



Climate Risk Assessments for Iraq

The Southern Marshes Eco-region and Persian Gulf and Shatt Al-Arab Eco-Region

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Version: 4.3 (Final)

Date: 18th January 2023

Summary:

This report has been produced for the purpose of supporting the UN Environment Programme's (UNEP) contribution to the delivery of climate change adaptation in the Asian region through the Green Climate Fund funded National Adaptation Plan (NAP) for Iraq project. The Walker Institute is working with UNEP, NAP partners and local officials to determine relevant gaps in relation to climate knowledge in Iraqi institutions and determine how to build capacity to address climate change.

This technical report summarises the results from a set of government-endorsed climate risk assessments in first order and second-order risk domains for the Southern Marshes eco-region and the Persian Gulf and Shatt Al-Arab eco-region. This involved the development of climate projections and indices which were used to construct climate storylines. These storylines provide Iraq decision-makers with impact analyses and data to incorporate in their decision-making processes and support adaptation planning. This work will equip Iraq in identifying and planning for technical support activities and multi-sectoral cooperation to formulate and implement the NAP process

Table of Contents

Climate Risk Assessments for Iraq	1
The Southern Marshes Eco-region and Persian Gulf and Shatt Al-Arab Eco-Region	1
Acknowledgements	6
Abbreviations	7
1. Executive Summary	8
2. Report Objectives	11
3. Task Overview	11
4. Consultation Approach	12
Responding to Iraq’s Adaptation Knowledge Needs through Consultation and Partnerships.....	12
Engagement and Co-development of the Climate Risk Assessments in First Order and Second-Order Risk Domains	14
5. Approach to the Climate Risk Assessments	14
Methodology	14
Assumptions and Limitations	16
6. Data and Information Sources	17
7. Current and Future Climate Risk for Iraq	19
Observed Changes Since 1950s.....	19
Projected Future Changes	21
Current and Potential Future Impacts on Socio-Economic Sectors.....	22
National Scale Hazard Maps.....	26
8. Climate Change Scenarios for Persian Gulf and Shatt Al-Arab Region	33
Topography and Hydrology of the Shatt Al-Arab Region.....	33
Climate	33
Economics.....	33
Agriculture.....	34
Climate Hazards and Impacts.....	35
Climate Change and Vulnerability Storylines	38
9. Climate Change Scenarios for The Southern Marshes	45
Topography, Climate and Hydrology of the Marshes	45
Change in the 20 th Century	45
Climate Hazards and Impacts.....	47
Water Levels.....	47
Climate Change and Vulnerability Storylines	50
10. Common impacts across storylines	56
Persian Gulf and Shatt Al-Arab Region.....	56
Southern Marshes Region	57
11. Final Remarks	58
REFERENCES	60
Appendix A	63
Guidance to Representative Concentration Pathways	63
Appendix B	64
Background to the Self-Organising Maps (SOMs) Approach	64

Appendix C	67
Indices produced from the downscaling.....	67
Appendix D	70
Changes in Maximum Annual Number of Consecutive Dry Days and Annual Average Intensity of Precipitation by 2085.....	70
Appendix E	71
Workshop consultation on the storylines for the Persian Guld and Shatt Al-Arab ecoregion	71
Appendix F	73
Workshop consultation on the storylines for the Southern Marshes ecoregion	73
Appendix G	75
Executive Summary from the Iraqi Climate Modelling Unit - Strategy Guide (2022).....	75
G.1 Challenges to Implementation of a Fully Functional National Climate Service in Iraq	75
G.2 Evidence Synthesis and Co-Production to Build Climate Resilience	77
G.3 Increased Access to Timely Meteorological Information is for the Implementation of Early warning Systems that can Build Resilience	77
G.4 The Foundation Stones of the New Iraqi Climate Modelling Unit for Building Resilience.....	78

LIST OF FIGURES

Figure 1: Institutional Engagement Plan For Iraq Climate Risk Assessments. Adapted from UNFCCC Nairobi Work Plan, FCCC/SBSTA/2021/INF.2	13
Figure 2: Indicative storylines for (left) Basra and the Shatt al-Arab region; and (RIGHT) the Southern Marshlands. These quadrants were refined once the results of the climate Risk Assessment were complete (See p.39 8. Climate Change Scenarios for Persian Gulf and Shatt Al-Arab Region and P.50 for the climate storylines for the Southern Marshes).....	16
Figure 3: Change in precipitation between December and by the end of century (Figure 4.24 in IPCC AR6 report, Working Group 1, Chapter 12). Note SSP3-7.0 is considered a high emission scenario more likely that RCP8.5 used in AR5. Change in sign across Iraq at both periods illustrated is apparent but the hatching indicates a lack of statistical significance throughout.	21
Figure 4: Most produced food commodities in Iraq. (FAOSTAT, 2022)	23
Figure 5 Farmers concern regarding climate change (left) and Factors affecting the slow onset of soil salinization influenced by climate change (RIGHT).....	24
Figure 6: Meters of sea level rise with respect to the level of the 1995-2014 period. The emission scenario is RCP8.5 and the location is a point in the Persian Gulf close to the Iraqi coast at 28 ° latitude and 49 ° longitude. The blue points show the <i>medium confidence</i> scenario. the orange points show a <i>low confidence</i> scenario which includes the potential impact of deeply uncertain ice sheet processes, about which there is currently a low level of agreement and limited evidence (see futher description in the text). The cross marker shows the median estimate, bracketed with the 5, 17, 83 and 95 quantiles as triangles. For the medium confidence scenario, the 17th-83rd percentile ranges are interpreted as <i>likely</i> ranges, or a probability of at least 66%; Note this interpretation does not apply to the low confidence scenario.	28
Figure 7: (a-d) Area potentially exposed to sea level rise for 0, 1, 2 and 3 meters of increased sea level compared to 1995-2014 level. The governorate of Al Basrah, Dhi-Qar and Maysan are highlighted. (e) Percentage of total area of the three governorates under a given value of SLR. The median (line) and 5,95 percentiles (dashed linEs) of projected SLR under the RCP4.5 medium confidence (orange), RCP8.5 medium confidence (purple) and RCP8.5 low confidence (brown) BY 2150 are marked in the plot to show the corresponding percentage of area affected.	29
Figure 8: Change in frequency of wet years (SPI12 > 1) by 2085 compared to historical, in the regional climate models (SOMS) selected for RCP8.5 (top row) and RCP4.5 (bottom row).	30
Figure 9: Change in frequency of dry years (SPI12 < -1) by 2085 compared to historical, in the regional climate models (SOMS) selected for RCP8.5 (top row) and RCP4.5 (bottom row).	30
Figure 10: Change in annual number of days with heat index above 32°C by 2085 in the regional climate models (SOMS) selected for RCP8.5 (top row) and RCP4.5 (bottom row).	31

Figure 11: Change in Annual number of warm and dry days by 2085, in the regional climate models (SOMS) selected for RCP8.5 (top row) and RCP4.5 (bottom row).	32
Figure 12: (Left) Map of Iraq with governorates (grey lines), settlements locations in Iraq (purple dots) and The three Southern marshes analysed in this report (light green). (Right) Population map from worldpop.org.	32
Figure 13: The Persian Gulf region and view of Shatt Al-Arab from the northern part of Basra city. Source: Aziz, Wikimedia. https://commons.wikimedia.org/wiki/File:Shatt_al-arab-22.JPG . Accessed 6 April 2022	33
Figure 14: Neglected date palms in Basra. Source: https://www.arabnews.com/node/1379061/middle-east . Accessed 6 April 2022	34
Figure 15: Change in annual number of days with HI above 32°C (top) and above 41°C (bottom) over Al-Basrah. The change is with respect to the historical period (1981-2005). RCP4.5 SOMS are shown in Orange and RCP 8.5 in Purple. The 'noise' level to detect change is marked by yellow horizontal bars, which correspond to the historical 25 and 75 percentiles variability.	35
Figure 16: The settlements and southern marshes location (left). Area potentially exposed to 1m and 2m of sea level rise (center and right).	36
Figure 17: Relative percentage change in R90pTOT (top) and R99pTOT (bottom) from historical levels. RCP4.5 SOMS are shown in Orange and RCP 8.5 in Purple. The 'noise' level to detect change is marked by yellow horizontal bars, which correspond to the historical 25 and 75 percentiles Variability.	37
Figure 18: Relative percentage change in annual 30-day maximum effective precipitation from historical levels. RCP4.5 SOMS are shown in Orange and RCP 8.5 in Purple. The 'noise' level to detect change is marked by yellow horizontal bars, which correspond to the historical 25 and 75 percentiles Variability.	38
Figure 19: Climate Change and Vulnerability Storylines for the Persian Gulf and Shatt Al-Arab Eco-Region. change in extreme precipitation (vertical axis) versus change in heat index above 32°C (horizontal axis). RCP8.5 (purple) and RCP4.5 (orange) mean estimates for the 25 years centered at 2035 (empty dot), 2050 (filled light dot) and 2085 (filled dark dot). The lines dividing the four quadrants represent no change in precipitation extreme (0 horizontal line) and moderate change in hot-humid extremes (+30 days vertical line; note this threshold may be adjusted depending on impact assessment).	39
Figure 20: Climate Storyline 1 - Persian Gulf & Shatt Al-Arab Region	40
Figure 21: Climate Storyline 2 - Persian Gulf & Shatt Al-Arab Region	42
Figure 22: Main connections between the marshes and the hydrological network. Source: https://water.fanack.com/specials/iraqi-marshes/physical-setting/#_ftn1 . Accessed February 2022	45
Figure 23: (Left) Boundaries of the marshes according to the RAMSAR database: Central (pink), Hammar (light blue) and Hawizeh (green). Tigris and Euphrates rivers catchment (purple area) and rivers (Blue lines). (Right) T&E Catchment area upstream of the marshes.	48
Figure 24: Effective precipitation change by 2085 (2072-2097) compared to 1981-2005 level in the area encompassing the Tigris and euphrates catchment upstream of the marshes (top; percentage change) and locally in the southern marshes (bottom; change). RCP4.5 SOMS are shown in Orange and RCP 8.5 in Purple. Change for each month of November, December, January, and February, corresponding to the rainy season. The 'noise' level to detect change is marked by yellow horizontal bars, which correspond to the historical 25 and 75 percentiles variability.	48
Figure 25 Percentage change of the de martonne aridity index. The change is with respect to the historical period (1981-2005). RCP4.5 SOMS are shown in orange and RCP 8.5 in purple. The 'noise' level to detect change is marked by yellow horizontal bars, which correspond to the historical 25 and 75 percentiles variability.	49
Figure 26: Climate Change and Vulnerability Storylines for the Southern marshes. (left) change in inflow (vertical axis) versus change in local aridity (horizontal axis); (right) change in inflow (vertical axis) versus change in local heat index (horizontal axis). RCP8.5 (purple) and RCP4.5 (orange) mean estimates for the 25 years centred at 2035 (empty dot), 2050 (filled light dot) and 2085 (filled dark dot). The lines dividing the four quadrants represent no change (0 line).	51
Figure 27: Climate Storyline 1 - Southern Marshes	52
Figure 28: Climate Storyline 2 - Southern Marshes	54
Figure 29: Global mean temperature projections from a climate model (called MAGICC6) relative to a pre-industrial average (1850-1900) for RCP2.6 (blue), RCP4.5 (green), RCP6.0 (yellow) and RCP8.5 (red) and the older SRES scenarios (dashed coloured	

lines). Source: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---representative-concentration-pathways.pdf	63
Figure 30 Ensemble mean rainfall charts under RCP8.5. Source: WGI Chapter 12 of the IPCC AR5 (FIGURE 12.22, P.1078)	64
Figure 31 Precipitation change express in percentage (with respect to the period 1950-2015) under RCP8.5 for an area that includes Iraq. from the IPCC AR6 interactive atlas.....	65
Figure 32: Change in maximum annual number of consecutive dry days by 2085 compared to historical, in the regional climate models (SOMS) selected for RCP8.5 (top row) and RCP4.5 (bottom row).	70
Figure 33: Change in annual average intensity of rain during wet days by 2085 compared to historical, in the regional climate models (SOMS) selected for RCP8.5 (top row) and RCP4.5 (bottom row).	70
Figure 34: Administrative Boundaries of the Agro-Meteorological Network. Source: fig. 1 from the CMU Strategy Guide (Cornforth et al., 2022).....	76

