RICCAR

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

Integrated Vulnerability Assessment: Arab Regional Application

TECHNICAL NOTE

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THE LEAGUE OF ARAB STATES
THE ARAB CENTER FOR THE STUDIES OF ARID ZONES AND DRY LANDS
ACSAD 1968 أكساد

UNITED NATIONS
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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 United Nations Economic and Social Commission for Western Asia (ESCWA), the 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), the League of Arab States, Swedish Meteorological and Hydrological Institute (SMHI), United Nations Environment Programme (UN Environment), United Nations Educational, Scientific and Cultural Organization (UNESCO) Office in Cairo, United Nations Office for Disaster Risk Reduction (UNISDR), United Nations University Institute for Water, Environment and Health (UNU-INWEH), and World Meteorological Organization (WMO). ESCWA coordinates the regional initiative. Funding for RICCAR is provided by the Government of Sweden and the Government of the Federal Republic of Germany.

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

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ACRONYMS AND ABBREVIATIONS

AR4	Fourth Assessment Report (IPCC)
CDD	maximum length of dry spell
CI	composite indicator
CWD	maximum length of wet spell
DSM	Direct Scoring Method
EGM	Expert Group Meeting
ESCWA	Economic and Social Commission for Western Asia
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GIS	Geographic Information Systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HYPE	Hydrological Predictions for the Environment (hydrological model)
IPCC	Intergovernmental Panel on Climate Change
Km^2	square kilometres
mm	millimetres
PI	potential impact
RCM	Regional Climate Model
RCP	representative concentration pathway
RHM	Regional Hydrological Model
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
R10	Annual count of days with precipitation greater than 10mm
R20	Annual count of days with precipitation greater than 20mm
SU35	number of hot days
SU40	number of very hot days
UN-DESA	United Nations Department of Economic and Social Affairs
VA	vulnerability assessment
VA-WG	Vulnerability Assessment Working Group
VI	vulnerability index
VIC	Variable Infiltration Capacity (hydrological model)
°C	degree Celsius
%	per cent

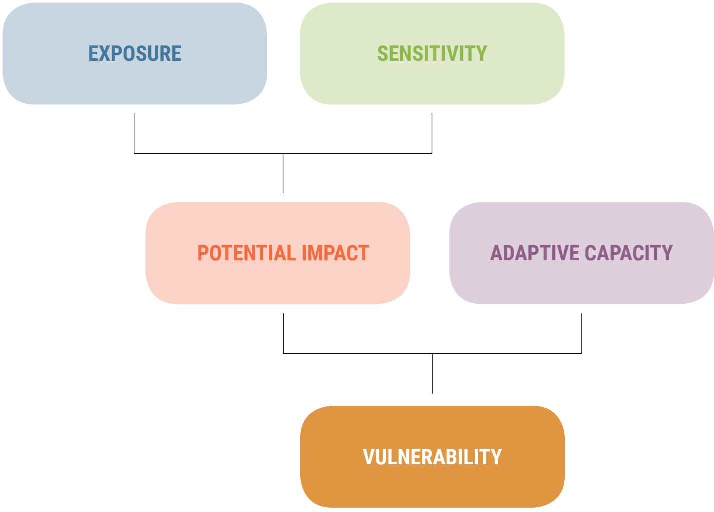
1 INTRODUCTION

This Technical Note serves as an explanatory reference that describes the work undertaken on the Vulnerability Assessment (VA) 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). The intention is to provide technical clarification of the vulnerability assessment methodology to develop the maps presented in the *Arab Climate Change Assessment Report – Main Report* and its *Technical Annex* which are issued under RICCAR in coordination with the United Nations Economic and Social Commission for Western Asia (ESCWA) and the other RICCAR implementing partners. This Technical Note also serves both as a supplement and update to the *RICCAR Training Manual on the Integrated Vulnerability Assessment Methodology*.

2 THE CONCEPT OF VULNERABILITY

Vulnerability is a concept used to express the complex interaction of climate change effects and the susceptibility of a system to its impacts, with several existing definitions and approaches to characterize this concept. The integrated vulnerability assessment methodology applied in RICCAR is based on an understanding of vulnerability as a function of a system's climate change exposure, sensitivity and adaptive capacity to cope with climate change effects, consistent with the approach put forward by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (AR4) and as illustrated in Figure 1.

FIGURE 1: Components of vulnerability based on the IPCC AR4 approach



Source: RICCAR as drawn upon in IPCC, 2007.

Within this conceptual framework:

• **Exposure** refers to changes in climate parameters that might affect socio-ecological systems. Such parameters are temperature and precipitation, for example, which climate change alters the respective magnitude and intensity as well as spatial and temporal distribution.

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

• **Potential Impact** is determined by combining the exposure and sensitivity of a system to climate change.

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

Combining exposure, sensitivity and adaptive capacity allows assessing the vulnerability of a system to climate change.

3 DEFINITION OF SECTORS AND IMPACTS

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

Based on the outcomes of consultations conducted by the RICCAR Vulnerability Assessment Working Group (VA-WG) in 2013 and 2014, five key sectors were identified for examination along with associated sub sectors, as illustrated in Figure 2. These were subsequently endorsed at the RICCAR Expert Group Meetings and by the Arab Ministerial Water Council. They consist of the following: (1) Water, focused on water availability; (2) Biodiversity and ecosystems, including (a) Forests, and (b) Wetlands; (3) Agriculture, including (a) Water available for crops, and (b) Water available for livestock; (4) Infrastructure and human settlements, focused on inland flooding; and (5) People, including (a) Water available for drinking, (b) Health conditions due to heat stress, and (c) Employment rate for the agricultural sector.

FIGURE 2: Sectors and subsectors selected for the Arab region vulnerability assessment

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

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

The development of the methodology progressed through a set of meetings of the VA-WG and task forces that were held regularly over the course of the project to refine its key components and associated processes (Table 1). In particular, slight changes to the indicator framework were found necessary over the course of the testing of the methodology in order to adjust to data gaps or where data quality was suboptimal.

TABLE 1: Meetings and activities of the VA-WG and VA Task Forces

VA-WG: 1st Meeting Beirut, 29-30 January 2013	Discussion of underlying vulnerability concepts, identification of objectives and key sectors, consideration of the climate change impacts upon which the vulnerability assessment should built.
VA-WG: 2nd Meeting Beirut, 27-28 May 2013	Validation of selected climate change impacts and sectors, listing of potential indicators for assessing vulnerability in the different sectors, discussion of possible data sources.
VA-WG: 3rd Meeting Amman, 25-26 November 2013	Review list of proposed indicators, discussion of the aggregation methodology, and conduct of exercise on indicator evaluation.
Virtual exchange April 2014	Solicitation of comments and feedback on the vulnerability indicators and methodology, continued on a virtual basis through April 2014.
VA Task Force on Sensitivity Indicators Beirut, 20-21 October 2014	Vetting of final list of possible indicators based on review of data available at the regional level, with a view to ensuring balance across the proposed dimensions for characterizing sensitivity.
VA Task Force on Adaptive Capacity Indicators Beirut, 22-23 October 2014	Vetting of final list of possible socio-economic indicators based on review of data available at the regional level, with a view to ensuring balance across the proposed dimensions for characterizing adaptive capacity.
VA-WG: 4th Meeting Beirut, 8-10 June 2015	Training on the use of climate change impact assessment outputs to support vulnerability assessments.

