severely impairing the production, quality and stability of forests and other natural ecosystems. The aridity of the region and low forest cover, coupled with high deforestation rates in some countries, make forests more vulnerable to the negative consequences of climate changes. More specifically, the impact on four major forestry systems were investigated (Figure 97).

FIGURE 97: Location of the pilot sites for investigating the impacts of climate change



The Maâmora Forest in Morocco is currently undergoing strong anthropic pressure corresponding to wood collection for all uses, overgrazing and systematic collection of cork-oak (*Quercus suber*) acorns for food and trade. Because it prevents natural regeneration, overgrazing is one of the causes of forest ageing. The main impact of climate change on the Maâmora Forest is expected to be water stress. This will be further amplified by anthropic pressure (overgrazing, fuelwood collection, non-wood forest product collection, urbanization, and tourism) and, to a lesser extent, by pest attacks. Eastern zones of the Maâmora Forest are more vulnerable than its western zones.

The mid-century impact of a moderate-case scenario shows an increased vulnerability in all forest areas. Eastern zones will be mostly impacted by water deficit, while western zones will be mostly impacted by forest ageing and health. End-century sees a significant increment in vulnerability.

The Senalba Forest in Algeria has been quite well preserved, thanks to its altitudinal position (900 m–1,600 m asl). There is, however, a strong lack of regeneration of the forest stands, whose average age is 105 years. Moreover, more than 50% of the lands of the Djelfa Wilaya, where the Senalba Forest is located, are sensitive – even highly sensitive – to desertification. The expected impact of climate change will result in an absence of regeneration and an overall ageing of the Aleppo pine populations, defoliation due to water stress and pest attacks and a diminution of the diversity of plants. The vulnerability to climate change of the Senalba Forest for mid- and end-century (and for both scenarios) is mostly influenced by water stress, amplified by overgrazing.

The Siliana Forest in Tunisia decreased in size by 13% from 1990 to 2000 on the basis of various forest inventories. Forest land has mostly been converted into cropland, wooded bushland, non-wooded bushland and young plantations. In the same time frame, 93% of the wooded bushland has been replaced with forest, non-wooded bushland, young plantations and cropland. The vulnerability to climate change of the Siliana Forest is mostly influenced by water deficit, amplified by anthropic activities (overgrazing, fuelwood collection, forest fires, land tenure and land encroachment). As regards climatic factors, forest cover is mostly influenced by extended droughts that bring dieback due to water stress, impede Aleppo pine regeneration and increase tree sensitivity to pest attacks.

In the Jabal Moussa Biosphere Reserve in Lebanon, major tree species like *Quercus cerris* or *Juniperus drupacea* are declining because of climate change, principally because of extreme dry and hot years. Other tree species are also declining because of unregulated activities such as charcoal production and overgrazing.

Moreover, soil erosion is accentuated in degraded areas, resulting in the contamination of watercourses. This process is aggravated by extreme meteorological events that tend to become more frequent according to climate change scenarios. The Jabal Moussa Biosphere Reserve is currently under a humid regime and projections under the moderate-case scenario (RCP 4.5) predict that the northern part of the Reserve will become sub-humid by 2070, while projections under the worst-case scenario (RCP 8.5) predict that the whole Reserve will become sub-humid by 2070.

The most vulnerable forest feature according to the vulnerability assessment is the potentiality for *Quercus cerris* populations for reproduction.

The lessons learned from these case studies in Arab countries is that the vulnerability of Mediterranean forests to climate change is exacerbated by human activities, mostly overgrazing and fuelwood collection and, to a lesser extent, tourism (particularly when coming closer to cities). Even if climate change alone is unlikely to jeopardize the presence of forests, it is likely to impact forest productivity and bring shifts in species composition.

6.5 IMPACT ON SELECTED CROPS IN EGYPT, LEBANON AND JORDAN

When conducting an assessment of projected impacts of climate change on different crops, the so-called fertilizing effect due to CO_2 increase should also be considered.

Moreover, the impact of CO_2 on different crops varies according to their photosynthetic pathway. C3 crops such as wheat, rice or barley are generally expected to benefit from elevated CO_2 concentration in the atmosphere. This is not the case with C4 crops like maize or sorghum.[3]

A specific assessment of the comprehensive impact of climate change on selected crops in pilot areas of selected countries was therefore conducted, using the FAO AquaCrop model, given its ability to consider water-stress conditions and elevated CO_2 concentrations in the atmosphere.

The selected crops were wheat, maize and cotton for the North Delta in Egypt, representing irrigated agriculture; rainfed wheat and barley for Karak Governorate in Jordan, representing very dry (arid) zones; and irrigated eggplant, maize and potato were selected for the Orontes watershed in Lebanon, representing mixed agriculture zones.

After calibration of the model, the simulations were conducted for the selected crops and zones for both moderate-case and worst-case scenarios and for both time horizons (mid-century and end-century). A summary of the impact of climate change on the yield and duration of the growth period are reported in Figure 98, Figure 99 and Figure 100 for Egypt, Lebanon and Jordan, respectively.

The results of the simulation confirm the overall positive response of the C3 crops investigated (wheat, barley, eggplant, potato and cotton) and the non-response of the C4 crop investigated (maize), to elevated atmospheric CO_2 concentration. With C3 crops, we need to distinguish between irrigated and rainfed systems. In fact, irrigated wheat (in Egypt) shows a yield increase of about 14% with both scenarios (RCP 4.5 and RCP 8.5) at mid-century and a yield increase of about 11% and 16% with scenarios RCP 4.5 and RCP 8.5, respectively, at end-century.

This indicates that the projected changes in temperature are not influencing wheat productivity, as long as water is available and that irrigated wheat may take advantage of the climate change due to the increase in CO_2 concentrations. The same can be said for the other C3 plants investigated: cotton (in Egypt), eggplant and potato (in Lebanon) under irrigated conditions. The current, overall water scarcity situation in the Arab region will deteriorate decade by decade, however, and agriculture's share of available water resources will drop continually. This will impact irrigated crop production and crop yield, requiring integrated and highly efficient water resources management.

When we observe the results of the AquaCrop simulation for cereals under rainfed conditions, the yield is affected negatively in all cases, as well as scenarios, with the exception of wheat and barley for mid-century.

The increasingly uneven distribution of rainfall, long periods of dry spells and stronger rainstorms, causing erosion and water losses, will affect rainfed crops significantly. Supplemental irrigation, soil- and water-conservation and water-harvesting measures might ease the negative impacts of climate change on rainfed cropping in the Arab region to a certain extent.

The AquaCrop simulation results also show that climate change will shorten the growing seasons by between 3% and 14% for irrigated wheat in the North Delta in Egypt and between 4% and 27% for the Orontes watershed, Lebanon. This decrease in the length of growing season, mainly due to projected higher temperatures, might result in a slight reduction in crop evapotranspiration.

Wheat harvesting, Egypt, 2017. Source: Amr Hamed.

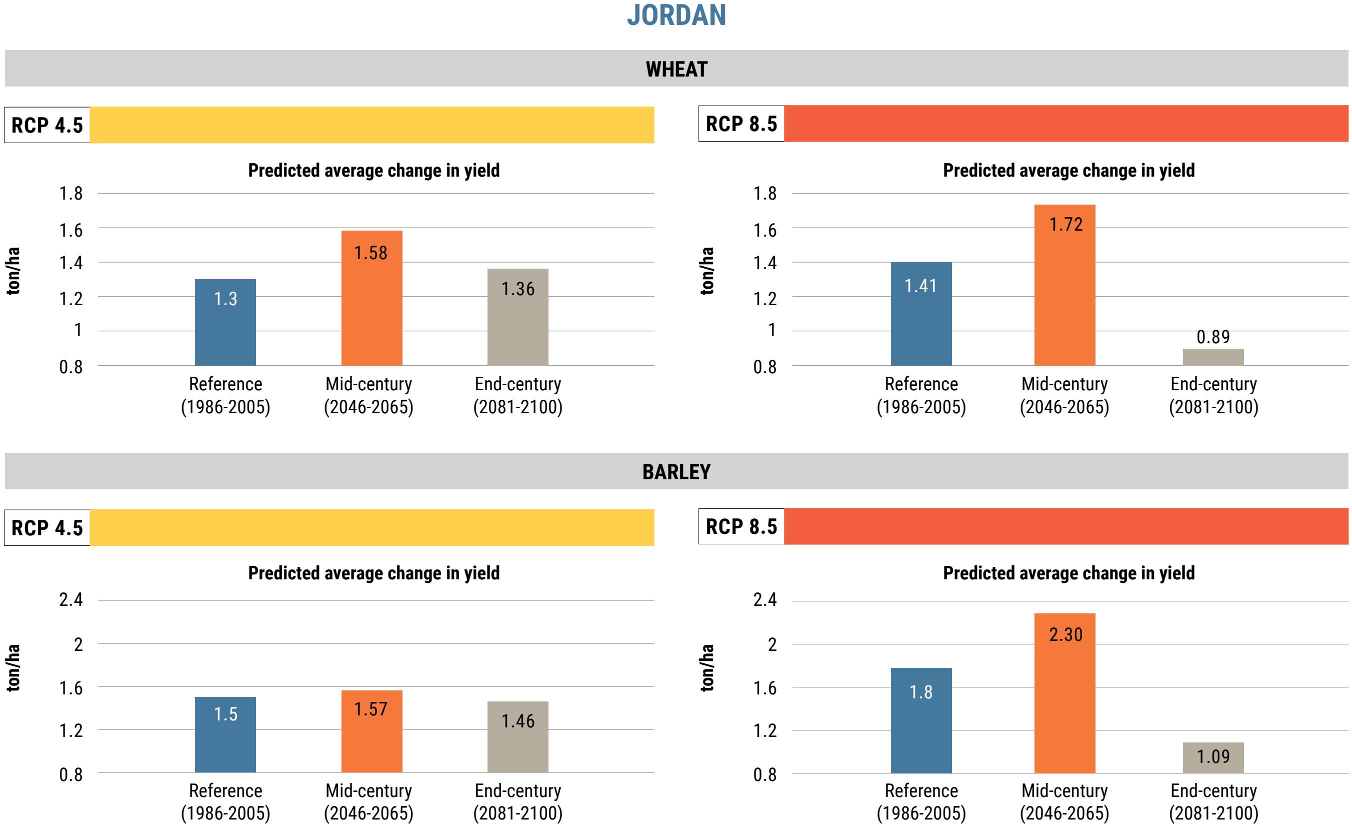
FIGURE 98: Simulated yield and growing-period duration of maize, wheat and cotton for the reference period, mid-century and end-century for RCP 4.5 and RCP 8.5 in Egypt

Source: FAO, 2017

FIGURE 99: Simulated yield and growing-period duration of eggplant, maize and potato for the reference period, mid-century and end-century for RCP 4.5 and RCP 8.5 in Lebanon

Source: FAO, 2017

FIGURE 100: Simulated yield and growing-period duration of wheat and barley for the reference period, mid-century and end-century for RCP 4.5 and RCP 8.5 in Jordan



Source: FAO, 2017

6.6 CONCLUSION

The following conclusions can thus be made with respect to the climate change impacts on the productivity of the green sectors of the Arab region:

- Over 50% of the surface area of the Arab region's major cropland systems (including wheat, maize, sorghum, potatoes, vegetables and olives) are exposed to the highest two classes of vulnerability. The highest vulnerability is assessed for the Nile Valley, the Tigris–Euphrates basin, the south-western Arab Peninsula and the western parts of North Africa. As expected, vulnerability increases from the moderate-case to the worst-case scenario and from mid-century to end-century.

- The impact of climate change on livestock is related to the decline of the water and food resource base due to recurrent droughts, degradation of rangelands and desertification. Most vulnerable areas are located along the Nile Valley, the Horn of Africa and south-western Arabian Peninsula, followed by areas of the Fertile Crescent and North Africa. Cattle are the most affected by climate change, followed by goats and sheep. Livestock raised under grassland production systems will be more prone to climate vulnerability than those raised under mixed systems.

- Drought, floods and high temperatures are the major factors of climate change impacts on the fishery and aquaculture sector. Coupled with over-exploitation by humans, climate change may induce the collapse of certain stocks.

- The aridity of the region and low forest cover, coupled with high deforestation rates in some countries make forests more vulnerable to the negative consequences of climate changes. A major impact is expected from 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 expected. Vulnerability increases significantly at end-century and with the worst-case scenario. Vulnerability is exacerbated by human activities, mostly overgrazing and the collection of fuelwood.

- C3 crops, such as wheat and cotton under irrigation (non-limited water conditions) appear to benefit from elevated atmospheric CO_2 concentrations. Excellent water management then becomes an adaptation measure for saving water and exploiting the potential in C3 crops to convert the higher CO_2 concentration into higher yields. These findings highlight clearly how the resulting increase in water scarcity is one of the major impacts of climate change on the green sector of the Arab region.

This is particularly the case for crops and forests. If water was not limited, some crops would even benefit from the elevated CO_2 concentrations. Even the impact on livestock is mostly through the grassland production system for feeding the animals. For fishery and aquaculture, the increase in temperature is the more relevant factor. Extreme events such as drought and floods, as further impacts of climate change, can have devastating impacts on all sectors.

ENDNOTES

1. Swain and Jägerskog, 2016
2. See FAO et al., 2017
3. C3 and C4 are the names derived from the first stable compound synthesized by the crop (3 carbon or 4 carbon compound) during CO_2 fixation in photosynthesis. The photosynthetic efficiency of C3 plants is relatively less due to the high rate of photorespiration compared to C4 crops which don't' undergo photorespiration (Furbank and Taylor, 1995).

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CHAPTER 7

IMPACT OF CLIMATE CHANGE ON HUMAN HEALTH IN SELECTED AREAS

Climate change in the Arab region has the potential to threaten health and well-being by influencing patterns of communicable and non-communicable diseases through a range of direct and indirect pathways characterized by complex interactions. Direct effects include increases in heat-related illnesses and extreme events, while indirect effects include deterioration of air quality, changes to the distribution of disease vectors, undernutrition and mental health impacts associated with displacement and loss of livelihoods.[1]

For instance, in many parts of the Arab region, the impacts of climate change on agricultural production can threaten food security with significant implications for children's health, as well as contributing disproportionately to undernutrition in low-income households because of the higher costs of food. Many of these climate change impacts on health are amplified in areas where other environmental changes or social and political crises occur, such as desertification or conflict.

The health impacts resulting from climate change will be experienced differently across diverse geographical areas and populations in the region. Varying exposure to health hazards, as well as the susceptibility of different populations and their ability to cope or adapt, will determine the overall impacts on human health and well-being.

The IPCC AR5 states that there has "very likely" been an overall increase in the number of warm days and nights in the region.[2] These increasing temperatures lead to greater risks of heat-related morbidity and mortality in both high- and low-income countries in the Arab region, predominantly in urban areas.[3] Extreme heat causes higher rates of hospitalization and mortality in certain groups, including the elderly, people with existing conditions such as cardiovascular or respiratory disease, people living in lower-quality housing and outdoor workers. While humans can adapt to changes in temperature, there are physiological limits that may be passed in some climate change scenarios.[4]

Additionally, warmer temperatures may magnify the effects of poor air quality, such as ground-level ozone, and increase the production of airborne allergens which can further exacerbate respiratory diseases.

Diseases transmitted by water- or food-borne agents are sensitive to changes in temperature and are common in the Arab region. Higher rates of diarrhoeal disease caused by bacteria such as *Salmonella* and *Campylobacter* occur during warmer temperatures and are projected to rise due to climate change.[5] Transmission of pathogens associated with contaminated drinking water and certain food crops such as enteric viruses and *Cryptosporidium* has additionally been associated with precipitation patterns, including conditions of flooding and drought.

Due to existing gender roles in many countries, this may particularly impact women and girls who spend a great deal of time performing water-, sanitation- and hygiene-related tasks, as well as caring for sick family members. Vector-borne diseases, such as leishmaniasis, malaria, dengue and schistosomiasis, are also very sensitive to a range of climate variables and constitute a major, increasing public health concern in the region. Favourable climate conditions influence the growth, survival and transmission of vectors and rising minimum and maximum temperatures may result in vector range changes or expansions. In addition, climate change can perturb ecosystems and habitats of zoonotic reservoir species, indirectly influencing disease transmission.[6]

Some of these diseases are referred to as neglected tropical diseases (NTDs) a group of infectious diseases which disproportionally impact the poorest people in tropical and subtropical regions. Many NTDs are chronic parasitic infections which reinforce poverty owing to their significant impacts on child development, worker productivity and pregnancy outcomes, costing developing economies billions of dollars every year.[7]

In the Arab region, Egypt and Yemen experience the highest rates of many NTDs followed by Algeria, Libya and Morocco.[8] Understanding how climate change will impact efforts to control and eliminate NTDs is of critical importance to reducing the infectious disease burden in the region.

7.1 HEAT INDEX CONSIDERATIONS AND FINDINGS

Heat stress can induce adverse impacts on human health and is a leading cause of mortality due to meteorological phenomena. Heat-related illnesses are not due solely to extremely high air temperatures, however. High humidity coupled with temperature reduces the body's ability to self-regulate its temperature.[9] The heat index is one of the most common methods to measure apparent temperature and is valid for air temperature exceeding 26.67 °C and over 40% relative humidity.[10] The heat index was calculated for eight selected cities located in coastal areas in the Arab region, which are more likely to be affected by heat-index impacts due to proximity to the sea elevating relative humidity.[11] The heat index was screened for two thresholds: exercise caution (> 26.7 °C), suggesting possible fatigue with prolonged exposure and physical activity; and danger (> 40.6 °C), when heat cramps and heat exhaustion are likely and heatstroke is possible.[12]

The area most vulnerable to heat stress is the African Atlantic coastline (including Nouakchott). For the reference period, there are 194 days/year of caution days and 11 days/year classified as danger days. Caution days increase from 56 (RCP 4.5) to 76 (RCP 8.5) days/year for mid-century, whereby danger days increase from 45 (RCP 4.5) to 68 (RCP 8.5) days/year. For end-century, increases in caution days range from 69 (RCP 4.5) to 144 (RCP 8.5) days/year. Danger days increase from 66 (RCP 4.5) to 143 (RCP 8.5) days/year when compared to the reference period.

The central Arabian Gulf (Doha, Dubai, Manama) is also highly susceptible to heat stress. For the reference period, 181 days/year are recommended to exercise caution due to heat stress. Dangerous heat-stress levels are found 74 days/year. For mid-century, an increase of 13 (RCP 4.5) to 24 (RCP 8.5) days/year is expected in caution days. The increase in the number of danger days is higher, from 33 (RCP 4.5) to 46 (RCP 8.5) days/year. The increase continues for end-century. The number of caution days increases from 21 (RCP 4.5) to 41 (RCP 8.5) days/year when compared to the reference period. Similarly, the number of danger days increase from 45 (RCP 4.5) to 80 (RCP 8.5) days/year.

The heat index is a lesser factor in the northern and southern Arabian Gulf (Kuwait City and Muscat). For the northern Gulf, 30 days/year are recommended to exercise caution, with only 1 day/year with dangerous heat stress levels, for the reference period. More cautionary days are apparent in the southern Gulf (42 days/year) with no danger days.

The number of cautionary days increase from 14 (RCP 4.5) to 15 days/year (RCP 8.5) for mid-century in the northern Gulf and from 15 (RCP 4.5) to 20 days/year (RCP 8.5) in the southern Gulf. Likewise, danger days increase from 4 (RCP 4.5) to 10 days/year (RCP 8.5) in the northern Gulf, whereas no increase in danger days is expected in the southern Gulf for mid-century. For end-century, increases in caution days range from 16 (RCP 4.5) to 26 (RCP 8.5) days/year and from 23 (RCP 4.5) to 31 (RCP 8.5) days/year, in the northern and southern Gulf, respectively. The number of danger days increase from 7 (RCP 4.5) to 38 (RCP 8.5) days/year in the northern Gulf with no expected increases in the southern Gulf.

Along the North African coastline near the Mediterranean (Tripoli), 50 days/year are recommended to exercise caution during the reference period, with no danger days. No danger days are expected for future periods. However, caution days increase from 16 (RCP 4.5) to 34 (RCP 8.5) days/year for mid-century and from 31 (RCP 4.5) to 56 (RCP 8.5) days/year for end-century.

The least vulnerable area evaluated is the eastern Mediterranean (Beirut). No heat-stress days were determined for the reference period. Caution days increase from 3 (RCP 4.5) to 6 (RCP 8.5) days/year for mid-century and from 5 (RCP 4.5) to 23 (RCP 8.5) for end-century. No danger days are projected for any future period.

It should be noted that this evaluation was based upon daily average temperature and relative humidity and can be affected by daily maxima, as well as uncertainties stemming from the coarseness of the climate data. Moreover, the heat index is oversimplified and thus underestimated in conditions with full sun and conversely underestimated in very cloudy conditions.[13] Lastly, although the evaluation was conducted in major cities, the urban heat island effect, which can also elevate temperatures, was not considered. Heat stress is expected to increase in coastal regions throughout the Arab region. Outdoor manual labourers are most exposed to impacts, resulting in diminished work capacity (approximately 60% decline) and increased water consumption.[14] The elderly are also at risk because mortality rates are higher on heat-stress days.[15] Nevertheless, heat-related illnesses are preventable. Decision-makers can employ hot-weather warning systems, develop emergency response plans and educate the public. In addition, sufficient breaks should be allowed for outdoor labourers on heat-stress days.

7.2 CASE STUDIES OF NEGLECTED TROPICAL DISEASES

7.2.1 Conceptual framework

This assessment focuses on leishmaniasis and schistosomiasis, two NTDs endemic to the Arab region that are sensitive to changing climate conditions. Cases in western North Africa and Egypt were selected for further investigation due to high prevalence of leishmaniasis and schistosomiasis respectively, and because of the availability of social and environmental datasets that are integrated with climate information. This study focuses in particular on exposure dimensions to understand how climate change will impact conditions required for the transmission of leishmaniasis and schistosomiasis.

This case study adapts the Water-Associated Disease Index (WADI) approach,[16] which aims to improve understanding of vulnerability to health hazards associated with global changes, to the case of leishmaniasis and schistosomiasis in the Arab region. It brings together different types of information in the form of an index, comprising dimensions of exposure, susceptibility and adaptive capacity in order to identify regions most vulnerable to specific health hazards of interest.

In this approach, vulnerability is defined as the propensity to be adversely impacted and exposure is defined as the conditions that support the presence and transmission of a disease agent. Susceptibility refers to sensitivity when exposed to a hazard, which may include social, economic and political conditions.[17] Adaptive capacity is defined as an ability to respond or adapt to a hazard.

To identify components comprising exposure, susceptibility and adaptive capacity, conceptual frameworks were developed for leishmaniasis and schistosomiasis and were used to identify components describing relationships between the disease agent, human health and the environment in the research literature and their potential indicators. Based on these indicators and corresponding thresholds, datasets to populate indicators were identified and included in the assessment.[18]

Data were selected based on the quality and availability of datasets identified from publicly accessible data repositories online. RCM climate projections developed for the MENA Domain were used among other datasets to compare historical exposure conditions for both diseases to those for mid- and end-century using RCP 4.5 and RCP 8.5. Datasets for the exposure components and associated indicators were imported into a geographical information system (ArcGIS) and converted into raster format for manipulation with pixels representing a value from 0 to 1. Monthly temperature and humidity rasters were developed to understand seasonal trends. As susceptibility and adaptive capacity components can be difficult to differentiate in empirical assessments (e.g. education level), they were combined in this analysis to create one map output representing susceptibility and lack of adaptive capacity.[19] These raster layer components contained pixels representing a value from 0 to 1, and were created by normalization.

To create map outputs, components were assumed to have equal importance and were aggregated to form composites for exposure, susceptibility and lack of adaptive capacity using an arithmetic average.[20] While equal weighting was used, other weighting approaches could be adopted with understanding of the local importance of these components, such as expert weighting.

Rather than creating an overall vulnerability index, these separate maps were created for each disease to highlight areas of particular concern for decision-makers. Full details of the methodology, such as dataset selection and sources, are provided in the RICCAR technical report dedicated to this case study prepared by UNU-INWEH.[21]

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

7.2.2 Leishmaniasis

Leishmaniasis is an endemic disease in the region caused by infection with a *Leishmania* parasite transmitted by a sandfly vector and persists as a serious public health concern. There is frequently little information on incidence because surveillance and reporting is limited in many countries affected by the disease.

The zoonotic cutaneous form (ZCL) carried by animals, especially rodents, and the anthroponotic cutaneous form (ACL) carried by humans are both transmitted in the region in rural arid areas and urban areas respectively. ZCL is widely distributed in areas with types of vegetation that support the rodent carrier *(P. obesus)* and occurs in Algeria, Egypt, Iraq, Jordan, Libya, Morocco, State of Palestine, Saudia Arabia, Somalia, Syrian Arab Republic, Sudan, Tunisia and Yemen. ACL is transmitted in areas with densely populated towns and villages and is found in Iraq, Morocco, Saudi Arabia, Syrian Arab Republic and Yemen.[22]

Western North Africa was chosen for this case study because cutaneous leishmaniasis (CL) is a growing public health problem in the region and Morocco was chosen for more detailed analysis of susceptibility and adaptive capacity because relevant datasets were available. Based on the conceptual framework developed for leishmaniasis, current and future exposure were assessed, based on components for suitable temperature and humidity conditions for the sandfly vector that carries the disease, combined with an indicator on land-cover types that support transmission of ZCL. Regionally downscaled future climate projections for the MENA Domain developed as part of RICCAR were used for temperature datasets. Susceptibility to leishmaniasis was determined using available datasets for sanitary conditions which can increase sandfly breeding and resting sites and provide easier access to human hosts[23] as well as migration, which has the potential to bring non-immune people into areas with transmission cycles, which is particularly relevant in the MENA region. Adaptive capacity included prevention and control interventions to stop the transmission of leishmaniasis. For this assessment, this component included the indicator related to education, which ensures that people recognize an infection and seek treatment quickly.

Results of this assessment suggest that changes in climate may have an important impact on the range of leishmaniasis transmission in the Arab region. Like many vector-borne diseases, leishmaniasis incidence displays a strong seasonality due to the influence of climate variables. Minimum temperatures in the study area historically drop below the sandfly vector's survival thresholds (10 °C) during colder months, limiting the transmission of leishmaniasis. Based on exposure projections, results indicate that warmer temperatures during colder months could extend the period of suitability for disease transmission due to minimum temperatures occurring less frequently below the sandfly survival threshold. As shown in Figure 101 for November, areas indicating no exposure (in white) become progressively limited by end- century, in particular for RCP 8.5. In some areas, however, exposure may be reduced where maximum temperatures exceed 40 °C for longer periods, such as in summer months, due to the upper end of the sandfly survival range. Although the extent of areas characterized by temperatures > 40 °C will potentially expand, many of these areas are in sparsely inhabited regions and will therefore have less impact on human populations. In addition to temperature conditions, vegetation for the animal host may decrease in some areas with decreasing moisture availability associated with changes in humidity.

It is, however, important to note that climate conditions are only one aspect of exposure and overall vulnerability and ZCL is characterized within exposed areas by focal outbreaks. Foci occur in areas with suitable vegetation for the rodent reservoir host in proximity to human populations. Foci may also occur where susceptibility is higher due to factors such as poor housing quality and sanitary conditions that provide breeding sites for the vector or high rates of in-migration that increase the non-immune population. Figure 102 indicates that many areas that are exposed to ZCL in Morocco are more susceptible and have lower adaptive capacity than other parts of the country. This means that public health authorities can apportion resources to vector-control activities which decrease exposure during longer seasons of transmission, as well as improving capacity of the population to cope with outbreaks.

The *P. papatasi* sandfly, vector of *Leishmania* parasites. Source: Center for Disease Control and Prevention (USA).

FIGURE 101: Historical and projected exposure to Leishmaniasis in North Africa in November

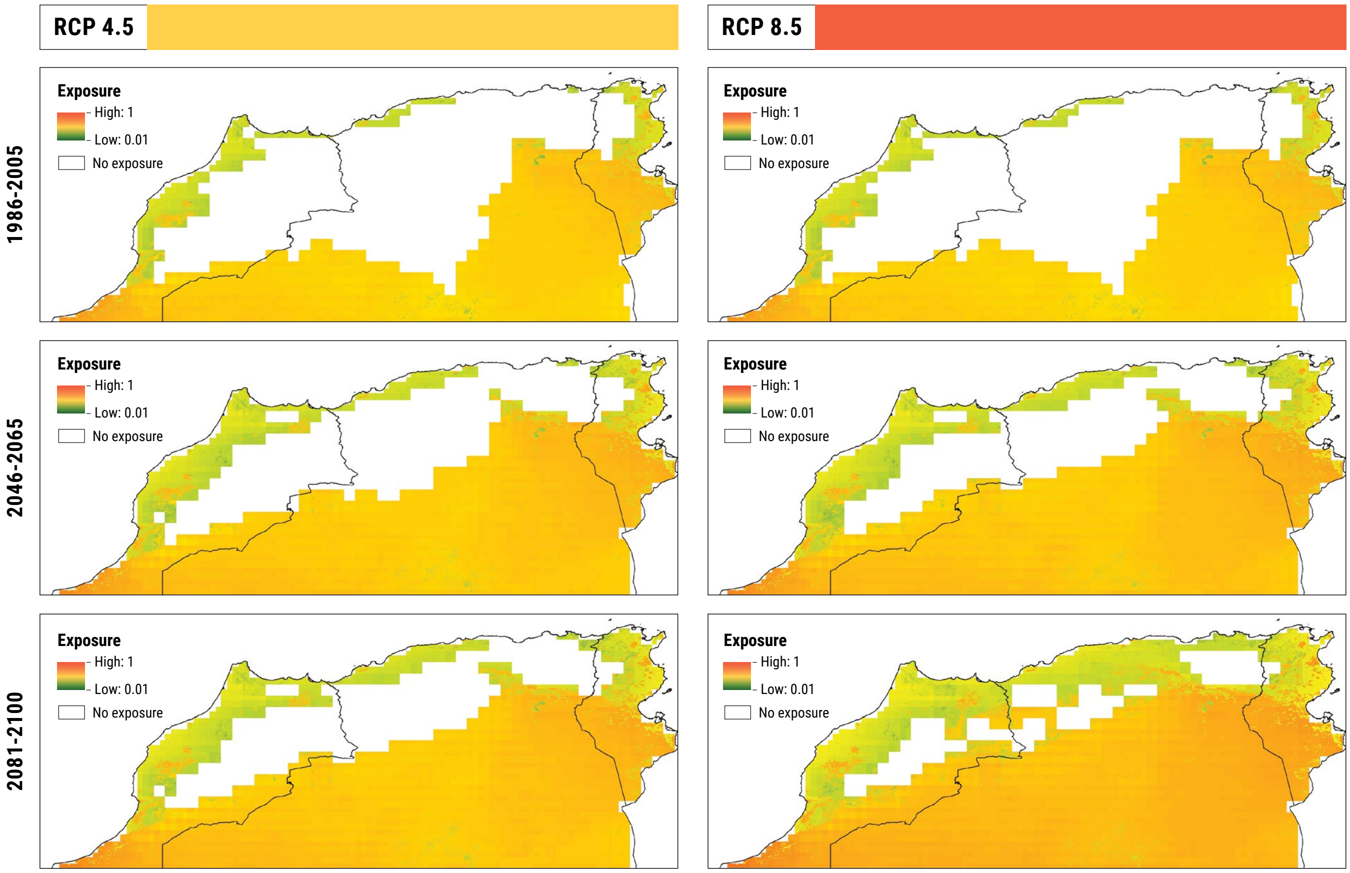
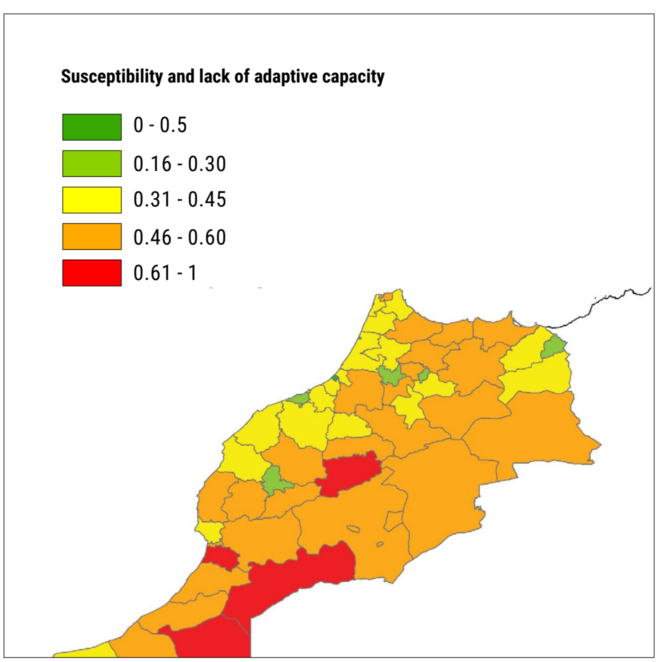


FIGURE 102: Susceptibility and lack of adaptive capacity to leishmaniasis in Morocco

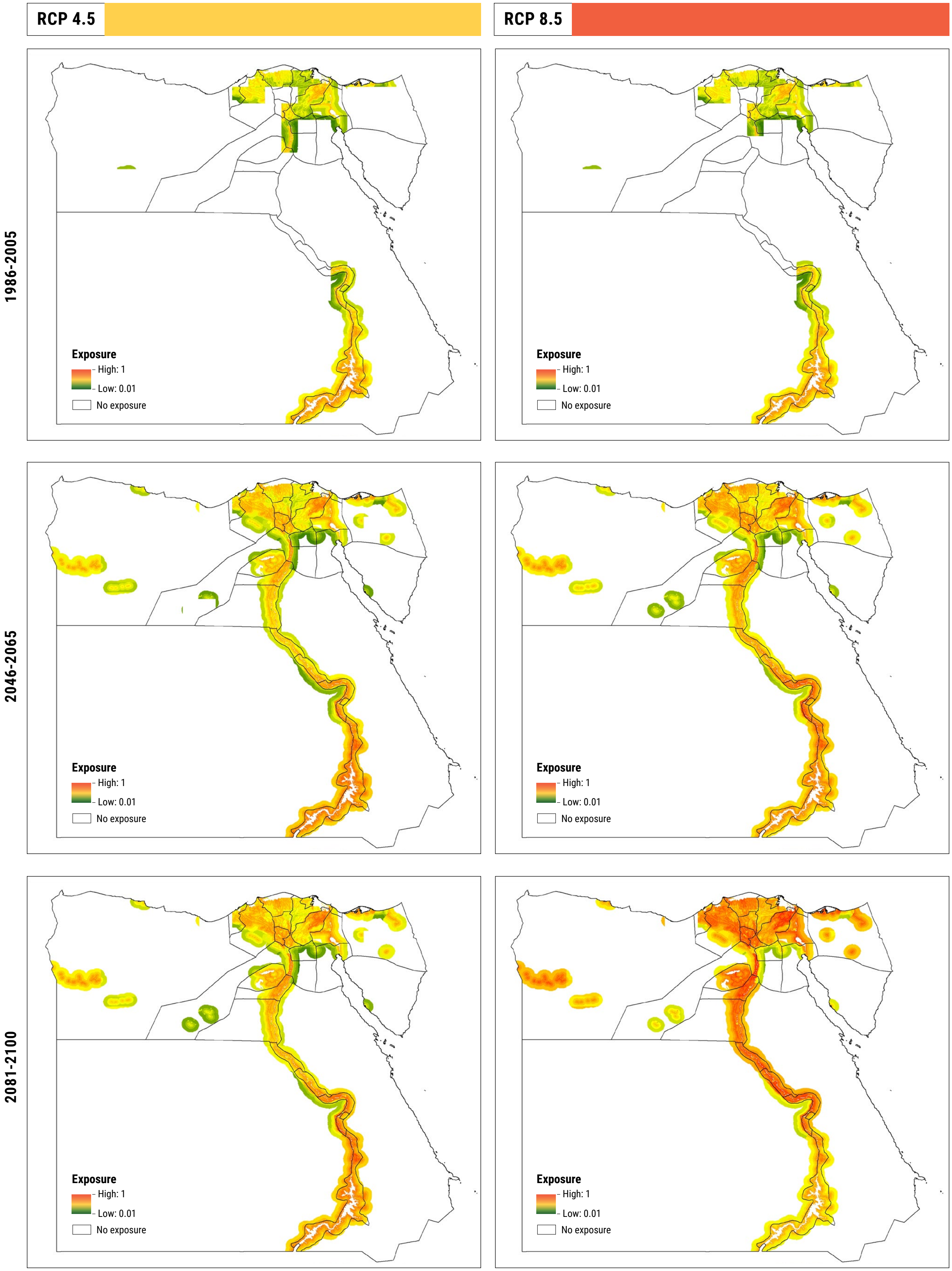


7.2.3 Schistosomiasis

Schistosomiasis is a parasitic disease resulting from contact with contaminated freshwater sources and transmitted by blood flukes known as schistosomes which live in freshwater snail hosts. The disease disproportionately affects the poorest people in endemic areas, including those without access to safe water and sanitation, and those with water-based livelihoods such as fishing and rice cultivation.[24]
In the MENA region, schistosomiasis is the second most prevalent NTD with an estimated 12.7 million cases affecting Egypt, Somalia, Sudan and Yemen. The highest prevalence is reported in Egypt where *S. mansoni*, which is the parasite causing intestinal schistosomiasis, is endemic in northern regions and was thus chosen for this case study.[25] While efforts to control schistosomiasis in Egypt have been successful, certain communities in the Nile Delta with high prevalence rates sustain transmission of the disease.[26]

Based on the conceptual framework for schistosomiasis, this case study assessed current and future exposure to the disease in Egypt, based on suitable conditions for *B. alexandrina* snail populations that transmit *S. mansoni*.

FIGURE 103: Historical and projected exposure to schistosomiasis in Egypt in December



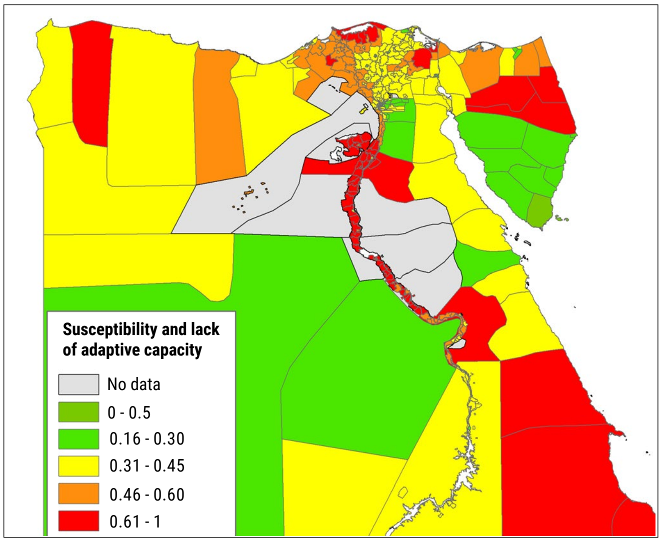
Air temperature was used as a proxy for water temperature, which is not available in climate models, and temperature suitability was integrated with information on proximity to water sources and extent of sewerage networks that impact the transmission cycle. As schistosomiasis is strongly influenced by social determinants, susceptibility was based on indicators related to the access to water resources in rural areas, populations engaged in water-related livelihoods, as well as age and health status indicators. The indicators used to identify areas of adaptive capacity were related to health care access and education.

Results of the assessment indicate that changes in climate may influence the seasonal pattern of schistosomiasis transmission in Egypt. The disease transmission in the region occurs on a seasonal basis, with most cases occurring during the warmer summer months and in the Nile Delta, where there are intensive contacts with water due to water-based livelihoods. While transmission is limited in colder months, the results of this case study suggest that increasing temperatures projected in RCP 4.5 and RCP 8.5 at mid- and end-century in winter will create conditions that increase infection risk during winter months. Figure 103 highlights historical exposure in December during the winter, when fewer cases currently occur, compared to exposure at mid- and end-century. Because these changes in temperature occur near thresholds for schistosome infection risk, small increases can make a large difference. In addition, other species of snail, such as *B. pfeifferi*, the most widespread intermediate host of *S. mansoni* in Africa, survive at slightly warmer temperatures than *B. alexandrina*, so could become established in greater numbers in the area in warmer conditions.[27]

These findings have implications for public health authorities who currently undertake vector-control activities during the warmer months, when most infections occur. Changing climate conditions could also impact the success of treatment measures, such as de-worming programmes, if they are timed for warmer periods. Importantly, changes in exposure are projected to occur in areas in the Nile Delta where the population currently experiences higher susceptibility due to water-based livelihoods and limited sewerage connections (Figure 104).

In these areas, climate change could have a greater impact on the burden of disease by increasing the length of the transmission season. In addition to climate change, other positive or negative social and ecological changes in the Arab region, such as increasing access to sanitation, land degradation or conflicts which disrupt control and elimination efforts, could have important impacts on the disease cycle.

FIGURE 104 : Susceptibility and lack of adaptive capacity to schistosomiasis in Egypt



7.2.4 Implications and conclusions

The results of this assessment, which focuses particularly on exposure dimensions, indicate that climate change may impact the seasonal duration of disease transmission. These findings have implications for vector control, surveillance and awareness-building activities carried out by public authorities. Beyond the serious health burden associated with NTDs, these chronic infections can entrap people in a cycle of poverty and are often associated with social stigma.

The impact of climate change is not simply limited to changes in climate variables but also comprises extreme events that may also considerably affect the distribution of NTDs and efforts to develop sustainable control strategies. Moreover, these climate change impacts must be considered within the context of concurrent social and other environmental changes, such as extensive human and animal migrations, conflict and associated breakdowns in public health systems and socio-economic development.[28] In addition, desertification and water resource development projects to address increasing water scarcity have played a role in supporting the transmission of NTDs such as leishmaniasis, as they can increase exposure to the disease.[29] Migrations of people within their countries or to other parts of the region can also lead to large outbreaks in new areas and therefore exacerbate exposure and susceptibility conditions.

It is important to highlight the fact that the burden of NTDs is higher in poor and marginalized communities[30], indicating a disproportionate threat due to changing climate conditions.

In the case of leishmaniasis, the disease has been found to present a greater threat to the health and socio-economic status of women.[31] In Tunisia, women involved in agriculture have higher vulnerability as they receive increased exposure to irrigation activities and are more sensitive to the negative social implications of the disease.[32] In Yemen, the incidence of leishmaniasis was found to be higher among rural children and female populations, which may be due to their work in agriculture and animal care, as well as water collection, when they may be exposed to sandfly bites.[33] In addition, women's limited access to financial resources may reduce access to healthcare for treatment for the disease. Cutaneous leishmaniasis, which can cause disfiguring scars, can have a severe impact on women's psychological well-being, as well as quality of life due to social stigmatization. For schistosomiasis, changes in exposure are projected to occur in areas of the Nile Delta, where the population currently experiences higher susceptibility. As this is a water-associated disease, there are particular implications for women and girls who often spend large amounts of time performing water-, sanitation- and hygiene-related tasks, as well as caring for sick family members.

While significant progress is being made to control and eliminate many NTDs in the Arab region, there is a pressing need to consider how these efforts may be threatened by climate change. This is made challenging by poor surveillance and reporting capacities, as well as a lack of information on incidence rates in many affected countries. Further research to deepen understanding of the complex processes through which climate change will impact NTD dynamics is thus required in order to identify and adapt appropriate and equitable health-promotion strategies.

7.2.5 Limitations

Several limitations should be considered regarding this case study. While this assessment applied regional climate projections, disease incidence is characterized by extremely focal outbreaks within exposed areas. The results should not be taken as being predictive of future prevalence of schistosomiasis or leishmaniasis, but as indicative of areas where projected changes in climate may influence the suitable conditions for transmission. Not all possible indicators are considered in the case studies, as there is limited evidence on some linkages in the Arab region or because datasets are unavailable. For example, given the case of schistosomiasis and the available indicators considered in the exposure assessment, results show that disease exposure covers the course of the Nile River, while the actual disease prevalence is more restricted to the lower Nile River. On the other hand, while not the focus of this study, limited data were freely available on indicators of susceptibility and adaptive capacity in this assessment, which highlights data gaps that could improve vulnerability assessments.

Northern Nile Delta, Egypt, 2015. Source: Ihab Jnad.

BOX 6: Recent disease outbreaks due to climate conditions: yellow fever and other diseases

Over the past decade, the region has witnessed recurrent outbreaks from emerging or re-emerging infectious diseases, leading to numerous cases of morbidity and mortality. The major ones recently detected in the region include yellow fever, dengue and rift valley fever, all transmitted by the Aedes mosquito and presented below. Other infectious diseases also reported include the Middle East respiratory syndrome (Bahrain, Oman, Oatar, Saudi Arabia, UAE and Yemen, 2013–2015) and some cases of cholera in Iraq (2015).

YELLOW FEVER

Yellow fever is commonly transmitted by infected *Aedes aegypti* mosquitoes and known to be endemic in tropical areas of Africa and Latin America. As a highly seasonal disease, rainfall is an important determinant in its prevalence. The warmer the ambient temperature, the shorter the incubation period from the time the mosquito imbibes the infective blood till it is able to transmit by bite. Warmer temperatures also provide shorter time for larvae to mature as water temperatures rise, leading to a greater capacity to produce more offspring during the transmission period. Another important contributing factor to the disease spread is urbanization, with the rapid growth of densely populated towns and cities providing an increasingly favourable environment for transmission. Water-storage containers in urban areas or other similar materials (buckets, flowerpots, discarded tyres, etc.) can also serve as breeding sites if they accumulate rainwater. A recent disease outbreak in the region occurred in Sudan in 2012; 849 suspected cases, including 171 deaths, were reported in Darfur. Prior to this, outbreaks in 2003 and 2005 were the first reports of yellow fever in Sudan in approximately 50 years. Another outbreak occurred in 2013 leading to 15 deaths in the state of West Kordofan. A risk assessment conducted in 2012 in Sudan identified potential areas of risk for yellow fever virus transmission and found it in circulation in all ecological areas of the country, with an estimated 30.7 million people living in areas of high risk or at potential risk of contracting yellow fever. As a result, Sudan launched its first ever mass preventive vaccination campaigns in 2014 with some 7.5 million people vaccinated in seven high-risk states. Apart from Sudan, evidence of circulation of the virus was reported in Djibouti and Somalia based on serological studies.[34]

DENGUE FEVER

In 2012, dengue fever was classified by WHO as the “most important mosquito-borne viral disease in the world” due to its significant geographical spread into previously unaffected areas and the subsequent costly burden of disease. Dengue has recently resurged in the region, causing sporadic yet increasingly common outbreaks, particularly in Saudi Arabia and Egypt (2015), Sudan and Yemen (2012–2015). Smaller outbreaks involving multiple serotypes of the virus are also being reported more frequently from countries such as Djibouti and Somalia, indicating the presence of vectors with the risk of local transmission. Several studies have investigated the role climate change plays in the resurgence of the disease in recent decades and is an ongoing area of research. It has been shown that reasons for the currently observed and predicted expansion are multifactorial, including viral introduction through migration and travel, as well as changes in climatic conditions. While the scarcity of rainfall in the Arab region results in climatic conditions that are not ideal for dengue vectors, expected increasing temperatures and water stress will contribute to stimulate dengue incidence with the increase of water storage containers (ideal for vector breeding) in anticipation of drier conditions.[35]

RIFT VALLEY FEVER

The first outbreak of rift valley fever (RVF) outside the African continent was witnessed along the south-western coast of Saudi Arabia and neighbouring coastal areas of Yemen in September 2000. The outbreak resulted in more than 120 human deaths and major losses in livestock populations from disease and slaughter. It followed increased rainfall in nearby highlands that flooded the coastal areas and created ideal environments for mosquito populations similar to those found in RVF-endemic regions of East Africa. Most RVF activity was associated with flooded wadi agricultural systems, and no cases were reported in the mountains or in the dry sandy regions, where surface water does not accumulate long enough to sustain mosquito breeding. Another spread was reported in Sudan in 2008 and then in six different regions of Mauritania in 2012.[36]

ENDNOTES

1. Watts et al., 2015
2. Hewitson et al., 2014
3. Habib et al., 2010
4. Pal and Eltahir, 2016
5. El-Fadel et al., 2012
6. Haines et al., 2014
7. Hotez, 2009
8. Hotez et al., 2012
9. Willett and Sherwood, 2012
10. Rothfusz, 1990
11. Diffenbaugh et al., 2007
12. NWS, 2016
13. Willett and Sherwood, 2012
14. Tawatsupa et al., 2010
15. Smoyer et al., 2000
16. Dickin et al., 2013
17. Birkmann et al., 2013
18. Alimi et al., 2016
19. De Sherbinin, 2014
20. Dickin et al., 2013
21. See UNU-INWEH, 2017
22. Postigo, 2010
23. WHO, 2017
24. Hotez and Fenwick, 2009
25. Hotez et al., 2012
26. Elmorshedy et al., 2015
27. McCreesh and Booth, 2014
28. Hotez et al., 2012
29. Boubaker and Chahed, 2011
30. Du et al., 2016
31. Al-Kamel, 2016a; Boubaker et al., 2011
32. Boubaker, 2016
33. Al-Kamel, 2016b
34. Reiter, 2001; WHO, 2014; WHO, 2016; Yuill et al., 2013; Karunamoorthi, 2013; Jentes et al., 2010
35. Amarasinghe and Letson, 2012; Murray et al., 2013; IRIN News, 2010; Pinkerton and Rom, 2014; Humphrey et al., 2016
36. Martin et al., 2008; El-Mamy et al., 2011; WHO, 2012; Himeidan et al., 2014; Sayed-Ahmed et al., 2015

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PART II

INTEGRATED VULNERABILITY ASSESSMENT

CHAPTER 8

BACKGROUND AND METHODOLOGY

Based on the impact assessment findings, the vulnerability assessment was conducted across the Arab region in targeted sectors and sub-sectors identified through a consultative process, and based on the classification and weighting of region specific geospatial indicators that characterize each sector's exposure, sensitivity and adaptive capacity with respect to climate change. This chapter introduces the conceptual framework of the vulnerability assessment used in RICCAR, and provides background information on the methodology followed, including the different steps applied through the integrated mapping process.

8.1 CONCEPTUAL FRAMEWORK

Vulnerability is a concept used to express the complex interaction of climate change effects and the susceptibility of a system to its impacts, with several existing definitions and approaches to characterize this concept. 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 105.

Within this conceptual framework:

- **Exposure** refers to changes in climate parameters that might affect socio-ecological systems. Such parameters are, for example, temperature and precipitation, which climate change alters in terms of quantity and quality, as well as spatial and temporal distribution.

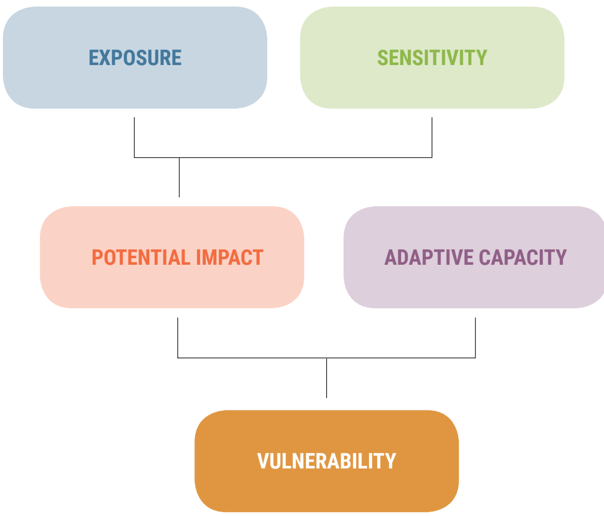
- **Sensitivity** provides information about the status quo of the physical and natural environment that makes the affected systems particularly susceptible to climate change. For example, a sensitivity factor could be topography, land use, land cover, distribution and density of population, built environment, proximity to the coast, etc.

- **Potential impact** is determined by combining the exposure and sensitivity to climate change on a system.

- **Adaptive capacity** refers to "the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" as defined in IPCC AR4.[1]

Combining indicators related to exposure, sensitivity and adaptive capacity through an integrated mapping methodology allows for assessing the vulnerability of a system to climate change.

FIGURE 105: Components of vulnerability based on the IPCC AR4 approach



Source: Based on IPCC, 2007

8.2 TARGET SECTORS AND IMPACTS

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, the Vulnerability Assessment Working Group (VA-WG) was established in 2013 and identified five key sectors for examination along with associated subsectors, as illustrated in Figure 106. These were subsequently endorsed at the RICCAR Expert Group Meetings and by the Arab Ministerial Water Council. 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.

FIGURE 106: 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

8.3 METHODOLOGY DEVELOPMENT PROCESS

The vulnerability assessment methodology was developed through a consultative and participatory process with experts from the Arab region. It was elaborated based on discussions during annual Expert Group Meetings (EGMs) and through the establishment of the VA-WG, comprising representatives of Arab Governments, as well as the League of Arab States, the United Nations and expert organizations serving the Arab region. The VA-WG was also assisted by a technical advisory team supported by GIZ. Two task forces were additionally formed to support the vetting and review of regionally appropriate vulnerability indicators related to sensitivity and adaptive capacity in the Arab region. Moreover, expert knowledge was sought from regional stakeholders that contributed to the selection of indicators through a questionnaire in which they were asked to select and assign the values or categories an indicator could have to a pre-defined scale, taking into consideration how the indicator value relates to the vulnerability component it is part of.

The development of the methodology progressed through a set of meetings of the VA-WG and task forces that were held regularly over the course of the project to refine its key components and associated processes, as elaborated in the RICCAR technical note *Integrated Vulnerability Assessment: Arab Regional Application (2017)*.[2] Adjustments to the indicator framework were made during the testing of the methodology in order to overcome data gaps or concerns about data quality.

Experts, as well as members of regional research centres with expertise in the area of climate change assessment and geographic information system (GIS) applications, were invited to review, test and comment on the draft vulnerability assessment methodology during a regional workshop (Beirut, May 2014) and its progress was presented for consideration by Arab Governments, regional organizations and the RICCAR partners at the Fifth RICCAR Expert Group Meeting (Amman, December 2013) and the Sixth RICCAR Expert Group Meeting (Cairo, December 2014), respectively. The methodology was finalized in May 2015, and an expert group review was subsequently organized in 2016 to fully review and vet the application of the methodology with regard to the final set of indicators, as well as the weights and normalization scheme applied during the preparation of the assessment (Beirut, April 2016). Finally, the results and findings of the integrated VA were peer-reviewed during an expert peer review meeting (Beirut, December 2016) to examine the aggregated results for the nine subsectors, namely the maps related to exposure, sensitivity, potential impact, adaptive capacity and overall vulnerability in view of identifying the potential vulnerability hotspots in the region.

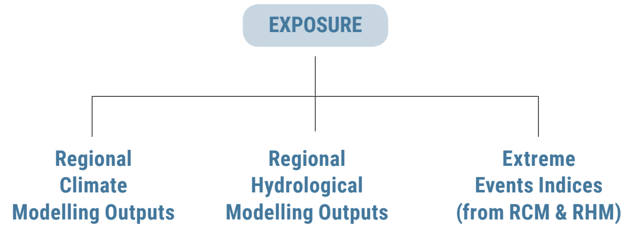
8.4 INTEGRATED MAPPING METHODOLOGY

Integrated mapping methodology for the integrated vulnerability assessment 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. The methodology applied in RICCAR for the Arab region draws upon regionally appropriate and available indicators, 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 were then reflected in a geometric aggregation method used to combine these components to determine climate change vulnerability. This process was carried out using the ArcGIS software which enabled the production of vulnerability maps that display current and potential future vulnerabilities to climate change through a multi-step process. Detailed guidance on the methodology with precisions on each step is presented in the RICCAR technical note *Integrated Vulnerability Assessment: Arab Regional Application (2017)*.[3] Additional information is provided in the *Training Manual on the Integrated Vulnerability Assessment Methodology (2017)* prepared within the framework of the ACCWaM programme support to RICCAR.[4] The applied methodology is briefly summarized below:

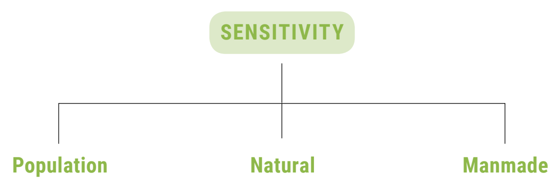
Step 1: Developing impact chains.
A long list of exposure, sensitivity and adaptive capacity indicators that could characterize the effects of climate change on the selected sector and subsectors was undertaken. For each climate change impact, indicators were identified with the help of an impact chain. These are analytical tools that illustrate the cause-effect relationships between indicators, dimensions, components and the relevant impact.

Step 2: Identifying and selecting indicators.
Indicators were selected based on their relevance, homogeneity, validity, reliability and coverage for the entire Arab Domain. They were assigned for each component as deemed relevant and classified under different dimensions.

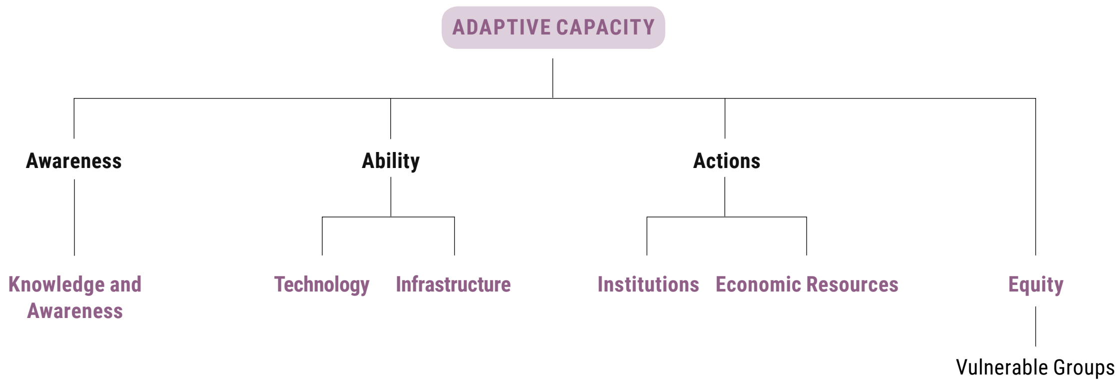
- **Exposure** indicators were derived from the regional climate modelling and regional hydrological modelling outputs and are the sole dynamic datasets applied in the assessment. They were developed for five differing time periods and climate scenarios: reference period; future mid-century based on a moderate scenario (RCP 4.5); future mid-century based on an extreme scenario (RCP 8.5); future end century based on a moderate scenario; and future end-century based on an extreme scenario.



- The **sensitivity** component includes 25 indicators classified in three dimensions: population, natural and man-made. The population dimension is comprised of societal factors which place pressure on the physical system due to population growth, including human migration and resource depletion. The natural dimension considers environmental and ecological elements such as soil type and land cover[5] which may be subject to degradation. Lastly, the man-made dimension incorporates anthropogenic factors which may be exacerbated due to climate change. While many elements which can be evaluated as part of sensitivity are dynamic (population growth), because of data-availability limitations, all indicators used for RICCAR are static, based on the most recent available information for all future climate scenarios.



- **Adaptive capacity** comprises 27 indicators categorized into six dimensions: knowledge and awareness, technology, infrastructure, institutions, economic resources, and equity. The first dimension reflects general education and cognizance regarding climate change. These transition into technology and infrastructure, which support the ability to adapt. At a macro level, adaptation is promoted further via institutions and economic resources. Lastly, equity factors in gender, age structure and access for people with disabilities. Infrastructure indicators were selected based on five pillars: energy, transportation, health, water and sanitation, and environment. Like the sensitivity indicators, the adaptive capacity indicators are static.



Step 3: Data acquisition.
Data pertaining to each indicator were acquired from a wide variety of sources. Exposure indicator datasets were based on outputs from RCMs and RHMs which comprise projected changes in temperature, precipitation and other hydrological parameters for different emission scenarios and time periods. Data corresponding to exposure from RHMs were based on the outputs from the VIC hydrological model only. In quantifying sensitivity and adaptive capacity indicators, data were mainly extracted from statistical databases and international organizations providing maps and datasets covering the selected 21 countries in the Arab region.

The assessment drew extensively on data at the national and subnational scale when available. An overview of the main data sources used such as demographics, economic resources or equity-related databases are briefly described in the introduction to this report. Detailed information on the data source for each indicator including date, resolution, scale, how the data was developed, etc., is provided on an indicator factsheet to be made available on the regional knowledge hub.

Step 4: Normalization and classification of indicator data.
As indicators are characterized by varying magnitudes and units of measurement, they were normalized and classified based on a common scale from 1 to 10 prior to aggregation. For exposure and sensitivity indicators, 1 represents a positive condition (low exposure) and 10 suggests a negative condition. For adaptive capacity, the scale is reversed (1 represents low adaptive capacity) and, therefore, prior to aggregation, values must be inverted to correlate positive and negative conditions together. Indicators were generally classified in accordance with water-availability vulnerability.

It is important to point out that this concept was not applicable for some subsectors and indicators were reclassified for applicable subsectors. In addition, indicators were classified based on relative vulnerability within the Arab region, not globally.

Step 5: Weighing and aggregation of indicators.
Indicators were assigned weights to measure their relative importance for a given climate change impact and were determined using a multi-step process based on the results obtained from an expert survey. Experts were solicited from differing fields related to the vulnerability assessment from around the Arab region who evaluated the relative importance of differing indicators. Results were then vetted by an expert panel to ensure validity. Finally, the most relevant sensitivity indicator was selected for each climate change impact and assigned a heavier weight to help highlight the specific impact. In turn, the most relevant adaptive capacity indicator was also an equally heavy weight to balance the physical and natural impacts with mankind's ability to overcome. Indicators were aggregated through geometric aggregation using their respective weights. Geometric aggregation is a non-linear approach which is preferred to other methods because it is multiplicative and synergetic.[6] Individual indicators were aggregated by pillar, then by dimension, if applicable, to obtain a composite indicator for each component.

Step 6: Aggregation of vulnerability components.
The exposure and sensitivity composite indicators were subsequently aggregated to obtain the potential impact described for each time period and climate scenario. Finally, the potential impact and adaptive capacity composite indicators were aggregated to obtain the overall vulnerability for each climate change impact subsector. In cases where there were two or more climate change impacts identified for a sector, the impacts were then aggregated to obtain overall vulnerability for the sector.

Step 7: Presenting outcomes as vulnerability maps.
Vulnerability assessment results were ultimately presented as maps describing precise locations where people, the environment or natural resources are at high risk. Visualization of vulnerable areas and hotspots on maps facilitates communication and provides entry points for a regional dialogue on joint adaptation efforts to cope with the challenges of climate change in the Arab region.

8.5 PRESENTATION OF RESULTS

Integrated vulnerability assessment outputs are presented in maps for five sectors and nine subsectors. The presentation of findings in this report related to each sector and subsector includes the impact chain and results generated for the reference period, future periods (mid-century, end-century) for two RCPs and the identification of sector-specific hotspots (Figure 107). Additional outputs are available in the Technical Annex of this report.

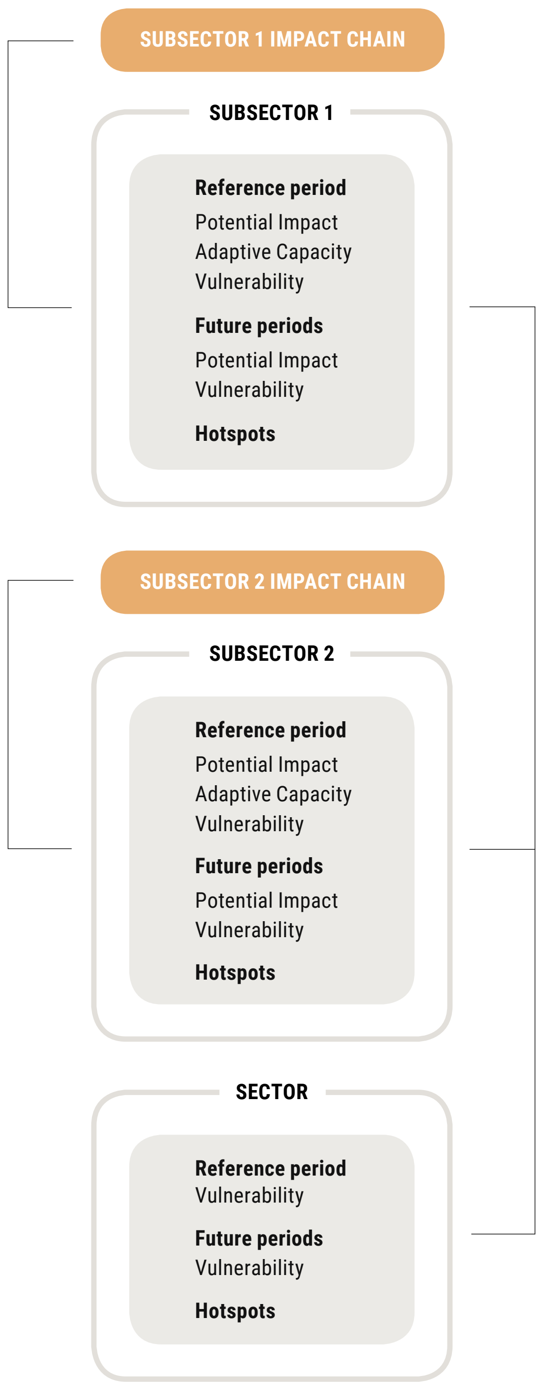
It is important to note that rather than reveal results obtained for the entire region, maps solely highlight the specific area of interest for a given sector or subsector. Areas of interest were based on one or more indicators. For example, for the Area covered by forests subsector, maps only show results obtained in areas with forest cover and all climate change impacts studied under the People sector show populated areas only. This approach helps to focus discussions on the relevant 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.

Vulnerability hotspots identify areas that are especially vulnerable to climate change impacts. Such areas are intended to highlight high instances of vulnerability in a particular sector or subsector at the Arab regional level. Conceptual and methodological methods to define hotspots are varied among studies conducted elsewhere and are affected by spatial scale and uncertainties in data and outputs. For RICCAR, hotspots were identified based on the top percentage of overall vulnerability among the two time periods and two scenarios for each climate change impact. In terms of spatial scale, the scale – or pixel size – of the different input datasets varies significantly and these datasets are overlaid in the integrated mapping in order to create maps on vulnerability, as well as its respective components. The different spatial resolution of the data therefore poses a limit to the spatial accuracy of the maps, e.g. in regard to the location of climate change hotspots. Hence the results of the mapping roughly indicate areas at risk to climate change impacts on a subnational level.

This 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 107: Presentation of results



ENDNOTES

1. IPCC, 2007
2. ESCWA et al., 2017
3. See ESCWA et al., 2017
4. See ACSAD et al., 2017
5. Fritzsche et al., 2014
6. El-Zein and Tonmoy, 2015
7. De Sherbinin, 2014

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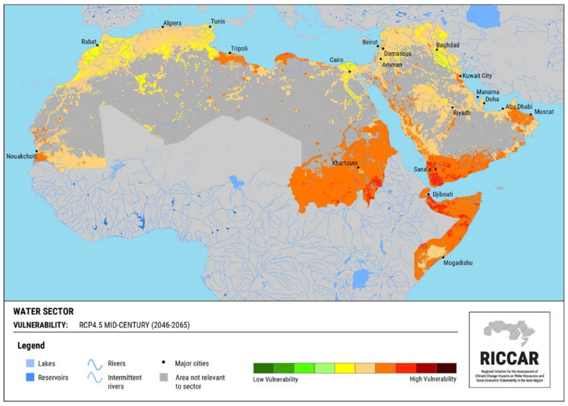
WATER SECTOR

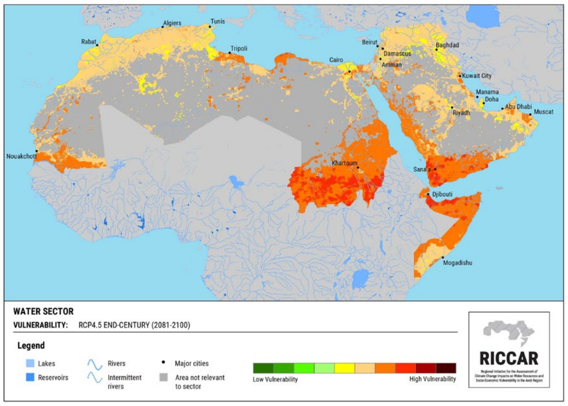
OVERALL VULNERABILITY

RCP 4.5

2046-2065

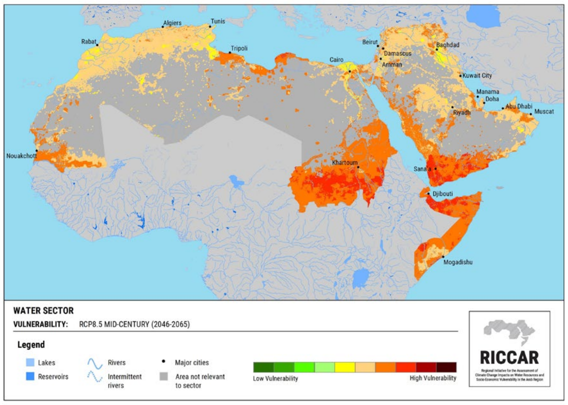


2081-2100

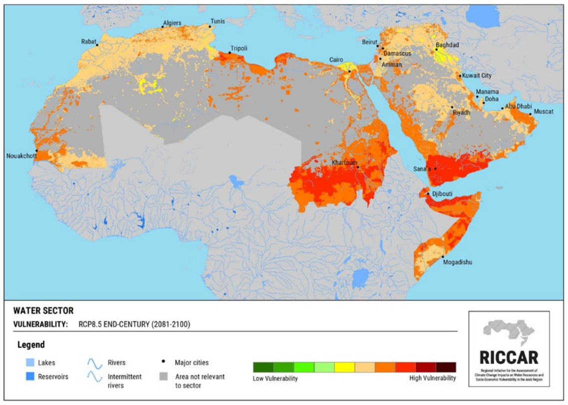


RCP 8.5

2046-2065



2081-2100



CHAPTER 9

WATER SECTOR – VULNERABILITY

Water demand is ubiquitous, essential for food supply, the human population, livestock, ecosystems and industries. Although a renewable resource, its availability is constrained. According to the Falkenmark Water Stress Indicator,[1] a country is water-stressed once annual water supplies drop below 1,700 m^3 per person per year. Freshwater shortages are expected when levels range between 1,000 m^3 to 1,700 m^3 per person per year and, once it drops below 1,000 m^3 per person per year, the country is water-scarce. The Arab region is thus considered water-scarce, with an estimated 610 m^3 per person per year of total available renewable water resources, and as low as 5 m^3 per person per year in some countries.[2]

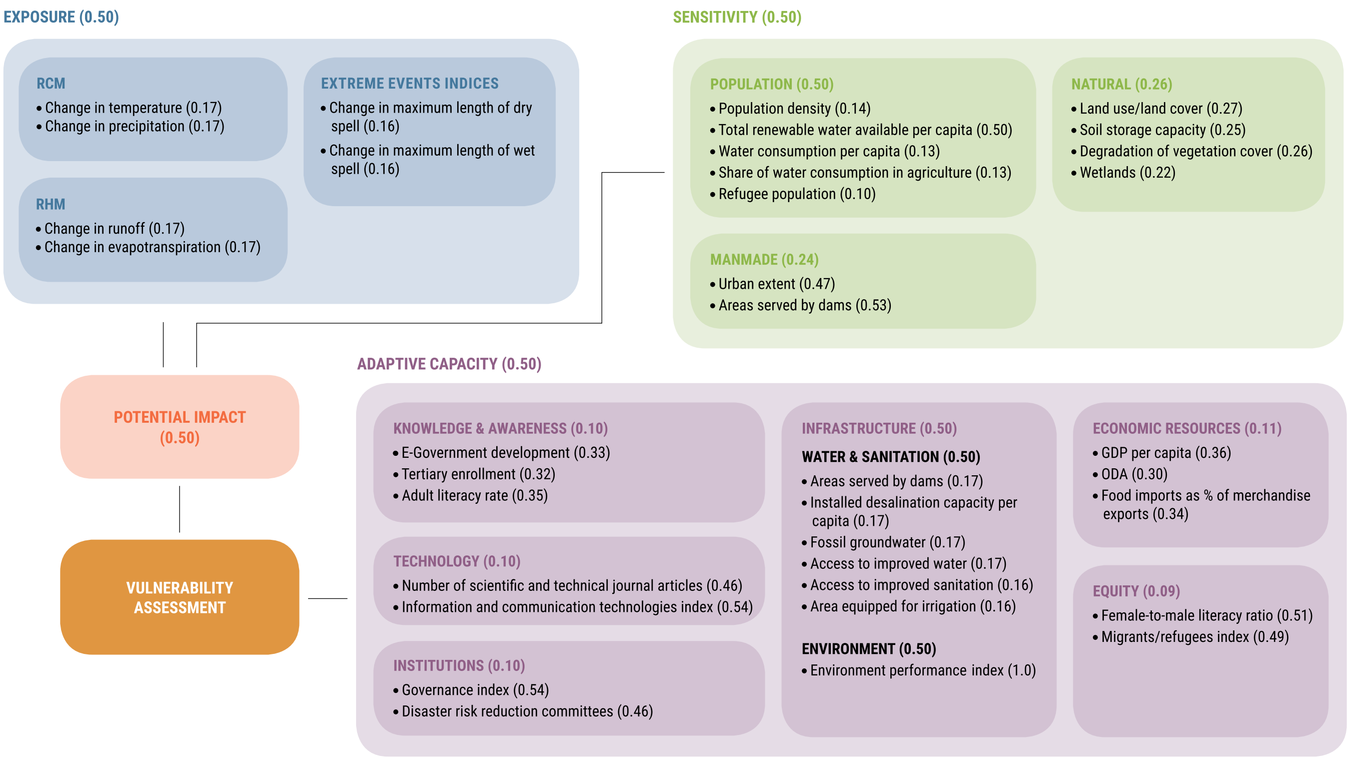
Given the central role of freshwater in the region and its importance in daily life and all economic sectors, the *Water* sector was selected as the starting point when preparing the vulnerability assessment of the Arab region, focusing on the potential impact of *Change in water availability*. It is commonly understood by regional stakeholders to be an overarching, cross-cutting issue that directly influences the vulnerability of the other targeted sectors to climate change. Results from the vulnerability assessment pertaining to this sector are presented in the sections below.

