Climate-proof watershed management design and resilience synthesis report

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

The Economic and Social Commission for Western Asia (ESCWA) is contributing to the implementation of the Food and Agriculture Organization of the United Nations (FAO) project entitled “Implementing the 2030 Agenda for Water Efficiency, Productivity and Sustainability in the Near East and North Africa Countries (NENA-WepS)”. The project is funded by the Swedish International Development Cooperation Agency (Sida).

Substantive contributions and analysis in this report were provided by George Mitri, Sabine Saba, Maya Atie and an ESCWA team composed of Sara Hess, Marlene Ann Tomaszewicz, Mohamed Abd Salam El Vilaly, Elie Alrahi, Ziad Khayat, Tracy Zaarour, Sarah Daniel and Carol Chouchani Cherfane.

This technical report was prepared in consultation with national stakeholders in Lebanon, including the Ministry of Energy and Water, the Ministry of Agriculture, the Ministry of Environment, the FAO office in Lebanon and the FAO Regional Office for the Near East and North Africa.

Technical support and input were also provided by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD).

Special thanks go to all key stakeholders who have actively participated in consultations related to the study.
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.

The Initiative was launched under the auspices of the Arab Ministerial Water Council in 2010 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 Ministerial Session of the Economic and Social Commission for Western Asia (ESCWA).

The Initiative is implemented through a collaborative partnership involving 11 regional and specialized organizations. The RICCAR Regional Knowledge Hub (RKH) is managed by ESCWA and the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) with the Food and Agriculture Organization of the United Nations (FAO) hosting the Arab/Middle East and North Africa (MENA) Domain data portal and ESCWA hosting the Mashreq Domain data portal. ESCWA coordinates the regional initiative under the umbrella of its Arab Centre for Climate Change Policies.

This technical report was prepared through a collaborative partnership between ESCWA and ACSAD in consultation with the Ministry of Water Resources and Water Security of Algeria and Ministry of Energy and Water of Lebanon.

This study was conducted through the FAO-ESCWA Interagency Contribution Agreement aimed at “Increasing watershed resilience to climate change: Implementing the 2030 Agenda for water efficiency/productivity and water sustainability in NENA countries - Work Package Component on achieving SDG 6.4” to support the implementation of the FAO project entitled Implementing the 2030 Agenda for Water Efficiency, Productivity and Sustainability in the Near East and North Africa Countries (WEPS-NENA). This project is led by FAO with funding from the Swedish International Development Cooperation Agency (Sida) from December 2016 to December 2022.
# ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACSAD</td>
<td>Arab Centre for the Studies of Arid Zones and Dry Lands</td>
</tr>
<tr>
<td>ESCWA</td>
<td>Economic and Social Commission for Western Asia</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
</tr>
<tr>
<td>GCM</td>
<td>Global climate model</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>RCM</td>
<td>Regional climate model</td>
</tr>
<tr>
<td>RCP</td>
<td>Representative concentration pathway</td>
</tr>
<tr>
<td>RICCAR</td>
<td>Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region</td>
</tr>
<tr>
<td>RKH</td>
<td>Regional Knowledge Hub</td>
</tr>
<tr>
<td>SDG</td>
<td>Sustainable Development Goal</td>
</tr>
<tr>
<td>SIDA</td>
<td>Swedish International Development Cooperation Agency</td>
</tr>
<tr>
<td>SSP</td>
<td>Shared socioeconomic pathway</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>VA</td>
<td>Vulnerability assessment</td>
</tr>
</tbody>
</table>
CONTENTS

ACKNOWLEDGEMENTS

PREFACE

ABBREVIATIONS AND ACRONYMS

1 INTRODUCTION

2 CONSULTATION PROCESS METHODOLOGY

3 CONSULTATION PROCESS

4 WATERSHED CHARACTERISTICS

5 CLIMATE CHANGE PROJECTIONS

A. Algerois

B. Nahr el Kabir

C. Nahr el Kalb

6 ANALYSIS OF THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

A. Algerois

B. Nahr el Kabir

C. Nahr el Kalb

7 SUMMARY OF INTEGRATED VULNERABILITY ASSESSMENT RESULTS

A. Algerois

B. Nahr el Kabir

C. Nahr el Kalb

8 SUMMARY OF INTERVENTION DESIGN AND ACTIONS

9 KEY LESSONS LEARNED

REFERENCES

ENDNOTES

FIGURES

FIGURE 1
Ten-step methodology for developing climate-proof watershed management plan and resilience package

FIGURE 2
Map of the Algerois watershed

FIGURE 3
Map of the Nahr el Kabir basin

FIGURE 4
Map of the Nahr el Kalb basin
FIGURE 5
Mean change in annual temperature compared to the reference period based on an ensemble of bias-corrected models from the Euro-CORDEX Domain

FIGURE 6
Mean change in the annual precipitation compared to the reference period based on an ensemble of bias-corrected models from the Euro-CORDEX Domain

FIGURE 7
Mean change in annual temperature compared to the reference period based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

FIGURE 8
Mean change in annual precipitation compared to the reference period based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

FIGURE 9
Mean change in annual temperature for the near-term (2021–2040) and the mid-term (2041–2060) compared to the reference period (1995–2014) based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

FIGURE 10
Mean change in annual precipitation for the near-term (2021–2040) and the mid-term (2041–2060) compared to the reference period (1995–2014) based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

FIGURE 11
Mean change in annual snow cover for the near-term (2021–2040) and the mid-term (2041–2060) compared to the reference period (1995–2014) based on an ensemble of 6 models from the Euro-CORDEX Domain, RCP 8.5

FIGURE 12
Components of vulnerability based on the IPCC AR4 approach

FIGURE 13
Impact chain for the agriculture sector in the Algerois watershed to assess its vulnerability to climate change

FIGURE 14
Impact chain for the agriculture sector in the Nahr el Kabir basin to assess its vulnerability to climate change

FIGURE 15
Impact chain for the agriculture sector in the Nahr el Kalb basin to assess its vulnerability to climate change

FIGURE 16
Vulnerability at reference period (1986–2005)

FIGURE 17
Vulnerability at near-term (2021–2040)

FIGURE 18
Vulnerability at mid-term (2041–2060)

FIGURE 19

FIGURE 20
Vulnerability at near-term (2021–2040)

FIGURE 21
Vulnerability at mid-term (2041–2060)