Experts as well as members of regional research centres with expertise in the area of climate change assessment and Geographic Information System (GIS) applications were invited to review, test and comment on the draft vulnerability assessment methodology during a regional workshop (Beirut, May 2014). Throughout its development, progress made on the methodology was presented for consideration by Arab Governments, regional organizations and RICCAR partners during the Fifth RICCAR Expert Group Meeting (Amman, December 2013) and the Sixth RICCAR Expert Group Meeting (Cairo, December 2014). As it was finalized in May 2015, an expert group review was subsequently organized in 2016 to fully review and vet the methodology application with regards to the final set of indicators as well as weights and normalization schemes applied during the preparation of the assessment (Beirut, April 2016). Finally, results and findings of the integrated VA were peer reviewed during an expert peer review meeting (Beirut, December 2016) to examine the aggregated results for the nine sub-sectors, namely the maps related to exposure, sensitivity, potential impact, adaptive capacity and vulnerability in view of identifying the potential vulnerability hotspots in the region.[2]

4 INTEGRATED MAPPING METHODOLOGY

4.1 Development of Impact Chains

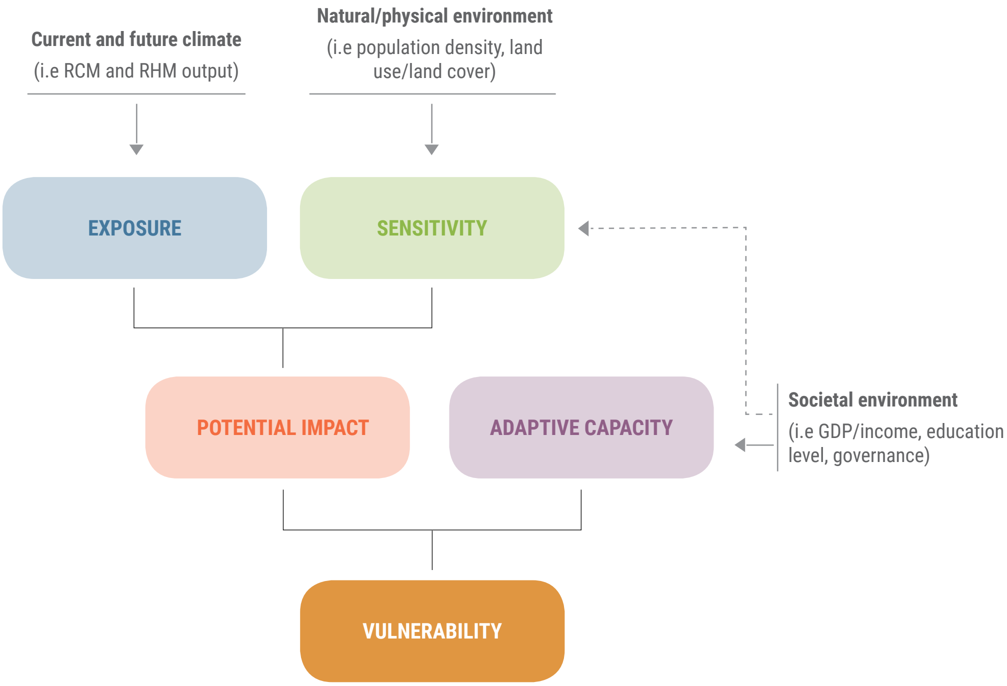
Impact chains are analytical tools which can help describe cause and effect relationships to assess vulnerability for a given climate change impact. They are developed by starting from the climate change impacts and then identifying which key factors contribute towards each vulnerability component i.e exposure, sensitivity, and adaptive capacity (Figure 3). Development of the impact chains was based on a multistep approach and was subject to revision throughout the VA methodology development.

The approach consisted of the following steps:

1. Identify potential exposure, sensitivity, and adaptive capacity indicators.
2. Cluster potential indicators into dimensions.
3. Assess which exposure indicators are applicable for each subsector.
4. Assess which sensitivity indicators are applicable for each subsector.
5. Assess which adaptive indicators are applicable for each subsector.
6. Assign a relative importance for each indicator.

The final impact chains for each sector or subsector are found in the *Arab Climate Change Assessment Report – Main Report* and its *Technical Annex*.

FIGURE 3: Impact chain structure



4.2 Selection of Indicators

Indicators were selected based on the impact chains to describe the factors contributing towards vulnerability. The selection of indicators involved an in-depth process which considered several factors. These include, but were not limited to:

- **Relevance:** Is the indicator relevant to the subsector?
- **Data Availability:** Is the data available at regional level?
- **Measurability:** Can the indicator be quantified?
- **Homogeneity:** Is the data available for the entire region of study, for similar time periods, and from the same source?
- **Reliability:** Is the indicator from a reliable source, and is the source acceptable for Arab States?

Exposure indicators were derived from climate and hydrological modelling outputs and were the sole dynamic datasets. They were developed based on five different time periods and emission scenarios or Representative Concentration Pathways (RCPs), as shown in Table 2.

TABLE 2: Exposure indicators characteristics

Time Period	Emission scenario	Description
Reference period	–	Baseline period representative of 1986-2005
Mid-century	RCP 4.5	Intermediate future scenario representative of the period 2046-2065 and based on RCP 4.5 (moderate impact)
Mid-century	RCP 8.5	Intermediate future scenario representative of the period 2046-2065 and based on RCP 8.5 (extreme impact)
End-century	RCP 4.5	Far future scenario representative of the period 2081-2100 and based on RCP 4.5 (moderate impact)
End-century	RCP 8.5	Far future scenario representative of the period 2081-2100 and based on RCP 8.5 (extreme impact)

The sensitivity indicators were classified into three dimensions: population, natural, and manmade. The population dimension is comprised of societal factors which place pressure upon the physical system due to population growth including human migration and resource depletion. The natural dimension considers environmental and ecological elements such as soil type and land cover which may be subjected to degradation. Lastly, the manmade dimension incorporates anthropogenic factors which may be exacerbated due to climate change. The usage of dimensions helps maintain balance between differing aspects of sensitivity. Moreover, dimensions help summarize and streamline indicators to allow easier interpretation of data.
Due to data availability limitations, and even though many elements which can be evaluated as part of sensitivity are dynamic (i.e. population growth), all indicators used for RICCAR are static and based on the most recent available information for all future climate scenarios.

Lastly, adaptive capacity was categorized into six dimensions: knowledge and awareness, technology, infrastructure, institutions, economic resources, and equity. Knowledge and awareness demonstrates the ability of a community to access and understand information to enable the identification of adaptation measures. Both technology and infrastructure can be considered as ability mechanisms whereby they characterize the accessibility to the built environment as a means to adapt. Together, institutions and economic resources can be classified as action devices that describe the enabling environment that allow a society to adapt. Lastly, equity considers vulnerable population groups which can be based on gender, socio-economic status, or marginalization. Infrastructure indicators were selected based on five pillars: energy, transportation, health, water and sanitation, and environment. Because indicators from one aspect of adaptive capacity may outnumber indicators from another aspect, categorization into dimensions and pillars helps maintain balance between all aspects. Similar to sensitivity indicators, adaptive capacity indicators are static.

4.3 Data Acquisition

Once indicators were identified, sources for data acquisition were selected. Exposure indicators were based on RCM and RHM outputs. Other indicators were mostly based on freely available sources such as data from UN agencies, research organizations, and open source GIS data. Efforts were conducted to retrieve data at the smallest available scale.

Data from selected indicators was subsequently evaluated for quality through an iterative process whereby initial indicator selections occasionally needed to be replaced by more suitable parameters. Some indicators were based on tabular statistical data were converted to geospatial data using a map based on 1967 and 2011 borders, which occasionally resulted in data gaps. Therefore, it was decided that in the case where an indicator had large spatial data gaps across the region (over 30%), the indicator was discarded during the selection process. As the GIS software could not perform calculations in areas where data was missing, and since data gaps could potentially affect results, no gapped data was considered in the selection process. Small data gaps were resolved using proxy data and averaging values from neighboring areas when necessary. Also, some indicators were based on multiple datasets from one or more related sources. Lastly, a part of the indicators was updated based on complementary datasets and regional expert knowledge.