The water-availability study area represents 49% of the Arab region and is defined by selected indicators and water users, as reflected by the areas drawing upon freshwater resources: Forested areas; Wetland areas; Rainfed cropland areas; Irrigated cropland areas; Livestock areas (greater than 10 heads per square kilometre); Populated areas (greater than 2 inhabitants per square kilometre). Because the *Water* sector comprises only one subsector, resultant maps and discussion are assumed to be identical and are thus not included herein at the sector level.

9.1 WATER AVAILABILITY

The different indicators used under each component for this sector and their corresponding weights are presented in the impact chain (Figure 108).

FIGURE 108: Impact chain and weights for water availability



9.1.1 Reference period

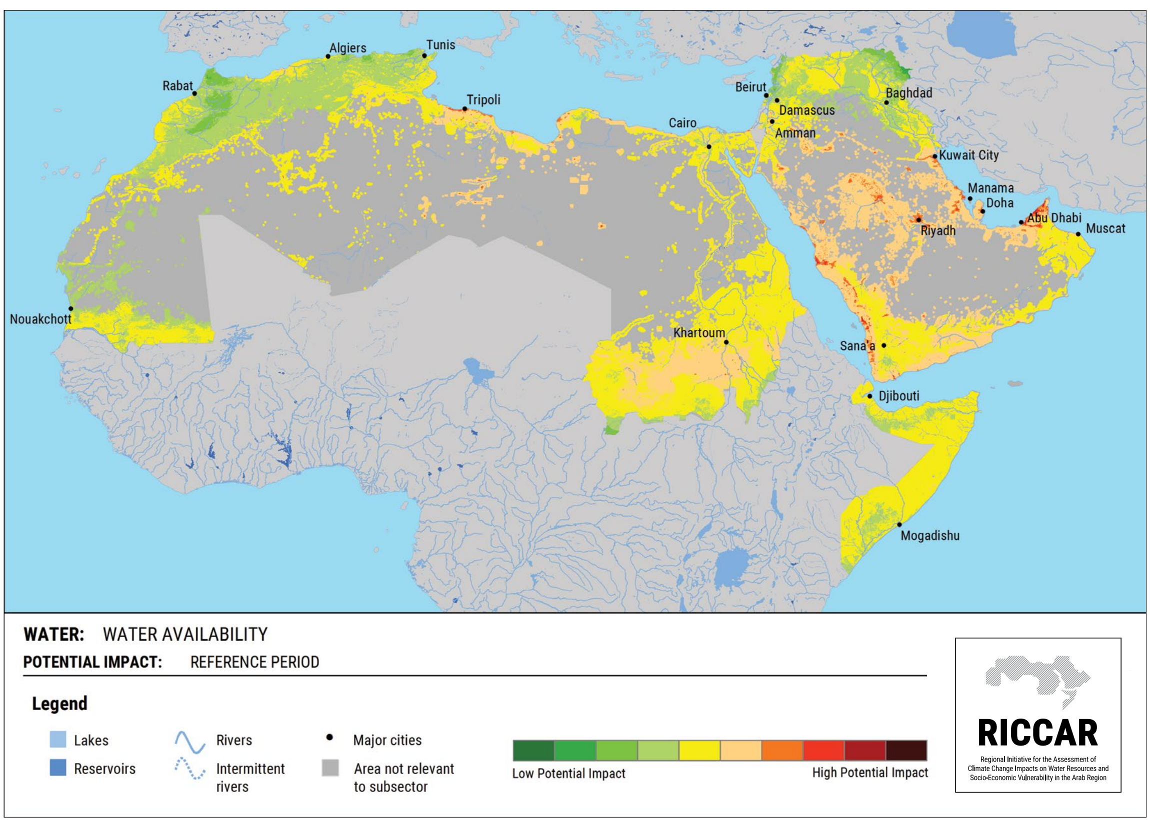
9.1.1.1 Potential impact

Potential impact is the aggregated result of both exposure and sensitivity. Selected exposure indicators focus on those parameters which are related to hydrology, as well as wet- and dry-spell durations, all of which can have a dramatic impact on water availability. Because much of the Arab region is considered water-scarce, expected exposure for the reference period is high in most of the study area (74%). Nearly a quarter of the study area (24%) is regarded as moderate exposure with remaining areas considered as low exposure. Areas of low exposure are contained in the Atlas Mountains and adjacent coastal areas, the coastal Levant, the Zagros Mountains, the Asir Mountains and the south-eastern Sahel. These areas of low exposure transition to moderate and eventually to high exposure.

Available water is expected to meet the needs of differing competing water users. Agriculture warrants the largest demand, using an average 73% of total available water in the Arab region and often exceeds 90%.[3] Water is also needed for industrial, municipal and domestic use. Selected sensitivity indicators reflect the various water users. The study area suggests a nearly equal division between low (48%) and moderate (51%) sensitivity, with isolated areas of high sensitivity. Areas with moderate-to-high sensitivity include the Tell Atlas region, the Jafara Plain basin and the Green Mountains in North Africa, the Asir Mountains and the central Arabian Desert. Sensitivity tends to be highest in areas where total available renewable water per capita is lowest, and in population centres.

Nearly the entire region (96%) has indicated moderate potential impact, with remaining areas divided between low and moderate potential impact. Potential impact correlates with total available renewable water. Areas with moderate-to-high potential impact include the central Arabian Desert and the Asir Mountains, whereas areas with low potential impact include the Atlas Mountains, the coastal Levant and much of the Tigris–Euphrates basin (Figure 109).

FIGURE 109: Water availability – Reference Period – Potential Impact

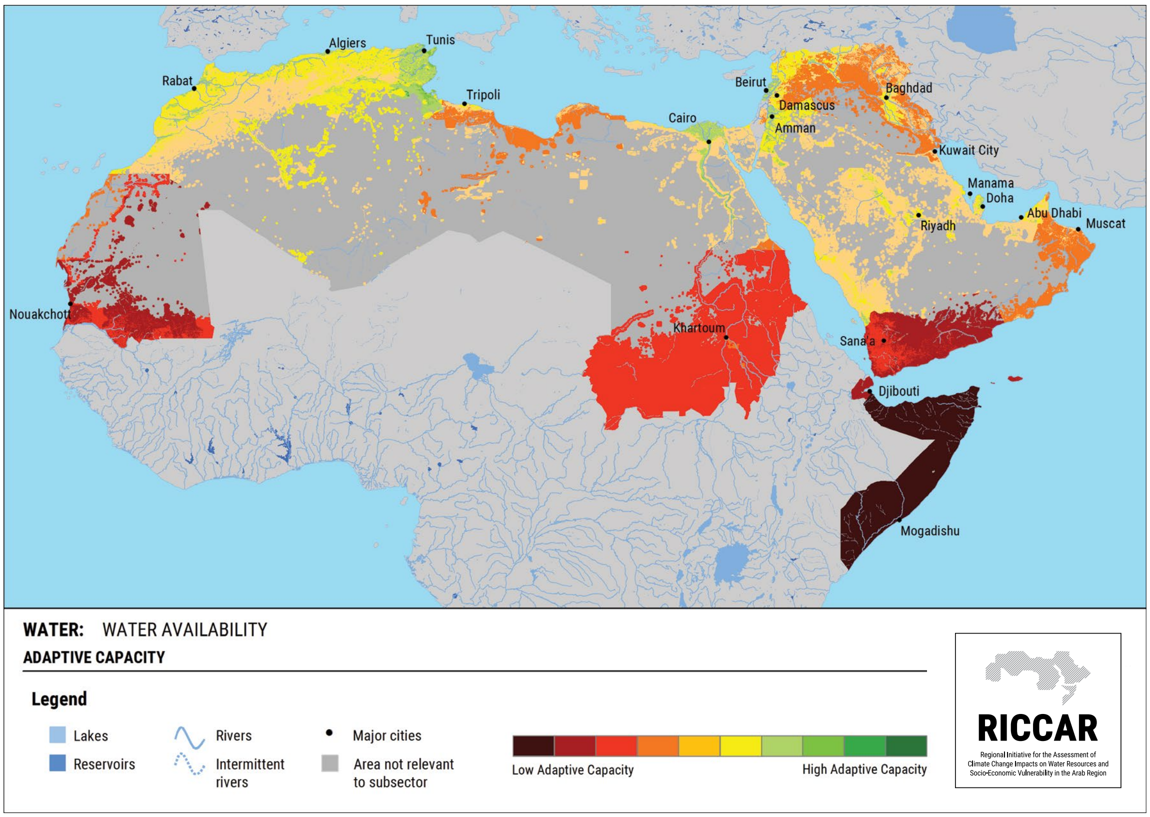


9.1.1.2 Adaptive capacity

The ability to cope is dependent upon several interrelated variables. For example, geopolitical factors consider shared water basins, which can impact regional stability, socio-economic development, environmental protection and security in areas downstream. Infrastructure and management are linked by water usage and efficiency. Gender plays a role because, in some areas, women must devote time every day to fetching water, potentially risking health and safety.

Nearly half (43%) of the study area has indicated low adaptive capacity and includes the Horn of Africa, the southern Tindouf basin and the south-western Arabian Peninsula due to weak infrastructure and other variables. Conversely, areas of high adaptive capacity represent 4% of the study area and include the lower Nile Valley, areas of the coastal Levant and the eastern Atlas Mountains. Remaining areas indicate moderate adaptive capacity (Figure 110).

FIGURE 110: Water availability – Adaptive capacity

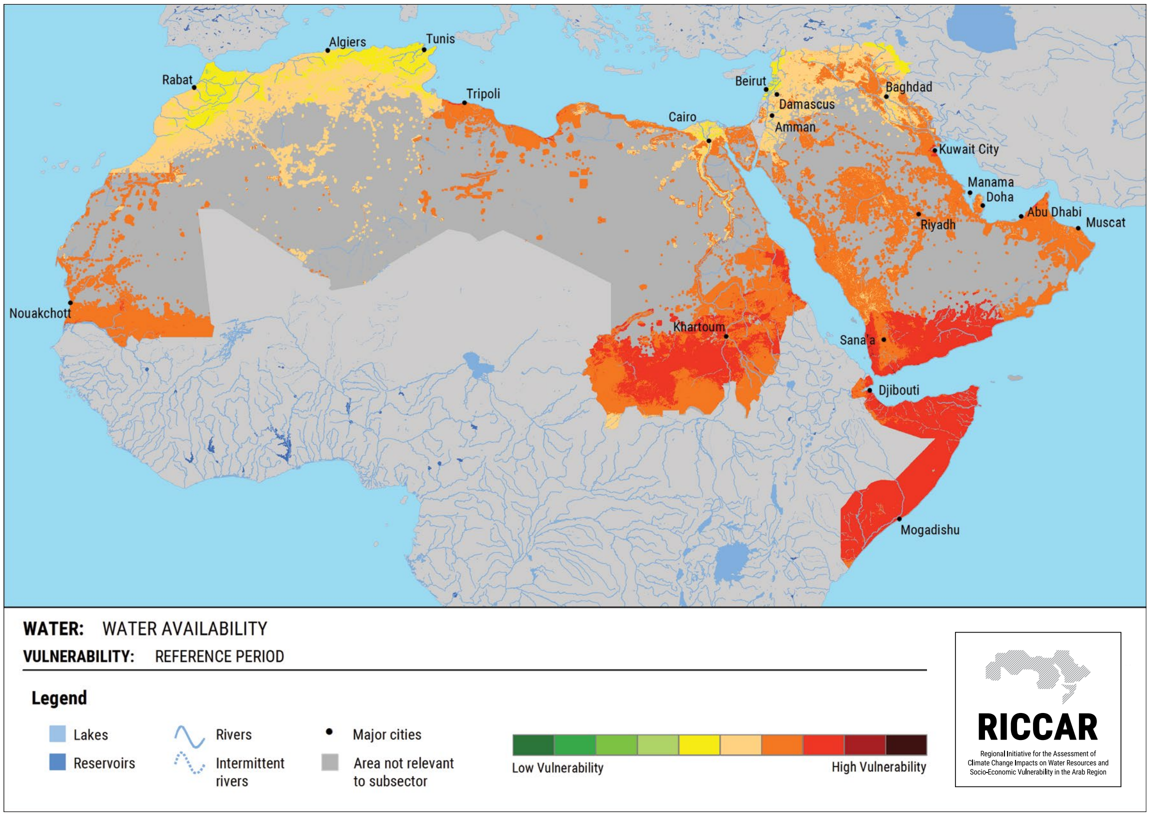


9.1.1.3 Vulnerability

For the reference period, a majority of the study area (70%) signifies high vulnerability for water availability, with remaining areas indicating moderate vulnerability (Figure 111). Areas with the highest vulnerability are clustered around the Marra Mountains in Sudan, the upper Nile Valley, Wadi Hadramaut in the southern Arabian Peninsula and the Horn of Africa. The Atlas Mountains and adjacent coastal areas, the Levantine coast and upper Mesopotamia represent lowest vulnerability compared to the rest of the Arab region. Due to adaptive capacity, areas that have the least total available renewable water resources are not necessarily the most vulnerable. Such areas include countries of the Gulf Cooperation Council, which benefit from economic wealth, facilitating water infrastructure projects like desalinization.

A comparison of different sectors reveals livestock was most vulnerable for water availability. Contributing factors include marginalization of pastoralists and deterioration of rangeland areas. Conversely, the least vulnerable user was croplands. Even so, cropland areas signified moderate vulnerability in general and should not be neglected.

FIGURE 111: Water availability – Reference Period – Vulnerability



9.1.2 Future periods

9.1.2.1 Potential impact

Future potential impact is influenced by both projected dynamic exposure and static sensitivity. Exposure is largely moderate at mid-century, representing 64% (RCP 8.5) to 88% (RCP 4.5) of the study area; areas of high exposure include 7% (RCP 4.5) to 33% (RCP 8.5) of the study area. Such areas include Dinder National Park in Sudan and the Dhamar Montane Plains. At end-century, moderate exposure signifies 39% (RCP 8.5) to 68% (RCP 4.5) of the study area while 27% (RCP 4.5) to 58% (RCP 8.5) is of high exposure.

Affected areas include those included at mid-century, as well as the coastal Levant and east of the Jebel Marra massif. In terms of trends from mid- to end-century, areas with the largest increases in exposure include the lower Nile Valley, the Jebel Marra massif and the central Senegal River Valley for RCP 4.5 and the eastern Murzuk basin and the eastern Red Hamada basin for RCP 8.5.

Assuming static sensitivity, forecast potential impact is largely moderate for both mid- and end-century for both scenarios, representing > 88% of the study area (Figure 112 to Figure 115). Areas of high potential impact are up to 2% at end-century (RCP 8.5). Remaining areas suggest low potential impact. As a result, the current status of the natural and physical environment counterbalance climate change effects. Should these sensitivity parameters change, however, potential impact will suffer.

Potential impact is highest near the Asir Mountains, the Green Mountains and the eastern Jafara Plain basin. Though moderate, potential impact is expected to follow similar trends as exposure with increasing areas noted above. Areas with decreasing potential impact include the southern Horn of Africa and the central Tigris–Euphrates basin for both scenarios.

FIGURE 112: Water availability – Mid-century RCP 4.5 – Potential impact

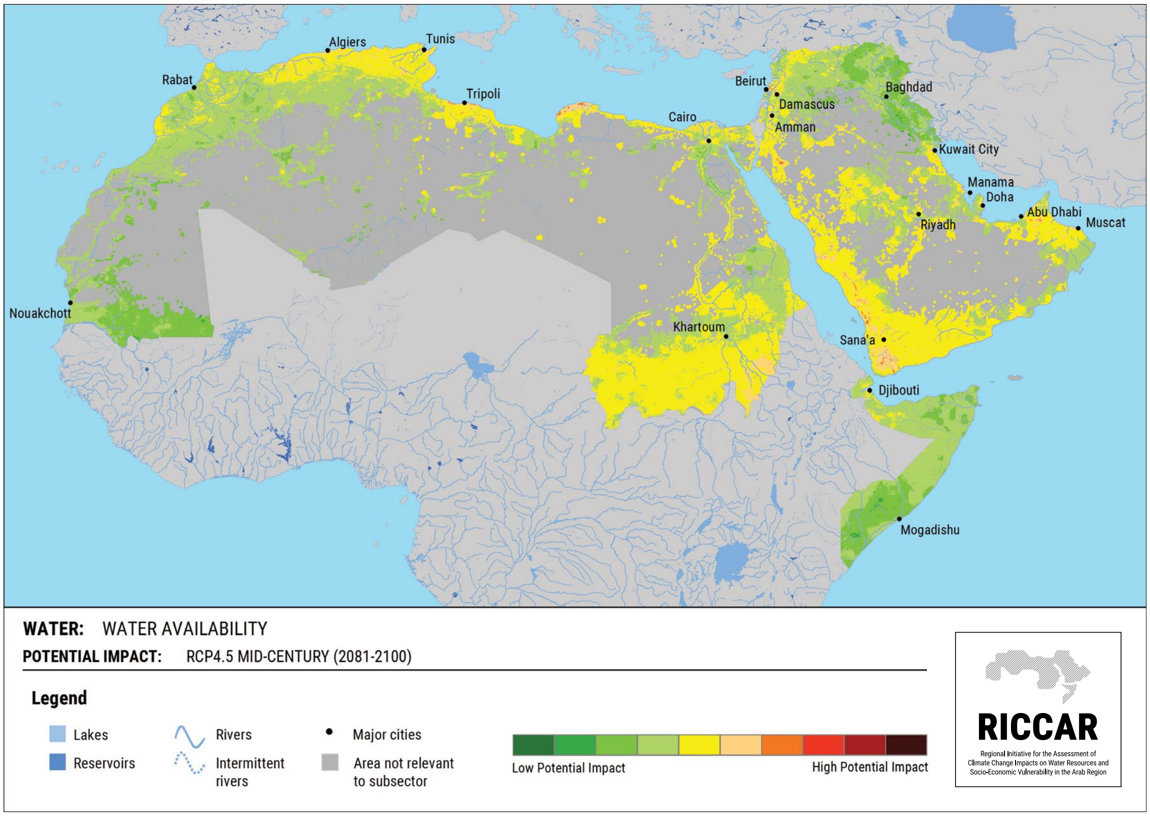


FIGURE 113: Water availability – Mid-century RCP 8.5 – Potential impact

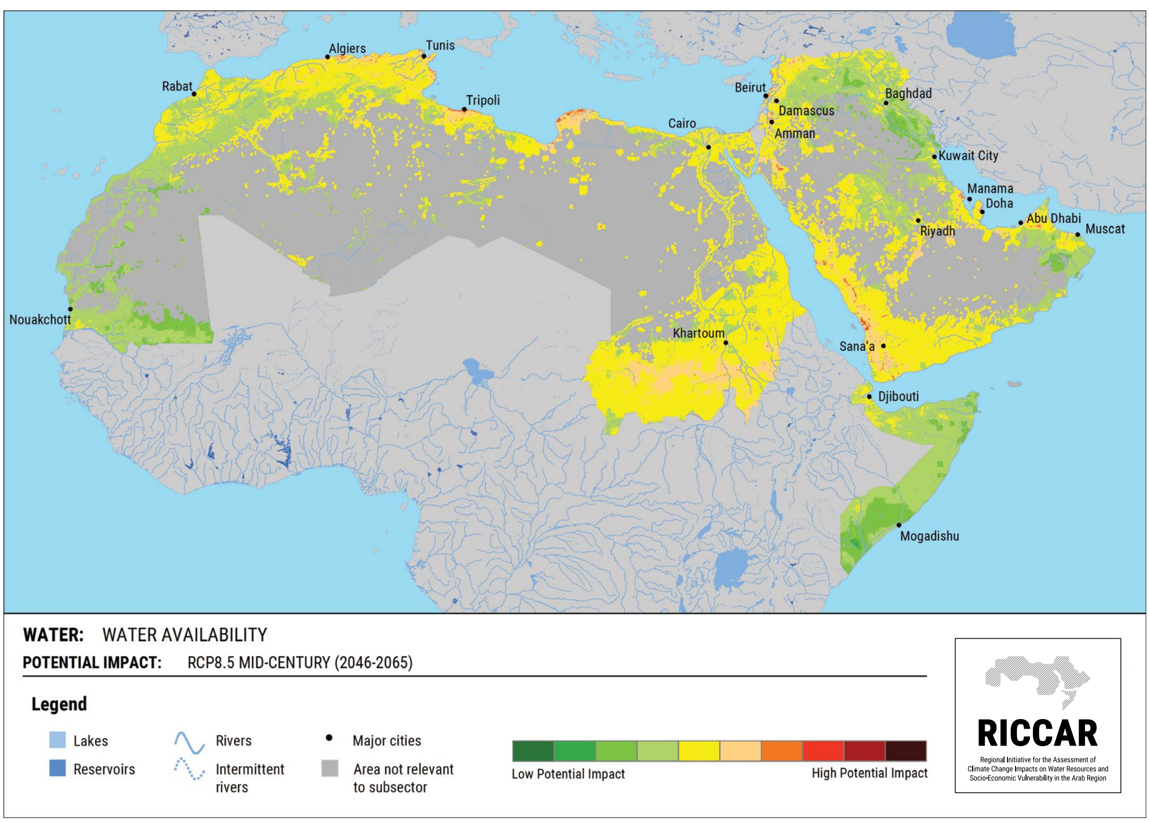


FIGURE 114: Water availability – End-century RCP 4.5 – Potential impact

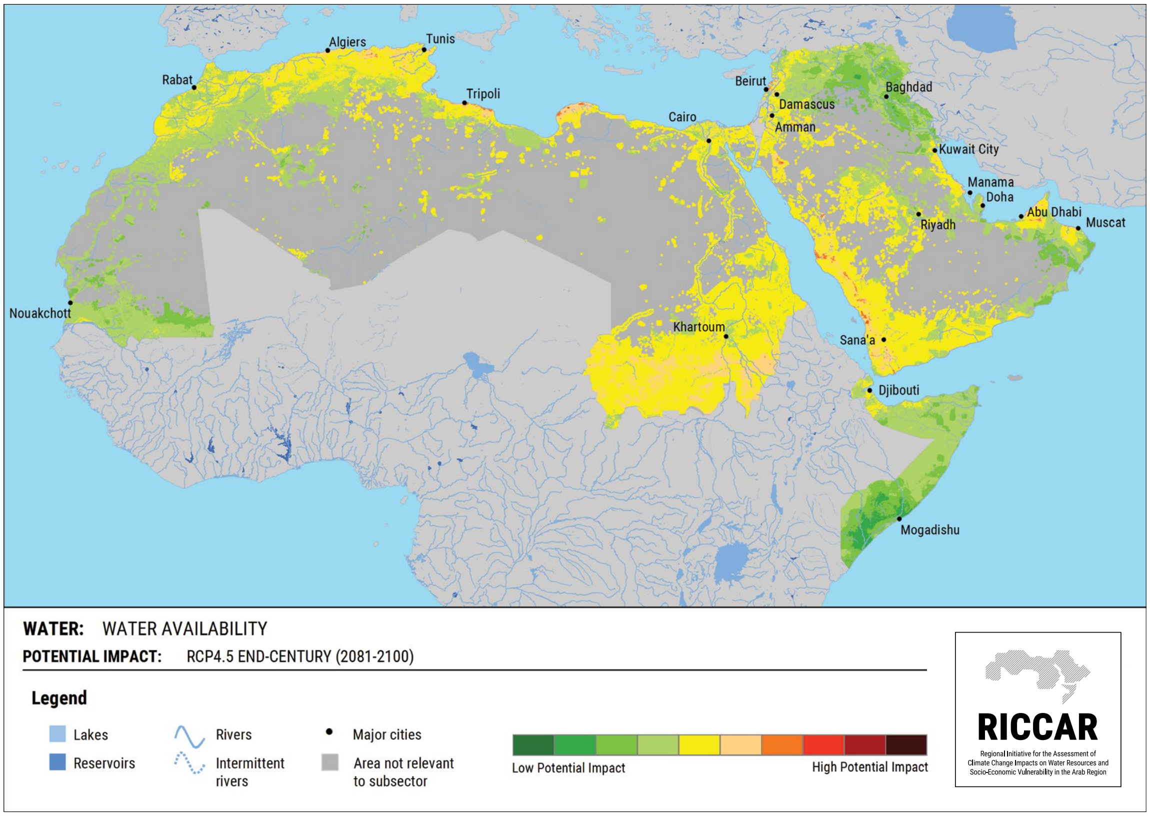
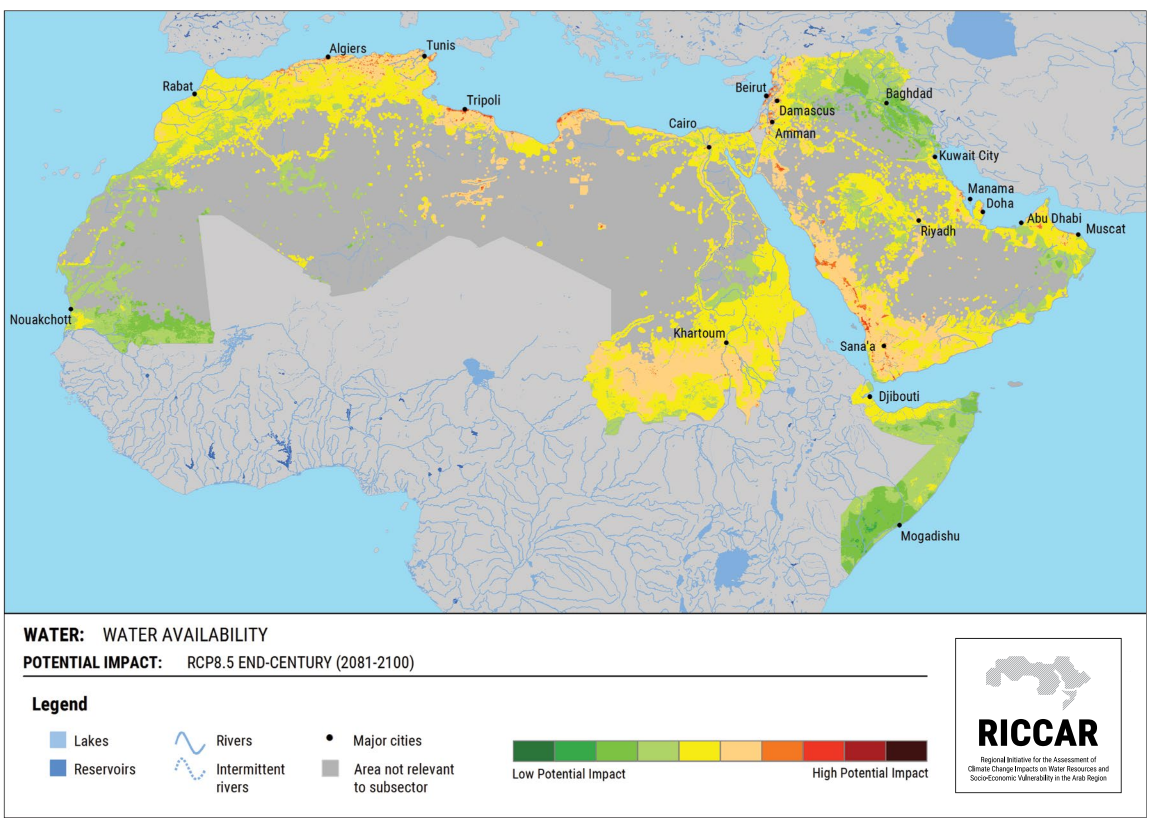


FIGURE 115: Water availability – End-century RCP 8.5 – Potential impact



9.1.2.2 Vulnerability

Vulnerability for both mid- and end-century is nearly equally divided between areas of moderate and high vulnerability. At mid-century, 43% (RCP 4.5) to 52% (RCP 8.5) of the study area predicts high vulnerability.

Areas of high vulnerability increase slightly at end-century, representing 48% (RCP 4.5) to 57% (RCP 8.5) of the study area (Table 21). Such areas include the upper Nile Valley, the south-western Arabian Peninsula and the northern Horn of Africa, due to low adaptive capacity. Remaining areas suggest moderate vulnerability. Areas with relatively low vulnerability include the Tigris–Euphrates basin and the lower Nile Valley, including the Nile Delta (Figure 116 to Figure 119).

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. Like the reference period, the most vulnerable water users are projected as pastoralists and livestock. Livestock require large quantities of water to produce feed, allow grazing and for direct water usage. Populated areas are, comparatively, the least vulnerable. Nevertheless, aspects not considered as part of this study, including population growth, projected environmental degradation and water quality, give rise to concerns regarding water availability.

TABLE 21: Percentage of study area by vulnerability classification for water availability

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	0%	57%	43%
Mid-Century RCP 8.5	0%	48%	52%
End-Century RCP 4.5	0%	52%	48%
End-Century RCP 8.5	0%	43%	57%

FIGURE 116: Water availability – Mid-century RCP 4.5 – Vulnerability

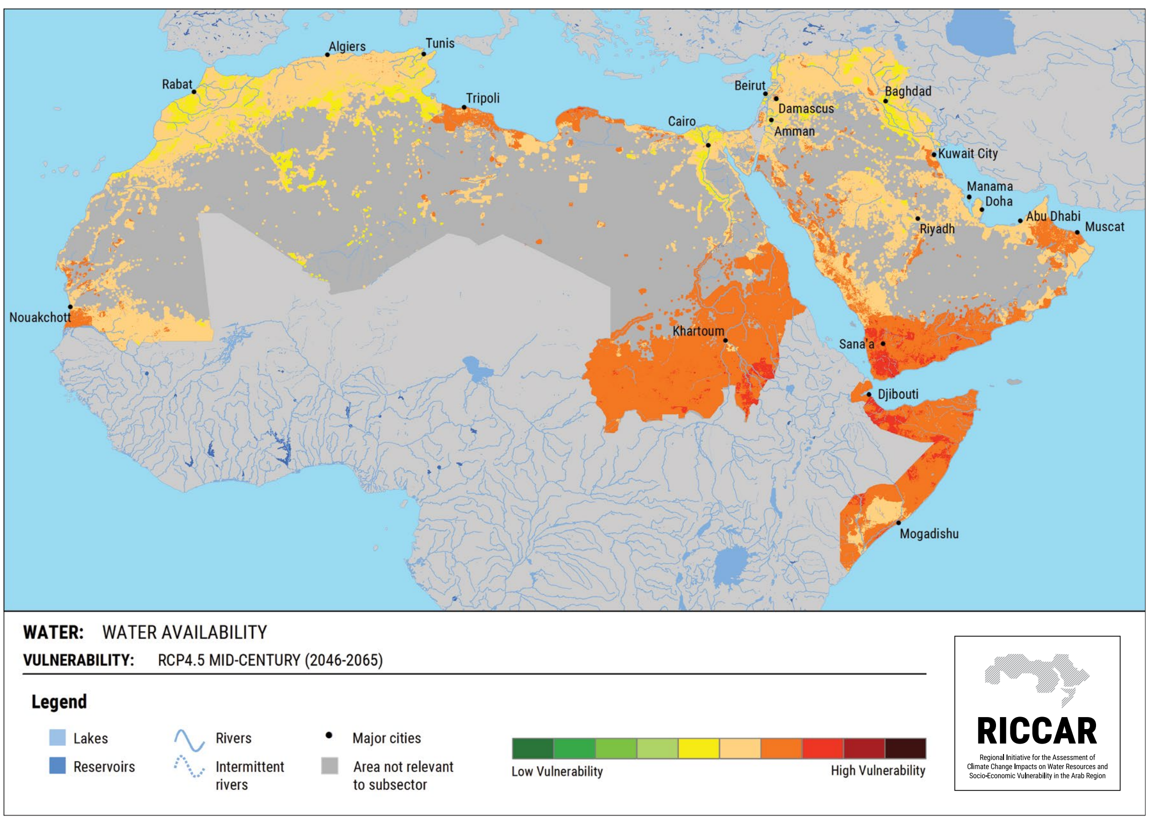


FIGURE 117: Water availability – Mid-century RCP 8.5 – Vulnerability

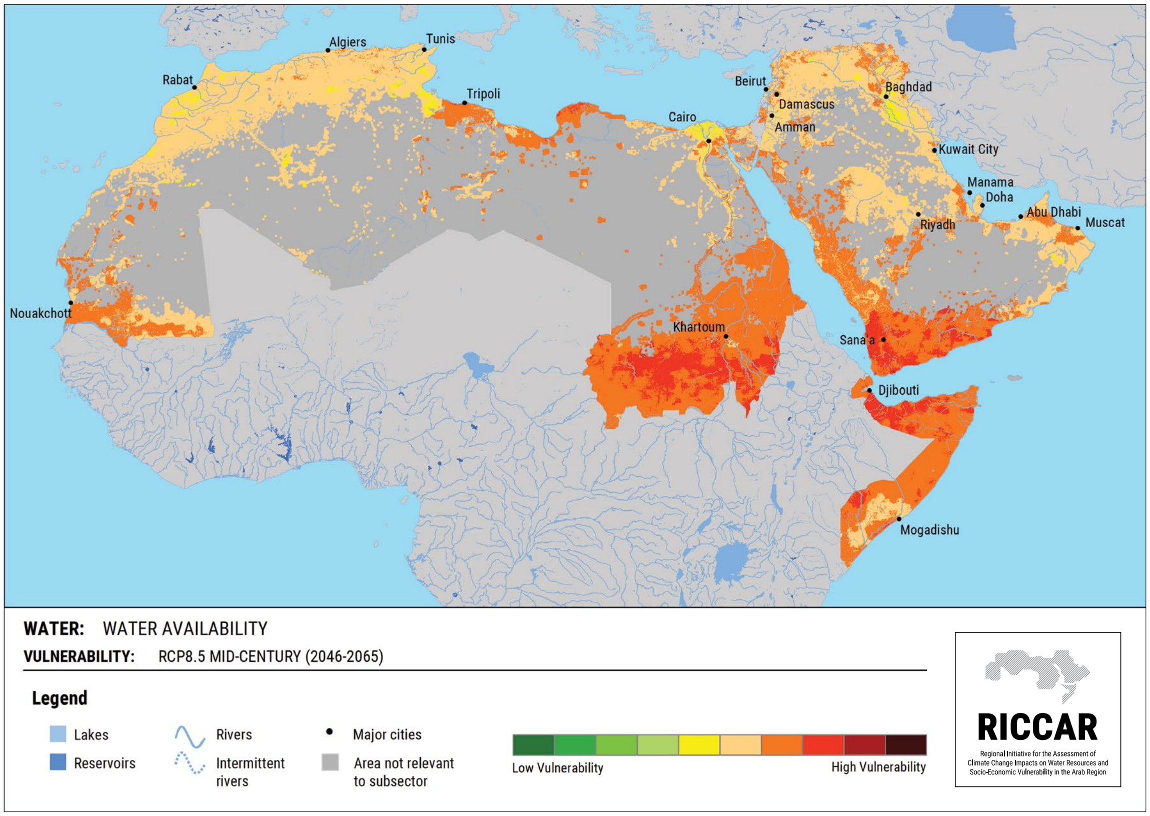


FIGURE 118: Water availability – End-century RCP 4.5 – Vulnerability

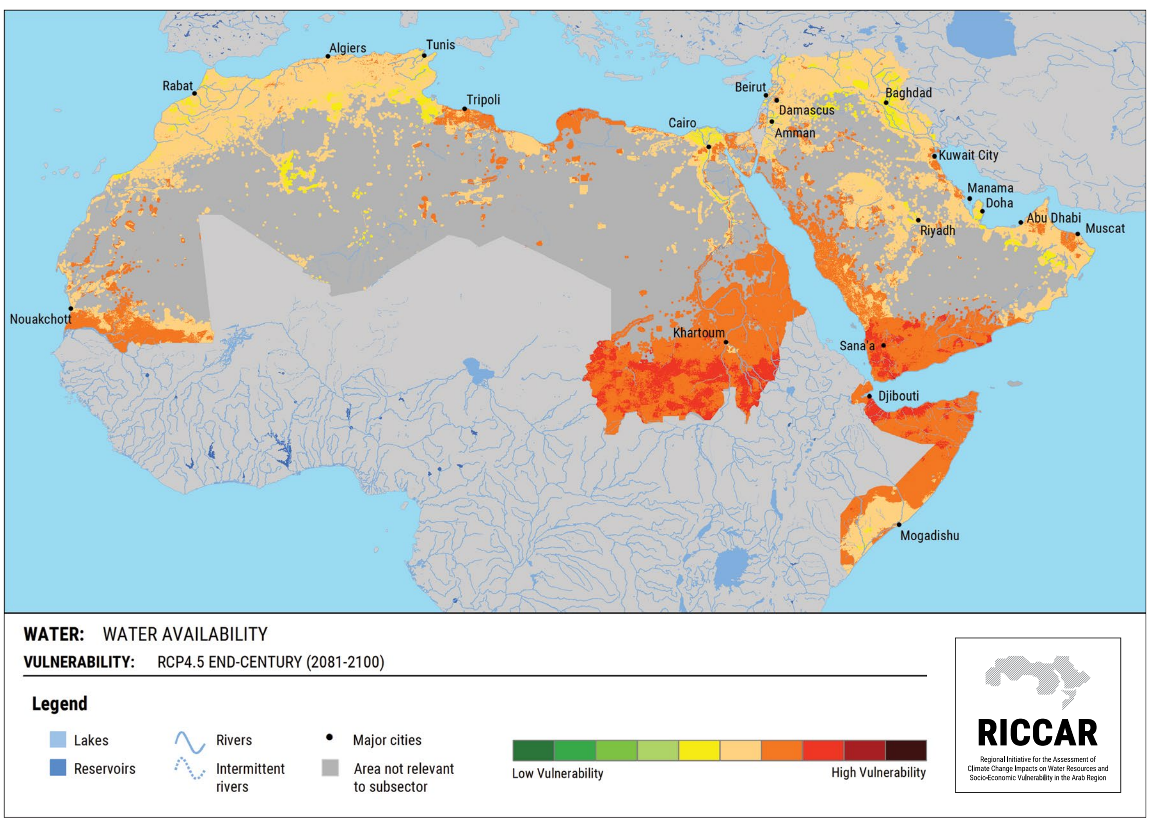
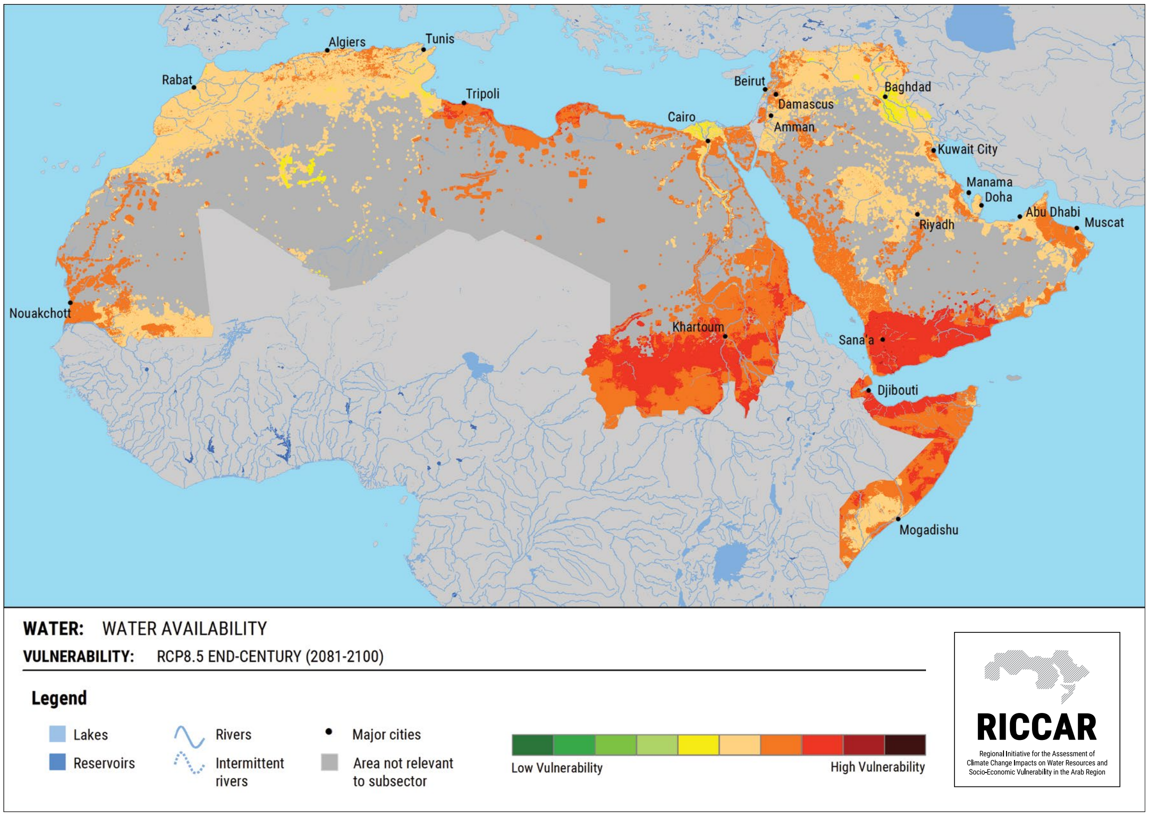


FIGURE 119: Water availability – End-century RCP 8.5 – Vulnerability



9.1.3 Hotspots

Hotspots represent the areas with the highest projected vulnerability and up to 14% of the study area. They constitute a call to action where decision-makers and aid agencies should focus efforts. Hotspots 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 because 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.

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

ENDNOTES

1. Falkenmark, 1989
2. FAO, 2017
3. Ibid.

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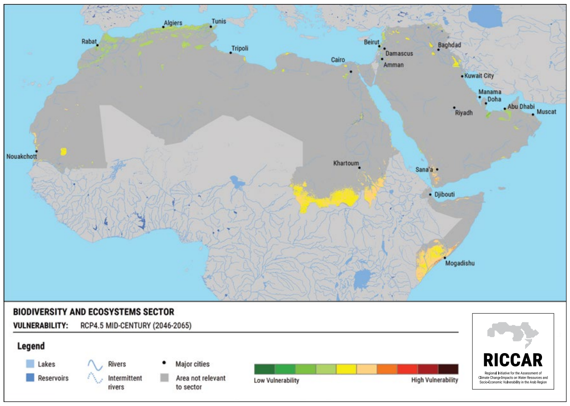
BIODIVERSITY AND ECOSYSTEMS SECTOR

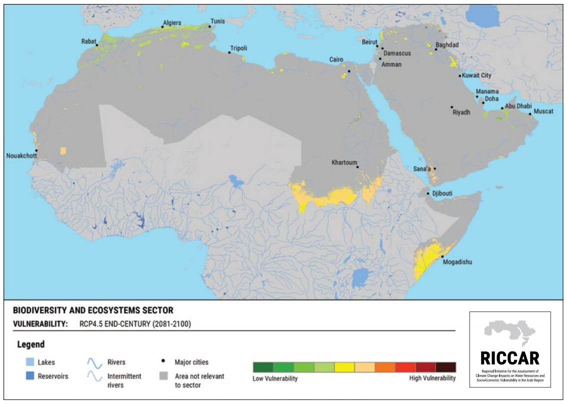
OVERALL VULNERABILITY

RCP 4.5

2046-2065

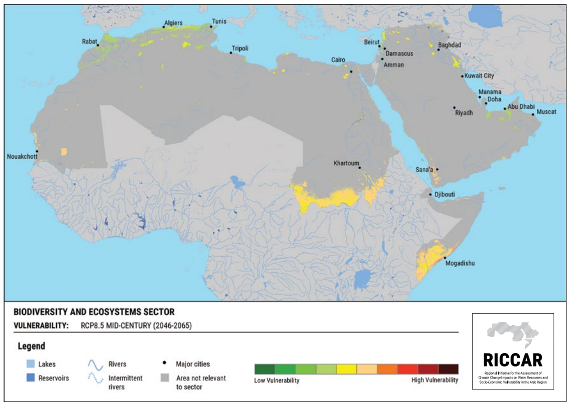


2081-2100

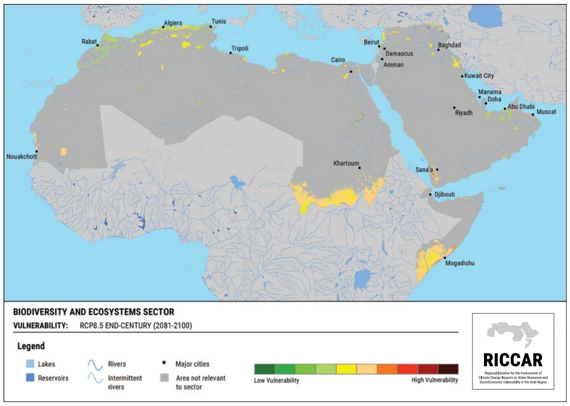


RCP 8.5

2046-2065



2081-2100



CHAPTER 10

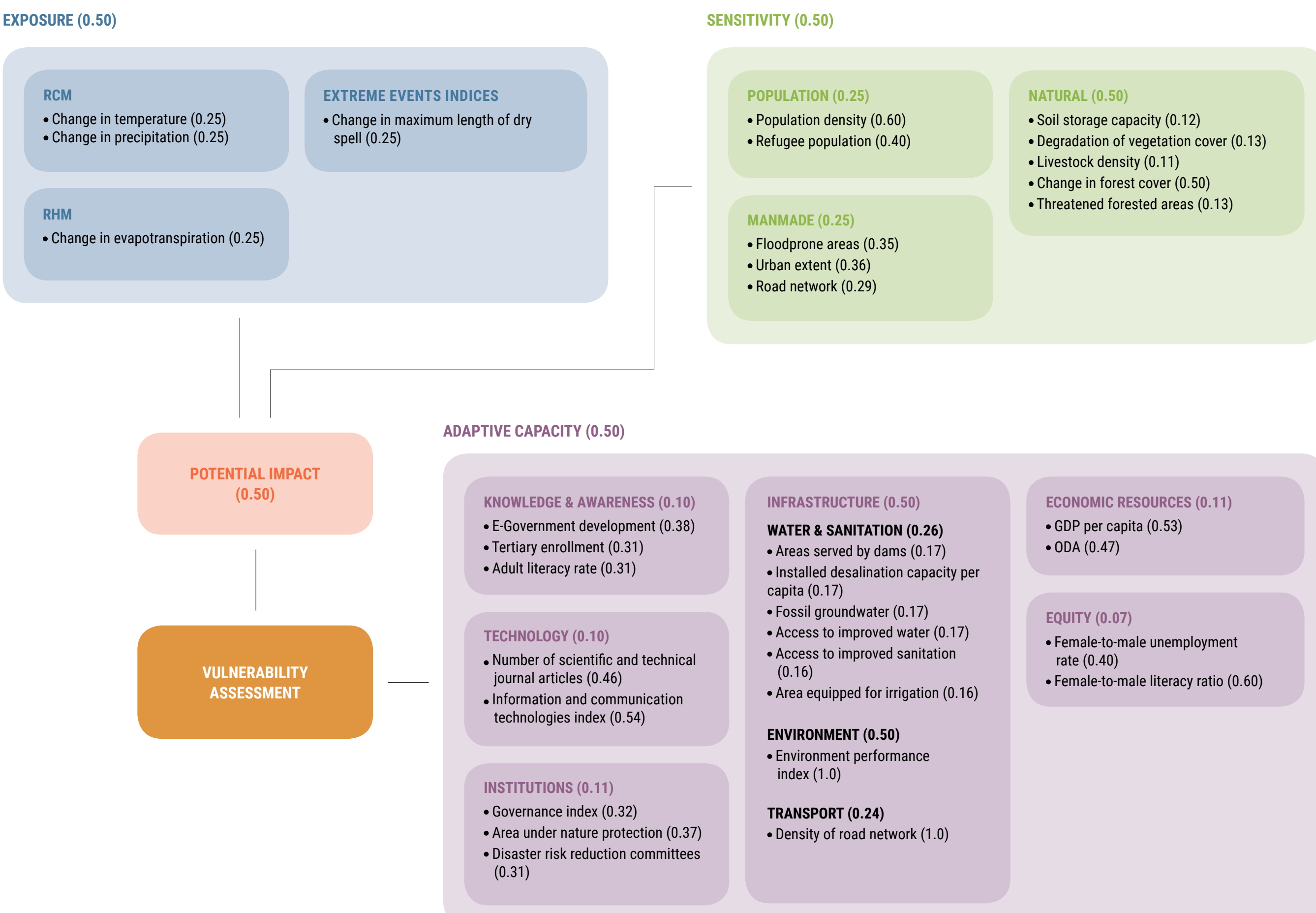
BIODIVERSITY AND ECOSYSTEMS SECTOR – VULNERABILITY

Ecosystems provide valuable services, regulate chemical and physical processes and supply food and water. Biodiversity is essential to ecosystem health, but also provides a basis for human economic activity, health and recreation. High population growth, urbanization and industrialization converging with unsustainable management of land and water resources have led to a decline in biodiversity and a destruction of valuable habitats and ecosystems all over the Arab region.[1] In this context, forests and wetlands are among the ecosystems considered to be highly vulnerable regarding changing temperatures and a reduction in water availability in a context of climate change. The VA-WG thus selected the *Biodiversity and ecosystems sector* to be included in the vulnerability assessment with particular focus on climate change effects upon the *change in the area covered by forests* and the *change in the area covered by wetlands*. Outcomes from the vulnerability assessment for this sector and associated subsectors are presented in this chapter.
Both forested and wetland areas represent a small fraction of the Arab region (5% and 2%, respectively). The respective study areas are defined by indicators and include forested areas from 2000 to 2014 for the *Area covered by forests* subsector. The *Area covered by wetlands* subsector includes Ramsar sites and their buffers, coastal wetlands, riverine wetlands, sabkhas and saltpans. For the sector, the combined area evaluated represents 7% of the Arab region.

10.1 AREA COVERED BY FORESTS

The impact chain highlighting the different indicators and weights for this subsector is presented in Figure 120.

FIGURE 120: Impact chain and weights for area covered by forests



10.1.1 Reference period

10.1.1.1 Potential impact

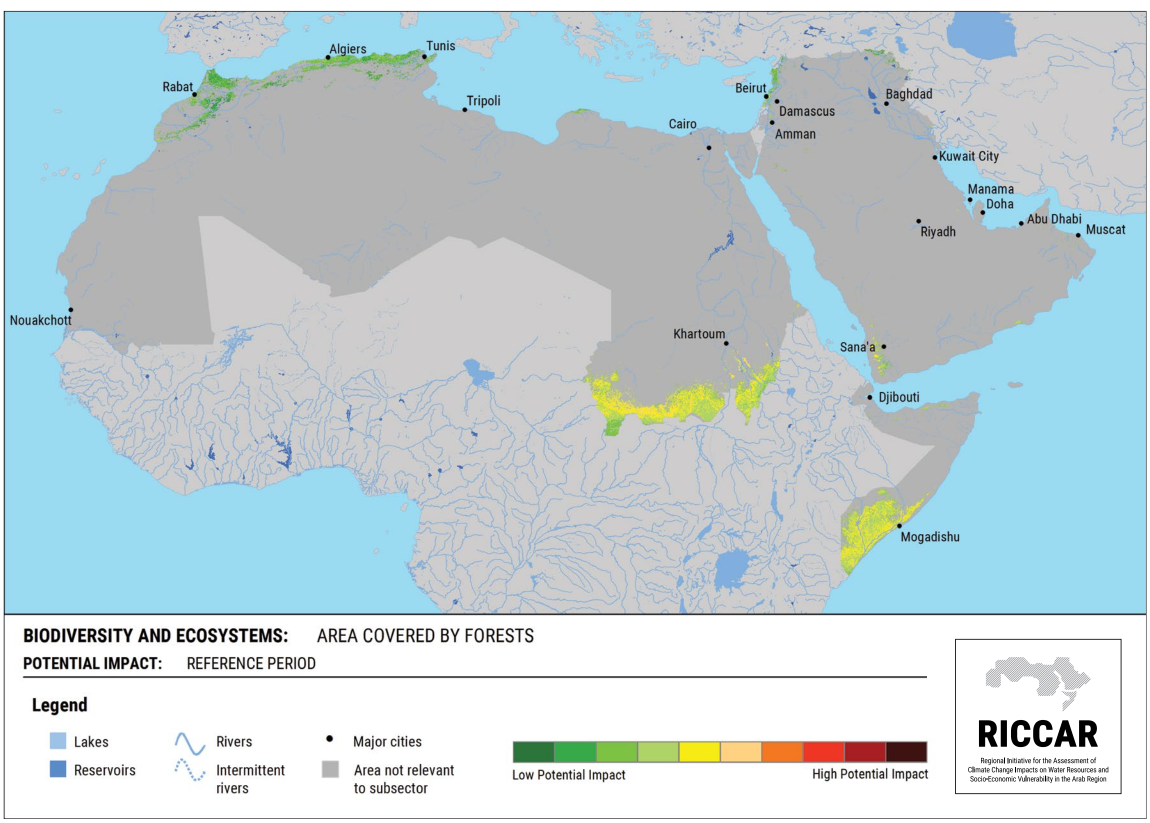
Forest areas represent a small percentage of the Arab landscape but play a significant role in natural resource and environmental conservation which, in turn, influences rural development. Forests contribute toward watershed management through soil conservation, erosion control and flood mitigation. They also benefit rural livelihoods by generating fuelwood, charcoal and other commodities.

Potential impact reflects both exposure and sensitivity. Four exposure indicators were selected to assess areas most prone to drought: temperature, precipitation, evapotranspiration and maximum length of dry spell (CDD). Drought can induce tree mortality as well as physiological stresses such as insect outbreaks and wildfires. For the reference period, 21% of forests are identified by low exposure, 72% moderate exposure, and 6% high exposure. Areas with high exposure include tropical shrublands located in a belt south of Khartoum. Forests in the Atlas Mountains and the Levant represent the lowest exposure for the reference period.

Forests in the region have faced other threats: population growth, urbanization, agricultural encroachment, deforestation and inadequate social and economic conditions. Population growth and urbanization are reflected in four selected sensitivity indicators: population density, refugee population, urban extent and road network. Threatened forest areas and livestock density are both factors in agricultural encroachment. Lastly, degradation of vegetation cover, change in forest cover, threatened forested areas and floodprone areas are all considered as part of deforestation. A majority of the region's forests (54%) are indicative of low sensitivity, while moderate sensitivity areas represent 46% of the study area. Areas of moderate to high sensitivity are interspersed throughout the region and are not confined to a particular area, although sensitivity tends to be higher in areas with higher population density.

The resultant potential impact for the reference period (Figure 121) is primarily moderate, representing 68% of the region's forests. The remaining study area indicates low potential impact. Areas of moderate impact include the woodland savannah in the eastern Sahel, the Jabal Bura Valley forest in the south-western Arabian Peninsula and the riverine forests of the Jubba River Valley in the Horn of Africa.

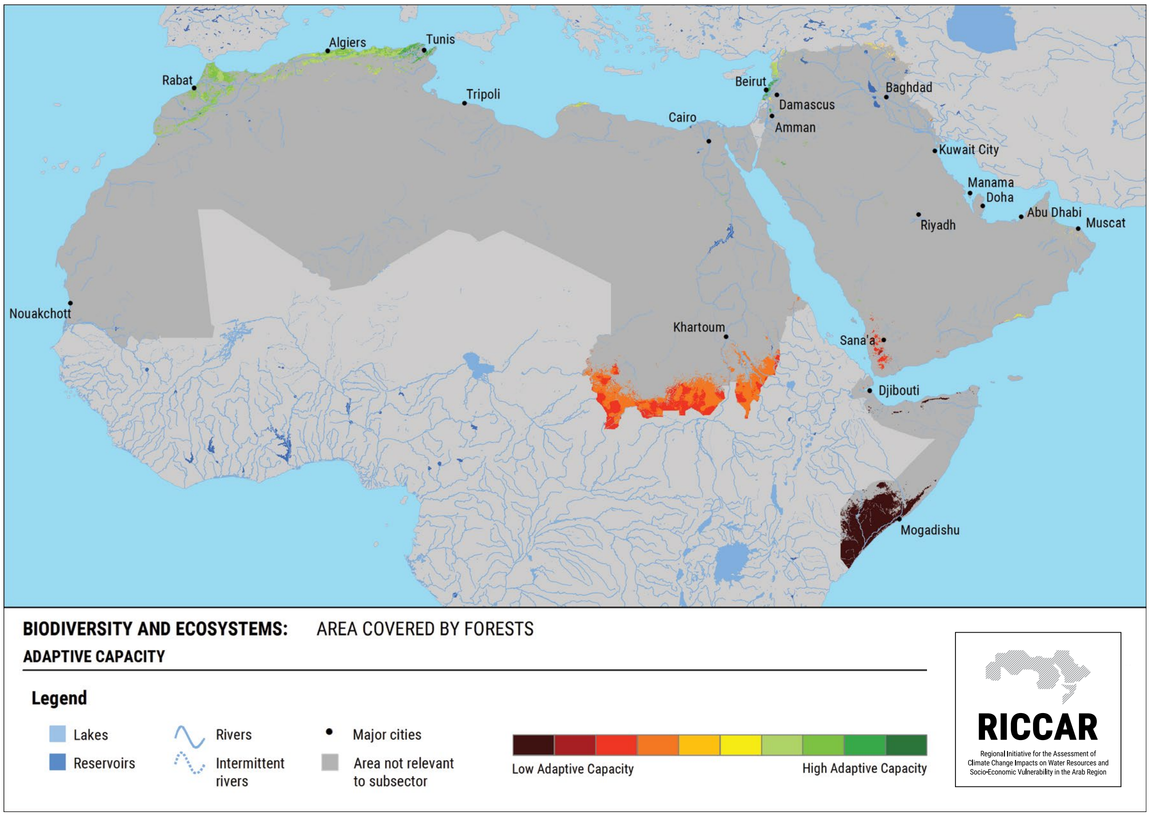
FIGURE 121: Area covered by forests – Reference period – Potential impact



10.1.1.2 Adaptive capacity

Adaptive capacity was based on 20 differing indicators, with emphasis placed upon environmental infrastructure. In this context, environmental infrastructure includes environmental regulations, establishment of effectively managed protected area networks and corridors, areas/ecosystems implementing Ecosystem-Based Management (EBM), sustainable forest management, social markets, product certification, and land acquisition. Nearly half the region's forests (46%) indicate low adaptive capacity. These areas include the selected savannah woodlands in the eastern Sahel, the Jabal Bura Valley forest and the riverine forests of the Jubba River Valley. Other savannah woodlands in the eastern Sahel represent moderate adaptive capacity (Figure 122). About a quarter of the study area (23%) represents high adaptive capacity relative to the region and includes forests in the Atlas Mountains and the Levant.

FIGURE 122: Area covered by forests – Adaptive capacity



10.1.1.3 Vulnerability

Over half the study area (55%) indicates high vulnerability for the reference period, largely stemming from low adaptive capacity, and include the eastern Sahel, the Jubal Bura Valley forest and the Jubba riverine forests (Figure 123). These forests are threatened by overgrazing, overcultivation and deforestation. For example, in the eastern Sahel, gum trees – which produce a lucrative cash crop called gum arabic – have largely been destroyed and thus the economy has been harmed. Degradation of forests has affected formerly abundant wildlife species such as oryx, gazelle, ostrich, ibex and Barbary sheep. Those that remain are endangered owing to loss of habitat and uncontrolled hunting.

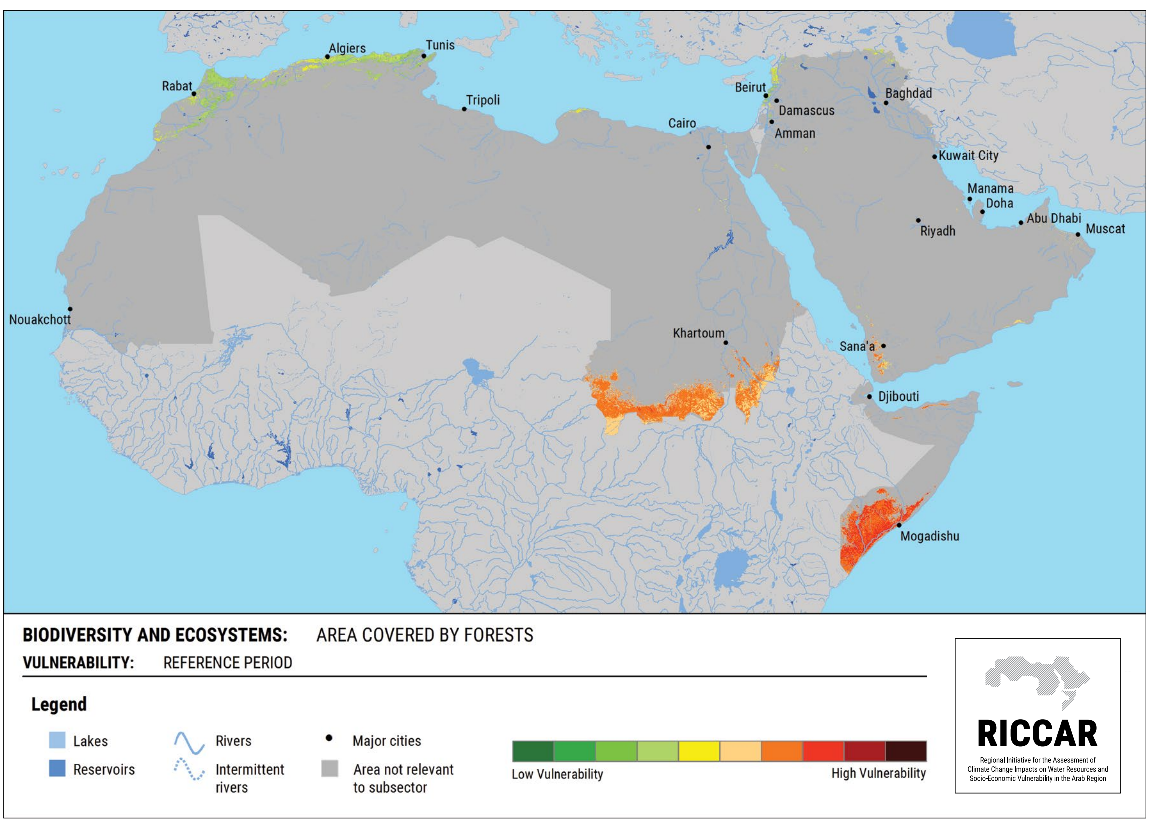
Forests in south-western Arabia include small patches in valleys near Jabal Raymah, Jabal Melhan, and Jabal Bura, the latter being the largest. The habitat is unique in the Arabian Peninsula and is home to certain endemic plant and animal species. Successful lobbying resulted in declaring Jubal Bura a protected area. In addition, until recently, the region was relatively underdeveloped and thus conserved. Recent roadway construction through the forest, however, has contributed to deforestation, among other threats.

Forests in the Horn of Africa, particularly in the Juba River Valley, are at risk from deforestation, agricultural expansion and erosion from flooding. The forest is home to birds and animals such as storks, pelicans, squirrels and duikers. In addition to habitat loss, these birds and animals are threatened by hunting, despite its being illegal. Local livelihoods depend upon the forest for commodities such as timber, coppiced canes, charcoal, edible fruits and dyestuffs. Apiculture is profitable, but dependent on a sustainable ecosystem.

Most other areas indicate moderate vulnerability for the reference period (41% of the study area) and includes subtropical dry forest of the Tell Atlas region, which underwent up to 30% deforestation from 2000 to 2014.[2] Another area indicating moderate vulnerability is forested land in the Levant, which has actually experienced gains in extent[3], possibly reducing its inherent vulnerability.

Forest in Aseer Mountains, Saudi Arabia, 2010. Source: Ihab Jnad.

FIGURE 123: Area covered by forests – Reference period – Vulnerability



10.1.2 Future periods

10.1.2.1 Potential impact

Climate change impacts can be detrimental to forests. Although species can theoretically relocate to more favourable climatic areas, they do so at a slower rate than predicted climate change. Moreover, suitable areas may be fragmented and movement is restricted. Tree growth is affected by water balance stemming from precipitation and evapotranspiration. Extreme events can be detrimental to tree survival and climate phenomena can also impact tree phenology. Lastly, responses to climate change can vary according to the different plants and animals in forest ecosystems.

Forecast exposure is expected to be largely moderate: at mid-century (Figure 124 and Figure 125), it ranges from 81% (RCP 4.5) to 84% (RCP 8.5); at end-century (Figure 126 and Figure 127), moderate exposure is predicted at 53% (RCP 8.5) to 78% (RCP 4.5) of the study area. A small percentage of the study area indicates high exposure at mid-century to be 1% (RCP 4.5) and 8% (RCP 8.5) but, at end-century, this increases to 3% (RCP 4.5) and 44% (RCP 8.5) of the study area. Areas with the highest exposure include the Barzan area and the Gali Balnda Nature Reserve in the Zagros Mountains, the Jabal Bura Valley forest in the south-western Arabian Peninsula and forests in the Levant, including the Al Shouf Cedars Nature Reserve. Conversely, low exposure is forecast in the forests of the Golis Mountains and deciduous bushland of the Lag Badana ecosystem, both in the Horn of Africa. Assuming static sensitivity, potential impact is also largely moderate, ranging from 65% (RCP 4.5) to 74% (RCP 8.5) at mid-century and 67% (RCP 4.5) to 81% (RCP 8.5) at end-century. Remaining areas suggest low potential impact. The current state of the natural and physical environment helps compensate for projected climate change impacts. Sensitivity, however, can vary, according to factors such as increased deforestation and urbanization and parameters not considered as part of this study, such as forest fires and disease. Areas with the highest potential impact include forests of the Levant, Acacia nilotica plantations along the banks of the Blue Nile south of Khartoum and the Taza Biosphere Reserve in the Tell Atlas region.

In terms of trends, most forests exhibit steady-to-increasing potential impact from mid- to end century. In particular, forecasts for forests in the Levant, including the Al Shouf Cedars Nature Reserve, indicate a sharp increase in potential impact, particularly under the RCP 8.5 scenario, as a result of exposure. The sole region to anticipate a decline in potential impact are the forests of the southern Horn of Africa, owing to a predicted increase in precipitation.

FIGURE 124: Area covered by forests – Mid-century RCP 4.5 – Potential impact

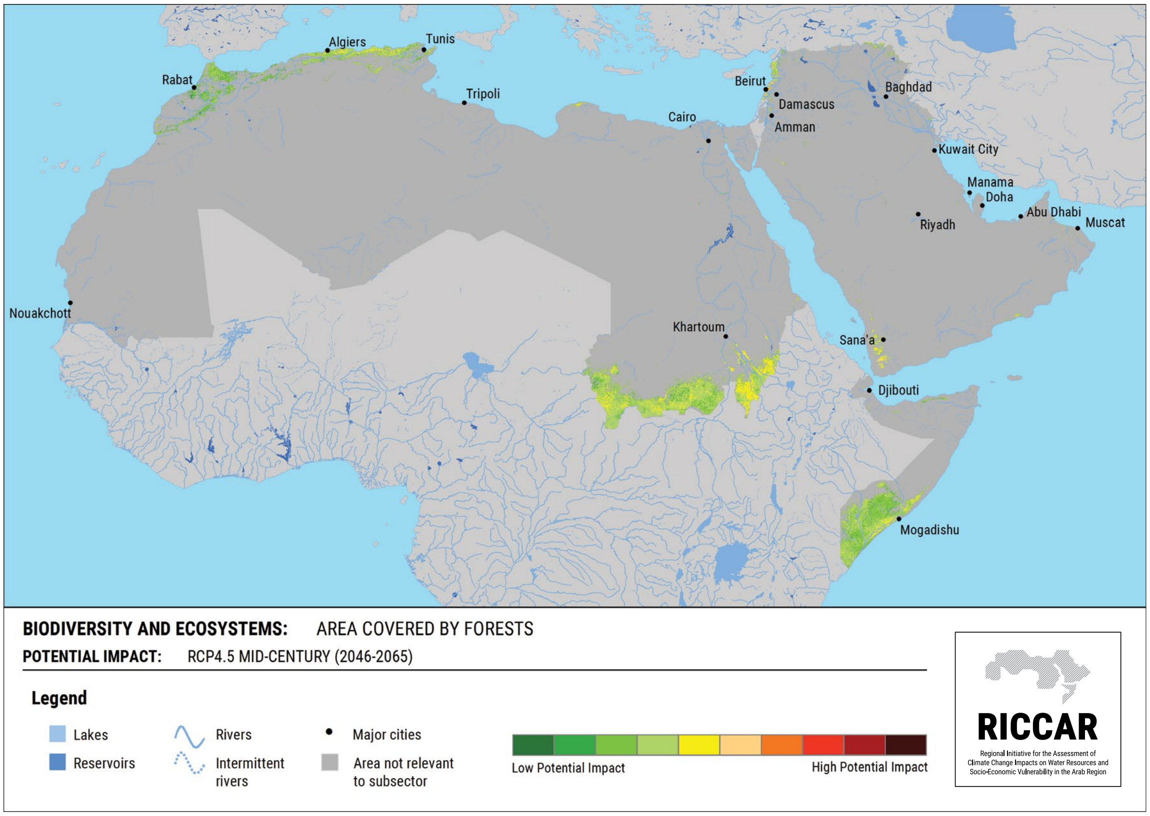


FIGURE 125: Area covered by forests – Mid-century RCP 8.5 – Potential impact

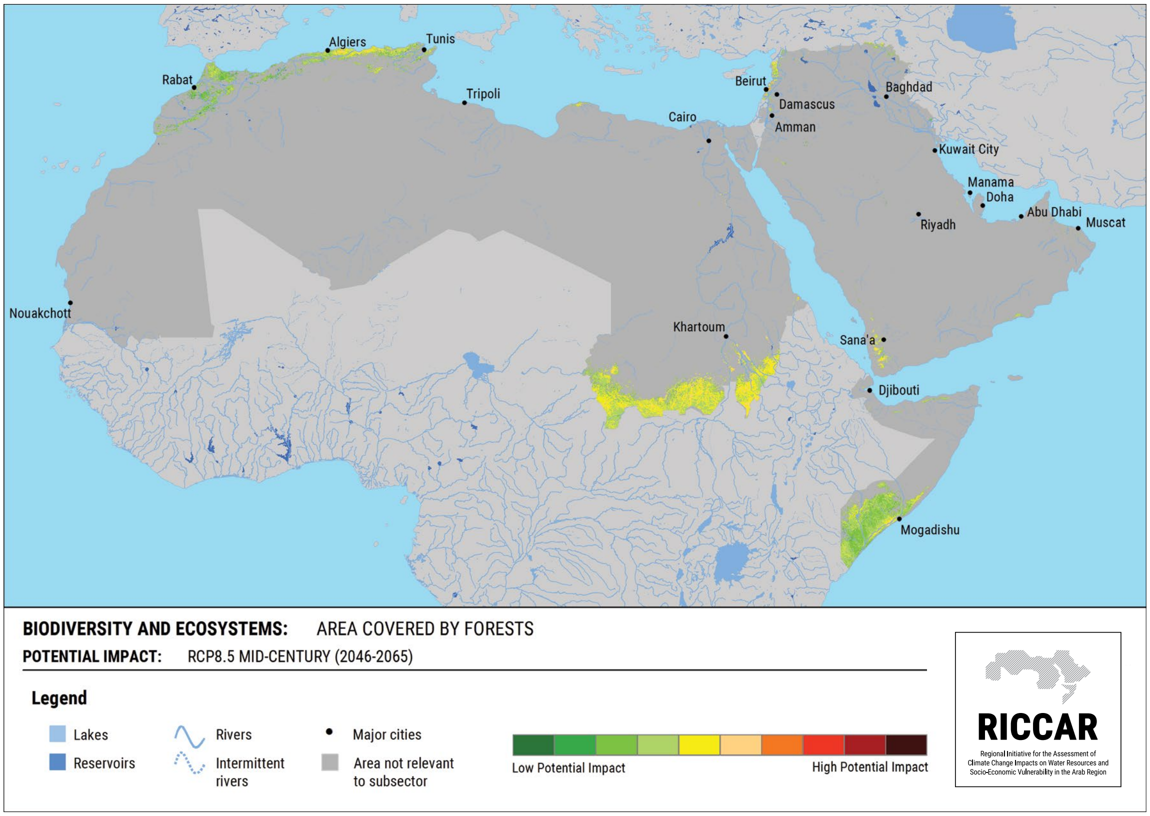


FIGURE 126: Area covered by forests – End-century RCP 4.5 – Potential impact

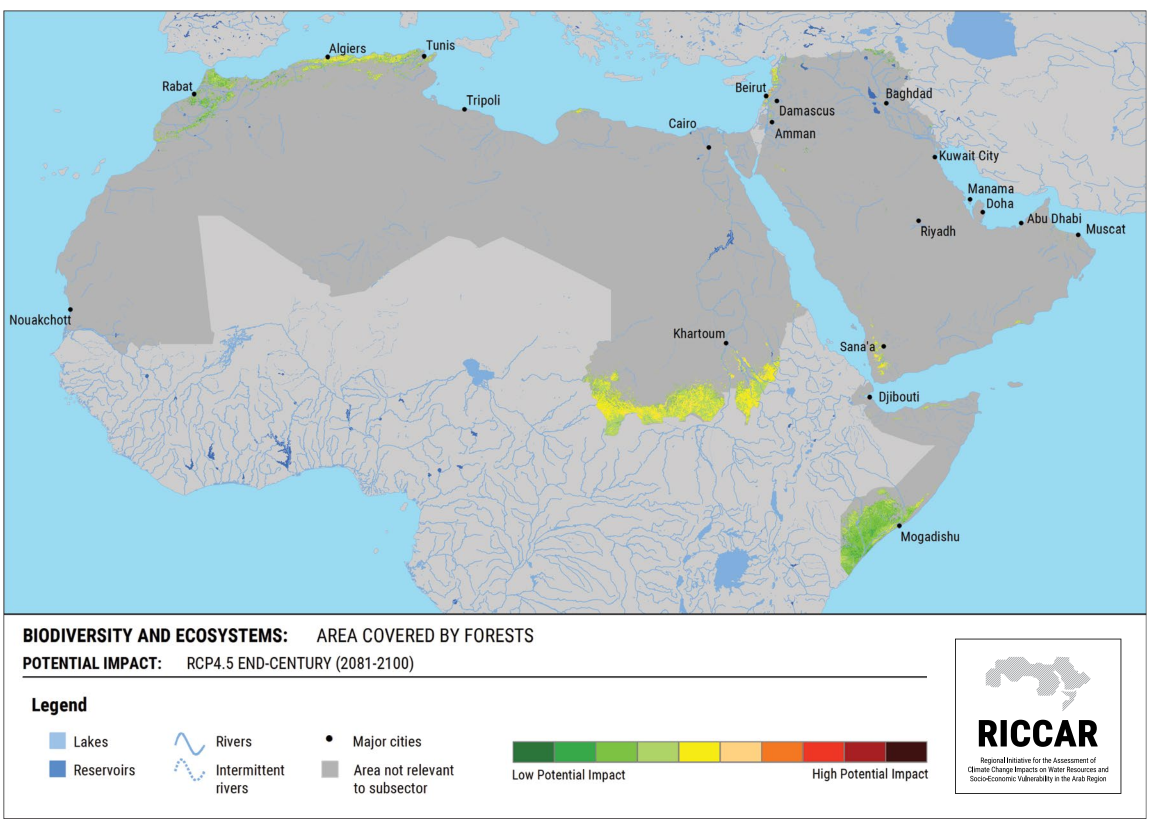
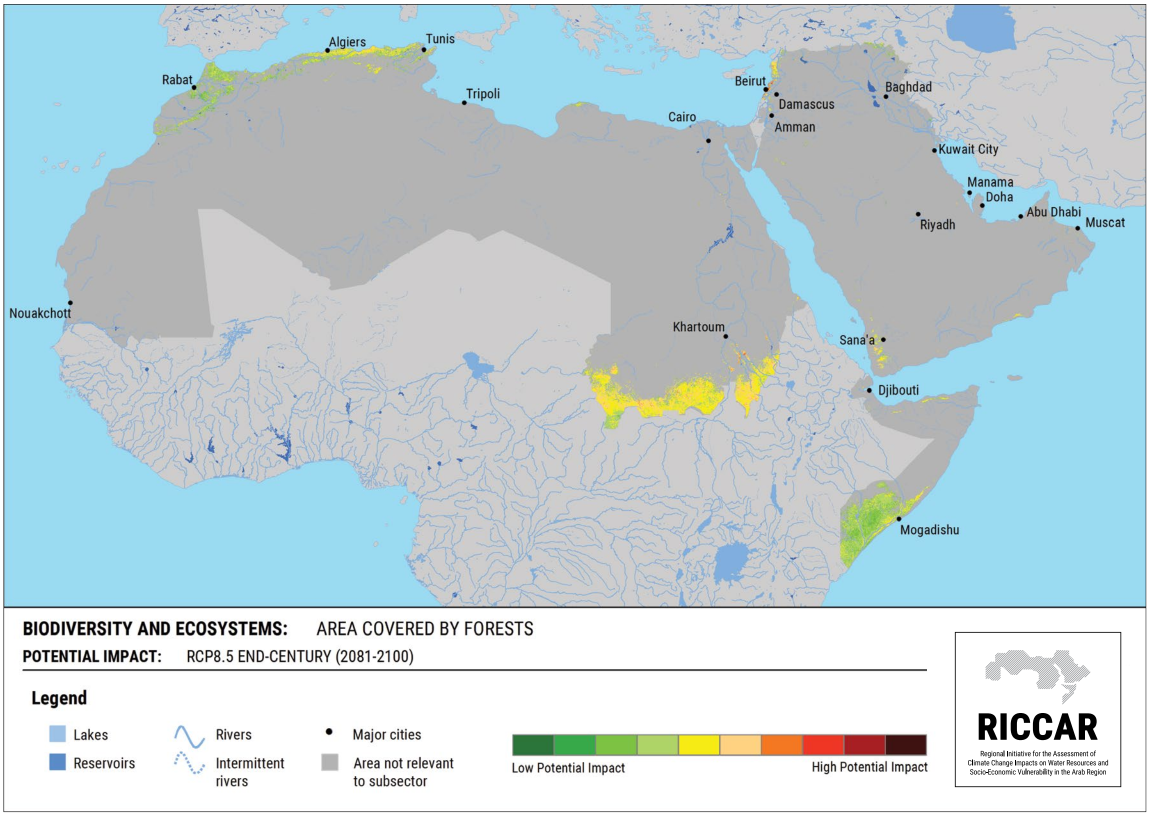


FIGURE 127: Area covered by forests – End-century RCP 8.5 – Potential impact



10.1.2.2 Vulnerability

The varying threats facing forests in the Arab region can be summarized as three primary issues: environmental degradation, declining quality and quantity of forests, and loss of biodiversity.