LIST OF TABLES

Table 1: Assignment Task Descriptions for the Climate Risk Assessment	12
Table 2: Proposed Risk Indicators to generate climate storylines.....	15
Table 3: IPCC AR5 global warming increase projections compared to pre-industrial (1850-1900)	19
Table 4: Comparison of WBGT exposure limits for acclimatised workers. Note that Unacclimatised workers would have greater heat expenditures during the same amount of work and temperature. Adapted from Niosh (2016)	25
Table 5: Hazard maps indices.....	27
Table 6: Heat Index in Al Basrah by the end of the 21 st century under RCP4.5 and RCP8.5 emission scenarios.....	36
Table 7: Percentage of men and women employed in Agriculture, Industry and Services. Source: World Bank (2018)	41
Table 8: The increase in global mean surface temperature averaged over 2081-2100 compared to the pre-industrial period (average between 1850-1900) for the RCP pathways (best estimate, 5-95% range). From IPCC AR5 WG1 Table 12.3.....	63
Table 9: Likelihood of rainfall changes from RCP2.6 from the 4 SOMs, and for the Ensemble Upper and Lower Extremes (UE and LE).....	65
Table 10: Temperature-based indices available for each RCP and SOM (CORDEX data).	67
Table 11: Precipitation-based indices available for each RCP and SOM (CORDEX data).....	67
Table 12: Ice and Snow-based indices available for each RCP and SOM (CORDEX data).....	68
Table 13: Wind-based indices available for each RCP and SOM (CORDEX data).....	68
Table 14: Radiation-based indices, sea level pressure and humidity available for each RCP and SOM (CORDEX data).....	68
Table 15: Derived indices (Cordex data).	69

LIST OF BOXES

Box 1: Climate Change Projections: RCPs and SSPs	18
Box 2: Summary of Projected Changes	21

ACKNOWLEDGEMENTS

The team that compiled this report was managed by Rosalind Cornforth. The report was drafted by Rosalind Cornforth, Elena Saggiaro, Rob Wilby, Celia Petty, Harley Pope, Elena Tarnavsky (Walker Institute), reviewed by Christine Wissink and issued by Simon Dale-Lace (Wood) from the project team. Additional written background notes and input were provided during virtual consultations on 21st October 2021 for the proposed Iraq Climate Modelling Unit by Qais Al-Yasiri (UNEP), Mohammed Angawi (UNEP), the Ministry of Health and Environment (MoHE) and the General Authority for Meteorology and Seismic Monitoring (or Iraqi Meteorology and Seismology Organisation; IMSO). Additional key Iraqi stakeholders included the National Adaptation Planning (NAP) management team, and onwards engagement with the MoHE during the risk assessment (see Institutional Engagement Plan; Cornforth et al., 2022).

The Project Team is grateful to Dr. Tristan Hauser (Wood) for his help in sourcing data, producing the hazard maps and providing further support to the analysis of climate hazard indices, and to Oli Thomas, Dr Niek Goorman and Dr. Neil Thurston (Wood) for support on sourcing exposure data.

The team would also like to thank Dr. Diar Hassan (Wood), Dr. Mike Harrison, Prof. Stephan Harrison, and Prof. Matt Wilson (CCRM) for their inputs on the selection and interpretation of climate indices for the hazard maps, the gulf and marshes eco-regions and the SOM analysis.

The project team is also grateful for the endorsement of the proposed actions provided in this report by UNEP and for the ideas and guidance provided by Sahar Hussein also from the of Ministry of Health and Environment in Iraq.

Finally, the team would like to thank UNEP and The Government of Iraq for the funding of this task through the Green Climate Fund “Building Capacity to Advance National Adaptation Plan (NAP) Process in Iraq” project under the ‘Provision of Consultancy Services Related to Producing Climate Change Scenarios and Risk assessments for Asia- Pacific’ programme (Contract No. UNEP/2019/008 (4700016597)).

ABBREVIATIONS

ABBREVIATION	DEFINITION
AR5	IPCC 5 th Assessment Report
AR6	IPCC 6 th Assessment Report
CMIP5	WCRP Coupled Model Intercomparison Project - Phase 5
CMIP6	WCRP Coupled Model Intercomparison Project - Phase 6
CMU	Iraq Climate Modelling Unit
COE	Centre of Excellence
COP	Communities of Practice
COP	UNFCCC Conference of the Parties
GCM	Global Circulation Model
GHG	Greenhouse gas
GIS	Geographic Information System
HI	Heat Index
IMSO	General Authority for Meteorology and Seismic Monitoring
IPCC	Intergovernmental Panel on Climate Change
JCMC	Joint Coordination and Monitoring Centre
MOA	Ministry of Agriculture
MOHE	Ministry of Health and Environment
NAP	National Adaptation Plan
NCCC	National Committee on Climate Change
NMS	National Meteorological Services
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SLR	Sea Level Rise
SOM	Self-Organising Maps
SSP	Shared Socioeconomic Pathways
T&E	Tigris and Euphrates rivers
TEB	Tigris-Euphrates rivers' Basin
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNOPS	United Nations Office for Project Services
USAID	U.S. Agency for International Development
WB	World Bank
WCRP	World Climate Research Programme
WFP	World Food Programme
WI	Walker Institute
WMO	World Meteorological Organization



1. EXECUTIVE SUMMARY

The overall aim of this assignment was to develop a set of government-endorsed climate risk assessments in first-order climate level risk domains (i.e., directly impacted by natural hazards such as water scarcity, river flooding, agricultural productivity, heat-related extremes), and second-order risk domains (i.e., impacts mediated by first order risks such as socio-economic, health impacts, infrastructure, livestock productivity), identified and prioritised through a stakeholder consultation process.

Establishing early dialogue with the government agencies and national actors was central to this task to improve understanding of climate change projections and their impacts in selected eco-regions of Iraq, specifically the Southern Marshes eco-region and the Persian Gulf and Shatt Al-Arab eco-region. The main objectives were to:

- To provide Iraq decision-makers with impact analyses and data to incorporate in their decision-making processes;
- To equip Iraq in identifying and planning for technical support activities; and
- To support multi-sectoral cooperation to formulate and implement the NAP process.

This technical report may serve as the analytical underpinning for ongoing discussions taking place within the Iraq government, including the Ministries of Health and Environment and the Iraq General Authority for Meteorology and Seismic Monitoring (IMSO) of the Ministry of Transport, on how to best move forward in building climate resilience to climate change.

In the report, we have described the observed changes in Iraq's climate since 1950 and projected future changes with a specific focus on the two eco-regions. Current and potential future impacts on water resources, agriculture, and human health were analysed from grey and published literature. National climate hazard maps have been developed to geographically visualise the changes in exposure to different natural hazards, in terms of magnitude and/or frequency. Four indicators of potential climate impact were developed for the Persian Gulf and Shatt Al-Arab eco-region, and three indicators for the Southern Marshes. The indicators were then used to characterise two plausible climate storylines for both eco-regions.

For the climate hazard indicators, downscaled climate indices were produced and adapted to the geographical area corresponding to the two eco-regions. Two global greenhouse gas (GHG) emission scenarios were considered (medium RCP4.5 and high-end RCP8.5) to span the range of possible levels of climate hazard for Iraq. RCP stands for representative concentration pathways (see Box 1 Table 3). Short term (2035), medium term (2050) and long term (2085) hazard levels were considered. However, the metrics used here are globally consistent and serve only as *indicators* of the effects of climate change rather than locally relevant projections of specific design or planning measures. The final set of indicators was adjusted in line with discussions with Iraqi government stakeholders, in accordance with the Institutional Engagement Plan (see Cornforth, et al., 2022a). For the exposure indicators, data drawn from grey and published literature and/or local experts were used for this initial assessment.

The primary climate risk factors for **the Persian Gulf and the Shatt Al-Arab eco-region** in Southern Iraq are likely to be from extreme heat/humidity, combined with changes in extreme rainfall as well as the threat posed by sea level rise and related saltwater intrusion. Two primary climate storylines (i.e., **‘Warm (hot)-humid and more extreme precipitation’** and **‘warm (hot)-humid and less extreme precipitation’**) were then used to evaluate impacts on human health, labour capacity, crop yields, flash flooding, and soil/water salinity. With the caveat that only an analysis with hydrological modelling can properly quantify the risk to surface water flooding for the Gulf eco-region since extreme precipitation does not necessarily result in flooding.

The primary climate risk factors in the **Southern Marshes eco-region** are linked to changed water balance, due to hydrological drought affecting inflows and heat/evaporation affecting losses to the atmosphere, as well as the threat posed by sea level rise and related saltwater intrusion. Two climate storylines (i.e., **‘more arid and less upstream recharge’**, and **‘warm (hot)-humid and less upstream recharge’**) were used to evaluate impacts on human health, crop and fisheries productivity, and water security. Given the short duration for the climate risk assessment, the potential changes in upstream regulation of inflows by dams and water diversions were not considered, but these conditions could amplify or dampen the climate storylines evaluated. This would require detailed hydrological modelling to properly quantify the actual change in water balance for the marshes; here they were only approximated with changes in effective precipitation inflow and outflow to give a first assessment of future conditions driven by climate change.

However, it must be recognised that precipitation is a particularly complicated process to model due to the many physical processes that can affect it. These processes tend to be represented in different ways across different models. This leads to some models being less able to simulate the past precipitation (climatology). To address the model biases and make reasonable inferences about the future changes in precipitation, the precipitation changes were compared *to the model’s representation of the past rather than climatology*. This would make a useful focus in the early days of the implementation of the new Climate Modelling Unit (see Appendix B).

Currently, this deep uncertainty cannot be resolved in any other way than by considering each of the different scenarios (storylines) that arise in the models as plausible and, for adaptation planning, considering what impacts these different scenarios may have and if, for example, there are any common strategies to mitigate them. This is one of the key reasons for introducing the different future climate change storylines for Iraq. In essence, each of the climate change storylines are plausible, physically consistent narratives (Shepherd, 2019) of future climate conditions that can be used to explore how biophysical and human systems might respond to climate change with and without adaptation. Here, we use the different storylines of climate change to analyse risks and identify actions that might be taken in the immediate, short, medium and long-term, and the impacts each storyline and set of actions would have.

This work has been constrained by the lack of quantitative data on exposure and the short timeframe for the analysis. Different data sets, parameters and models may be more appropriate at the local scale or may give slightly different quantifications of the impacts of climate change. For example, there are many potential variations of indicators for each eco-region, and the projected impacts are likely to be sensitive to the precise definitions of the climate indices used. This has led to information loss, and the local and time-horizon differences are not discernible. Given this, the climate storylines could only be translated qualitatively into anticipated socio-economic impacts. Future work will be undertaken to quantify these impacts.

With these caveats in mind, the climate risk assessment concluded:

For the Persian Gulf and Shatt Al-Arab River eco-region, the critical changes expected are an increase in hot and humid days (different magnitudes depending on the emissions scenario), and an increase or decrease in local precipitation extremes. The two storylines developed (Climate Storyline 1: ‘warm (hot)-humid and more extreme precipitation’, and Climate Storyline 2: ‘warm (hot)-humid and less extreme precipitation’) reflect a common underlying trend of change with less precipitation upstream and less water in rivers, more dust and sandstorms and a range of sea level rises affecting the coast (as described above).