All data was consistently converted to raster format prior to subsequent use. This format represents data as a gridded matrix of cells each containing a discrete value, as opposed to the vector format in which spatial information is stored in shapes with distinct boundaries. Thus, statistical data available at a national level was first added to national vector files (also known as shapefiles) and then converted to raster. Some other sub-national datasets were also obtained in vector format and have undergone conversion.

In terms of resolution, all raster files were converted to a common 1 km x 1 km resolution to provide a finer grade of outputs, which required resampling of some datasets. In particular, all exposure indicators have undergone resampling because RCM and RHM data was at a coarser resolution (50 km x 50 km). In addition, due to data coarseness and the elimination of major water bodies during the bias correction process, several coastal areas were missing from RCM and RHM data whenever over 50% of a given grid cell covered water bodies. For this reason, climate data was extrapolated and resampled to permit analysis in coastal areas. Based on spot checking, the resampling method resulted in negligible changes between the original dataset and final exposure indicators.

4.3.1 Exposure Indicators

Ten different exposure indicators were selected from the RCM and RHM ensemble outputs[3] determined for the Arab Domain as seen in Table 3, based on each of the aforementioned scenarios. Indicators obtained from the RHM outputs were solely based on the Variable Infiltration Capacity (VIC) hydrological model outputs because the dataset was more manageable due its significantly smaller file size. It is assumed that data obtained from the Hydrological Predictions for the Environment (HYPE) model would yield similar vulnerability assessment results. Indicator values corresponding to the reference period were based on actual values, while the ones for the four future scenarios were based on the change in value compared to the reference period.

TABLE 3: Exposure indicators selected for the vulnerability assessment

Indicator Type	Indicator Name
RCM related parameters	(Change in) Temperature
	(Change in) Precipitation
RHM related parameters	(Change in) Evapotranspiration
	(Change in) Runoff
Extreme Climate Indices	(Change in) Annual number of days when Tmax > 35 °C (SU35)
	(Change in) Annual number of days when Tmax >40 °C (SU40)
	(Change in) Maximum length of dry spell (CDD)
	(Change in) Maximum length of wet spell (CWD)
	(Change in) Annual number of days when precipitation ≥ 10 mm (R10)
	(Change in) Annual number of days when precipitation ≥ 20 mm (R20)

Note: Further details on each indicator can be obtained from the respective indicator factsheets.

4.3.2 Sensitivity Indicators

A total of 25 different sensitivity indicators (Table 4) were obtained primarily from open sources using the latest available data based on the three dimensions considered (population, natural, and manmade). Indicators under the population dimension were largely obtained from statistical data available from organizations such as the Food and Agriculture Organization of the United Nations (FAO) and the UN Department of Economic and Social Affairs Population Division (UN DESA). Indicators from the natural and manmade dimensions were often not directly available from a single database and were thus synthesized from multiple datasets from one or more sources. Sensitivity indicators were assumed to retain the same values for the reference period and future periods.

4.3.3 Adaptive Capacity Indicators

For adaptive capacity, 27 indicators were selected based on the six dimensions (knowledge and awareness, technology, infrastructure, institutions, economic resources, and equity) as shown in Table 5. Infrastructure indicators were further classified into five pillars (energy, transportation, health, water and sanitation, and environment). Data was largely obtained from statistical datasets using the latest available open source data and most indicators were therefore spatially presented at a national level. Similar to sensitivity indicators, adaptive capacity indicators were assumed to retain the same values for the reference period and future periods.

TABLE 4: Sensitivity indicators selected for the vulnerability assessment

Dimension	Indicator Name	Data Type	Source	Year
Population	Population density	Raster	Landscan Global Population Database	2015
	Agricultural labor force as percentage of total labor force	Statistical	Arab Organization for Agricultural Development (AOAD)	2012
	Share of children and elderly of the population	Statistical	UN Department of Economic and Social Affairs (UN DESA), Population Division	2015
	Total available renewable water resources per capita	Statistical	Food and Agriculture Organization of the United Nations (FAO)	2014
	Water consumption per capita	Statistical	Food and Agriculture Organization of the United Nations (FAO)	Latest available (2000-2012)
	Share of water withdrawal in agriculture	Statistical	Food and Agriculture Organization of the United Nations (FAO)	Latest available (2000-2014)
	Share of agriculture in GDP	Statistical	Arab Organization for Agricultural Development (AOAD)	2010
	Refugee population	Statistical	United Nations High Commissioner for Refugees (UNHCR)	2015
	Migrant population	Statistical	UN Department of Economic and Social Affairs (UN DESA), Population Division	2010-2015
Natural	Land use/land cover	Raster	Food and Agriculture Organization of the United Nations (FAO)	2014
	Soil storage capacity	Vector	Harmonized World Soil Database	2008
	Degradation of vegetation cover	Raster	Based on data from MODIS images	2000-2011
	Livestock density	Raster	Food and Agriculture Organization of the United Nations (FAO)	2014
	Change in forest cover	Raster	University of Maryland Department of Geographical Sciences	2000-2014
	Wetlands	Vector	UN Environment (UNEP), Ramsar, GlobWetland II WebGIS	2004
	Rainfed cropland areas	Raster	Harmonized World Soil Database	2008
	Threatened forest areas	Raster	Based on data from University of Maryland Department of Geographical Sciences	2000
	Soil erodibility	Vector	Based on data from Harmonized World Soil Database	2008
Manmade	Irrigated croplands	Raster	Food and Agriculture Organization of the United Nations (FAO)	2013
	Floodprone areas	Raster	Based on data from World Health Organization (WHO) and World Meteorological Organization (WMO)	1985-2003
	Urban extent	Raster	Center for International Earth Science Information Network (CIESIN)	1995
	Road network	Raster	Center for International Earth Science Information Network (CIESIN)	2013
	Cultural heritage sites	Vector	United Nations Educational Scientific and Cultural Organization (UNESCO)	2012
	Areas served by dams	Raster	Based on data from Food and Agriculture Organization of the United Nations (FAO)	2005
	Wastewater treatment	Statistical	United Nations Economic and Social Commission for Western Asia (ESCWA)	2016

Note: Further details on each indicator and its source(s) can be obtained from the respective indicator factsheets.