FIGURE 22
FIGURE 23
Vulnerability at near-term (2021–2040) 22

FIGURE 24
Vulnerability at mid-term (2041–2060) 23

TABLES

TABLE 1
Summary of climate change projections in the near-term (2021–2040) and the mid-term (2041–2060) 7

TABLE 2
Changes in wheat yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois watershed, Algeria, for the five studied GCM models under scenario RCP 8.5, assuming fixed CO₂ concentration at 400 ppm 11

TABLE 3
Changes in wheat yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois watershed, Algeria, for the five studied GCM models under scenario RCP 8.5 with elevated atmospheric CO₂ concentration 12

TABLE 4
Changes in tomato yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois watershed, Algeria, for the five studied GCM models under scenario RCP 8.5, assuming a fixed CO₂ concentration at 400 ppm 12

TABLE 5
Changes in tomato yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois basin, Algeria, for the five studied GCM models under scenario RCP 8.5 with elevated atmospheric CO₂ concentration 12

TABLE 6
Changes in potato yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois basin, Algeria, for the five studied GCM models under scenario RCP 8.5, assuming a fixed CO₂ concentration at 400 ppm 12

TABLE 7
Changes in potato yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois basin, Algeria, for the five studied GCM models under scenario RCP 8.5 with elevated atmospheric CO₂ concentration 13

TABLE 8
Yield trends for oranges in five climate models. Scenario 8.5 in the near-term (2021–2040) and the mid-term (2041–2060) 13

TABLE 9
Projected barley yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1995–2014) in Akkar plain, Lebanon, for six RCM models, assuming a fixed CO₂ concentration at 400 ppm 13

TABLE 10
Projected barley yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1995–2014) in Akkar plain, Lebanon, for the six RCM models, with elevated atmospheric CO₂ concentration 14

TABLE 11
Projected apple tree yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1995–2014) in Nahr el Kalb basin, Lebanon, for six RCM models, assuming a fixed CO₂ concentration at 400 ppm 14

TABLE 12
Projected apple tree yield for the periods (2021–2040) and (2041–2060) compared to the reference period (1995–2014) in Nahr el Kalb basin, Lebanon, for the six RCM models 14

TABLE 13
Percentages of affected land as per the vulnerability assessment classification of the agriculture sector to climate change 17
<table>
<thead>
<tr>
<th>TABLE 14</th>
<th>Percentage distribution of vulnerability classes across the three periods</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE 15</td>
<td>Percentage area that exhibits low, moderate and high vulnerability in the reference, near-term and mid-term periods</td>
<td>21</td>
</tr>
<tr>
<td>TABLE 16</td>
<td>Proposed short list of interventions</td>
<td>24</td>
</tr>
</tbody>
</table>
1  INTRODUCTION

In a context of global climate change and growing concern surrounding water stress, the Arab region is among the most water-scarce regions of the world. Nineteen out of twenty-two States can count on less than 1,000 m$^3$ of renewable water resources per capita annually, the water scarcity threshold. Thirteen States have less than 500 m$^3$ per capita annually. This reality makes Sustainable Development Goal (SDG) 6, clean water and sanitation for all, an important priority for the Arab world, and comprises the motivation for launching a FAO-ESCWA collaboration.

The joint project entitled Implementing the 2030 Agenda for Water Efficiency, Productivity and Sustainability in the Near East and North Africa Countries (WEPS-NENA)” focuses specifically on SDG target 6.4 – to “substantially increase water use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity”. Funded by the Government of Sweden via the Swedish International Development Cooperation Agency (Sida), the project seeks to develop climate-proof watershed management plans and resilience packages to improve water resources management in the Arab region, in light of freshwater scarcity and climate change challenges. Watershed management plans and resilience packages were developed for three watersheds in the Arab region – the Nahr el Kabir and Nahr el Kalb basins in Lebanon and the Algerois watershed in Algeria, all selected in consultation with national authorities in Lebanon and Algeria.

Intended to support the replicability and upscaling of the work completed on these three watersheds in other watersheds regionally and globally, this synthesis report provides an overview of the methodology used in the project, followed by a summary of key climate projections and climate risks. Analysis results (climate change impact on agriculture assessments and integrated vulnerability assessments) are shared for the three watersheds. The final sections of this report describe the process and considerations for developing intervention recommendations and key lessons learned.

Readers who would like to learn about the work conducted in any of the three watersheds in greater detail may reference the published watershed management plans and resilience packages for each watershed.

2  CONSULTATION PROCESS METHODOLOGY

The watershed management plans and resilience packages were developed following a 10-step methodology, which entailed an in-depth consultation with relevant stakeholders, as well as rigorous scientific analysis.

![Image of 10-step methodology](source)

Consultations were conducted with different institutions and watershed stakeholder groups, concerning the scope of the work, as well as the drafting of a series of climate-resilient watershed management and resilience measures. As part of a 10-step methodology, the following activities were carried out:

1. Initial consultations: these were held with national government counterparts and the FAO country office to review the scope of the work and identify which national institutions and local stakeholder groups to engage in the consultations.

2. Institutional mapping and organizational analysis: this analysis was performed to reflect changes in land and water resource governance based on evolving land use and land cover in the watersheds and/or recent political developments.

3. Creation of a regional set of climate modelling projections for the selected watersheds: climate projections were based on the latest regional climate modelling (regional climate model, RCM) outputs available for each watershed. For the Algerois watershed, projections were drawn from the EURO-CORDEX Domain, which is based on CMIP5 at 12.5 km² grid resolution using bias-adjusted data for representative concentration pathway (RCP) 4.5 and RCP 8.5. For the two basins in Lebanon, data for the climate models were drawn from the RICCAR Mashreq Domain for SSP5-8.5 at a scale of 10 km² grid resolution.

4. Specific assessment of the watershed to determine changes in agricultural productivity: different models were used to assess agricultural productivity in each of the watersheds based on the specific crop types and site conditions. In Algeria, CropSyst was used to analyse the impact of climate change on wheat, tomato and potato crops, while a multiple regression analysis, among other tools, was used for citrus. For Nahr el Kalb, CropSyst was used to assess the impact of climate change on apple orchards. The water-energy-food security nexus was also taken into consideration, based on consultation with the Ministry of Energy and Water in Lebanon. For Nahr el Kabir, AquaCrop was used to assess the impact of climate change on barley crops.