These threats are exacerbated by climate change impacts. Coping mechanisms to combat deforestation have been set forth by Arab institutions, including reforestation strategies, sustainable forest management and the declaration of forest reserves.

The net difference between threats and adaptive measures is reflected in the projected vulnerability for forests. Based on the indicators described herein, vulnerability is nearly evenly divided between moderate and high for the study area, with no evidence of low vulnerability (Figure 128 to Figure 131).

Areas of high vulnerability range from 41% (RCP 4.5) to 58% (RCP 8.5) at mid-century and 50% (RCP 4.5) to 64% (RCP 8.5) at end-century (Table 22).

Forests with the highest vulnerability include tropical dry forest and tropical shrubland in sub-Saharan Africa and the tropical mountain system forests in the south-western Arabian Peninsula. Areas with relatively lower vulnerability include subtropical dry forest in the Rif region of North-West Africa and forests in and around Ichkeul National Park near the central North African coastline.

Trend analysis from mid- to end-century reveals many forests in the Arab region are generally exhibiting increasing vulnerability for RCP 4.5, particularly in the woodland savannah forests in and around Radom National Park, which has been designated as a biosphere reserve by UNESCO.

Forests in the southern Horn of Africa, however, reveal decreasing vulnerability due to changes in exposure. For RCP 8.5, vulnerability is largely constant from mid- to end-century in all forests.

Al Shouf Cedar Nature Reserve, Lebanon, 2005. Source: Wikimedia Commons/Habbouche.

TABLE 22: Percentage of study area by vulnerability classification for area covered by forests

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	0%	59%	41%
Mid-Century RCP 8.5	0%	42%	58%
End-Century RCP 4.5	0%	50%	50%
End-Century RCP 8.5	0%	36%	64%

FIGURE 128: Area covered by forests – Mid-century RCP 4.5 – Vulnerability

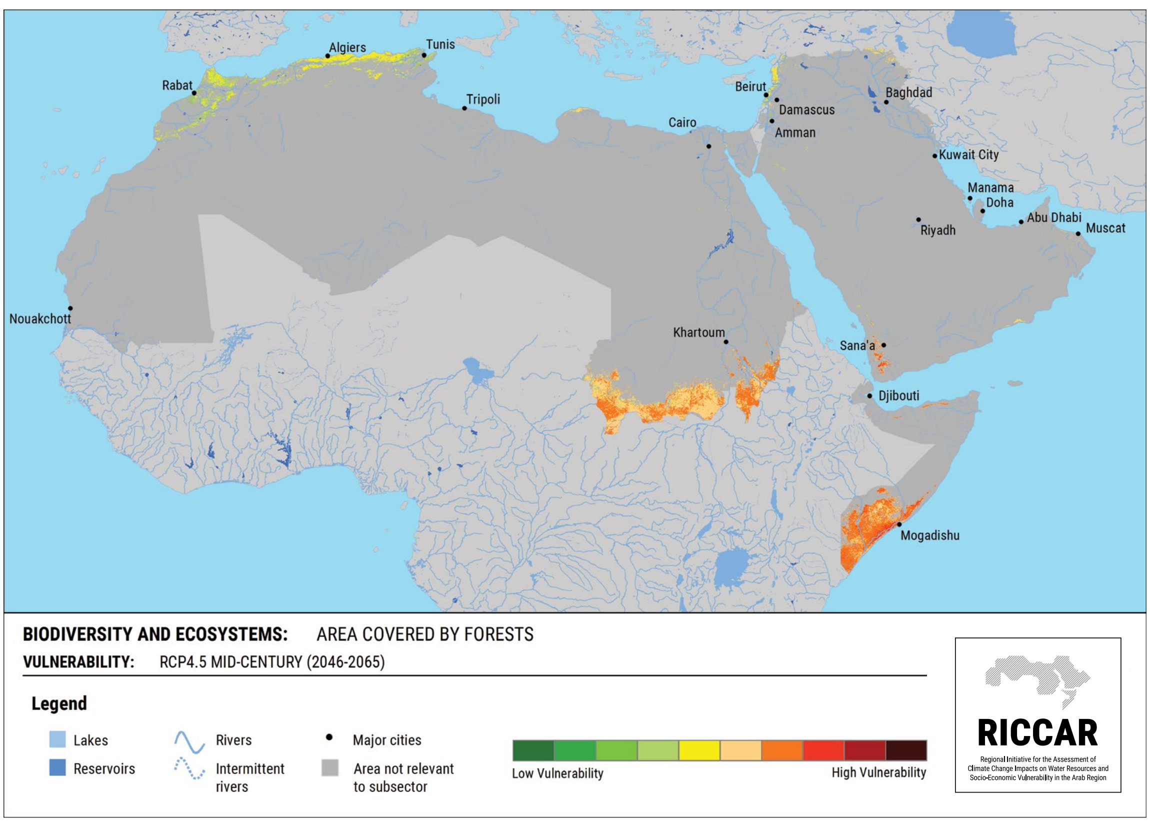


FIGURE 129: Area covered by forests – Mid-century RCP 8.5 – Vulnerability

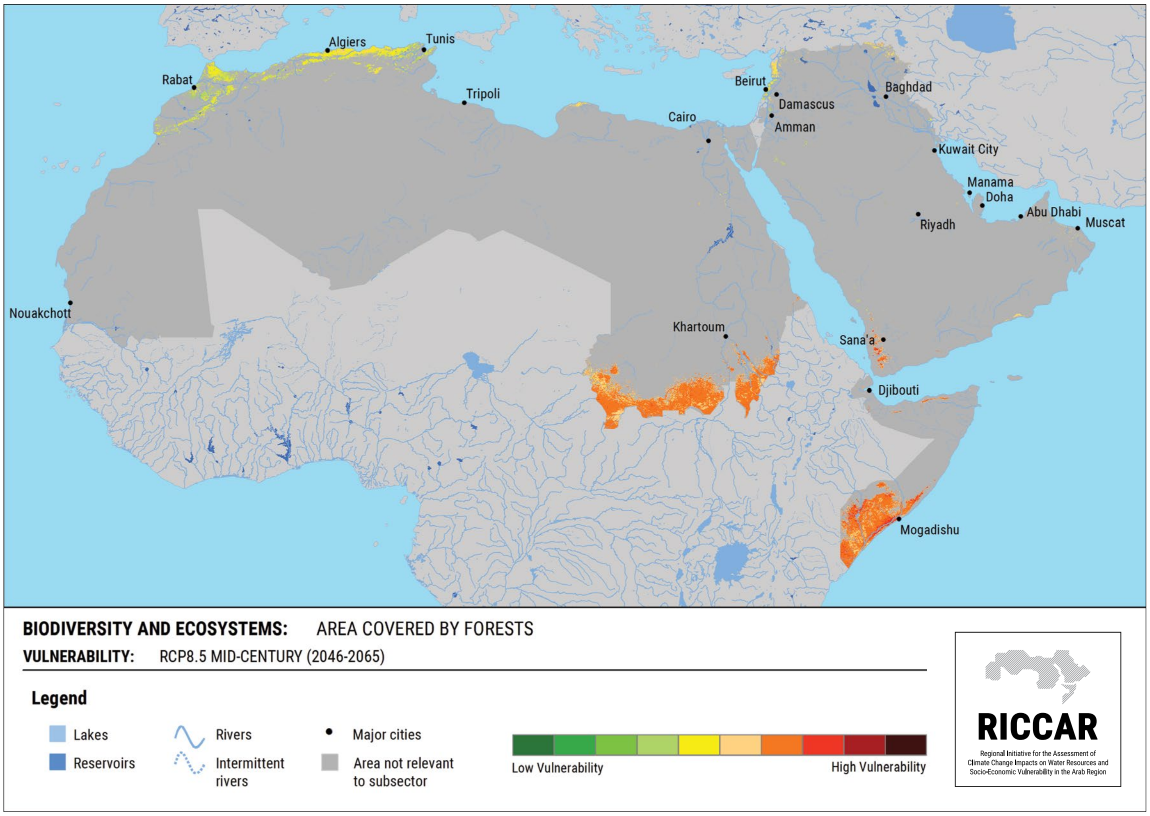


FIGURE 130: Area covered by forests – End-century RCP 4.5 – Vulnerability

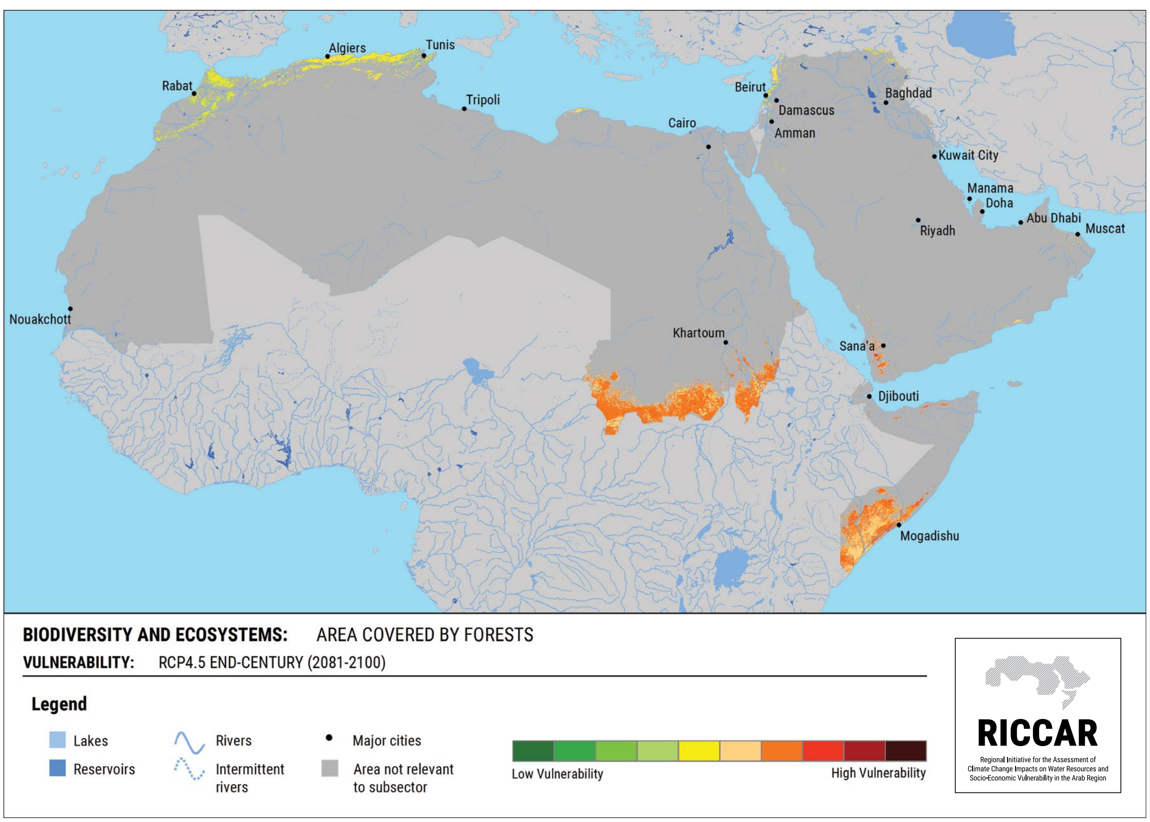
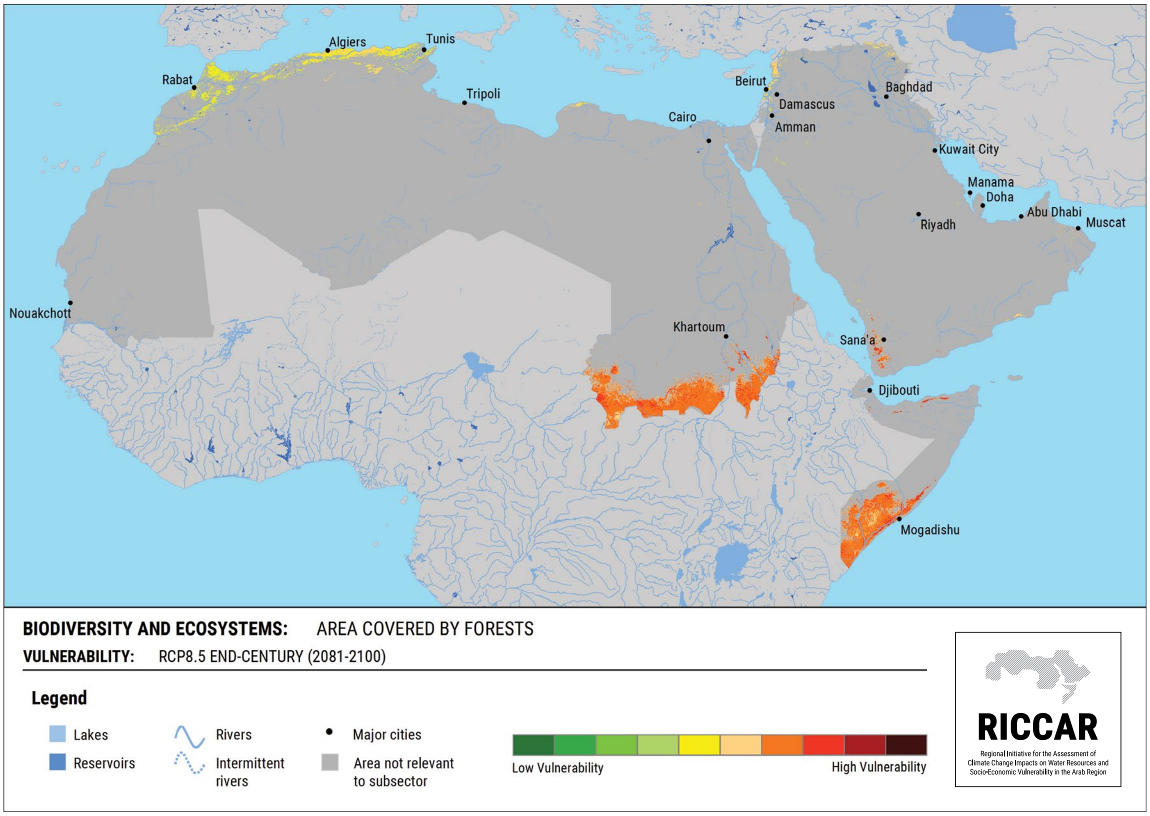


FIGURE 131: Area covered by forests – End-century RCP 8.5 – Vulnerability



10.1.3 Hotspots

Hotspots are areas with the highest projected vulnerability: up to 11% (RCP 8.5 end-century) of the study area signify forest-area hotspots.

Forests of the Horn of Africa, such as evergreen stands in the Golis mountain range, for example, have been subjected to increased exploitation pressure from human settlements directly in the forest, deciduous bushland of *Acacia spp*. in the south and Lag Badana National Park – the first national park in Somalia. After a temporary halt, development there has resumed, aimed at local youth to strengthen environmental preservation and ecotourism.

Other areas are located in the eastern Sahel, which include the El-Rawashda and Wad Kabo natural forest reserves and *Acacia nilotica* riparian forests along the White and Blue Nile rivers such as Khartoum Sunt Forest.

The former sites have long been subjected to overgrazing, lopping of trees for animal feed, and deforestation. Community initiatives to restore the forest have been introduced, which recognize the benefits of natural resources and encourage community participation though volunteerism.

The final forest hotspot region is located in the south-western Arabian Peninsula and includes the Jabal Bura Valley forest, which contains acacia (*A. asak*) and myrrh trees.

The forest has been decimated due to several factors, notably recent roadway construction, which destroyed 20%–30% of the area. Associated impacts include clogging of wells and streams from roadwork waste.

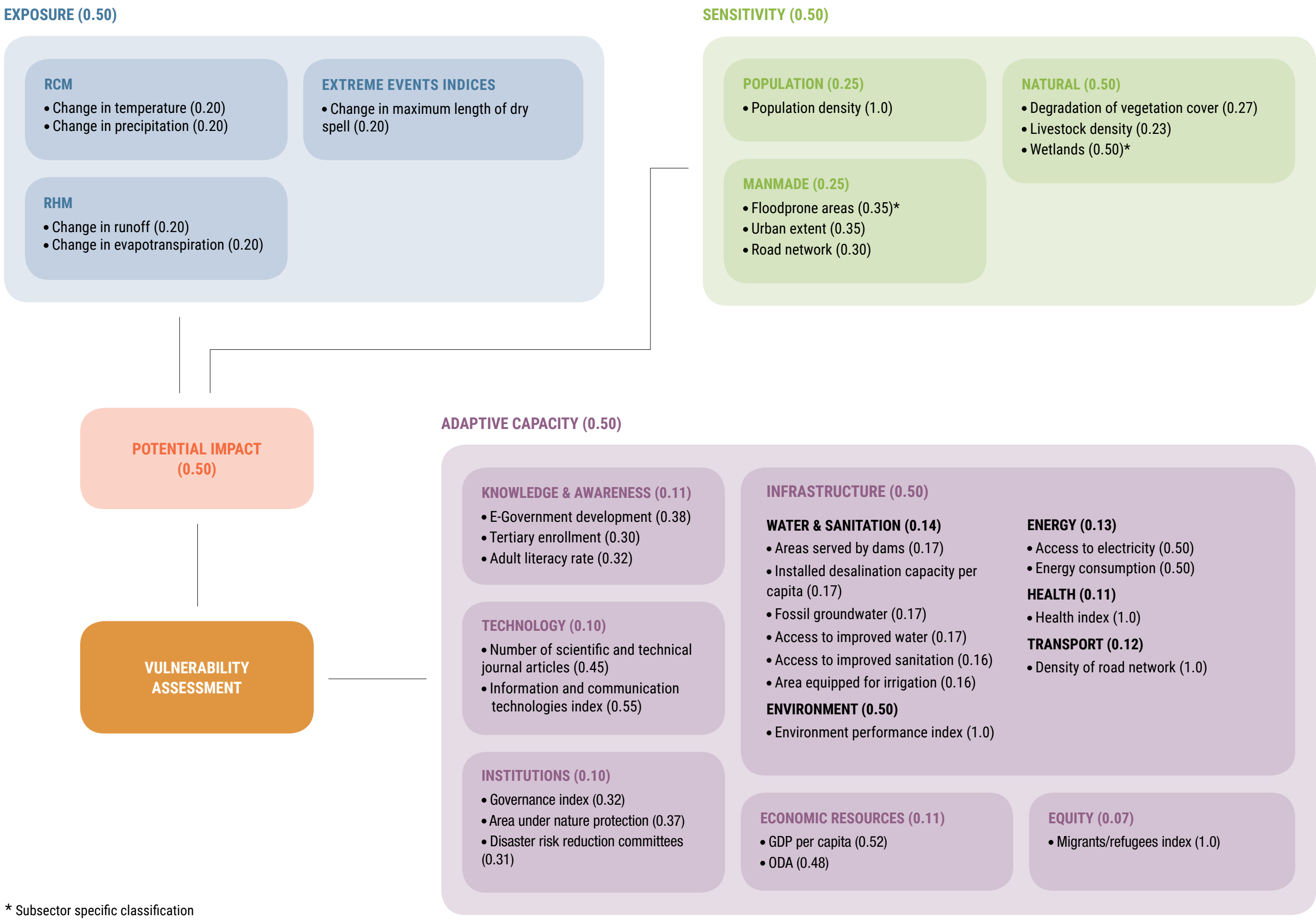
In addition, easier access to the forest permitted increased logging, while the prickly pear, an invasive species, was introduced, threatening native plants.

Nonetheless, the region is recognized for its biodiversity and was added to the UNESCO World Network of Biosphere Reserves in 2011. Community initiatives have been introduced to promote forestry management and ecotourism.

10.2 AREA COVERED BY WETLANDS

The impact chain presented in Figure 132 presents the indicators used under each component and its associated weights for this subsector. Methodology related to asterisked indicators is available in ESCWA et al., 2017.

FIGURE 132: Impact chain and weights for area covered by wetlands



10.2.1 Reference period

10.2.1.1 Potential impact

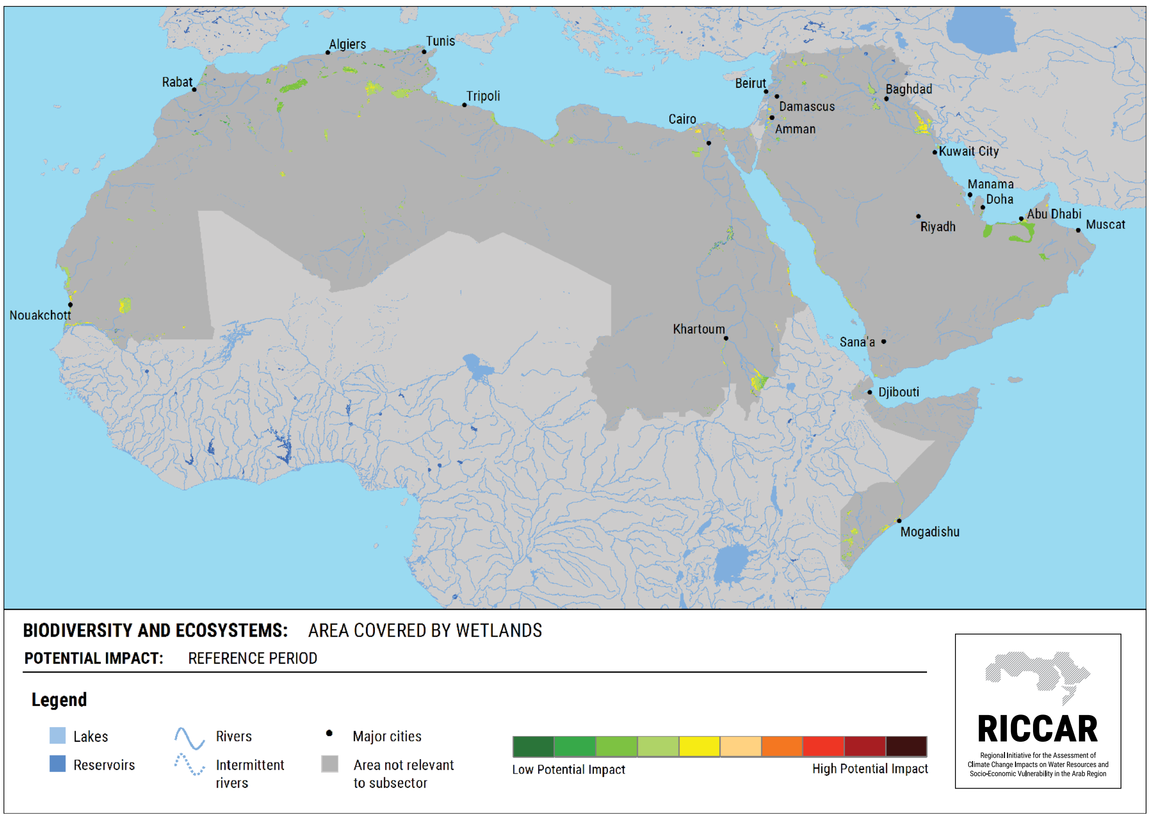
For RICCAR, the wetlands study area includes sabkhas, saltpans and oases in addition to coastal and riverine wetlands. Ramsar sites, the international entity for the protection of wetlands, are also included.

Potential impact reflects the aggregated result of exposure and sensitivity. For exposure, meteorological phenomena such as precipitation, runoff and evaporation can affect flow into wetlands and inundation. Temperature and dry spells can impact wetland ecosystems. For these reasons, temperature, precipitation, runoff, evapotranspiration and the maximum length of dry spell (CDD) were selected as exposure indicators. A majority of the area (71%) is indicative of moderate exposure for the reference period. Less than a quarter (20%) suggests high exposure and includes wetlands near the Senegal River, as well as nearby Lac Gabou and the Parc National du Banc d'Arguin, and wetlands near the Gulf, including Sabkha Matti. Remaining areas suggest low exposure.

Wetlands can be threatened by elements such as urbanization, land-use changes and other factors. Land-use changes are reflected in the following selected sensitivity indicators: population density, degradation of vegetation cover, livestock density, urban extent and road network. The wetlands indicator, which has the heaviest sensitivity weighting, was classified according to freshwater demand. Lastly, the floodprone areas indicator was selected and classified in accordance with water availability as floods benefit wetland areas. A majority of the wetlands study area (80%) suggests low sensitivity. Most of the remaining areas (19%) are of moderate sensitivity and include isolated areas within wetlands throughout the region, including the Iraqi Marshes, riverine wetlands of the Euphrates and estuarine wetlands of the Nile Delta.

Resultant potential impact for the reference period (Figure 133) is indicated as moderate for most of the study area (69%), including riverine wetlands of the Senegal, Jubba, Shabelle, White Nile and Blue Nile rivers. In addition, coastal wetlands near the Gulf of Aden, as well as nearby Lake Abb, indicate moderate-to-high potential impact. Remaining wetlands suggest low potential impact as there are no wetlands exhibiting high potential impact.

FIGURE 133: Area covered by wetlands – Reference period – Potential impact



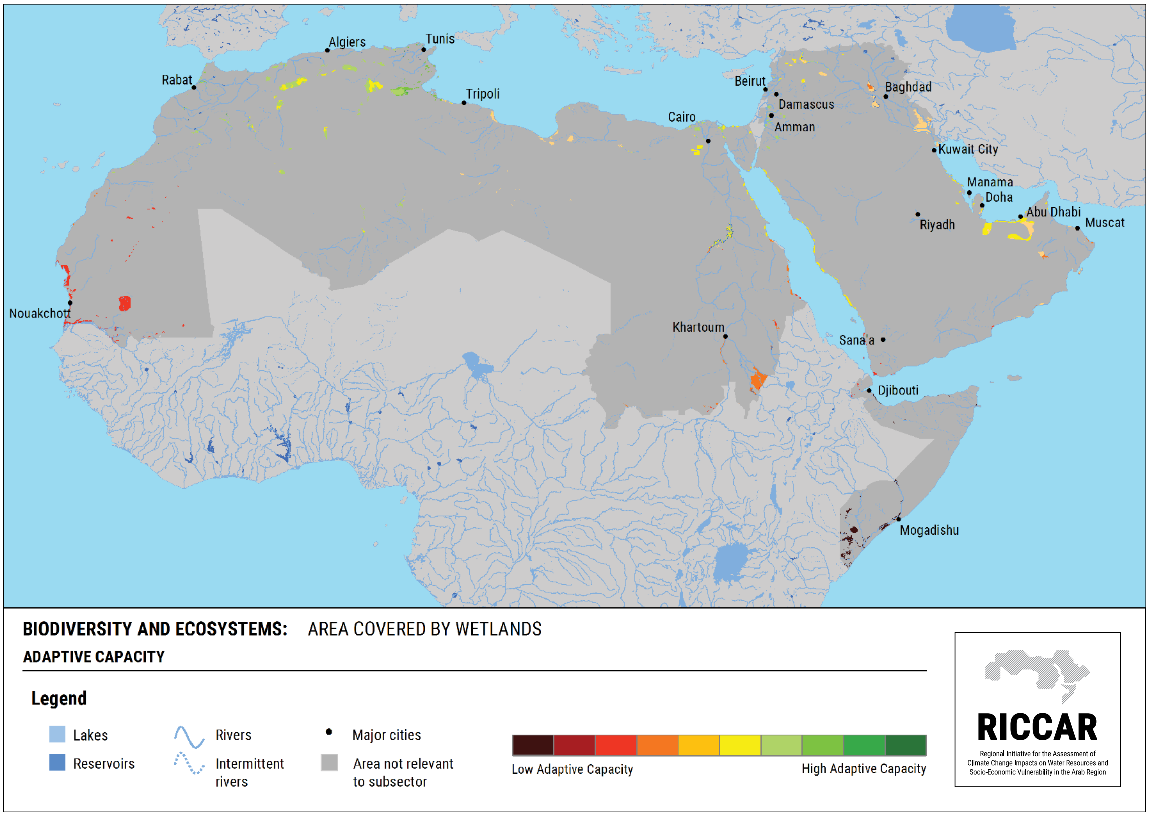
10.2.1.2 Adaptive capacity

According to Ramsar, a framework for the wise use of wetlands must consider several adaptive measures, including human well-being and poverty reduction in addition to ecosystem services. The former considers health, environmental, economic and cultural security, as well as equity. Ecosystem services include the provision of natural resources, wetland regulation, cultural significance and support of the ecosystem as a whole.[4]

The adaptive capacity indicators selected reflect the recommendations of Ramsar. The environmental pillar under infrastructure is weighted most heavily and represents a proxy for ecosystem services. Over half the study area (53%) indicates moderate potential impact with remaining areas divided between low and high potential impact (21% and 26%, respectively). Even though all indicators denote a weak correlation with composite adaptive capacity, the environmental pillar is the strongest.

The aggregated result indicates low adaptive capacity for wetlands in sub-Saharan Africa. Higher adaptive capacity is evident, progressing northwards towards the Mediterranean Sea (Figure 134).

FIGURE 134: Area covered by wetlands – Adaptive capacity



10.2.1.3 Vulnerability

Resultant vulnerability for the reference period (Figure 135) reveals moderate vulnerability for most of the study area (90%) with high vulnerability in isolated areas (7%). Remaining areas suggest low vulnerability.

Wetlands with the highest vulnerability are located in the Horn of Africa with some tidal wetlands along the Gulf of Aden, swamps and floodplains near the Shabelle and Jubba rivers (*desheks*), mangroves and lagoons. High vulnerability in the region is primarily attributed to low adaptive capacity.

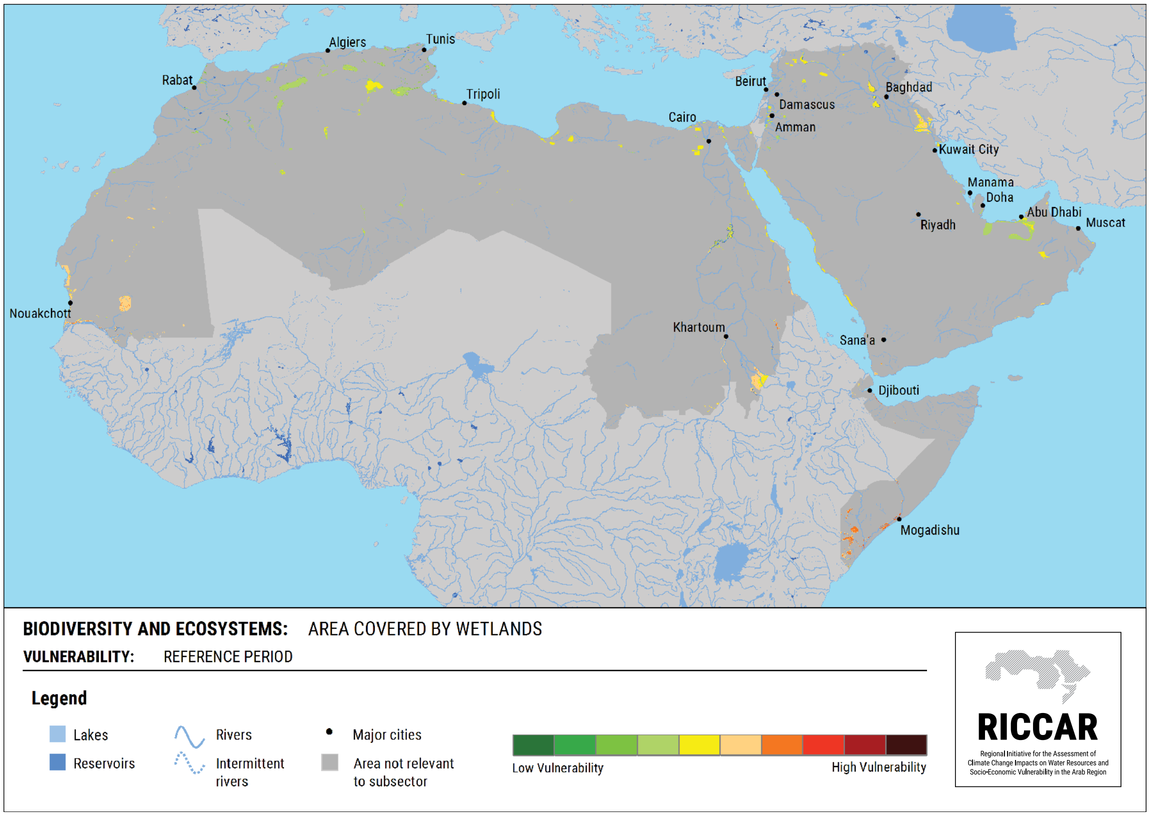
An area of moderate-to-high vulnerability includes wetlands located within the Tindouf basin. One area is the Banc d'Arguin, which was established as a national park in 1976. It is recognized as the most significant waterbird site in western Africa. Wetlands located farther inland are also waterbird migration sites, serving avifauna like the black stork. Conservation of these wetlands has been minimalized due to other priorities, such as agricultural development.

The Iraqi Marshes (Al-Ahwar) suggest moderate potential impact and were once the largest wetlands in the Middle East, serving as a habitat for migrating birds. This region has suffered from water resource development, including the Southeastern Anatolian Project, the Tabqa Dam, and the Karkheh River Dam adversely affecting food and livelihood for inhabitants. Users located downstream of these projects have exacerbated problems by depending on the remaining flows for water resources.

A final area of moderate-to-high potential impact includes the wetlands of Dinder National Park in Sudan. Known locally as *mayas*, these floodplain wetlands serve as the primary food and water source for wildlife, particularly during the dry season extending from November to June.

Like other wetlands in the Arab region, these *mayas* are also habitats for migrating birds. Human migration, however, has resulted in development and agricultural expansion. New livestock has competed with indigenous wildlife for resources and have introduced diseases. A grant was provided in the early 2000s aiming to increase wildlife capacity and improve park management, but funding has since ceased.

FIGURE 135: Area covered by wetlands – Reference period – Vulnerability



10.2.2 Future periods

10.2.2.1 Potential impact

Climate change impacts on wetlands include changes in hydrology and temperature. Hydrological parameters include precipitation, runoff and evaporation, which induce flood threat, reduction in flows and increased soil erosion. Temperature can alter evaporation rates and affect other aspects of wetland ecosystems such as increased heat stress to wildlife and water-quality degradation.

At mid-century, most wetlands project moderate exposure, ranging from 86% (RCP 4.5) to 88% (RCP 8.5). At end-century, 63% (RCP 8.5) to 82% (RCP 4.5) of wetlands reveal moderate exposure with areas of high exposure indicated in 28% of the study area under RCP 8.5 only. Wetlands with the highest exposure include Lake Nasser, coastal wetlands on the western shore of the Red Sea and Ammiq Wetland and Buhayrat al-Laha in the Levant. Other locations in the study area indicate low exposure.

The resultant potential impact, assuming static sensitivity, suggests mostly moderate potential impact at mid-century, ranging from 53% (RCP 4.5) to 70% (RCP 8.5) of the study area (Figure 136 and Figure 137). At end-century, moderate potential impact is forecast in 65% (RCP 4.5) to 70% (RCP 8.5) of the region's wetlands (Figure 138 and Figure 139). Most remaining areas predict low exposure other than a trace (1% of the study area) at end-century under RCP 8.5. Areas of moderate-to-high potential impact include wetlands of the Levant, Nile Delta region and wetlands in the northern Maghreb.

Note that potential impact does not take sea-level rise – one of the primary threats against coastal wetlands – into consideration, due to data limitations. Although wetlands can adapt to minimal changes through landward migration (provided there are no other limiting factors), larger changes in sea level can result in ecosystem collapse.

Some research has projected that a 1-m increase in sea level would result in the loss of over 96% of coastal wetlands in the Arab region.[5] UN Environment rapid economic assessments of wetlands have also predicted impacts over the coming 50 years.

FIGURE 136: Area covered by wetlands – Mid-century RCP 4.5 – Potential impact

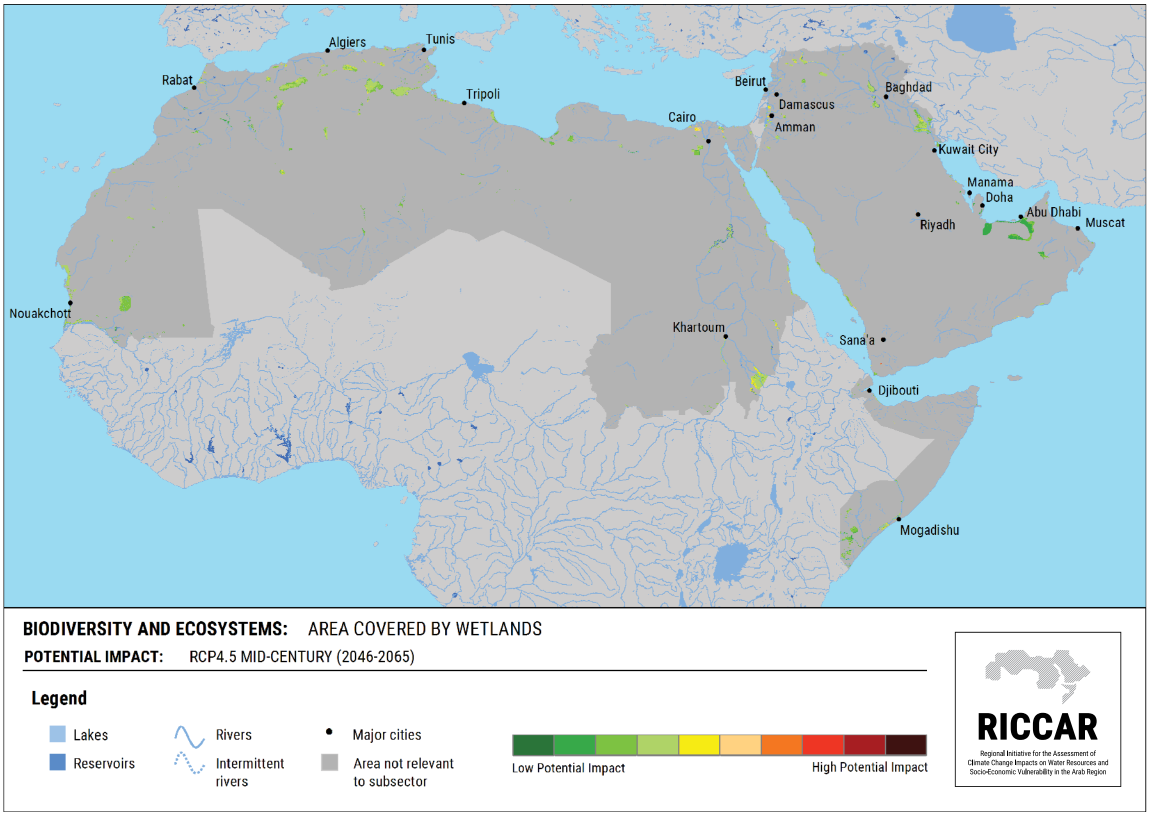


FIGURE 137: Area covered by wetlands – Mid-century RCP 8.5 – Potential impact

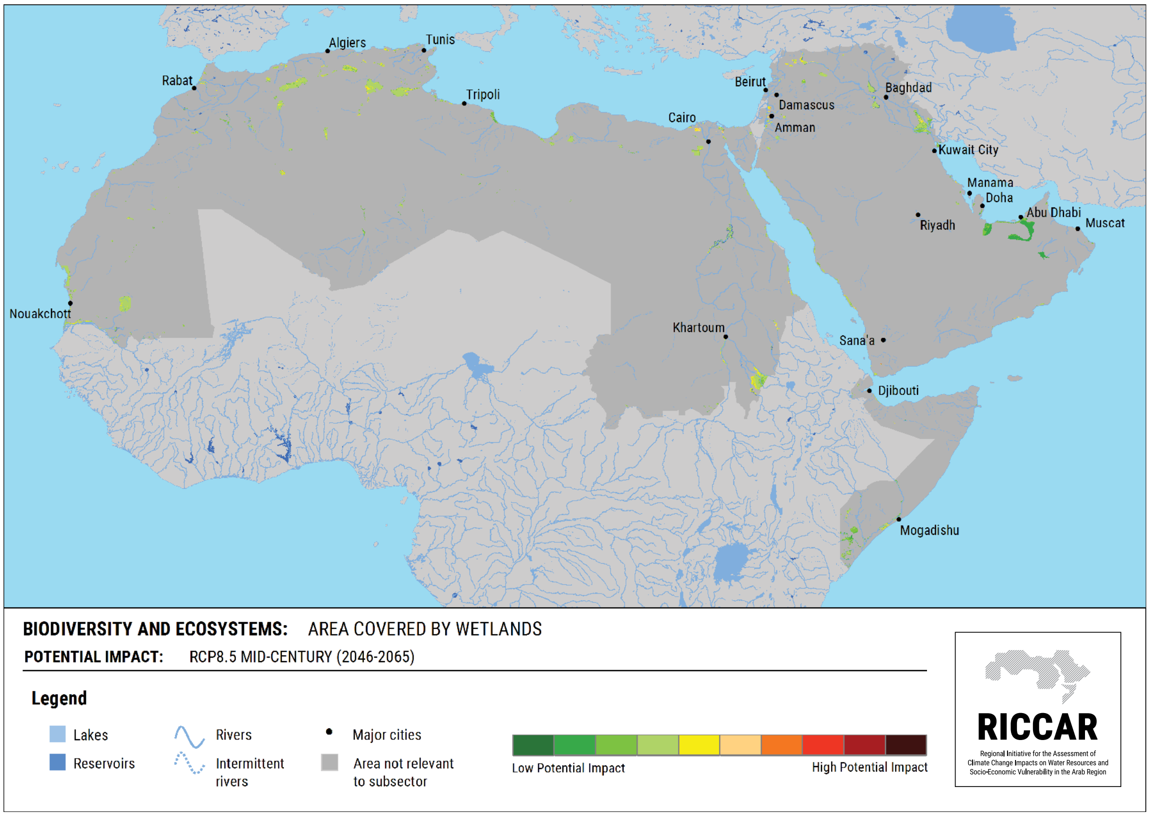


FIGURE 138: Area covered by wetlands – End-century RCP 4.5 – Potential impact

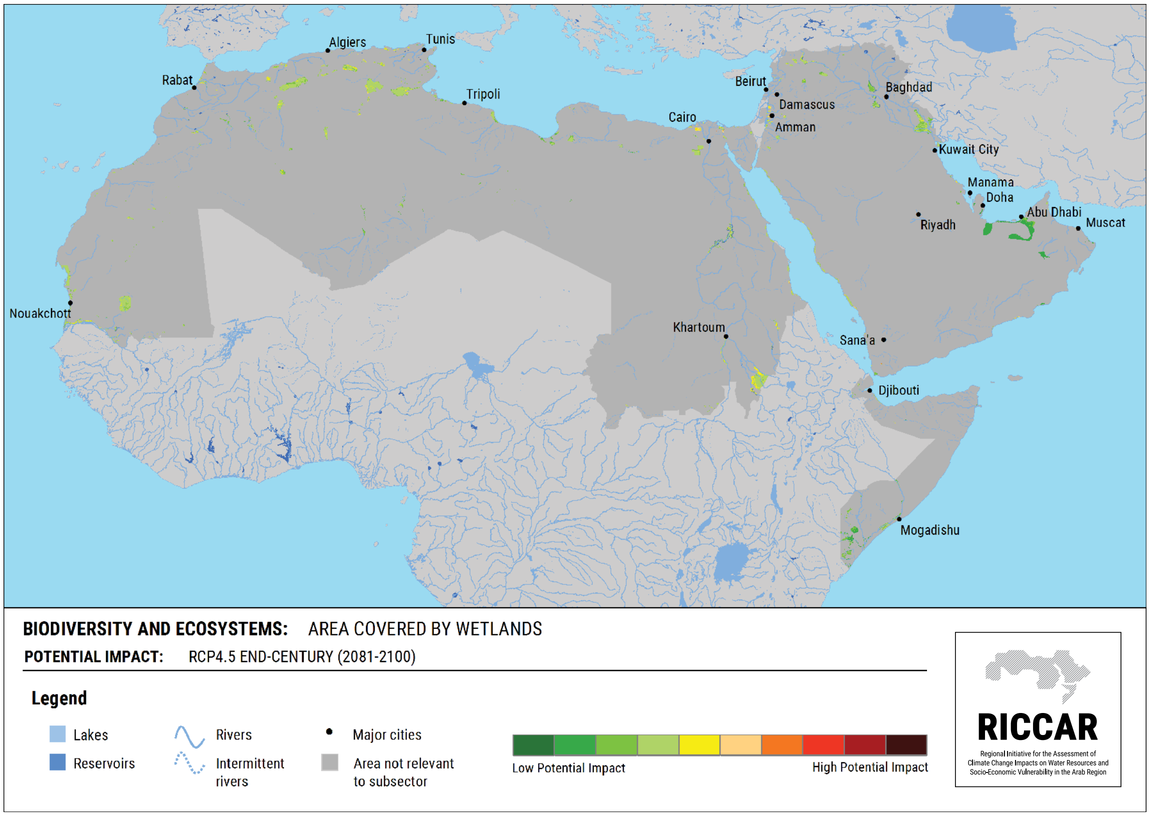
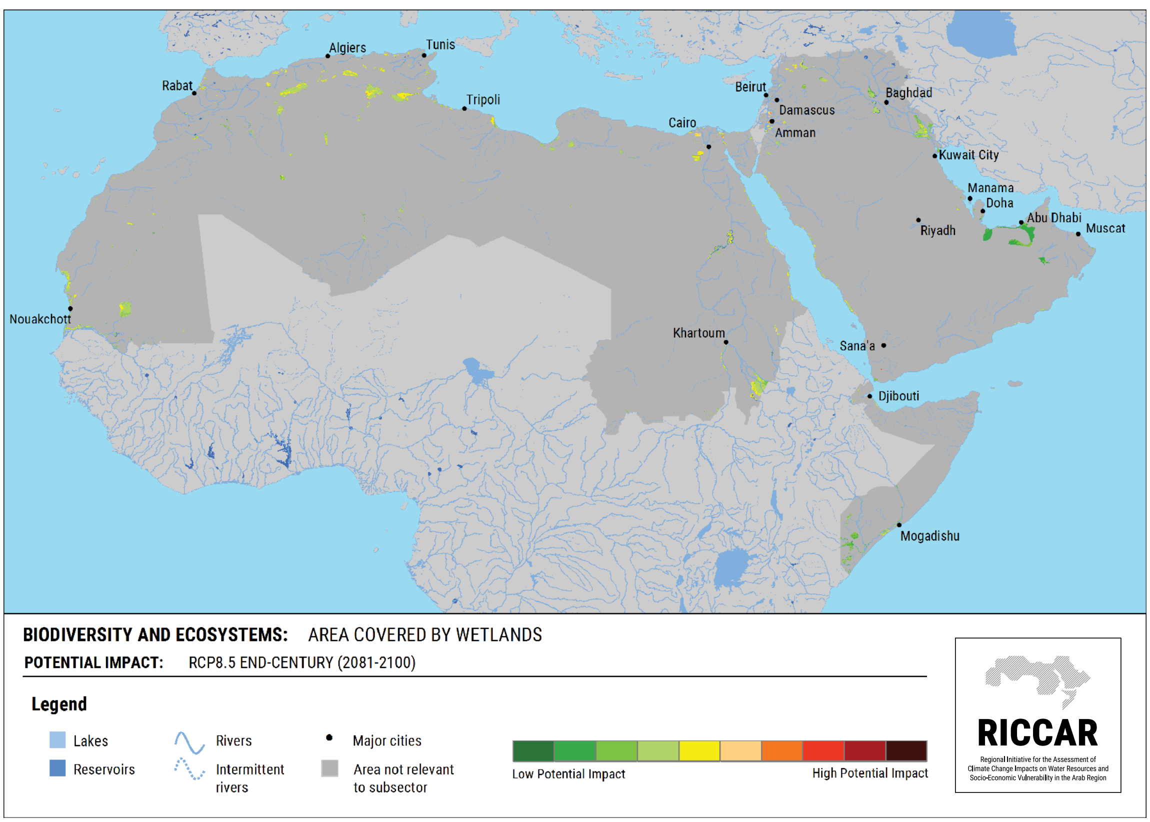


FIGURE 139: Area covered by wetlands – End-century RCP 8.5 – Potential impact



10.2.2.2 Vulnerability

Nearly all wetlands in the region (over 93%) project moderate vulnerability for both mid- and end century. Remaining areas are split between low and high vulnerability (Table 23). Vulnerability exhibits a strong correlation with both sensitivity and adaptive capacity and thus any changes in either component will considerably affect vulnerability. Areas with the lowest vulnerability relative to the Arab region include several wetlands in the eastern Atlas region, such as the Shott el Djerid/Shott el Fedjadj Complex, Sebkhet Sidi el Hani and Sebkhet el Melah, wetlands in the southern Maghreb, including Oasis de Tamantit et Sid Ahmed Timmi, and some wetlands near the Gulf such as Sabkha Matti (Figure 140 to Figure 143).

There are several mechanisms to reduce wetland vulnerability: protection, mitigation, rehabilitation and management. One of the avenues to achieving these goals is through the Ramsar Convention. To date, most countries within the Arab Region have become contracting parties and 108 designated Wetlands of International Importance cover over 75,000 km^2. By participating in the Ramsar Convention, shareholders agree to work towards the wise use of wetlands via policy, education and management and international cooperation on transboundary wetlands.

TABLE 23: Percentage of study area by vulnerability classification for area covered by wetlands

Scenario	Vulnerability (% of study area)		
	Low	**Moderate**	**High**
Mid-Century RCP 4.5	5%	94%	1%
Mid-Century RCP 8.5	1%	97%	2%
End-Century RCP 4.5	6%	93%	1%
End-Century RCP 8.5	1%	97%	2%

FIGURE 140: Area covered by wetlands – Mid-century RCP 4.5 – Vulnerability

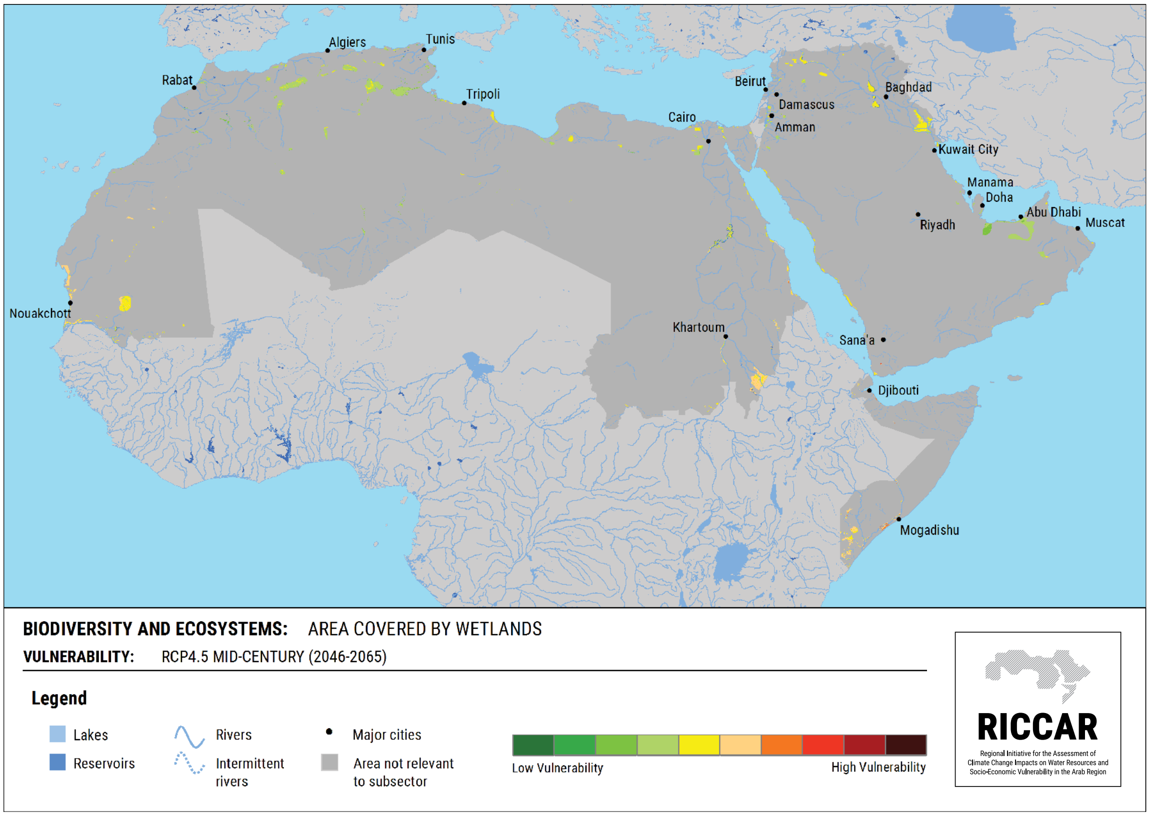


FIGURE 141: Area covered by wetlands – Mid-century RCP 8.5 – Vulnerability

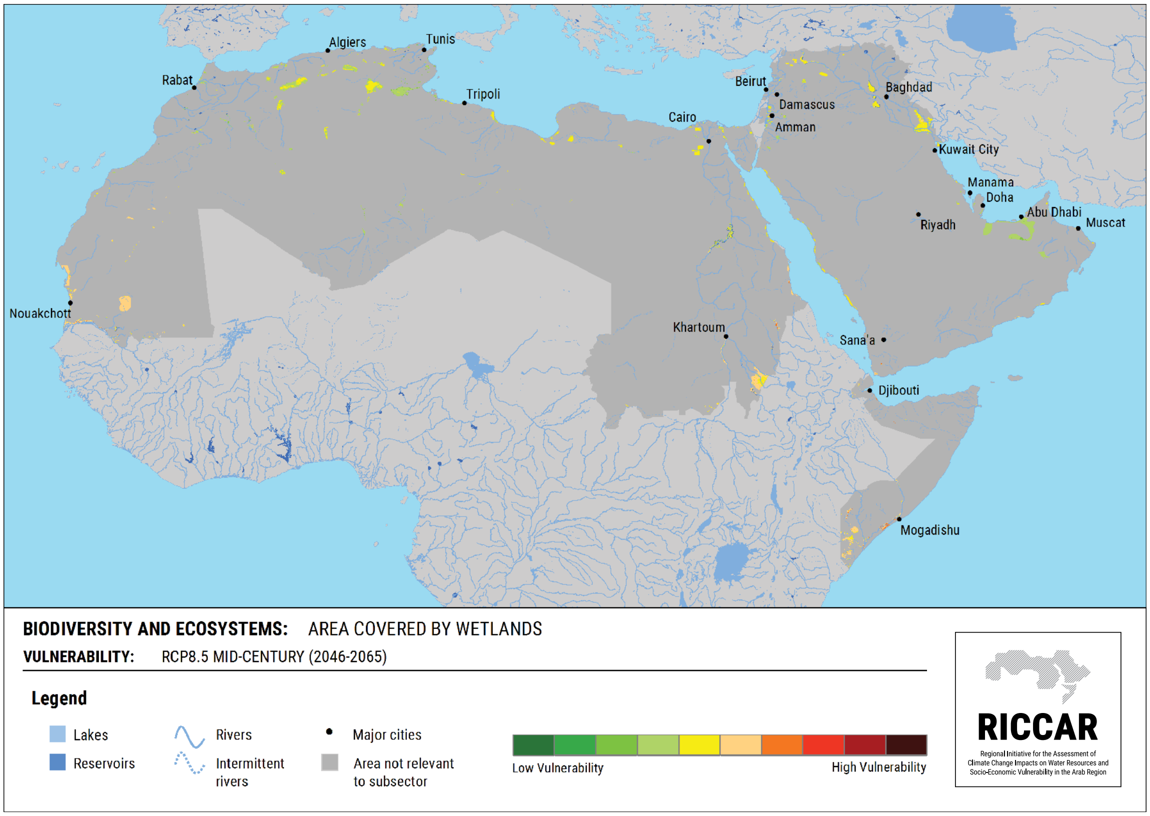


FIGURE 142: Area covered by wetlands – End-century RCP 4.5 – Vulnerability

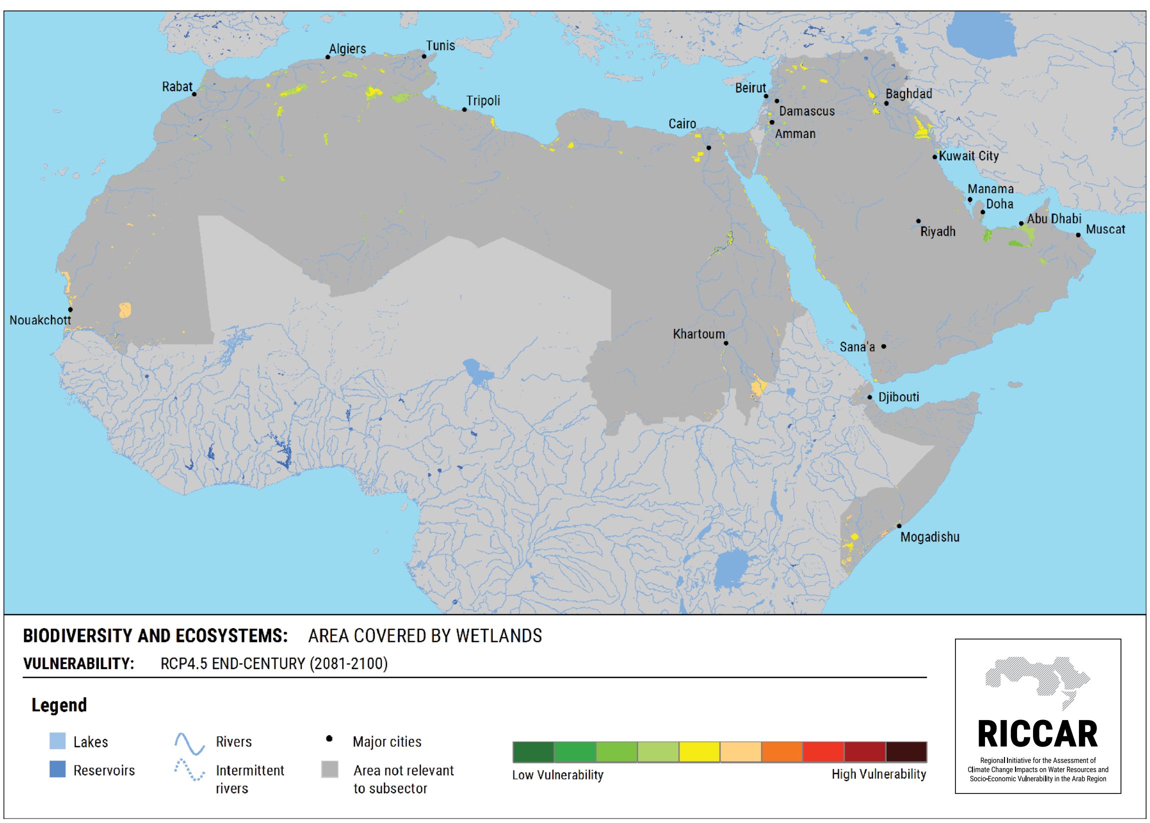
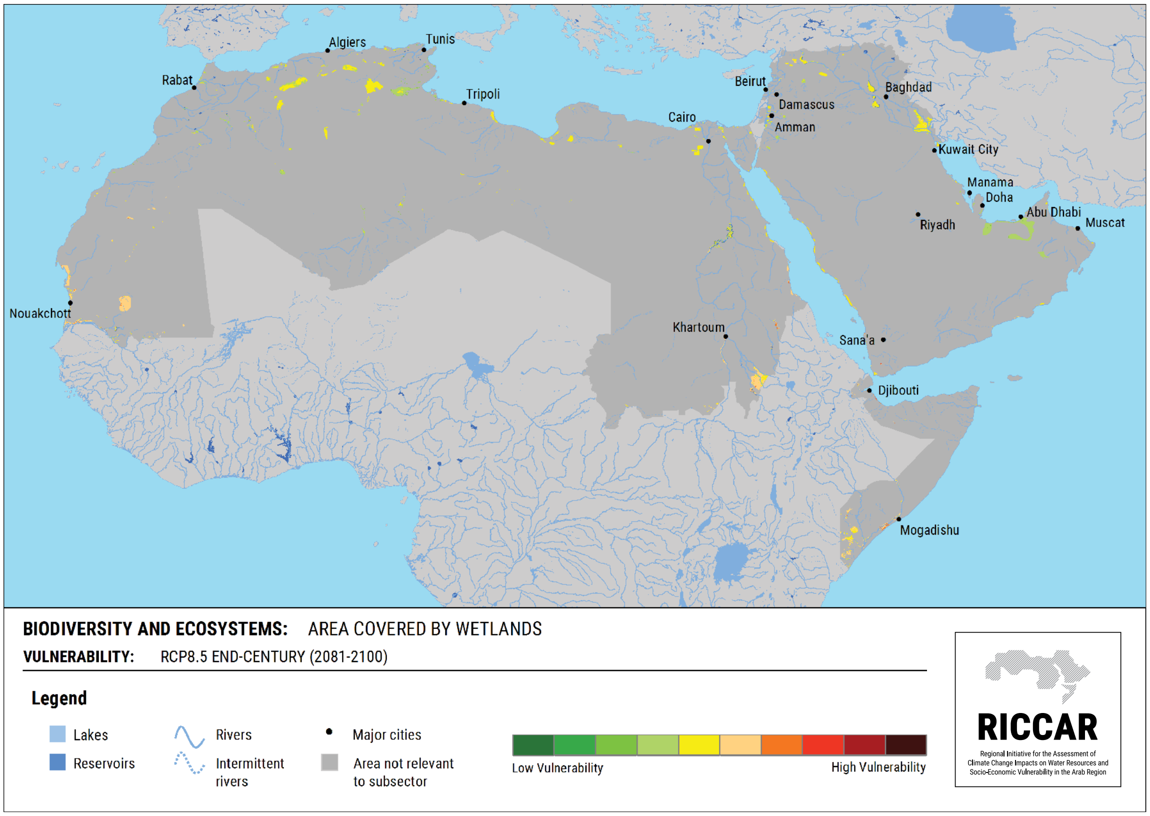


FIGURE 143: Area covered by wetlands – End-century RCP 8.5 – Vulnerability



10.2.3 Hotspots

Hotspot areas reflect those wetlands with the highest projected vulnerability. Only about 1% of wetlands in the Arab region are hotspots. Nevertheless, they include several wetlands in sub-Saharan Africa and some wetlands near the southern Red Sea and Gulf of Aden. Wetland hotspots in the Tindouf basin include Aftout es Saheli along the Atlantic Ocean shoreline, freshwater marshes in the Senegal River Valley, Lac Gabou and the hydrographic network of the Tagant Plateau.

The latter was designated a Ramsar site in 2009 and has a network of rivers which flow from the mountains to form Lac Gabou, temporary lagoons and ponds, freshwater springs and oases. Like other wetlands in the area, it supports significant flora and fauna and is a migratory bird site. Nevertheless, these wetlands have been subjected to poor agricultural management, water resources development and other threats.

Wetland hotspots located in the eastern Sahel include freshwater marshland along the White Nile River, Er Rosieres Reservoir on the Blue Nile River, Khawr Abu Muhhar (a tributary of the Blue Nile), intermittent lakes fed by the Qash River, and coastal wetlands of the Red Sea. Wetlands such as the Blue Nile *mayas* have suffered from severe degradation stemming from water resources development and siltation, felling of riverine forests, overgrazing and other factors. The Red Sea mangroves are badly degraded and shrinking in extent: they may also be subject to loss from sea-level rise, but this was not evaluated as part of RICCAR.

In the Horn of Africa, wetland hotspots include tidal wetlands adjacent to the Gulf of Aden, freshwater marshes of the Shabelle River and freshwater marshes of the Jubba River. Mangrove stands located in tidal wetlands have been plundered for firewood and timber such that little vegetation remains and the wetlands are now salt marshes.

The riverine wetlands are important for local wildlife but have deteriorated due to cultivation, water demand and migration. Lastly, wetlands located in the south-western Arabian Peninsula such as the Ta'izz wetlands and the Gulf of Aden mudflats have been designated hotspots. These wetlands are also bird habitats, supporting avifauna like the bald ibis. Similar to other wetland hotspots, these areas have been subject to increased development and other threats.

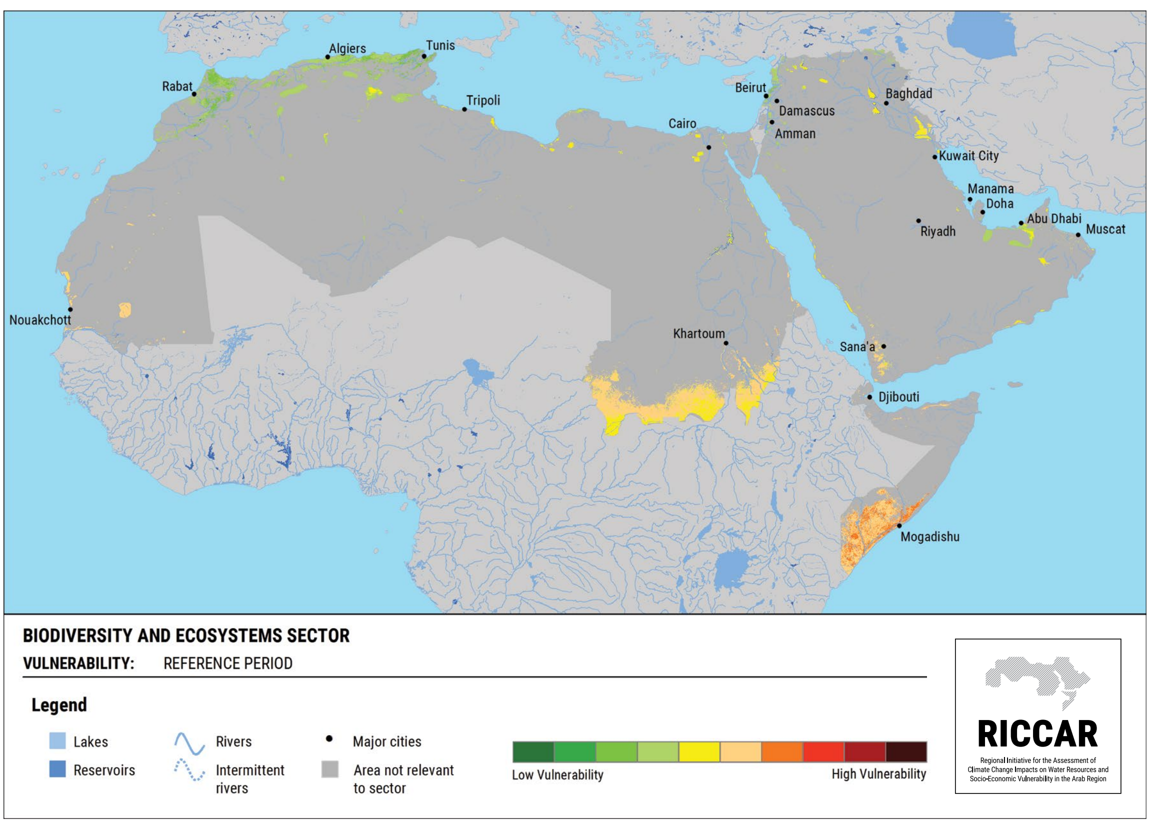
10.3 BIODIVERSITY AND ECOSYSTEMS SECTOR: OVERALL VULNERABILITY

10.3.1 Reference period

Vulnerability for the *Biodiversity and ecosystems* sector is the aggregation of vulnerability of both the forests and wetlands subsectors. A majority of the study area (86%) indicates moderate vulnerability, whereas 7% suggests high vulnerability. Areas of high vulnerability are confined to the southern Horn of Africa and include tropical shrubland, as well as tropical desert. Conversely, areas of low vulnerability are located in the northern Maghreb, in a subtropical dry forest ecosystem and subtropical mountain system, as well as the Levantine subtropical dry forest ecosystem. Wetland systems are contained within these areas (Figure 144). Although both subsectors contribute equally towards sector vulnerability, the subsector *Area covered by forests* has a stronger correlation.

Jebel Tammun Nature Reserve, State of Palestine, 2017. Source: Alaa Kanan.

FIGURE 144: Biodiversity and ecosystems sector – Vulnerability – Reference period



10.3.2 Future periods

10.3.2.1 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 (Table 24). Nevertheless, like the trends described 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 suggest 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 (Figure 145 to Figure 148).

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.