TABLE 5: Adaptive capacity indicators selected for the vulnerability assessment

Dimension	Pillar	Indicator Name	Data Type	Source	Year
Knowledge and Awareness	–	E-Government development index	Statistical	UN Department of Economic and Social Affairs (UN DESA)	2014
	–	Enrollment in tertiary education	Statistical	United Nations Educational Scientific and Cultural Organization (UNESCO) Institute for Statistics	Latest available (2003-2014)
	–	Adult literacy rate	Statistical	United Nations Educational Scientific and Cultural Organization (UNESCO) Institute for Statistics	Latest available (2003-2014)
Technology	–	Number of scientific and technical journal articles	Statistical	Statistical, Economic and Social Research and Training Centre for Islamic Countries (SESRIC)	2007
	–	Information and communication technologies index	Statistical	International Telecommunication Union (ITU)	2013
Infrastructure	Energy	Access to electricity	Statistical	International Energy Agency (IEA)	2015
	Energy	Energy consumption	Statistical	Organization of Arab Petroleum Exporting Countries (OAPEC)	2014
	Transportation	Road density	Vector	Based on data from Center for International Earth Science Information Network (CIESIN)	2013
	Health	Health index	Statistical	World Health Organization (WHO)	2014
	Water and sanitation	Areas served by dams	Vector	Based on data from Food and Agriculture Organization of the United Nations (FAO)	2010
	Water and sanitation	Areas equipped for irrigation	Vector	Food and Agriculture Organization of the United Nations (FAO)	2005
	Water and sanitation	Access to improved water	Statistical	World Health Organization (WHO)/ United Nations International Children's Emergency Fund (UNICEF)	2015
	Water and sanitation	Access to improved sanitation	Statistical	World Health Organization (WHO)/ United Nations International Children's Emergency Fund (UNICEF)	2015
	Water and sanitation	Desalination capacity	Statistical	DesalData	2008
	Water and sanitation	Fossil groundwater	Vector	Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)	2014
	Environment	Environment performance index	Statistical	Yale University	2016
Institutions	–	Governance index	Statistical	Worldwide Governance Indicators	2014
	–	Protected areas	Statistical	UN Environment World Conservation Monitoring Centre (UNEP-WCMC)	2014
	–	Disaster risk reduction committees	Statistical	United Nations Office for Disaster Risk Reduction (UNISDR)	2014
Economic resources	–	GDP per capita	Statistical	The World Bank; Organisation for Economic Cooperation and Development (OECD)	Latest available (2007-2014)
	–	Age dependency ratio	Statistical	The World Bank	2015
	–	Official development assistance	Statistical	Organisation for Economic Cooperation and Development (OECD)	Latest available (2007-2014)
	–	Food imports as percentage of merchandise exports	Statistical	Food and Agriculture Organization of the United Nations (FAO)	2011-2013
Equity	–	Female-to-male unemployment rate	Statistical	International Labour Organization (ILO)	Latest available (2007-2014)
	–	Years of health lost due to disability	Statistical	World Health Organization (WHO)	2004
	–	Female-to-male literacy ratio	Statistical	United Nations Educational Scientific and Cultural Organization (UNESCO) Institute for Statistics	2015
	–	Migrants/refugees index	Statistical	UN Department of Economic and Social Affairs (UN DESA), Population Division	2015

Note: Further details on each indicator and its source(s) can be obtained from the respective indicator factsheets.

4.4 Normalization and Classification of Indicator Data

As the different indicators were characterized by varying magnitudes and units of measurement, they were all classified using a consistent scale prior to analysis. Accordingly, in the case of exposure and sensitivity indicators, a class value of 1 was assigned to represent a favorable condition (e.g. low exposure or low sensitivity, respectively) while a class value of 10 designates an unfavorable condition. The case is opposite for adaptive capacity whereby a class value of 1 signifies an unfavorable condition (e.g. low adaptive capacity) and a value of 10 suggests a favorable condition.

Each indicator was classified using one of the following methods available in GIS:
• Manual interval
• Equal interval
• Natural breaks
• Quantile

The manual interval method was generally used for descriptive data or if other classification methods were inappropriate. The equal interval classification divides attribute values into identically-sized subranges. The natural breaks method, also known as the Jenks classification method[4], utilizes natural groupings inherent in the data based on similar values and maximizing differences between classes. Lastly, the quantile method is best suited for linearly distributed data by assigning the same number of data values to each class. In some cases, particularly when actual values were skewed, classification was based on log values rather than on the actual values themselves.

The method selection was dependent upon expert opinion and was generally determined based on the best wide representation of classes across the study region. Indicator values were positively or negatively correlated with the corresponding classified values based on the water availability corresponding vulnerability. This basis was invalid for some subsectors and in that case the indicator was re-classified for that particular subsector.

4.5 Weighting and Aggregation of Indicators

4.5.1 Indicator weights

Each indicator was weighted to reflect its relative contribution to the vulnerability of each subsector. Indicators may either be weighted differently by assigning heavier weights to assess a greater influence on the result, or they can be weighted equally. Weighting must be allocated such that each group of elements (i.e. indicators within a dimension, dimensions with a component) sum up to a value of 1. Methods used to determine indicator weights include including expert opinion, statistical analysis, and decision rules which consider indicator interdependencies. Equal weighting is generally reserved solely in the unavailability of resources.

For RICCAR, weighting was based on expert opinion and only sensitivity and adaptive capacity indicators (and their dimensions) were assigned varying weights. Exposure indicators were weighted equally since all contribute towards climate change. Similarly, each of the pillars, dimensions, and vulnerability components were weighted as well. Determination of weighting was first based on a questionnaire widely distributed to experts from differing areas of specialization and geographic coverage to solicit their opinions on the three vulnerability components, their dimensions, and their indicators. Response types were based on the Direct Scoring Method (DSM) approach using a scale ranging from 1 (not important at all) to 10 (very important). Overall, 350 responses were received and most of the Arab States studied under RICCAR were represented by at least one expert. The other participants (16%) were non-Arab but had been actively engaged in research activities within the Arab region.

Expert opinion was then solicited to finalize the weighting. The most significant sensitivity and adaptive capacity indicators for each subsector and their respective dimensions were ultimately assigned a weight of 0.5. Remaining indicators were weighted in accordance with the questionnaire results and expert opinion.

4.6 Aggregation of Vulnerability Components

4.6.1 Exposure Composite Indicator

Individual indicators were aggregated together using a geometric aggregation technique consisting of a non-linear approach. This method was preferred to other methods as it is multiplicative and synergetic. For each of the climate change impact subsectors, the selected exposure indicators were aggregated to determine the exposure Composite Indicator (CI) as described in Equation 1. This method of geometric aggregation is suitable solely when indicators are weighted equally such as exposure indicators for all subsectors.

Equation 1

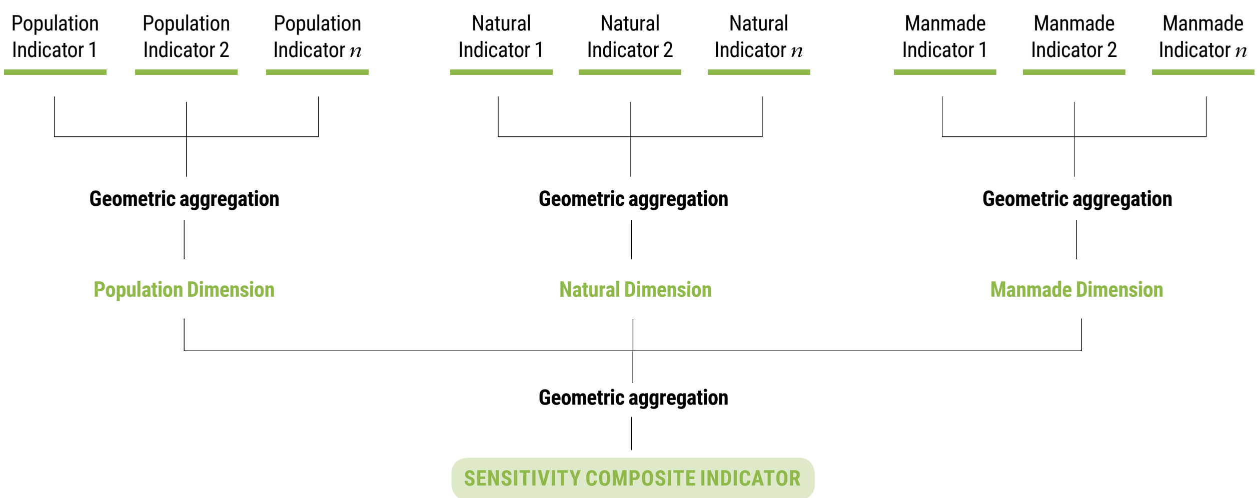
$$CI = (\text{Indicator}_1 \times \text{Indicator}_2 \times \text{Indicator}_3 \times \ldots \times \text{Indicator}_n)^{1/n}$$

Where n represents the number of indicators.

4.6.2 Sensitivity Composite Indicator

Geometric aggregation was also used to determine the sensitivity *CI*. However, as described in Figure 4, a multistep approach was needed to first aggregate the indicators by dimension (Equation 2) and then aggregate the dimensions to obtain the *CI* (Equation 3).