*For the Southern Marshes eco-region, critical changes expected are likely from a **decrease in water inflow from upstream** of the marshes (different magnitudes not clearly depending on the RCP scenario, likely due to uncertain precipitation changes) with **an increase in aridity levels** (different magnitudes not clearly depending on the RCP scenario, likely due to uncertain precipitation changes), **an increase in hot and humid days** (different magnitudes depending on the RCP scenario). Overall, the two storylines described here (**Climate Storyline 1: 'more arid and less upstream recharge'**, and **Climate Storyline 2: 'warm (hot)-humid and less upstream recharge'**) reflect a common underlying trend of change with less precipitation upstream and less water in rivers, and a more arid climate driven by higher temperature and higher evapotranspiration but also with increasing numbers of hot and humid days. Note that these storylines are not mutually exclusive. In addition, different ranges of sea level rises will also affect the Southern Marshes.*

Whilst the ultimate objective is a robust integration of first- and second-order climate level risks into the Iraq NAP, in the short term (the duration of this assignment and these specific tasks), it is anticipated that this analysis can be used to support and encourage engagement of the governorates with climate risks within the NAP development window of opportunity. Further refinement and closure of the adaptation knowledge gaps that still exist can be achieved through the long-term operationalisation of the proposed Iraq Climate Modelling Unit and strong partnerships between the IMSO and the higher education institutions. The reader is referred to the [Climate Modelling Unit Strategy Guide](#) (Cornforth et al., 2022b) and the recommendations therein, that link back to the results presented here. For ease of reference, these are reproduced here in Appendix G.

2. REPORT OBJECTIVES

This report aims to assist Iraq in understanding the specific challenges and adaptation options posed by climate change. The report presents first- and second-order climate level risks, informed by stakeholder input, to build climate resilience in both eco-regions. The objectives of this were:

- (1) to engage with Iraq decision-makers in a participatory way to improve the understanding of climate change projections and impacts in selected eco-regions of Iraq, specifically (i) the Southern Marshes eco region, and (ii) the Persian Gulf and Shatt Al-Arab eco-region;
- (2) to provide Iraq decision-makers with impact analyses and data to incorporate in their decision-making processes; and
- (3) to equip Iraq in identifying and planning for technical support activities and multi-sectoral cooperation to formulate and implement the NAP process.

Therefore, this technical report may serve as the analytical underpinning for ongoing discussions taking place within the Iraq government, including the Ministries of Health and Environment and the Iraq General Authority for Meteorology and Seismic Monitoring (IMSO) of the Ministry of Transport, on how to best move forward in building climate resilience to climate change.

3. TASK OVERVIEW

The approach adopted for the climate risk assessments represents the combined output of a formalised research approach together with expert input based on the substantive, and collective experience of the authors and contributors. They have interacted for many years with a wide range of projects addressing the challenges of both current climate variability, as well as future climate change impacts. They have undertaken this in a wide range of locations including Sub-Saharan Africa and South Asia, partnering with local institutions, and providing extensive training and support to researchers to enable them to acquire the scientific skills required to undertake such research.

Where possible, the approach has been aligned to good practice adopted by the wider community of UN stakeholders (Figure 1) in supporting National Adaptation Planning for other countries and linked UNFCCC programmes (e.g., UNFCCC Nairobi Work Programme “knowledge-to-action” approach¹) that similarly aimed to engender ownership of the process and results (see Section ‘

Consultation Approach’).

A key outcome was the development of a set of climate risk assessments in first-order risk domains endorsed by the government through stakeholder consultation with users of climate risk assessment. An overview of the tasks for this assessment is provided in Table 1.

Whilst the ultimate objective is a robust integration of first- and second-order climate level risks into the Iraq NAP, in the short term (the duration of this project and these specific tasks), the output will aim to encourage engagement of the governorates with climate risks within the NAP development window of opportunity.

Given the limited availability of data and short timescales of this assignment, bespoke climate impact information for each eco-region will not be produced beyond the summary information described in Table 1. Instead, a more robust and integrated overview at the national scale will be delivered as part of further assignments focusing on an analysis of adaptation options based on a more detailed socio-economic appraisal to inform the NAP processes. This planned work will continue to be demand-led with more sustained and bespoke support made available, with more detailed climate risk narratives and impact assessments produced building on the preliminary analysis described in this report.

¹UNFCCC Nairobi Work Programme <https://www4.unfccc.int/sites/NWPStaging/Pages/NWP-knowledge-resources.aspx>. Accessed 28 February 2022.

TABLE 1: ASSIGNMENT TASK DESCRIPTIONS FOR THE CLIMATE RISK ASSESSMENT

UNEP Task	Description	Lead/support
Task 3.1	Data review and documentation of climate hazards, exposure and vulnerability: Document current and future climate risks for Iraq from existing published information, including the two eco-regions. Provide national climate hazard maps based on generalised hazard thresholds and frequency statistics appropriate to support the NAP.	Walker on the literature review, Wood and CCRM on the hazard maps
Task 3.2	Production of up to four climate indicators for each eco-region with analysis of their trends in the short (2035), medium (2050) and longer term (2085)	Walker lead with support from Wood and CCRM
Task 4.1	Constructing two climate change and vulnerability storylines for each eco-region . The storylines are intended to summarise the uncertainty space described by the climate hazard indicators into few future scenarios, for which socio-economic impacts will be discussed.	Walker
Task 4.2	Translating the storylines into anticipated socio-economic impacts . This work provides linkages between the produced climate risk information and adaptation options to address identified risks for the NAP, highlighting sectoral priorities where possible. This framing does not involve detailed analysis of how the Iraqi government can address risks due to the short timescales for Tasks 3 and 4, but rather “sign-post” key points to consider linking identified climate risks to their respective NAP.	Walker

4. CONSULTATION APPROACH

Responding to Iraq’s Adaptation Knowledge Needs through Consultation and Partnerships

The climate risk assessments in first-order risk domains were informed through the engagement process outlined in the Institutional Engagement Strategy (Cornforth et al., 2022a) which included co-development of the implementation plan for the proposed Climate Modelling Unit for Iraq’ (Cornforth et al., 2022b) with key Iraqi stakeholders. These stakeholders were selected for their insight and high-level responsibility in relevant areas, including climate change adaptation, disaster risk reduction, gender and social inclusion, natural resource management and humanitarian response and recovery. It is expected that these key stakeholders will also be closely involved in the operationalisation of the Climate Modelling Unit which will be implemented by the Ministry of Environment as the official body responsible for following up on climate change issues and disaster risk reduction in the National Centre for Climate Change (NCCC) / Division of Vulnerability Assessment and Adaptation Measures, in cooperation and joint coordination with the Ministry of Transport / General Authority for Meteorology and Seismic Monitoring, as the official body responsible for weather data and meteorology.

The “*knowledge-to-action*” approach for gathering stakeholder views on existing gaps in existing climate modelling capacity, the climate risk assessments and the mandate and operational model of the proposed Climate Modelling Unit, involved a novel interview protocol that directly aligned to the WMO standard for development planning and the Enabling Environmental Framework for Action (EFFA). The organization and implementation of these interviews was through a national consultant. However, due to the impact of Covid-19, these were limited in number and although the preliminary interviews identified the preliminary obstacles that various climate institutions, further consultations were required. There was a need for deeper engagement with critical stakeholders in key sectors to ensure ongoing alignment of the NAP activities with national needs.

These were conducted during the technical consultation workshop in September 2021, which linked into the CMU Consultation Methodology and highlighted the criticality of sustaining meaningful dialogue between the Governorates, and academic institutions.

The stepwise consultation “*knowledge-to-action*” methodology adopted comprised the basic components shown in Figure 1, (as identified by the UNFCCC e.g., Nairobi Work Programme) with the culmination of the consultation involving the government officials, stakeholders and scientific communities, informing the development of the climate risk in first order and second-order climate risk domains.

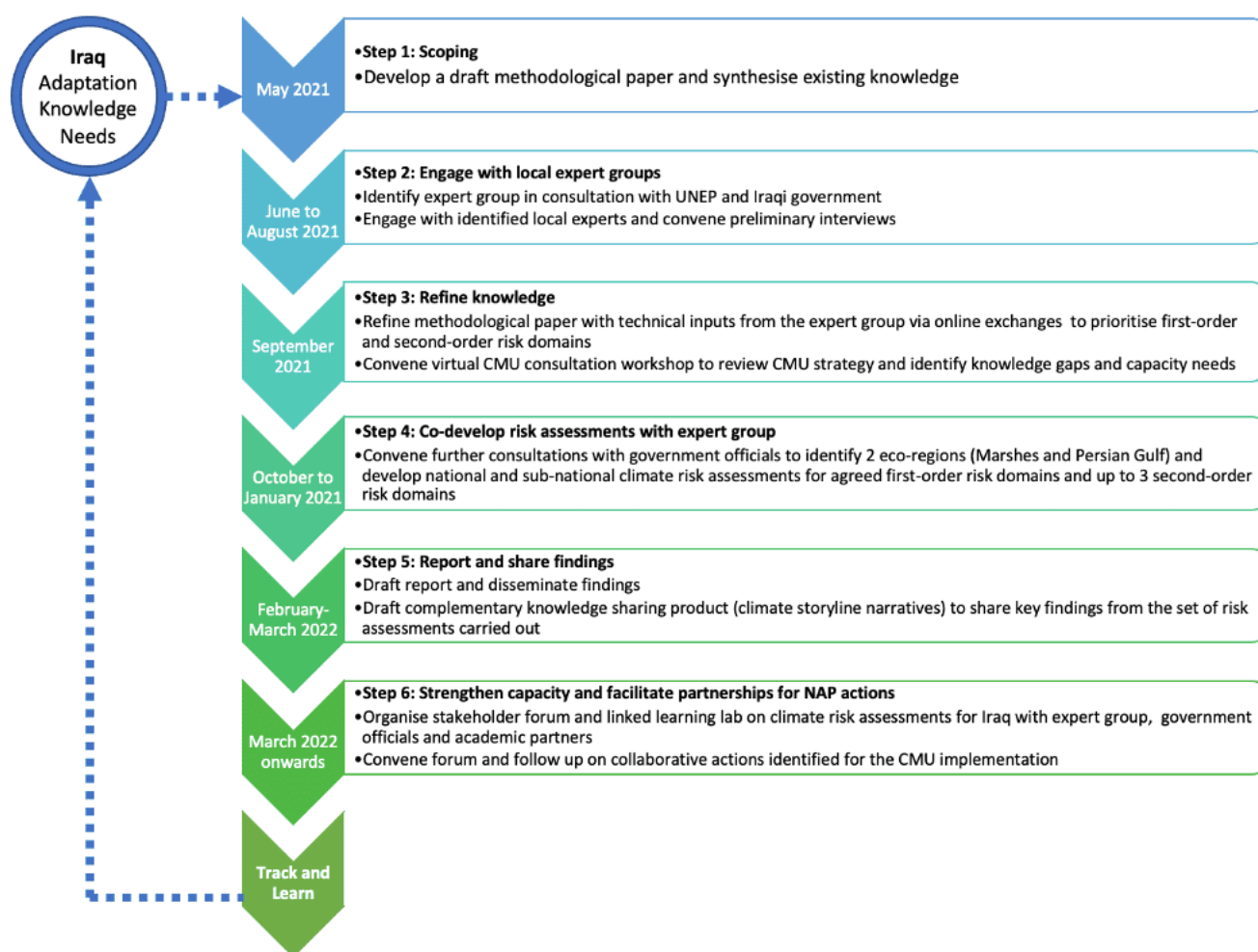


FIGURE 1: INSTITUTIONAL ENGAGEMENT PLAN FOR IRAQ CLIMATE RISK ASSESSMENTS. ADAPTED FROM UNFCCC NAIROBI WORK PLAN, FCCC/SBSTA/2021/INF.2

Defining knowledge needs: review, compilation, validation and refinement of adaptation knowledge needs (as specified by Iraq stakeholders) and formulation into questions that partners, and experts can respond to;

- Scoping:** Review and synthesis of existing adaptation knowledge and knowledge needs; using inputs such as authoritative reports (e.g., latest IPCC reports) and peer-reviewed literature to ensure that associated actions are demand driven from the outset; and exploration of linkages with work of the UNEP and Iraqi institutional structures.
- Engaging with expert groups:** Identification of relevant experts and institutions, and the establishment of a diverse and inclusive expert group to inform the climate risk assessments and co-develop the long-term strategic operation of the Iraq CMU and forward partnerships.
- Refining knowledge:** Identification of priority knowledge gaps and first order and second-order risk domains, in partnership with the Iraqi government and expert groups, and exploration of further opportunities to share the knowledge gaps with the government, experts and institutions with knowledge gaps and needs are further refined based on feedback.
- Co-designing actions:** Co-development of NAP actions with the expert groups, partners and/or government agencies to address knowledge needs and enhance national, regional, and local adaptation actions and capacity.
- Reporting and disseminating findings:** Dissemination and sharing of risk assessments into usable formats for Iraqi government officials, scientific communities, and the public.
- Facilitating collaboration and partnerships:** Foster and strengthen partnerships between the expert groups and other stakeholders including the government agencies and academic communities to mobilize support for implementing NAP actions and to close knowledge gaps, while facilitating collaboration among the expert groups to sustain the proposed CMU.
- Implementing actions:** Implement actions in partnership to close existing knowledge gaps.
- Tracking and learning:** In partnership with the expert groups, document and reports outcomes of the risk assessments and actions undertaken to close knowledge gaps, sharing lessons learned and updating knowledge needs to improve future research interventions and NAP activities.