5. Participatory stakeholder consultations: in the three watersheds, consultations were carried out with stakeholders to discuss the results of the analyses in steps 3 and 4, community capacity to adapt to climate change, and the indicators to be included in the vulnerability analysis (step 6).

6. Watershed-level climate change vulnerability assessment (VA): this analysis of the agriculture sector was conducted using the RICCAR Integrated Vulnerability Assessment Methodology. It incorporated the indicators identified in the consultations. The goal of this analysis was to assess how climate change is impacting community livelihoods in the watershed.

7. Consultations with national stakeholders: these consultations were held to vet and validate the vulnerability assessment, as well as solicit input on preliminary response measures from an integrated watershed management perspective.

8. Draft climate-proof watershed management design and resilience package: the draft reports were prepared in consultation with the FAO regional and country offices, and in close coordination with relevant ministries.

9. Consultation on the series of interventions: this final consultation was held to discuss with national and local counterparts the proposed climate-proof watershed management plan, resilience package and suggested interventions.

10. Finalized climate-proof watershed management design and resilience package, based on feedback received, were submitted to FAO national environment counterparts.
3  CONSULTATION PROCESS

A wide array of stakeholders was consulted in the three watersheds, including both public and private sector, and civil society actors. Similar projects in the future may consider including the following non-exhaustive list of potential stakeholders:

- Farmers
- Agricultural engineers
- National government: ministries of water, agriculture and environment, and water establishments
- Municipal government in the watershed area
- Non-governmental organizations (NGOs) working on agriculture, natural resource management or community-based projects
- Local financial institutions
- United Nations agencies working in the area
- Universities and research centers
- Youth organizations
- Industry and private sector representatives

As stated in the 10-step methodology, four rounds of consultations were held:

- Round I was held primarily with United Nations agencies (FAO) and national government counterparts. This round was intended to introduce the project, to build understanding around the scope of the work, and also to solicit opinions on which organizations and individuals should be involved in the consultations going forward.

- Round II concentrated on sharing the results of the climate modelling exercises and the assessment of the impact of climate change on agriculture in the watersheds. A more varied group of participants in comparison to the first round were asked to discuss their viewpoints on community capacity to adapt to climate change and to provide input on the indicators that should be included in the integrated vulnerability assessment. This round also included efforts to identify key crops to include in the agricultural analysis.

- Round III shared the results of the vulnerability assessment and invited stakeholders to vet and validate the findings.

- Round IV presented stakeholders with a draft of the climate-proof watershed management plan and resilience package and solicited their feedback on the relevance and feasibility of the proposed interventions.

The importance of stakeholder consultations cannot be overemphasized as a means to ensure the project is relevant to the community and to increase buy-in for the implementation of proposed interventions going forward.

4  WATERSHED CHARACTERISTICS

This section of the report provides a brief overview of the natural characteristics of the watersheds, including potentially useful information for readers considering implementing similar projects in areas with comparable biophysical characteristics. In addition to providing background on the geography of the watersheds, including their land cover characteristics and main water sources, this section features a brief background on the socioeconomic characteristics of the watersheds.

In terms of size, the Algerois watershed is by far the largest analysed, covering a total area of 4,570 km$^2$ (figure 2). The primary aquifer is the Mitjida, which covers an area of 1,450 km$^2$, and it ranks as Algeria’s largest subcoastal plain. The watershed is bordered by the Mediterranean Sea to the north and by the Tell Atlas Mountains to the south. The watershed includes six large man-made reservoirs, with a combined capacity of 540 million cubic meters (MCM). One of the most important agricultural zones in Algeria is also located there. Agriculture is the key economic activity, as this area produces most of Algeria’s citrus fruits. There is also some metal product manufacturing and tourism activity along the coast and in mountainous regions.
By comparison, the Nahr el Kabir and Nahr el Kalb basins in Lebanon are significantly smaller, covering 954 and 291 km$^2$ respectively. Nahr el Kabir is a transboundary water basin, with 26 per cent of its total area located in Lebanon and the remaining 74 per cent in the Syrian Arab Republic (figure 3). Bound by a small Mediterranean section to the west, it is primarily a mountainous area with a central plateau/gorge along the border. Nahr el Kabir has several tributaries and a large proportion of forest cover, which is key when considering the appropriate interventions in a primarily wooded area. The basin is in one of the lowest income areas of Lebanon. The conflict in the Syrian Arab Republic also resulted in many refugees seeking housing in the region, thus placing additional pressure on basic services, including water supply, which is also impacted by local agricultural production.

The Nahr el Kalb basin, also in Lebanon, is bound to the east by a small section connecting it to the Mediterranean Sea. The upper basin is mountainous, reaching a 2,622 m elevation, and is characterized by winter snowfall (figure 4). Three main tributaries discharge into the Nahr el Kalb, with the main water sources originating from seasonal rainfall and snowmelt. In the last few years, agricultural land has increasingly been replaced with urban areas, thus impacting the hydrology of the surrounding area. There are also specific concerns surrounding wastewater in this basin as there are no wastewater treatment plants. Nahr el Kalb is known for its tourist attractions including ski resorts, coastal resorts, natural attractions (Jeita cavern, Wadi al Salib), archeological and religious sites, and shopping precincts.
A stakeholder mapping exercise was also conducted for each basin as part of the description. Stakeholders were categorized as per various characteristics, including type of organization (public, private, civil society, etc.), and the relationship of the stakeholder to the water supply (users, regulators/managers or advisers).

5 CLIMATE CHANGE PROJECTIONS

Climate change projections were based on the latest generation of regional climate modelling outputs available for each watershed. For the Algerois, climate data presented were based on the Coordinated Regional Climate Downscaling Experiment of the Europe Domain (Euro-CORDEX), itself based on the Fifth Phase of the Coupled Model Intercomparison Project (CMIP5), described in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) for the RCP 4.5 and RCP 8.5 scenarios. For Nahr el Kabir and Nahr el Kalb, the climate data presented were based on RCM outputs obtained from the Mashreq Domain (ESCWA, 2021), using the sixth phase of the Coupled Model Intercomparison Project (CMIP6) described in the IPCC Sixth Assessment Report (AR6) (IPCC, 2021) for the SSP5-8.5 scenario.

The RCM outputs presented in the final reports for each watershed included annual temperature, precipitation and selected extreme event indices derived from the two climate parameters. A summary table of the climate projections is provided (table 1), followed by maps illustrating projected changes in temperature, precipitation and snow cover in each watershed. Note that snow cover was analysed only in Nahr el Kalb.