FIGURE 4: Aggregation approach for the sensitivity component



Equation 2

$$CI_{\text{Dimension}} = (\text{Indicator}_1)^{w_1} \times (\text{Indicator}_2)^{w_2} \times \ldots \times (\text{Indicator}_n)^{w_n}$$

Equation 3

$$CI = (CI_{\text{Dimension}_1})^{\text{Dim}w_1} \times (CI_{\text{Dimension}_2})^{\text{Dim}w_2} \times \ldots \times (CI_{\text{Dimension}_n})^{\text{Dim}w_n}$$

Where w_n represents the indicator weights.

4.6.3 Adaptive Capacity Composite Indicator

Similar to the sensitivity component, the adaptive capacity component was dependent upon a multi-step aggregated approach using geometric aggregation. In this approach, as described by Figure 5, indicators which were classified into one of the infrastructure pillars were aggregated first and were weighted equally within the pillar (Equation 4). Then similar to Equation 2 and Equation 3, the pillars were aggregated along with indicators from the remaining dimensions using their respective weights (Figure 6).

Equation 4

$$CI_{Pillar} = (\text{Indicator}_1 \times \text{Indicator}_2 \times \ldots \times \text{Indicator}_n)^{1/n}$$

FIGURE 5: Aggregation approach for the five infrastructure pillars

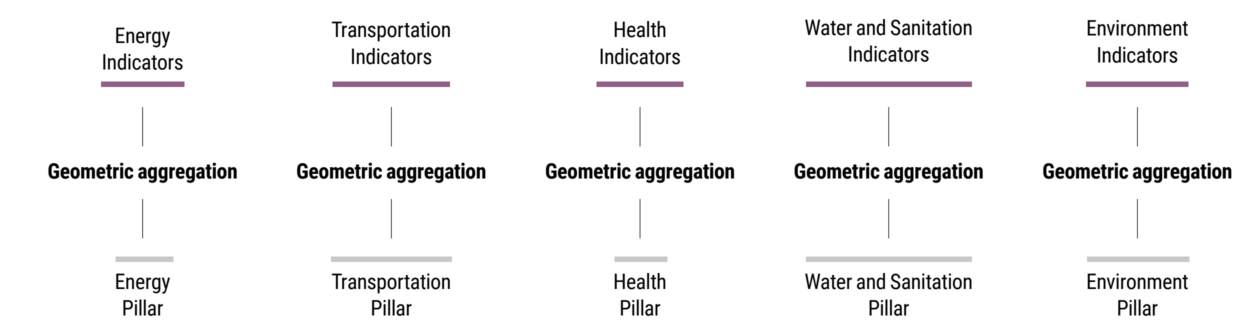
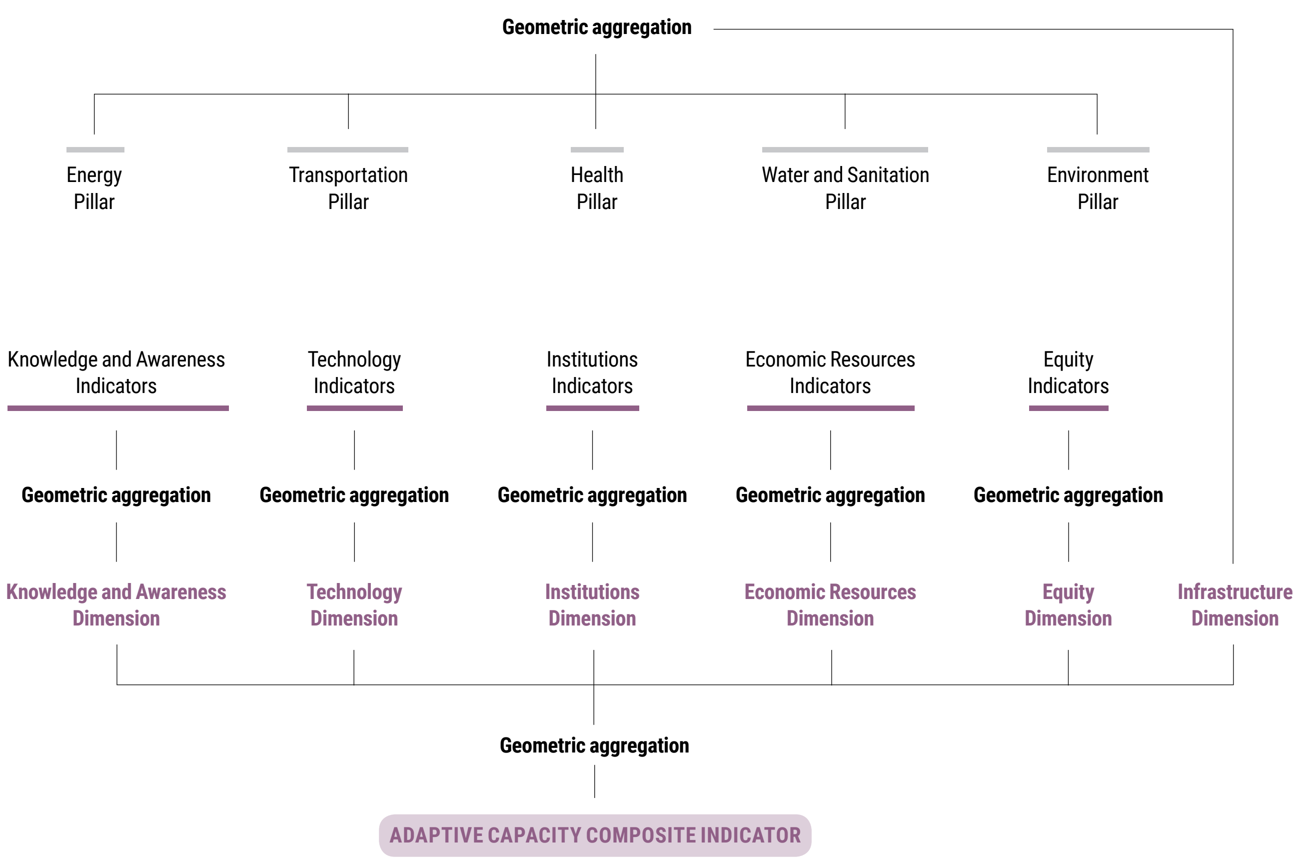


FIGURE 6: Aggregation approach for the adaptive capacity component



4.6.4 Potential Impact and Vulnerability Index Aggregation

Potential impact (PI) represents the compilation of the exposure and sensitivity composite indicators which were geometrically aggregated using equal weights (Equation 5). Because a value of 1 represents a favorable condition for PI and an unfavorable condition for adaptive capacity (with the opposite being the case for a value of 10), it was necessary to invert adaptive capacity values prior to subsequent aggregation to obtain the Vulnerability Index (VI) as described in Equation 6.

The PI was then aggregated with the inverted adaptive capacity composite indicator to obtain the VI for a given climate change impact (Equation 7). The net result is that exposure and sensitivity each contribute 25% toward the vulnerability index and adaptive capacity comprises 50%. This approach assumes that the ability of mankind to implement adaptation measures is stronger than climate change impacts.

Equation 5

$$PI = (CI_{\text{Exposure}} \times CI_{\text{Sensitivity}})^{1/2}$$

Equation 6

$$CI_{\text{Adaptive Capacity (Inv)}} = 11 - CI_{\text{Adaptive Capacity}}$$

Equation 7

$$VI = (PI \times CI_{\text{Adaptive Capacity (Inv)}})^{1/2}$$

4.6.5 Sector and Overall Vulnerability Index

In the cases where sectors comprised multiple climate change impact subsectors (e.g. Biodiversity and Ecosystems, Agriculture, and People), the *VI* for subsectors were geometrically aggregated together to obtain a *VI* for the given sector (Equation 8).