Engagement and Co-development of the Climate Risk Assessments in First Order and Second-Order Risk Domains

To kickstart the knowledge-to-action process, an identified expert group was established in May 2021, which comprised the policy advisers and government officials, and researchers representing the key institutions listed in the Introduction, facilitated by the Ministry of Health and Environment.

The expert group provided inputs to the methodological paper and identified the eco-regions of interest, as well as capacity gaps and climate modelling needs for the CMU (See Task 6 and Strategy Guide). The expert group identified will continue to collaborate in developing and participating in the Stakeholder Forum and Learning Lab as well as future actions for refining and closing adaptation knowledge gaps through the long-term operationalisation of the Iraq Climate Modelling Unit.

A successful interactive virtual stakeholder consultation meeting was held in September 2021 with the local expert group. Here challenges, knowledge gaps, needs and action regarding adaptation in Iraq were discussed and the strategy and implementation plan for the Iraq Climate Modelling Unit were reviewed. The Strategy guide referred to above synthesized the challenges and knowledge gaps, including those in relation to data and methods, capacity and governance and cross-cutting gaps, based on the discussions at this meeting, the subsequent online exchanges, and through a review of national reports and peer-reviewed literature. Online exchanges continued with government officials as the set of climate risk assessments in up to 4 first-order risk domains were generated for the two identified eco-regions.

In June 2022, a Stakeholder forum and Learning Lab will be held to share the key findings from the climate risk assessments and target several specific capacity building needs. Following this, final reports will be published, and forward actions will be followed up, noting that the model for working with the Governorates and academic partners and strong communication flows will be a key determinant in the successful operation of the Iraq CMU.

5. APPROACH TO THE CLIMATE RISK ASSESSMENTS

Methodology

Production of climate impact indicators for each eco-region

Up to four indicators of potential climate impact were developed for each of the two eco-regions. The indicators were used to characterise the climate storylines.

For the climate hazard indicators, downscaled climate indices produced through previous assignments were used. The indicators were adapted to the geographical area corresponding to the two eco-regions. Two global GHG emission scenarios were considered (medium-end RCP4.5 and high-end RCP8.5) to span the range of possible levels of climate hazard for Iraq. Short term (2035), medium term (2050) and long term (2085) hazard levels were considered.

For the exposure indicators, data drawn from grey and published literature and/or local experts were used for this initial assessment.

Table 5 summarises the indicators of national level hazard that were produced for this assessment. The other proposed indicators of hazard targeted at the impacts relevant for the two eco-regions are summarised in Table 2 below and described in the relevant sections. Note that due to lack of quantitative data on exposure and the short timeframe for this analysis, the potential impacts (last column in Table 2) have been described only qualitatively. Future work will be devoted to quantifying the anticipated socio-economic impacts for the different storylines.

Note that there are many potential variations on indicators for each eco-region, and the projected impacts are likely to be sensitive to the precise definitions of the climate indices used. Different data sets, parameters and models may be more appropriate at the local scale or may give slightly different quantifications of the effects of climate change. However, the metrics used here are globally consistent and serve only as *indicators* of the effects of climate change rather than locally relevant projections of specific design or planning measures. The final set of indicators was adjusted in line with discussions with Iraqi government stakeholders, in accordance with the Institutional Engagement Plan (Cornforth et al., 2022a).

TABLE 2: PROPOSED RISK INDICATORS TO GENERATE CLIMATE STORYLINES

	Risk	Indicator of climate hazard	Indicator of exposure	Potential climate impact
Eco-region 1: Iraqi coasts of the Persian Gulf and Shatt al-Arab, including the city of Basra.				
Heat extremes				
Hot-humid extremes	Labour productivity and public health	Annual number of days with heat index (HI) above 32°C or 41°C	Working population (e.g., number of people between 20 and 65) Vulnerable population (elderly, children)	Working age population exposed to an unworkable spell Vulnerable population exposed to heat stress
Flooding				
Sea-level rise	Loss of land, soil and water salinisation	Area exposed to sea-level rise	Number of people/buildings/transport infrastructure/agriculture land in coastal hazard zone	People/buildings/transport infrastructure/agriculture land exposed to sea-level rise by end of the century
Extreme precipitation	Loss of lives, damage to property and infrastructure	Area exposed to extreme precipitation that may lead to surface water flooding ²	Number of people/critical infrastructure in potential flood hazard zone	People/infrastructure affected by extreme precipitation that may lead to surface water flooding
Eco-region 2: Iraqi Southern Marshes: Eastern Central and Al Hammar Marshes, north-western and southern fringes of the transboundary Hawr Al Hawizeh Marsh				
Water levels				
Water balance	Change in runoff and recharge of marshes	Change of water inflow and outflow into the marshes ³	Area of marshland used for agriculture and fisheries	Less productive agricultural land and fisheries due to drying out of the marshes Loss of habitat for biodiversity due to unregulated flow into the marshes
Heat impact	Change in evaporation from marshes	Change in aridity Index for marshes	Area of marshland used for agriculture and fisheries	Less productive agricultural land and fisheries due to local aridity change Decline in water quality

² Only an analysis with detailed hydrological modelling can properly quantify the risk to surface water flooding for the Persian Gulf and Shatt Al-Arab eco-region, since extreme precipitation does not necessarily result in flooding. This is explained in detail in Section Climate Change Scenarios for Persian Gulf and Shatt Al-Arab Region.

³ Only an analysis with detailed hydrological modelling can properly quantify the actual change in water balance for the marshes, here only approximated with change in effective precipitation inflow and outflow. This is explained in detail in Section Climate Change Scenarios for The Southern Marshes.

Development of Climate Storylines and Application to Decision Making Contexts

This task brought together summary information on current and future climate risks and interpretation of the new impact indicators for each eco-region connecting and validating it with wider existing information.

The impacts on socio-economic sectors were analysed at a high-level through the introduction of the possible future climate storylines for each eco-region. To account meaningfully for the range of possible future emission scenarios (e.g., affecting global mean temperature) and the uncertainty in projections of regional circulation change (e.g., affecting local precipitation change), several climate storylines for each eco-region were constructed. Climate change storylines provide plausible descriptions of future climate conditions in a synthesised form that can be used to translate complex global-scale projections to practical local-scale impacts. Each storyline is analysed in terms of its impacts on up to three socio-economic sectors, selected through expert judgment and through consultations with national stakeholders.

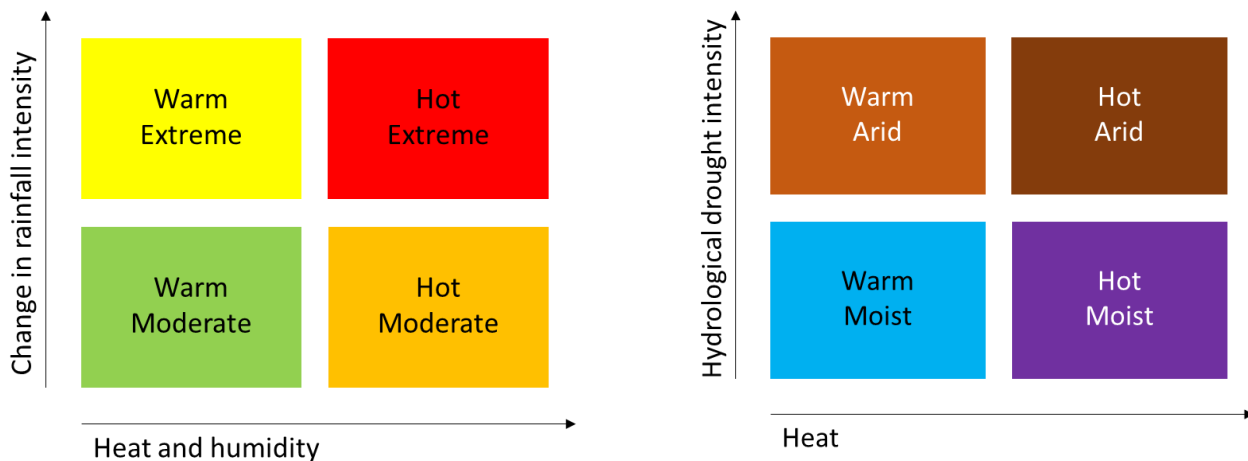


FIGURE 2: INDICATIVE STORYLINES FOR (LEFT) BASRA AND THE SHATT AL-ARAB REGION; AND (RIGHT) THE SOUTHERN MARSHLANDS. THESE QUADRANTS WERE REFINED ONCE THE RESULTS OF THE CLIMATE RISK ASSESSMENT WERE COMPLETE (SEE P.38 CLIMATE CHANGE SCENARIOS FOR PERSIAN GULF AND SHATT AL-ARAB REGION AND P.50 FOR THE CLIMATE STORYLINES FOR THE SOUTHERN MARSHES).

Storylines for the two eco-regions in Iraq were generated following the approach adopted by the Netherlands for their national scenarios (KNMI, 2015). Large numbers of climate model projections and variables are distilled into a small number (four) of consistent descriptions of most relevant climate information for evaluating potential risks and adaptation measures. These conditions are expressed by two major axes describing future changes in for example, global temperature (and associated sea levels) combined with future changes in atmospheric circulation (and associated storminess/ rainfall). For the Basra and the Shatt al-Arab region (Figure 2, left) and the marshlands (Figure 2, right), two climate dimensions were chosen such that they:

- (i) Represent most of the expected changes in the local climate, and
- (ii) Connect with the resulting socio-economic impact of interest.

The revised Persian Gulf storylines and Southern Marshes can be found in the relevant sections on p.38 and p.50 respectively.

Assumptions and Limitations

The assumption behind using climate projections to estimate future risk relies on the ability of the climate model to represent correctly all the many processes that determine the climate, its variability and change under forcing such as greenhouse gas emissions. This is a very challenging task that climate models can satisfy to different extents.

One way to gauge if a climate model is realistic is to use it to reproduce the past, for example the late 20th century, for which we have good observations. It is well known that climate models can struggle to reproduce the behaviour of specific climate variables, especially precipitation, especially for some regions of the globe. Precipitation is a particularly complicated process to model due to the many components that can affect it, some of which are described differently across models. As a result, some models cannot reproduce the past precipitation climatology satisfactorily (climatology means the average behaviour, for example quantified as mean total precipitation in a given month of the year). In the present analysis, we have looked at how

each of the models selected for downscaling compares to a reanalysis dataset (ERA5, a proxy for observations⁴) and found that most models struggle to reproduce the peak in precipitation in January in various regions of Iraq. The appropriate way to handle these biases, and still make reasonable inferences about the future changes in precipitation, is to quantify *the change compared to the model's representation of the past*. This approach was followed in downscaling climate projections for Iraq where precipitation changes are expressed as percent change from the historical period 1986 to 2005. This assignment follows the same approach by looking at changes and not interpreting the projected absolute values. However, even so there are some models that show a very unrealistic high precipitation across the region, for example model S3 in emission scenario RCP8.5. This is one of the three regional climate models used to describe the range of potential future regional climate under emission scenario RCP8.5 (models are labelled S1, S2 and S3) (see Section Data and Information Sources). The authors regard the projections of RCP8.5 S3 model as very uncertain and assign low confidence to it.

