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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Available through:
United Nations Publication
E/ESCWA/SDPD/2017/RICCAR/Report

Reference as:
United Nations Economic and Social Commission for Western Asia (ESCWA) et al. 2017. Arab Climate Change Assessment Report – Main Report. Beirut, E/ESCWA/SDPD/2017/RICCAR/Report.

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Layout: Ghazal Lababidi
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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.

Funding for the preparation of this report and its technical annex was provided by the Swedish Government through the Swedish International Development Cooperation Agency.

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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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The preparation of this report was made possible by the contribution of the RICCAR implementing partners and the financial support provided by the:

Government of Sweden - Swedish International Development Cooperation Agency (Sida)

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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]

Funding for the initiative has been provided by the in-kind contributions of the implementing partners as well as by the generous support of the Government of Sweden through the Swedish International Development Cooperation Agency (Sida) since 2010. The Government of the Federal Government of Germany, through the German Federal Ministry for Economic Cooperation and Development (BMZ), launched the Adaptation to Climate Change in the Water Sector in the MENA Region (ACCWaM) programme in 2011, which is led by GIZ. GIZ subsequently joined RICCAR as an implementing partner and has actively supported the initiative ever since. FAO formally joined the initiative in 2013 and has been contributing to RICCAR through its Near East and North Africa Water Scarcity Initiative.

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

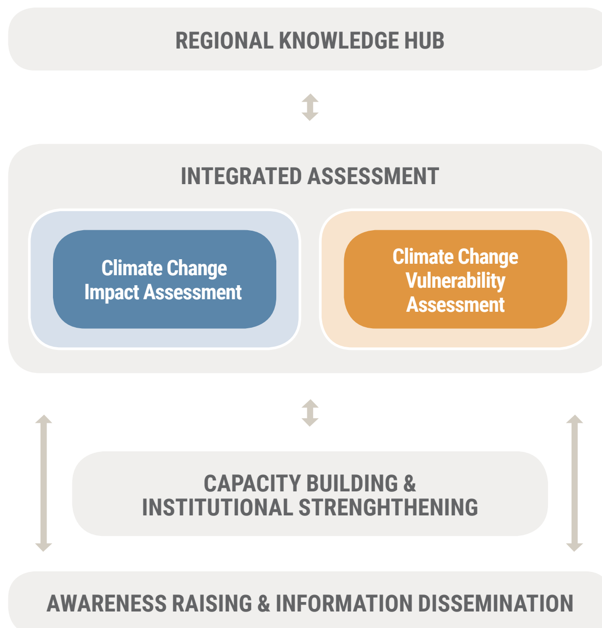
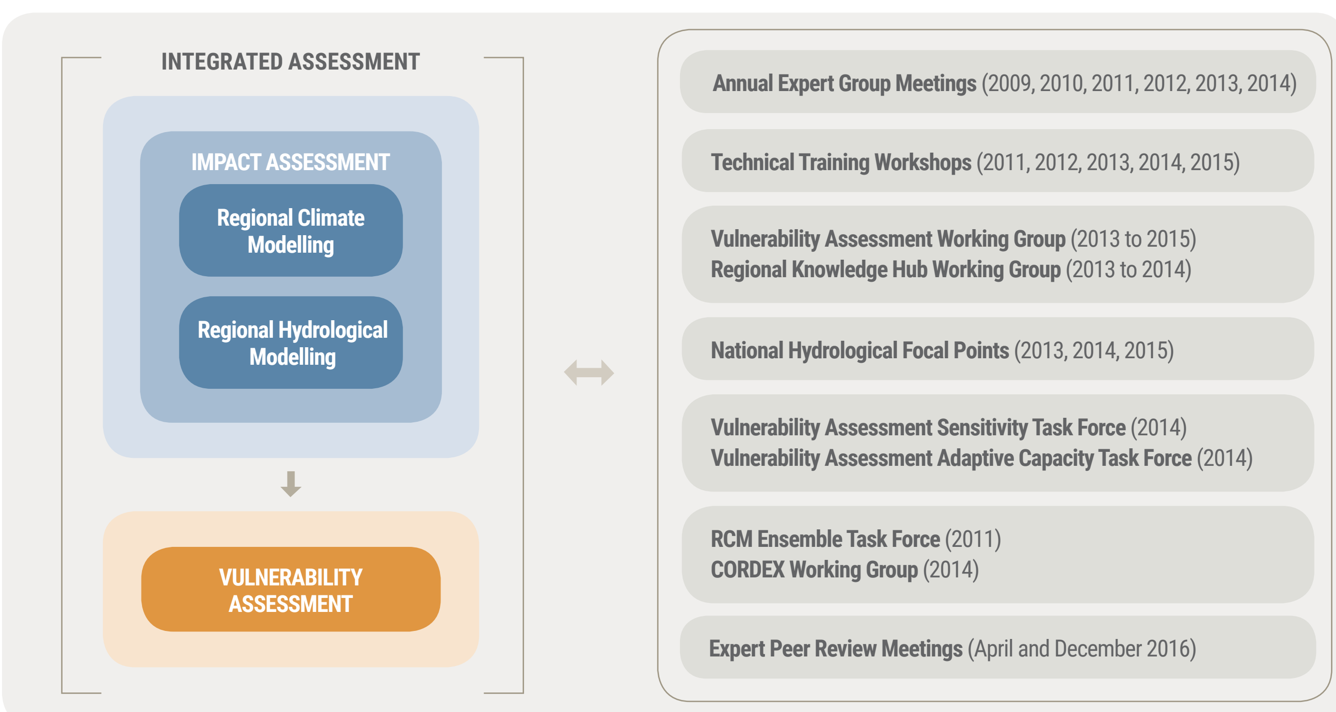