<p>| TABLE 1: Summary of climate change projections in the near-term (2021–2040) and the mid-term (2041–2060) |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|</p>
<table>
<thead>
<tr>
<th>Mean annual temperature change (°C)</th>
<th>Number of summer days (Tmax&gt;25°C) annual change</th>
<th>Mean annual precipitation change (mm/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Algerois</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near-term</td>
<td>+0.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>+13° – +14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mid-term</td>
<td>+1.2° – +1.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>+19° – +29&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Nahr el Kabir</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near-term</td>
<td>+0.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>+9&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mid-term</td>
<td>+2.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>+22&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Nahr el Kalb</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near-term</td>
<td>+1.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>+13&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mid-term</td>
<td>+2.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>+29&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Source: Authors.
<sup>a</sup> RCP 4.5, compared to reference period 1986–2005.
<sup>b</sup> RCP 8.5, compared to reference period 1986–2005.
<sup>c</sup> SSP5-8.5, compared to reference period 1995–2014.
A. Algerois

**FIGURE 5:** Mean change in annual temperature compared to the reference period based on an ensemble of bias-corrected models from the Euro-CORDEX Domain

**FIGURE 6:** Mean change in the annual precipitation compared to the reference period based on an ensemble of bias-corrected models from the Euro-CORDEX Domain

Source: Authors.
B. Nahr el Kabir

FIGURE 7: Mean change in annual temperature compared to the reference period based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

FIGURE 8: Mean change in annual precipitation compared to the reference period based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

Source: Authors.
C. Nahr el Kalb

FIGURE 9: Mean change in annual temperature for the near-term (2021–2040) and the mid-term (2041–2060) compared to the reference period (1995–2014) based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

Source: Authors.

FIGURE 10: Mean change in annual precipitation for the near-term (2021–2040) and the mid-term (2041–2060) compared to the reference period (1995–2014) based on an ensemble of 6 models from the Mashreq Domain, SSP5-8.5

Source: Authors.
6 ANALYSIS OF THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

At this stage (step 4 of the 10-step methodology), the objective was to assess the impact of climate change on the yields of key food crops in each of the watersheds. The crops analysed were selected during the first two stakeholder consultations. Different models were used based on the crop types and site characteristics. AquaCrop, developed by FAO, was used only to analyse barley yield in Nahr el Kabir, as this model has certain limitations when assessing fruit tree yields. Consequently, local expertise used a regression model to evaluate orange yield in Algerois. The CropSyst model, developed by Washington State University, was used to analyse apple yield in Nahr el Kalb, whereas the CropSyst model was used to analyse wheat, tomato and potato yield in Algeria, because of saltwater intrusion. Projected yields were analysed under scenario RCP 8.5, assuming both a fixed atmospheric CO$_2$ concentration (400 ppm), and an elevated atmospheric CO$_2$ concentration. This was done to account for the fact that increases in CO$_2$ have a positive effect on certain crop yields.

While a summary of the impact of climate change on yield is provided here, the complete analysis also included changes in the growth cycle and water demand for each crop. This is available in the complete reports on each watershed.

A. Algerois

In Algeria, when CO$_2$ is fixed, the wheat yield is projected to decrease by 22 per cent by 2060 (table 2).

<table>
<thead>
<tr>
<th></th>
<th>EC-EARTH</th>
<th>HadGEM2-ES</th>
<th>IPSL-CM5A-MR</th>
<th>MPI-ESM-LR</th>
<th>CNRM-CM5</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986–2005</td>
<td>2.8</td>
<td>2.6</td>
<td>2.7</td>
<td>2.6</td>
<td>2.6</td>
<td>2.7</td>
</tr>
<tr>
<td>2021–2040</td>
<td>2.3</td>
<td>2.2</td>
<td>2.5</td>
<td>2.5</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>2041–2060</td>
<td>2.1</td>
<td>2.0</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Relative change (mid-term/reference period)</td>
<td>-26%</td>
<td>-25%</td>
<td>-26%</td>
<td>-21%</td>
<td>-14%</td>
<td>-22%</td>
</tr>
</tbody>
</table>

Source: Authors.
Under an elevated CO$_2$ scenario, the future impact of climate change is somewhat mitigated with yields projected to drop by only 10 per cent by 2060 in comparison to the reference period (1986–2005) (table 3). Prior studies have shown that CO$_2$ fertilization may offset the impacts of climate change and lead to an increase in certain crop yields (Knox and others, 2010).

**TABLE 3**: Changes in wheat yield (t/ha) for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois watershed, Algeria, for the five studied GCM models under scenario RCP 8.5 with elevated atmospheric CO$_2$ concentration

<table>
<thead>
<tr>
<th></th>
<th>EC-EARTH</th>
<th>HadGEM2-ES</th>
<th>IPSL-CM5A-MR</th>
<th>MPI-ESM-LR</th>
<th>CNRM-CM5</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986–2005</td>
<td>2.6</td>
<td>2.5</td>
<td>2.6</td>
<td>2.5</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td>2021–2040</td>
<td>2.4</td>
<td>2.3</td>
<td>2.6</td>
<td>2.6</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>2041–2060</td>
<td>2.3</td>
<td>2.2</td>
<td>2.2</td>
<td>2.3</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Relative change (mid-term/ ref period)</td>
<td>-13%</td>
<td>-12%</td>
<td>-14%</td>
<td>-8%</td>
<td>-</td>
<td>-10%</td>
</tr>
</tbody>
</table>

Source: Authors.

With fixed CO$_2$, the tomato yield is projected to decrease by 8 per cent by 2060 (table 4), but when the positive impact of CO$_2$ is taken into consideration the tomato yield is projected to increase by 16 per cent (table 5).