Note that climate models are not perfect. They necessarily involve approximations, particularly related to small-scale processes that cannot be simulated directly because of limited computer power and insufficient observations. How clouds are represented in climate models is a particular challenge because this involves a wide range of processes and different space and time scales. Predictions from different models are qualitatively similar on large scale changes but can differ considerably in magnitude and regional detail. For example, it is a well-known issue that not all climate models project the same *change* in precipitation (regardless of the starting point) in all parts of the world. For example, while a drying in the Mediterranean region is seen in most of models, the change in precipitation over the Arab peninsula can be positive and negative for different models. Currently, this deep uncertainty cannot be resolved other than considering these different scenarios as plausible. In the context of planning for adaptation, this results in considering which effects these different scenarios may have and if, for example, there are common strategies to mitigate their impacts. This is one of the key reasons for introducing storylines of future climate for Iraq.

6. DATA AND INFORMATION SOURCES

Two future emission scenarios, called RCPs (see Box 1 and Table 3), were considered as agreed in consultations with the Ministry of Environment: RCP4.5 (moderate emissions) and RCP8.5 (high emissions). According to the IPCC 5th Assessment Report, RCP4.5 will see global mean temperature increase that are more likely than not to exceed 2°C (likely range 1.7°C - 3.2°C) by the end of the century compared to pre-industrial times (1850-1900) (IPCC, 2013). RCP4.5 thus misses the targets of the Paris Agreement of stabilising temperatures 'well below 2°C'.⁵ RCP8.5 represents an unmitigated emissions scenario and is currently considered a conservative scenario and unlikely in practice due to too high and unrealistic emission pathways. However, given corresponding high warming may be achieved via other mechanism, such as climate feedbacks and tipping points, RCP8.5 was considered as useful in terms of understanding the higher range of possible change in the climate. Practically, RCP8.5 is also useful to detect and understand the climate change signal as its high forcing makes it emerge more clearly above confounding factors like interannual and decadal variability. We note that RCP2.6 is the scenario projecting a maximum temperature increase compatible with around +2.0°C by the end of the century and therefore less climate change impacts. However, RCP2.6 is also associated with relatively rapid emission reductions, reaching net-zero in the second half of the century, which can be argued to be too optimistic for adaptation planning. For these reasons, RCP4.5 and RCP8.5 are regarded as the most relevant RCPs to analyse for adaptation planning in the coming decades. Finally, note that the emission scenario in line with the Paris Agreement is SSP1-1.9 (radiative forcing of 1.9 W/m² by 2100) which sees a very rapid emission reduction reaching net-zero by 2050 and negative emissions later.

The primary data used in this analysis is from the set CORDEX regional climate models (RCMs) that were selected in Task 2 via a statistical downscaling technique, called self-organising maps (SOMs), applied to CMIP5 global climate models. In summary, SOMs were used to identify a small but representative number of possible future climates for Iraq within the large spread of projections that CMIP5 encompass. Each SOM represents a possible future for Iraq in terms of local rainfall and temperature changes. Once identified, the SOMs were used to select the CORDEX RCMs that looked most similar to them in terms of

⁴ Note reanalysis data, such as ERA5, are a combination of observations and model simulation, hence despite their overall good accuracy they still have uncertainty and may not represent the actual ground truth, especially in regions where observations are sparse.

⁵ The latest IPCC 6th Assessment Report (IPCC, 2021) uses Shared Socioeconomic Pathways (SSPs, see Box 1) which can be mapped approximately onto RCPs: the SSP2-4.5 projects a slightly higher very likely range of temperature increase of 2.1-3.5°C compared to pre-industrial, due mostly to higher climate sensitivity.

precipitation and temperature change. This process is what we refer to as downscaling since the RCMs have a much finer representation of the climate compared to the GCMs, in terms of temporal and spatial resolution (see Technical Note: Downscaling projections for Iraq). The total number of SOMs (and associated RCMs) for RCP4.5 is 2 (called S1 and S2) and for RCP8.5 is 3 (called S1, S2, S3). Note that there are two additional SOMs, called LE and UE, which are 'extreme' scenarios with respect to their projections for Central Iraq, as described in the above-mentioned Technical Note. These models will only be shown in the storylines mapping of Figure 19 and

Figure 26.

Further background information about the SOMs approach, and the reasons for probabilistic projections, some of which included increased rainfall, is included in Appendix B.

BOX 1: CLIMATE CHANGE PROJECTIONS: RCPS AND SSPS

Climate Change Projections: RCPs and SSPs

The degree of changes to the global and regional climate will depend on future cumulative global greenhouse gases (GHG) emissions levels. These emission scenarios have been modelled by the scientific community with four representative concentration pathways (RCP, Appendix A), spanning a broad range of GHG forcing by the year 2100 (radiative forcing level of 2.6, 4.5, 6.0, and 8.5 W/m²). RCPs are used in the IPCC 5th Assessment Report (AR5). More recently, RCPs have been complemented with shared socioeconomic pathways (SSP) which are introduced in the IPCC 6th Assessment Report (AR6). SSPs include socioeconomic factors that may change over the next century, such as population, economic growth, education, urbanisation, and the rate of technological development. SSPs can be approximately mapped onto RCPs looking at the approximate radiative forcings level they project by the end of the century. In this work we use RCPs.

Following the downscaling, a range of climate indices (~30) were identified with progressive rounds of peer review and consultation with regional stakeholders to identify a comprehensive, but manageable, list of climate indices that reflect the project requirements and resource constraints. Their list can be found in Appendix C.

A sub-selection of the most useful indices for the analysis carried out in the present was performed via internal expert discussion across Wood, CCRM and the Walker Institute teams, as well as in consultation with the UNEP office in Iraq and the Iraqi Ministry of Environment. Where indices were not directly available from CORDEX data, derived indices have been produced. The criteria used were to identify indices that can be easily linked to potential impacts on people and ecosystems. The indices will be introduced in following sections of this report.

For sea level rise (SLR) projections, data used in the IPCC 6th Assessment report have been sourced from NASA's SLR tool website⁶, since the most recent set of global climate models became available by the time this analysis started. Elevation data to evaluate the area potentially affected by SLR is NOAA digital elevation model⁷ (Fox-Kemper et al., 2021, Garner et al., 2021). Note that SLR projections can be grouped into *medium confidence* and *low confidence*. The term medium confidence considers only processes for which projections can be made with at least medium confidence. On the other hand, the low confidence scenario, includes the additional potential impact of deeply uncertain ice sheet processes involving especially the Greenland and Antarctic ice sheets, but is worth being aware of since this can have a disruptive impact on coastal areas.

Exposure data presented here are population, settlements location, marsh areas and Tigris and Euphrates rivers catchment boundaries. The population dataset is downloaded from WorldPop⁸ (Bondarenko M., 2020). The data has a resolution of 3 arc seconds (approximately 100m at the equator). The units are number of people per pixel with country totals adjusted to match the corresponding official United Nations population estimates that have been prepared by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. The settlement location is available on the Human Data Exchange portal, an OCHA Service⁹. The area of the Southern Marshes is taken from the World Database of Protected

6 <https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool>

7 NOAA National Geophysical Data Center. 2009: ETOPO1 1 Arc-Minute Global Relief Model. NOAA National Centers for Environmental Information. Accessed February 2022. <https://ngdc.noaa.gov/mgg/global/global.html>

8 <https://www.worldpop.org/geodata/summary?id=49994>. Accessed February 2022.

9 <https://data.humdata.org/dataset/0c92944d-a6dd-4d08-a101-74ba1c2e3429>. Accessed February 2022.

Aeras¹⁰ (UNEP-WCMC, 2022). The Tigris and Euphrates (T&E) rivers catchment boundaries are from the WWF HydroBASINS database (Lehner, 2013).

Scenario	2046–2065 Mean (likely range ¹¹)	2081–2100 Mean (likely range)
RCP2.6	+1.6 °C (1.0 to 2.2)	+1.6 °C (0.9 to 2.3)
RCP4.5	+2.0 °C (1.5 to 2.6)	+2.4 °C (1.7 to 3.2)
RCP8.5	+2.6 °C (2.0 to 3.2)	+4.3 °C (3.2 to 4.4)

TABLE 3: IPCC AR5 GLOBAL WARMING INCREASE PROJECTIONS COMPARED TO PRE-INDUSTRIAL (1850-1900) ¹²

7. CURRENT AND FUTURE CLIMATE RISK FOR IRAQ

Iraq's climate can be characterised by three climatic zones, primarily related to rainfall which is a very seasonal phenomenon. In the west, a largely uninhabited and extremely arid lowland desert, with temperature that range from very hot to sub-zero degrees, and little to no rain. A subtropical semi-arid steppe, which includes the region of Baghdad, with very hot summer (26-46°C daily temperatures), annual rainfall ranging 200 to 400 mm from November to February. The north and north-eastern, mountainous regions have a Mediterranean climate which is wetter than the steppe (400-1,000 mm/year from November to April) but not much cooler temperatures. The country generally experiences winters that vary between cool and cold, and summers are dry with variations between hot and extremely hot temperatures. The climate is also influenced by South and South-easterly Sharqi, which are dry dust winds that impact the country from April to June and September to November. The North, Northwest Shamal Winds also impact the climate, leading to extensive surface heating. High evaporation, especially in desert is of about 2,100 mm/year (Ministry of Foreign Affairs of the Netherlands, 2018; USAID, 2017; World Bank, 2022).

A focus on the eco-region climates (Southern Marshes and Persian Gulf) is found at the beginning of dedicated sections.

Currently, about half of Iraq's total cultivated area is rainfed and is concentrated in the north-eastern plains and mountain valleys, which is reliant on rainfall to sustain agriculture through surface and groundwater use. Conversely, the remainder of Iraq's agriculture lands in the valleys of the Tigris and Euphrates rivers (T&E) experience significantly less rainfall and instead relies on surface water diverted from the two rivers for irrigation (Adamo et al. 2018). Groundwater is about 7% of water resources of Iraq (Iraq communication to the UNFCCC, 2016). Both the T&E are fed by melting snow and rain in southern-eastern Turkey, north-eastern Syria, north-western Iran and northeast and east of Iraq. Peak river discharges occur in March and in May, with annual flows being highly variable, with some years resulting in destructive flooding and in other years low flows which make irrigation and agriculture more difficult.

Observed Changes Since 1950s

Temperature

Mean annual temperature has increased at a rate of approximately 0.7°C per century. The number of cool nights and days are also significantly decreasing, accompanied by a trend in increasing minimum and maximum temperature (ESCWA, 2017).

¹⁰ <https://www.protectedplanet.net/903064> Accessed February 2022.

¹¹ Likely range calculated from projections as 5–95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models.

¹² From Table SPM-2 adjusted of +0.61°C to bring to pre-industrial reference period 1850-1900, in: (IPCC, 2013, p. 12)

Rainfall

Observed annual and winter precipitation changes averaged across all Iraq show a decreasing trend for the period 1971-2020 (Hashim et al., 2022). Annual rainfall has however experienced spatially variable changes and large interannual variability makes it hard to infer robust trends. According to the World Bank climate change knowledge portal for Iraq (World Bank, 2022), for the period 1951 to 2000, the nearest station precipitation records for the northeast of Iraq show an increase of annual rainfall at a rate of 2.4 mm/month per century; while in the southeast it has *decreased* at a rate of 0.88 mm/month per century and in the west has *decreased* at 5.93 mm/month per century.

Sand and Dust Storms

These have increased in frequency of occurrences (Sissakian et al., 2013). Iraq is now a very high potential zone for dust storms, other than in the extreme northeast of the country which is moderate. One of the main reasons behind the development of sand and dust storms is the climatic changes within the region, especially the decrease in the annual rate of rainfall in the west, besides environmental changes, such as drying of the marshes, land degradation, and desertification.