FIGURE 2: RICCAR-related consultative mechanisms informing integrated assessment



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.

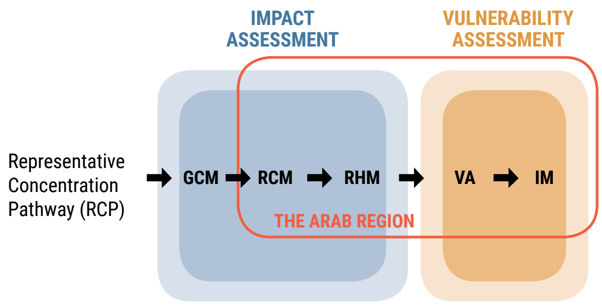
Impact assessment studies focusing on extreme climate events, the agricultural sector and human health provide additional insights on how climate change is projected to impact Arab States. In so doing, the report identifies vulnerability hotspots and vulnerable sectors across the Arab region and illustrates 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

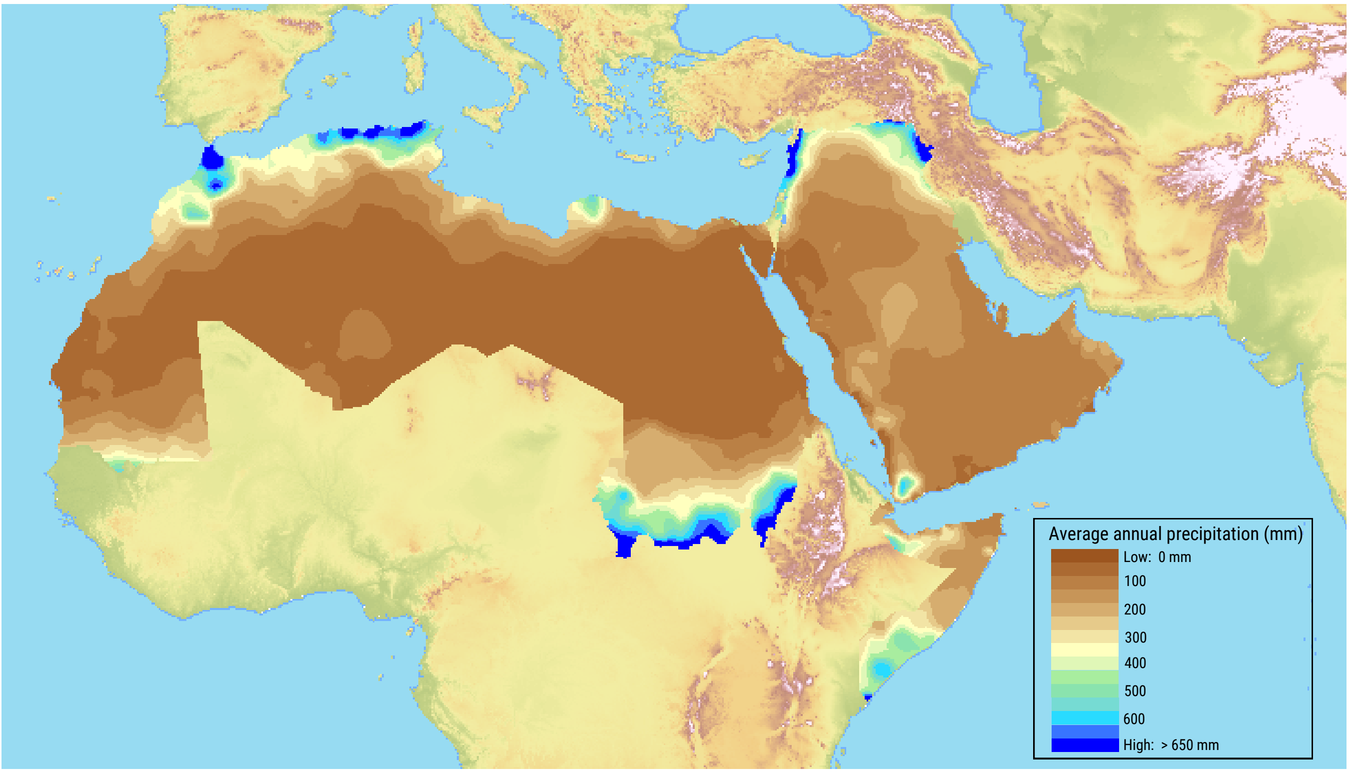