Equation 8

$$VI_{\text{Sector}} = (VI_{\text{Subsector}_1} \times \ldots \times VI_{\text{Subsector}_n})^{1/n}$$

Upon evaluation of results, it was determined not to evaluate overall vulnerability by aggregating two or more sectors.

5 PRESENTATION OF VULNERABILITY ASSESSMENT OUTCOMES

5.1 Masked Area of Interest

In order to provide clearer visualisation of data, it was decided to only reveal results for the specific climate change subsector or sector of interest (called masking) rather than displaying results for the entire Arab region. In addition to focusing solely on a specific region (i.e. forested areas for the Area covered by forests subsector), this approach also eliminates any suggestion of borders stemming from indicators based on statistical data which is often at a national level. Aggregated data was extracted based on shapefiles containing the combined area from selected indicators (Table 6).

5.2 Final Classification

In order to improve the visualization of the integrated outputs, final reclassification was conducted to maximize the range of colors on the maps. This was applied based on the minimum and maximum aggregated values obtained from each of the composite indicators, the potential impact, and the vulnerability for each subsector and distributed in ten equal intervals (Table 7). The resultant final classification was applied to all maps for a given subsector or sector to facilitate comparisons. It should be noted that this approach only used for mapping purposes while actual aggregated values were used for subsequent aggregation iterations. A color scheme was devised in the form of a ‘stretched stoplight’, in which a very deep red color represents an unfavorable condition as opposed to a very deep green indicating a favorable condition.

TABLE 6: Extracted area of interest for climate change impact sectors and subsectors

Climate change impact sector/subsector	Masked area of interest
Water availability	Forested areas
	Wetland areas
	Rainfed areas
	Irrigated areas
	Livestock areas > 10 heads/km^2
	Population density > 2 inhabitants/km^2
Water sector	Forested areas
	Wetland areas
	Rainfed areas
	Irrigated areas
	Livestock areas > 10 heads/km^2
	Population density > 2 inhabitants/km^2
Area covered by forests	Forested areas
Area covered by wetlands	Wetland areas
Biodiversity and Ecosystems sector	Forested areas
	Wetlands areas
Water available for crops	Rainfed areas
	Irrigated areas
Water available for livestock	Livestock areas > 10 heads/km^2
Agriculture sector	Rainfed areas
	Irrigated areas
	Livestock areas > 10 heads/km^2
Inland flooding areas	Low or greater floodprone potential
Infrastructure and Human Settlements sector	Low or greater floodprone potential
Availability of water for drinking	Population density > 2 inhabitants/km^2
Health conditions due to heat stress	Population density > 2 inhabitants/km^2
Employment rate for the agricultural sector	Population density > 2 inhabitants/km^2
People sector	Population density > 2 inhabitants/km^2

TABLE 7: Ranges of aggregated values and final classification for vulnerability assessment maps

Subsector	Ranges of aggregated values and final classification									
	1	2	3	4	5	6	7	8	9	10
Water availability	1.55 – 2.23	2.23 – 2.91	2.91 – 3.59	3.59 – 4.27	4.27 – 4.95	4.95 – 5.63	5.63 – 6.31	6.31 – 6.99	6.99 – 7.67	7.67 – 8.35
Water sector	1.55 – 2.23	2.23 – 2.91	2.91 – 3.59	3.59 – 4.27	4.27 – 4.95	4.95 – 5.63	5.63 – 6.31	6.31 – 6.99	6.99 – 7.67	7.67 – 8.35
Area covered by forests	1.35 – 2.06	2.06 – 2.77	2.77 – 3.48	3.48 – 4.20	4.20 – 4.91	4.91 – 5.62	5.62 – 6.34	6.34 – 7.05	7.05 – 7.76	7.76 – 8.48
Area covered by wetlands	1.33 – 1.93	1.93 – 2.52	2.52 – 3.11	3.11 – 3.71	3.71 – 4.30	4.30 – 4.90	4.90 – 5.49	5.49 – 6.08	6.08 – 6.68	6.68 – 7.27
Biodiversity and Ecosystems sector	1.33 – 2.05	2.05 – 2.76	2.76 – 3.48	3.48 – 4.19	4.19 – 4.91	4.91 – 5.62	5.62 – 6.34	6.34 – 7.05	7.05 – 7.77	7.77 – 8.48
Water available for crops	1.62 – 2.23	2.23 – 2.83	2.83 – 3.44	3.44 – 4.05	4.05 – 4.65	4.65 – 5.26	5.26 – 5.87	5.87 – 6.48	6.48 – 7.08	7.08 – 7.69
Water available for livestock	1.60 – 2.30	2.30 – 3.00	3.00 – 3.70	3.70 – 4.40	4.40 – 5.10	5.10 – 5.80	5.80 – 6.49	6.49 – 7.19	7.19 – 7.89	7.89 – 8.59
Agriculture sector	1.60 – 2.30	2.30 – 3.00	3.00 – 3.70	3.70 – 4.40	4.40 – 5.10	5.10 – 5.80	5.80 – 6.49	6.49 – 7.19	7.19 – 7.89	7.89 – 8.59
Inland flooding area	1.00 – 1.90	1.90 – 2.80	2.80 – 3.70	3.70 – 4.60	4.60 – 5.50	5.50 – 6.40	6.40 – 7.30	7.30 – 8.20	8.20 – 9.10	9.10 – 10.0
Infrastructure and Human Settlements sector	1.00 – 1.90	1.90 – 2.80	2.80 – 3.70	3.70 – 4.60	4.60 – 5.50	5.50 – 6.40	6.40 – 7.30	7.30 – 8.20	8.20 – 9.10	9.10 – 10.0
Water available for drinking	1.00 – 1.90	1.90 – 2.80	2.80 – 3.70	3.70 – 4.60	4.60 – 5.50	5.50 – 6.40	6.40 – 7.30	7.30 – 8.20	8.20 – 9.10	9.10 – 10.0
Health due to heat stress	1.00 – 1.90	1.90 – 2.80	2.80 – 3.69	3.69 – 4.59	4.59 – 5.49	5.49 – 6.39	6.39 – 7.28	7.28 – 8.18	8.18 – 9.08	9.08 – 9.98
Employment rate for the agricultural sector	1.62 – 2.36	2.36 – 3.11	3.11 – 3.85	3.85 – 4.59	4.59 – 5.34	5.34 – 6.08	6.08 – 6.82	6.82 – 7.56	7.56 – 8.31	8.31 – 9.05
People sector	1.00 – 1.90	1.90 – 2.80	2.80 – 3.70	3.70 – 4.60	4.60 – 5.50	5.50 – 6.40	6.40 – 7.30	7.30 – 8.20	8.20 – 9.10	9.10 – 10.0

5.3 Hotspots

Representing areas especially vulnerable to climate change impacts or 'hotspot' areas can be used as an effective analytical and visual communication tool. There is no universal method to identify hotspots. Some studies have utilized the *Getis-Ord* G_i* method[5] which employs spatial statistics in GIS to identify areas which exceed a threshold unique to a particular climate change impact, and detect areas with the greatest exposure. For RICCAR, hotspot areas represent those with the highest overall vulnerability. The top 10% of aggregated values from vulnerability for each sector and subsector are considered as hotspots. Because this resultant area is very small (often less than 10 km^2), buffer zones representing the top 20% and top 30% of aggregated values were also included as hotspots. At the sector level, hotspots denote a composite of hotspots from the contributing subsectors. Although the hotspots are a valuable tool, they are often not apparent on a regional map, even if selected areas are enlarged (i.e. see Figure 7 to Figure 10). For this reason, hotspots were discussed in the Arab Climate Change Assessment Reports, but included maps were limited to those developed at the sector level which represent the worst-case scenario (RCP8.5 end-century) and have the greatest coverage.