Sea Level Rise

Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm/year between 1901 and 1971, increasing to 1.9 mm/year between 1971 and 2006, and further increasing to 3.7 mm/yr between 2006 and 2018 (IPCC, 2021).

Water Resources

Iraq greatly relies in its water resources on the Tigris and Euphrates rivers (T&E) as a surface water resource, and several productive groundwater aquifers (Foothill, Al-Jazira, Aquifer System, Mandali-Badra-Teeb, Mesopotamian, and Desert Aquifer system). The T&E rivers flow have changed both due to climate change but also, and significantly, due to the construction of dams in the upper part of the catchment and irrigation projects. The change of recorded discharges at stations in both the T&E rivers show a drastic reduction after the 1990s when large dam projects were built (Al-Ansari N. A., 2019). Their level has fallen to less than a third of natural levels¹³. The maximum flow has also changed, from taking place historically during April and May around Baghdad, it has become flatter and flatter since 1990 due to the reduction of flow, largely caused by regulating schemes in Iraq, Iran and Turkey as well as climate change (Al-Ansari N. A., 2019; see also Section Topography, Climate and Hydrology of the Marshes). In terms of extremes, prolonged droughts have been found to be the norm rather than the exception in the Tigris-Euphrates Basin (TEB) over the past four decades (Rateb, 2021).

The decrease in surface water levels and precipitation during the last three decades reflects the drop in the levels of water, reservoirs, lakes, and rivers. The government estimates that its water reserves have been reduced precariously. According to the survey from the Ministry of Water Resources, millions of Iraqi people have experienced a severe shortage of drinking water (Al-Ansari N. S., 2021).

The transboundary nature of the TEB complicates management of water in a water-scarce region. Overall, issues of water scarcity in Iraq today are related to aridity, climate extremes, limited supplies, upstream reservoir storage, rising water demand, and population growth.

Soil

Iraq has experienced significant desertification and soil salination, which was further exacerbated by water drainage and irrigation projects as well as conflict during the 1980s and 1990s. It is believed that the vulnerable marshlands in Iraq have begun to recover since the dissolution of Ba'athist Iraq in 2003. However, in recent years these have been placed at risk of drying out due to intensive dam construction and upstream irrigation schemes (Section Topography, Climate and Hydrology of the Marshes).

¹³ For example, schemes built on the river Tigris have decreased the average monthly discharge of the river according to the records of the Sarai Baghdad gauging station from 1207m³/s (1931 – 1959) to 927m³/s (1960 – 1999) and dropped to 522m³/s (2000-2013), a decrease of more than 60% compared to 1940s levels.

Projected Future Changes

A summary¹⁴ of projected changes (Box 2) is drawn from USAID (2017) and World Bank (2022) national climate reports, as reliable sources for climate information. This section focuses on these two reports in addition to relevant studies carried out by local Iraqi universities and research institutions.

Across the region, climate change will likely manifest as **increased temperatures, reduced rainfall, and more erratic weather patterns, resulting in decreased annual flows in both the T&E rivers** (Adamo et al. 2018). These atmospheric changes have been principally attributed to variations of the North Atlantic Pressure Oscillation (NAO) attributed to climate change. Temperature increases might be less severe should the Paris Agreement be met (RCP2.6 scenario).

BOX 2: SUMMARY OF PROJECTED CHANGES

Summary

- Mean annual temperature: +2°C by 2050 under RCP4.5; +2.5°C under RCP8.5
- More heatwaves and less frost days
- More intense droughts
- Declining precipitation (-9% average annual by 2050, with -17% in DJF which is the wetter time)
- Less sustained rain (maximum amount of rain that falls in any 5-day period is projected to decrease) but higher rainfall intensity
- Less water runoff (-20 % country average)
- Sea level rise and resulting salinization of inland
- Increasing prevalence of dust storms, could go from 100/y today to 300/y in 2030

Precipitation changes projected by the CMIP6 models analysed in the IPCC 6th Assessment report (AR6) shows **drying to the northwest but a wetter climate in the southeast, although there is no statistical significance in these details** (Figure 3). The 'Regional Fact Sheets' of the IPCC AR6 report for the macro region including Iraq states that "annual precipitation totals, intensity, and frequency of heavy precipitation are projected to increase with increasing warming levels. Strong spatiotemporal differences with overall decreasing precipitation are projected in summer with the opposite tendency in winter." However, these statements may be too deterministic and need to be approached accordingly after full consideration of the evidence (see paper Task2 - Projections and Climate Change Scenarios for Iraq). The different projections of trends across models suggest that a 'storyline' approach, as developed later for the two eco-regions, is a more robust and pragmatic approach to deal with this uncertainty.

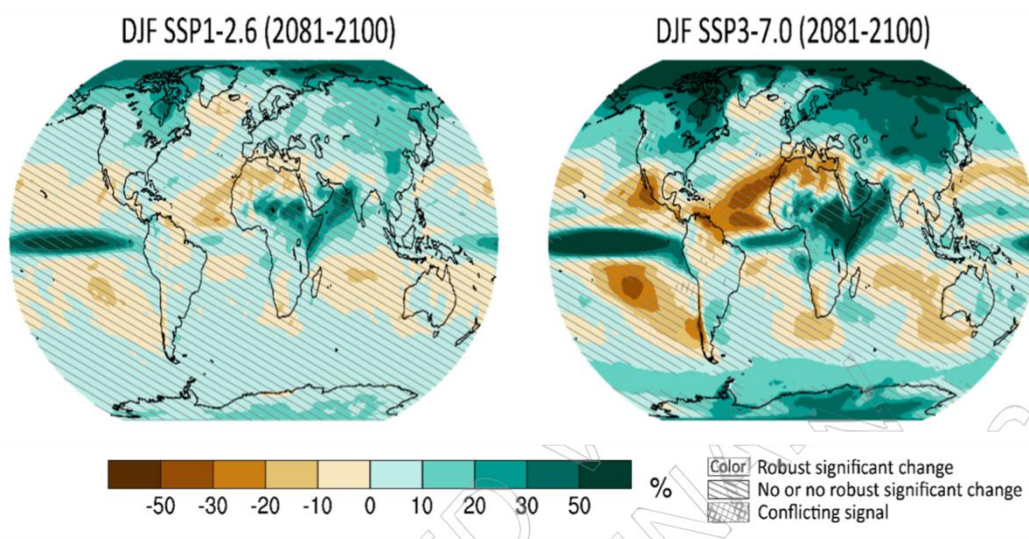


FIGURE 3: CHANGE IN PRECIPITATION BETWEEN DECEMBER AND BY THE END OF CENTURY (FIGURE 4.24 IN IPCC AR6 REPORT, WORKING GROUP 1, CHAPTER 12). NOTE SSP3-7.0 IS CONSIDERED A HIGH EMISSION SCENARIO MORE LIKELY THAN RCP8.5 USED IN AR5. CHANGE IN SIGN ACROSS IRAQ AT BOTH PERIODS ILLUSTRATED IS APPARENT BUT THE HATCHING INDICATES A LACK OF STATISTICAL SIGNIFICANCE THROUGHOUT.

¹⁴ Values are mean change across a number climate models (CMIP5), range of uncertainty although not reported. The uncertainty is generally larger for precipitation changes and smaller for temperature changes.

Downscaled statistical studies try to refine the information of Global Circulation Models (GCM). The maximum temperature increase is suggested to be higher in South Iraq (e.g., Hassan & Hashim (2020) downscaled analysis of HadCM3 and CanESM GCMs). Al-Mukhtar & Qasim (2019) found an overall consistent decreasing trend of precipitation, with RCP8.5 scenario showing the worst trend of annual mean and country mean precipitation reduction and temperature increase (one GCM model, the Canadian CanESM2). Osman et al. (2017) applied a weather generator combined with 7 CGMs forced with SRESA2 (a scenario between RCP6 and RCP8.5) and found that most of the Iraq regions are projected to suffer a reduction in annual mean precipitation by the end of the 21st century, while on a seasonal basis most of the regions are anticipated to be wetter in autumn and winter.

Overall, while the current available climate change projections differ in their potential trends in some sub-regions of Iraq, they generally indicate **a worsening situation for the country and the T&E region, characterised by decreased water availability and loss of vulnerable ecosystems**. Some studies have indicated that water resources across the TEB could decline by as much as 30-70% by the end of the century (Adamo et al., 2018), threatening the very existence of the 'Fertile Crescent'. Other studies resulted in an equivalent discharge reduction of 9.5% by 2040 and 2069, with the largest decline in Turkey (12%) and a much smaller decline in Iraq (4%) (SRES A1B emission scenario, Adamo et al, 2018). Bozkurt et al., (2013) find winter surface temperature rises over the entire TEB for all scenario simulations¹⁵ (especially larger in the highlands) and decrease to the snow water equivalent in the highlands (-55% to -87% for lower and higher emission scenarios). Statistically significant declines are also found for the annual surface runoff of the main headwaters area (25–55%). Importantly, projected annual surface runoff changes in all simulations suggested that the territories of Turkey and Syria within the basin are most vulnerable to climate change, experiencing significant decreases in annual surface runoff. Eventually, however, the downstream countries, notably Iraq, may suffer more as they rely primarily on the water released by the upstream countries.

Global sea level rise is accelerating and will continue to rise over the 21st century and the next millennia even if emissions were stopped today (IPCC, 2021). Under all emission scenarios, the mean sea level rise by 2050 will be of about 0.3-0.4m relative to 1995–2014. After 2050, the difference between emission pathways will be seen more clearly: the likely global mean sea level rise by 2100 is 0.44–0.76 m under the intermediate GHG emissions scenario (SSP2-4.5); and 0.63–1.01 m under the very high GHG emissions scenario (SSP5-8.5). In the next 50-80 years, the effect of these projected changes in sea level in Iraq will almost certainly affect the areas directly on the Persian Gulf coast but could reach inland to Basra and the Southern marshes, especially if sea level rise of about 1m is reached (El Raey, 2010; Abbas, 2020). Note that this process will continue beyond the 21st century for centuries to millennia, due to continuing deep-ocean warming and icesheet melt and will remain elevated for thousands of years (IPCC, 2021). Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5°C, 2 to 6 m if limited to 2°C.

Current and Potential Future Impacts on Socio-Economic Sectors

Water Resources

Riparian countries of the TEB are extremely concerned by climate change (Al-Ansari N., 2013, Al-Ansari N., 2016, IPCC, 2007). Analysis of rainfall long term records show that the annual average rainfall is decreasing with time, this will have serious consequences on the river basins. As an example, 71% of the water of the Euphrates River is from precipitation in Turkey (UNDP, 2011). Decrease of rainfall is associated with increase in temperature (Al-Ansari N. , 2013). These trends suggest more evaporation and there will be more drought periods. In addition, intense rainfall events may increase, and this could result in negative consequences as well. For example, groundwater recharge may decrease since infiltration rates are lower in shorter periods of time such as these intense but short rainfall events. Moreover, when such rainfall events take place after drought periods, sediment erosion increases and reduces land production. Maddocks (2015) indicated that most countries in the Middle East will be already water stressed by 2040, including all countries within the TEB. Iran will have relatively the maximum water stress followed by Iraq, Syria, and Turkey (Maddocks, 2015).

Agriculture (Crops and Fisheries)

Major crops, GDP, irrigation/rainfed, food security, crop stress/adaptation

¹⁵ Dynamically downscaled outputs of different GCM (ECHAM5, CCSM3 and HadCM3) and emissions scenario (A1FI, A2 and B1) simulations.

Food is a central component within the water-energy-food nexus framework in which these socio-ecological subsystems are viewed as interdependent, thereby exerting influence over each other, responding to external and internal pressures and generating synergies and trade-offs across multiple scales (Rasul, 2016). Agriculture and food can be strongly impacted by climate change.