**TABLE 4**: Changes in tomato yield (t/ha) for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois watershed, Algeria, for the five studied GCM models under scenario RCP 8.5, assuming a fixed CO$_2$ concentration at 400 ppm

<table>
<thead>
<tr>
<th></th>
<th>EC-EARTH</th>
<th>HadGEM2-ES</th>
<th>IPSL-CM5A-MR</th>
<th>MPI-ESM-LR</th>
<th>CNRM-CM5</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986–2005</td>
<td>5.7</td>
<td>6.0</td>
<td>6.6</td>
<td>6.0</td>
<td>6.0</td>
<td>6.1</td>
</tr>
<tr>
<td>2021–2040</td>
<td>6.0</td>
<td>6.6</td>
<td>6.4</td>
<td>5.7</td>
<td>5.8</td>
<td>6.1</td>
</tr>
<tr>
<td>2041–2060</td>
<td>5.3</td>
<td>5.6</td>
<td>6.2</td>
<td>5.7</td>
<td>5.1</td>
<td>5.6</td>
</tr>
<tr>
<td>Relative change (mid-term/ reference period)</td>
<td>-7%</td>
<td>-6%</td>
<td>-6%</td>
<td>-5%</td>
<td>-15%</td>
<td>-8%</td>
</tr>
</tbody>
</table>

Source: Authors.

**TABLE 5**: Changes in tomato yield (t/ha) for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois watershed, Algeria, for the five studied GCM models under scenario RCP 8.5 with elevated atmospheric CO$_2$ concentration

<table>
<thead>
<tr>
<th></th>
<th>EC-EARTH</th>
<th>HadGEM2-ES</th>
<th>IPSL-CM5A-MR</th>
<th>MPI-ESM-LR</th>
<th>CNRM-CM5</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986–2005</td>
<td>5.4</td>
<td>5.6</td>
<td>6.2</td>
<td>5.6</td>
<td>5.6</td>
<td>5.7</td>
</tr>
<tr>
<td>2021–2040</td>
<td>6.5</td>
<td>7.0</td>
<td>6.9</td>
<td>6.1</td>
<td>6.2</td>
<td>6.5</td>
</tr>
<tr>
<td>2041–2060</td>
<td>6.3</td>
<td>6.6</td>
<td>7.3</td>
<td>6.7</td>
<td>6.1</td>
<td>6.6</td>
</tr>
<tr>
<td>Relative change (mid-term/ reference period)</td>
<td>18%</td>
<td>18%</td>
<td>18%</td>
<td>19%</td>
<td>8%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Source: Authors.

By 2060, due to climate change, the potato yield is expected to decrease by 3 per cent (table 6), but when the positive impact of CO$_2$ is taken into consideration the potato yield is projected to increase by 14 per cent (table 7).

**TABLE 6**: Changes in potato yield (t/ha) for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois basin, Algeria, for the five studied GCM models under scenario RCP 8.5, assuming a fixed CO$_2$ concentration at 400 ppm

<table>
<thead>
<tr>
<th></th>
<th>EC-EARTH</th>
<th>HadGEM2-ES</th>
<th>IPSL-CM5A-MR</th>
<th>MPI-ESM-LR</th>
<th>CNRM-CM5</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986–2005</td>
<td>6.3</td>
<td>6.4</td>
<td>6.3</td>
<td>6.4</td>
<td>6.4</td>
<td>6.3</td>
</tr>
<tr>
<td>2021–2040</td>
<td>6.3</td>
<td>6.3</td>
<td>6.2</td>
<td>6.2</td>
<td>6.3</td>
<td>6.2</td>
</tr>
<tr>
<td>2041–2060</td>
<td>6.1</td>
<td>6.1</td>
<td>6.2</td>
<td>6.2</td>
<td>6.3</td>
<td>6.2</td>
</tr>
<tr>
<td>Relative change (mid-term/ reference period)</td>
<td>-2%</td>
<td>-4%</td>
<td>-3%</td>
<td>-3%</td>
<td>-1%</td>
<td>-3%</td>
</tr>
</tbody>
</table>

Source: Authors.
TABLE 7: Changes in potato yield (t/ha) for the periods (2021–2040) and (2041–2060) compared to the reference period (1986–2005) in the Algerois basin, Algeria, for the five studied GCM models under scenario RCP 8.5 with elevated atmospheric CO₂ concentration

<table>
<thead>
<tr>
<th></th>
<th>EC-EARTH</th>
<th>HadGEM2-ES</th>
<th>IPSL-CM5A-MR</th>
<th>MPI-ESM-LR</th>
<th>CNRM-CM5</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986–2005</td>
<td>5.9</td>
<td>6.1</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>2021–2040</td>
<td>6.6</td>
<td>6.6</td>
<td>6.6</td>
<td>6.5</td>
<td>6.6</td>
<td>6.6</td>
</tr>
<tr>
<td>2041–2060</td>
<td>6.8</td>
<td>6.8</td>
<td>6.8</td>
<td>6.9</td>
<td>7.0</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Relative change (mid-term/reference period) 15% 12% 13% 14% 16% 14%

Source: Authors.

Orange tree yields are projected to decrease (table 8) due to a reduction in rainfall, coupled with increased water needs because of higher temperatures that increase evapotranspiration.

TABLE 8: Yield trends for oranges in five climate models. Scenario 8.5 in the near-term (2021–2040) and the mid-term (2041–2060)

<table>
<thead>
<tr>
<th>Model</th>
<th>CNRM-CM5</th>
<th>EC-EARTH</th>
<th>HadGEM2-ES</th>
<th>MPI-ESM-LR</th>
<th>IPSL-CM5A-MR</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (Qx/ha)</td>
<td>1983–2002</td>
<td>239.0</td>
<td>307.9</td>
<td>265.0</td>
<td>249.8</td>
<td>272.8</td>
</tr>
<tr>
<td></td>
<td>2040–2021</td>
<td>209.6</td>
<td>219.4</td>
<td>208.1</td>
<td>238.8</td>
<td>261.0</td>
</tr>
<tr>
<td></td>
<td>2060–2041</td>
<td>148.2</td>
<td>144.4</td>
<td>100.4</td>
<td>111.4</td>
<td>145.7</td>
</tr>
<tr>
<td></td>
<td>2060–2021</td>
<td>178.9</td>
<td>181.9</td>
<td>154.3</td>
<td>175.1</td>
<td>203.4</td>
</tr>
<tr>
<td>Change in yield</td>
<td>2021–2040</td>
<td>-12.3</td>
<td>-28.7</td>
<td>-21.5</td>
<td>-4.4</td>
<td>-4.3</td>
</tr>
<tr>
<td>(percentage)</td>
<td>2041–2060</td>
<td>-38.0</td>
<td>-53.1</td>
<td>-62.1</td>
<td>-55.4</td>
<td>-46.6</td>
</tr>
<tr>
<td></td>
<td>2021–2060</td>
<td>-25.1</td>
<td>-40.9</td>
<td>-41.8</td>
<td>-29.9</td>
<td>-25.5</td>
</tr>
</tbody>
</table>

Source: Authors.