FIGURE 7: Health conditions due to heat stress – RCP 4.5 Mid-century – Vulnerability hotspots

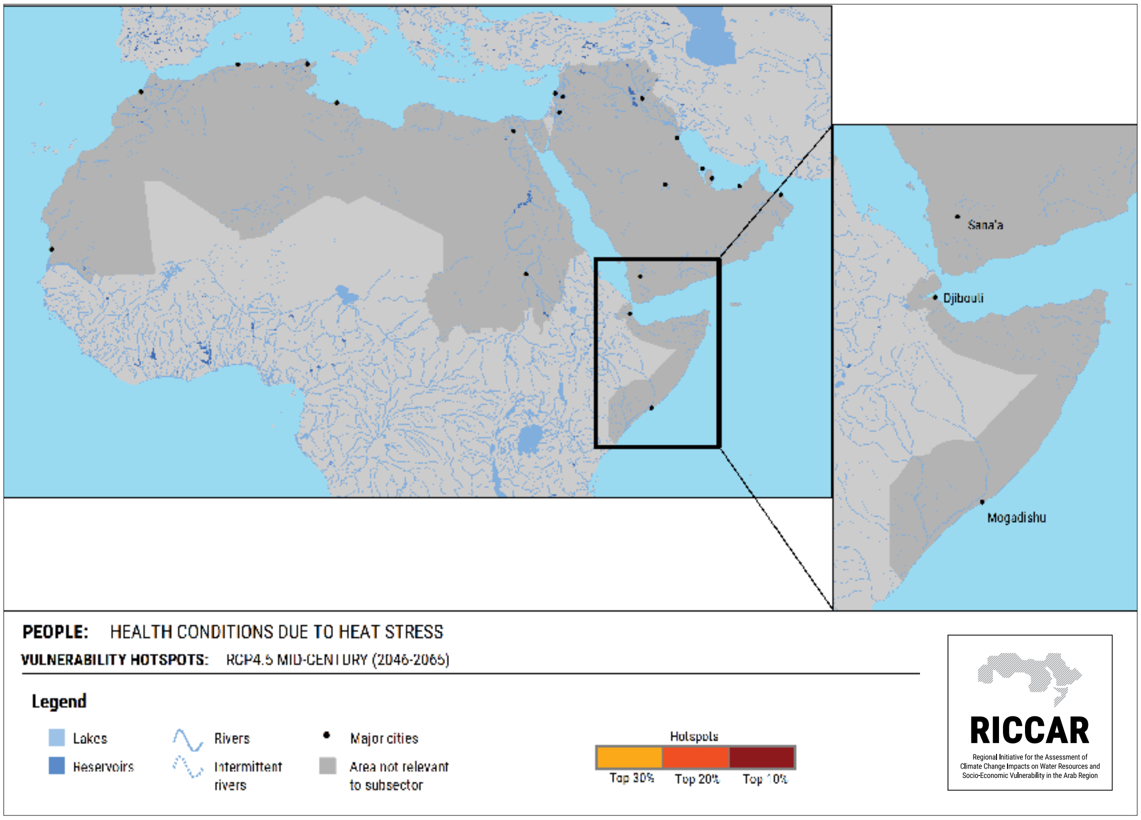


FIGURE 8: Health conditions due to heat stress – RCP 8.5 Mid-century – Vulnerability hotspots

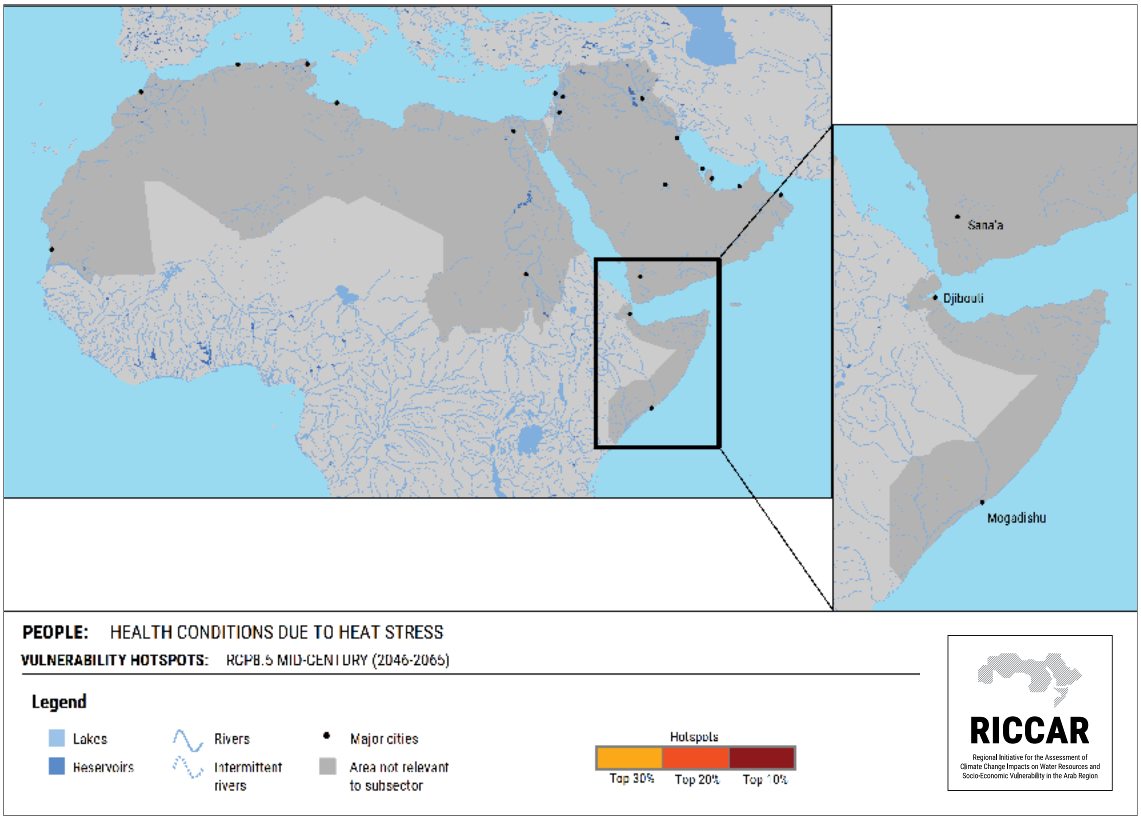


FIGURE 9: Health conditions due to heat stress – RCP 4.5 End-century – Vulnerability hotspots