Despite only contributing **approximately 5% to Iraq’s GDP**, agriculture represents the second largest contribution to GDP after the oil sector (42%) (FAO, 2021). Of Iraq’s population of 39.34 million people, 30% live in a rural setting and 20% are employed in agriculture (FAO, 2021; FAOSTAT, 2018). In 2017, **agriculture represented 43.7% of total female employment and 16.1% of male employment** (World Bank, 2018). In 2019, 27.7% of Iraqi territory, or 9.25 million ha, was classified as agricultural land (FAOSTAT, 2018). Space is not the principle limiting factor when considering expansion of crop and livestock production, rather it is aridity, the availability of water, and infrastructure that need to be considered. In 2012, only 5 million ha were cultivated, and the sector is categorised as being dominated by smallholders (FAO, 2012).

Iraq grows a range of crops across its agroclimatic zones. Figure 4 illustrates the commodities that are produced in the greatest amount averaged across the last 20 years. Cereals represent the most produced commodities, followed by vegetables and fruit.

Wheat and Barley are the main crops in the north and central rainfed zones, although there is still some production in the south (FAO, 2012). Wheat is critical to Iraq’s food security and is managed through a government controlled Public Distribution Scheme (PDS). It is a winter crop, sown in October to November and harvested March to April (FAO, 2012). In the recent past, the country has been the second largest importer of wheat in the region. Barley is largely used as a fodder crop for livestock and Iraq is largely self-sufficient. Iraq has lost its self-sufficiency in wheat and been a net importer due to population growth, three wars, international sanctions, and inclement weather. Most recently there has been large internal displacements of people due to the activities of the Islamic State of Iraq and the Levant (ISIL) in 2014. The Iraqi Ministry of Agriculture estimated production losses of 40% during the ISIL crisis. However, since 2017 ISIL has been greatly diminished and some farmers have reclaimed their lands in the north. This resulted in a bumper harvest of 6.2 million tonnes being produced in 2020 – more than the 4.5 million tonnes required for the PDS system. The wheat commodity is in part reliant on the water stored in reservoirs in the north and east of the country and 70% occurs on irrigated land (FAO, 2021). Grapes are also predominantly grown in the north of the country.

Central and Southern Iraq are characterised by more mixed farming than in the north. Agriculture in the southern regions is more dependent on irrigation from the Tigris and Euphrates rivers (FAO, 2012). Dates represent an important food and cash crop, and orchards are often interplanted with fruit trees such as olives, oranges, apples, and grapes (*Ibid.*). Prior to the Gulf War Iraq represented 75% of global date production, and there are 300,000 ha permanently cultivated with fruit trees (FAO, 2021). Vegetables such as tomatoes, aubergines and potatoes are important irrigated crops, both in respect to the amount produced and market price they receive. Livestock raising is common practice alongside inland fisheries and domestic poultry rearing which together constitute important income streams and sources of protein for rural populations.

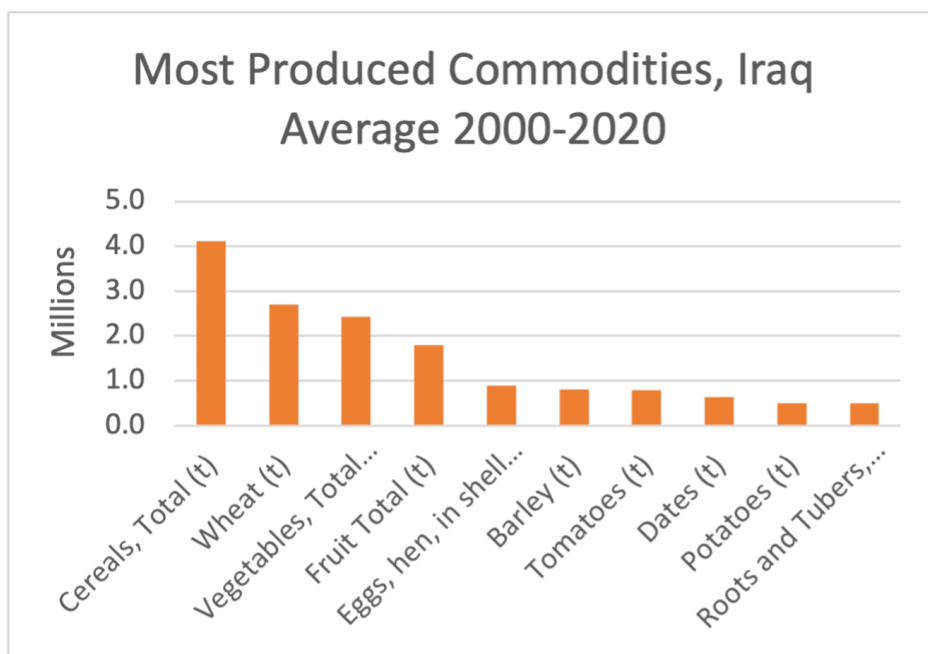


FIGURE 4: MOST PRODUCED FOOD COMMODITIES IN IRAQ. (FAOSTAT, 2022)

Climate change can directly affect crops and livestock and the broader farm-, food- and eco-systems in several deleterious ways.

Heat stress: With respect to plants, **heat stress** is defined as a period during which temperatures are sufficient to induce irreversible damage to plant development or function (Hemantaranjan, 2014). The extent of damage done to plants via heat stress is related to the magnitude and rate of temperature elevation outside their optimal growing conditions and the development stage at which it occurs. Understanding the phenological development and growth stages of plants is of importance in understanding the effects of climate change, as they will differ according to the plant stage. Heat stress is further compounded by the duration of the stress, water availability and ambient humidity (Seyhun, 2018). Critically, and similarly to humans, low water availability and high humidity lower the heat stress threshold (*Ibid.*). **High relative humidity** has been shown to increase grain sterility in rice and affects the ability of plants to effectively cool via transpiration (*Ibid.*). Plants can be categorised as C3 or C4 types depending on their different metabolisms. Wheat and rice are C3-type plants that are less efficient at photosynthesising higher temperatures. **Optimum temperature** for wheat is 17-23°C throughout the growing period. Tolerance to extreme temperatures varies with cultivars. Wheat typically has an upper growing temperature of Tmax 37°C (John, 1999). Temperatures are important throughout growth stages, for example, super- or sub-optimal temperatures during flowering stages can directly impact on eventual yields, although optimal temperatures can be higher at the grain filling stage. Heat stress in wheat can affect yield and nutritional content of the grain.

Plants may seek to avoid heat stress through a range of broad mechanisms. Plants can develop enhanced tolerance to heat stress through expression of heat shock proteins. They may also employ escape and avoidance mechanisms. Escape mechanisms are ways for plants to shift developmental stages e.g., flowering. This can be helped by agricultural practices such as earlier sowing dates. Avoidance mechanisms refer to approaches made by the plant to acclimatise themselves to higher temperatures (Barnabás, 2008). Often these mechanisms are something that evolves with the plant and therefore there are limitations to which plant species can use them.

Developing cultivars to heat stress is an important approach to **climate change adaptation**, but they are technically challenging to develop due to difficulty plant breeders have in identifying and confirming heat stress traits. To mitigate the effects of climate change it will therefore be important to grow crops in appropriate agroclimatic zones that minimise the degree of heat stress they will face. Irrigation will be important to mitigate the effects of drought and heat stress, although it will be more difficult to control the effects of high humidity, particularly in the south.

Drought stress: Refers to plants that lack water and causes a range of physiological and metabolic damage to the plant. Drought stress is most sensitive at flowering and grain filling stages of plant growth, especially in wheat. Yield loss is dependent on the magnitude and duration of drought. Drought stress often occurs alongside heat stress.

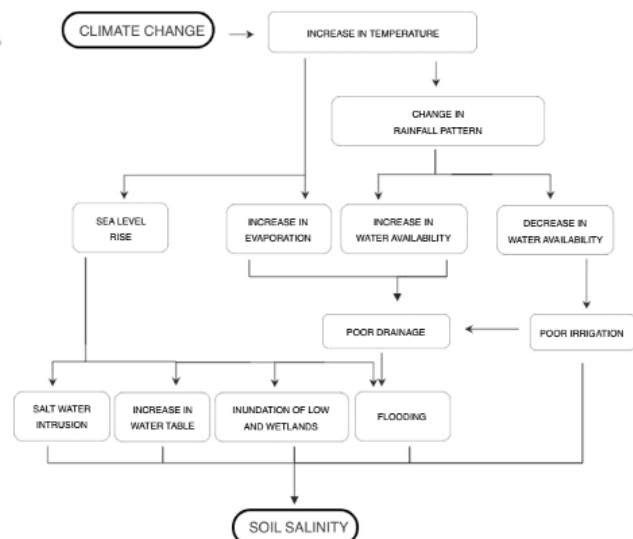
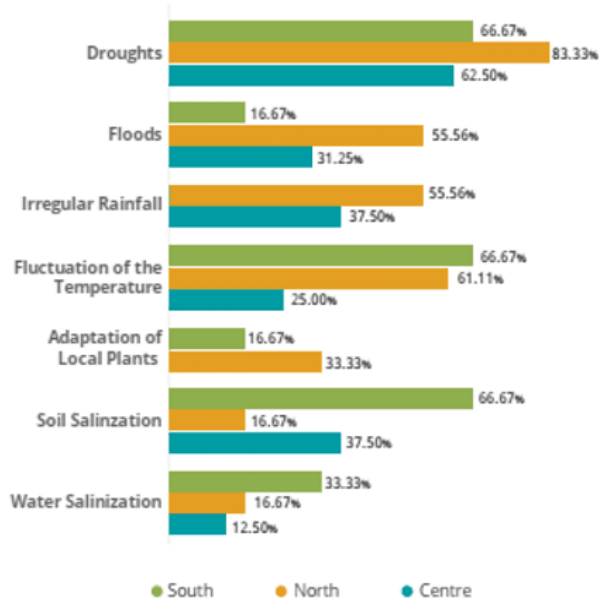


FIGURE 5: FARMERS CONCERN REGARDING CLIMATE CHANGE (LEFT) AND FACTORS AFFECTING THE SLOW ONSET OF SOIL SALINIZATION INFLUENCED BY CLIMATE CHANGE (RIGHT).

Soil salinisation: In a recent study on wheat value chains in Iraq, farmers stated their concerns regarding the effects of climate change on wheat production (FAO, 2021) (Figure 5, left). Farmers in the south were largely concerned about droughts, temperature fluctuation and soil salinisation. Soil salinisation is a major concern as it is exacerbated by climate change, sea level rise and saltwater intrusion. Irrigation induced salinisation is the most significant cause of land degradation in arid and semi-arid regions (Eswar, 2021) (Figure 5, right). Soil salinisation can lead to erosion, biodiversity loss and contribute to desertification processes. Soil salinisation is a particular issue in the south given the potential for saltwater inundation due to rising sea levels combined with aridity, detrimental contributing agricultural practices. A loss of productive agricultural land due to salinisation will impact on food security and rural livelihoods. If severe, it may also cause people to migrate thereby increasing the number of internally displaced people and rural-urban migration (FAO, 2012).

In terms of food security, the number of malnourished people has climbed from 5.4 million in 2002 to 14.7 million in 2020 – an increase of 60% (FAOSTAT, 2022). There have been some improvements over this period, for example, the percentage of children suffering from stunting has decreased 17% over this same period (*Ibid.*).

Human Health

Higher temperatures and humidity will negatively impact on human health, labour capacity, and economic productivity. There are a variety of heat stress indices and corresponding temperature thresholds that are relevant to human health (Schwingshackl et al., 2021), with no single indicator being inherently better than others (e.g., NOAA heat index; humidex; perceived temperature; wet-bulb globe temperature, WBGT; universal thermal climate index, UTCI (Brimicombe et al., 2021), etc.).

However, Schwingshackl also notes that there are differences between indicators and thresholds, with a direct link between higher temperatures and human health impacts. Human beings perform optimally in an ambient temperature range of 18°C to 22°C to maintain a core body temperature between 36.5°C and 37.5°C (Heal & Park, 2016) with heat exposure caused by a range of factors that include air temperature, humidity, wind speed, direct sunlight exposure, clothing type and work intensity.