Note: “Qx” refers to a quintile and is the equivalent of 100 kilograms.

B. Nahr el Kabir

In Nahr el Kabir, when CO₂ is held constant, barley yields are projected to increase by 1 per cent (table 9).

TABLE 9: Projected barley yield (t/ha) for the periods (2021–2040) and (2041–2060) compared to the reference period (1995–2014) in Akkar plain, Lebanon, for six RCM models, assuming a fixed CO₂ concentration at 400 ppm

<table>
<thead>
<tr>
<th>Time period</th>
<th>CMCC-CM2-SR5</th>
<th>CNRM-ESM2-1</th>
<th>EC-Earth3-Veg</th>
<th>MPI-ESM1-2-LR</th>
<th>MRI-ESM2-0</th>
<th>NorESM2-MM</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021–2040</td>
<td>3.42</td>
<td>3.49</td>
<td>3.46</td>
<td>3.46</td>
<td>3.26</td>
<td>3.41</td>
<td>3.42</td>
</tr>
<tr>
<td>2041–2060</td>
<td>3.38</td>
<td>3.39</td>
<td>3.42</td>
<td>3.34</td>
<td>3.33</td>
<td>3.42</td>
<td>3.38</td>
</tr>
</tbody>
</table>

Relative change (mid-term/reference period) 1% 2% 1% -1% -1% 4% 1%

Source: Authors.
When the effect of elevated CO\(_2\) is added, barley yields are projected to increase more (table 10).

<table>
<thead>
<tr>
<th>Time period</th>
<th>Barley yield (t/ha)</th>
<th>CMCC-CM2-SR5</th>
<th>CNRM-ESM2-1</th>
<th>EC-Earth3-Veg</th>
<th>MPI-ESM1-2-LR</th>
<th>MRI-ESM2-0</th>
<th>NorESM2-MM</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995–2014</td>
<td>3.4</td>
<td>3.3</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
<td>3.3</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>2021–2040</td>
<td>3.6</td>
<td>3.7</td>
<td>3.7</td>
<td>3.7</td>
<td>3.5</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>2041–2060</td>
<td>3.7</td>
<td>3.7</td>
<td>3.8</td>
<td>3.7</td>
<td>3.7</td>
<td>3.8</td>
<td>3.7</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Relative change (mid-term/reference period) 11% 12% 10% 10% 9% 15% 11%

Source: Authors.

C. Nahr el Kalb

For Nahr el Kalb, when CO\(_2\) is held constant, apple tree yields are projected to decrease by 48 per cent by 2060 (table 11).

<table>
<thead>
<tr>
<th>Time period</th>
<th>Apple tree yield (kg/ha)</th>
<th>CMCC-CM2-SR5</th>
<th>CNRM-ESM2-1</th>
<th>EC-Earth3-Veg</th>
<th>MPI-ESM1-2-LR</th>
<th>MRI-ESM2-0</th>
<th>NorESM2-MM</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995–2014</td>
<td>2 961</td>
<td>2 523</td>
<td>2 258</td>
<td>2 639</td>
<td>2 281</td>
<td>2 775</td>
<td>2 573</td>
<td>2 573</td>
</tr>
<tr>
<td>2021–2040</td>
<td>2 643</td>
<td>2 454</td>
<td>2 169</td>
<td>1 843</td>
<td>2 764</td>
<td>2 017</td>
<td>2 315</td>
<td>2 315</td>
</tr>
<tr>
<td>2041–2060</td>
<td>698</td>
<td>1 800</td>
<td>2 130</td>
<td>1 063</td>
<td>1 051</td>
<td>572</td>
<td>1 348</td>
<td>1 348</td>
</tr>
</tbody>
</table>

Relative change (mid-term/reference period) -76% -29% -6% -60% -54% -79% -48%

Source: Authors.

For apple yields, an increase in temperature will lead to shortening the growth cycle and increasing water consumption. Overall, taking elevated levels of CO\(_2\) into account, the yield will decrease by a more moderate 16 per cent (table 12).

<table>
<thead>
<tr>
<th>Time period</th>
<th>Apple tree yield (kg/ha)</th>
<th>CMCC-CM2-SR5</th>
<th>CNRM-ESM2-1</th>
<th>EC-Earth3-Veg</th>
<th>MPI-ESM1-2-LR</th>
<th>MRI-ESM2-0</th>
<th>NorESM2-MM</th>
<th>Ensemble mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021–2040</td>
<td>3 067</td>
<td>2 821</td>
<td>2 576</td>
<td>2 153</td>
<td>3 204</td>
<td>2 386</td>
<td>2 701</td>
<td>2 701</td>
</tr>
<tr>
<td>2041–2060</td>
<td>989</td>
<td>2 490</td>
<td>2 990</td>
<td>1 846</td>
<td>1 388</td>
<td>803</td>
<td>1 941</td>
<td>1 941</td>
</tr>
</tbody>
</table>

Relative change (mid-term/reference period) -64% 17% 45% -24% -33% -68% -16%

Source: Authors.
7 SUMMARY OF INTEGRATED VULNERABILITY ASSESSMENT RESULTS

Integrated vulnerability assessments (IVAs) were performed for each watershed using the GIS-based approach developed by RICCAR. In this approach, vulnerability is based on three components: exposure, sensitivity and adaptive capacity. Exposure refers to the measurable impacts of climate change, such as changes in temperature and precipitation. Sensitivity describes the natural and physical environment and different population groups that are particularly susceptible to climate change. The potential impact of climate change results from a combination of exposure and sensitivity. Adaptive capacity describes the ability to cope, mitigate and adapt to climate change. Vulnerability results from a gap between the adaptive capacity and potential impact of climate change (figure 12).

Source: United Nations Economic and Social Commission for Western Asia (ESCWA), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), Integrated Vulnerability Assessment: Arab Regional Application, E/ESCWA/SDPD/2017/RICCAR/TechnicalNote.2 (Beirut, 2017).
Within the vulnerability assessment components, an impact chain was developed for each watershed. Developed collaboratively with stakeholders, impact chains are frameworks that serve to identify causal relationships, so as to assess vulnerability to various impacts of climate change. Relevant indicators are identified for each of the impact chain components. The impact chains for the Algerois, Nahr el Kabir and Nahr el Kalb are provided in figures 13, 14 and 15, respectively.