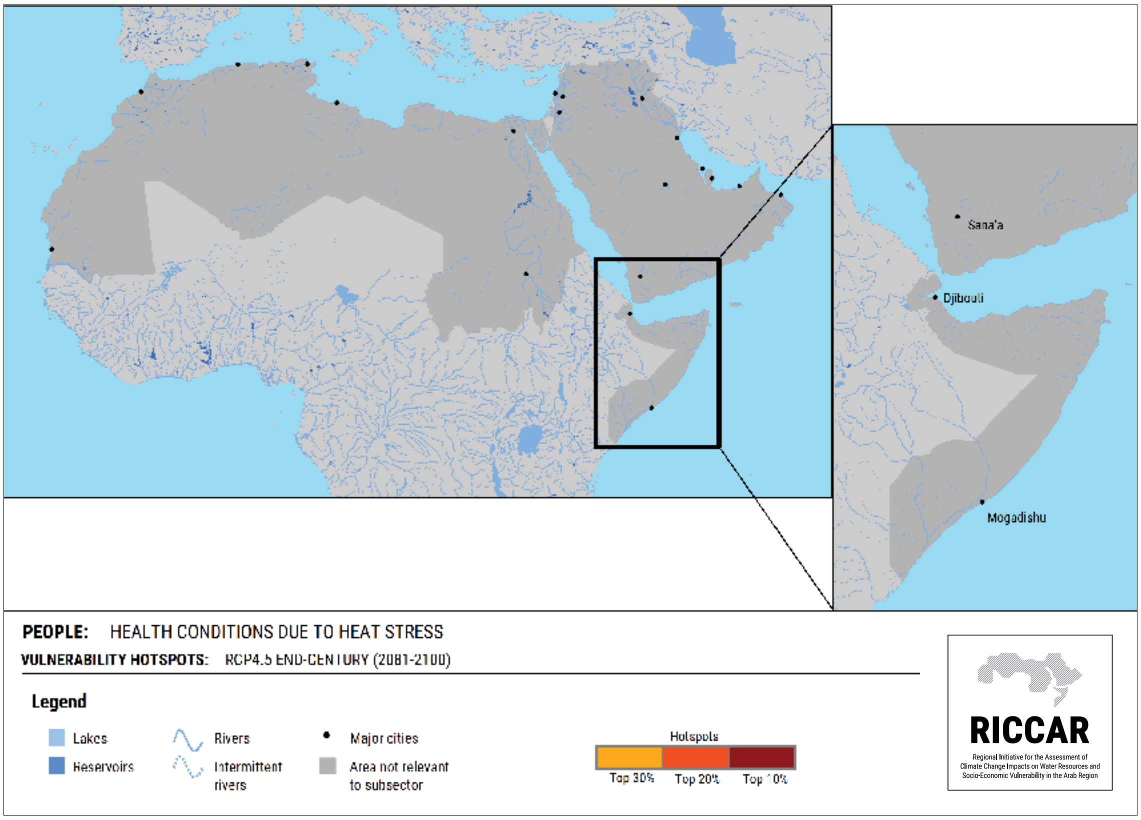
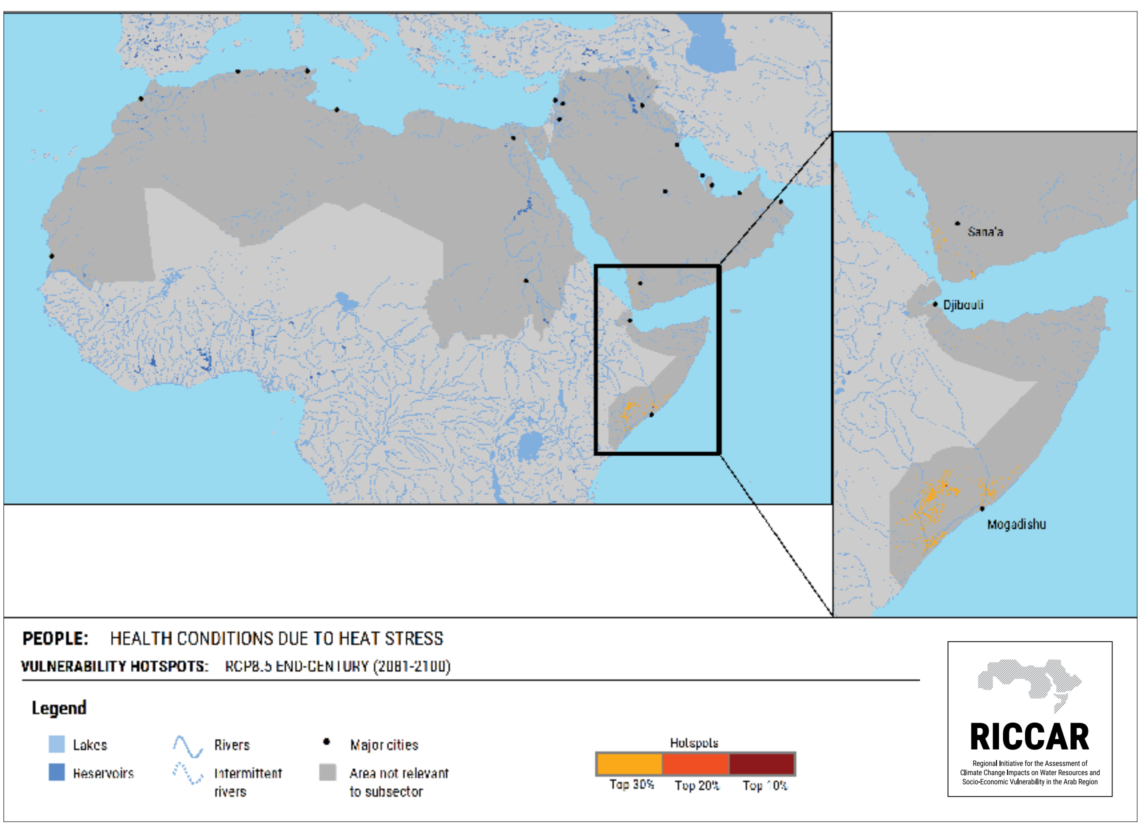


FIGURE 10: Health conditions due to heat stress – RCP 8.5 End-century – Vulnerability hotspots



6 INDICATOR RECORDS

The indicators and aggregated outputs were filed to be uploaded into an online platform known as the Regional Knowledge Hub. Datasets were organized into a specific structure (Figure 11) with each indicator consisting of the following associated components:

- two raster files (one for the actual values and one for the classified values)
- a map for both actual and classified values
- a factsheet describing the data source, resolution, classification methodology, and other relevant information (see Figure 12)
- a spreadsheet which includes indicator statistics suitable for quick reference

FIGURE 11: Typical indicators file structure for the Regional Knowledge Hub

- 01_Exposure Indicators
  - **01_Reference Period**
    - 01_RCM Output
      - 01_Precipitation
        - 01_Raster Files_Actual Values
        - 02_Raster Files_Classified Values
        - 03_Map_Actual Values
        - 04_Map_Classified Values
        - 05_Factsheet
        - 06_Spreadsheet
      - 02_Temperature
    - 02_RHM Output
    - 03_Extreme Climate Indices
  - **02_Mid-century**
    - 01_RCP 4.5
    - 02_RCP 8.5
  - **03_End-century**
    - 01_RCP 4.5
    - 02_RCP 8.5
- 02_Sensitivity Indicators
  - **01_Population**
  - **02_Natural**
  - **03_Manmade**
- 03_Adaptive Capacity Indicators
- 04_Vulnerability Assessment Outputs
  - **01_Water Sector**
    - 01_Water Availability
      - 01_Exposure CI
      - 02_Sensitivity CI
      - 03_Potential Impact
      - 04_Adaptive Capacity CI
      - 05_Vulnerability

FIGURE 12: Sample indicator factsheet

Indicator Name

Indicator fact sheet		
Indicator	**Full name of indicator**	
Vulnerability component	Component (i.e. Exposure, Sensitivity)	Dimension
Description (position in the impact chain)	Full Description	
Applicable subsectors and impacts with corresponding weight of indicator for VA	**Sector:** *Subsector*	Weight
Classes and ranges/thresholds for Regional Knowledge Hub and Vulnerability Assessment	**Classification (for RKH and VA)** 1 2 3 4 5 6 7 8 9 10	
Influence on vulnerability		
Citation (source of data)		
Data information		
Type of data		
Spatial coverage		
Resolution		
Time reference		
Unit of measurement		
Methodology for general data calculation		
Methodology for classification and transformation of values		
Input-indicators needed	-	
Data supply and acquisition		
Date of processing and publication		
Availability and costs		
Right to use / disseminate the data		
Contact		
Download-link		
Date of acquirement		

ENDNOTES

1. IPCC, 2007
2. Full details and materials on the respective events and meetings can be found on the following link: https://www.unescwa.org/events/events-list
3. See SMHI, 2017
4. Jenks and Caspall, 1971
5. Songchitruksa and Zeng, 2010

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