TABLE 24: Percentage of study area by vulnerability classification for biodiversity and ecosystems sector

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	1%	98%	1%
Mid-Century RCP 8.5	0%	99%	1%
End-Century RCP 4.5	1%	99%	0%
End-Century RCP 8.5	0%	98%	2%

FIGURE 145: Biodiversity and ecosystems sector – Vulnerability – Mid-century RCP 4.5

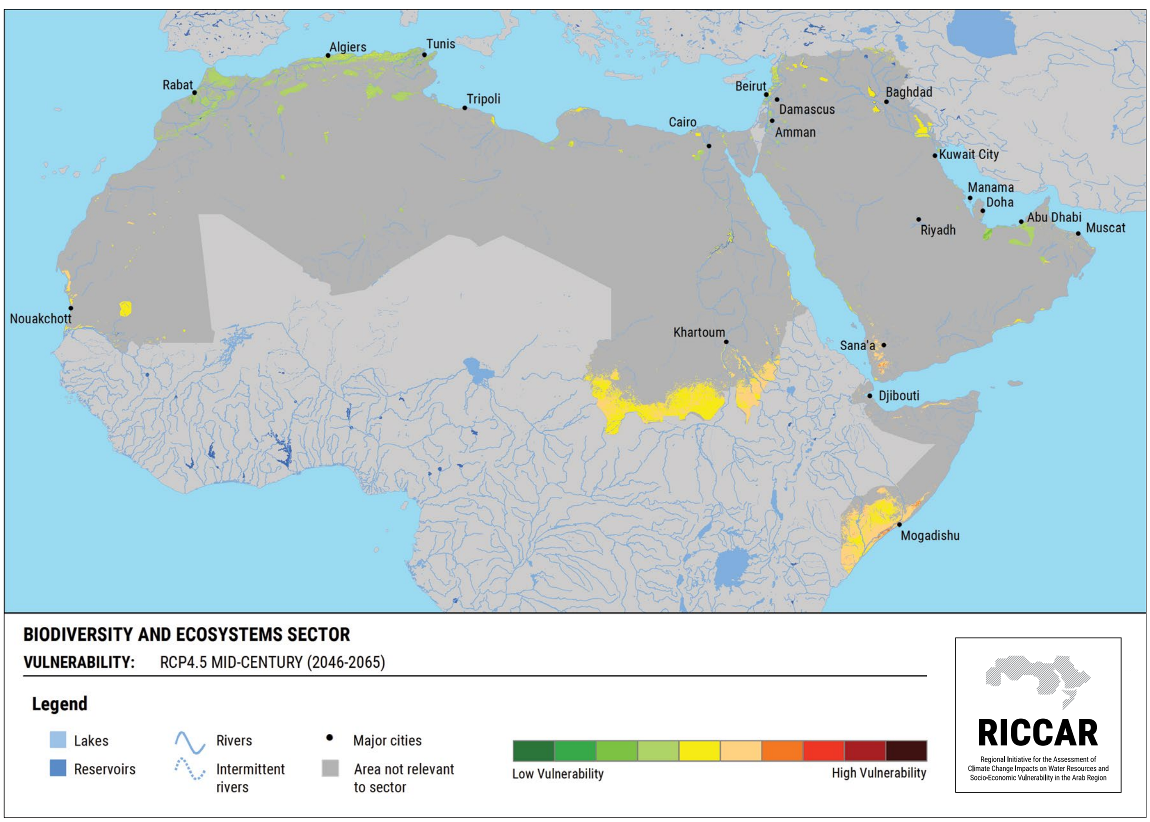


FIGURE 146: Biodiversity and ecosystems sector – Vulnerability – Mid-century RCP 8.5

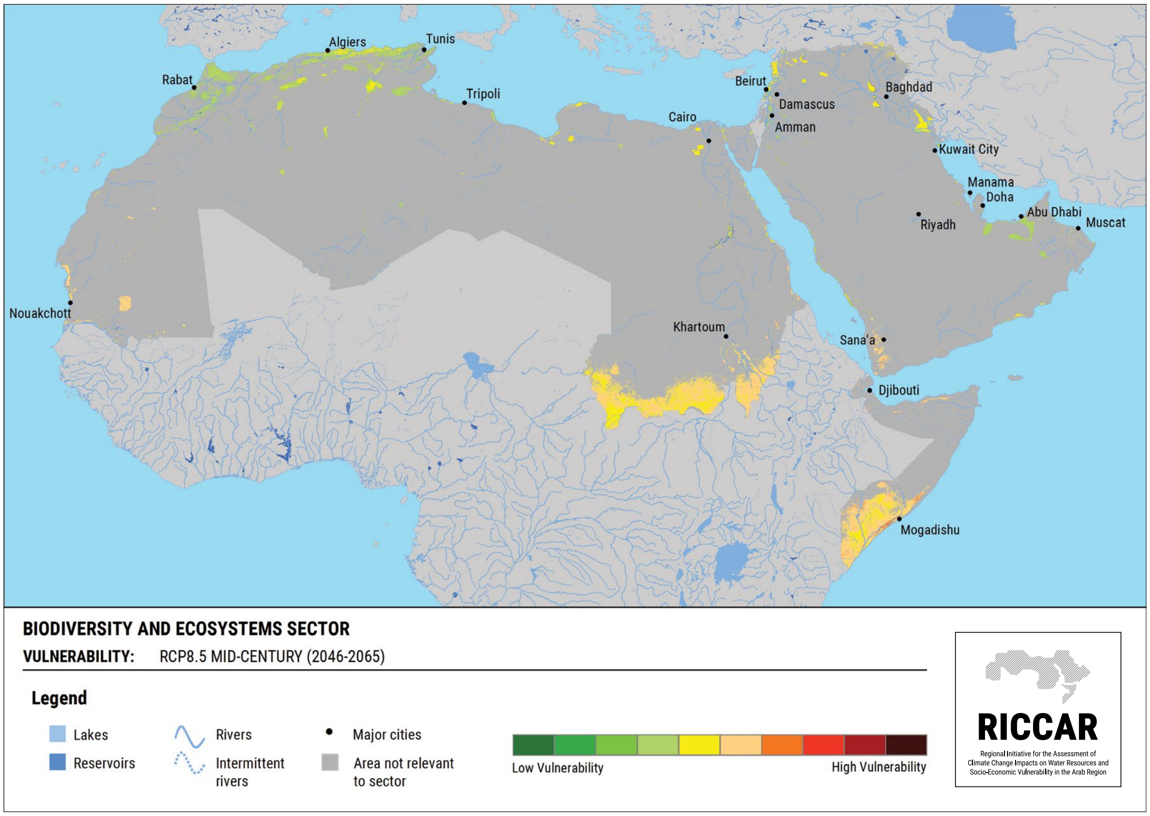


FIGURE 147: Biodiversity and ecosystems sector – Vulnerability – End-century RCP 4.5

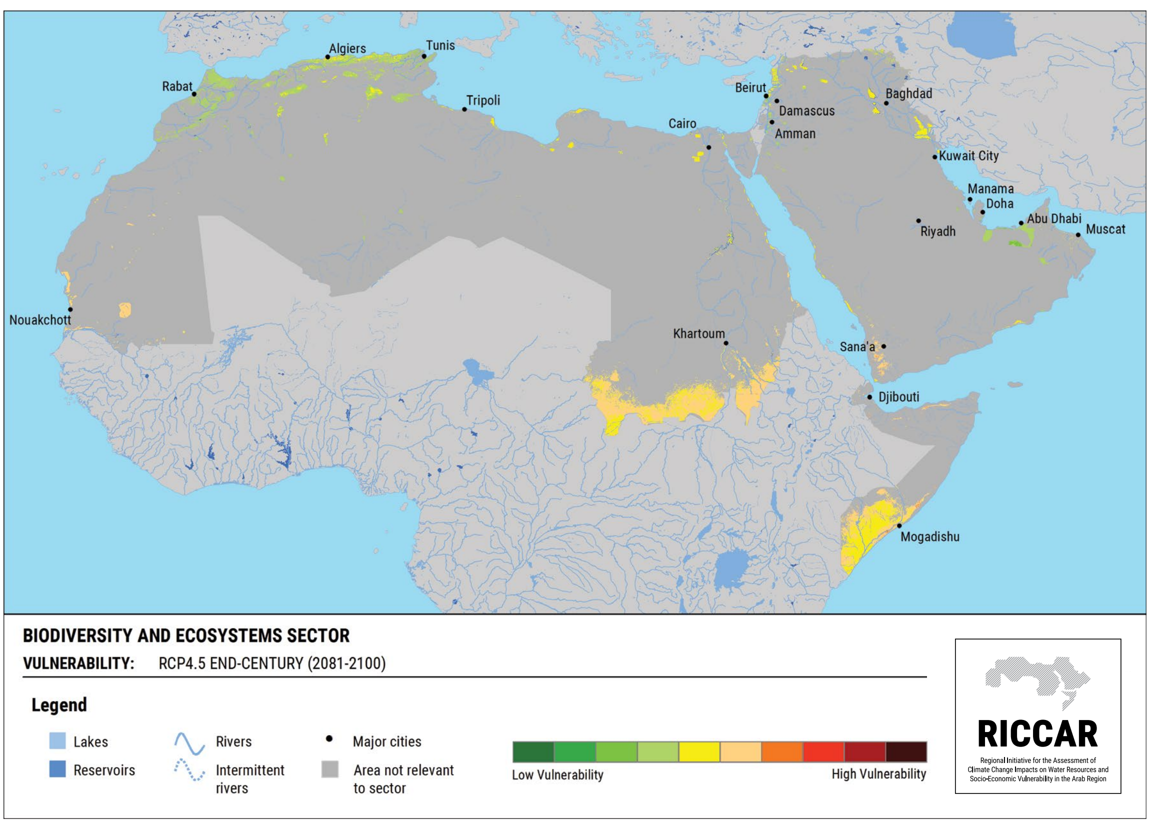
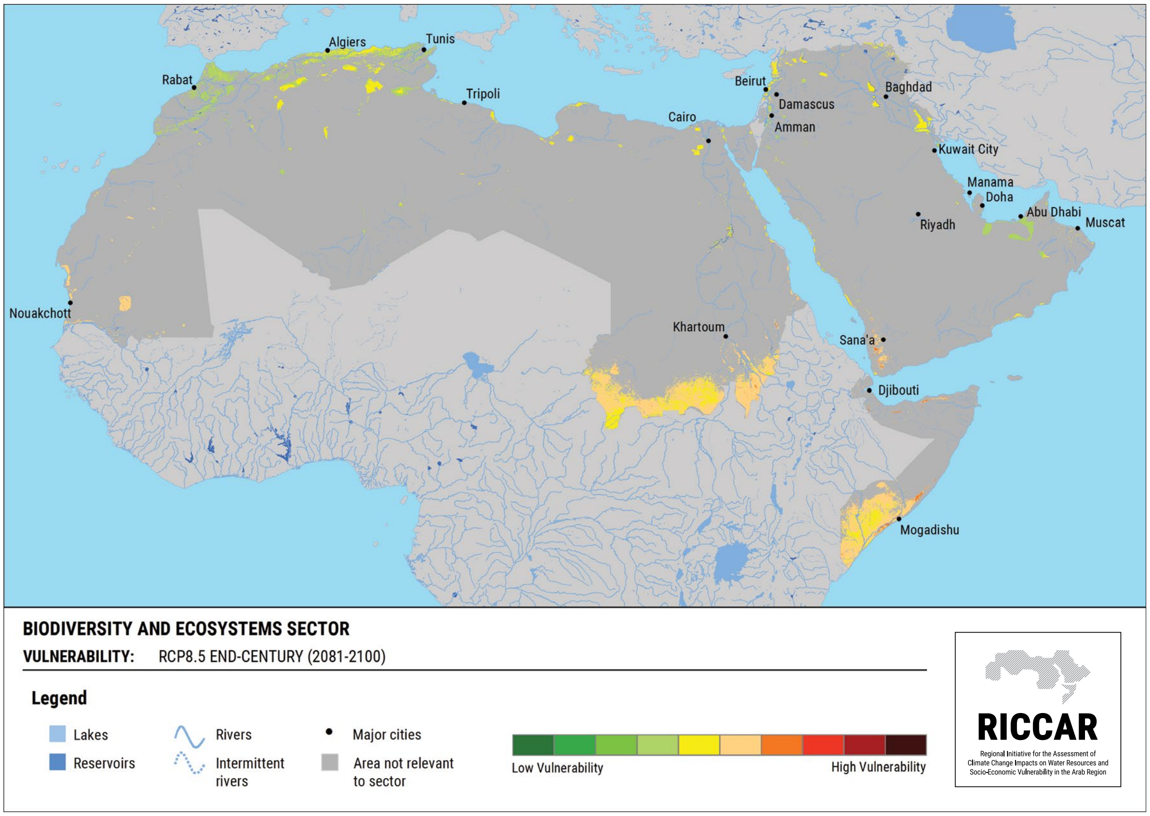


FIGURE 148: Biodiversity and ecosystems sector – Vulnerability – End-century RCP 8.5



10.3.3 Hotspots

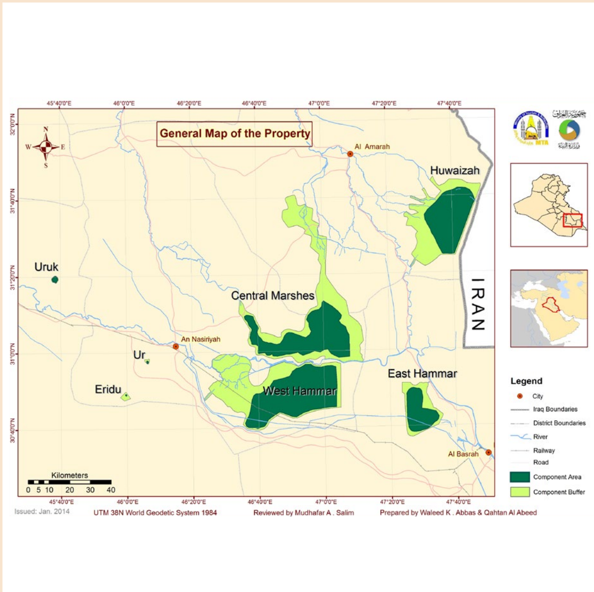
Identified hotspots represent the most vulnerable forests and wetlands in the Arab region and comprise 2% of the study area, including forest and wetland ecosystems in sub-Saharan Africa and the south-western Arabian Peninsula. In particular, the Ta'izz wetlands, tidal wetlands along the southern Gulf 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.

BOX 7: Implications of climate change for the Iraqi Marshlands

The Iraqi Marshlands, considered to be the largest wetland ecosystem in the West Asia region of environmental, historical and socio-cultural significance extend over more than 20,000 km^2 and are located in the areas surrounding the confluence of the Euphrates and Tigris rivers (Figure 149). They represent an ecosystem of fundamental importance to natural and human life in the region, providing local communities with an essential habitat and source of livelihood. Hosting an extraordinary biodiversity and cultural richness, the Marshlands used to provide a permanent settlement and a migratory flyway point for numerous bird species, as well as a central habitat for the Gulf's freshwater fish.[6] Historically, the Marshes filtered out the waste and other pollutants from the Tigris and Euphrates rivers, preserving a pristine ecosystem and preventing the degradation of the Gulf coast.

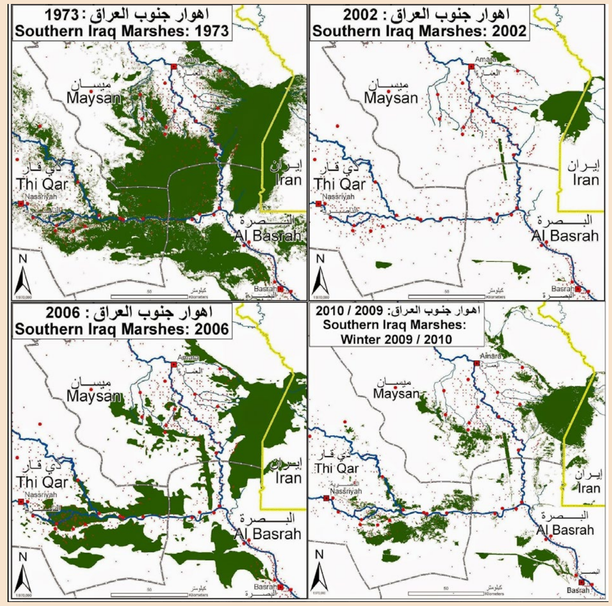
Since the 1970s, over 90% of the original Marshlands area has been desiccated through the combined actions of upstream damming, systematic draining, and oil excavation. As a result, by the year 2000, the only remaining marsh was a portion of Al-Hawizeh on the southern border with the Islamic Republic of Iran, leaving the area extremely vulnerable to drought, climate change and sand- and dust storms. Since 2003, some efforts have been made by a number of organizations to rehabilitate the Marshlands.

FIGURE 149: Map of the Iraqi Marshlands highlighting the four key areas



Source: Ministry of Environment, Republic of Iraq, in UNESCO, 2016a

FIGURE 150: Change in the size of the southern Marshes from 1973 to 2010



Source: CIMI, 2010 in Harhash et al., 2015

The upper reaches of the Euphrates and Tigris rivers are located at high altitudes and receive significant amounts of precipitation in winter months in the form of snow, which provides about 88% of runoff as it melts in the spring, flowing downstream all the way to the Gulf through the rivers and their tributaries.[7] Recently, the water input into the Marshes has been severely affected by changes in climate patterns, as well as human intervention.

Climate change is one of the major challenges currently facing the Iraqi Marshlands. Regional climate modelling outputs by RICCAR indicate a consistent projected increase of temperature in this region by end-century. Several studies also project decreases in precipitation levels in the upper Euphrates and Tigris rivers which will ultimately affect river flow towards the Marshlands.[8] It is expected that, by 2025, water flow will decrease by more than 50% in the Euphrates and 25% in the Tigris.[9] There is also evidence of the rapid expansion of desertification, increasingly frequent and intense duststorms, prolonged drought conditions and unprecedented heatwaves with temperatures exceeding 50 °C in the summer months.[10]

These combined phenomena are having substantial effects on water availability, as well as water quality, and are causing additional stress for biodiversity, particularly in the Marshlands. For example, a mass reduction and loss of key populations of mammals, such as wild boars and water buffaloes have been reported. Species of great ecological, economic and cultural importance could be lost forever, including 18 globally threatened species of fish, mammals and insects found in the Marshlands.[11]

The impacts of climate change are further magnified by human intervention. A series of major dams, diversion schemes and oil-related activities on the Euphrates and Tigris rivers in neighbouring countries (Islamic Republic of Iran, Syrian Arab Republic and Turkey) have significantly altered the hydrological cycle by restricting the amount of water entering the Marshes, as well as interfering with the seasonal pattern of water during the rainy season.[12] The development of these dams has also resulted in the resettlement or displacement of local people impacted by the change in water flow.

Iraqi Marshlands, 2017. Source: Qahtan Abid.


Iraqi Marshlands, 2017. Source: Qahtan Abid.

Along with the draining of the marshes, extensive ecological damage was observed, furthering the deterioration of the Marshlands and significantly affecting their biodiversity and people's livelihoods.

As part of the rehabilitation and restoration efforts, several water-diversion projects into the Marshlands have been implemented as examples of interventions trying to influence positive change.[13] In 2003, the Iraqi government identified the need and importance to rehabilitate the Marshlands with the support of a number of national and international organizations, leading to the restoration of about 45% of the original Marshlands (Figure 150).[14]

In 2009, UN Environment and UNESCO launched the joint project Natural and Cultural Management of the Iraqi Marshlands to establish and implement a longer-term sustainable management framework leading to the inclusion of the Iraqi Marshlands in the UNESCO World Heritage List at the 40th session of the World Heritage Committee in July 2016.[15]

A successive nomination of three Sumerian Mesopotamian cities (Ur, Uruk and Tel-Erido) and four marshland areas on the World Heritage List followed. This recognition highlights the historical and ecological importance of the site and the necessity to establish a consolidated management plan for the area combining its cultural, historical and natural characteristics. The UN Environment and UNESCO initiative aimed to provide guidance and support to the Iraqi stakeholders in implementing a sustainable preservation and management plan to mitigate the complex effects of climate change on biodiversity and water resources, the overexploitation of natural resources, as well as pollution, drought, sand and dust storms and dam construction upstream.

The management plan sought also to build capacity and raise awareness among the local population to ensure their livelihoods and encourage their participation in the management of the Marshlands and the sustainable use of its ecosystem services and traditional knowledge, which is 5,000 years old.

ENDNOTES

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2. Hansen et al., 2013
3. Ibid.
4. Ramsar Convention Secretariat, 2010
5. Blankespoor et al., 2014
6. United Nations Integrated Water Task Force for Iraq, 2011
7. Ministry of Health and Environment in Iraq, 2014
8. Ibid.
9. United Nations Integrated Water Task Force for Iraq, 2011
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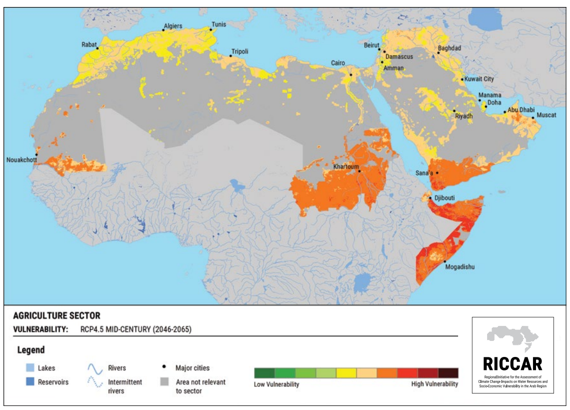
AGRICULTURE SECTOR

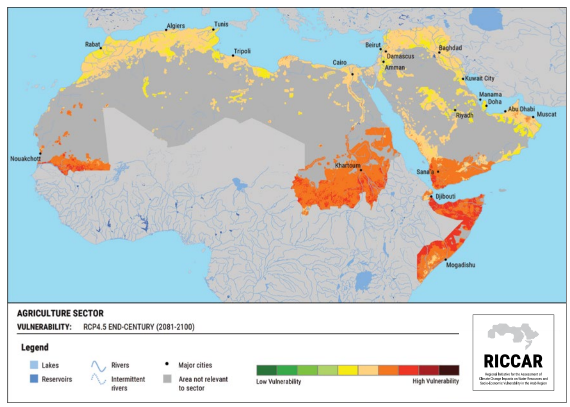
OVERALL VULNERABILITY

RCP 4.5

2046-2065

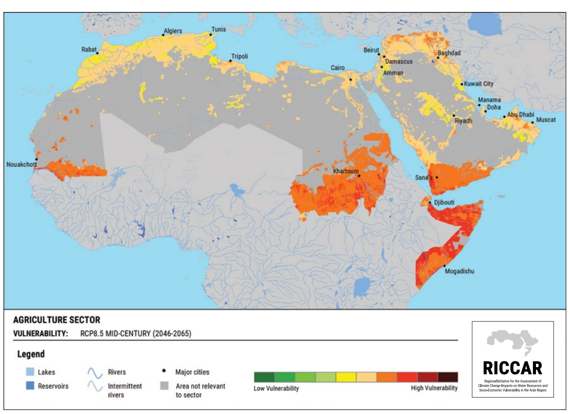


2081-2100

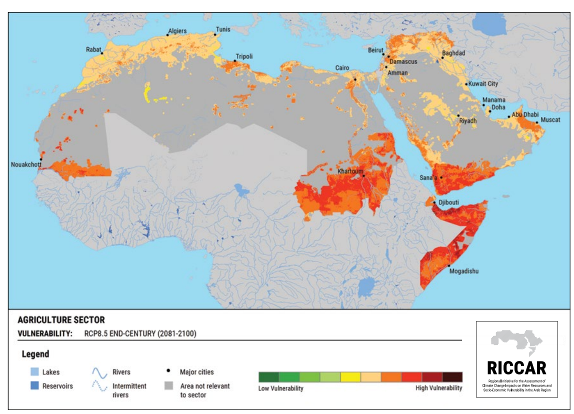


RCP 8.5

2046-2065



2081-2100



CHAPTER 11

AGRICULTURE SECTOR – VULNERABILITY

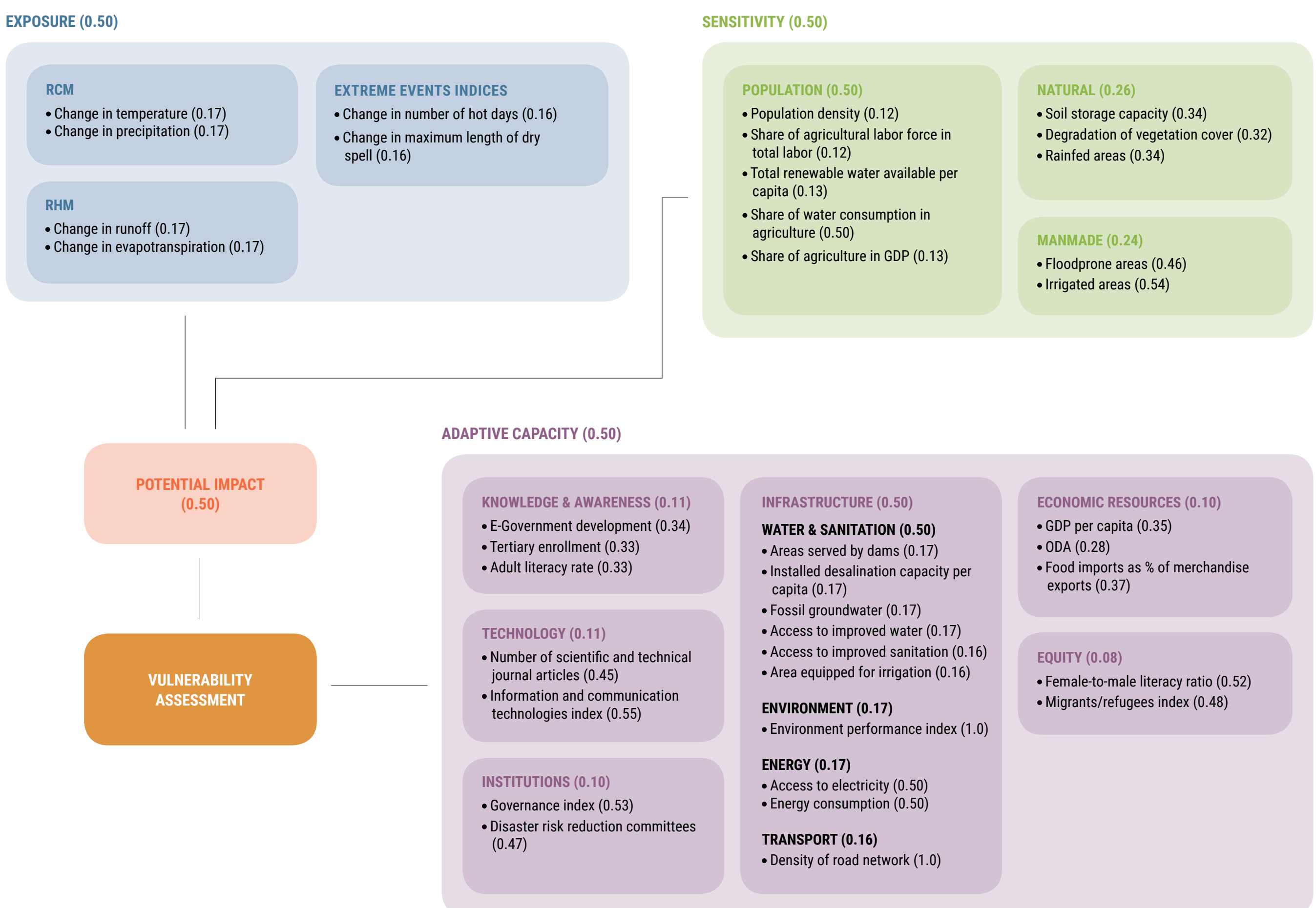
The agricultural sector plays an important role in most economies of the Arab region and is also the largest consumer of freshwater, constituting more than 80% of total water use. Crops such as wheat, barley and sorghum require an estimated 1,000 to 3,800 m^3 of water per tonne of harvested produce.[1] Research has shown that livestock require substantially more due to feed, grazing and direct water demand; dairy cows require the most water: an estimated 89,000 to 160,000 m^3/t over an animal's lifespan.[2] Being highly dependent on water and fertile soils – both scarce natural resources in the region – the agricultural sector is particularly prone to adverse climate change impacts. It was thus selected for inclusion in vulnerability, with particular focus on the potential impacts of *Change in the water available for crops* and *Change in the water available for livestock*, of which the outcomes are presented in the following sections.

The study areas for both subsectors have been defined by selected indicators. In the case of water available for crops, both rainfed and irrigated cropland areas were included. In this context, if at least a portion of a given grid cell represents cropland, the entire cell was considered part of the study area. For the *Water available for livestock* subsector, the study area was based on livestock density over 10 heads per square kilometre. The managed water available for crops and water available for livestock represents 22% and 33% of the Arab region, respectively. The study area for the *Agriculture* sector represents the combined study areas of the subsectors, which often overlap, and includes 37% of the Arab region.

11.1 WATER AVAILABLE FOR CROPS

Figure 151 highlights the impact chain for this subsector, showing the set of indicators considered for analysis and its assigned weights.

FIGURE 151: Impact chain and weights for water available for crops



11.1.1 Reference period

11.1.1.1 Potential impact

Potential impact represents the aggregated result of both exposure and sensitivity. In terms of exposure, a change in water availability for crops is related to drought, most commonly attributed to meteorological phenomena, specifically changes in precipitation patterns. Six differing exposure indicators were selected, including precipitation (see Figure 151).

For the reference period, the exposure composite indicator is primarily influenced by temperature and the annual number of hot days (SU35). High temperatures can accelerate soil-water evaporation, particularly in arid and semi-arid environments, where crops do not completely cover the ground. For the reference period, 19% of the study area is considered to have low exposure, 38% moderate exposure and 43% high exposure. Areas with the highest exposure include the southern Tindouf basin, the Nile Valley near Khartoum, selected locations near the Red Sea coastline and selected locations near the Gulf coastline.

Sensitivity, in this context, is typically defined by other water surfaces, soil type, land use and irrigation practices. Under RICCAR, 10 different sensitivity indicators were selected, of which the share of water consumption in agriculture – an indicator based on population statistics – was given the highest weight. Agriculture is the largest consumer of water, using 84% of total water available in the Arab region and over 90% in certain countries.[3] Neither crop yield nor harvested losses were considered part of this study due to region-wide data unavailability.

The results suggest that a majority of the study area (84%) indicates moderate sensitivity, while 9% suggests high sensitivity. The area with the highest sensitivity is that of the lower Nile Valley and Nile Delta. Other areas of moderate-to-high sensitivity are dispersed throughout the study area. Sensitivity exhibits the strongest correlation with the floodprone areas indicator; minor floods can be beneficial to crops in terms of water availability. Sensitivity is also reasonably correlated with irrigated areas and population density.

However, despite the heavy weight assigned to the share of water consumption in agriculture indicator, it reveals a weak correlation with sensitivity, partly because the indicator is solely available at a national scale and the composite sensitivity is subnational.

Potential impact implies the effect upon a system assuming no implementation of adaptation measures. In this case, it suggests areas which are most likely to be subject to a decline in water availability for crops. A majority of the study area (86%) signifies moderate potential impact, while 9% shows high potential impact (Figure 152).

The entire Nile Valley denotes high potential impact for the reference period, as well as much of the Sahel, the eastern Red Sea coastline, the Jubba and Shabelle rivers in the Horn of Africa, certain areas in the Arabian Desert and the lower Tigris–Euphrates basin.

11.1.1.2 Adaptive capacity

Adaptive capacity reflects the current ability of a system to adjust to climate change (both variability and extremes), lessen potential damage and exploit potential solutions. Selection of relevant indicators was based on all six dimensions, focusing on water infrastructure.

The Arab region has long been subject to deteriorating water infrastructure due to deferred maintenance and the inability to dedicate financial resources for new investments. Facets from the other adaptive capacity dimensions also matter. Current science and technology methods practised in the region include plant cultivation and animal breeding, biotechnology, mineral fertilizers and water-efficient irrigation. Economic resources include production of goods for trade, alternative means of income generation, cooperation with industry and financial aid. However, these techniques are utilized on a limited scale only.

Approximately 28% of the study area can be considered to have low adaptive capacity and are located in the croplands of the Horn of Africa, the Sahel, and the south-western Arabian Peninsula. Most of the study area (66%) reveals moderate adaptive capacity. High adaptive capacity is limited to 7% of the study area and is generally confined to the lower Nile Valley and Delta, areas of the Levant and the eastern Tell Atlas region (Figure 153).

FIGURE 152: Water available for crops – Reference period – Potential impact

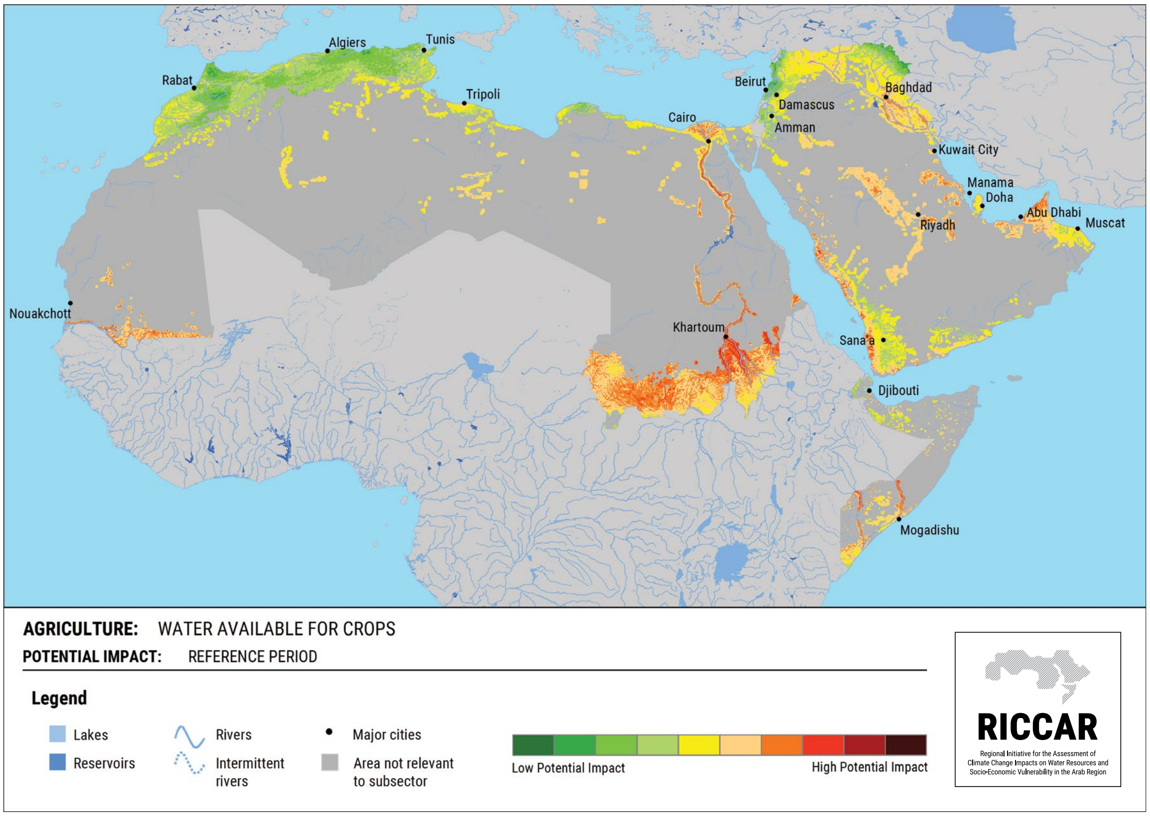
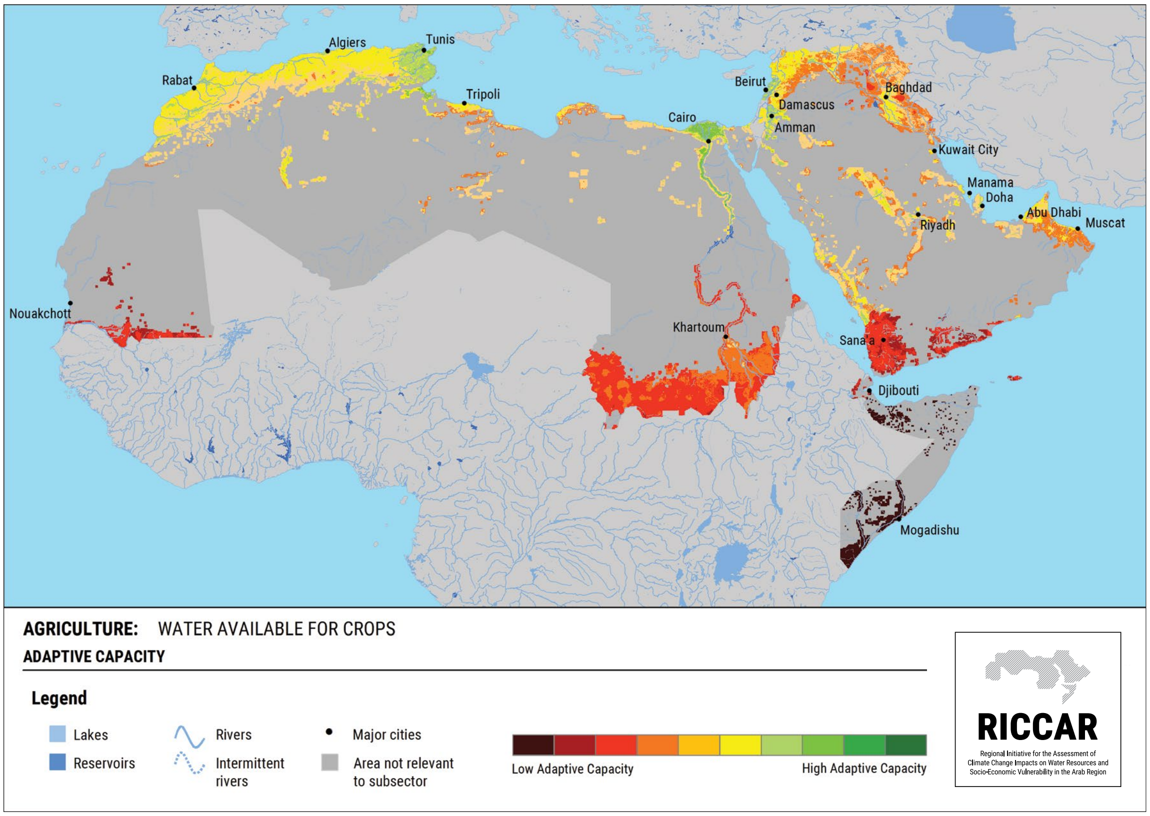


FIGURE 153: Water available for crops – Adaptive capacity

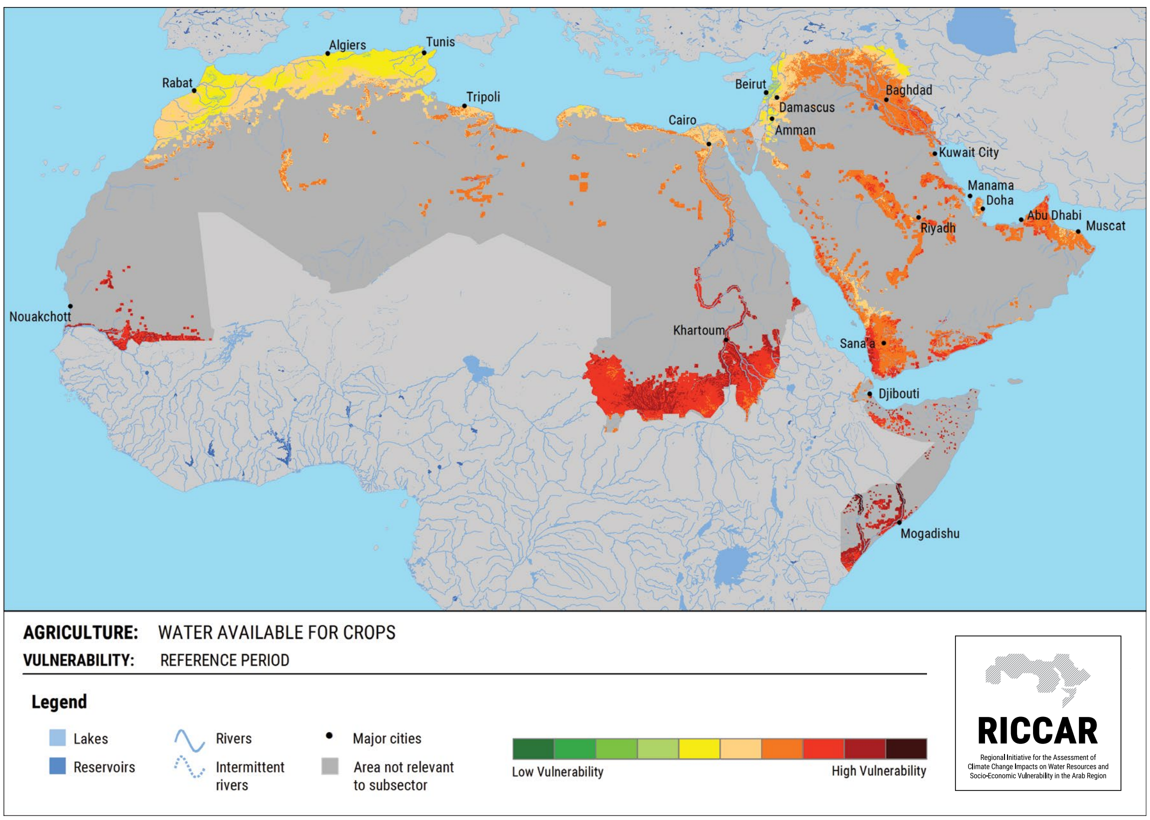


11.1.1.3 Vulnerability

Vulnerability reflects the balance between climate, the natural and physical environment and the ability to cope. Assessing the vulnerability related to water availability for crops stems from several interrelated issues, including limited water resources. Much of the study area (63%) signifies high vulnerability for the reference period, with remaining areas indicating moderate vulnerability. Areas with the highest vulnerability include the Sahel, the Jubba and Shabelle river valleys, and croplands south of the Asir Mountains. Vulnerability to water availability adversely impacts crops, but affects numerous other sectors, too, often in conjunction with high population growth, urbanization and industrialization. Results are for instance: overexploitation of ecosystems and loss of habitats, especially coastal and wetland habitats, followed by a decline in biodiversity and a deterioration of forests and grasslands all over the Arab region. Forests and wetlands are amongst the ecosystems most affected by current degradation processes.

Areas with moderately low vulnerability relative to the region include lands in the northern Maghreb, the Levant and the Zagros Mountains due to reduced potential impact and relatively high adaptive capacity (Figure 154).

FIGURE 154: Water available for crops – Reference period – Vulnerability



11.1.2 Future periods

11.1.2.1 Potential impact

Climate change can affect water availability, crop yield, crop–water productivity, soil–water balance, and ultimately food security. Water availability in this context considers how much water can be diverted toward the *Agriculture* sector, when it can be obtained and how much can be stored for future use. Water productivity differs as it reflects economics and management and similar issues. An increase in water productivity enables farmers to produce the same crop yield using fewer water resources.

Exposure is largely moderate for most of the study area at mid-century, signifying 67% (RCP 8.5) to 86% (RCP 4.5) of the study area. High exposure is predicted in 7% (RCP 4.5) to 32% (RCP 8.5) of the study area. At end-century, exposure increases and 26% (RCP 4.5) to 64% (RCP 8.5) of the study area is denoted high exposure with 35% (RCP 8.5) to 68% (RCP 4.5) as moderate exposure.

Areas of high exposure include the Blue Nile–White Nile basin, the south-western Arabian Peninsula and croplands near the Gulf of Oman. High-exposure areas expand dramatically for end-century RCP 8.5 to include the entire Mediterranean coast and the Nile River.

Sensitivity is assumed unchanged from the reference period due to data unavailability. However, sensitivity can change greatly over time if values from one or more indicators evolve greatly. For example, land subsidence due to over-pumping caused by expansion of urban areas in river deltas can provoke saltwater intrusion and hence increased competition for available freshwater resources. In addition, parameters not considered for RICCAR due to data limitations such as soil salinization and water quality degradation can increase sensitivity.

In the absence of available adaptation measures, potential impact is expected to increase under both RCP 4.5 and RCP 8.5 from mid- to end-of-century. For all scenarios, the majority of the area can anticipate moderate potential impact, affecting 90% (RCP 8.5) to 94% (RCP 4.5) of the study area at mid-century (Figure 155 and Figure 156) and 79% (RCP 8.5) to 89% (RCP 4.5) of the study area at end-century (Figure 157 and Figure 158). Areas of high potential impact reflect 4% (RCP 4.5) to 10% (RCP 8.5) of the study area at mid-century, and 9% (RCP 4.5) to 21% (RCP 8.5) at end-century. Areas with high projected potential impact tend to be the same as those with high projected exposure.

With respect to trends from mid- to end-century, areas that generally exhibit increasing potential impact under RCP 4.5 are the western Sahel and the lower Nile River Valley. Croplands revealing declining potential impact for RCP 4.5 include the Tigris–Euphrates basin and the Jubba–Shabelle river valleys. For RCP 8.5, the entire Sahel indicates decreasing potential impact, as well as the Tigris–Euphrates basin. Crop areas located in the central Sahara Desert exhibit increasing potential impact under RCP 8.5.

FIGURE 155: Water available for crops – Mid-century RCP 4.5 – Potential impact

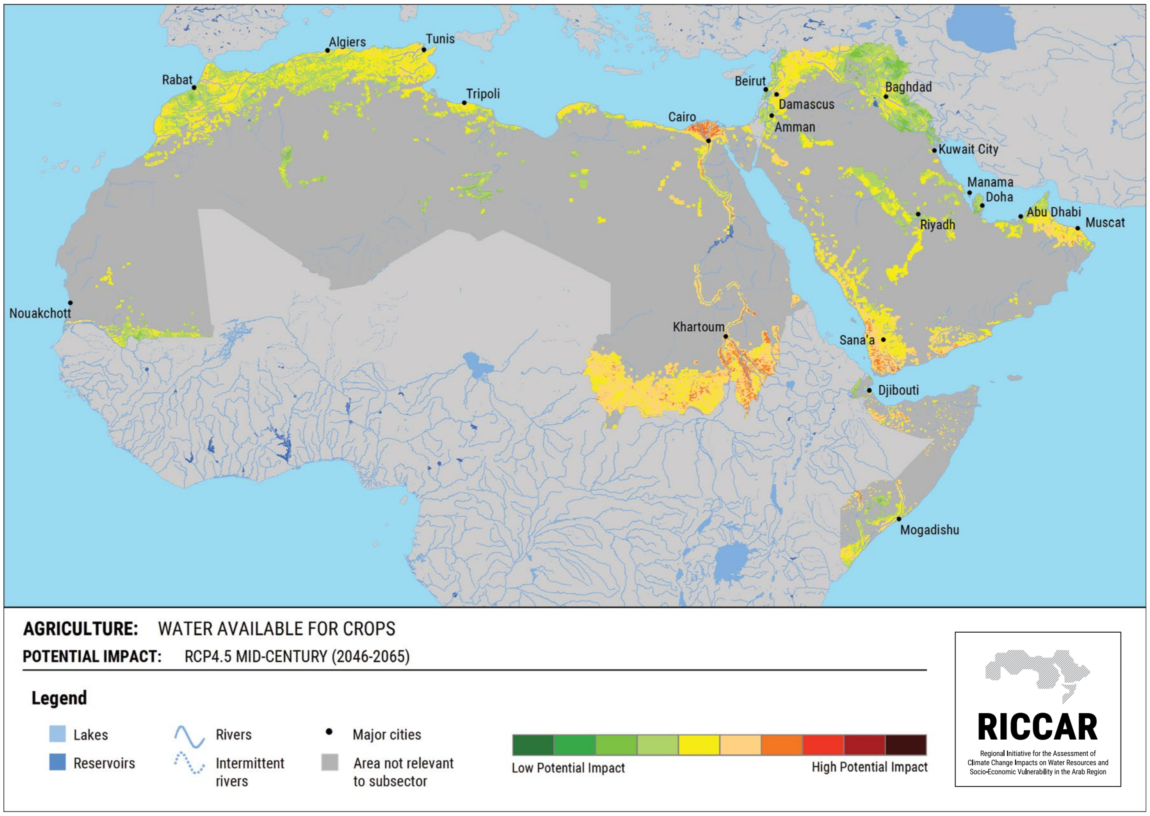


FIGURE 156: Water available for crops – Mid-century RCP 8.5 – Potential impact

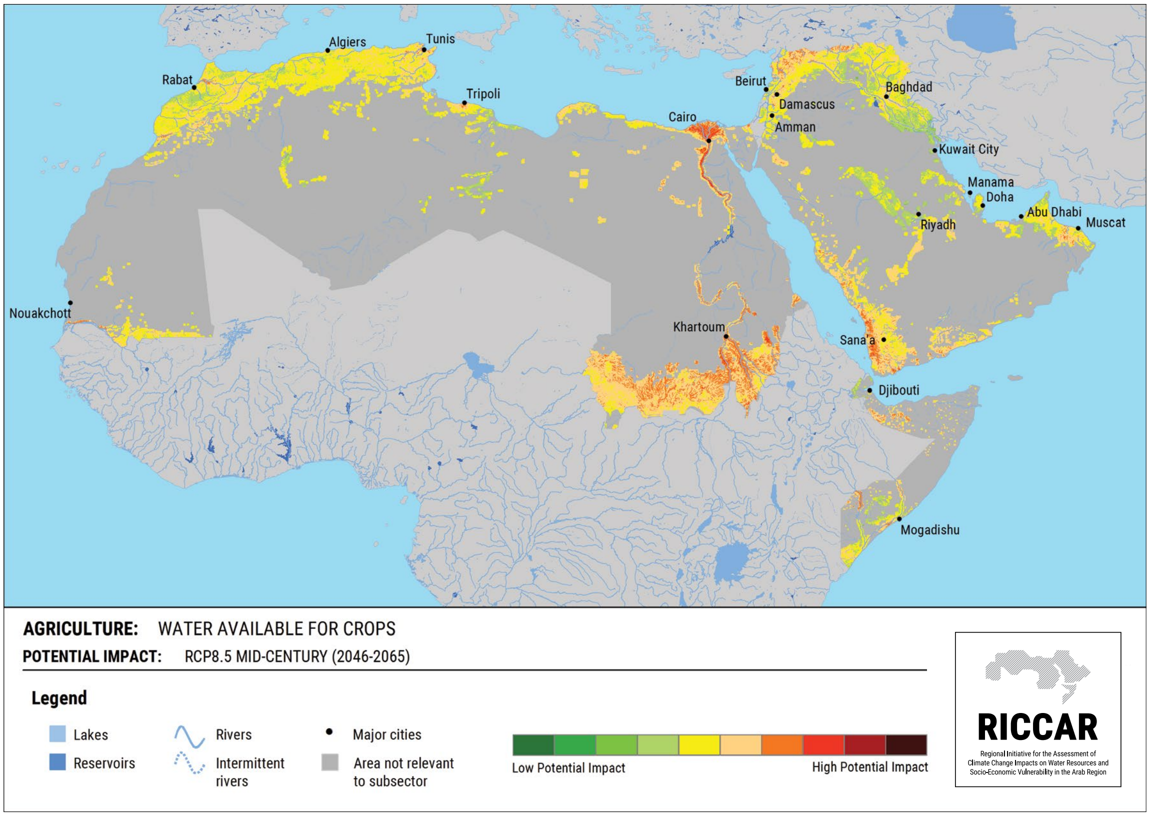


FIGURE 157: Water available for crops – End-century RCP 4.5 – Potential impact

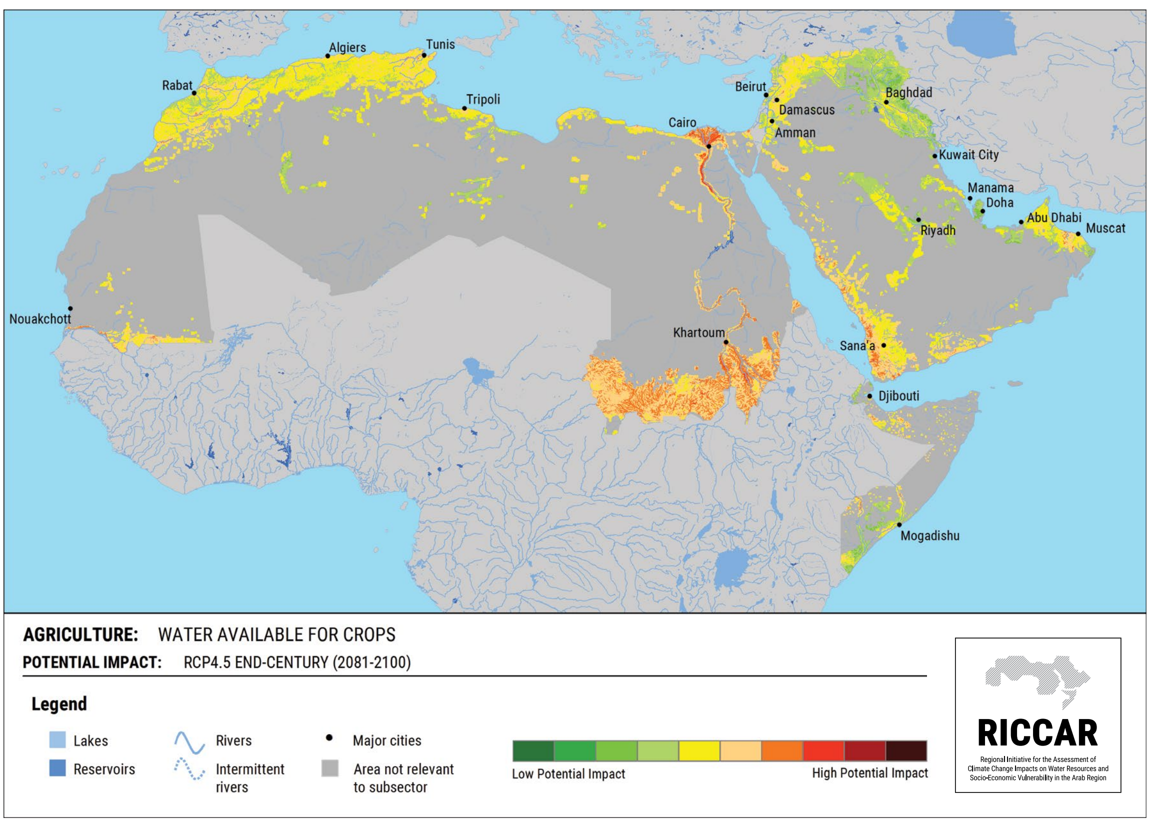
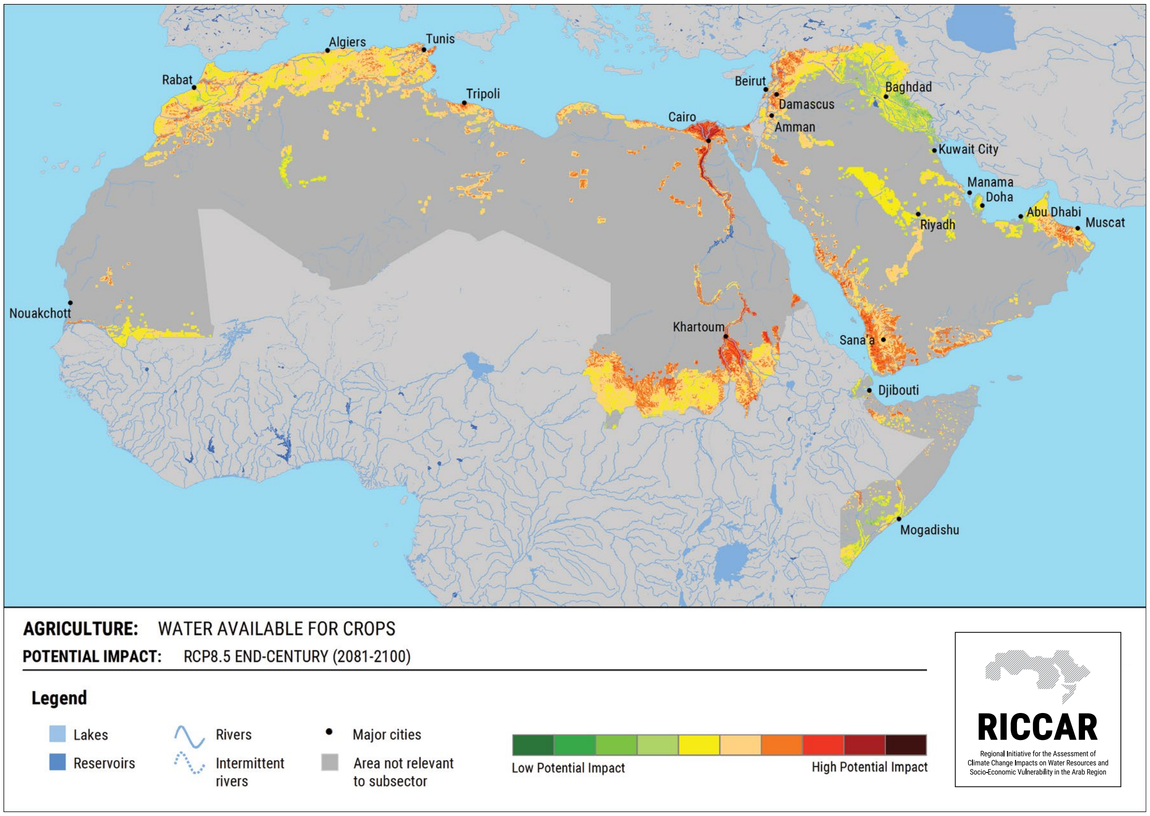


FIGURE 158: Water available for crops – End-century RCP 8.5 – Potential impact



11.1.2.2 Vulnerability

Croplands throughout the Arab region can be expected to endure moderate-to-high future vulnerability. At mid-century, 50% (RCP 4.5) to 67% (RCP 8.5) of the study area project high vulnerability and 57% (RCP 4.5) to 84% (RCP 8.5) signify high vulnerability at end-century (Table 25). Water demand for selected crops in the Arab region are presented in Table 26. Croplands which project relatively lower vulnerability include the Mediterranean coast of the Maghreb, the southern Grand Erg Oriental, parts of the Levant, the Tigris–Euphrates basin and the central eastern Arabian Desert (Figure 159 to Figure 162).

Vulnerability exhibits a strong correlation with adaptive capacity and a modest correlation with sensitivity. Correlation with exposure is relatively weak. Thus, improvements in adaptive capacity will have the greatest impact upon reducing vulnerability.
These measures can include improvement in water infrastructure and irrigation efficiency, as well as the use of non-conventional water resources such as wastewater re-use. An example of a success story in this regard is the Gezira Scheme.

TABLE 25: Percentage of study area by vulnerability classification for water availability for crops

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	0%	50%	50%
Mid-Century RCP 8.5	0%	33%	67%
End-Century RCP 4.5	0%	43%	57%
End-Century RCP 8.5	0%	16%	84%

TABLE 26: Water demand for selected crops in the Arab region

Crop	Virtual water demand (m^3 per ton)
Bananas	200–2,300
Millet	2,000–18,000
Palm	1,200–14,000
Potato	100–1,800
Sorghum	800–23,000
Tomato	100–600

Source: Hoekstra and Hung, 2002

FIGURE 159: Water available for crops – Mid-century RCP 4.5 – Vulnerability

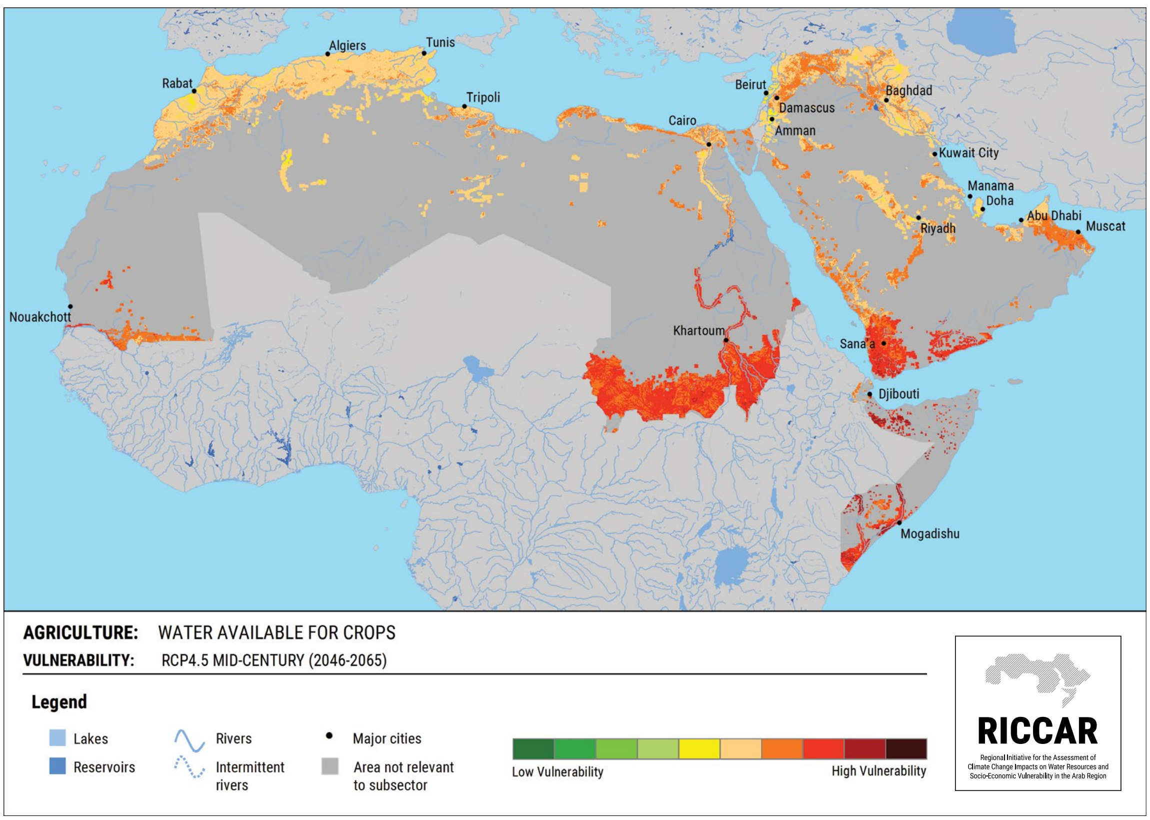


FIGURE 160: Water available for crops – Mid-century RCP 8.5 – Vulnerability

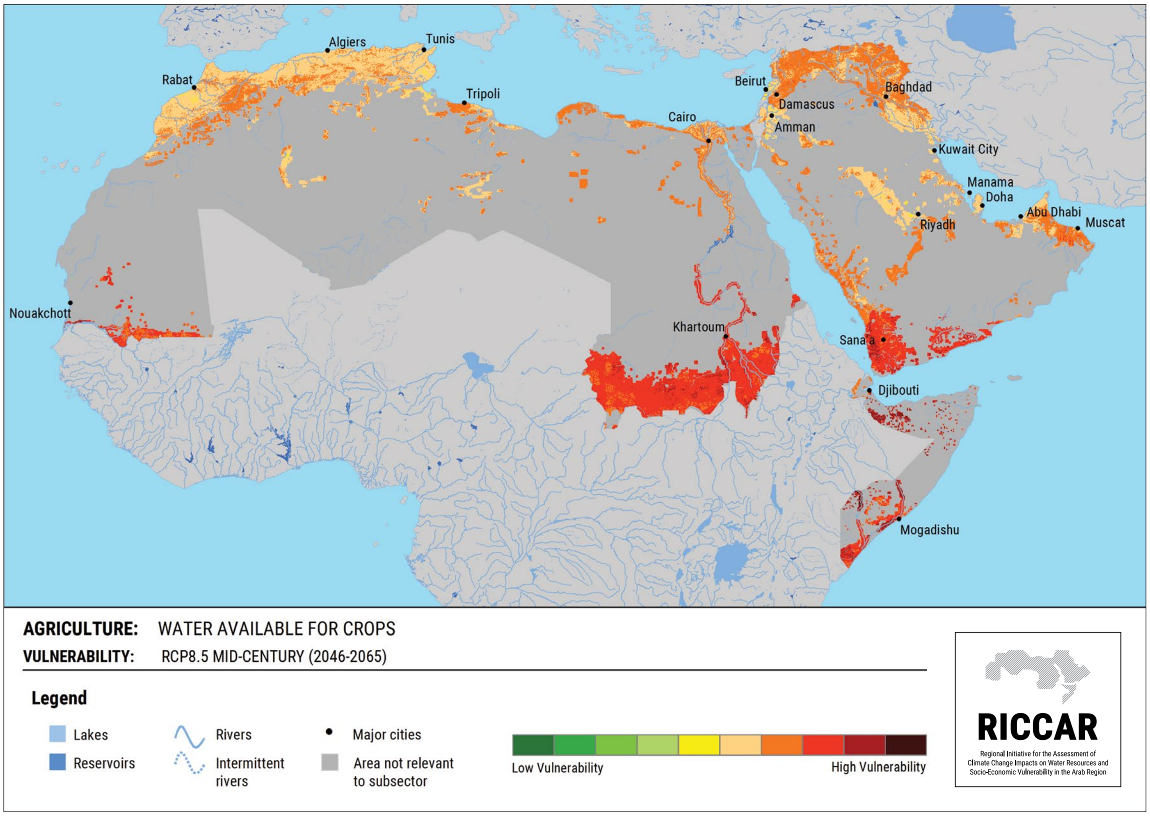


FIGURE 161: Water available for crops – End-century RCP 4.5 – Vulnerability

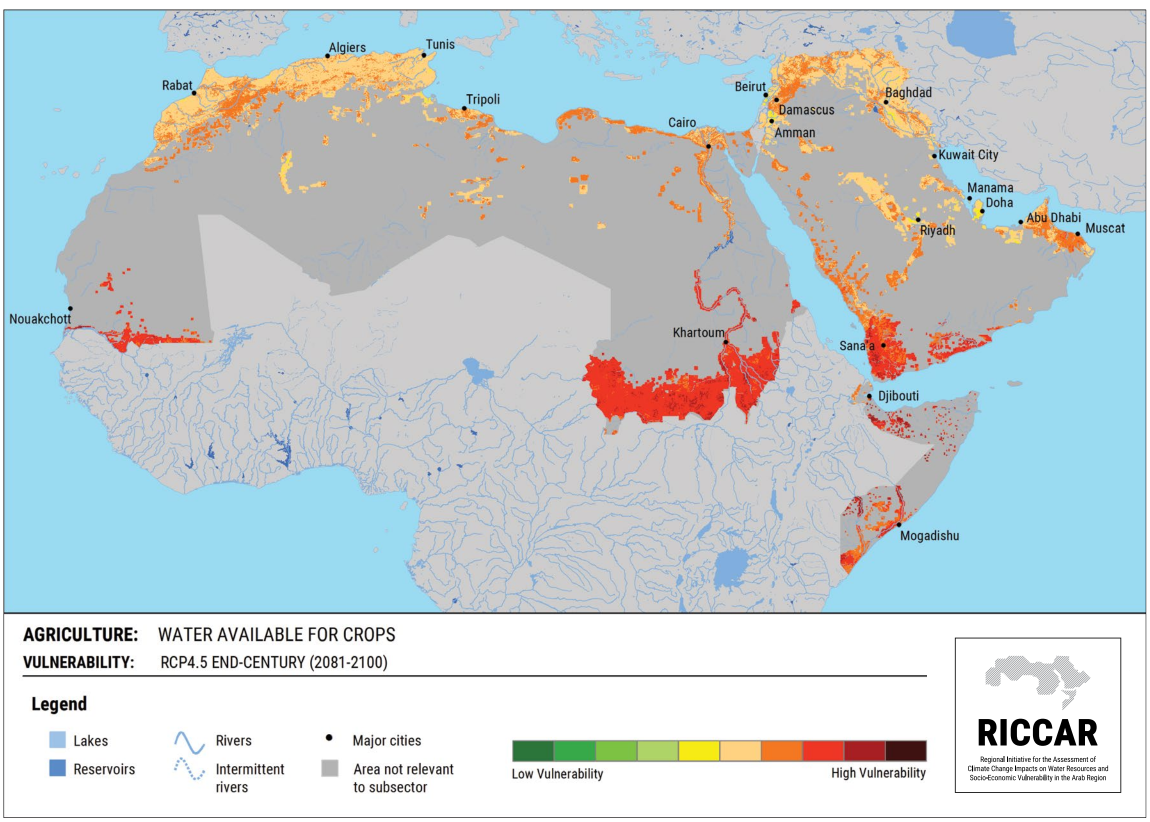
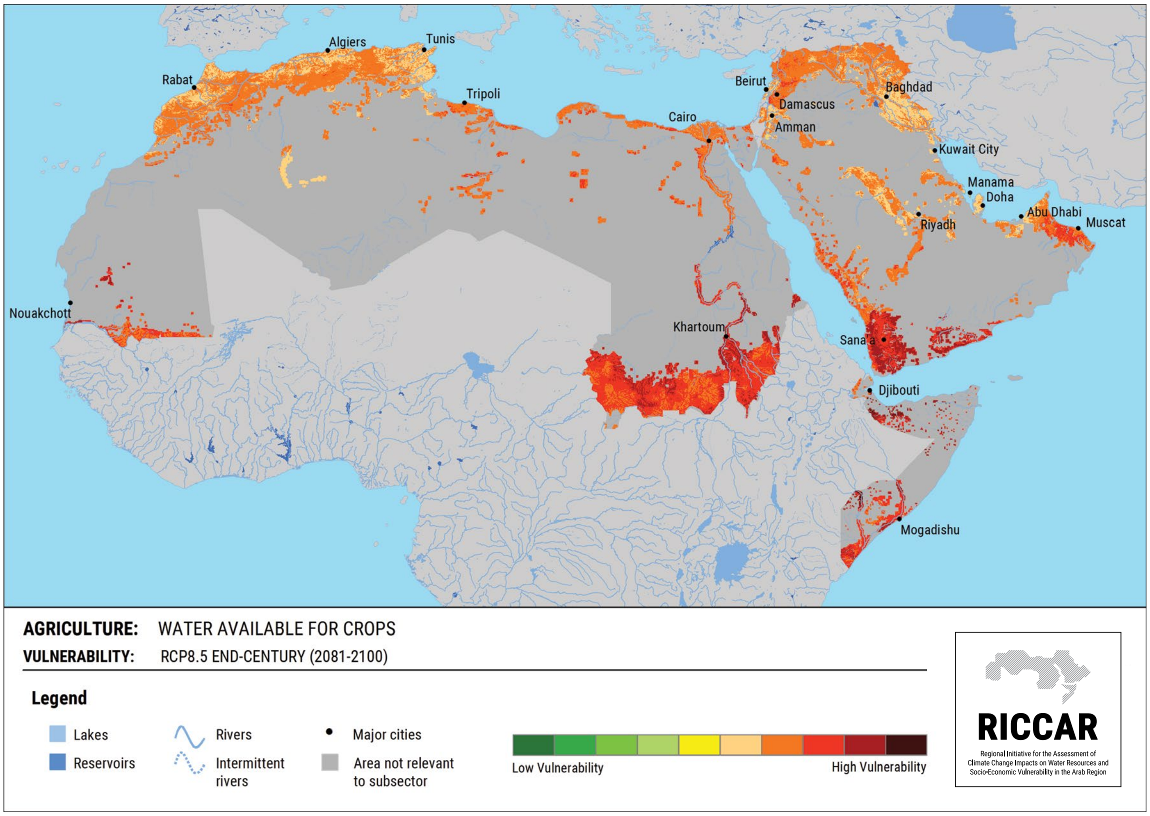


FIGURE 162: Water available for crops – End-century RCP 8.5 – Vulnerability



11.1.3 Hotspots

Hotspots are the most critical areas of high vulnerability, where resources are ideally allocated to relieve water scarcity. Up to 6% of the study area represents cropland hotspots. They include croplands of sub-Saharan Africa, the Horn of Africa and the south-western Arabian Peninsula. Among the crops grown in these locations are sorghum, sugarcane, millet, sesame, potatoes and mangoes, many of which need large quantities of water.

Croplands in these areas are largely rainfed and thus subject to projected decreases and variability in precipitation. The Horn of Africa projects increasing rainfall, so crops will benefit, but it also has the lowest adaptive capacity.

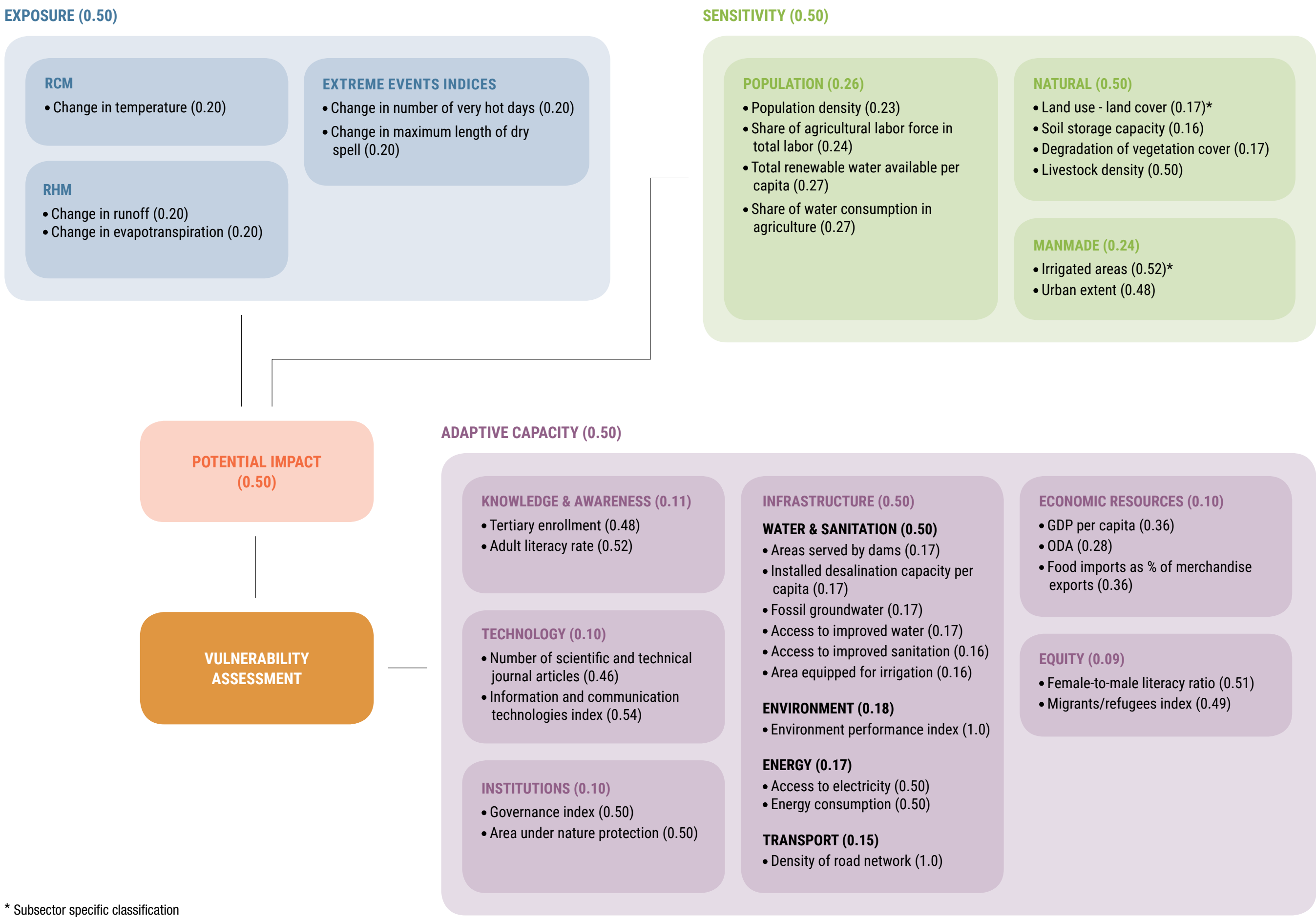
Some cropland hotspots are irrigated and will benefit the most from improvements in infrastructure.

Wasi El Masad, Iraq, 2013. Source: Sadeq Oleiwi Sulaiman.

11.2 WATER AVAILABLE FOR LIVESTOCK

The different indicators used under each component for this subsector and their corresponding weights are presented in the impact chain (Figure 163).

FIGURE 163: Impact chain and weights for water available for livestock



* Subsector specific classification

11.2.1 Reference period

11.2.1.1 Potential impact

Potential impact reveals the composite of exposure and sensitivity. In the Arab region, the recent estimated livestock population (2013) comprised 136 million sheep, 66 million goats, 23 million cattle and 6 million camels.[4] Livestock water demand is very high when considering all virtual water, which includes water for drinking, servicing and feed (Table 27). This water demand depends on several meteorological factors. Hydrologically, runoff contributes toward direct water demand and evapotranspiration rates control feed production and grazing capabilities. High temperatures and dry spells can induce heat stress, thereby increasing water demand and causing rangeland mortality.