Data for IVAs were sourced from national statistics offices, international organizations (United Nations Biodiversity Lab, for example), industrial associations and subnational government entities.


FIGURE 15: Impact chain for the agriculture sector in the Nahr el Kalb basin to assess its vulnerability to climate change

Exposure (0.5)
- Change in temperature (0.3)
- Change in precipitation (0.25)
- Change in snow cover fraction (0.1)
- Change in snow depth (0.1)
- Change in summer days (0.1)
- Change in drought frequency (0.1)

Sensitivity (0.5)
- Population (0.3)
  - Population density
- Man-made (0.3)
  - Flood risk (0.15)
  - Waste dumps (0.1)
  - Distribution of wells (0.2)
  - Built areas (0.25)
  - Artificial water areas (0.1)
  - Industries (0.1)
- Natural (0.4)
  - Slope (0.1)
  - Erosion risk (0.1)
  - Soil storage capacity (0.2)
  - Land degradation (0.1)
  - Karstification level (0.1)
  - Vegetation cover (0.2)
  - River (0.1)
  - Fire susceptibility (0.05)
  - Livestock density (0.05)

Potential impact (0.5)

Adaptive capacity (0.5)
- Infrastructure (0.2)
  - Road network density (0.5)
  - Water network density (0.5)
- Knowledge and awareness (0.1)
  - Public education centers
- Economic resources (0.16)
  - Expenditure (0.5)
  - Financial services (0.5)
- Equity (0.1)
  - Youth to adult ratio
- Institutions (0.2)
  - Associations targeting youth (0.5)
  - Access to healthcare (0.5)

Vulnerability


Note: In creating the impact chain in figures 13, 14 and 15, indicators were assigned weights to measure their relative importance for a given climate change impact and were determined using a multi-step process based on expert opinions.

A. Algerois

Figures 16, 17 and 18 show an increase in the territory highly vulnerable to climate change in the Algerois watershed. Table 13 summarizes the increase from 10 per cent of the area during the reference period to nearly 94 per cent of the total land area by the mid-term.

TABLE 13: Percentages of affected land as per the vulnerability assessment classification of the agriculture sector to climate change

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Vulnerability (percentage of the study area)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low (class 1–3)</td>
</tr>
<tr>
<td>Reference period</td>
<td>24</td>
</tr>
<tr>
<td>(1986–2005)</td>
<td></td>
</tr>
<tr>
<td>Near-term</td>
<td>7</td>
</tr>
<tr>
<td>(2021–2040)</td>
<td></td>
</tr>
<tr>
<td>Mid-term</td>
<td>&lt;1</td>
</tr>
<tr>
<td>(2041–2060)</td>
<td></td>
</tr>
</tbody>
</table>


FIGURE 17: Vulnerability at near-term (2021–2040)

Figure 18: Vulnerability at mid-term (2041–2060)

Although not strictly comparable, vulnerability to climate change does not appear to be as severe in Nahr el Kabir as in Algerois (figures 19–21). As shown in table 14, the area of the study exhibiting high vulnerability to climate change increases from almost nil during the reference period to 17 per cent in the mid-term period.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Low (class 1–4)</th>
<th>Moderate (class 5–6)</th>
<th>Moderate-high (class 7)</th>
<th>High (class 8–10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference period</td>
<td>46</td>
<td>52</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Near-term period</td>
<td>15</td>
<td>75</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Mid-term period</td>
<td>&lt;1</td>
<td>40</td>
<td>43</td>
<td>17</td>
</tr>
</tbody>
</table>


FIGURE 20: Vulnerability at near-term (2021–2040)

FIGURE 21: Vulnerability at mid-term (2041–2060)

C. Nahr el Kalb

Figures 22, 23 and 24 indicate that the area of the Nahr el Kalb basin highly vulnerable to climate change is anticipated to increase from 0.4 to 48 per cent by the mid-term as summarized in table 15.

TABLE 15: Percentage area that exhibits low, moderate and high vulnerability in the reference, near-term and mid-term periods

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Low (class 1-4)</th>
<th>Moderate (class 5-7)</th>
<th>High (class 8-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference period</td>
<td>99.6</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>Near-term period</td>
<td>71</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>Mid-term period</td>
<td>20</td>
<td>32</td>
<td>48</td>
</tr>
</tbody>
</table>

8 SUMMARY OF INTERVENTION DESIGN AND ACTIONS

The analyses of the previous sections resulted in devising a climate-proof watershed management design and resilience package for each watershed. Initially, this entailed creating a long list of interventions (approximately 10), including more general information on each intervention. With input from stakeholder consultations, this list was then narrowed down to 4 or 5 interventions that were elaborated to include objectives, justification, link to SDGs, involved stakeholders, activities, constraints, estimated cost and duration.

The short list of interventions for the watersheds can be categorized into five themes that may intersect: knowledge development and management, water resilience, agriculture resilience, livelihood resilience and land preservation. For example, interventions focused on agriculture resilience may also promote greater livelihood resilience. Interventions are grouped as per their primary theme in table 16.
The shortlisted interventions were elaborately presented to facilitate action, while providing stakeholders with a margin to make necessary modifications, so as to facilitate later implementation. As table 15 indicates, a variety of interventions across several categories were shortlisted for each watershed. Several interventions are summarized here for consideration in the event of replicating the watershed management design and resilience projects in other locations.

In an effort to increase water supply in areas of the Algerois watershed experiencing critically low levels thereof, one intervention focuses on rainwater and wastewater management and collection. Identified stakeholders include the Ministry of Water Resources and Water Security, the Ministry of Agriculture and Rural Development and the National Agency for Integrated Water Resources Management. To implement this intervention, stakeholders would need to manage the construction of the necessary infrastructure for rainwater harvesting, upgrade the capacity of existing wastewater treatment facilities in the watershed and reuse the treated wastewater for agriculture. Costs were estimated per activity, amounting to a total of $3.1 million, and with an implementation period of four years.