1.1 Climate zones and features

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]

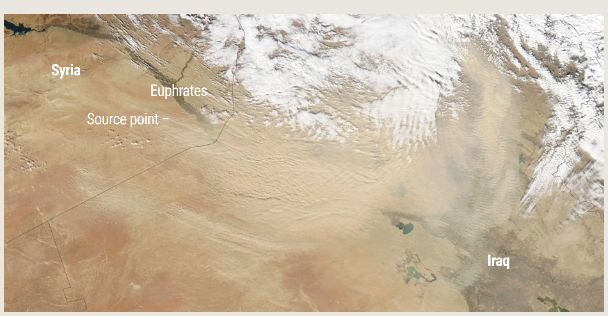
The Active Red Sea Trough (ARST) is an occasional weather phenomenon associated with extreme precipitation, flash floods, and severe societal impacts in the Middle East, as was the case with a major flood in Jeddah, Saudi Arabia, on 25 November 2009. ARST results from the interaction of a persistent 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]

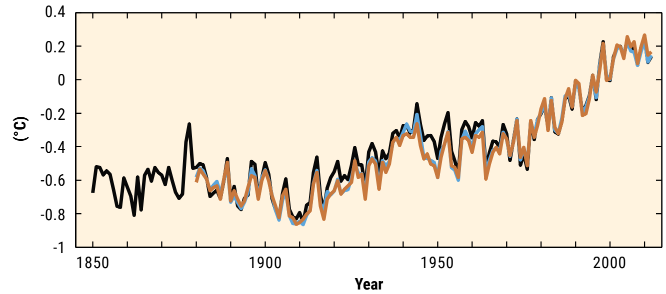
2 CLIMATE DIAGNOSTICS

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).