For these reasons, temperature, runoff, evapotranspiration, the number of very hot days (SU40), and maximum length of dry spell (CDD) were selected as exposure indicators. The study area is divided fairly equally between low, moderate and high aggregated exposure (26%, 42%, and 31%, respectively) for the reference period. Areas of high exposure include the southern Tindouf basin, the White and Blue Nile rivers near Khartoum, livestock areas in the central and eastern Arabian Desert near the Gulf coastline, and the lower Tigris–Euphrates basin.

Several factors can induce stress in livestock and their corresponding water demand, including competing sectors and rangeland degradation. These elements are reflected in the selected sensitivity indicators. A majority (66%) of the study area is indicative of low sensitivity. However, almost one third of the area suggests moderate sensitivity with isolated areas of high sensitivity.

Sensitivity signals the strongest correlation with population density, due to competition for water resources, followed by irrigated areas, urban extent and livestock density.

Areas of moderate-to-high sensitivity include the lower Nile River and Delta, as well as some isolated areas in the Levant and the Asir Mountains.

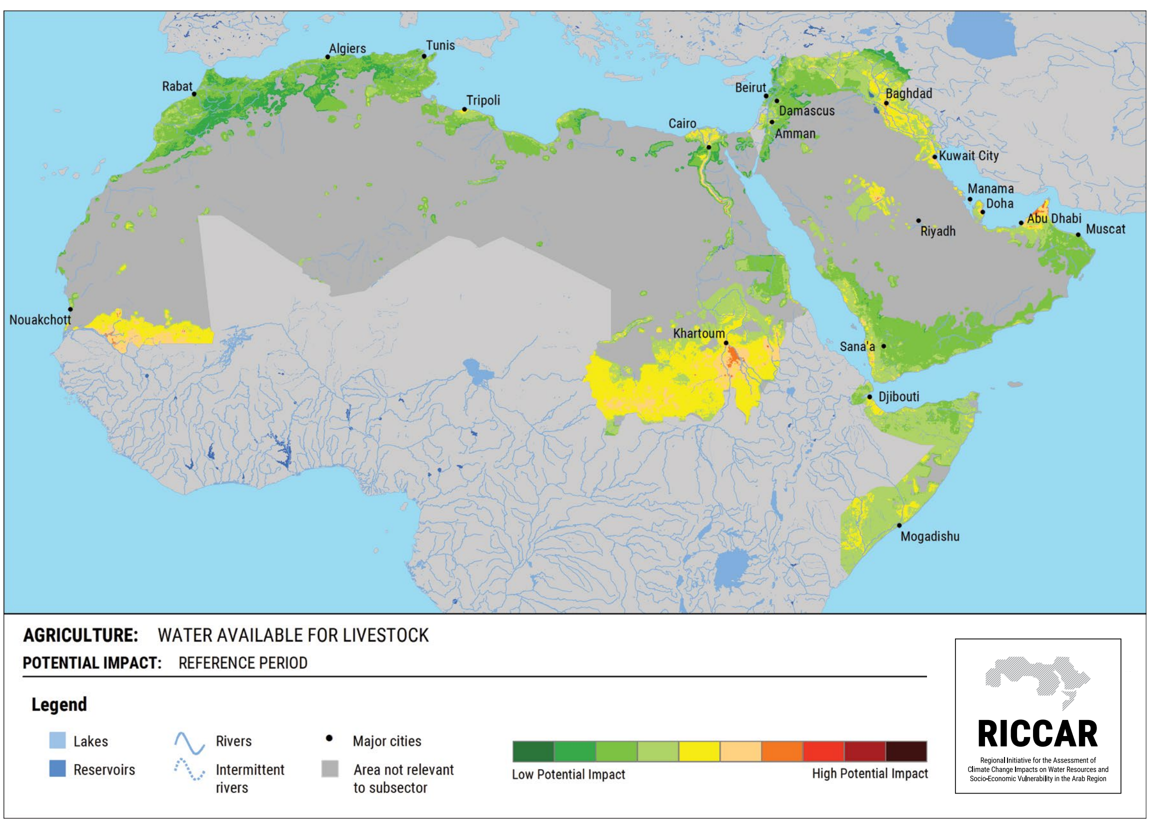
Over half (59%) of the study area has revealed moderate potential impact for the reference period. Less than 1% of the region suggests high potential impact and remaining areas indicate low potential impact. Areas of moderate-to-high potential impact include the Blue Nile valley just south of Khartoum and the lower Gulf near the Strait of Hormuz (Figure 164).

TABLE 27: Virtual water content of selected livestock in the Arab region

Animal	Total virtual water (m^3/t over life span)
Beef cattle	9,400–40,100
Dairy cows	89,000–330,000
Sheep	5,600–10,400
Goats	2,800–9,000

Source: Chapagain and Hoekstra, 2003

FIGURE 164: Water available for livestock – Reference Period – Potential impact

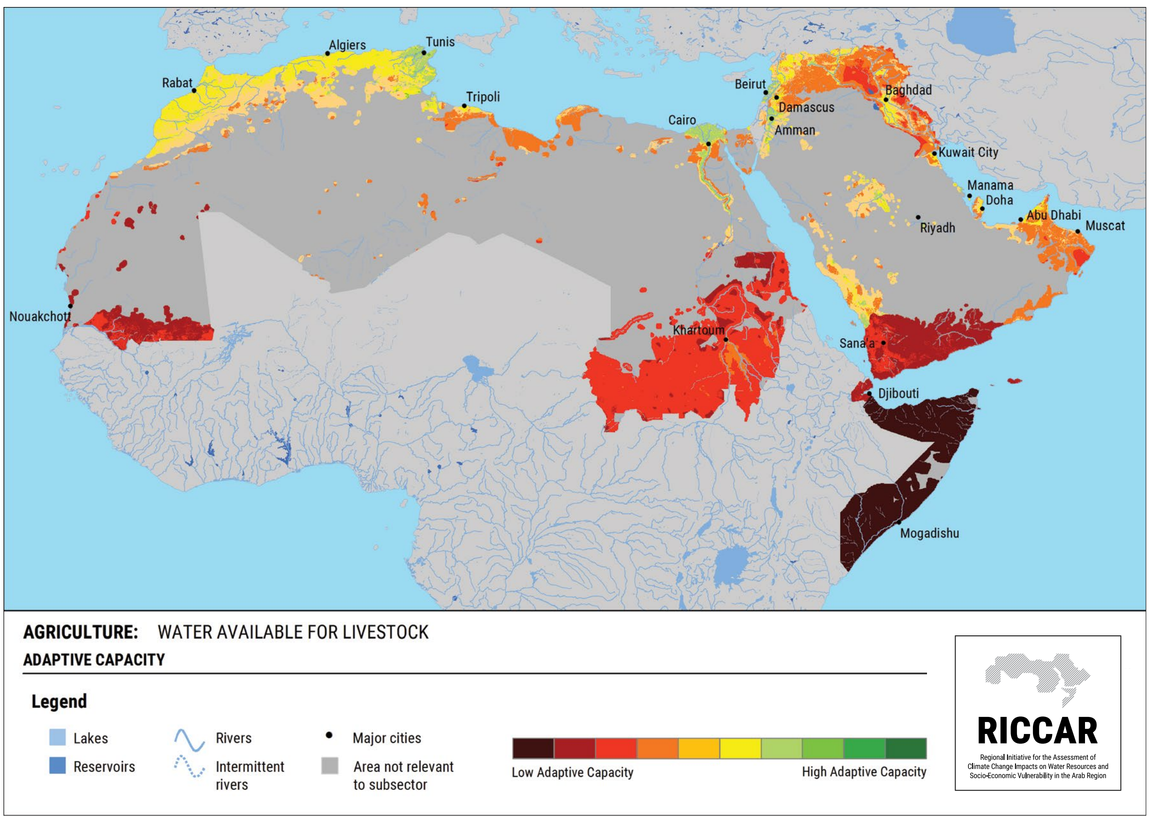


11.2.1.2 Adaptive capacity

In the Arab region, pastoralists have adopted some of their own adaptation measures to mitigate water scarcity for livestock through various government approaches.[5] Practices include investment in water infrastructure, which has been weighted most in the impact chain, by utilizing wells, cisterns and water harvesting. Another practice is to encourage reduction of land degradation by implementing nomadic grazing, which minimizes foraging in a particular location.

Despite these efforts, much of the study area (53%) signals low adaptive capacity often due to factors beyond pastoralists' control. Coping mechanisms must consider different facets. For example, policies with regard to livestock are generally lacking. Loose regulations based on self-sufficiency have resulted in limited trade and weak inter-Arab investments in agriculture, restricting economic development. Emphasis has been placed on increasing livestock production to meet demand, which entails cheaper food options for the urban population, but neglects those in rural areas. Gender also plays a role as women often do not own livestock but take care of them. Areas of low adaptive capacity include livestock areas in sub-Saharan Africa, the south-western Arabian Peninsula and areas within the Tigris–Euphrates basin. Most of the remaining area (44%) indicates moderate adaptive capacity (Figure 165).

FIGURE 165: Water available for livestock – Adaptive capacity



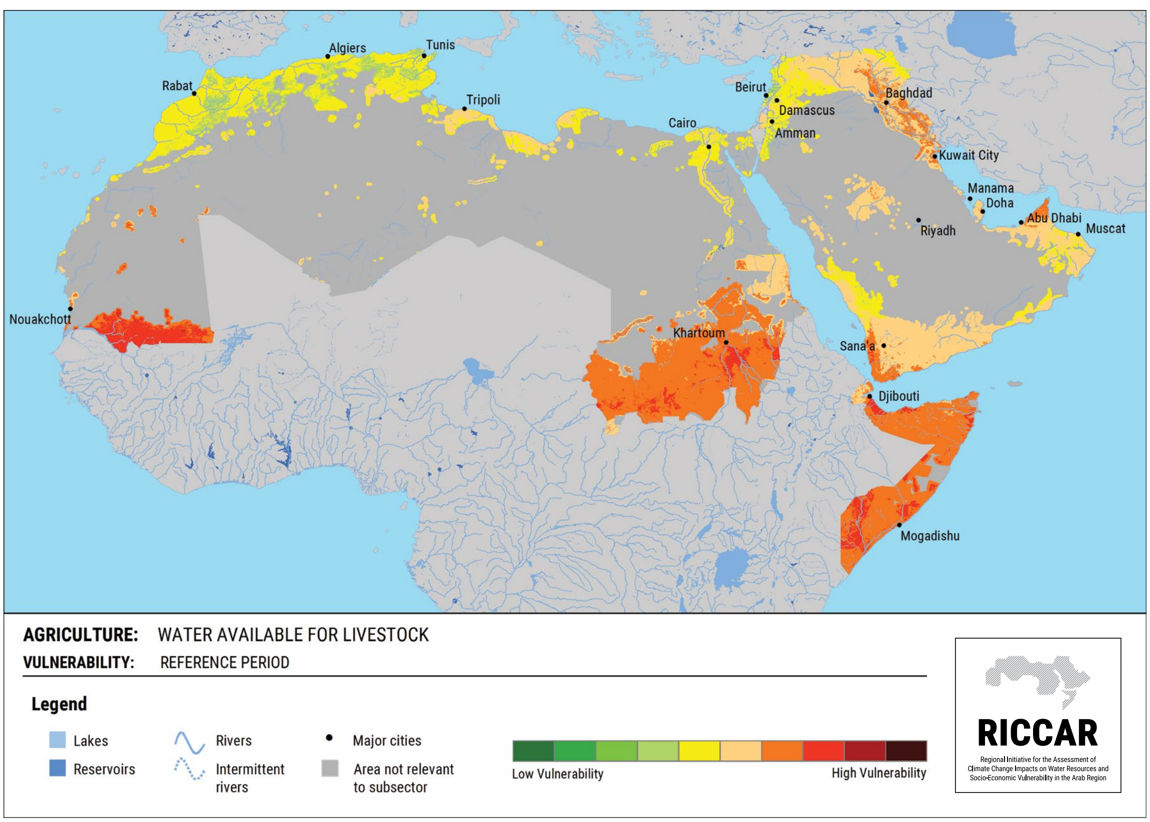
11.2.1.3 Vulnerability

The reference period signifies high vulnerability for 43% of the study area and remaining areas represent moderate vulnerability. Areas with the highest vulnerability include sections of the western Sahel, the Blue Nile River Valley just south of Khartoum, areas along the south Gulf of Aden coastline and areas within the Jubba River basin (Figure 166). Primarily, camels are impacted in the western Sahel and the Jubba River region. Goats, sheep, and cattle are raised in the Blue Nile River Valley and goats and sheep near the Gulf of Aden.

In the eastern Sahel, including the Blue Nile River Valley, livestock have long been faced with water scarcity. The region is characterized by high interannual precipitation variability. A wet phase during the 1950s and 1960s was followed by a dry phase extending into the reference period, including a drought in 1984/1985, which killed a considerable number of livestock. Resultant adaptation to climate variability has included a decreasing number of grazing cattle but an increase in sedentary draught and fattened cattle; expanding herd mobility and grazing/feeding patterns; income diversification; an increasing number of camels; and a movement of herds southwards towards more humid areas. In the Horn of Africa, which includes the southern Gulf of Aden coastline and the Jubba River region, the sector *Water available for livestock* is the largest contributor to local livelihoods. In Somalia, livestock and their products represent about 80% of all exports.[6] However, pastoralists in the region have faced many challenges such as fluctuating rainfall and drought. Drought leads to a decline in commodity prices which adversely impacts the livelihoods of pastoralists.

Livestock in Qadarf, Sudan, 2007. Source: Ihab Jnad.

FIGURE 166: Water available for livestock – Reference period – Vulnerability



11.2.2 Future periods

11.2.2.1 Potential impact

Livestock are subject to adverse impacts due to climate change, including increasing temperatures and declining water resources. Ruminants need increased water uptake in warmer weather. Rangeland areas can also perish. Lastly, disease vectors can multiply in warmer climates affecting animals' health. Changes in climatic variables reveal generally moderate future exposure, signalling 69% (RCP 8.5) to 76% (RCP 4.5) of the study area at mid-century and 53% (RCP 8.5) to 67% (RCP 4.5) at end-century. High exposure is revealed in 3% (RCP 4.5) to 23% (RCP 8.5) of the study area at mid-century and 18% (RCP 4.5) to 47% (RCP 8.5) at end-century. Remaining areas suggest low exposure. Areas with the highest exposure include the upper eastern Sahel, livestock areas in the Sahara Desert and coastal areas near the Gulf of Aden. Conversely, areas with the lowest projected exposure include the coastal Atlas Plains and the Rif region, the lower Tigris–Euphrates basin and the Green Mountains in Libya.

Assuming static sensitivity, a majority of the region signals moderate potential impact for the future. Specifically, at mid-century (Figure 167 and Figure 168), 58% (RCP 4.5) to 74% (RCP 8.5) of the study area reveals moderate potential impact and this increases to 66% (RCP 4.5) to 89% (RCP 8.5) at end-century (Figure 169 and Figure 170). Most other areas suggest low potential impact, although at end-century (RCP 8.5), a trace (1% of the study area) of high potential impact is revealed. Areas with the highest potential impact include the lower Nile River and Delta, the Blue Nile Valley just south of Khartoum and the Asir Mountains. Trend analysis indicates the largest increases in potential impact from mid- to end-century (RCP 4.5) in the western Sahel and the lower Nile Valley. The largest decreases in potential impact under RCP 4.5 include the Tigris–Euphrates basin, Al Hajar Mountains in Oman/UAE and the Shabelle River Valley in the Horn of Africa. For RCP 8.5, the Tigris–Euphrates basin exhibits a decreasing trend in potential impact and the lower Nile Valley shows an increasing trend, but the other areas described (western Sahel, Al Hajar Mountains and the Shabelle River Valley) signal an opposite trend from RCP 4.5.

Potential impact can be significantly impacted by changes in sensitivity to include population growth, differing livestock population and distribution and land degradation. Potential impact can also vary due to factors not evaluated. These include livestock diseases such as Rift valley fever, which have harmed livestock trade between the Horn of Africa and the Arabian Peninsula, which was exacerbated by lack of access to veterinary service.

FIGURE 167: Water available for livestock – Mid-century RCP 4.5 – Potential impact

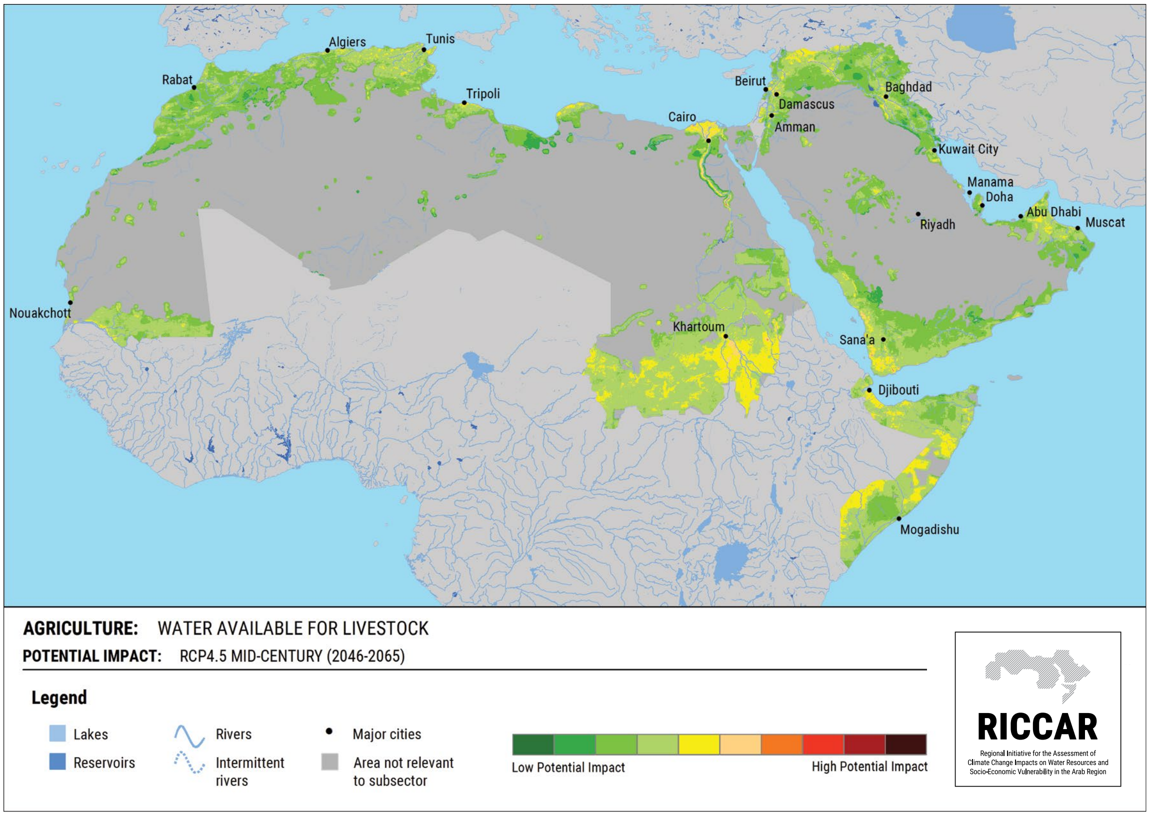


FIGURE 168: Water available for livestock – Mid-century RCP 8.5 – Potential impact

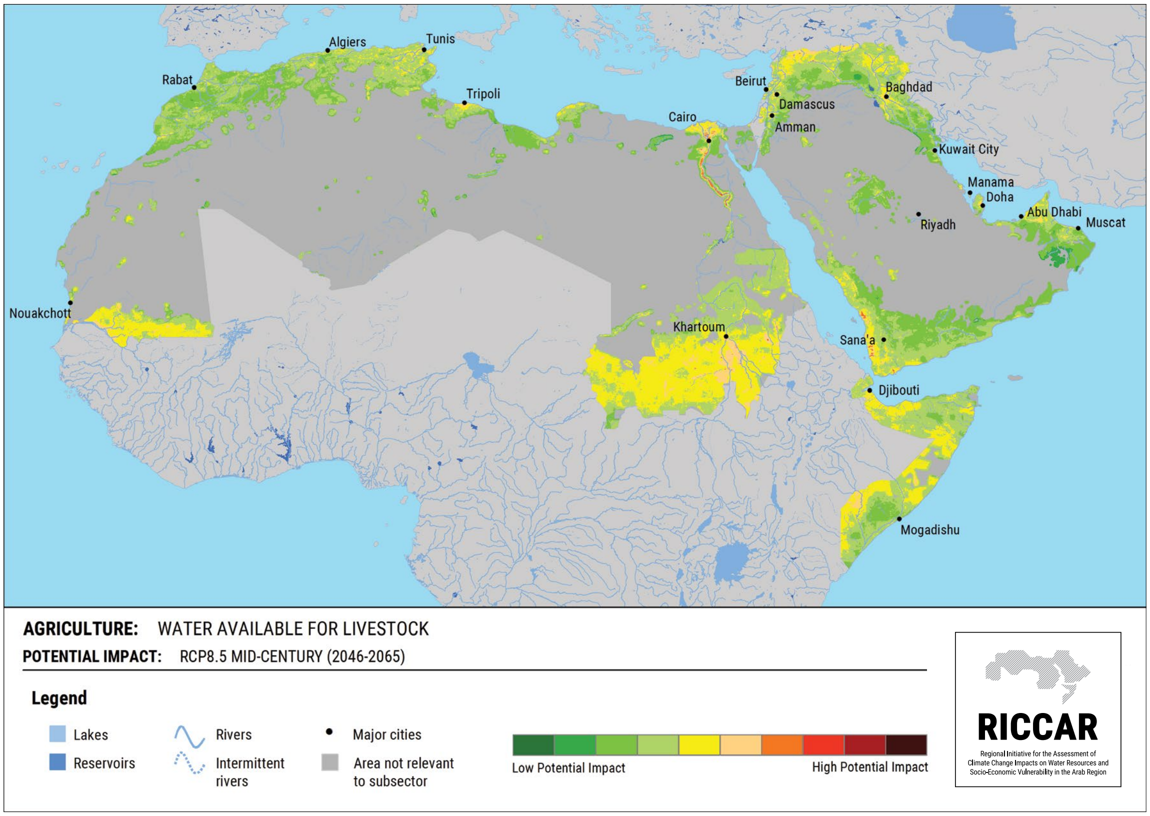


FIGURE 169: Water available for livestock – End-century RCP 4.5 – Potential impact

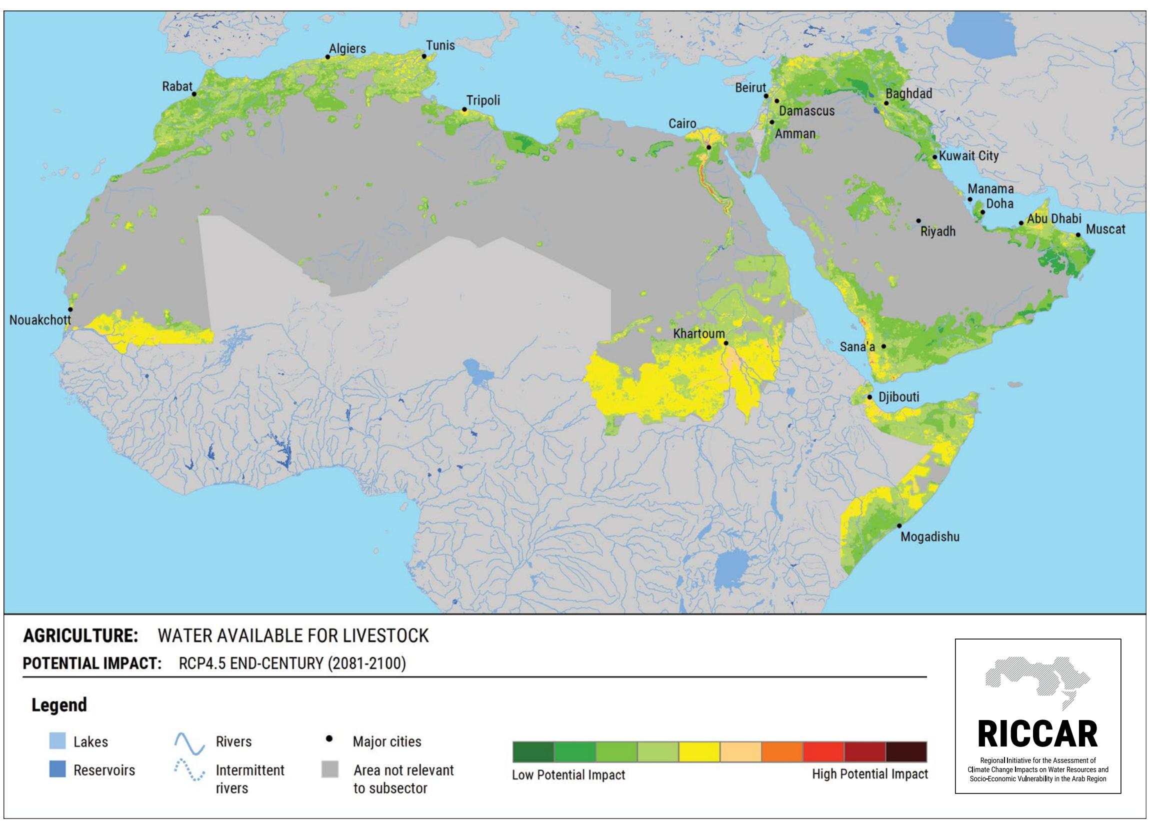
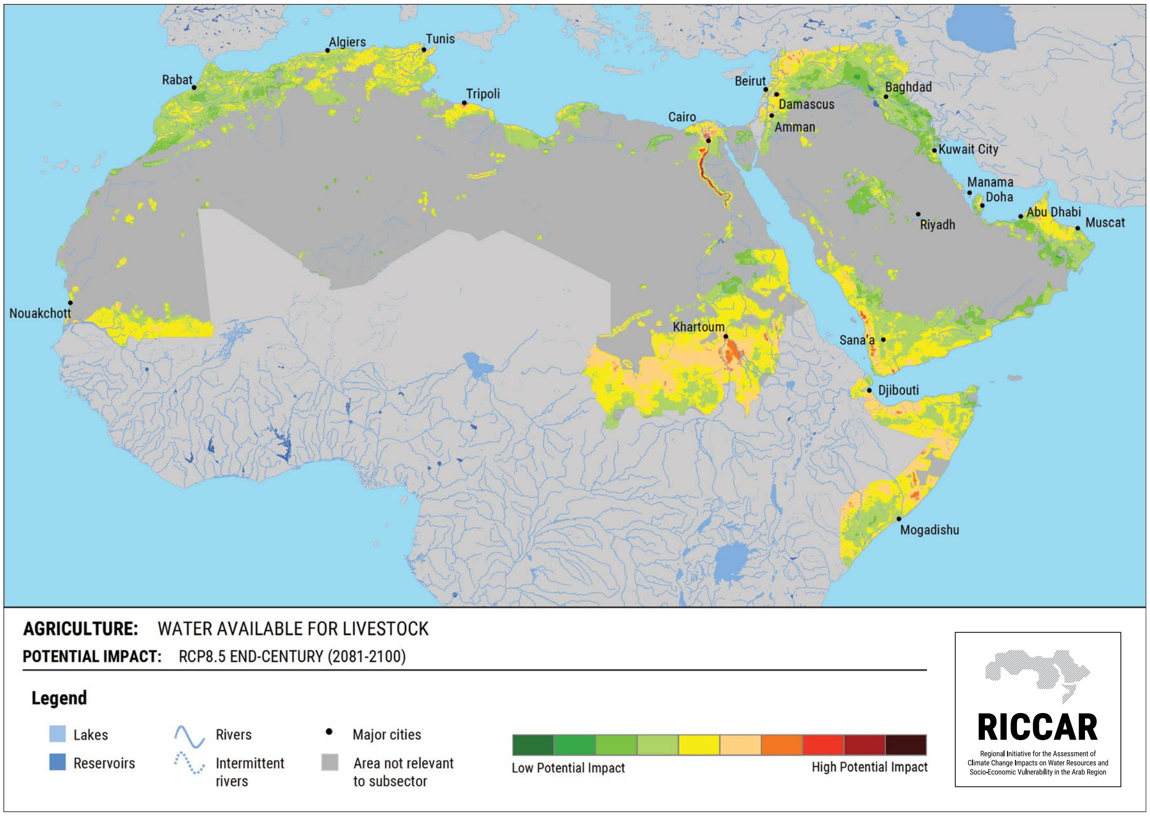


FIGURE 170: Water available for livestock – End-century RCP 8.5 – Potential impact



11.2.2.2 Vulnerability

Projected vulnerability rerated to water availability for livestock is either moderate or high. At mid-century, 33% (RCP 4.5) to 45% (RCP 8.5) of the study area shows high vulnerability and increases to 42% (RCP 4.5) to 54% (RCP 8.5) at end-century (Table 28).

Areas with relatively lower vulnerability tend to be in the Atlas Mountains and Plains and the central Arabian Desert; both exhibit comparatively higher adaptive capacity and lower potential impact. Areas with high vulnerability are located in sub-Saharan Africa, the Levant, the upper Tigris–Euphrates basin and the Al Hajar Mountains (Figure 171 to Figure 174).

Due to dynamic exposure and static sensitivity and adaptive capacity, increasing and decreasing trends in vulnerability tend to be parallel to potential impact trends. Nonetheless, for RCP 4.5, differences between mid- and end-century vulnerability tend to be relatively small, but changes under RCP 8.5 are more pronounced, revealing increasing vulnerability.

Up to 86% of the camel population (Table 29) is located in areas of high vulnerability. Luckily, camels are able to withstand changes in body temperature and water consumption to a much greater extent than other animals; even if they are located in highly vulnerable areas, the resulting impact on camels may be low.

The cattle and goat populations are also to a large extent located in areas of high vulnerability (up to 77% and 72%, respectively) and may be strongly impacted by changes in water availability. Sheep, however, are mostly located in areas of moderate vulnerability (up to 67%).

Vulnerability can be reduced by adopting adaptive capacity measures, often based on applied agricultural research. These can include methods to enhance knowledge and awareness. Integrated crop livestock systems, agroforestry systems and crop–aquaculture systems can help to promote agricultural diversification. Finally, improved water infrastructure can benefit intensive livestock farming.

TABLE 28: Percentage of study area by vulnerability classification for water availability for livestock

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	0%	67%	33%
Mid-Century RCP 8.5	0%	55%	45%
End-Century RCP 4.5	0%	58%	42%
End-Century RCP 8.5	0%	46%	54%

TABLE 29: Percentage of ruminant population by vulnerability classification for each projected scenario

Ruminant	Climate scenario	Percentage of population by vulnerability classification	
		Moderate	High
Camels	Mid-Century RCP 4.5	35%	65%
	Mid-Century RCP 8.5	21%	79%
	End-Century RCP 4.5	25%	75%
	End-Century RCP 8.5	14%	86%
Cattle	Mid-Century RCP 4.5	34%	66%
	Mid-Century RCP 8.5	27%	73%
	End-Century RCP 4.5	29%	71%
	End-Century RCP 8.5	23%	77%
Goats	Mid-Century RCP 4.5	44%	56%
	Mid-Century RCP 8.5	37%	63%
	End-Century RCP 4.5	39%	61%
	End-Century RCP 8.5	28%	72%
Sheep	Mid-Century RCP 4.5	67%	33%
	Mid-Century RCP 8.5	61%	39%
	End-Century RCP 4.5	64%	36%
	End-Century RCP 8.5	52%	48%

FIGURE 171: Water available for livestock – Mid-century RCP 4.5 – Vulnerability

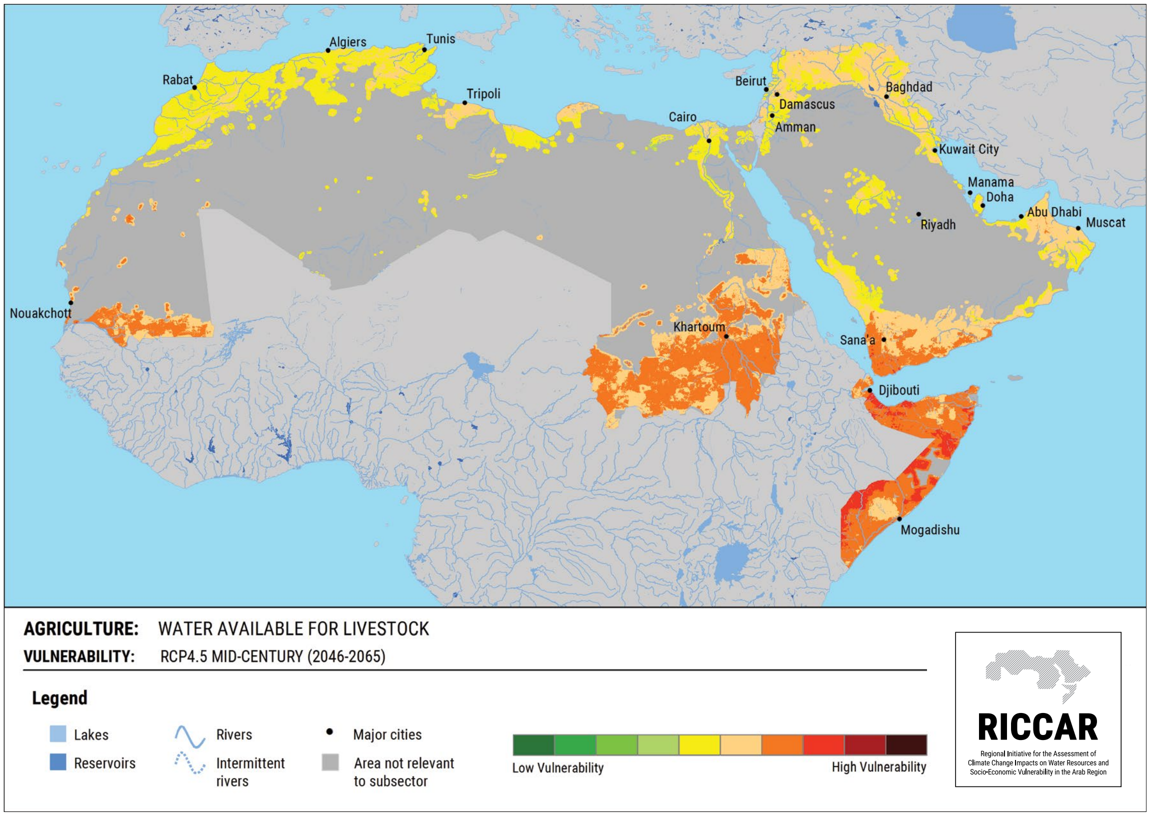


FIGURE 172: Water available for livestock – Mid-century RCP 8.5 – Vulnerability

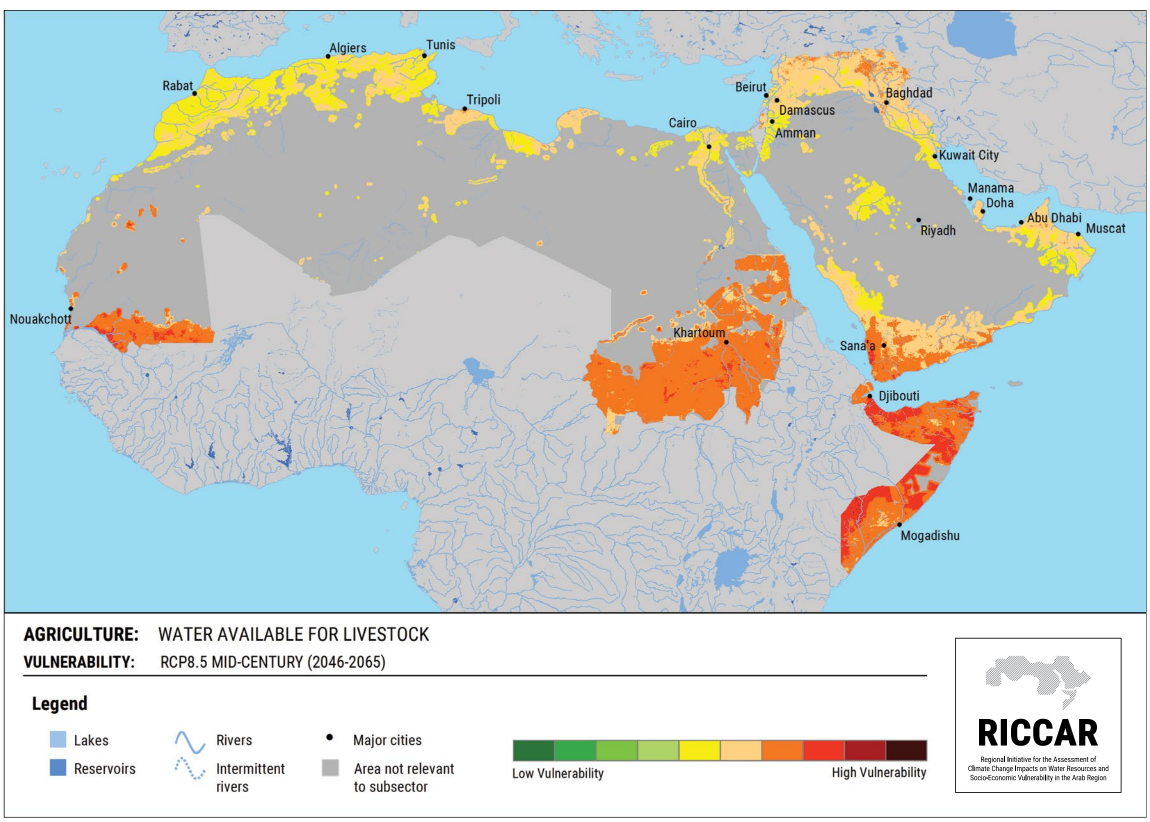


FIGURE 173: Water available for livestock – End-century RCP 4.5 – Vulnerability

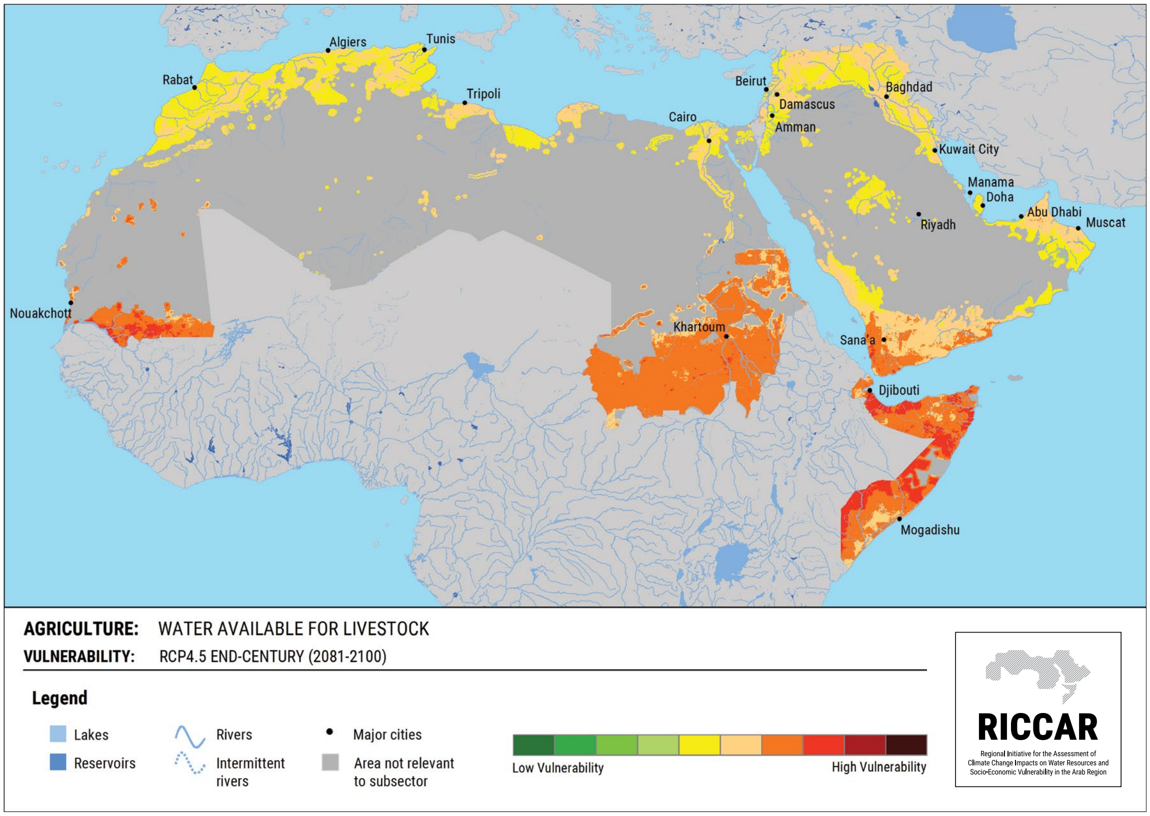
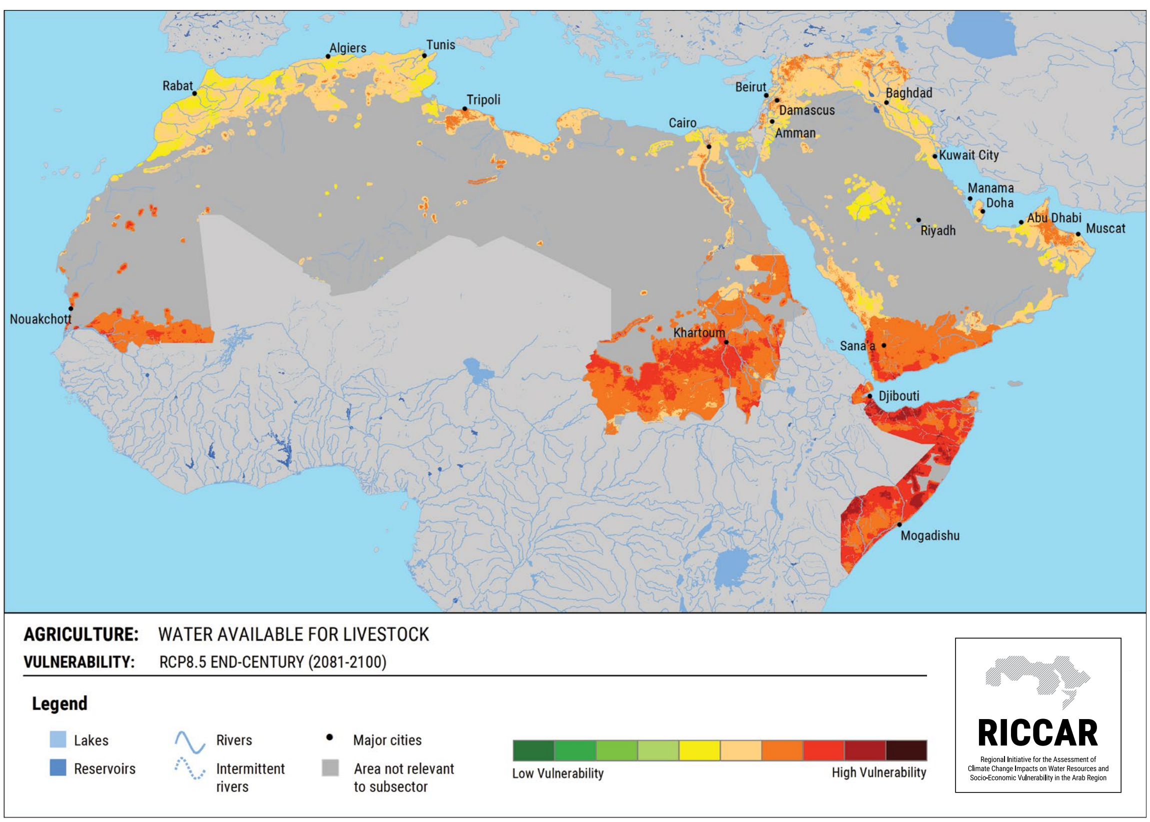


FIGURE 174: Water available for livestock – End-century RCP 8.5 – Vulnerability



11.2.3 Hotspots

Hotspots are those livestock areas subject to the highest projected vulnerability in terms of water availability. Up to 12% of the study area has been designated as hotspots, some of which are the Sahel, the south western Arabian Peninsula and the Horn of Africa.

All include a high camel population at present. Cattle and sheep tend to be confined to the eastern Sahel and the south-western Arabian Peninsula and goats are prevalent in all hotspots other than the western Sahel.

Severe vulnerability with regard to water availability for livestock can have detrimental impacts. During periods of drought, farmers are often forced to sell animals; in extreme cases, this means selling breeding stock, which constitute rural household wealth.

Insufficient fodder compels pastoralists to move to other rangelands, which can exacerbate land degradation in those areas. An option for sedentary herds is to buy hay or straw from irrigated farms or commercial traders.

11.3 AGRICULTURE SECTOR: OVERALL VULNERABILITY

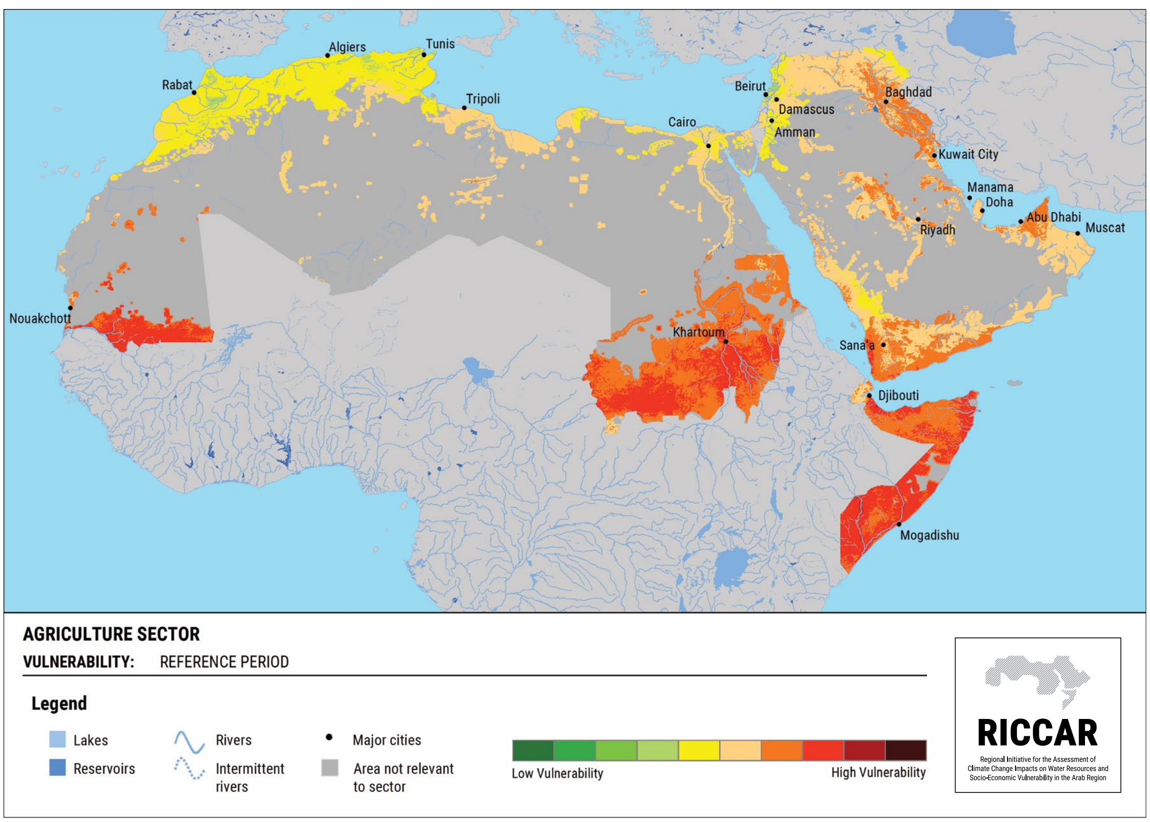
11.3.1 Reference period

Vulnerability for the *Agriculture* sector represents the equal aggregation of vulnerability obtained from the *Water available for crops* and *Water available for livestock* subsectors.

For the reference period, areas of moderate and high vulnerability represent 51% and 49% of the study area, respectively. Agricultural areas representing the highest relative vulnerability are the southern Horn of Africa and the Sahel, which includes both cropland and livestock areas (Figure 175).

Agriculture vulnerability signals a strong correlation with both subsectors but, of the two, the relationship is greater with water available for livestock. Thus, the threats on livestock have a greater impact on overall threats on agriculture.

FIGURE 175: Agriculture sector – Vulnerability – Reference period



11.3.2 Future periods

11.3.2.1 Vulnerability

As for 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 (Table 30). 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 as shown in Figure 176 to Figure 179. 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.

TABLE 30: Percentage of study area by vulnerability classification for the agriculture sector

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	0%	57%	43%
Mid-Century RCP 8.5	0%	51%	49%
End-Century RCP 4.5	0%	54%	46%
End-Century RCP 8.5	0%	42%	58%

FIGURE 176: Agriculture sector – Vulnerability – Mid-century RCP 4.5

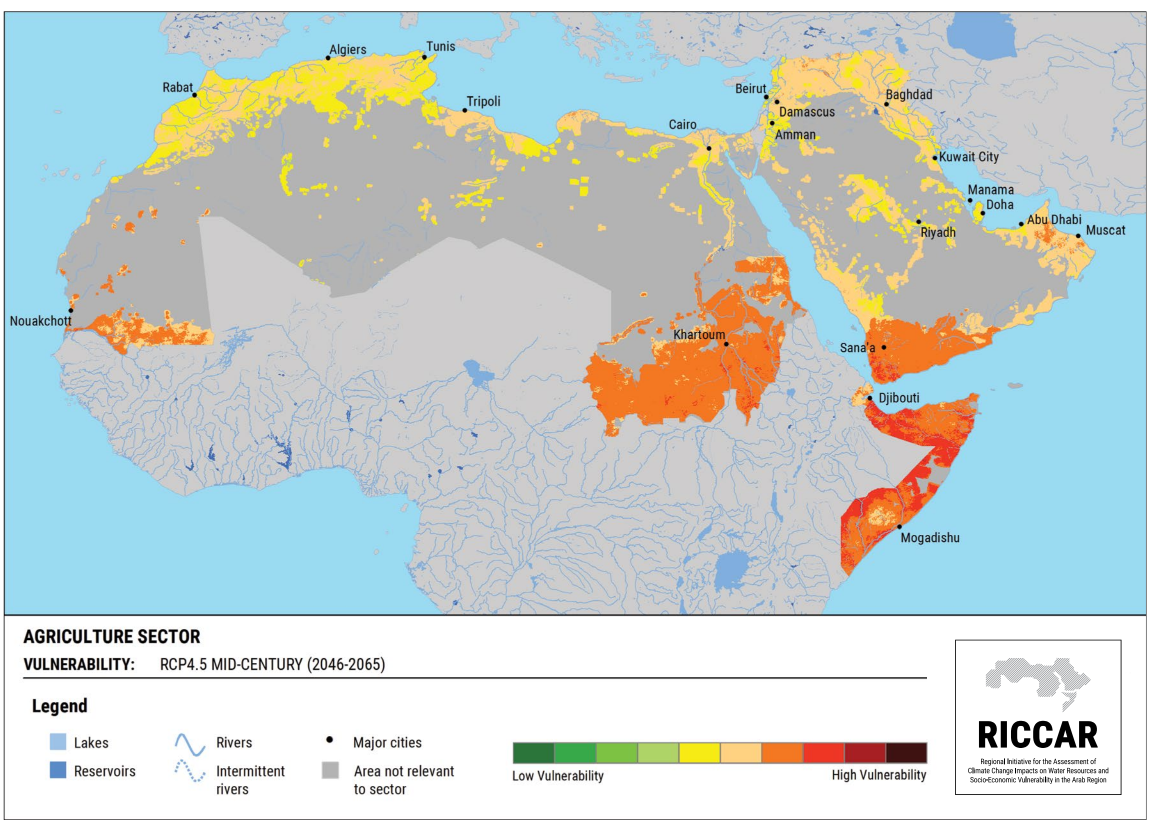


FIGURE 177: Agriculture sector – Vulnerability – Mid-century RCP 8.5

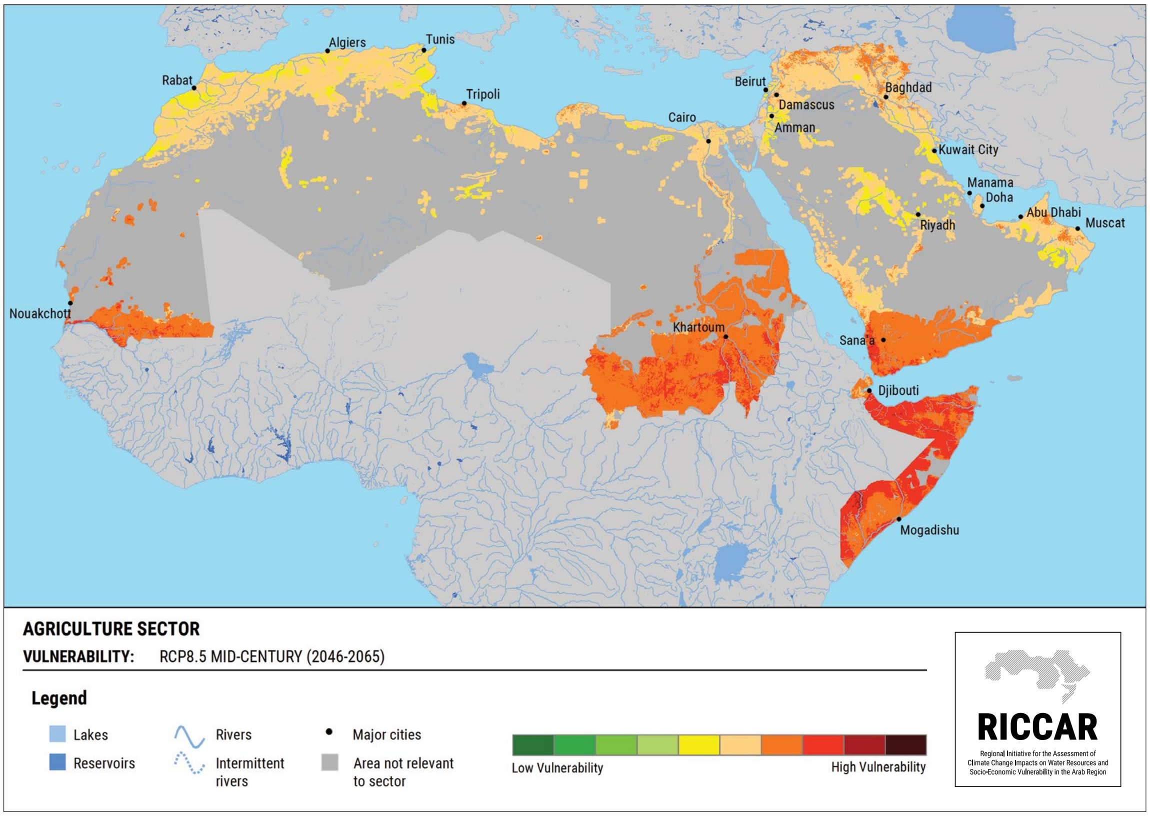


FIGURE 178: Agriculture sector – Vulnerability – End-century RCP 4.5

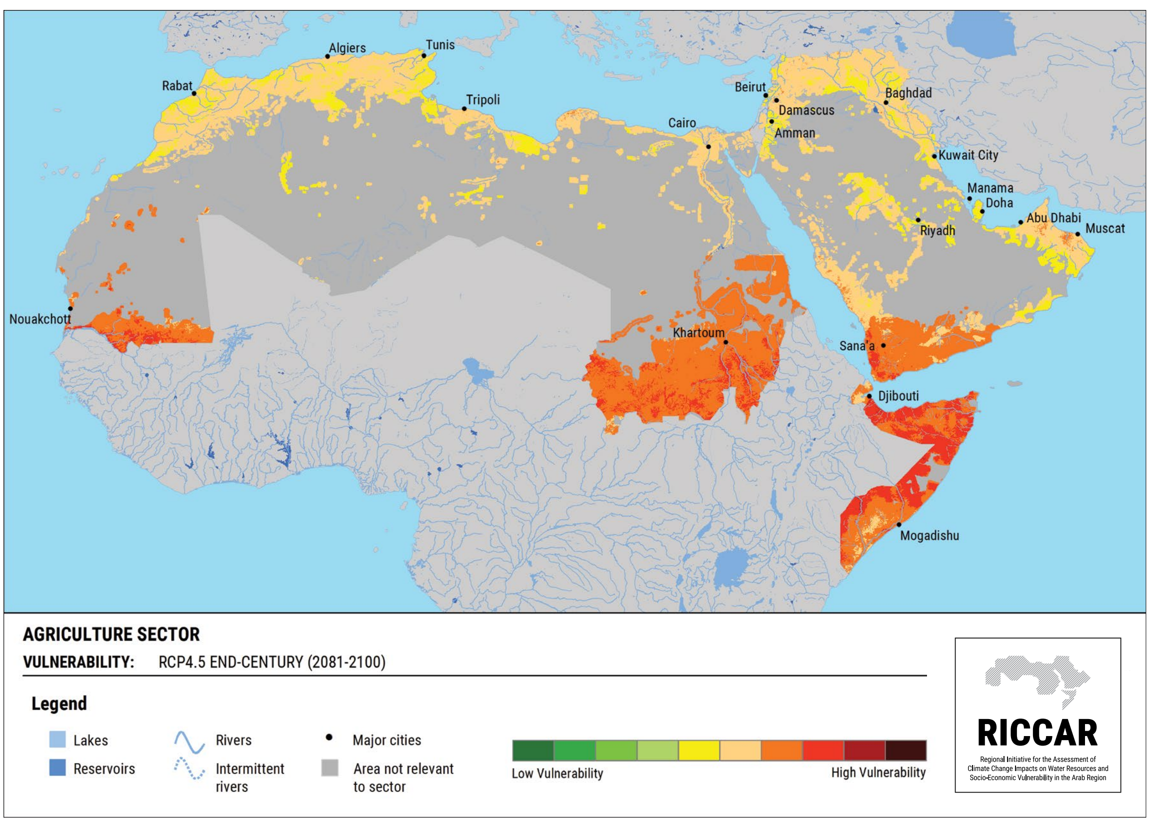
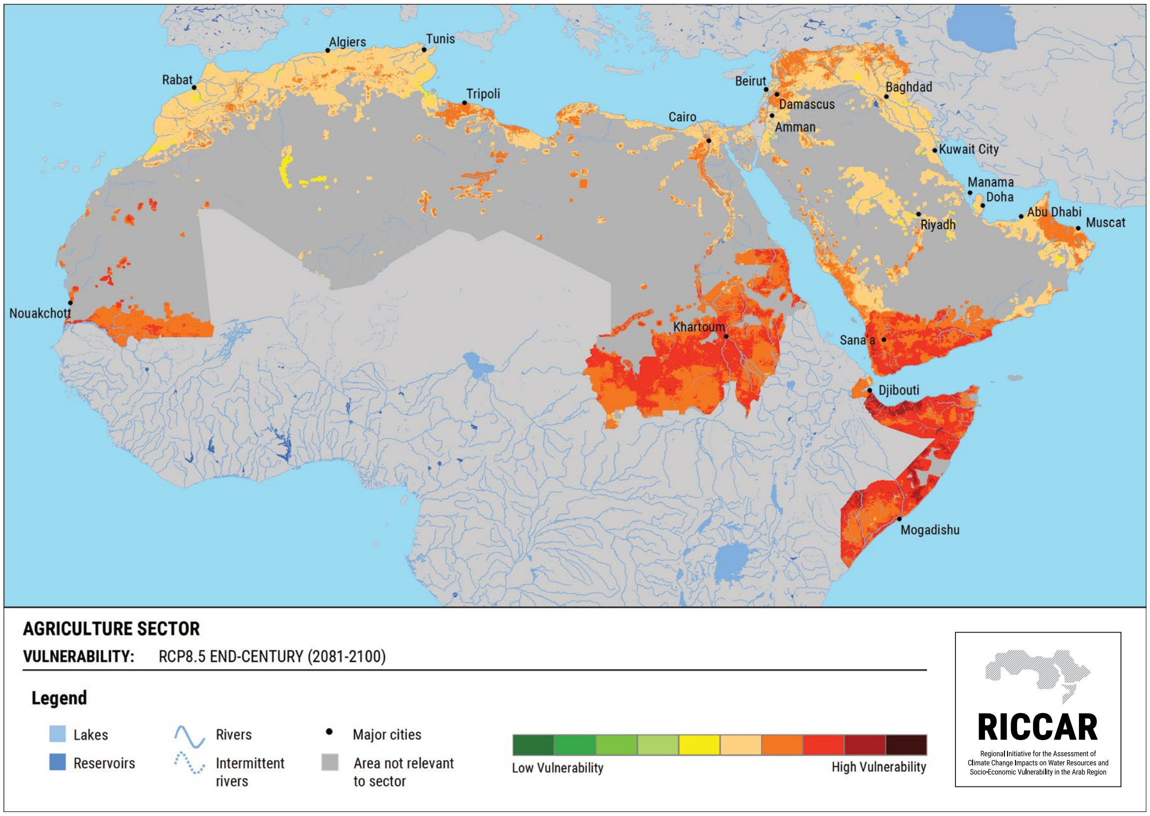


FIGURE 179: Agriculture sector – Vulnerability – End-century RCP 8.5



11.3.3 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.[7] 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.

ENDNOTES

1. Hoekstra and Hung, 2002
2. Chapagain and Hoekstra, 2003
3. FAO, 2017b
4. Ibid.
5. For example, see GEF and UNEP, 2016
6. FAO, 2017c
7. FAO, 2017a

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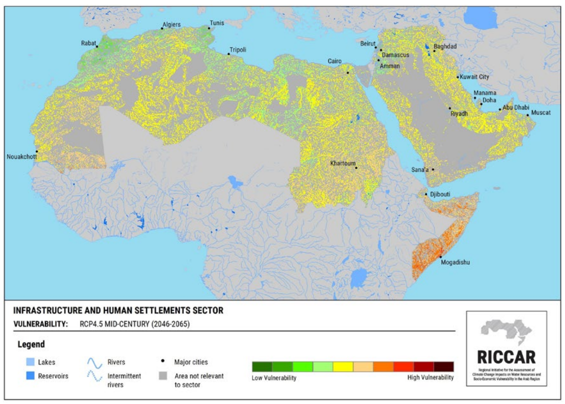
INFRASTRUCTURE AND HUMAN SETTLEMENTS SECTOR

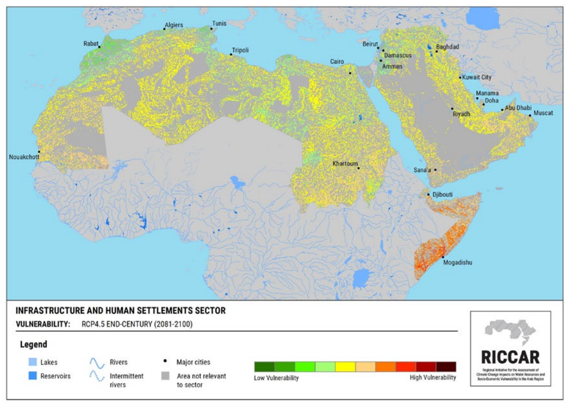
OVERALL VULNERABILITY

RCP 4.5

2046-2065

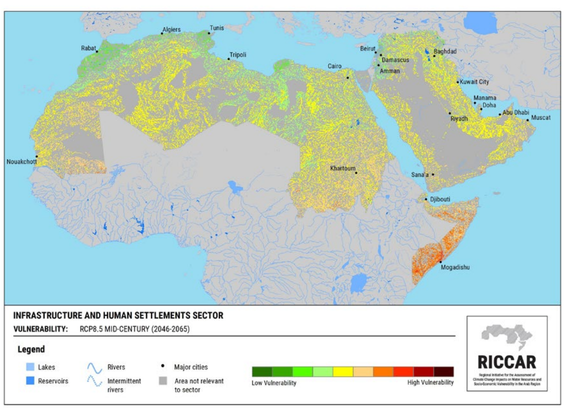


2081-2100

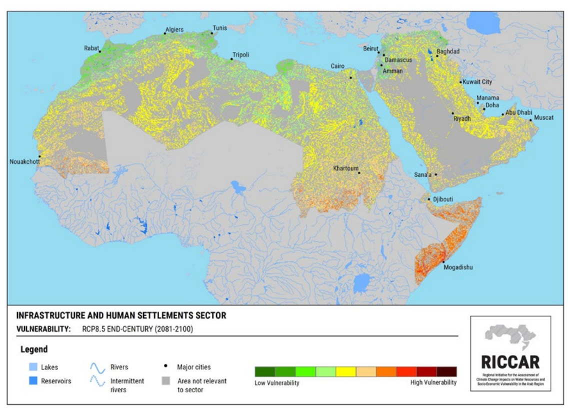


RCP 8.5

2046-2065



2081-2100



CHAPTER 12

INFRASTRUCTURE AND HUMAN SETTLEMENTS SECTOR – VULNERABILITY

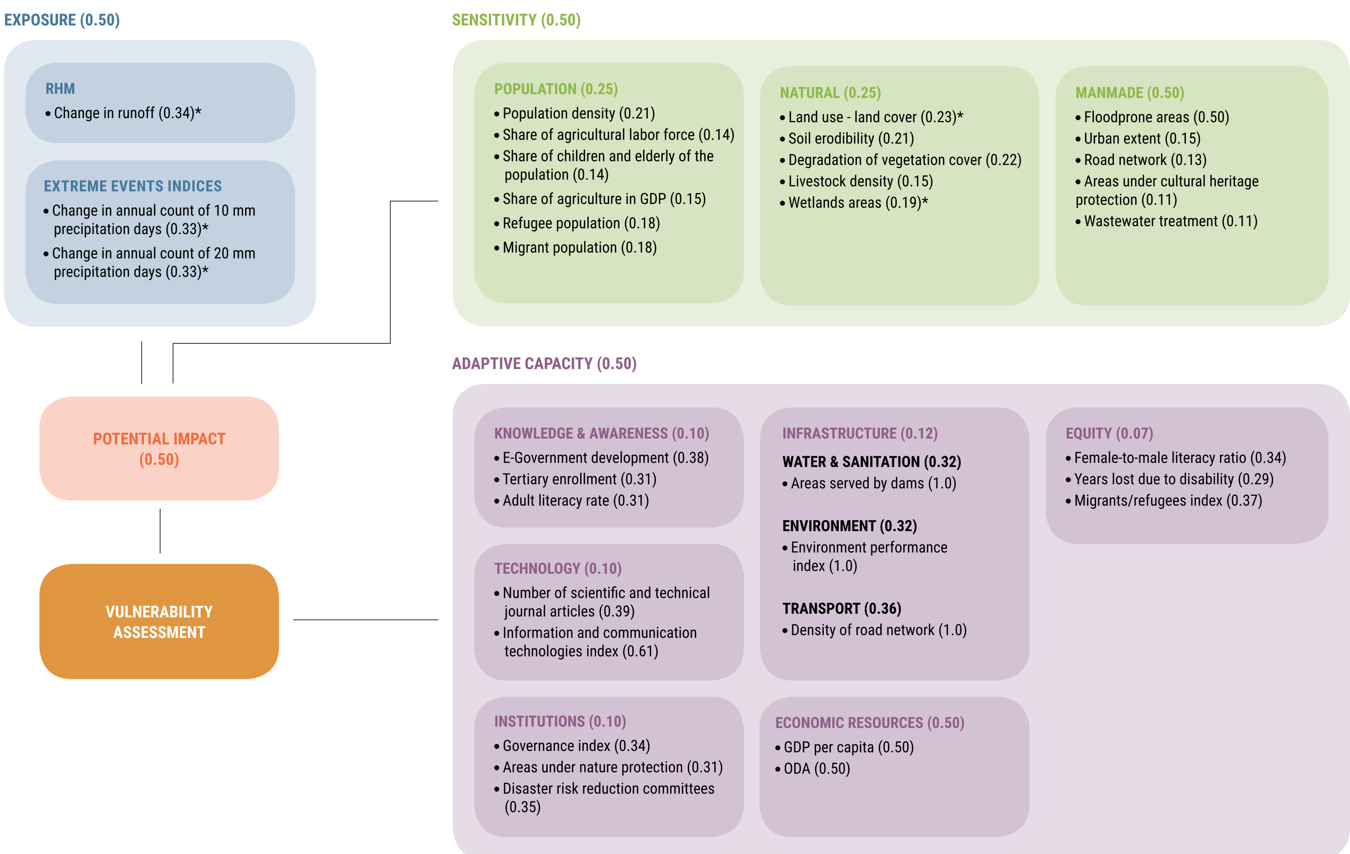
The Arab region has experienced unprecedented population growth over recent decades, with over half of the population now residing in urban areas.[1] Many of the urban centres are located along the coastline or along riverbanks, such as those of the Nile and Euphrates. Given the extent of the urban environment and the underdevelopment of stormwater networks in what is predominately an arid and semi-arid region, a particular challenge for these highly populated areas is to cope with the effects of flood events, including flash floods, due to extreme weather events. Low-lying coastal areas, deltas and artificial lands extending beyond the natural coastline are also sensitive to sea-level rise. The *Change in inland flooding area* was thus selected as a key climate change impact in the integrated assessment for the region. It should be noted that the outputs of regional climate models do not model sea-level rise and thus projections generated from GCMs would be necessary to assess the potential impacts of sea-level rise on coastal zones. Moreover, high-resolution digital elevation models (DEMs) are needed to conduct such analysis based on the climate change scenarios currently adopted by the IPCC and the required DEMs are not available at present. Vulnerability assessment results and findings for this sector are presented hereafter.

Because there is only one subsector included in the *Infrastructure and human settlements* sector, vulnerability assessment maps are assumed to be identical and are thus not included at the sector level. The study area is based upon the floodprone areas indicator, selecting all areas with low or greater flood potential and includes 32% of the Arab region. Areas with very low flood potential are not considered as part of the study area.

12.1 INLAND FLOODING AREA

The impact chain highlighting the different indicators and weights for this subsector is presented in Figure 180.

FIGURE 180: Impact chain and weights for inland flooding area



12.1.1 Reference period

12.1.1.1 Potential impact

Potential impact reflects the flood threats stemming from exposure and sensitivity. Arid and semi arid territories such as the Arab region are subject to inland flooding events which can threaten life, property and infrastructure. Yet, precipitation and runoff from larger events can be beneficial to replenish groundwater aquifers and other water resources. Flood risk is exacerbated once the water balance is upset by ongoing water scarcity coupled with extreme runoff. Heavy rainfall events can also jeopardize the water balance and pose a flood threat. For these reasons, runoff and the number of both heavy and very heavy precipitation days (R10 and R20, respectively) were selected as exposure indicators, which have been classified such that greater rainfall signifies higher exposure.

Most of the study area (89%) signals low exposure for the reference period. Only 9% indicates moderate exposure and remaining areas suggest high exposure. Areas with the highest exposure include the Rif region, the coastal Levant and the Zagros Mountains. Note that exposure is based on annual average parameters and can vary widely if seasonal effects are considered. Flooding is largely a function of precipitation duration and intensity. One extreme event can result in disaster, even if the average rainfall throughout the year is relatively low.

Sensitivity to inland flooding vulnerability is multi-faceted. The most important indicator evaluated, based on its respective weight, is floodprone areas, defined by a modelling study and historical flood events. Other indicators classified under the man-made dimension are also relevant: urban extent, road network, cultural heritage areas and wastewater treatment. Urban areas are more sensitive to flooding due to impervious areas and adequacy of stormwater drainage. Road networks are affected by flood risk because planned trips and evacuation routes may be flooded or available routes may be congested from traffic diversion. Damage to cultural heritage sites, such as UNESCO World Heritage Sites, induces adverse impacts upon local and national communities due to their significance and socio-economic value. Lastly, faulty wastewater treatment systems can increase pollution risks stemming from floods.

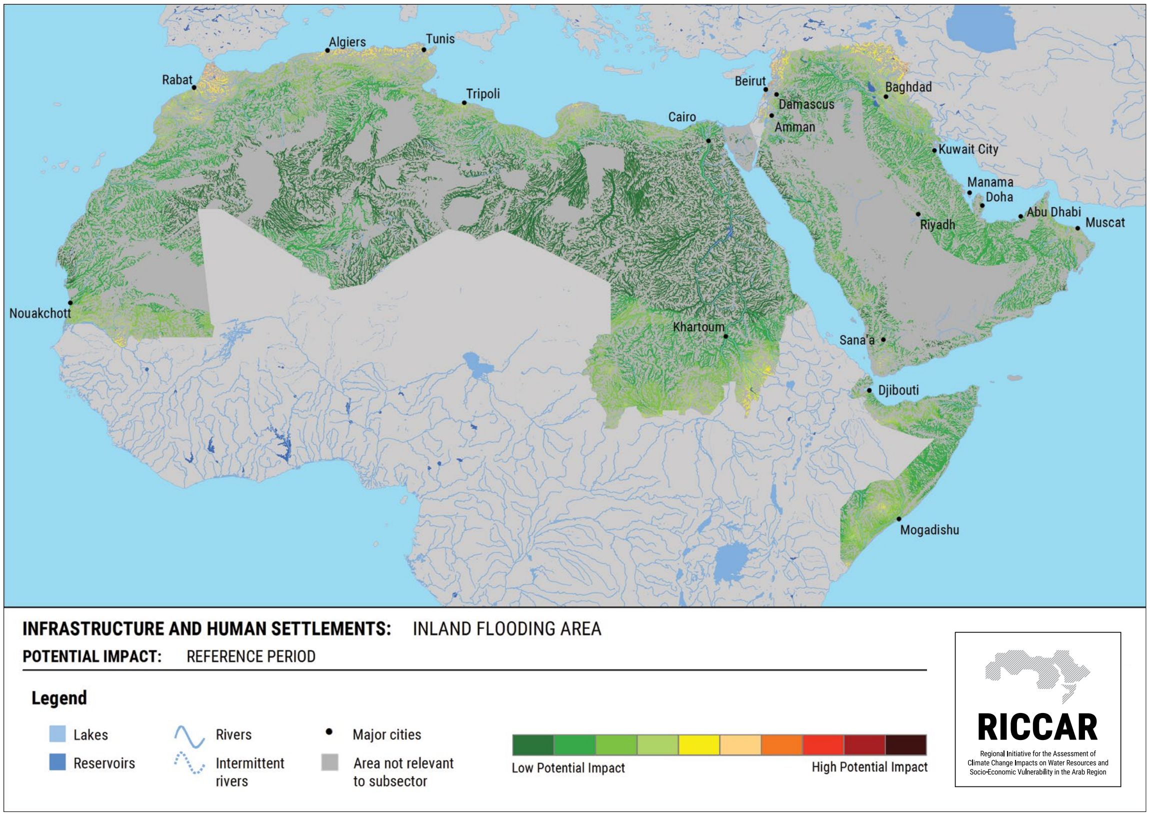
Inland flooding is also sensitive to population and natural elements. While the general population and structure are vulnerable to flooding, certain demographics are particularly susceptible to impacts such as children, the elderly and migrants and refugees who may reside in substandard housing. In terms of natural indicators, certain landscapes and soils are more prone to flood damage. Flooding of agricultural and rangeland areas can inflict economic losses but wetland areas, also considered, can benefit from floods.