As Nahr el Kabir lies in a heavily wooded area, interventions to combat land degradation were proposed in addition to water resilience ones. One such intervention focuses on improving forest management to reduce wildfires and enhance resilience. When wildfire risk is reduced, less water will be needed to extinguish flames in potential fire events. Dealing with fire risks results in improved soil water retention in forests, and the prevention of land degradation. Identified stakeholders include land managers and owners, NGOs, municipal authorities, the Ministry of Agriculture, Ministry of Environment and the Ministry of Water and Energy. Activities include undertaking preventative silviculture practices including fuel management actions such as grubbing, tree thinning and prescribed burning, as well as breaking the landscape homogeneity in fire-prone areas. The intervention incurs a total estimated cost of $2.7 million, with estimates provided by activity, and a projected implementation period of 36 months.
Given the prevalence of winter tourism activities in Nahr el Kalb and the potential impact of climate change and the change in snow cover on these activities, one proposed intervention in this basin focuses on livelihood diversification. The specific objective of this proposal is to provide alternatives to snow-dependent tourism and ultimately to diversify income sources. Suggested activities include rehabilitating and opening biking and hiking trails, organizing regular exhibitions and markets for local products, and developing and publishing a tourism map including main attraction sites. Identified stakeholders include municipal authorities in the area, business owners and the Ministry of Tourism. This intervention incurs an estimated cost of $810,000, and its projected implementation period is 18 months.

These interventions show how the basin realities in terms of geography, water scarcity, climate risk and socioeconomic profile inform the development of suggested interventions. Cost estimates were provided to give policymakers and stakeholders an idea of the approximate resources needed to implement the intervention, and thus appraise the need for financing and fundraising. That being said, the actual implementation costs are likely to vary.
9 KEY LESSONS LEARNED

Based on work in the three watersheds included in this study, there are several key lessons to consider when replicating similar projects in other locations.

1. Importance of stakeholder consultations: climate change is often most visible at the local level, while policies to mitigate and adapt to climate challenges are often made at the national level. For all three watersheds, it was essential to bring together a diverse array of stakeholders from both the national and subnational levels to discuss and understand their priorities in terms of the analysis and suggested interventions.

2. Selection of appropriate models for climate change and agriculture projections: every watershed presents its own challenges in terms of data availability and the type of crops that are most appropriate to analyse. This may impact the decision to use CropSyst, AquaCrop or other models. Multiple climate modelling outputs with fine spatial resolution should be used to minimize uncertainties and best represent the microclimate within the watershed.

3. Geospatial data for vulnerability assessments: vulnerability assessments are dependent upon key indicators represented by geospatial data. Careful consideration of indicators should be made, factoring in their relevance for project scope and watershed size.

4. Importance of government collaboration across ministries: while the Ministry of Environment, the Ministry of Water or the Ministry of Agriculture may be the most logical to include in the consultations for a project of this nature, it is important to bring to the table as many relevant ministries as possible. The water and agriculture sectors crosscut areas such as industry, transportation and energy. Inviting diverse perspectives into the discussion early on may increase buy-in for interventions later.

5. Importance of diversifying suggested interventions: the interventions for the three watersheds included in this study span several sectors and include diverse components, such as hard infrastructure, soft management skills, knowledge development and awareness-raising. Building resilience to the impact of climate change on the water sector requires interventions that extend outside the water sector itself, to include agriculture, land preservation and livelihood resilience.
References


Endnotes


3. Representative concentration pathways (RCPs) were introduced in the IPCC Fifth Assessment Report (AR5), which described four potential trajectories for greenhouse gas concentrations based on radiative forcing in the year 2100. These RCPs range from RCP 2.6 to RCP 8.5, reflecting a projected radiative forcing of 2.6 to 8.5 W/m², respectively, but purposely do not consider socioeconomic factors.

4. Shared socioeconomic pathways (SSPs) are modeled scenarios that take into account the way the RCPs will evolve given an implied set of socioeconomic characteristics (population growth and economic growth, for example). They were introduced in the Sixth Assessment Report of the IPCC (AR6). SSP5-8.5 models a development trajectory powered by fossil fuels with the upper bound of emissions. For more information, please reference: https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/SROCC_Ch01-SM_FINAL.pdf

5. CropSyst is a user-friendly, conceptually simple but effective multi-year multi-crop simulation model with daily time steps. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition and erosion. Management options include cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations (over 80 options) and residue management. CropSyst is provided by Washington State University free of charge, and it is easy to use. It also considers the effect of changes in temperature, precipitation, and CO₂ concentration on crop yields.

6. AquaCrop is a crop simulation model that describes the interactions between the plant and the soil. The Food and Agriculture Organization developed AquaCrop to address the issue of food security and to assess the effect of environment and management on crop production. When designing the model, an optimum balance between simplicity, accuracy and robustness was pursued. To be widely applicable, AquaCrop uses only a relatively small number of explicit parameters and mostly intuitive input-variables that can be determined by simple methods. The calculation procedures are grounded on basic and often complex biophysical processes to guarantee an accurate simulation of a crop response in the plant-soil system. AquaCrop can be used as a planning tool, or as a means to assist in management decisions for both irrigated and rainfed agriculture.

7. For more information on the vulnerability assessment methodology, please see: Economic and Social Commission for Western Asia (ESCWA), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). 2017. Integrated Vulnerability Assessment: Arab Regional Application. RICCAR technical note, Beirut, E/ESCWA/SDPD/2017/RICCAR/Technical Note.2.


12. For more information on the IVA methodology, including normalization, classification, weighting and aggregation of identified indicators, readers may refer back to: https://www.riccar.org/publications/integrated-vulnerability-assessment-arab-regional-application.

The Arab region is among the most water-scarce regions of the world. Nineteen out of twenty-two Arab States receive less than 1,000 m$^3$ of renewable water resources per capita annually, the water scarcity threshold. Thirteen States have less than 500 m$^3$ per capita annually. This reality makes Sustainable Development Goal (SDG) 6, Clean Water and Sanitation for All, an important priority for the Arab region and comprises the motivation behind a collaboration between the Food and Agriculture Organization and the United Nations Economic and Social Commission for Western Asia: “Implementing the 2030 Agenda for water efficiency, productivity and sustainability in the Near East and North Africa region.”

This joint project focuses specifically on SDG target 6.4 – to “substantially increase water use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity”. Funded by the Government of Sweden, the project seeks to improve water resource management in the Arab region. Watershed management plans and resilience packages were developed for the Nahr el Kabir and Nahr el Kalb basins in Lebanon and the Algerois watershed in Algeria.

This technical report provides an overview of the methodology used in the project, followed by a summary of key climate projections and climate risks and a description of the vulnerability assessments conducted for Nahr el Kabir, Nahr el Kalb and the Algerois watershed. The final sections of this report describe the process and considerations for developing intervention recommendations and the key lessons learned.