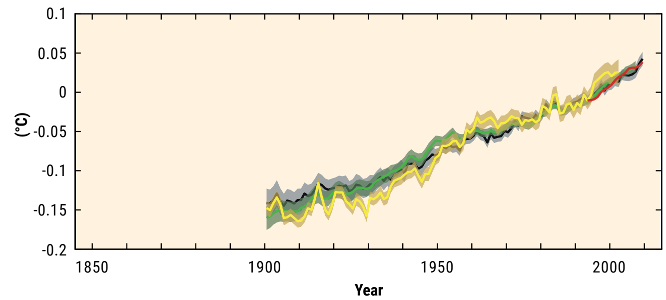
Recent observations and analysis by the US National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) have shown that, since instrumental record-keeping began in 1880, surface temperatures of the Earth were the warmest in the year 2016, making it the 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 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]

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



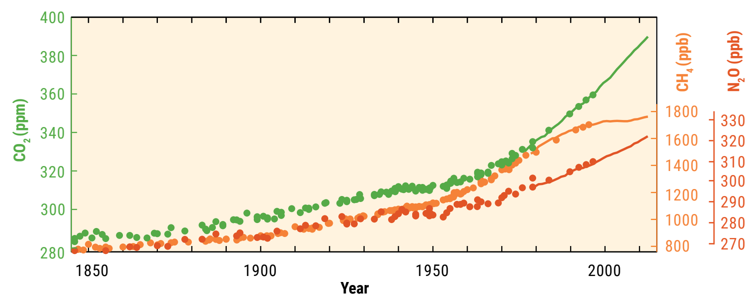
Source: IPCC, 2014

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

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 km³, 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.

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.

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

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$

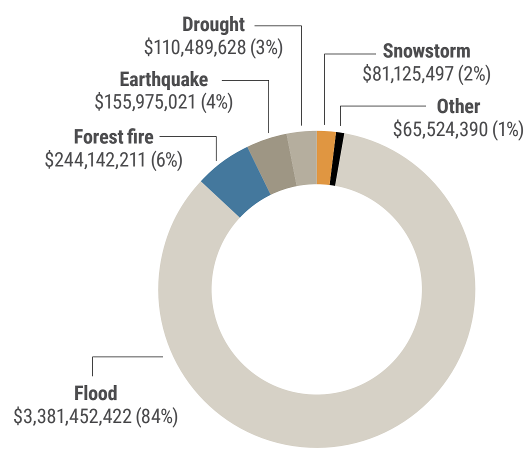
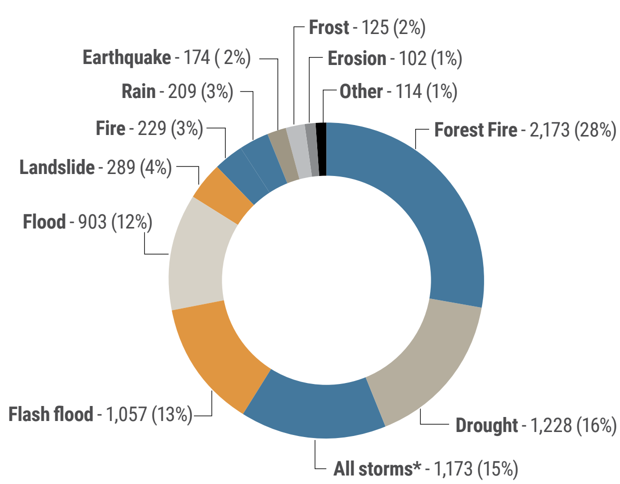
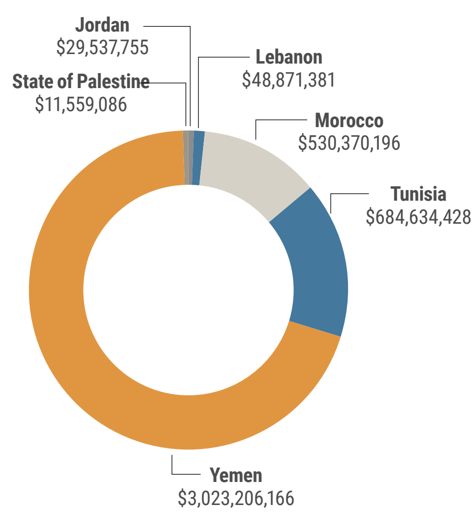


FIGURE 8: Hazard frequency by type (for the six countries combined)



* 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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