A majority of the study area (89%) is indicative of low sensitivity to inland flooding for the reference period. Most remaining areas are classified with moderate sensitivity and include major river valleys throughout the Arab region. High-sensitivity areas are negligible. Sensitivity was limited by data availability and can vary widely if other parameters are considered, including distribution of wealth, design and quality of construction, household demographics and terrain elevation and slope.

Resultant potential impact for the reference period is low overall, covering 91% of the study area (Figure 181). Moderate areas represent most of the remaining region, while high potential impact is negligible. Areas with greater potential impact include coastal areas near the Mediterranean, such as the Rif region. This area has been afflicted by several flood events: one in May 2003 resulted in over 20 deaths.[2] Another coastal area with increased potential impact is the Levant, west of Mount Lebanon, which was subjected to at least 77 flood and flash-flood events during the reference period, including one in December 1987, which necessitated evacuation.[3] Lastly, the Nahr Diyala watershed in the Zagros Mountains is an area of higher potential impact.

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

FIGURE 181: Inland flooding area – Reference period – Potential impact



12.1.1.2 Adaptive capacity

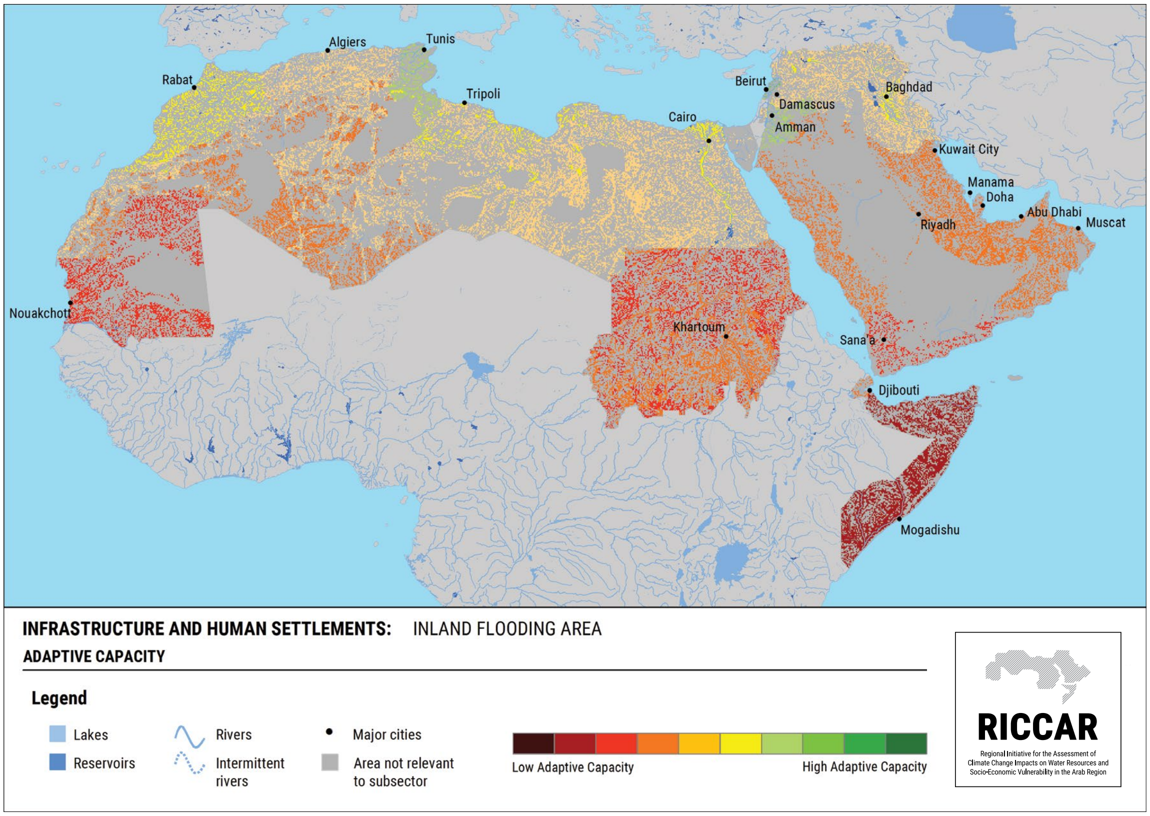
Sixteen different adaptive capacity indicators were selected, many of which can be considered proxies for typical structural and non-structural flood mitigation measures. Structural measures, including dams, channels, levees and improved construction, are considered part of the infrastructure dimension.

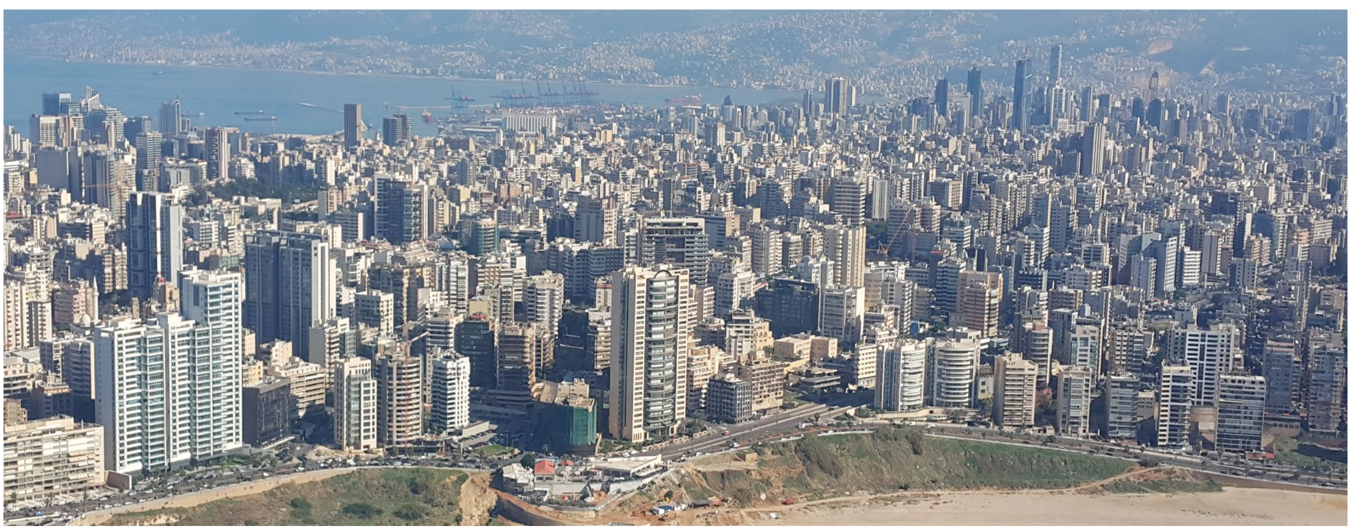
Non-structural measures, such as hazard forecasting, emergency plans, land-use planning and risk mapping, are incorporated under knowledge and awareness, technology, institutions and equity. Both types are dependent on economic resources; this dimension and its respective indicators have the largest weight for this component (see Figure 180).

A majority of the study area (73%) suggests moderate adaptive capacity for inland flooding, while a quarter (25%) indicates low adaptive capacity. Remaining areas reveal high adaptive capacity relative to the region. Areas with lower adaptive capacity include wadis and streams in sub-Saharan Africa and the south-western Arabian Peninsula (Figure 182).

Merowe Dam, Sudan, 2009. Source: Ihab Jnad.

FIGURE 182: Inland flooding area – Adaptive capacity





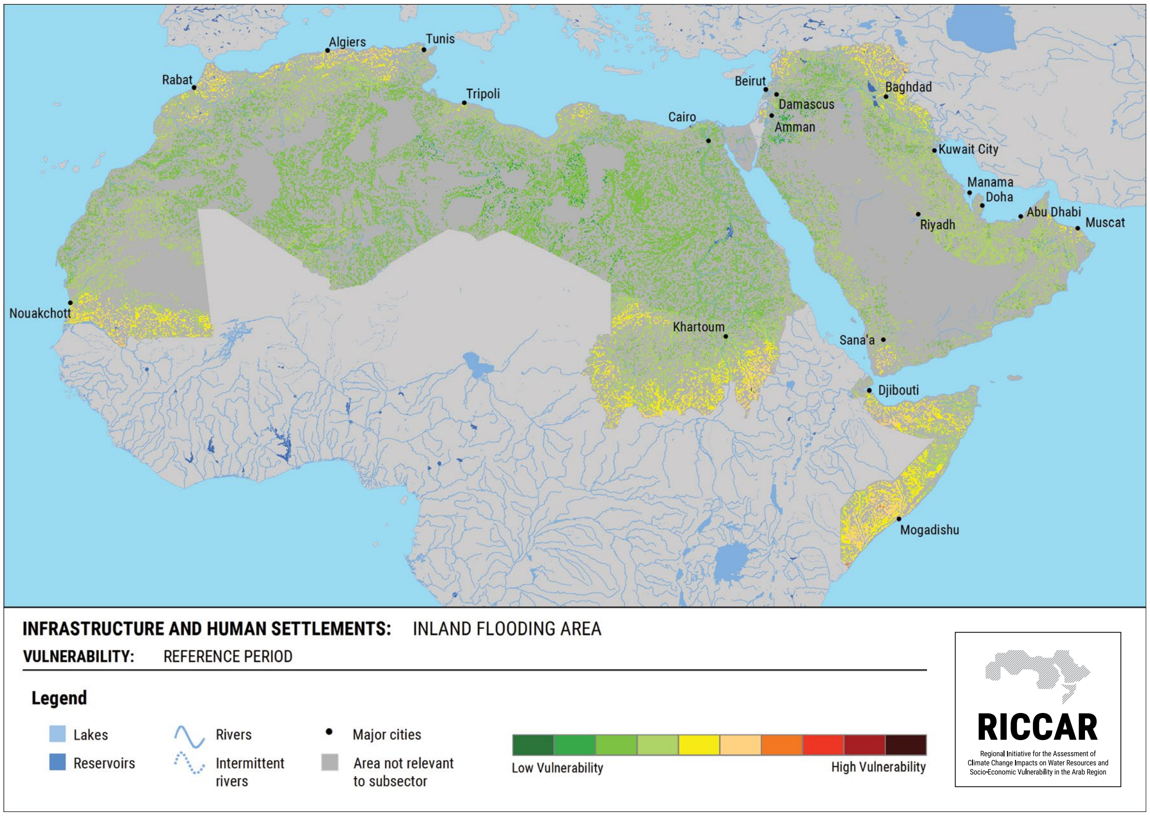
Beirut, Lebanon, 2015. Source: Carol Chouchani Cherfane.

12.1.1.3 Vulnerability

Vulnerability in this context indicates a combination of flood threat and the capability to cope therewith. Vulnerability for the reference period indicates a nearly even split between low and moderate vulnerability (48% and 52% of the study area, respectively).

Areas of high vulnerability are negligible. Locations with the highest vulnerability include the Senegal River middle valley, the Blue Nile watershed, and Bahr al Arab floodplains in the Sahel, the lower Orontes River floodplain in the Levant, tributary floodplains of the Tigris River, Red Sea coastal drainage in the south-western Arabian Peninsula, coastal drainage in the northern Horn of Africa, the Jubba and Shabelle river floodplains, the Rif region, and the Tell Atlas region (Figure 183).

FIGURE 183: Inland flooding area – Reference period – Vulnerability



12.1.2 Future periods

12.1.2.1 Potential impact

Projected flood risk is uncertain but various factors signal an increase in the Arab region, despite declining rainfall in some areas. Areas of low exposure, which is based on precipitation and number of heavy and very heavy precipitation days, generally reflect areas with decreasing precipitation at 5% of the study area at mid-century (RCP 4.5 and RCP 8.5) and 4% (RCP 4.5) to 7% (RCP 8.5) at end-century. Moderate exposure tends to indicate areas where precipitation is nearly unchanging from the reference period and includes 75% (RCP 8.5) to 79% (RCP 4.5) of the study area at mid-century and 60% (RCP 8.5) to 71% (RCP 4.5) at end-century. Lastly, areas of high exposure are those where precipitation is increasing and represent 16% (RCP 4.5) to 20% (RCP 8.5) of the study area at mid-century and 25% (RCP 4.5) to 34% (RCP 8.5) at end-century. Areas with the highest exposure vary by climate scenario but consistently include the floodplains of the Jubba and Shabelle rivers and the lower Tindouf basin.

Potential impact, the combination of exposure and sensitivity, is largely moderate. For mid-century, 73% (RCP 8.5) to 83% (RCP 4.5) of the study area indicates moderate potential impact (Figure 184 and Figure 185). Similarly, at end-century, 76% (RCP 8.5) to 79% (RCP 4.5) of the study area suggests moderate potential impact (Figure 186 and Figure 187). Remaining areas point towards low potential impact. Areas of high potential impact are negligible. Those with the highest potential impact are the middle valley of the Senegal River, the Jubba–Shabelle river floodplains, and the Bahr el Arab floodplain in the eastern Sahel. Conversely, areas with the lowest potential impact relative to the region include the Atlas Mountains and coastal plain, the Jafara Plain, the Green Mountains, the coastal Levant and the Zagros Mountains.

Changes in sensitivity can substantially transform projected potential impact. These include changes in the watershed, such as increased urbanization, which results in an increase in impervious area. Increased urbanization and migration can contribute to a rise in substandard housing which may be constructed on floodplains. Lastly, a rise in certain population groups such as children, women, the elderly and the disabled, will need differing needs to be considered concerning evacuation, shelter, relief distribution and flood recovery.

FIGURE 184: Inland flooding area – Mid-century RCP 4.5 – Potential impact

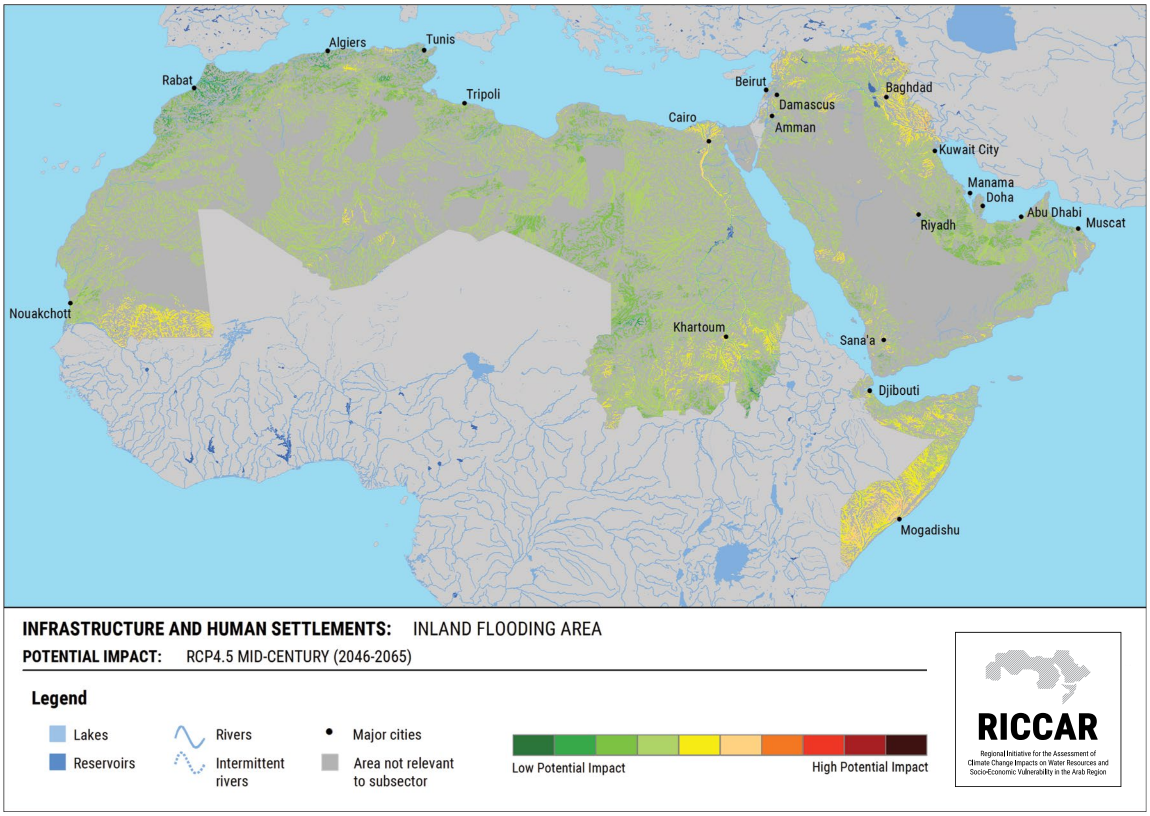


FIGURE 185: Inland flooding area – Mid-century RCP 8.5 – Potential impact

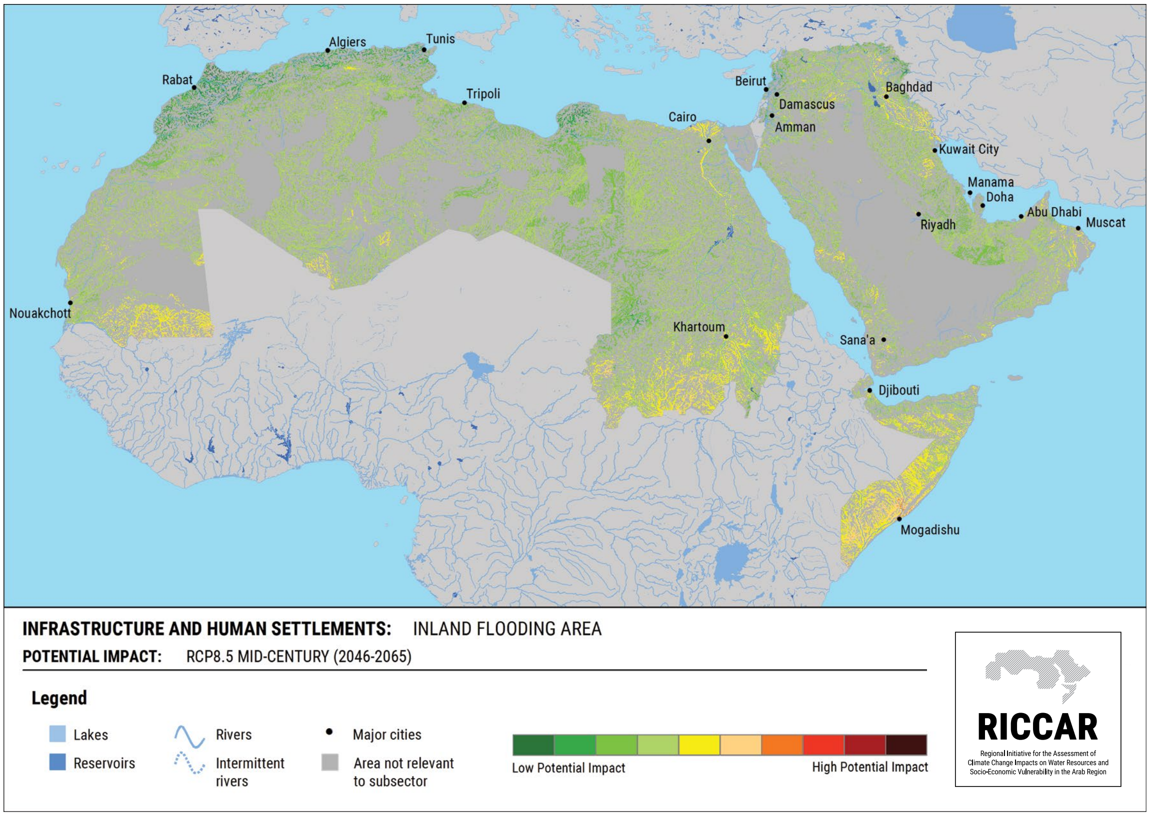


FIGURE 186: Inland flooding area – End-century RCP 4.5 – Potential impact

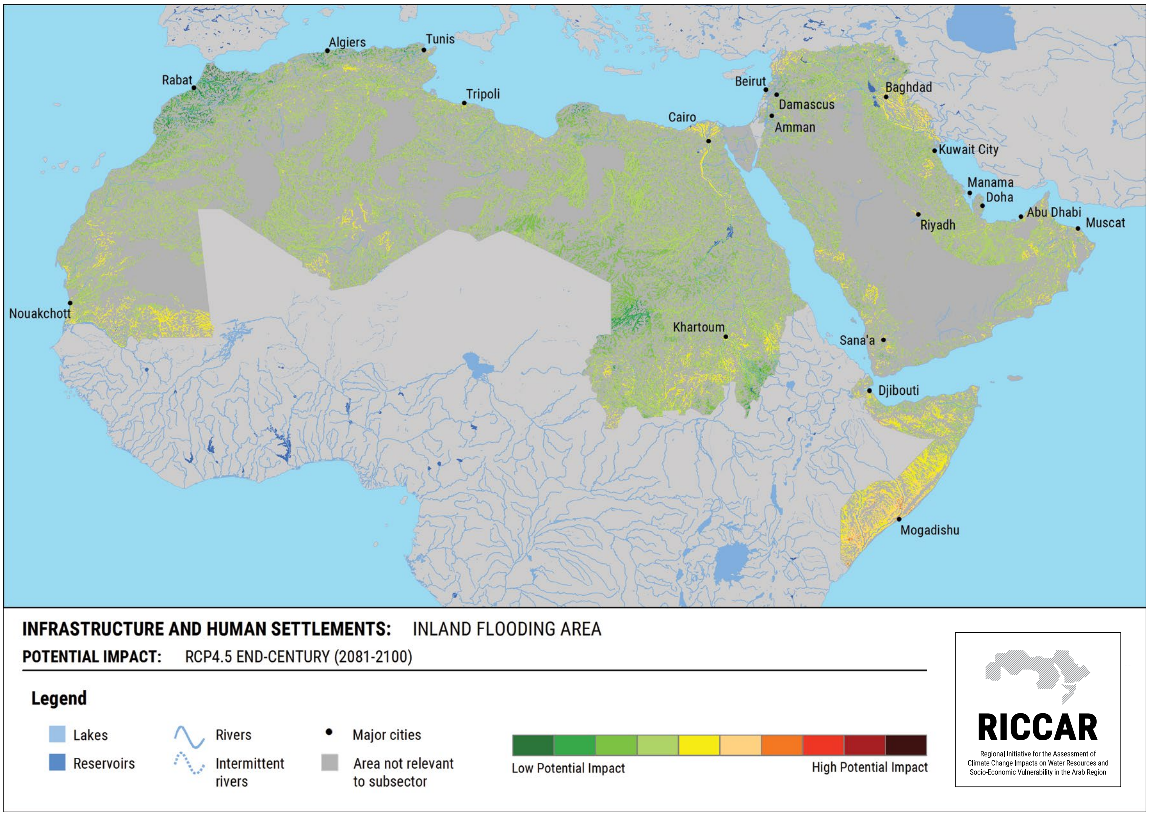
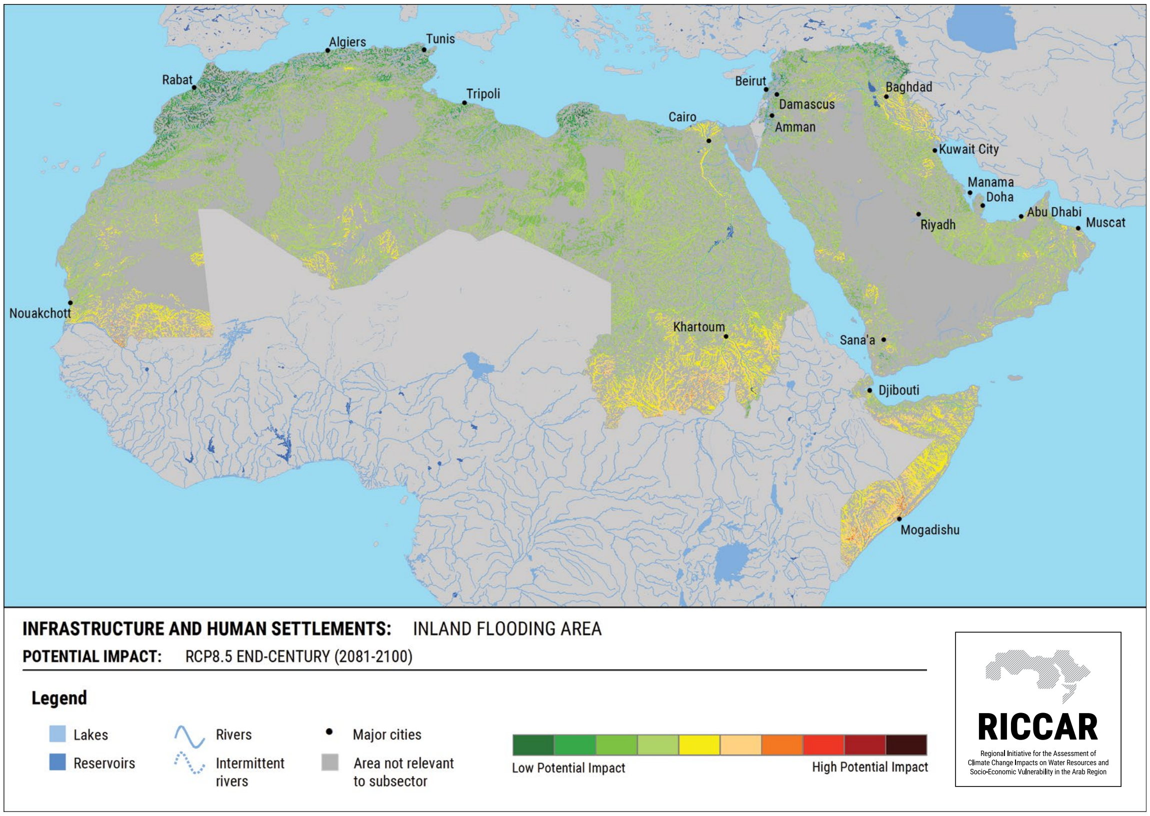


FIGURE 187: Inland flooding area – End-century RCP 8.5 – Potential impact



12.1.2.2 Vulnerability

Vulnerability is expected to increase in the region, particularly in urban areas, if there is little improvement in poverty reduction, disaster preparedness and improved construction standards. Assuming there are no changes in sensitivity or adaptive capacity, most of the study area (about 90%) suggests moderate vulnerability for all scenarios (Table 31). 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 (Figure 188 to Figure 191).

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.

TABLE 31: Percentage of study area by vulnerability classification for inland flooding area

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	2%	94%	4%
Mid-Century RCP 8.5	3%	93%	4%
End-Century RCP 4.5	2%	94%	4%
End-Century RCP 8.5	4%	89%	7%

FIGURE 188: Inland flooding area – Mid-century RCP 4.5 – Vulnerability

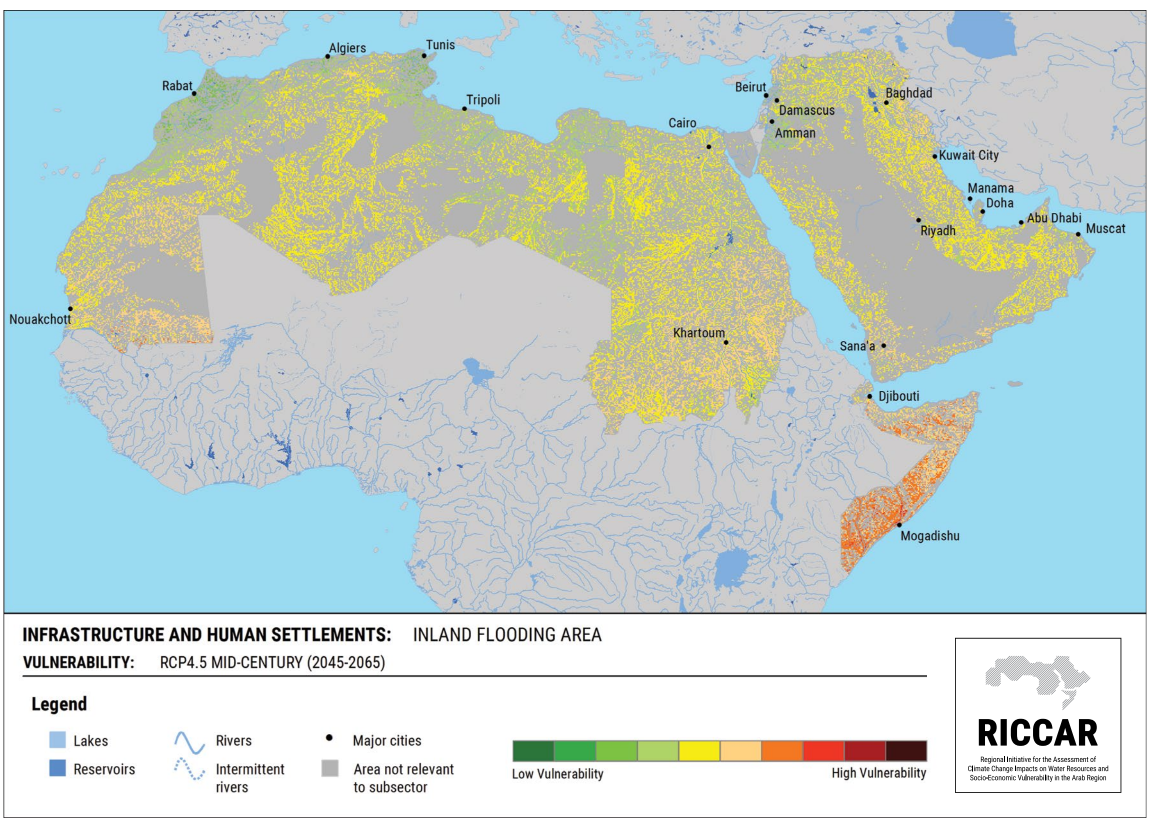


FIGURE 189: Inland flooding area – Mid-century RCP 8.5 – Vulnerability

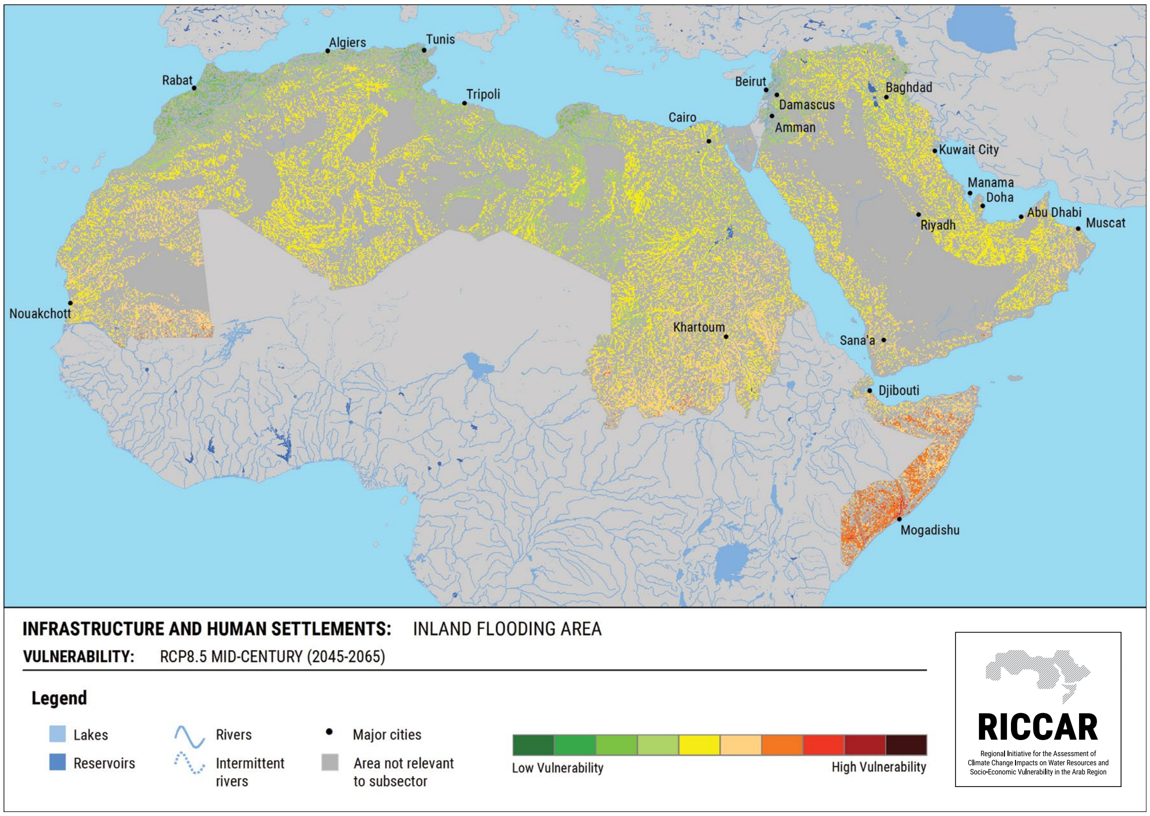


FIGURE 190: Inland flooding area – End-century RCP 4.5 – Vulnerability

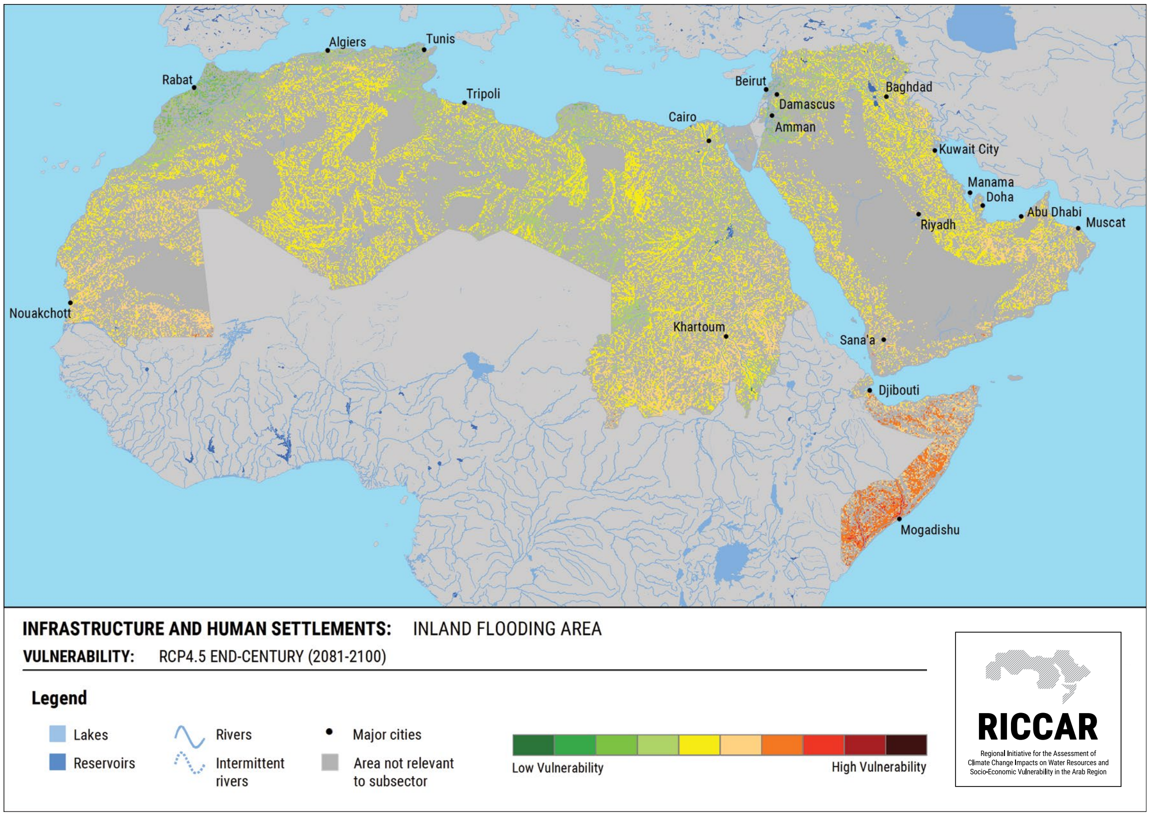
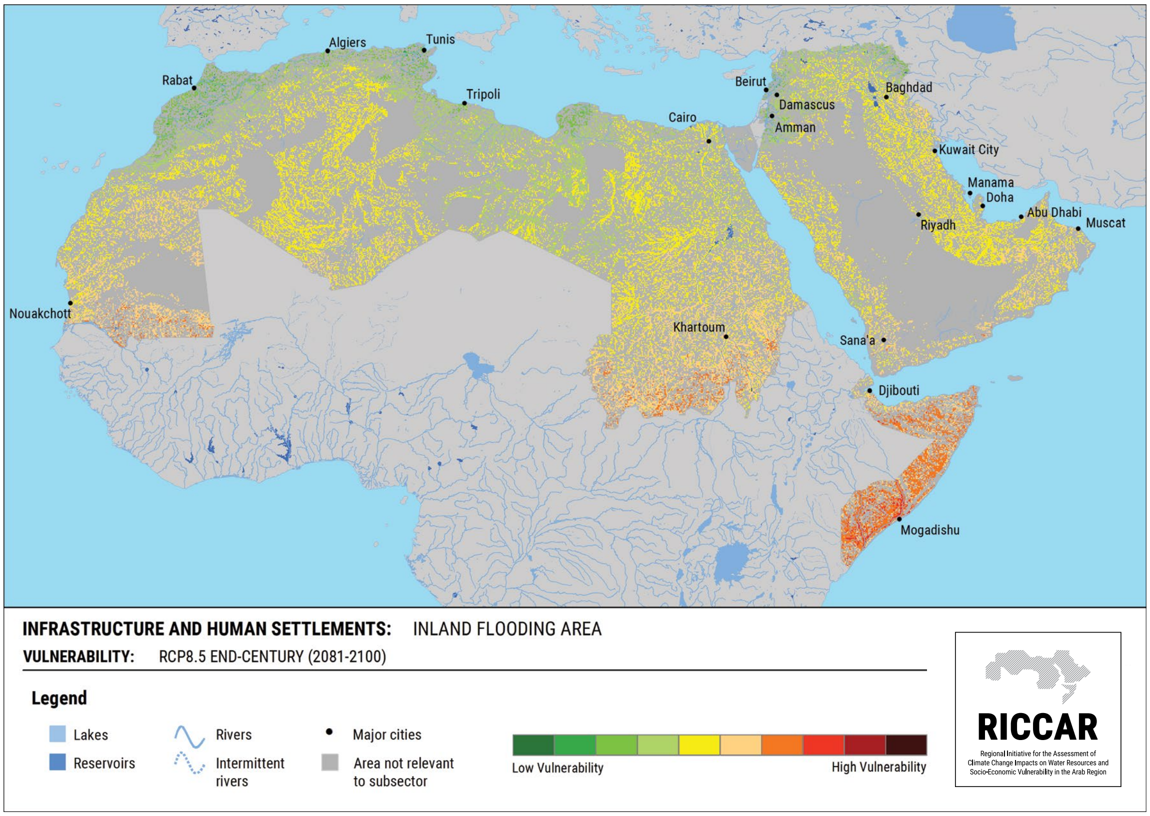


FIGURE 191: Inland flooding area – End-century RCP 8.5 – Vulnerability



12.1.3 Hotspots

Hotspots reveal areas with the highest projected vulnerability and represent up to 8% of the inland flooding study area. Hotspots 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. Recent flooding in the western Sahel (August to September 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 rivers; residents have built floodwalls which separate agricultural areas from the rivers.

The Jubba and Shabelle river floodplains have also been subjected to recurrent floods: recent events were in April 2010, April 2013 and May 2013. These floods tend to occur during two distinct rainy seasons: the *Gu* (April to June) and the *Deyr* (October to November). Steps to reduce vulnerability in this area include the development of a Flood Risk and Response Management Information System (FRRMIS), which is a web- and GIS-based information dissemination and sharing platform delivering regular updated flood information. It promotes flood preparedness and contingency planning and has developed a geodatabase of riverbank breakages and potential flooding areas.[4]

Luxor, Egypt, 2016. Source: Dounia Chouchani.

ENDNOTES

1. UN-HABITAT, 2016
2. DesInventar, 2016
3. Ibid.
4. SWALIM, 2017

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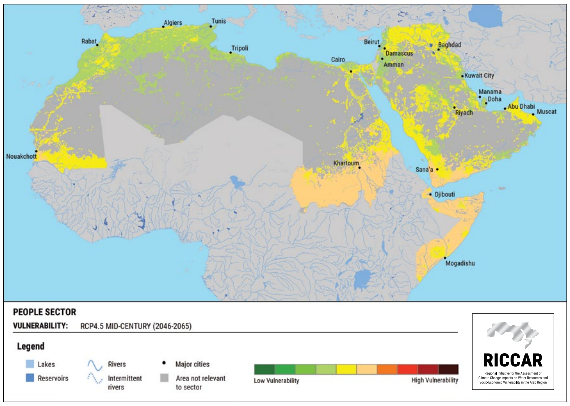
PEOPLE SECTOR

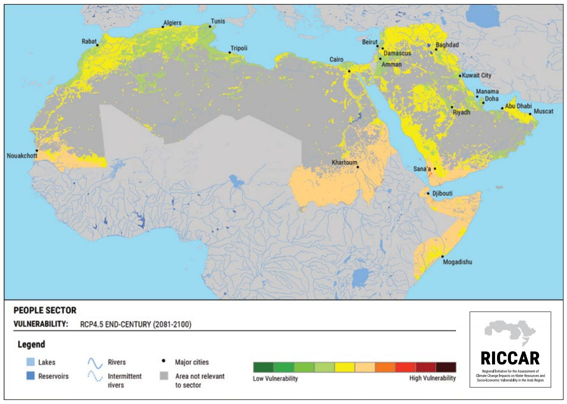
OVERALL VULNERABILITY

RCP 4.5

2046-2065

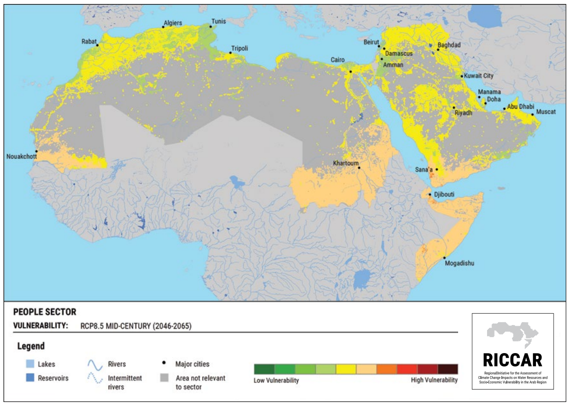


2081-2100

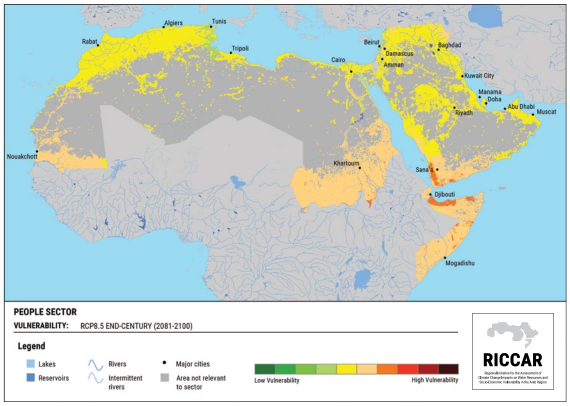


RCP 8.5

2046-2065



2081-2100



CHAPTER 13

PEOPLE SECTOR – VULNERABILITY

Water, already a scarce resource in the Arab region, may further decrease in quality and quantity which will put pressure on the availability of drinking water for the population. Climate change effects on agricultural production in already arid and semi-arid areas may lead to a loss of labour opportunities in the agricultural sector and trigger further migration to urban centres: this, in turn, may cause social disturbances and put further stress on already densely populated areas. About 20% of the current workforce in the Arab region is employed in the agricultural sector.[1]

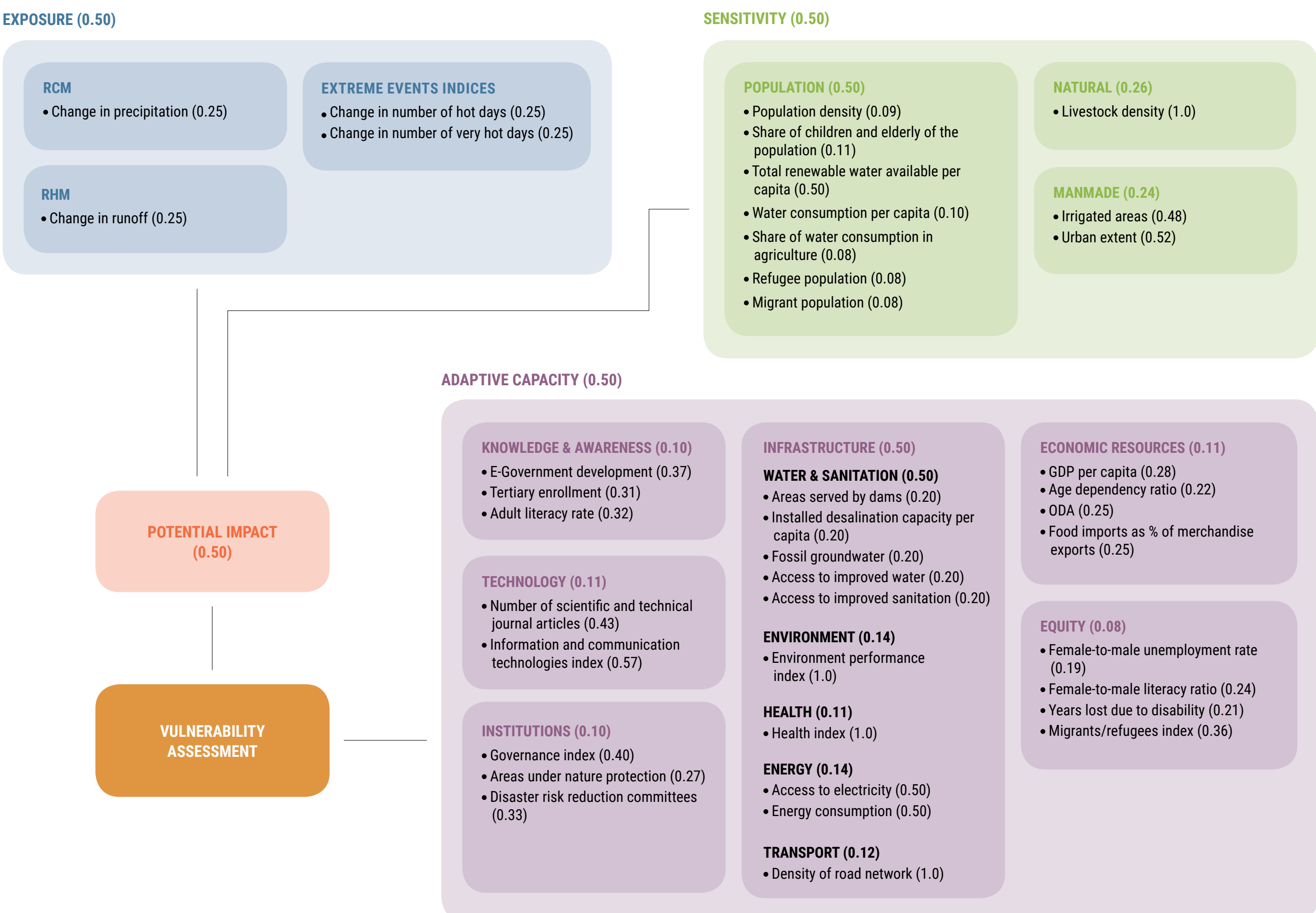
Moreover, higher temperatures, especially in the summer months, may have severe impacts on public health, in particular affecting the young and elderly and those working in economic sectors requiring outside work, such as agriculture, security and construction. For these reasons, the VA-WG members selected the following three key climate change impacts on people to be included into the assessment: (a) *Change in the water available for drinking*; (b) *Change in health conditions due to heat stress*, and (c) *Change in employment rate for the agricultural sector*. Outcomes from the vulnerability assessment for this sector and associated subsectors are described in the following sections.

The study area for all three subsectors, as well as the sector itself, is based on populated areas. This defined the population density indicator and includes areas with at least two inhabitants per square kilometre. The resultant study area represents 44% of the entire Arab region.

13.1 WATER AVAILABLE FOR DRINKING

The impact chain shown in Figure 192 presents the indicators used under each component and its associated weights for this subsector.

FIGURE 192: Impact chain and weights for water available for drinking



13.1.1 Reference period

13.1.1.1 Potential impact

Potential impact reflects the aggregated result between exposure and sensitivity. Exposure is based on four hydrological indicators (precipitation and runoff) and extreme heat indices to include number of hot days (SU35) and number of very hot days (SU40). As the number of hot days increase, drinking water consumption is expected to increase correspondingly.

Exposure for the reference period is nearly equally divided between low, moderate and high: moderate and high exposure represent 37% and 33% of the study area, respectively. Areas of high exposure are generally located within the Sahara and Arabian deserts, whereas areas of low exposure are primarily located along the Mediterranean coast and the Zagros Mountains. Moderate exposure transitions between the two areas.

Exposure does not consider humidity because bias-corrected data for this parameter were not developed under RICCAR. Humidity can, however, be an important factor with regard to drinking-water needs as humidity can impact the Heat Index or apparent temperature, as discussed in Chapter 7. Humidity and the resultant Heat Index are expected to be a factor in coastal areas such as the Gulf. These areas are subject to a conceivable increase in exposure, as well as a resultant increase in potential impact and exposure.

Sensitivity indicators were selected with a strong emphasis on the population dimension, particularly the total renewable water available per capita indicator. Indicators from the other dimensions were identified based on competing water users. In addition, urban areas are expected to induce an urban heat island effect (causing localized temperature increases) and highlight dense population centres. Most of the study area (87%) is indicative of low sensitivity relative to the region and remaining areas can be considered moderate.

Sensitivity maintains a modest correlation with indicators from the man-made dimension, population density, and total available renewable water. Areas with the highest sensitivity include the lower Nile River Valley and Delta, the Asir Mountains, the northern coast of the Gulf of Aden and the Strait of Hormuz coastal area. Sensitivity is arguably artificially low because it is limited by the available indicators. Not only is water limited by resource availability, drinking water must consider environmental factors and quality. Much of the region is faced with the degradation of water resources.

The resultant potential impact for the reference period (Figure 193) reveals a split between low and moderate potential impact (51% and 49% of the study area, respectively). Areas with the highest potential impact include the lower Nile River, the central Arabian Desert and the eastern Red Sea coastline. Conversely, areas with low potential impact relative to the region are the Atlas Mountains and adjacent coastal plains, the coastal Levant, the Zagros Mountains and sections in the northern Horn of Africa.

13.1.1.2 Adaptive capacity

Adaptive capacity indicators were selected with an emphasis on water and sanitation infrastructure. They include desalination, dams, fossil groundwater and repair and prevention of leaks. Coping mechanisms require capital investment, institutional reforms and capacity-building. In addition, as for sensitivity, water rights and ethics should be considered.

The Arab region is evenly divided between areas of low and moderate adaptive capacity (48% and 52%, respectively). Areas with the lowest adaptive capacity include the Horn of Africa, the western Sahel and the south-western Arabian Peninsula (Figure 194).

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

FIGURE 193: Water available for drinking – Reference period – Potential impact

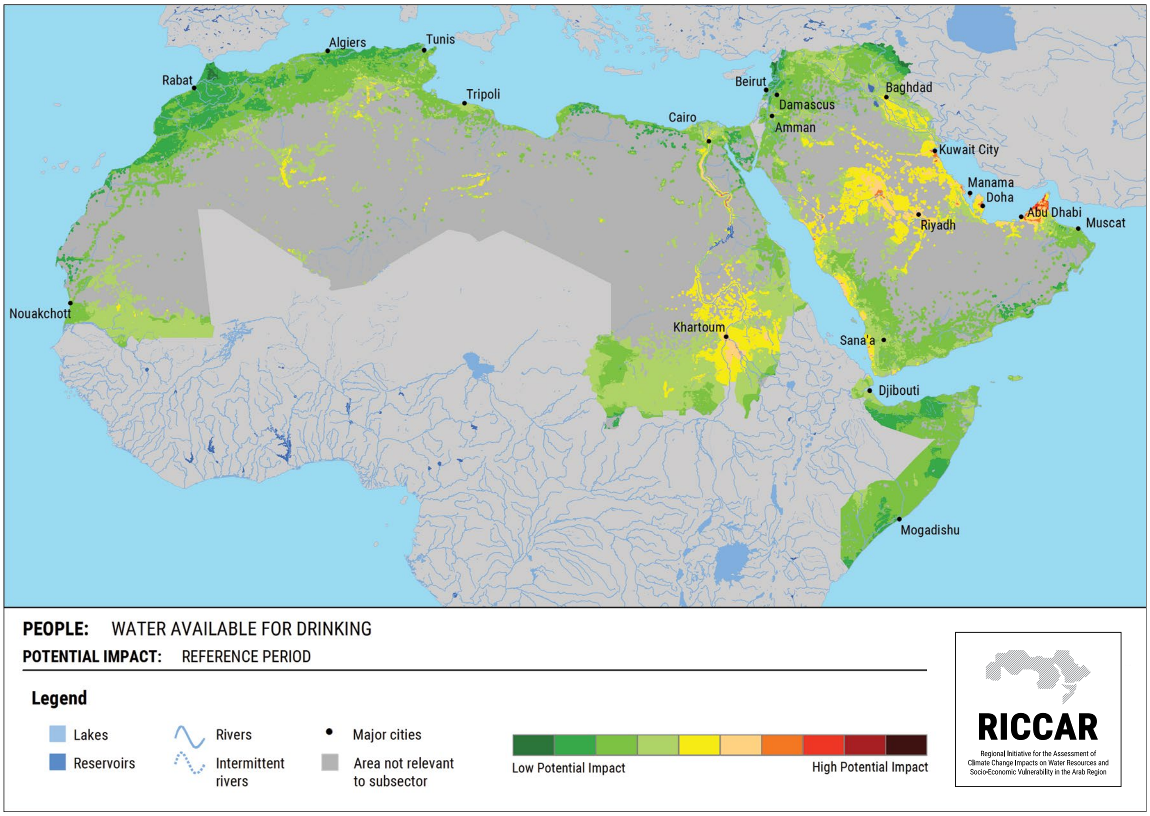
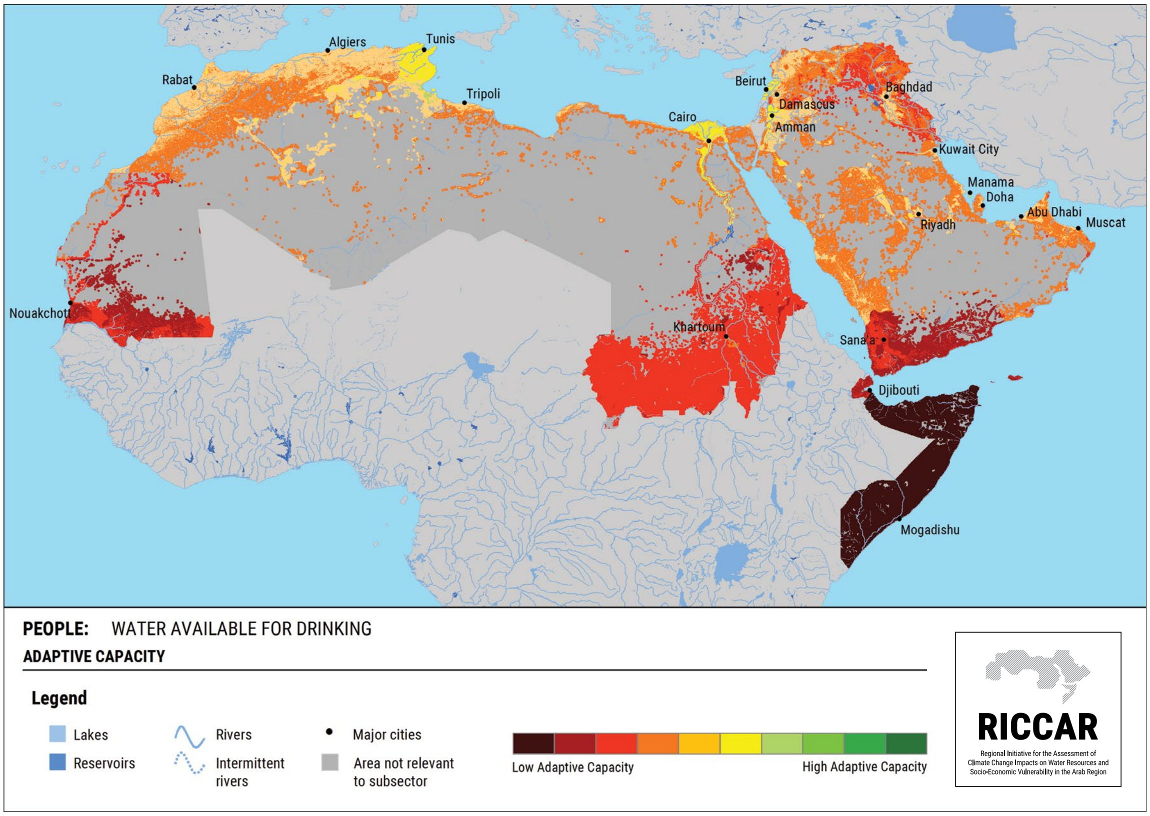


FIGURE 194: Water available for drinking – Adaptive capacity



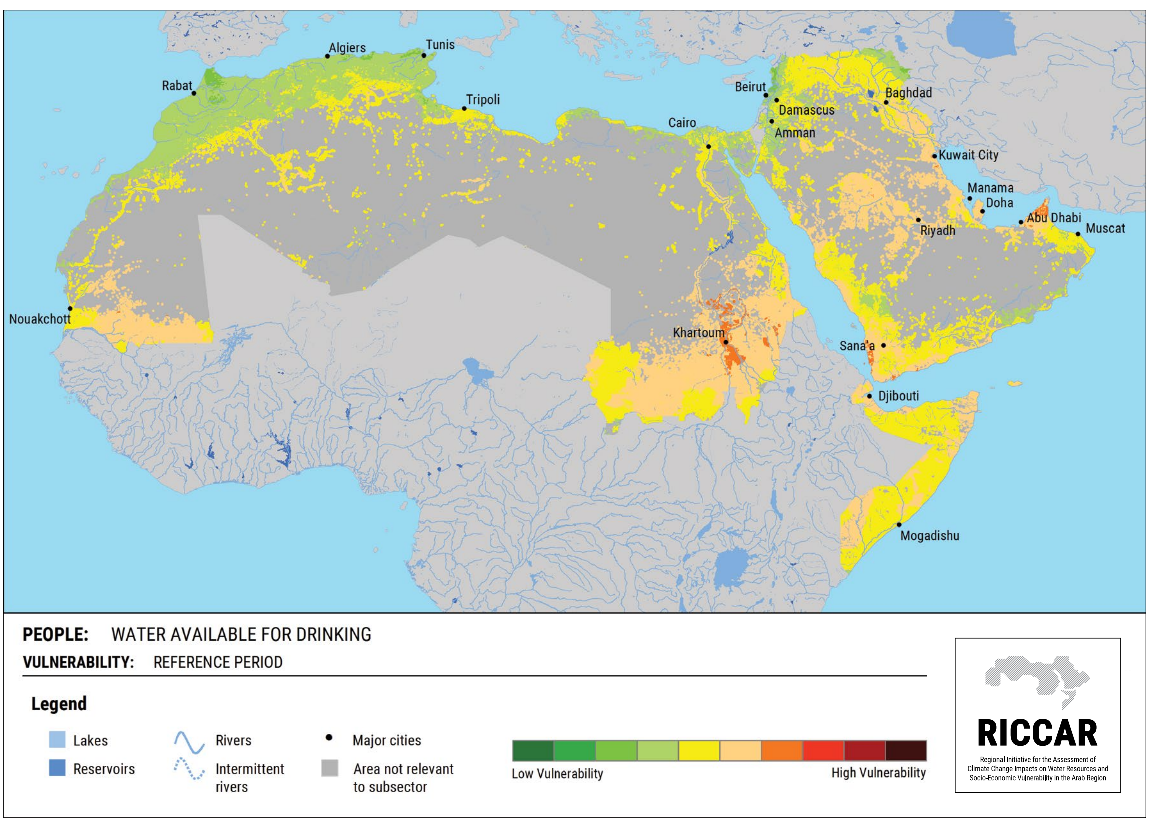
13.1.1.3 Vulnerability

Because of relatively low potential impact and low adaptive capacity for much of the region, the resultant vulnerability for the reference period is overwhelmingly moderate, covering 98% of the study area (Figure 195). Remaining areas are divided between areas of low and high vulnerability.

Areas with the highest vulnerability include the upper Nile region near the confluence of the Nile, Blue Nile and White Nile rivers, the south-western Arabian Peninsula coastline and the Jabal Yibir area near the Strait of Hormuz. Vulnerability is primarily a function of exposure for this subsector as evidenced by a strong correlation. In addition, areas with high exposure tend to coincide with areas of high vulnerability. Correlation with adaptive capacity is modest and correlation with sensitivity is very weak. Changes in sensitivity will thus have little impact on vulnerability, although it will have a modest effect on potential impact.

Women collecting water from well, Kuma Garadayat, Sudan, 2012. Source: UN Photo/Albert González Farran.

FIGURE 195: Water available for drinking – Reference period – Vulnerability



13.1.2 Future periods

13.1.2.1 Potential impact

Exposure is largely projected as moderate, representing 72% (RCP 4.5) to 77% (RCP 8.5) of the study area at mid-century and 52% (RCP 8.5) to 72% (RCP 4.5) at end-century. High exposure is revealed in 14% (RCP 4.5) to 18% (RCP 8.5) of the study area at mid-century and 18% (RCP 4.5) to 43% (RCP 8.5) at end-century. Thus, for RCP 4.5, exposure is mostly unchanging, but changes are magnified for RCP 8.5. As a result, areas of high exposure are generally confined to the eastern Sahel for most future scenarios but expand to several coastal areas for RCP 8.5 end-century while, for the same scenario, the eastern Sahel suggests a much lower exposure due to increasing precipitation and runoff.

Assuming static sensitivity, projected potential impact is generally split between low and moderate.

For mid-century (Figure 196 and Figure 197), moderate potential impact is revealed in 41% (RCP 4.5) to 54% (RCP 8.5) of the study area, but increases to 47% (RCP 4.5) to 72% (RCP 8.5) at end-century (Figure 198 and Figure 199). Other areas suggest low potential impact. Areas with elevated potential impact are the Asir Mountains, the lower Nile River and the Jabal Yibir area. Changes in sensitivity, including consideration of certain parameters like water quality, can ensue changes in potential impact.

FIGURE 196: Water available for drinking – Mid-century RCP 4.5 – Potential impact

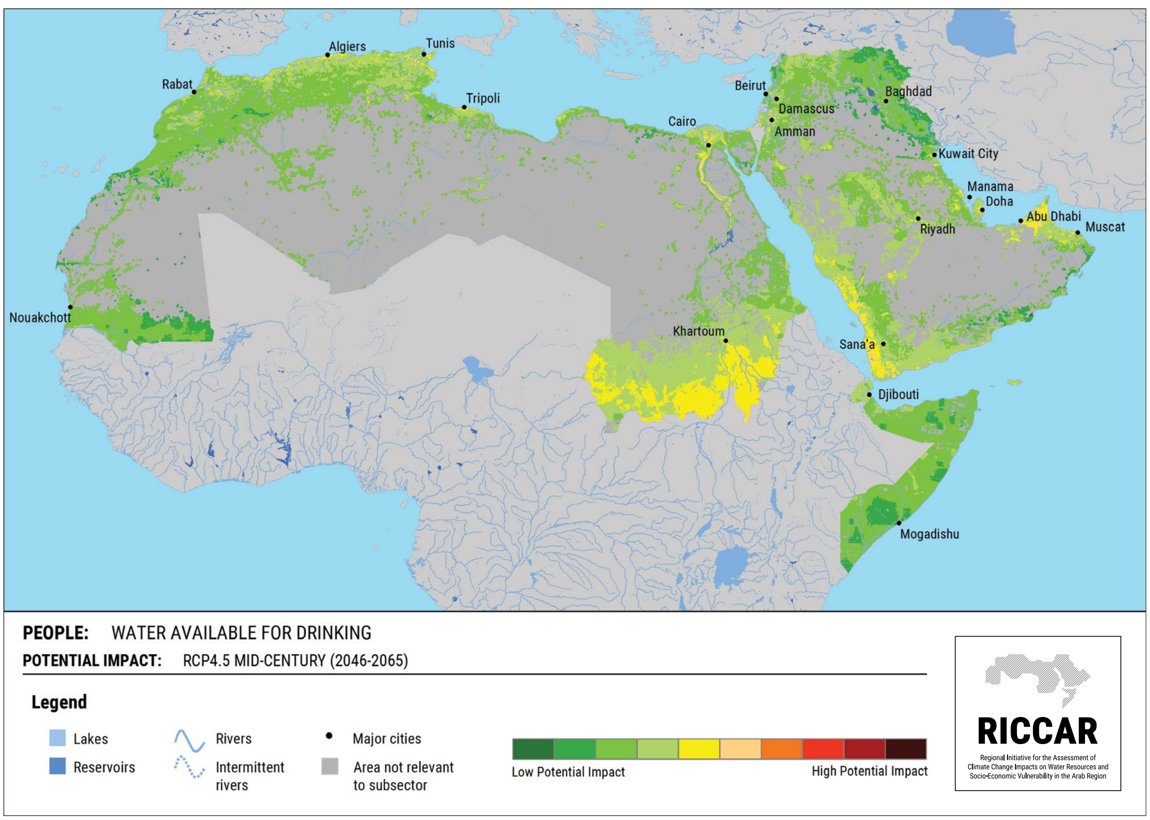


FIGURE 197: Water available for drinking – Mid-century RCP 8.5 – Potential impact

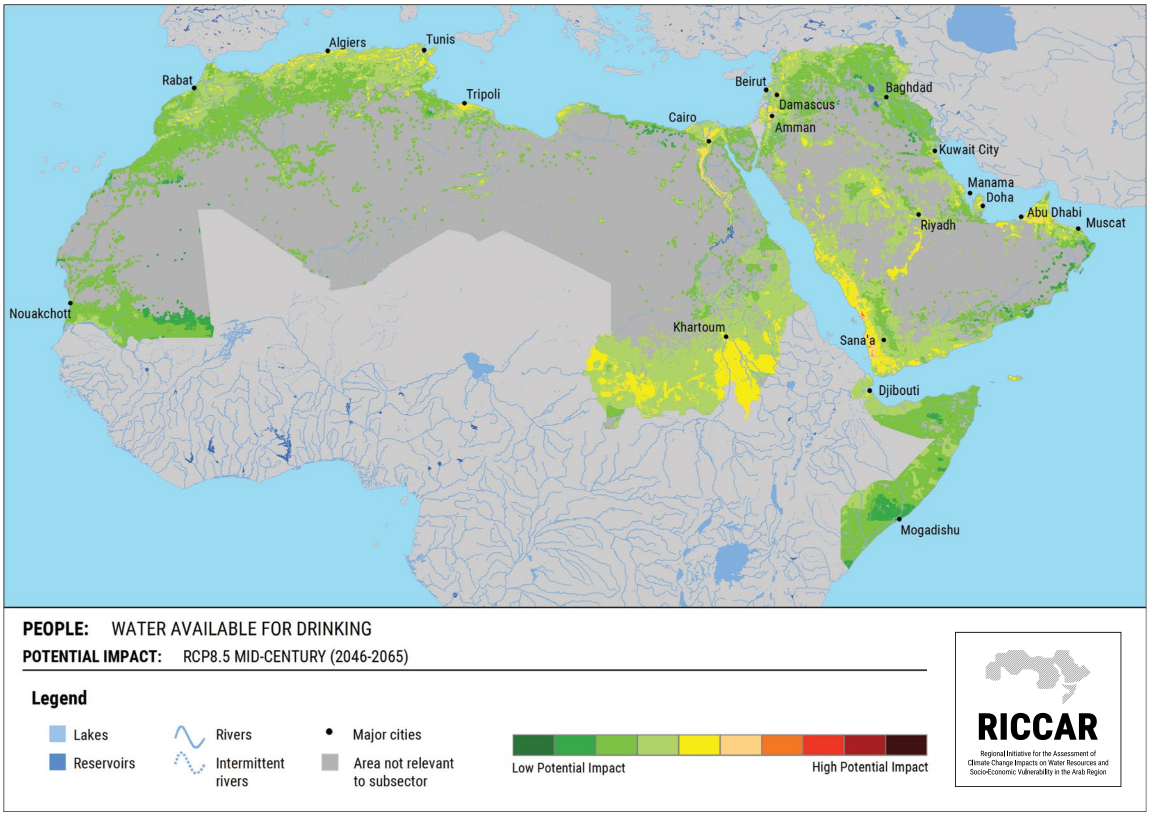


FIGURE 198: Water available for drinking – End-century RCP 4.5 – Potential impact

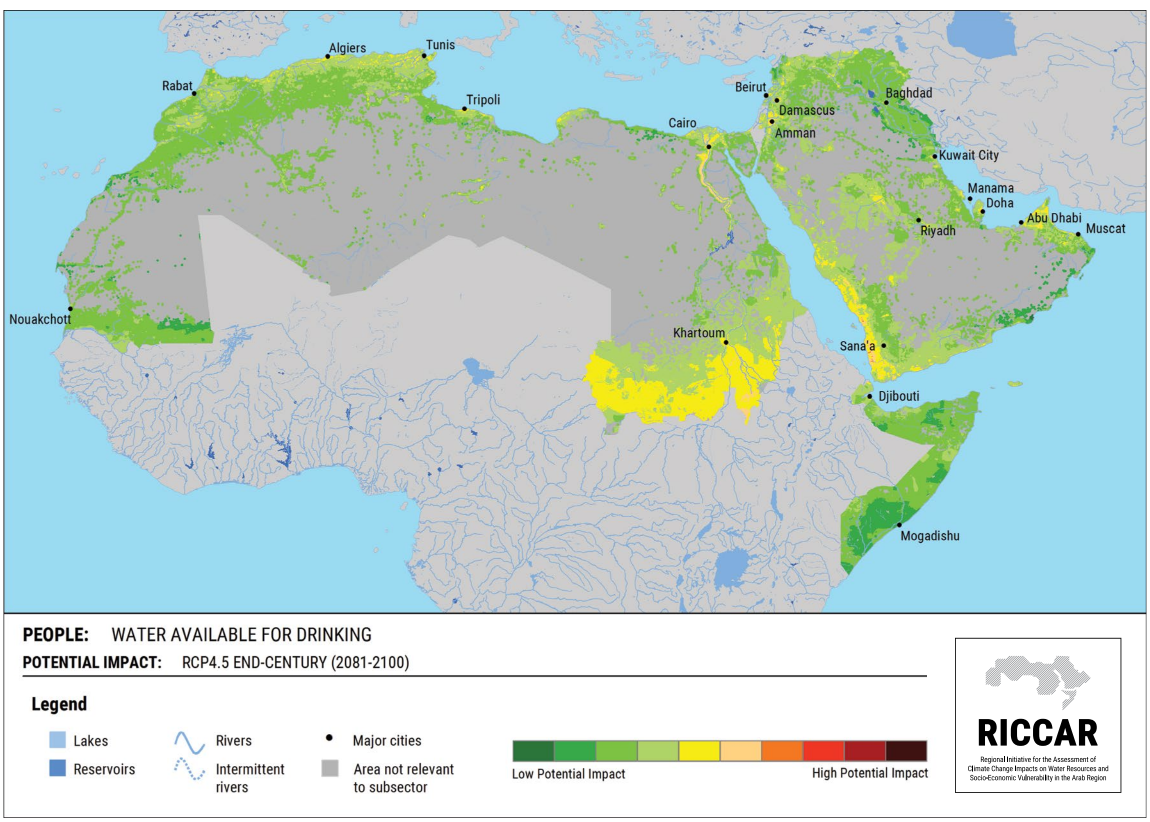
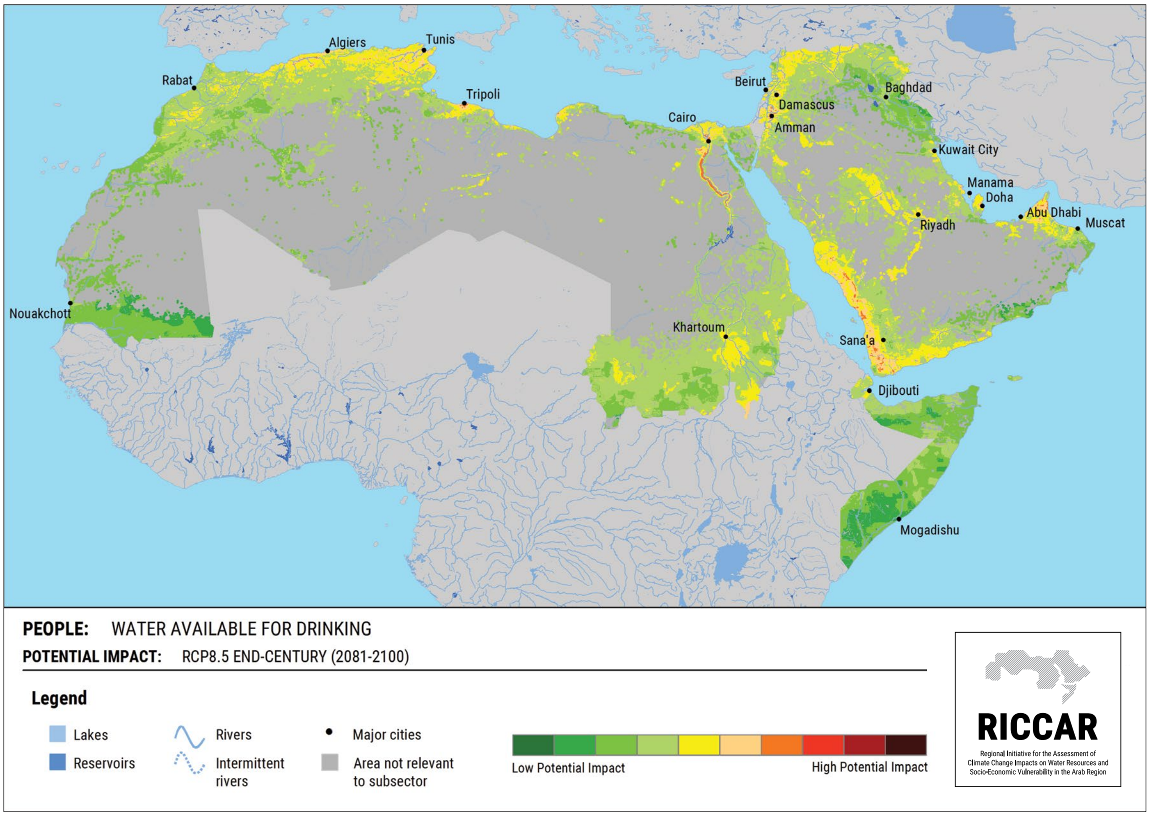


FIGURE 199: Water available for drinking – End-century RCP 8.5 – Potential impact



13.1.2.2 Vulnerability

Nearly the entire study area (greater than 98%) faces moderate drinking water vulnerability for both mid- and end-century under both RCP 4.5 and RCP 8.5, due primarily to exposure (Table 32). Areas with the lowest relative vulnerability are the lower Tigris-Euphrates Basin, the Gulf of Aden north central coastline, selected areas in the Maghreb and the lower Tindouf basin in the western Sahel (Figure 200 to Figure 203).

Vulnerability trends reveal only slight differences from mid- to end-century, particularly under RCP 4.5.

For this scenario, areas of increasing vulnerability tend to be located in the Zagros Mountains and the central western Red Sea coastal region. Conversely, areas of decreasing vulnerability are located in the Oman Mountains region, selected areas in the Horn of Africa and the northern Grand Erg Oriental region. Under RCP 8.5, changes are more pronounced and areas of increasing vulnerability include the Red Sea region, the northern Maghreb, the Levant and the Zagros Mountains. Areas of decreasing vulnerability are located in the Sahel and the Horn of Africa.

TABLE 32: Percentage of study area by vulnerability classification for water available for drinking

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	0%	100%	0%
Mid-Century RCP 8.5	0%	99%	1%
End-Century RCP 4.5	0%	99%	1%
End-Century RCP 8.5	0%	98%	2%

FIGURE 200: Water available for drinking – Mid-century RCP 4.5 – Vulnerability

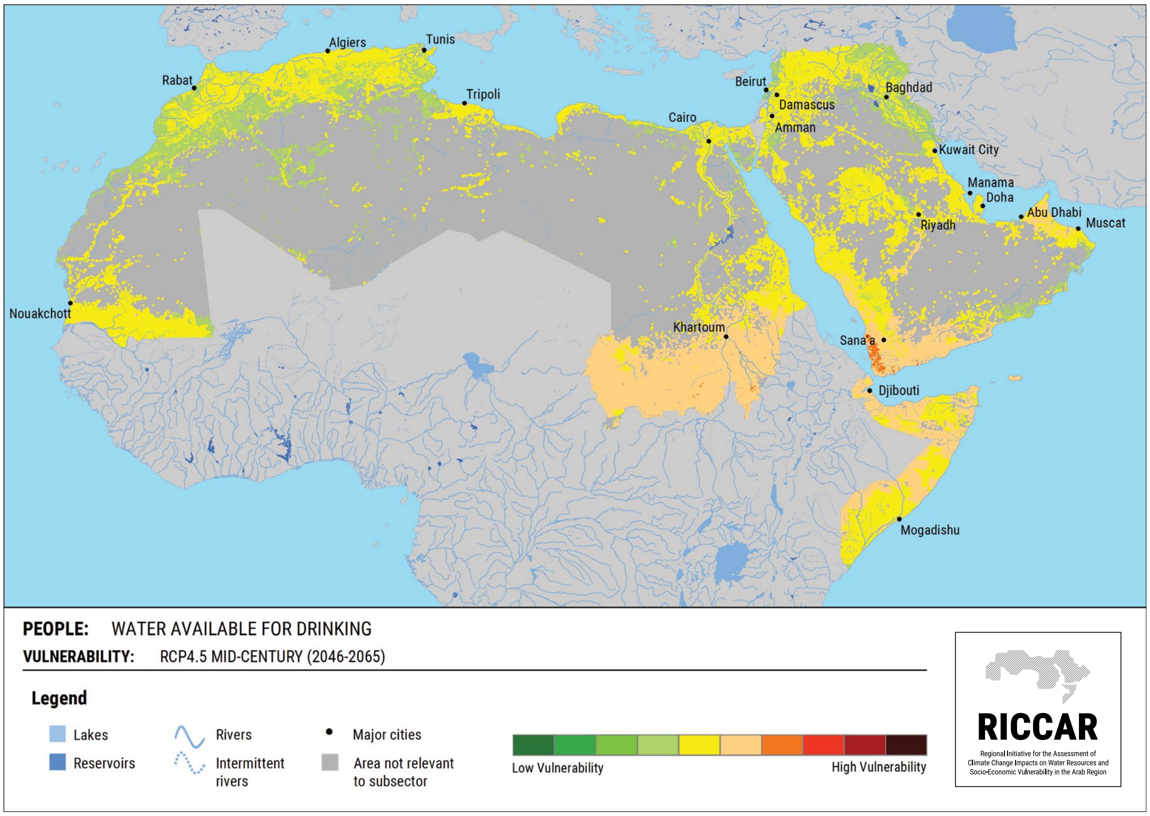


FIGURE 201: Water available for drinking – Mid-century RCP 8.5 – Vulnerability

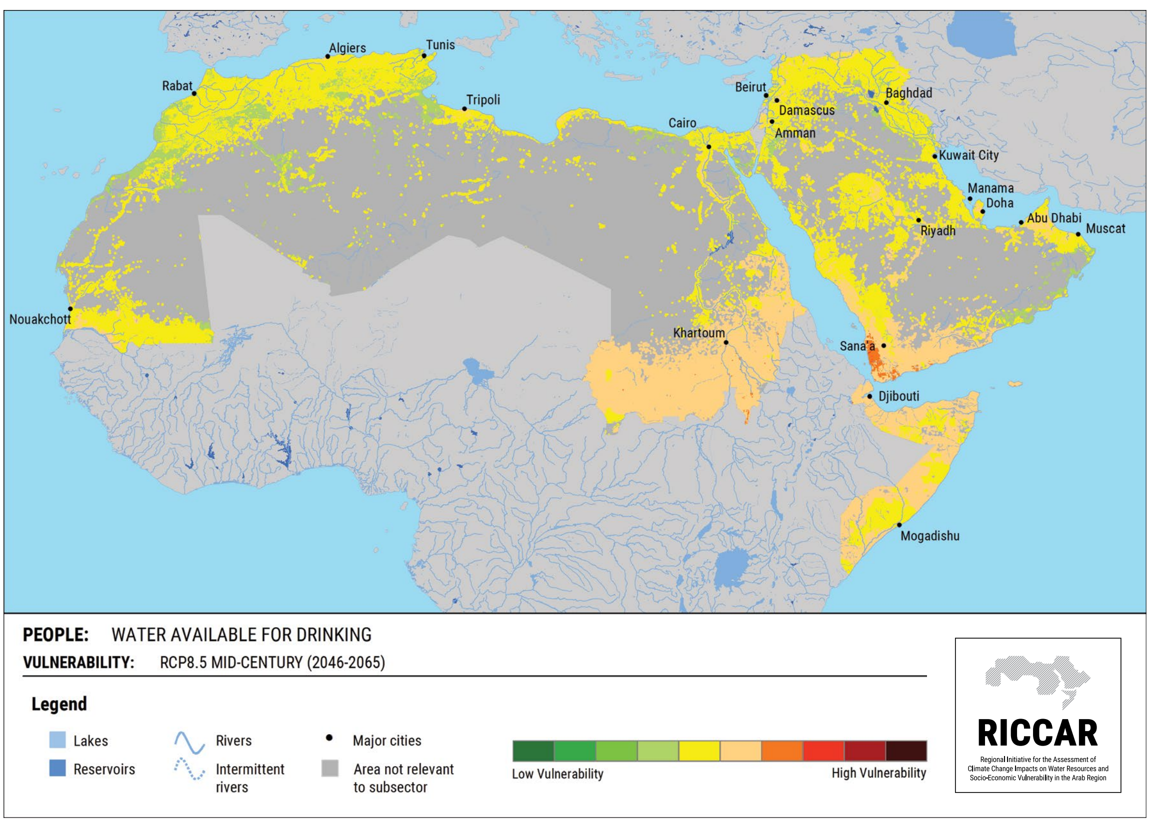


FIGURE 202: Water available for drinking – End-century RCP 4.5 – Vulnerability

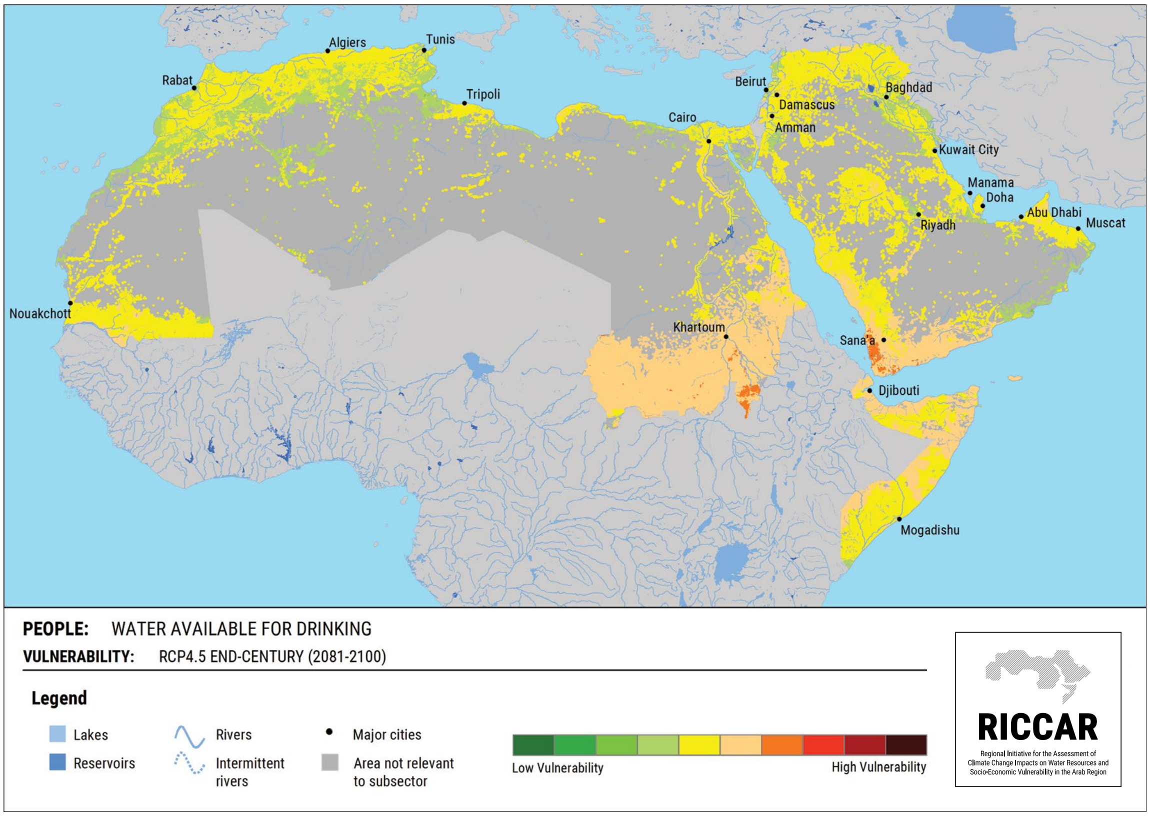
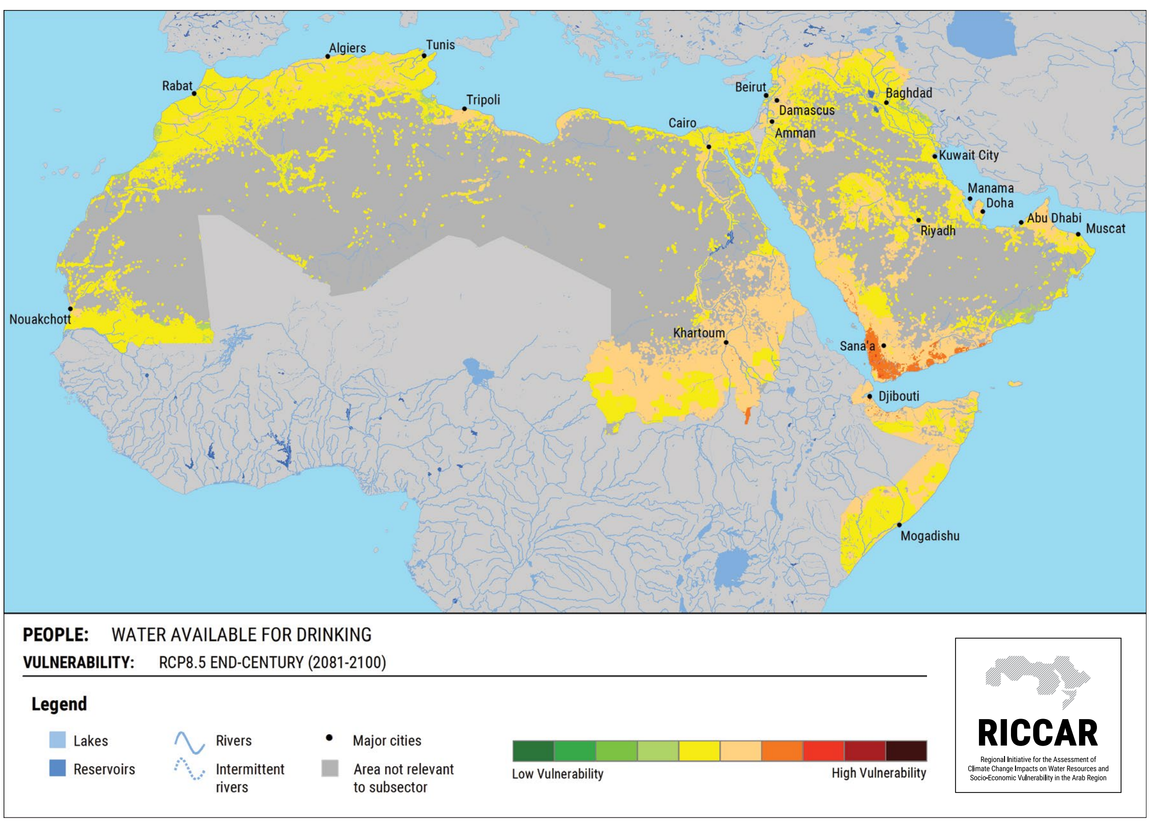


FIGURE 203: Water available for drinking – End-century RCP 8.5 – Vulnerability



13.1.3 Hotspots

Water available for drinking hotspots reveal areas with the highest vulnerability and represent about 1% of the study area. Hotspots include the south-western Arabian Peninsula near the Red Sea and Gulf of Aden coastlines, the northern coast of the Horn of Africa and the White Nile–Blue Nile watershed in the eastern Sahel. Most of these areas are rural and as low as 16% of the population have access to improved water sources.[2] These improved water sources do not factor water quality, so access to drinking water is probably significantly lower. Recently, the south-western Arabian Peninsula faced a very high incidence of cholera due to a lack of clean drinking water, resulting in several deaths.

In the Horn of Africa, drinking-water availability suffers due to lack of sanitation (only about 10% of the population has access)[3], recent drought and other problems. Although rainfall and runoff are expected to increase in much of the Horn of Africa, it will remain largely the same as the reference period along the northern coast. This, coupled with increasing numbers of hot days and very hot days, will potentially increase drought risk in the area. Local inhabitants use rainfall-harvesting storage, known as *berkads*, for a supplementary water supply, but these units are ineffective during prolonged drought.

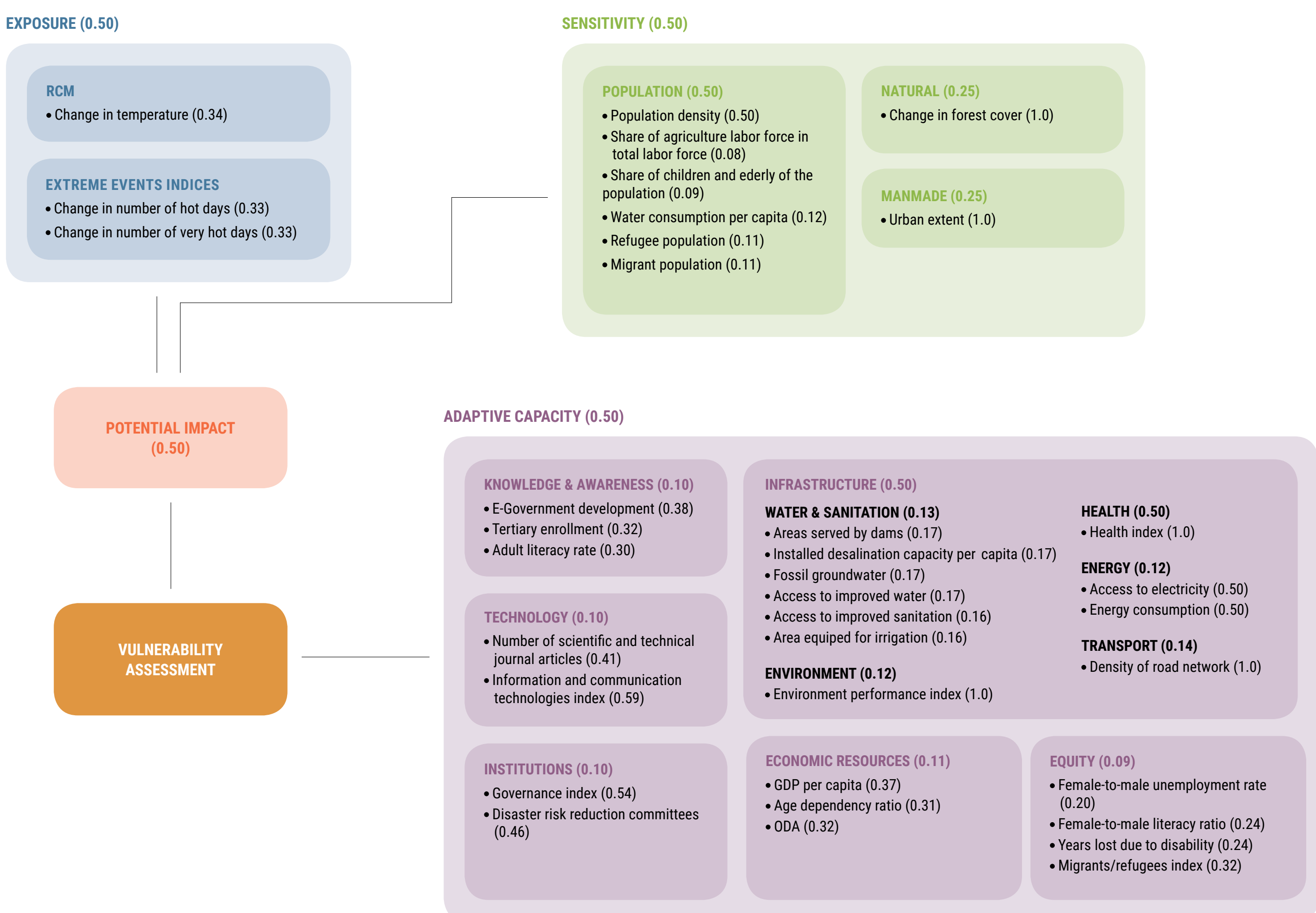
Despite the proximity to large rivers, the White Nile–Blue Nile watershed is also projected to suffer from the lack of available drinking water. Most water resources (about 96% of total available renewable water)[4] are allocated to agricultural needs.

Because the area is largely agricultural, drinking water sources are subject to contamination from fertilizers and pesticides. The region currently maintains a moderately dense population, which can be expected to grow in the future, placing a further strain on water resources.

13.2 HEALTH CONDITIONS DUE TO HEAT STRESS

Figure 204 highlights the impact chain for this subsector showing the set of indicators considered for analysis and its assigned weights.

FIGURE 204: Impact chain and weights for health conditions due to heat stress



13.2.1 Reference period

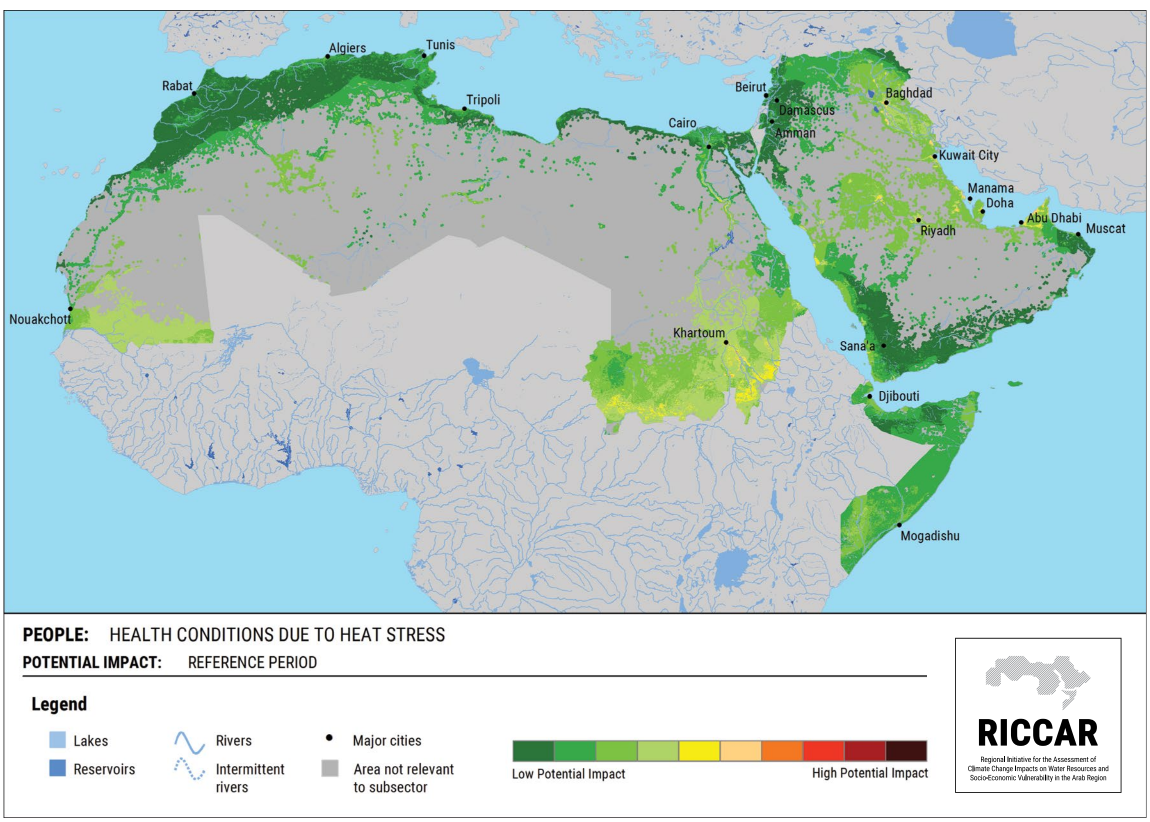
13.2.1.1 Potential impact

Potential impact reflects the combination of exposure and sensitivity. Abnormally high temperatures can provoke heat stress-related ailments, such as heat rash, heat cramps, heat exhaustion and heat stroke. Severe heat stroke can occur when the core body temperature exceeds 39 °C, potentially inducing organ failure or mortality. Nearly the entire study area (98%) has at least one day a year which exceeds 40 °C while 20% of the study area has at least 100 days per year which exceed 40 °C. Heat stress and its correlation with temperature-related factors was the basis for selecting temperature, the annual number of hot days (SU35) and the annual number of very hot days (SU40) as exposure indicators. Areas with highest exposure include the Sahara Desert, while areas of low exposure tend to be in coastal and mountainous regions. It should be noted that exposure is based on annual averages and thus seasonality is not considered; exposure is expected to be significantly higher during the summer months.

Selected sensitivity indicators focus on the population, particularly groups more susceptible to heat stress, including the elderly, children and marginalized groups. In addition, people who work outdoors are also stress-prone. Other sensitivity indicators consider change in forest cover based on shading and cooling effects and urban extent because of urban heat inland effects. Nearly the entire study area (98%) indicates low sensitivity; remaining areas suggest moderate sensitivity and are confined to isolated locations near urban settings.

The resultant potential impact (Figure 205) follows similar trends as exposure due to sensitivity homogeneity. Low potential impact is indicated in 82% of the study area and remaining areas suggest moderate potential impact. Areas with the highest potential impact relative to the region are located in the upper Nile Valley, isolated areas of the Arabian Desert and the Nahr Diyala Valley in Mesopotamia. Actual potential impact is likely higher in certain areas due to exposure factors such as humidity, which can increase apparent temperature. Additionally, sensitivity parameters such as the prevalence of cardiovascular disease, housing characteristics and air-conditioning availability are also not considered due to data unavailability.

FIGURE 205: Health conditions due to heat stress – Reference period – Potential impact



13.2.1.2 Adaptive capacity

Adaptive capacity is primarily affected by the health pillar under the infrastructure dimension, consisting solely of the Health index. This index is a composite of three parameters: per capita total expenditure on health, general government expenditure on health and number of hospital beds. Access to improved medical facilities enables the ability to treat ailments such as heat-related disorders quickly. Adaptive capacity is largely moderate, representing 75% of the study area. Low adaptive capacity is indicated in 21% of the study area, primarily in the Horn of Africa. Remaining areas suggest high adaptive capacity (Figure 206).

13.2.1.3 Vulnerability

Heat stress vulnerability for the reference period is largely moderate, representing 64% of the study area; remaining areas suggest low vulnerability.

Areas with relatively high vulnerability are the Sahel, sections along the northern coast of the Horn of Africa, the Jubba River Valley in the southern Horn of Africa and isolated areas within the Tigris–Euphrates basin. Conversely, areas with low vulnerability are the Atlas Mountains and the Levant (Figure 207).

As expected, heat stress vulnerability has a strong correlation with exposure. Areas with high vulnerability have an average of 254 hot days (SU35) and 115 very hot days (SU40) annually.

On the other hand, areas of low vulnerability have an average of 49 hot days and 6 very hot days; considering the threshold for heat-stroke risk (39 °C), even areas with low vulnerability warrant concern. At least 52 heatwave events occurred during the reference period in the Levant,[5] an area of relatively low vulnerability.

FIGURE 206: Health conditions due to heat stress – Adaptive capacity

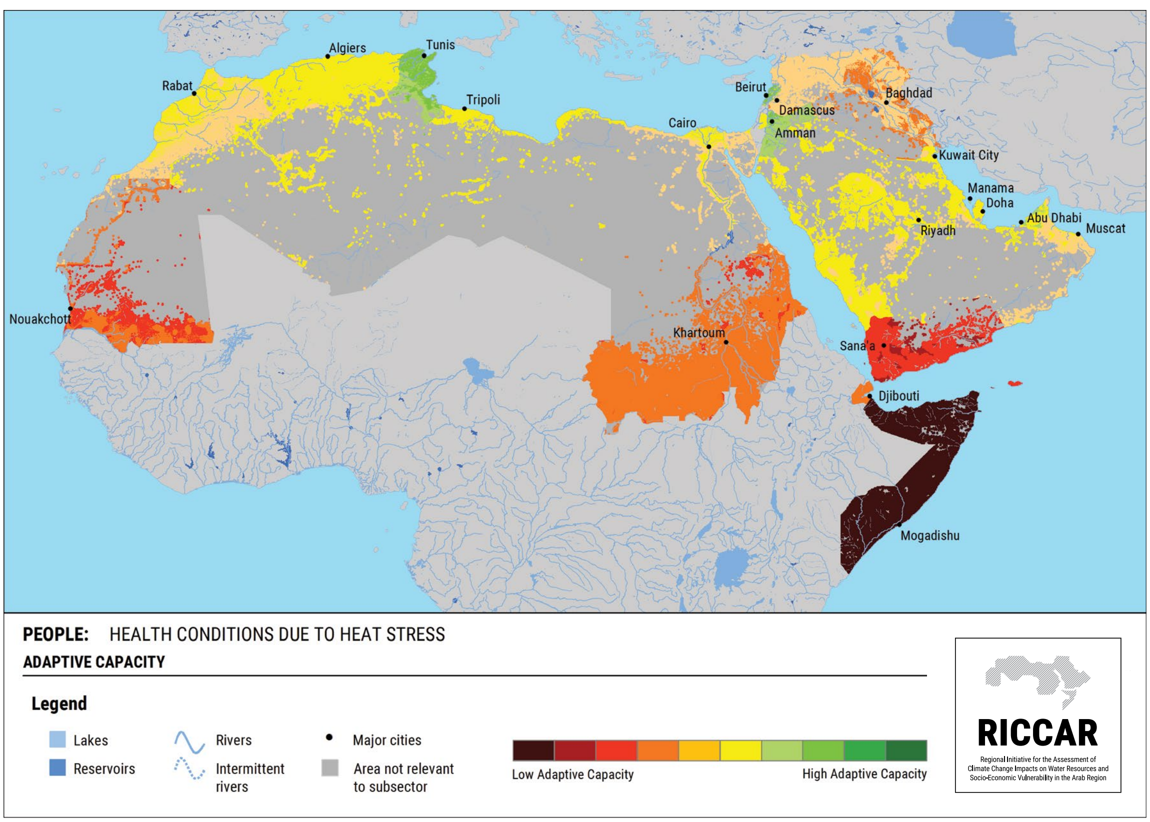
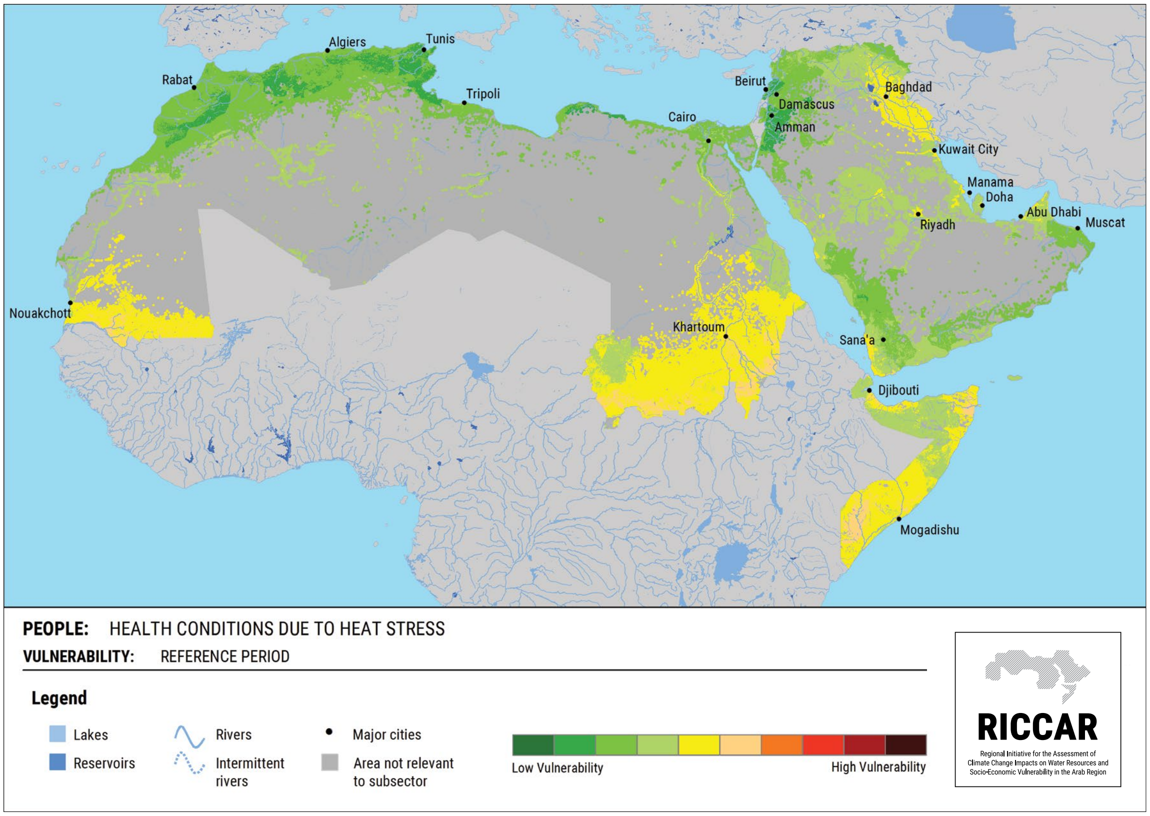


FIGURE 207: Health conditions due to heat stress – Reference period –Vulnerability



13.2.2 Future period

13.2.2.1 Potential impact

Like the reference period, areas of projected higher exposure tend to be located in desert regions, while low exposure is generally in coastal or mountainous areas. Nonetheless, areas of low, moderate and high exposure tend to be wide-ranging throughout the study area. At mid-century (Figure 208 and Figure 209), areas of moderate exposure range from 39% (RCP 4.5) to 51% (RCP 8.5) of the study area, while areas of high exposure range from 0% (RCP 4.5) to 22% (RCP 8.5). At end-century, exposure increases such that 23% (RCP 8.5) to 46% (RCP 4.5) of the study area represents moderate exposure and 15% (RCP 4.5) to 75% (RCP 8.5) indicates high exposure (Figure 210 and Figure 211). Remaining areas indicate low exposure. Humidity was not considered: it can impact the Heat Index and raise exposure in coastal areas such as the Gulf.

Due to low sensitivity, low potential impact is revealed in a majority of the study area for all scenarios, ranging from 89% (RCP 8.5) to 97% (RCP 4.5) at mid-century and from 63% (RCP 8.5) to 90% (RCP 4.5) at end-century. Remaining areas suggest moderate potential impact. Like the reference period, future potential impact is closely correlated with exposure due to sensitivity homogeneity.

Research has shown that in major cities, where the warmest months exceed 30 °C, a 3% increase in death rates is expected per 1 °C increase in temperature.[6] Based on this assumption, more than 330 million people in the Arab region (92% of total in 2014)[7] could be subjected to at least a 9% increase in death rates and over 111 million people (31% of total in 2012) will be subjected to at least a 12% increase under RCP 8.5 at the end of the century.

Potential impact can differ based on differences in sensitivity. For example, it is anticipated that population growth rates will correspondingly result in an increase in heat stress instances. In addition, population growth often coincides with areas of high urban heat island potential. On the other hand, areas with significant temperature increases may render the region uninhabitable and force migration.

FIGURE 208: Health conditions due to heat stress – Mid-century RCP 4.5 – Potential impact

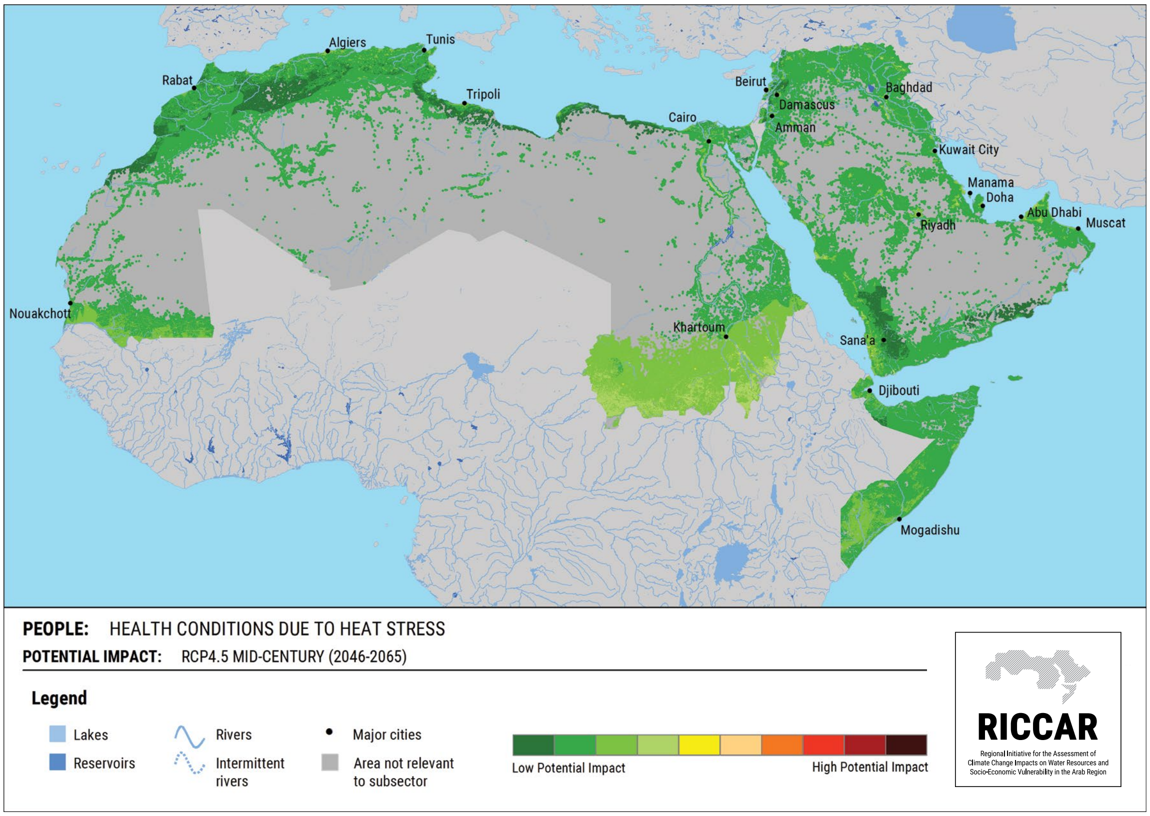


FIGURE 209: Health conditions due to heat stress – Mid-century RCP 8.5 – Potential impact

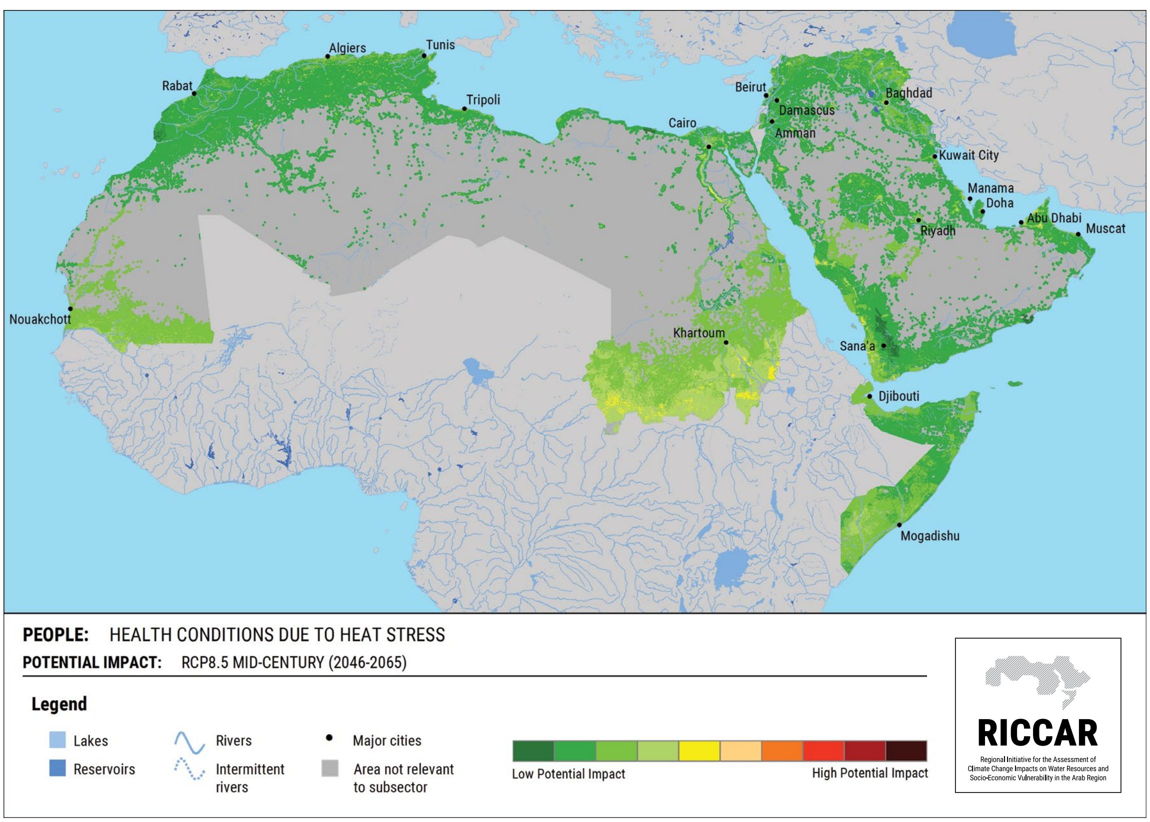


FIGURE 210: Health conditions due to heat stress – End-century RCP 4.5 – Potential impact

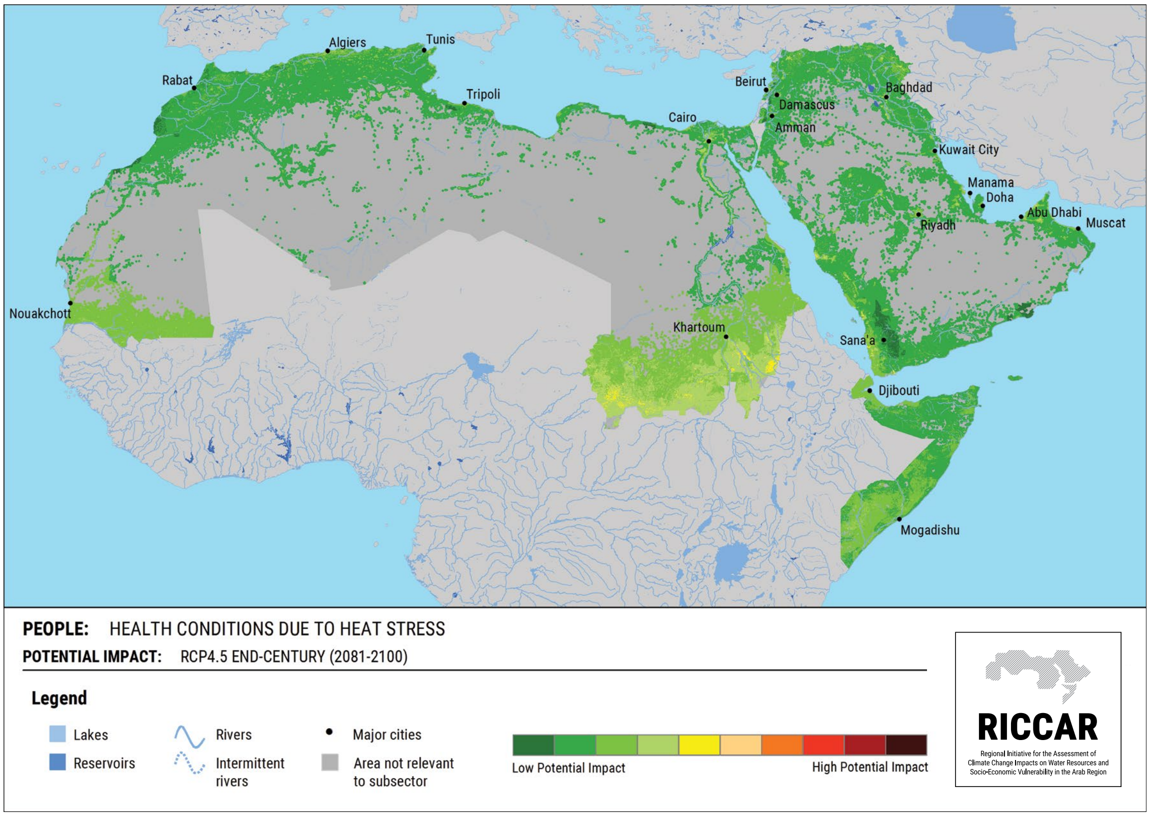
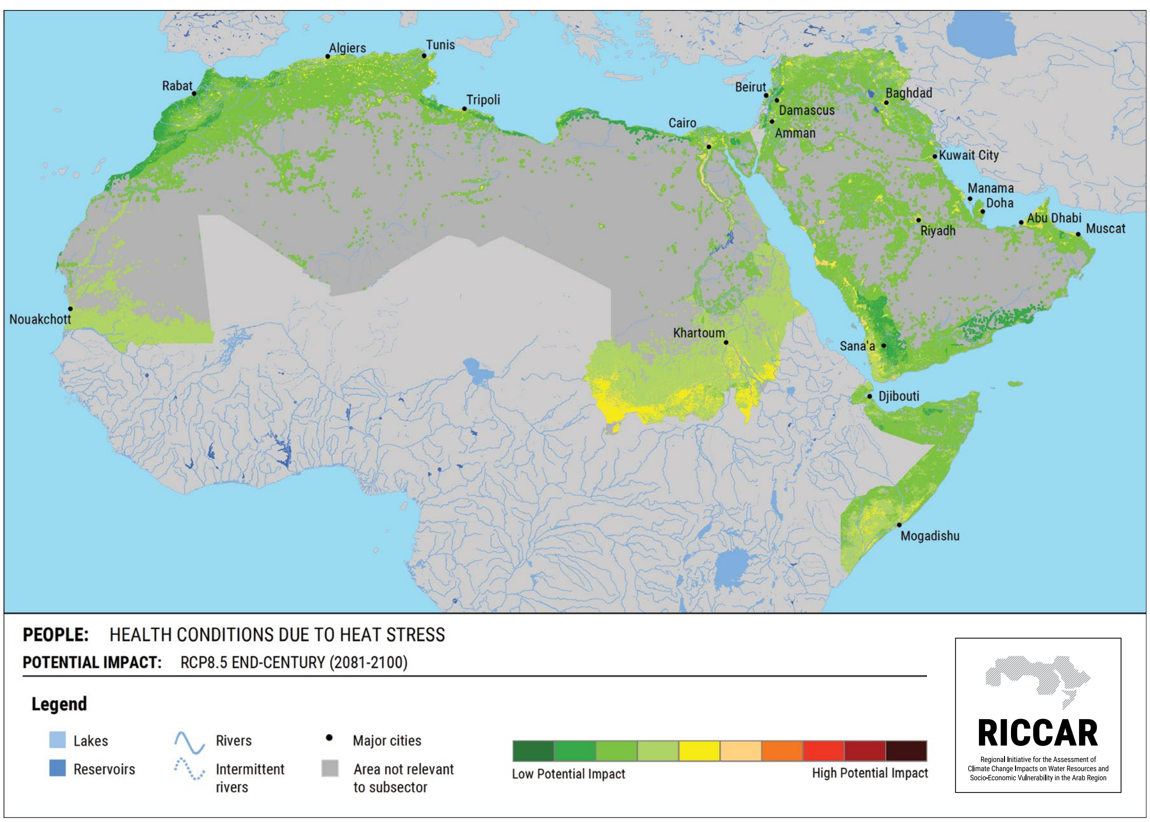


FIGURE 211: Health conditions due to heat stress – End-century RCP 8.5 – Potential impact



13.2.2.2 Vulnerability

At mid-century, moderate heat stress vulnerability is forecast for over half the study area, ranging from 55% (RCP 4.5) to 70% (RCP 8.5) of the study area. At end-century, this increases to 63% (RCP 4.5) to 95% (RCP 8.5) of the study area. Most remaining areas suggest low vulnerability, ranging from 30% (RCP 8.5) to 45% (RCP 4.5) of the study area at mid-century and 4% (RCP 8.5) to 37% (RCP 4.5) at end-century (Table 33). Vulnerability trends exhibit a low-to-moderate gradient from north to south, with areas of elevated vulnerability in the Levant and Mesopotamia (Figure 212 to Figure 215).

Because health problems due to heat stress vulnerability stems largely from exposure, the change in exposure indicators was evaluated by vulnerability classification (Table 34). Areas of high vulnerability retain a greater increase in indicator values than the Arab region as a whole. Because even areas of low vulnerability had periods when high temperatures were of concern, increases in these periods are problematic in terms of human health.

Trends reveal either nearly static vulnerability or increasing vulnerability from mid- to end-century. For RCP 4.5, areas of increasing vulnerability tend to be located in the Sahara Desert, the eastern Atlas Mountains, and the central Mashriq. However, these areas indicate nearly static vulnerability for RCP 8.5 but most of the remaining study area reveals increasing vulnerability.

TABLE 33: Percentage of study area by vulnerability classification for health due to heat stress

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	45%	55%	0%
Mid-Century RCP 8.5	30%	70%	0%
End-Century RCP 4.5	37%	63%	0%
End-Century RCP 8.5	4%	95%	1%

TABLE 34: Average climate parameters by vulnerability classification

Exposure indicator	Units	Climate scenario	Average indicator value by vulnerability classification for subsector		Average indicator value for Arab region
			Low	Moderate	
Change in temperature (compared to reference period)	°C	Mid-Century RCP 4.5	+1.4	+1.5	+1.5
		Mid-Century RCP 8.5	+2.1	+2.1	+2.1
		End-Century RCP 4.5	+1.8	+1.9	+1.9
		End-Century RCP 8.5	+3.5	+4.0	+4.0
Change in number of hot days (SU35) (compared to reference period)	days/year	Mid-Century RCP 4.5	+22	+46	+30
		Mid-Century RCP 8.5	+30	+55	+41
		End-Century RCP 4.5	+27	+54	+38
		End-Century RCP 8.5	+54	+84	+74
Change in number of very hot days (SU40) (compared to reference period)	days/year	Mid-Century RCP 4.5	+15	+38	+28
		Mid-Century RCP 8.5	+16	+48	+39
		End-Century RCP 4.5	+18	+46	+36
		End-Century RCP 8.5	+26	+77	+76

FIGURE 212: Health conditions due to heat stress – Mid-century RCP 4.5 – Vulnerability

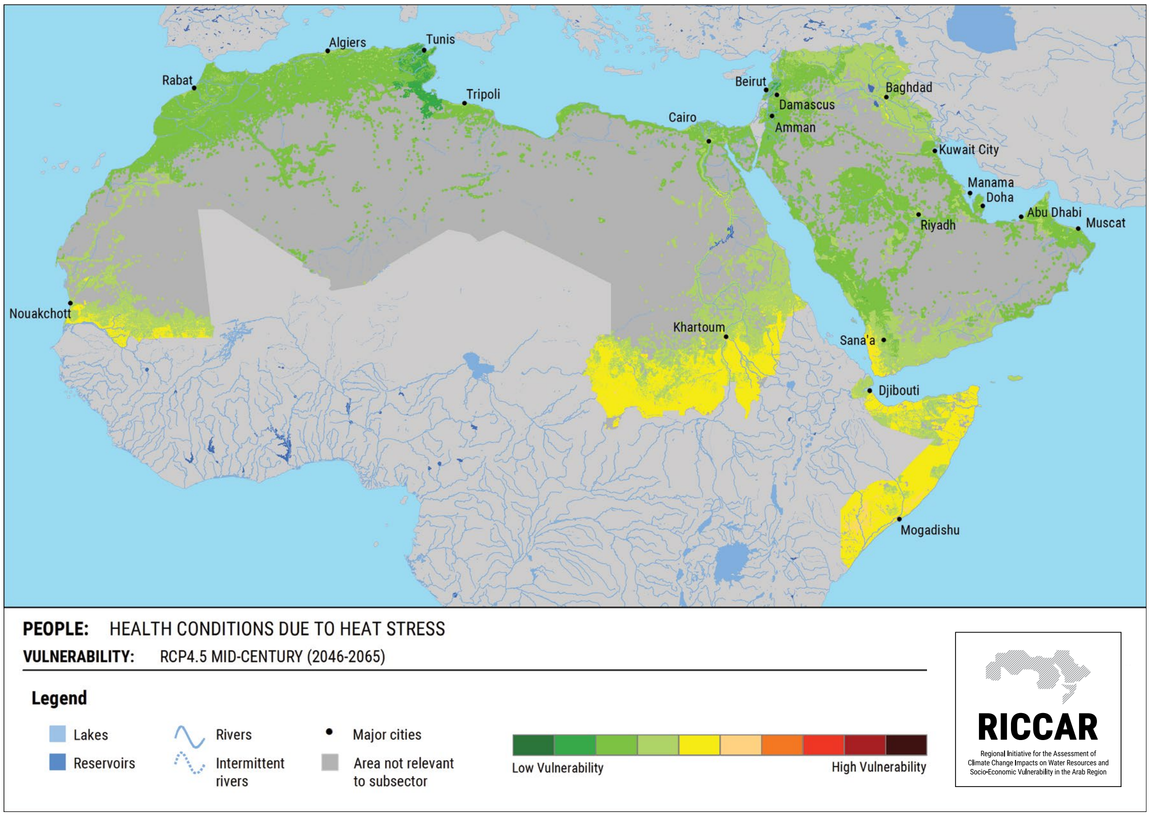


FIGURE 213: Health conditions due to heat stress – Mid-century RCP 8.5 – Vulnerability

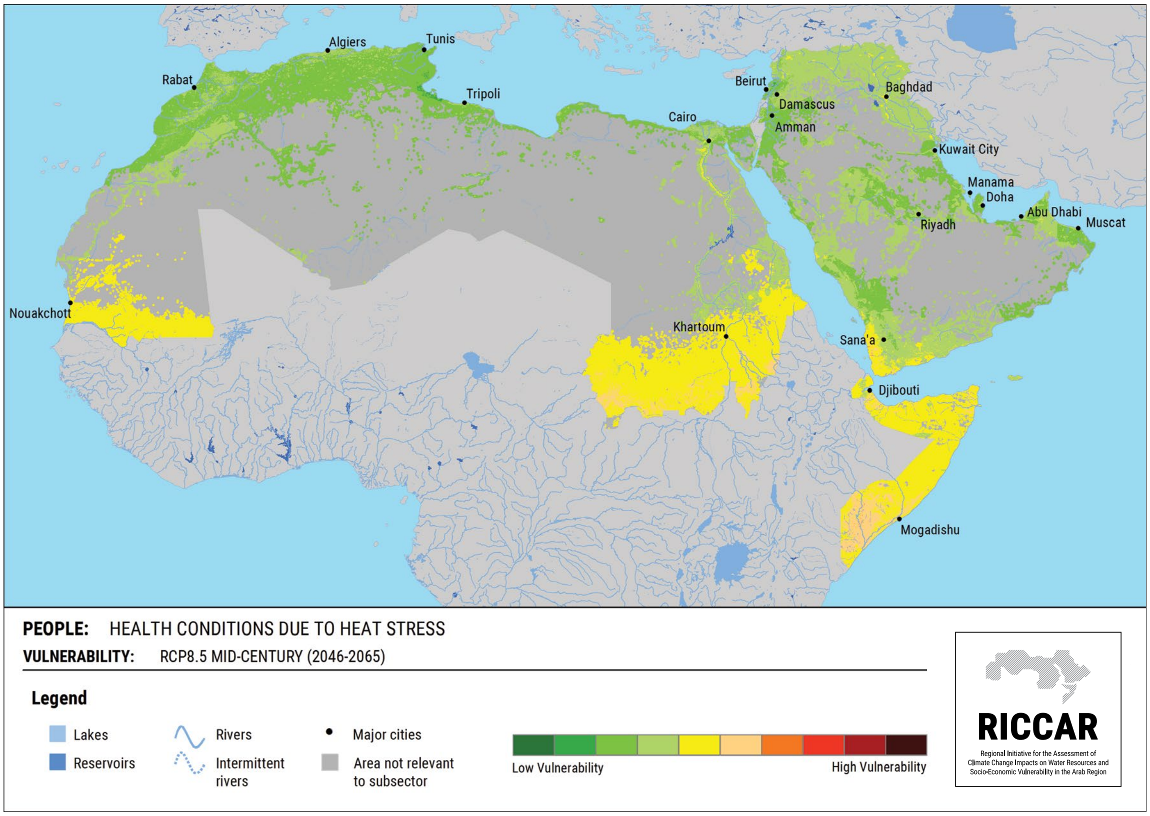


FIGURE 214: Health conditions due to heat stress – End-century RCP 4.5 – Vulnerability

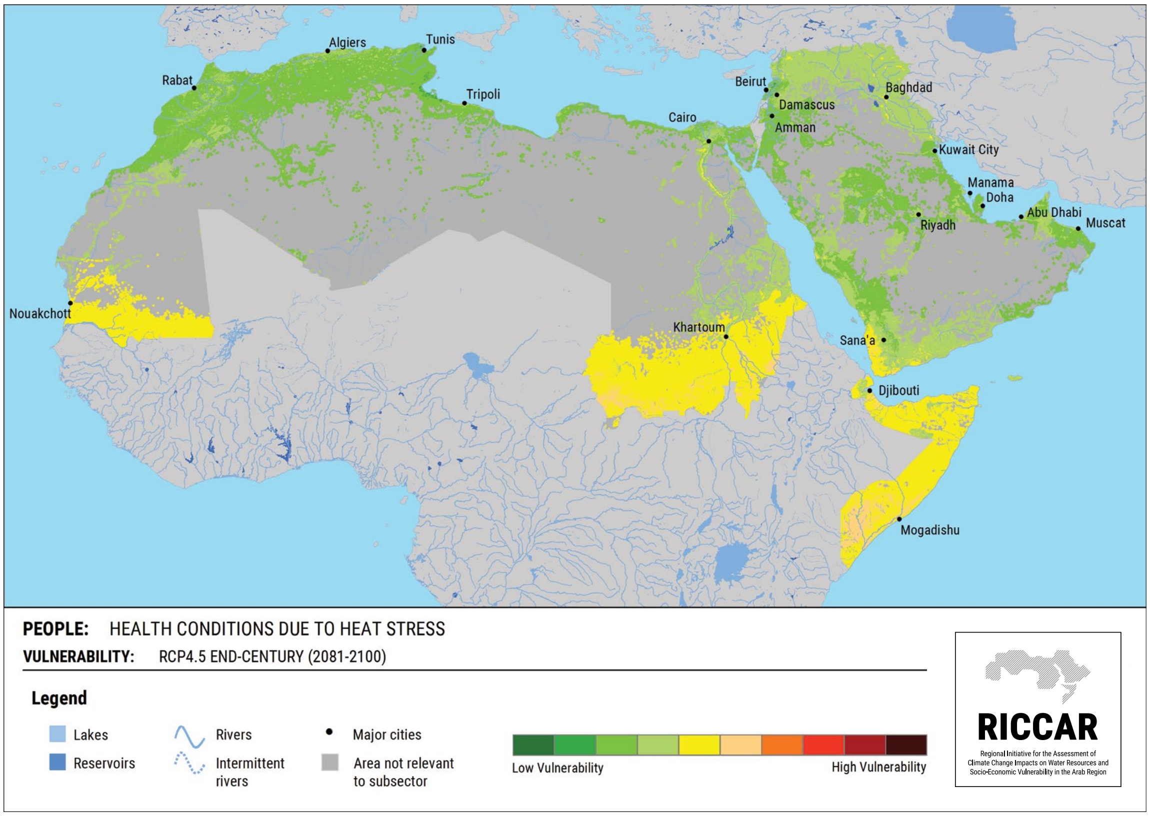
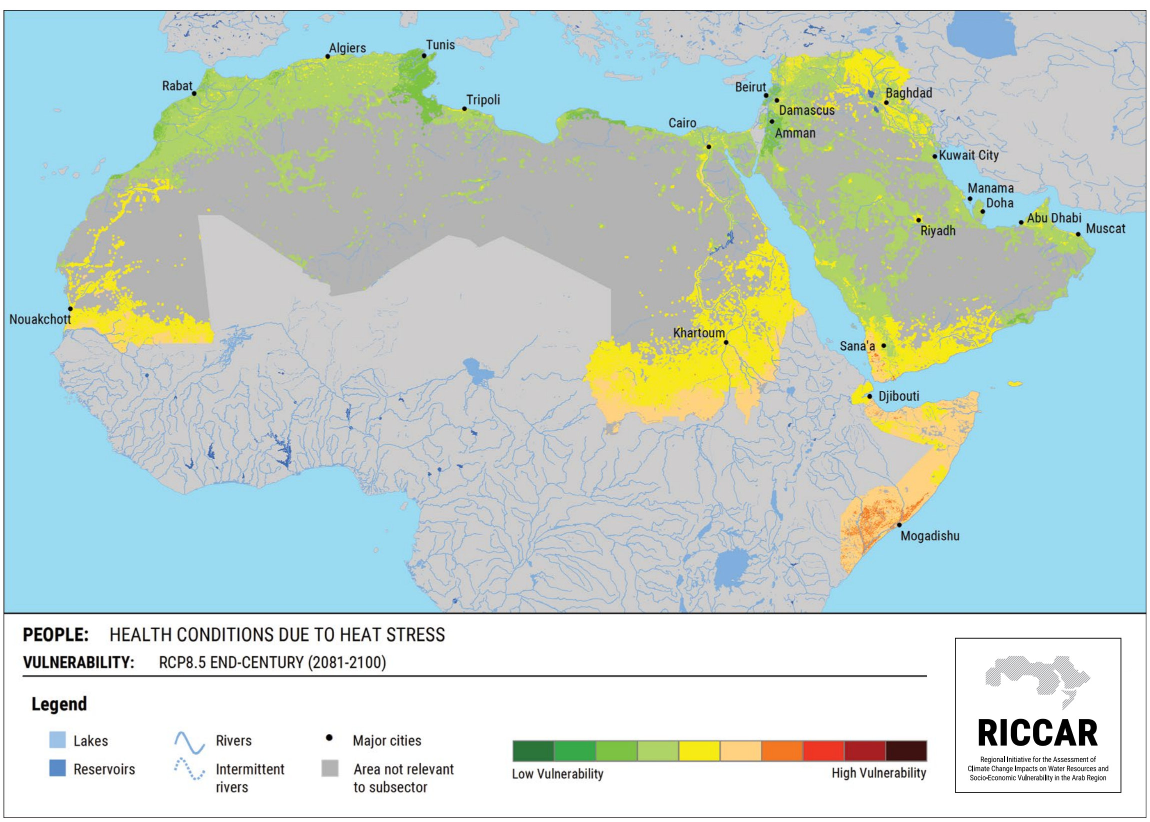


FIGURE 215: Health conditions due to heat stress – End-century RCP 8.5 – Vulnerability



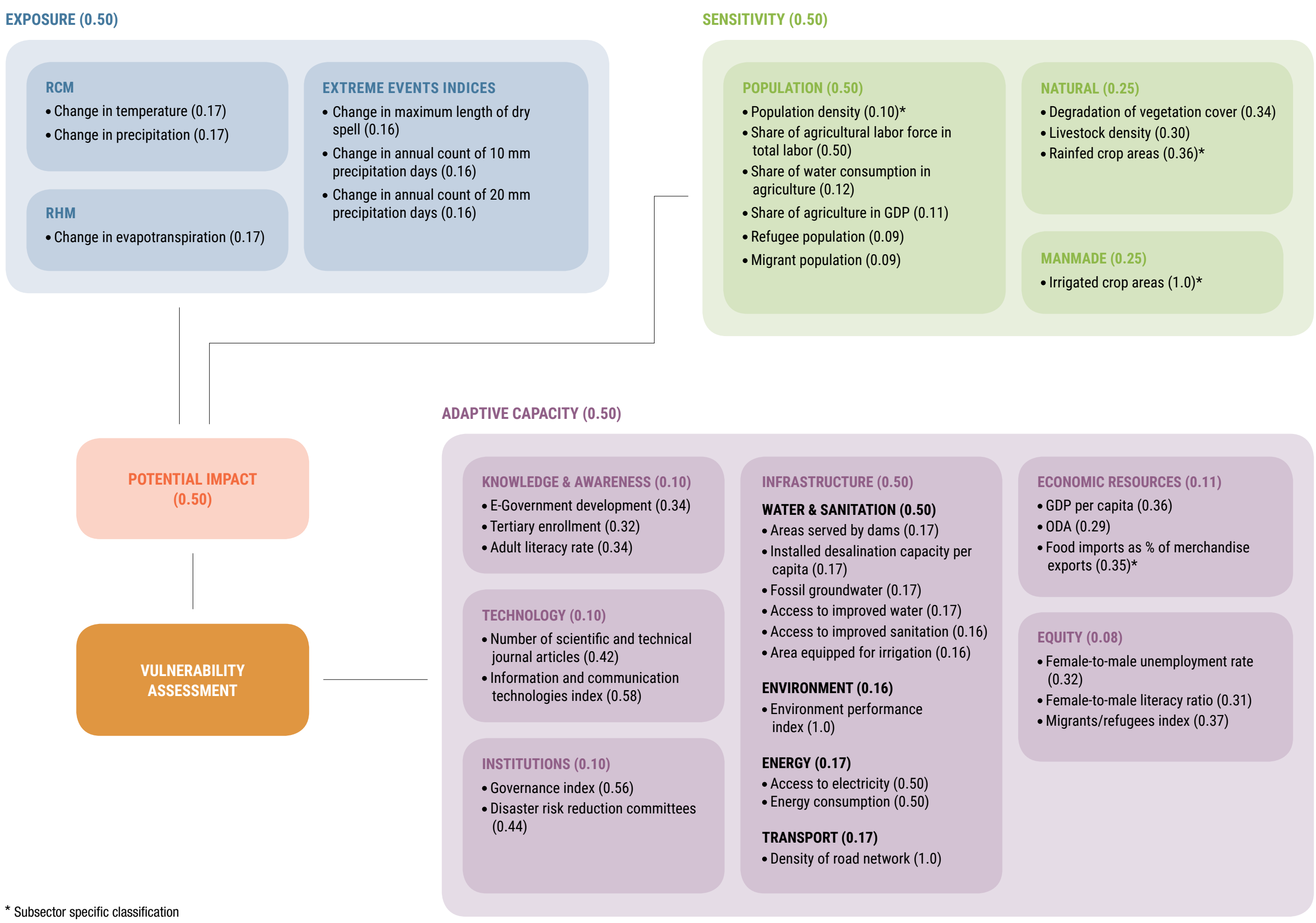
13.2.3 Hotspots

Areas with the highest vulnerability have been identified as hotspots and include very few areas, impacting up to 6% of the study area. Hotspots result from insufficient adaptation capacity measures in place, as well as temperature changes. Hotspots are located in sub-Saharan Africa, particularly in the southern Horn of Africa and the south-western Arabian Peninsula. Even though these areas are small on a regional scale, heat stress hotspots are projected to affect significantly more people by the end of the century, compared to the mid-century period, with the number of very hot days projected to reach 98 days annually.

13.3 EMPLOYMENT RATE FOR THE AGRICULTURAL SECTOR

The different indicators used under each component for this subsector and their corresponding weights are presented in the impact chain in Figure 216.

FIGURE 216: Impact chain and weights for employment rate for the agricultural sector



* Subsector specific classification

13.3.1 Reference period

13.3.1.1 Potential impact

Potential impact reflects the equal aggregation of exposure and sensitivity. Selection of exposure indicators for this subsector is not necessarily as evident as for other evaluated subsectors. Nevertheless, agriculture is highly contingent on meteorological parameters; thus, farmers and pastoralists also depend on suitable weather conditions.

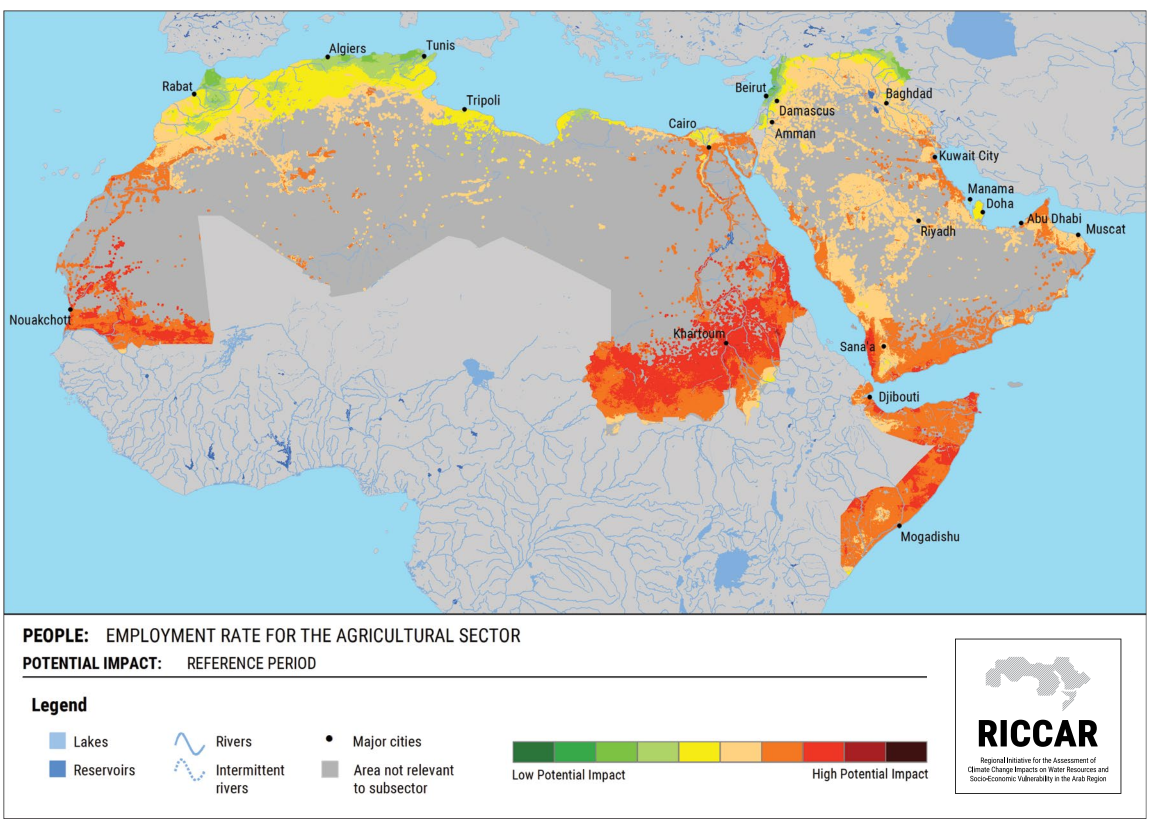
Moreover, as climate change impacts tend to be more severe for those who work in rainfed agriculture, precipitation-related indicators were selected, including those that can signify drought. Nearly half (42%) of the study suggests high exposure, primarily located in the Sahara Desert. High exposure transitions to moderate exposure (51% of the study area) until low exposure areas, which are located in the Rif region, the eastern Tell Atlas region, the coastal Levant and the Zagros Mountains.

Sensitivity indicators are largely population-based, with a focus on the rural population, who is most likely to work in agriculture. In addition, indicators related to agriculture were also considered. The resultant sensitivity is generally high. High sensitivity represents 64% of the study area and includes sub-Saharan Africa, the western Maghreb and the southern Arabian Peninsula.

Remaining areas suggest moderate sensitivity. Sensitivity for this subsector is generally higher than other subsectors because the rainfed croplands and irrigated croplands indicators were reclassified such that areas of lower cropland area were more sensitive due to limited agricultural employment opportunity in such areas.

The resultant potential impact for the reference period (Figure 217) is nearly equally divided between moderate (48% of the study area) and high (51% of the study area). Areas with the highest potential impact include sub-Saharan Africa (other than the Sahel), the central Horn of Africa and coastal areas of the south-western Arabian Peninsula.

FIGURE 217: Employment rate for the agricultural sector – Reference period – Potential impact



13.3.1.2 Adaptive capacity

Adaptive capacity is primarily influenced by the infrastructure dimension, specifically indicators which comprise the water pillar. While more advanced water infrastructure helps facilitate irrigation capabilities, the other five dimensions are also significant. Although the indicators within are not directly related to agricultural employment, they can be considered as proxies for the dimension they represent.

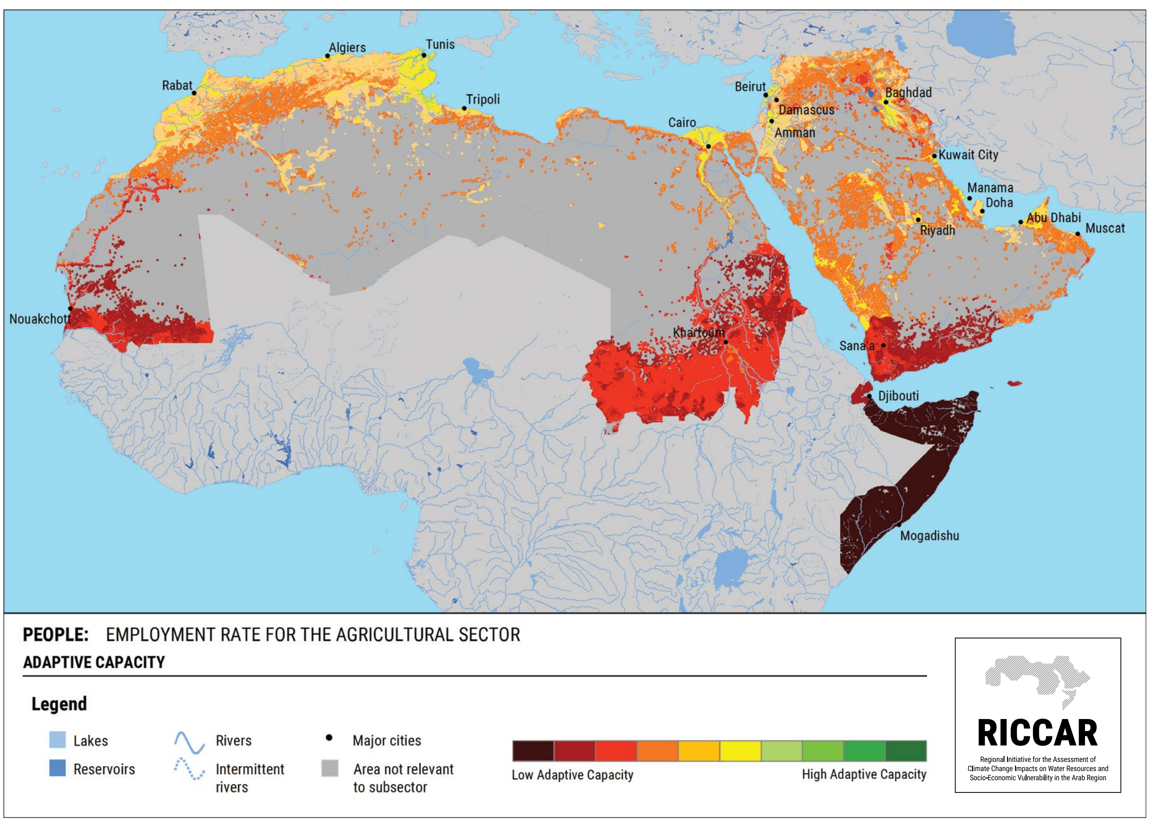
Knowledge and awareness can provide guidance for more advanced techniques using current technology. Government institutions can help facilitate participation by small farmers in decision-making processes and economic resources. Lastly, women have occupied a greater role in agriculture, representing about 30% of the agricultural workforce in the Arab region.[8]

The study area is divided between low and moderate adaptive capacity (45% and 54%, respectively) with the remaining area indicating high adaptive capacity (Figure 218). Areas with the lowest adaptive capacity include the Horn of Africa, parts of the Sahara Desert, and the Wadi Hadramawt region.

Conversely, areas with relatively high adaptive capacity include the eastern Atlas Mountains and Tell Atlas region, the Jafara Plain and small areas near the Jordan and Litani Rivers.

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

FIGURE 218: Employment rate for the agricultural sector – Adaptive capacity



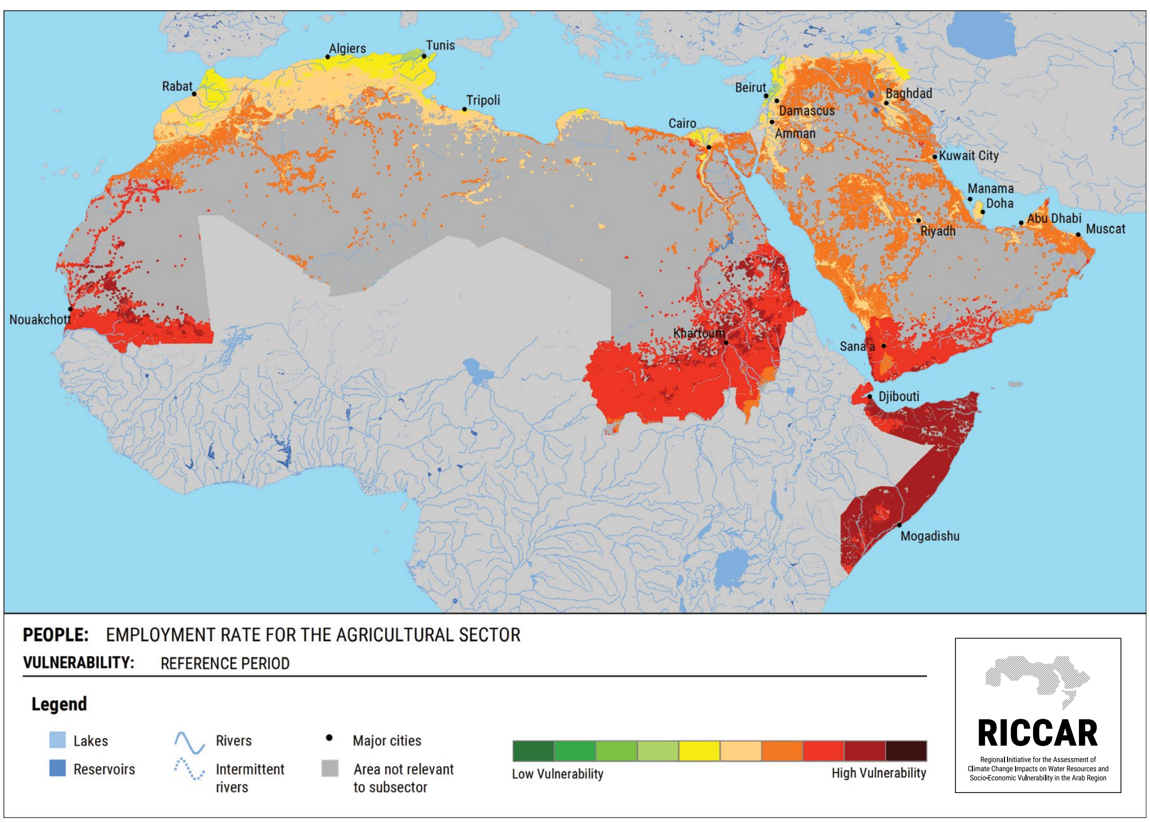
13.3.1.3 Vulnerability

Vulnerability for the reference period is rather high overall, representing 75% of the studied area (Figure 219). Remaining areas suggest moderate vulnerability. Areas of high vulnerability include the Horn of Africa, sub-Saharan Africa and the southern Arabian Peninsula. Pastoralists are considered most at risk for employment opportunities because vulnerability is highest (7.4) in livestock areas. Conversely, vulnerability is lowest (5.7) in irrigated areas. Vulnerability is moderate for both rainfed areas (6.5) and rural areas (6.6), although vulnerability tends to decrease as rural population increases.

Once the primary employment sector in the Arab region, agricultural occupations have been declining since the 1970s. The only area where agriculture represents > 50% of the labour market is the Horn of Africa.[9] Oil wealth and resultant opportunities in the industrial, construction and service sectors partly contributed to the decline. Rural-urban migration occurred as a result, shifting government priorities away from rural areas and agriculture towards urban challenges, further contributing to the decline.[10]

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

FIGURE 219: Employment rate for the agricultural sector – Reference period – Vulnerability



13.3.2 Future periods

13.3.2.1 Potential impact

Exposure is largely moderate for most scenarios, representing 92% (RCP 4.5) to 94% (RCP 8.5) of the study area at mid-century. At end-century, exposure remains largely unchanged under RCP 4.5 but, for RCP 8.5, areas of moderate exposure decline to 66% of the study area and high exposure areas increase to 30%. Other areas predict low exposure. Areas of moderate to high exposure are dispersed throughout the study area, depending on the climate scenario, but are consistently located in the Rif region, the western Tindouf basin, the western North Africa coastline, the upper Nile Basin and the southern coastline of the Arabian Peninsula.

Similarly, projected potential impact is generally moderate, assuming static sensitivity. Moderate potential impact represents 70% (RCP 8.5) to 86% (RCP 4.5) of the study area at mid-century (Figure 220 and Figure 221), decreasing to 54% (RCP 8.5) to 71% (RCP 4.5) at end-century (Figure 222 and Figure 223). Remaining areas suggest high potential impact. Areas of high potential impact are located near the Atlantic, the upper Nile Basin, the south-western Arabian Peninsula and the northern Horn of Africa.

Potential impact can change due to differing population demographics, cropland areas and rangeland areas. Although population trends predict a growth rate, Arab youth have signalled a declining interest in agricultural employment. Land-use changes can also affect the ability and accessibility to work in agriculture.

A man herding goats in Tunisia, 2005. Source: Priit Kallas.

FIGURE 220: Employment rate for the agricultural sector – Mid-century RCP 4.5 – Potential impact

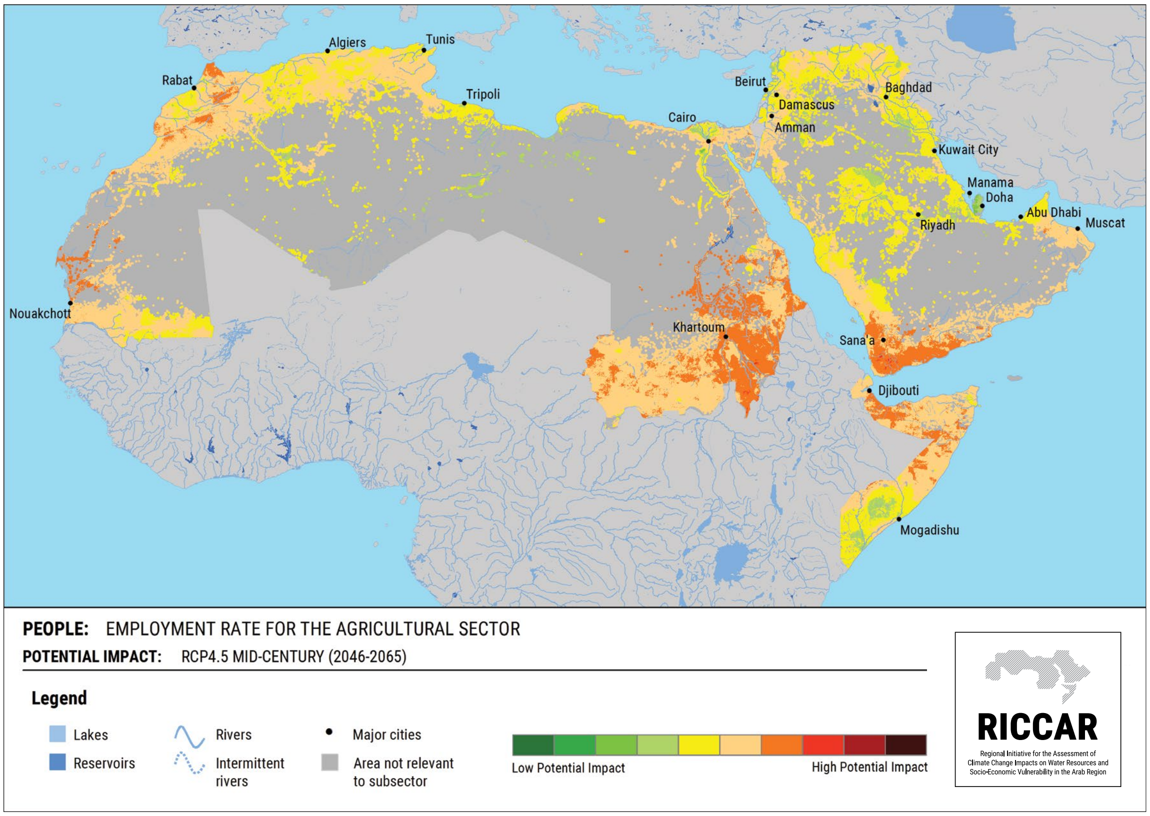


FIGURE 221: Employment rate for the agricultural sector – Mid-century RCP 8.5 – Potential impact

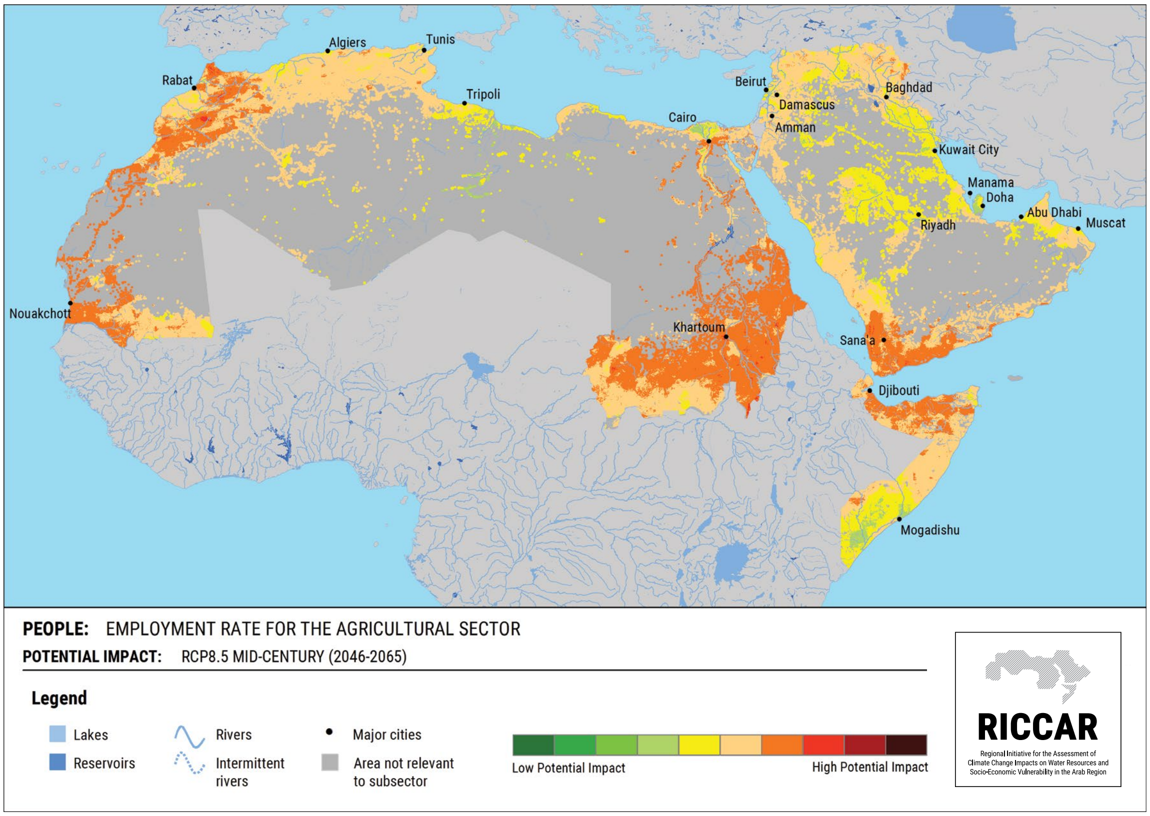


FIGURE 222: Employment rate for the agricultural sector – End-century RCP 4.5 – Potential impact

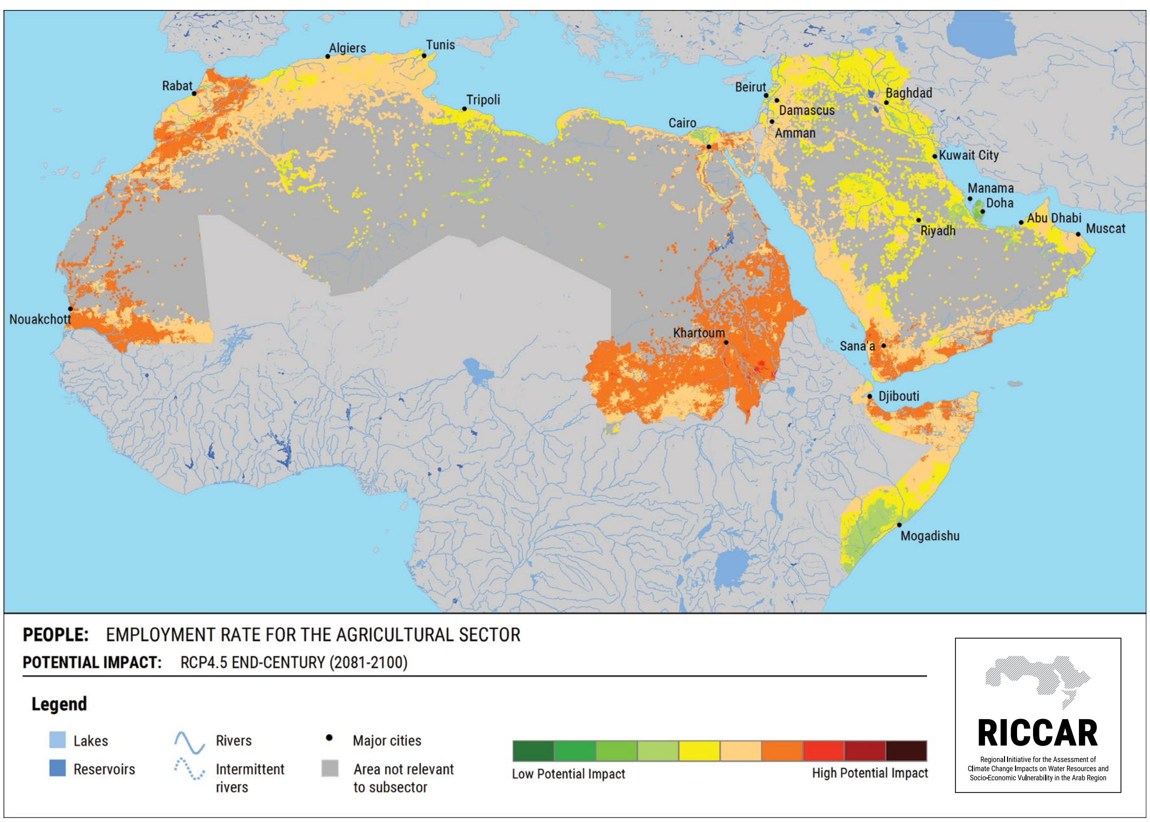
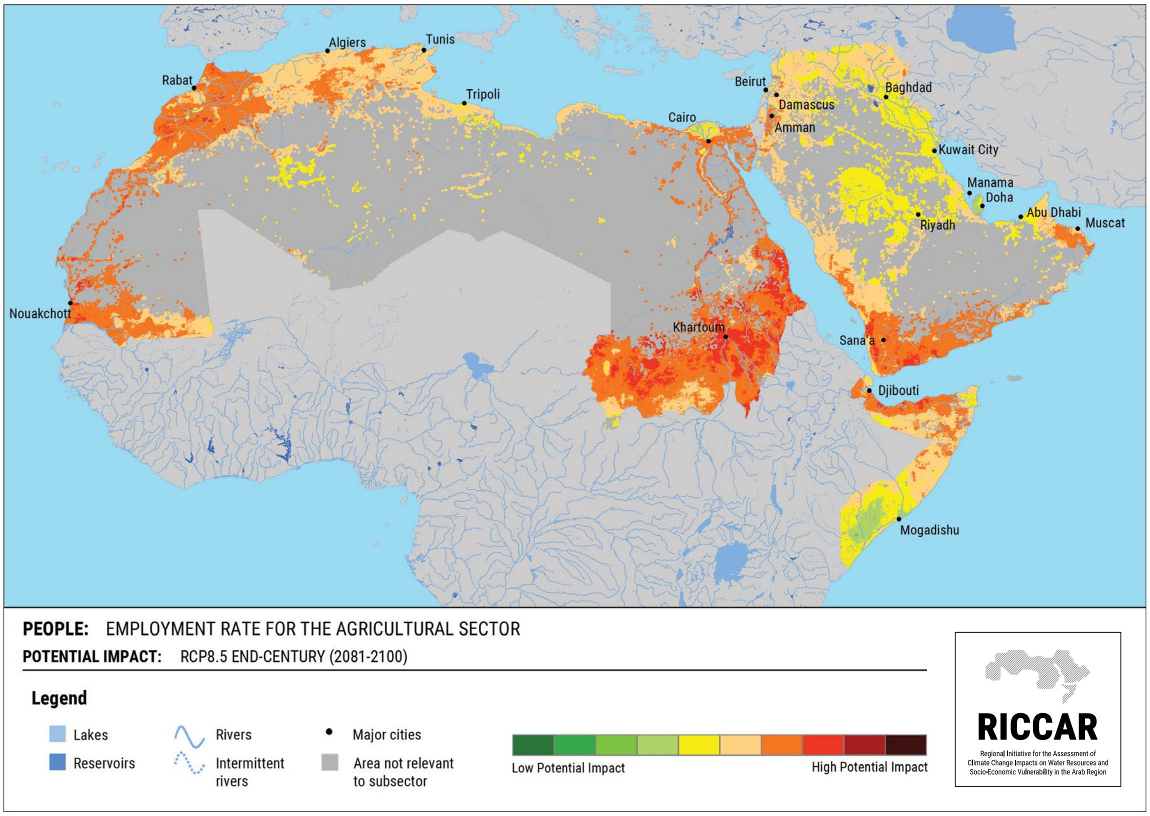


FIGURE 223: Employment rate for the agricultural sector – End-century RCP 8.5 – Potential impact



13.3.2.2 Vulnerability

A majority of the study area predicts high vulnerability, thus rendering employment difficult in the agricultural sector (Figure 224 to Figure 227). At mid-century, high vulnerability represents 61% (RCP 4.5) to 72% (RCP 8.5) of the study area, while, at end-century, high vulnerability is forecast in 65% (RCP 4.5) to 77% (RCP 8.5) of the study area (Table 35). Remaining areas suggest moderate vulnerability.

A comparison between selected sensitivity indicators and projected vulnerability indicates an above-average livestock density is located in areas of high projected vulnerability, while a below-average cropland area is located in this same area (Table 36). Thus, pastoralists are more vulnerable than farmers, assuming values from these indicators remain nearly the same.

Trend analysis reveals similar tendencies from mid- to end-century for both scenarios. Increasing vulnerability is apparent in sub-Saharan Africa, the northern Maghreb and the central eastern Red Sea area. Conversely, decreasing trends are apparent in the Horn of Africa, the Tigris–Euphrates basin and the Oman Mountains.

TABLE 35: Percentage of study area by vulnerability classification for employment rate for the agricultural sector

Scenario	Vulnerability (% of study area)		
	Low	Moderate	High
Mid-Century RCP 4.5	0%	39%	61%
Mid-Century RCP 8.5	0%	28%	72%
End-Century RCP 4.5	0%	35%	65%
End-Century RCP 8.5	0%	23%	77%

TABLE 36: Averages for selected sensitivity indicators for employment rate for the agricultural sector

Sensitivity indicator	Units	Climate scenario	Average vulnerability classification for subsector		Average all agricultural areas
			Moderate	High	
Per cent rainfed cropland area	%	Mid-Century RCP 4.5	14.5	5.4	10.2
		Mid-Century RCP 8.5	17.3	5.7	
		End-Century RCP 4.5	15.9	5.3	
		End-Century RCP 8.5	17.8	6.3	
Per cent irrigated cropland area	%	Mid-Century RCP 4.5	5.4	0.6	2.7
		Mid-Century RCP 8.5	7.1	0.6	
		End-Century RCP 4.5	6.0	0.6	
		End-Century RCP 8.5	8.4	0.6	
Average livestock density	heads/km^2	Mid-Century RCP 4.5	17	35	33
		Mid-Century RCP 8.5	18	32	
		End-Century RCP 4.5	18	34	
		End-Century RCP 8.5	18	31	

FIGURE 224: Employment rate for the agricultural sector – Mid-century RCP 4.5 – Vulnerability

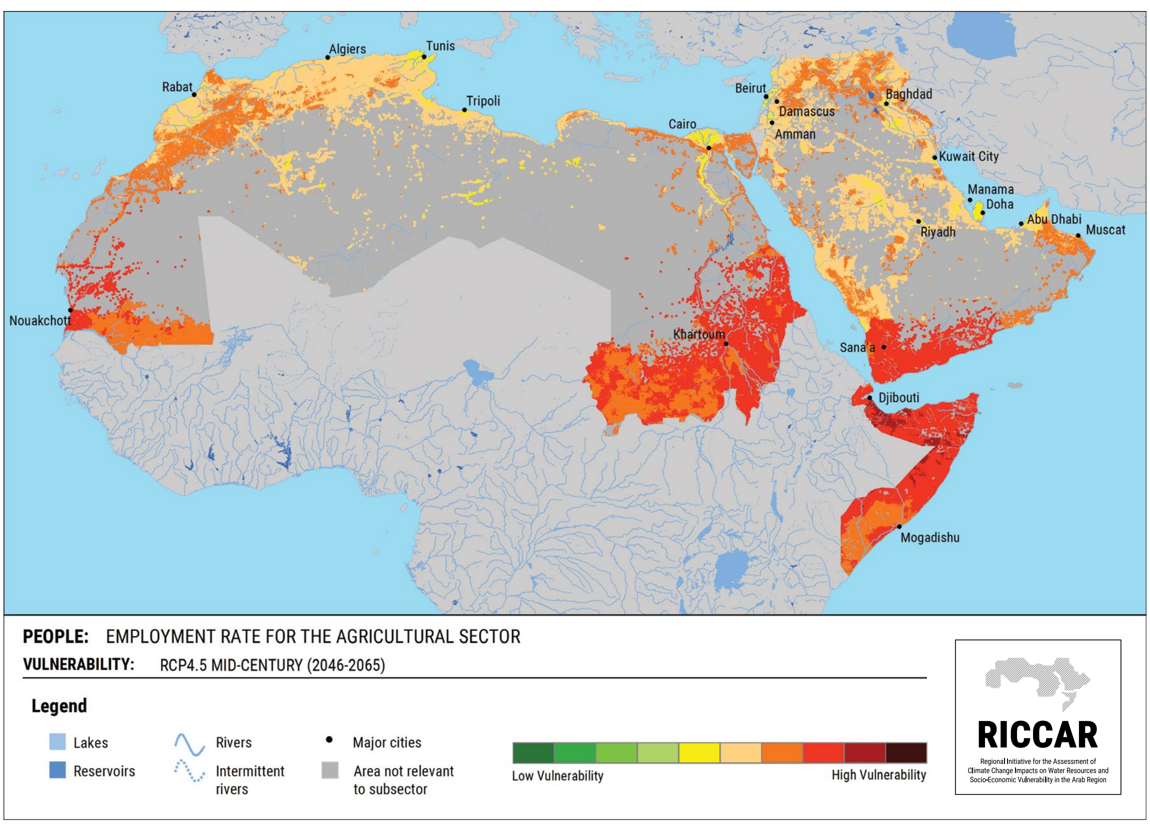


FIGURE 225: Employment rate for the agricultural sector – Mid-century RCP 8.5 – Vulnerability

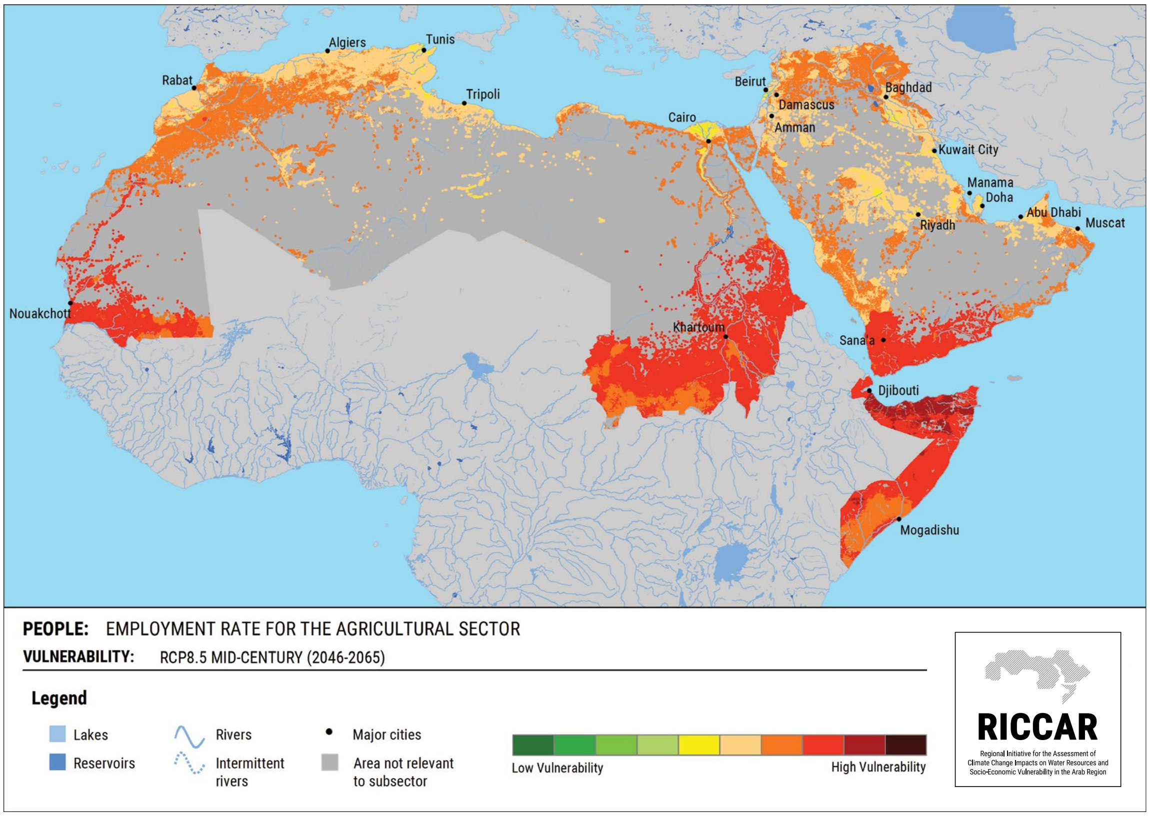


FIGURE 226: Employment rate for the agricultural sector – End-century RCP 4.5 – Vulnerability

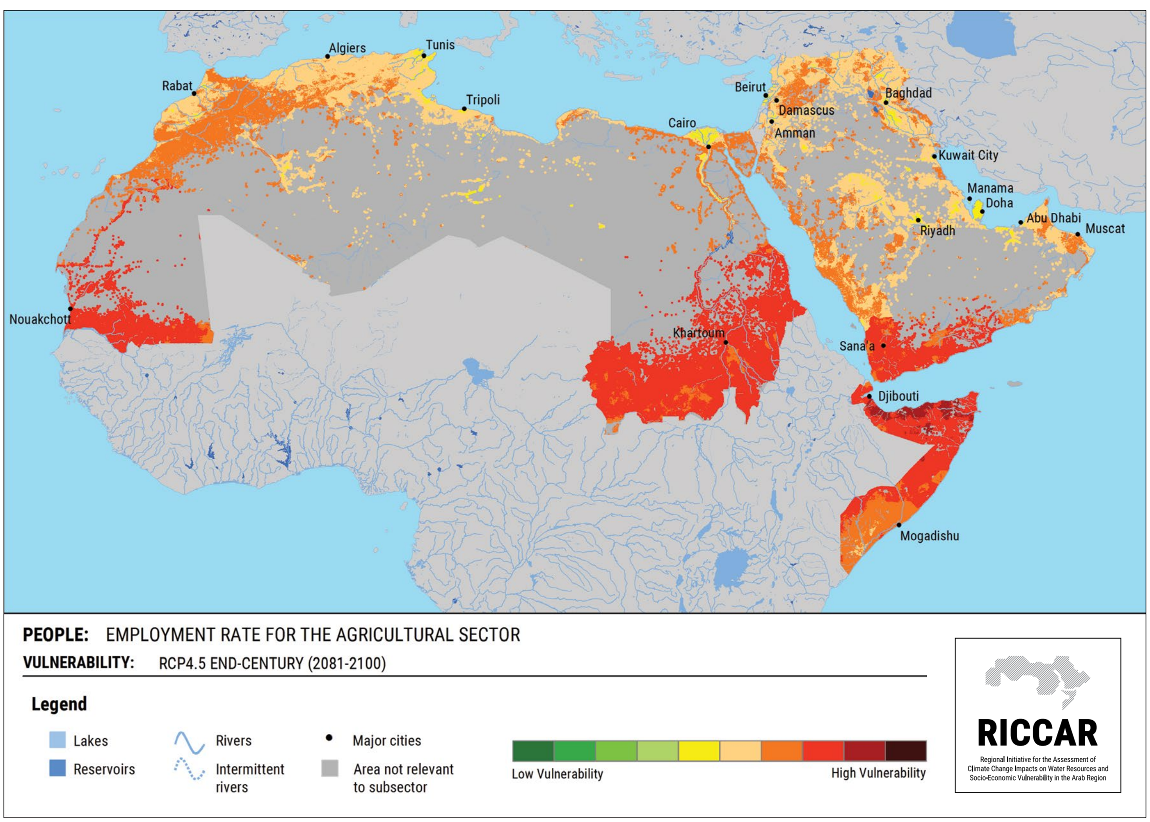
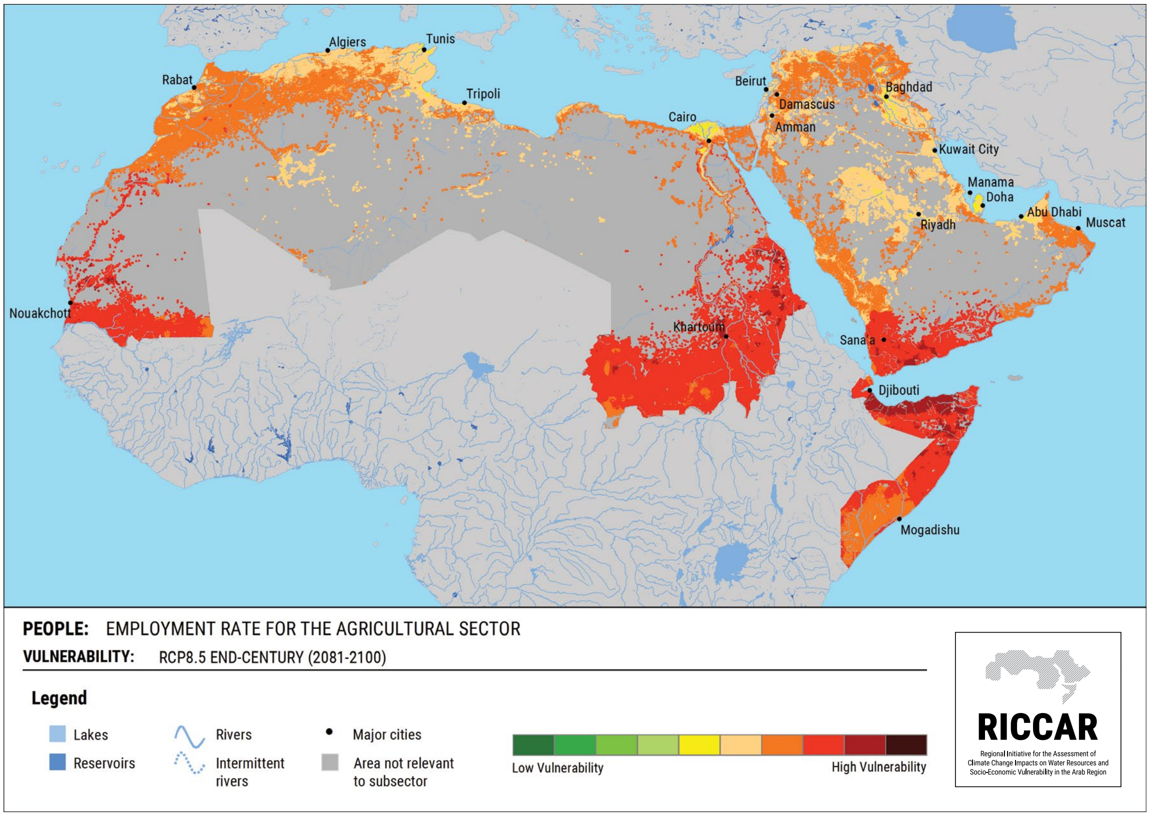


FIGURE 227: Employment rate for the agricultural sector – End-century RCP 8.5 – Vulnerability



13.3.3 Hotspots

Hotspots signify areas with the highest vulnerability for a given subsector. Hotspots revealed for the subsector *Employment rate for the agricultural sector* are the largest of all studied subsectors, representing up to 28% of the study area and up to 12% of the entire Arab region.

Such areas include the Tindouf basin, parts of the Taoudeni basin, the lower eastern Sahara Desert, the south-western Arabian Peninsula and the northern Horn of Africa. Most livelihoods in these hotspots depend on agriculture, often representing more than 50% of the workforce.

High vulnerability can result in adverse impacts to rural incomes, as well as a decline in food security for the region as a whole.

Nomadic herders, Djibouti, 2012. Source: EU/ECHO/Martin Karimi.

13.4 PEOPLE SECTOR: OVERALL VULNERABILITY

13.4.1 Reference period

Three subsectors contribute toward the *People* sector aggregated result, of which the subsector *Health conditions due to heat stress* has the strongest correlation.

Nearly the entire study area (98%) indicates moderate vulnerability for the reference period, with remaining areas divided between low and high vulnerability (Figure 228).

Areas with the highest vulnerability include the upper Nile Valley and lower Blue Nile basin near Khartoum; the north-western coast, Wadi Jaceyl Bid and the upper Jubba River in the Horn of Africa; and coastal areas in the south-western Arabian Peninsula. Conversely, areas with the lowest vulnerability include the Rif region, the eastern Tell Atlas region and the central Levantine coastal region.

13.4.2 Future periods

13.4.2.1 Vulnerability

Results for the *People* sector vulnerability are presented in Figure 229 and Figure 230 for mid-century, and in Figure 231 and Figure 232 for end-century. Like the reference period, projected vulnerability is also largely moderate, reflecting the entire region for all scenarios except for RCP 8.5 end-century (Table 37). 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. However, the southern Horn of Africa suggests static-to-declining vulnerability. 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.

FIGURE 228: People sector – Vulnerability – Reference period

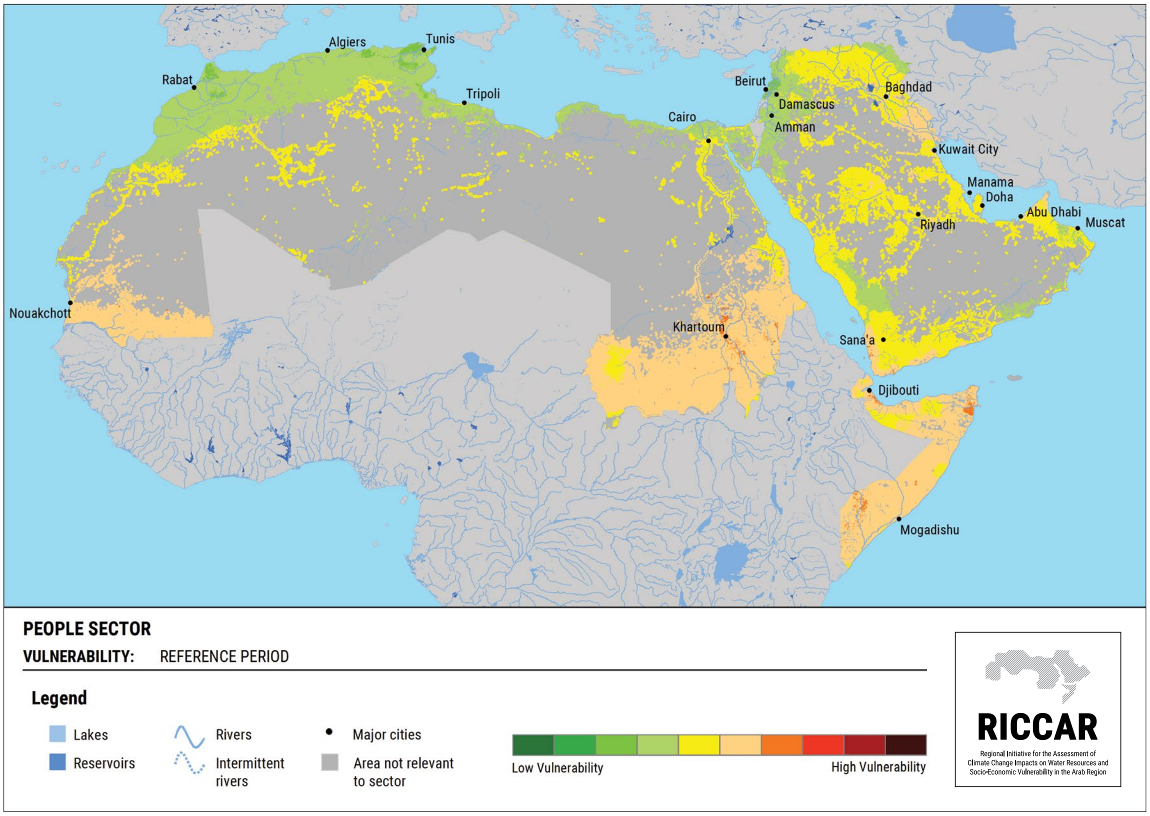


TABLE 37: Percentage of study area by vulnerability classification for people sector

Scenario	Vulnerability (% of study area)		
	Low	**Moderate**	**High**
Mid-Century RCP 4.5	0%	100%	0%
Mid-Century RCP 8.5	0%	100%	0%
End-Century RCP 4.5	0%	100%	0%
End-Century RCP 8.5	0%	98%	2%

13.4.3 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).

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

FIGURE 229: People Sector – Vulnerability – Mid-century RCP 4.5

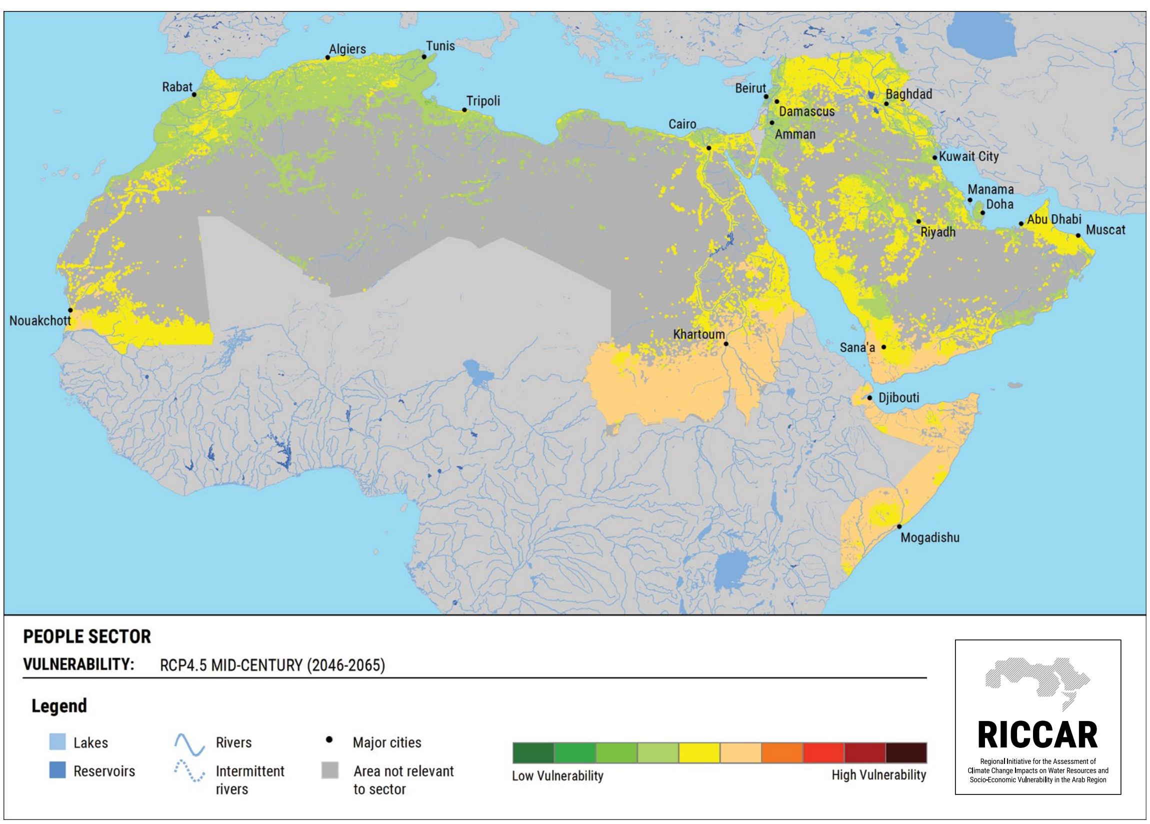


FIGURE 230: People Sector – Vulnerability – Mid-century RCP 8.5

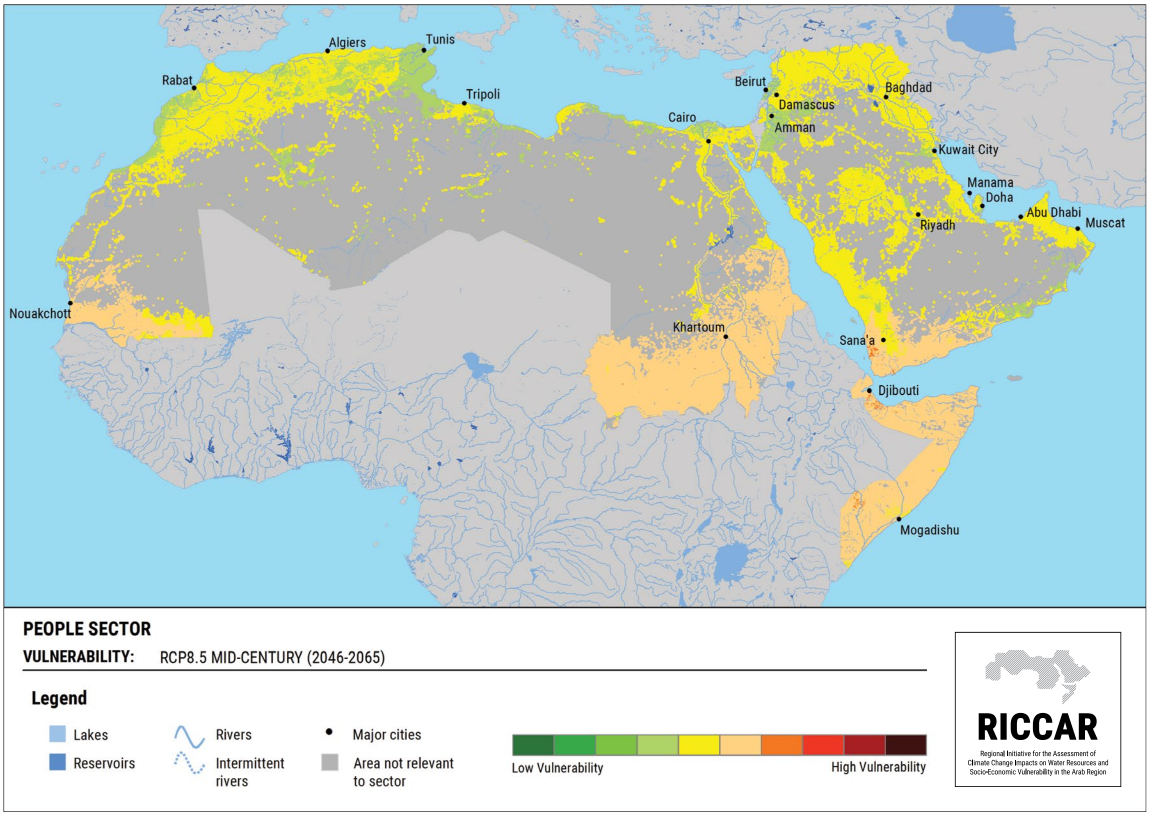


FIGURE 231: People Sector – Vulnerability – End-century RCP 4.5

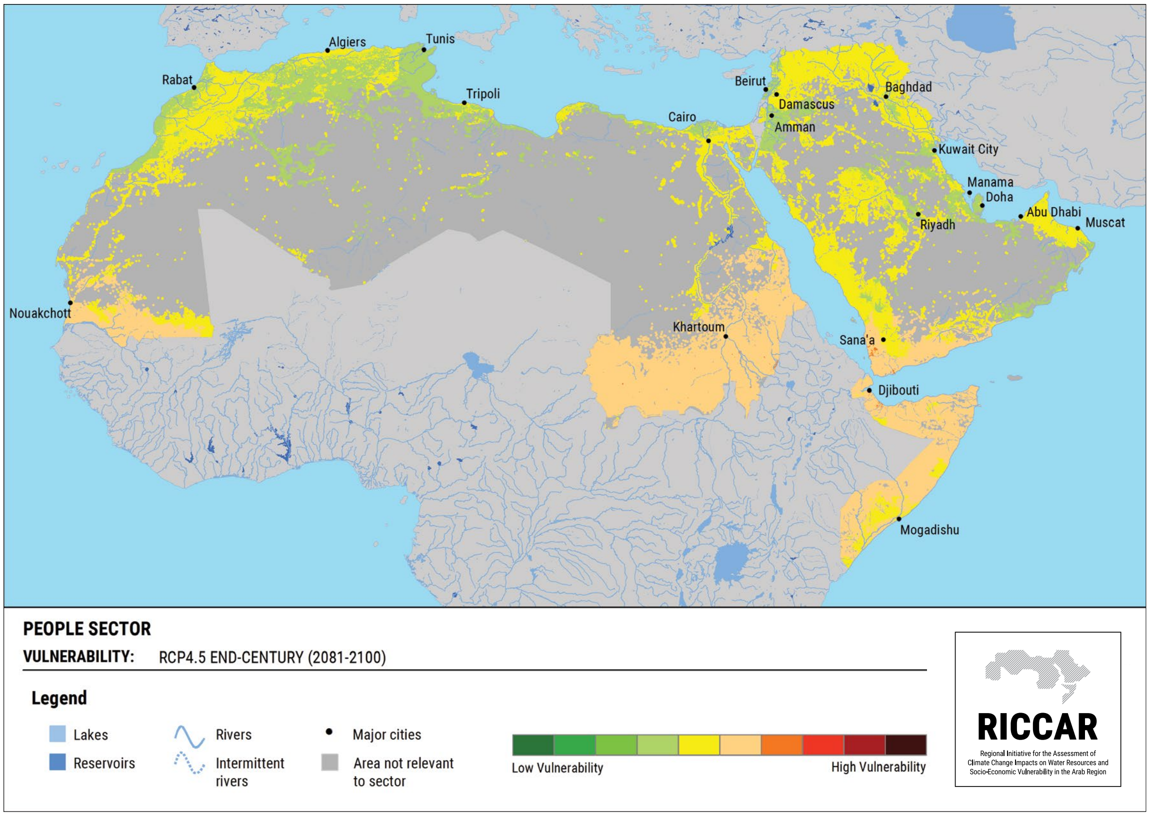
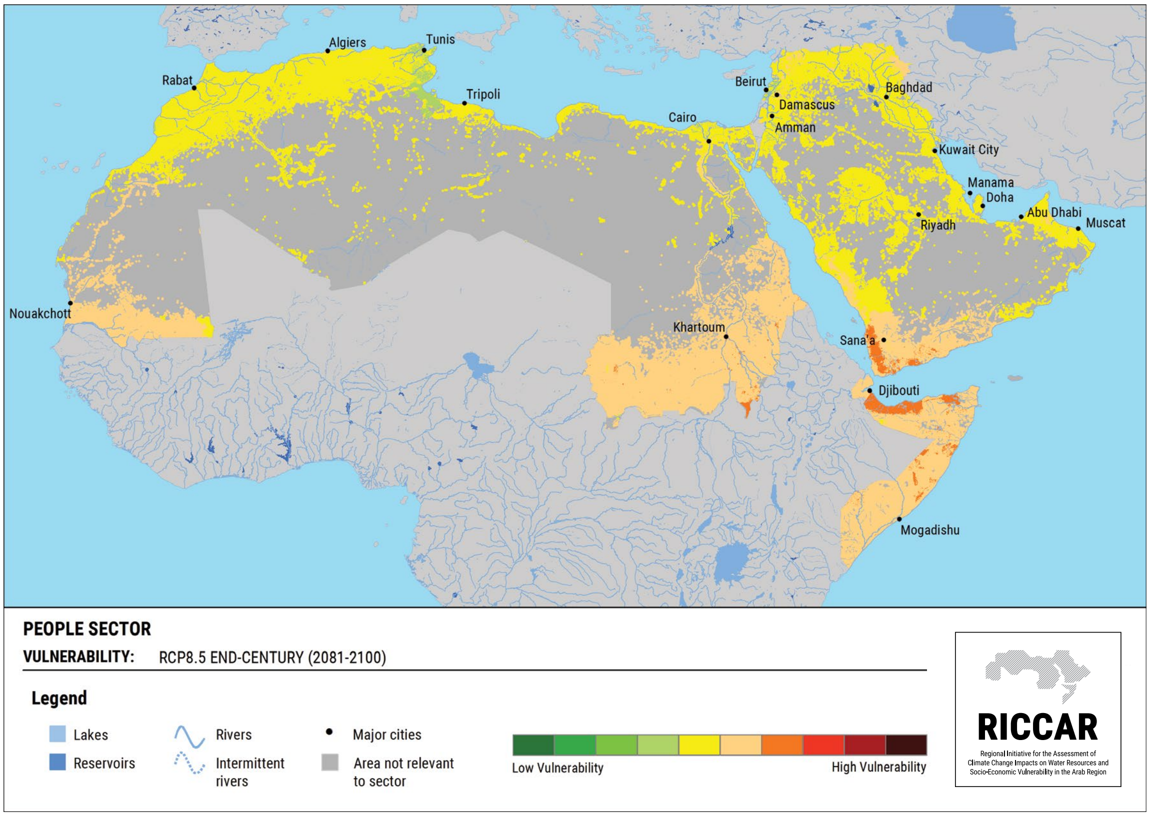


FIGURE 232: People Sector – Vulnerability – End-century RCP 8.5



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

ENDNOTES

1. ILO, 2017; AOAD, 2012
2. WHO and UNICEF, 2016
3. Ibid.
4. FAO, 2017
5. DesInventar, 2016
6. McCarthy et al., 2010
7. UN-DESA, 2017
8. ILO, 2017
9. AOAD, 2012
10. Shaban et al., 1994

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CHAPTER 14

INTEGRATED VULNERABILITY ASSESSMENT – SUMMARY

14.1 OVERVIEW OF GENERAL VULNERABILITY TRENDS

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.

Exposure exhibits spatial and temporal variability among the differing subsectors but reveals a stronger correlation with change in precipitation than change in temperature. Exposure is a function of various climate-related indicators which can be broadly classified into precipitation-based or temperature-based. 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, these indicators tend to dominate resultant exposure. This outcome is logical, given that most subsectors are based upon general or user-specific water availability.

Sensitivity is frequently correlated with population density, which generally confines areas of higher sensitivity to urbanized coastal areas and the lower Nile River Valley. Sensitivity is a function of selected indicators from the population, natural and man-made dimensions. Over half the subsectors have weighted the population dimension more than the other two dimensions. From the population dimension, solely population density reveals subnational data. For remaining subsectors, although emphasis is placed on either the natural or manmade dimension, indicators from these dimensions often correlate with population density to some extent.

Of the three components, adaptive capacity is most likely to influence vulnerability, suggesting the ability of mankind is stronger than climate change and environmental stressors. This is partly because the effective weight of adaptive capacity is higher than either exposure or sensitivity as revealed by the various impact chains. Even so, adaptive capacity often points toward a stronger correlation with vulnerability than potential impact (the aggregated result of exposure and sensitivity), despite being weighted equally. This is partly because areas of low adaptive capacity often occur in areas of high exposure, such as the Sahel and Gulf of Aden coastal zone.

Predicted vulnerability is largely moderate to high (Table 38) 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). More specifically, areas near the Mediterranean coast within the northern sector of the Arab region frequently point toward lower comparative vulnerability while areas in the southern third of the region predict higher vulnerability. Areas with the highest vulnerability are synonymous with hotspots and are summarized in detail in the following section. Lastly, the horizontal middle third of the Arab region suggests moderate vulnerability.

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

TABLE 38: Summary of vulnerability assessment results

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%	• Forested areas • Wetland areas • Rainfed areas • Irrigated areas • Livestock areas > 10 heads/km^2 • Population density > 2 inhabitants/km^2
		RCP 8.5	0%	48%	52%		
	End-century	RCP 4.5	0%	52%	48%		
		RCP 8.5	0%	43%	57%		
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%		
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%		
INFRASTRUCTURE AND HUMAN SETTLEMENTS Inland flooding area	Mid-century	RCP 4.5	2%	94%	4%	32%	• Low or greater floodprone potential
		RCP 8.5	3%	93%	4%		
	End-century	RCP 4.5	2%	94%	4%		
		RCP 8.5	4%	89%	7%		
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%		

Lower relative vulnerability is revealed near the Mediterranean coast, specifically the western Maghreb and the Levant, despite declining precipitation and runoff. These relatively large decreases in precipitation and runoff are coupled with comparatively small increases in temperature. The resultant exposure in this area is variable, ranging from low to high, based upon the climate scenario and selected indicators for a given subsector. Sensitivity within this subregion is generally low, except for population centres near the coast. Resultant potential impact is compensated by moderately high adaptive capacity.

Despite signalling strong warming trends, the central Mediterranean coastal and Green Mountains zone indicates moderate projected vulnerability. Within this subregion, exposure is variable; changes in temperature and precipitation are modest, while extreme climate indices such as number of hot days (SU35) reveal a substantial increase. Sensitivity is also wide-ranging, but is often high immediately adjacent to the Mediterranean coast. Lastly, adaptive capacity points toward moderate and most influences resultant vulnerability.

The lower Nile River basin is indicative of moderate projected vulnerability due to variable potential impact coupled with high adaptive capacity. This area is indicative of precarious environmental, economic and social conditions, including a very high population density, which gives rise to high sensitivity. Changes in precipitation and temperature are generally modest and resultant exposure is variable, depending on selected indicators and climate scenario. As elsewhere near the Mediterranean coast, the resultant potential impact is counterbalanced by adaptive capacity, which in this case is high, relative to the rest of the region.

The Euphrates and Tigris river basins subregion is also indicative of moderate vulnerability, despite demographic pressures, hydro-infrastructure developments and other challenges. Exposure in this area is variable, although precipitation is generally decreasing in the upper basin near the Zagros Mountains and slightly increasing in the lower basin. Sensitivity is generally low, even with an increased population density near Baghdad and a high degradation trend of vegetative cover. Adaptive capacity is variable and largely moderate, but relatively higher near Baghdad compared to elsewhere in the subregion.

The final major subregion revealing generally moderate vulnerability is the Gulf region, despite remaining among the hottest areas in the Arab region. The Gulf is projecting low-to-moderate exposure stemming from modest increases in temperature, coupled with unchanged precipitation, which remains low. Additionally, sensitivity indications are low to moderate while adaptive capacity is largely moderate.

Finally, although some of the areas may project lower vulnerability, 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 at least 94% of the region forecasts an increase in the number of very hot days (SU40). 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.

14.2 HOTSPOTS

Hotspots are those areas which signify 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. For this reason, they have been largely excluded from this report, but will be available on the Regional Knowledge Hub. Even so, hotspot maps developed at the sector level for RCP 8.5 end-century are discernible at a regional scale and have thus been presented herein (Figure 239 to Figure 243). Moreover, these maps represent the worst-case scenario.

Vulnerability hotspots generally recur in the Sahel extending northward into the Sahara Desert, the south-western Arabian Peninsula, and the Horn of Africa. All these areas share low adaptive capacity relative to the rest of the Arab region. In many cases, this low adaptive capacity is coupled with high exposure due to comparatively larger increases in temperature and declining precipitation. However, in much of the Horn of Africa (other than near the Gulf of Aden coast), precipitation is forecast to increase and increasing temperature is moderate. Nevertheless, the resultant generally low projected exposure is not sufficient to counterbalance low adaptive capacity in this case.

Hotspots are intended to draw attention to specific locations and can be effective tools for risk communication and decision-making. Identified areas may stimulate societal responses to climate change such as migration. Steps to increase adaptive capacity should also be investigated: for example, aid agencies and donors may be inclined to prioritize funding in hotspot areas. Above all else, hotspot maps aim to facilitate discourse.

FIGURE 233: Water sector – Vulnerability hotspots – End-century RCP 8.5

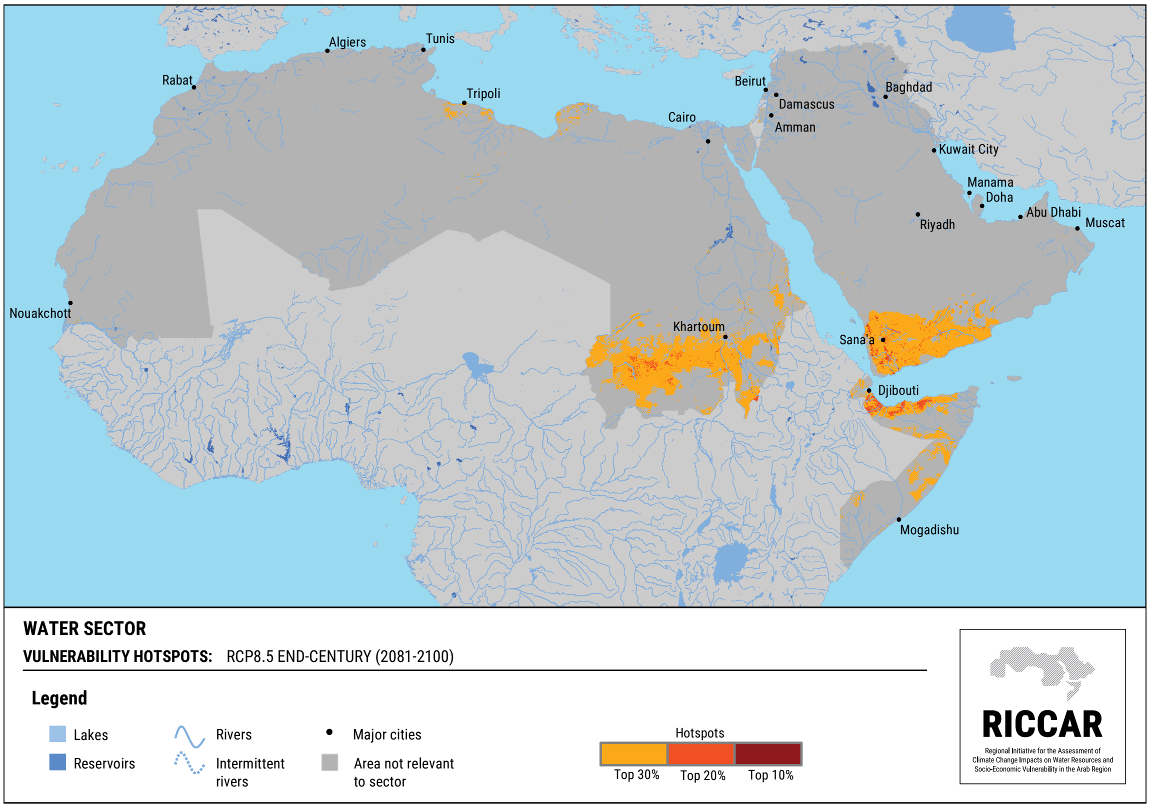


FIGURE 234: Biodiversity and ecosystems sector – Vulnerability hotspots – End-century RCP 8.5

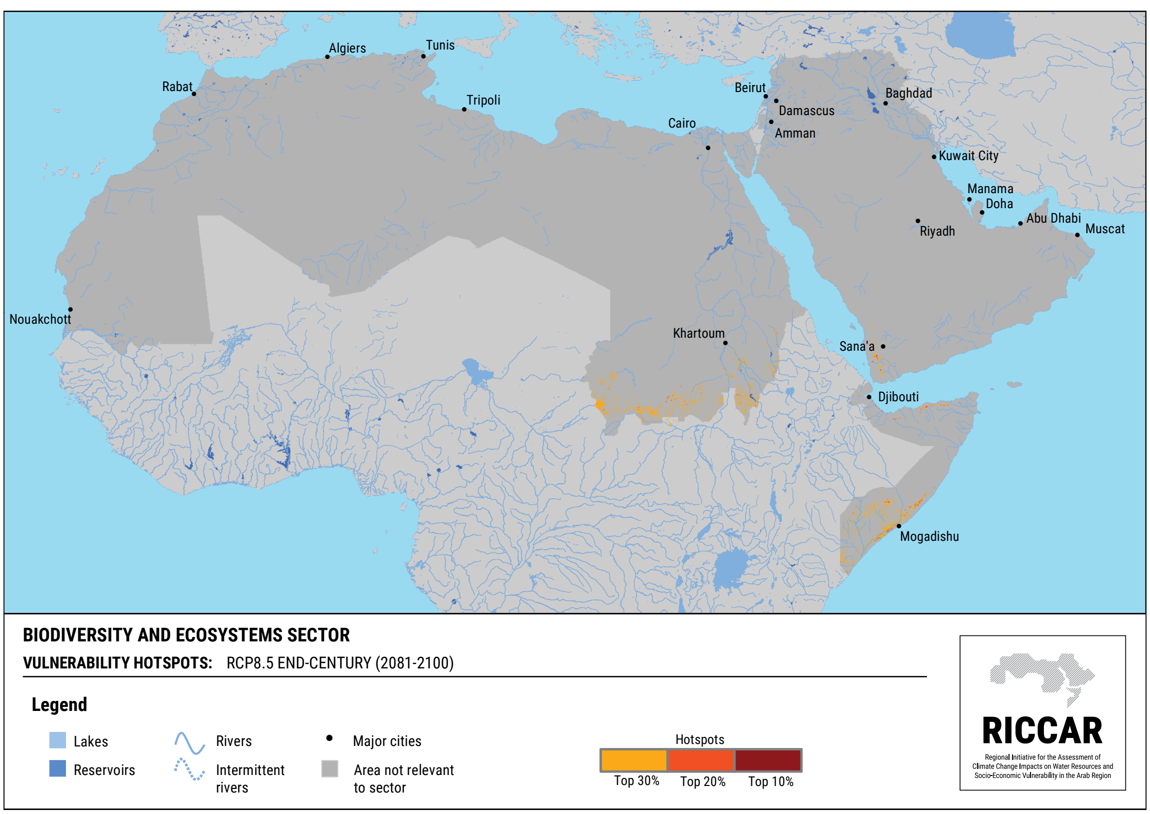


FIGURE 235: Agriculture sector – Vulnerability hotspots – End-century RCP 8.5

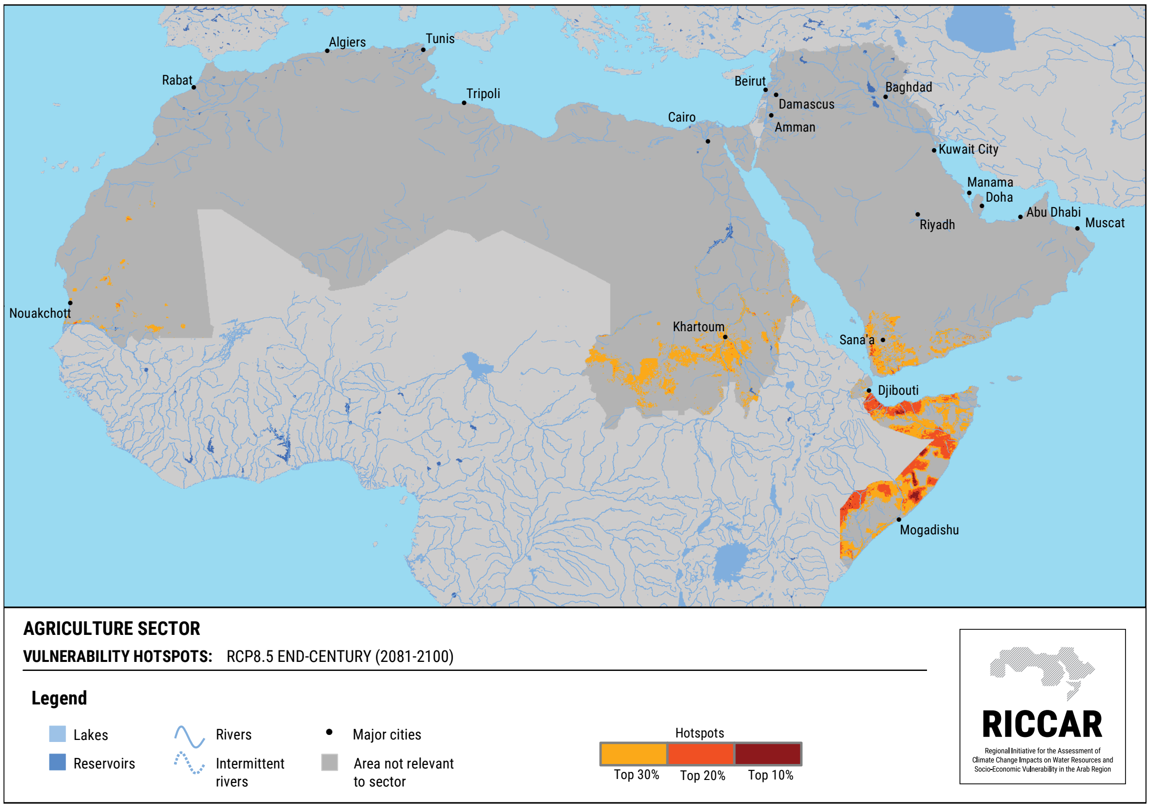


FIGURE 236: Infrastructure and human settlements sector – Vulnerability hotspots – End-century RCP 8.5

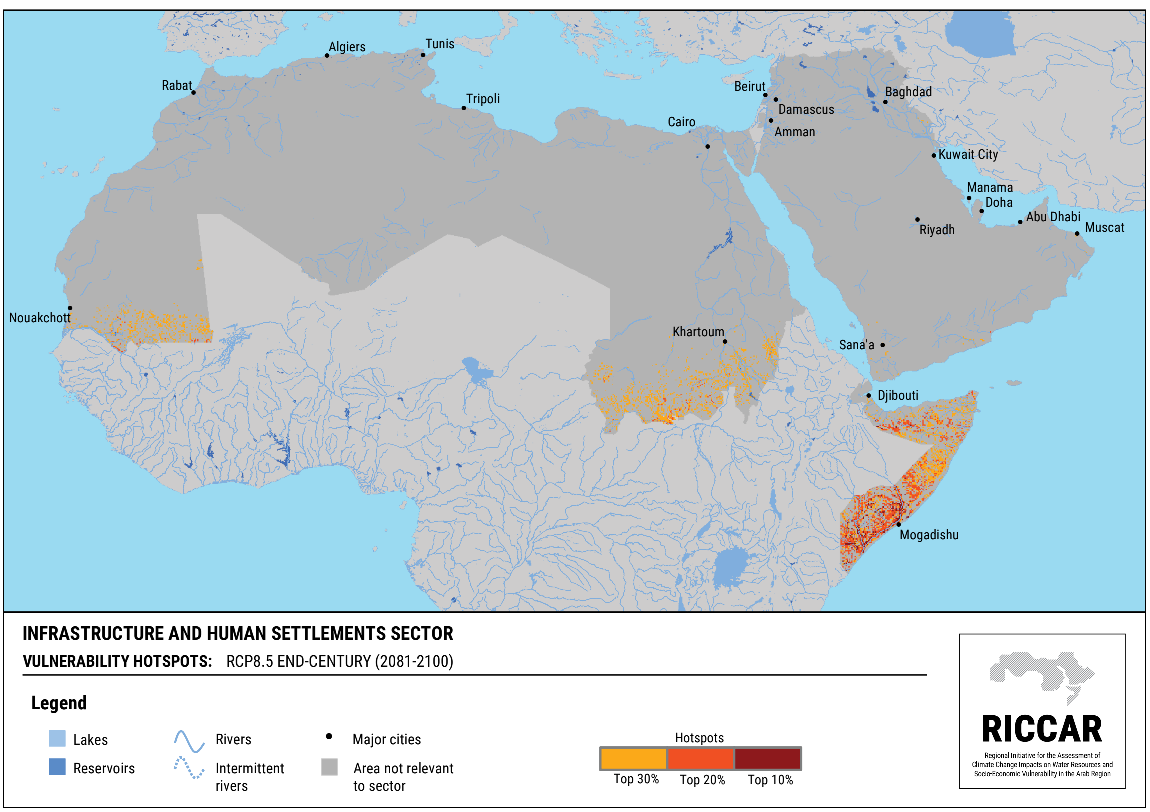
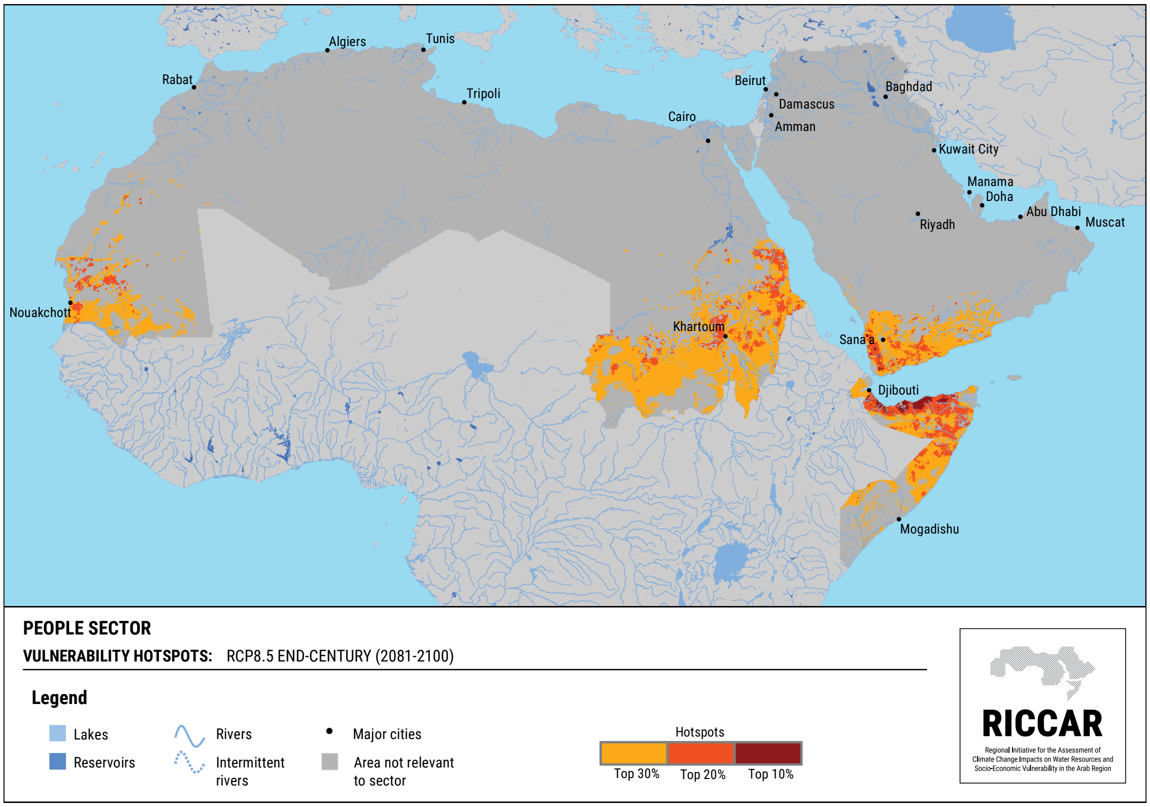


FIGURE 237: People sector – Vulnerability hotspots – End-century RCP 8.5



BOX 8: Country-level application of the integrated vulnerability assessment

RICCAR aims to provide a knowledge base for assessing and addressing climate change impacts on freshwater resources at the regional and national level. The outputs are already being used to inform several projects and processes in this regard, for example in Lebanon.

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, includes RICCAR outputs. Results on projected future changes in temperature and precipitation in Lebanon, as well as selected extreme indices, were presented and highlighted 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.

CONCLUSION

CONCLUSION

This Arab Climate Change 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.

MAIN FINDINGS AND CONCLUSIONS

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.

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

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 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.

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.

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.

Luxor, Egypt, 2016. Source: Dounia Chouchani.

NEXT STEPS

Continued support will be provided by the 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, 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 RICCAR publications that elaborate further on the work being pursued collectively under this regional initiative. 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 Intergovernmental Panel on Climate Change.

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-level, country-level and sector-level. 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.

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