For humans to dissipate heat naturally they need to perspire. However, the effectiveness of this cooling mechanism is dependent on the relative humidity of the surrounding air. An increase in relative humidity will impair the effectiveness of sweat evaporation and hence the ability of people and animals to thermoregulate and cool down. A wet-bulb temperature (T_{WB}) refers to the lowest temperature at which air can be cooled by evaporation. A T_{WB} of 35°C will induce hyperthermia in humans leading to heatstroke and death as the body is no longer able to dissipate heat (Sherwood & Huber, 2010). However, there have been deadly heatwaves with far lower T_{WB} of 28°C, and 35°C T_{WB} represents a maximum for people with no health comorbidities (*Ibid.*).

Current models suggest that T_{WB} under RCP8.5 scenario could regularly exceed 35°C in parts of the Middle East by 2075 (*Ibid.*). Areas of high humidity such as the Persian Gulf and adjacent coastline will be affected by high T_{WB} due to high land surface temperatures (LST) and sea surface temperatures (SST) (Pal & Eltahir, 2016). It is important to note that high T_{WB} may occur periodically for 1-2 hours' duration, and not be present for the entirety of a day.

Factors such as individual health and occupational context will determine a person's relative capacity to withstand heat and humidity. For example, age, obesity, pre-existing disease, low socio-economic status, pregnancy, immunological status, type of work clothing, level of activity, and genetic characteristics can all effect a person's vulnerability to heat stress (Schulte & Chun, 2009). Heat stress may cause physical and psychological discomfort, including but not limited to increased chemical intolerance, fatigue, heat stress and stroke, which may lead to death. Chronic heat exposure can reduce an individual's capacity to recover after exposure to heat (*Ibid.*)

TABLE 4: COMPARISON OF WBGT EXPOSURE LIMITS FOR ACCLIMATISED WORKERS. NOTE THAT UNACCLIMATISED WORKERS WOULD HAVE GREATER HEAT EXPENDITURES DURING THE SAME AMOUNT OF WORK AND TEMPERATURE. ADAPTED FROM NIOSH (2016)

Workload	US National Institute for Occupational Health and Safety (NIOSH)
Resting	30°C (86°F) <200 kcal·h ⁻¹ (233 W)
Light	28°C (82.4°F) 201–300 kcal·h ⁻¹ (234–349 W)
Moderate	26°C (78.8°F) 301–400 kcal·h ⁻¹ (350–465 W)
Heavy	25°C (77°F) 401–500 kcal·h ⁻¹ (466–580 W)

With respect to work, the type of work and industry will determine the degree of heat stress exposure. Industries and sectors most at risk include agriculture, construction, landscaping, delivery, oil and gas well operations, as well as bakeries, kitchens, laundries, (indoor heat generating appliances) fire services, iron and steel mills, foundries, manufacturing with furnaces, warehousing – any workplace where heat is generated within buildings, in addition to any physical activity. Urban areas are particularly at risk of higher temperatures than their surroundings due to their characteristic land use and land cover (LULC) patterns contributing to higher land surface temperatures (LST) through the urban heat island (UHI) effect (Hashim et al., 2022).

The degree of physical workload and energy expenditure will impact on the ability of workers to work at a given temperature and may require them to reduce effort or take breaks to remain safe (see Table 4).

Physical and psychological discomfort can lower task productivity, which in turn impacts on impact on labour productivity and supply (the hours worked), and effort. Depending on the work in question, the margin of return per unit of labour supplied can directly affect profitability. For example, one study shows that in the USA on days with temperatures above 30°C, workers in industries with exposure to high temperatures reduced their labour time by as much as one hour, which represents a 14 percent reduction in daily labour (Heal & Park, 2016).

National Scale Hazard Maps

National climate hazard maps have been developed to geographically visualise the changes in exposure to different natural hazards, in terms of magnitude and/or frequency (listed in Table 5 and shown in Figure 6 to Figure 11, and in Appendix D Figure 32, Figure 33).

Six hazard indices have been selected to cover a broad range of climate risks of practical relevance for adaptation, including for example heat stress and extreme precipitation. Their relevance to the analysis of the Persian Gulf and Southern Marshes was also considered. The selection process started with a prioritisation of 8 indices, coordinated across Wood, Walker and CCRM teams and using the full list of about 30 indices produced¹⁶. This was followed by a consultation with the Ministry of Environment which confirmed our top five but also requested an assessment of sea level rise. The final indices are listed and defined in Table 5.

For each hazard index in Table 5, we compute the change by 2085 (2072-2097) compared to historical levels (1978-2002). Note that, for each emission scenario (RCP), up to three possible projections (S1, S2, S3) as described by the SOMs analysis are computed, which summarise the spread in projections. As we shall see, the spread is particularly large for precipitation-related indices: as mentioned in the review of the literature, the trend in future projection is not clear in this part of the world and this is reflected in weak and/or diverging trends by the end of the century.

Figure 6 to Figure 11 below show the hazard maps for RCP4.5 and RCP8.5 for four of the six indices listed in Table 5: sea level rise (SLR), standardised precipitation index (SPI12) (above +1 and below -1), heat index (HI) above 32°C as well as warm and dry days. The maps for the other two indices are in Appendix D. It is noted that all the hazard maps and for other time periods (e.g., 2050) will be uploaded and available to explore via the UNEP Iraq Climate GIS Data portal.¹⁷

¹⁶ See full list in Appendix C.

¹⁷ UNEP Iraq Climate GIS Data portal: <https://home-unep-iraq.hub.arcgis.com/>

TABLE 5: HAZARD MAPS INDICES

Index	Units	Description	Risk Sector
Area exposed to sea level rise	Fraction of area of the three exposed governorates	Area at risk of inundation and/or water infiltration due to sea level rise. It has been very simply computed as area which elevation falls below the future sea level height.	Infrastructure, agriculture, water management and migration.
Heat index (HI)	°C	HI is a simple index to quantify heat stress from hot and humid conditions, and the adverse health impacts ¹⁸ . HI is operationally used by the US National Oceanic and Atmospheric Administration (NOAA) for issuing heat warnings; note that some climatic zones where it is used in the USA, like Arizona, can be regarded as comparable to Iraq. Is a multiple linear regression of temperature and relative humidity. <i>Thresholds considered: 32°C (extreme caution)</i>	Labour productivity, public health and agriculture.
Standardised precipitation index (SPI12)	[1]	SPI12 measures the 12-months average change in precipitation compared to reference levels. Negative values indicate drier conditions and positive values indicate wetter conditions. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean. <i>Thresholds considered: +1 (wetter) and -1 (drier)</i>	Agriculture and water management
Simple precipitation intensity index (SPII12)	mm/day	SPII12 quantifies the mean precipitation in wet days averaged over 12 months. It indicates the average intensity of rain in rainy days.	Agriculture and water management
Warm and dry days	days	Number of days in a year with daily mean temperature above historical 75th percentile and daily amount of rain below historical 25th percentile.	Agriculture, water management and urban design.
Dry spell	days	Maximum annual number of consecutive dry days (dry if daily precipitation < 1.0 mm)	Agriculture, water management and urban design.

Sea Level Rise

Under the RCP8.5 medium confidence scenario, sea level rise (SLR) is projected to increase of +0.3m by 2050, +0.9m by 2100 and +1.3m by 2150 compared to 1995-2014 levels (Figure 6, median values as blue crosses). The low confidence scenario, which includes additional potential impact of deeply uncertain ice sheet processes involving especially the Greenland and Antarctic ice sheets, shows median increase of up to +2m by 2150 (Figure 6, orange crosses), with high percentiles reaching as high as 4-5 meters.

¹⁸ e.g., Schwingshackl et al., 2021; IPCC AR6, Chapter 2

in Figure 7 (b-d) shows the potential area of the Al Basrah, Dhi-Qar and Maysan governorates potentially affected by 1m, 2m and 3m of SLR. The relationship between SLR and percentage of area affected is summarised in Figure 7(e), with SLR levels for both RCP4.5 and RCP8.5 marked for reference. The area is simply calculated as portion of the coastal area which elevation is below the future sea level. At +1m of sea level rise, the areas affected are large parts of the Persian Gulf coast and the major Iraqi ports, the city of Basra. The Southern Marshes are also threatened as the area below sea level connecting them to the sea reaches them through the low-lying area along the Shatt Al-Arab River. These results are in line with analysis by El Raey (2010) and Abbas (2020).

Note that the present computation of the inundated area due to the rising sea level does not exclude regions that are below sea level but will remain safe due to natural barriers, such as higher ground in between the coast and the area. Therefore, these results may be overestimating the actual threatened area. This can be seen clearly in Figure 7 (a) which shows there are some areas below 0m of sea level rise (i.e., current level), yet these places are currently not flooded by the sea waters as they are either too far inland or likely protected by other types of defences. Once the SLR is high enough to connect it with the coast via a low-lying land, then also the areas marked in the 0m map will become threatened, as seen for example in the 2m map. Another caveat to this analysis is that the vertical resolution of the elevation dataset we used is of 1 m, which is comparable with the magnitude of projected SLR. Therefore, uncertainty in the estimation presented here may be high. Finally, our analysis does not account for further threat due to storm surges, which may exacerbate the situation. To validate our simple analysis with more complex modelling, we have compared our results with the online coastal risk screening tool of Climate Central¹⁹ which uses the CoastalDEM digital elevation model with higher vertical and horizontal resolution than NOAA ETOPO1 and excludes areas lower than the selected water level but with an obstructed path to the ocean. It also accounts for risk due to storm surges and tides. The main difference between Climate Central and our estimates are for SLR between 0m and 1m, however there is broad agreement in the areas marked at high risk.

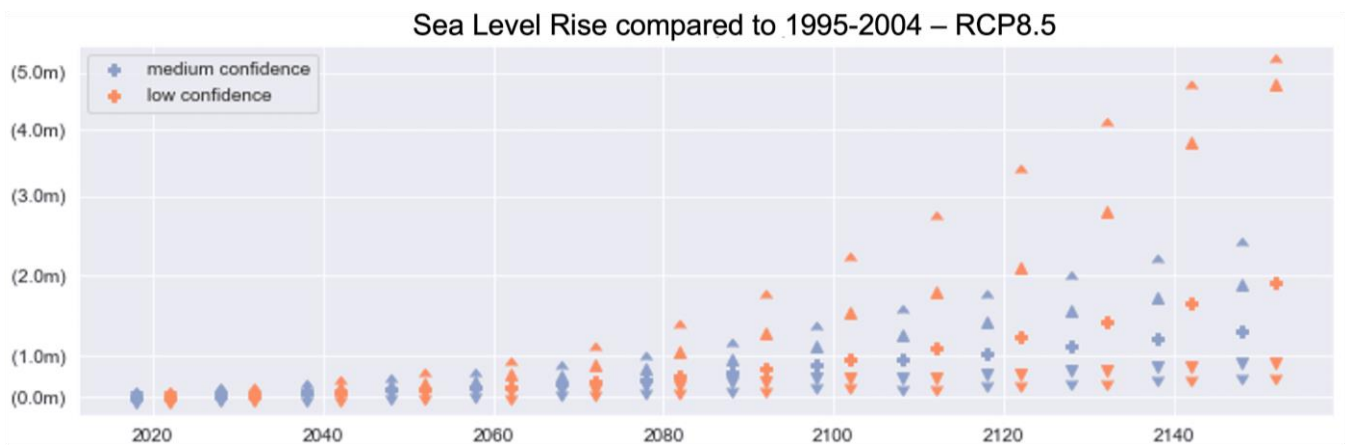


FIGURE 6: METERS OF SEA LEVEL RISE WITH RESPECT TO THE LEVEL OF THE 1995-2014 PERIOD. THE EMISSION SCENARIO IS RCP8.5 AND THE LOCATION IS A POINT IN THE PERSIAN GULF CLOSE TO THE IRAQI COAST AT 28 ° LATITUDE AND 49 ° LONGITUDE. THE BLUE POINTS SHOW THE *MEDIUM CONFIDENCE* SCENARIO. THE ORANGE POINTS SHOW A *LOW CONFIDENCE* SCENARIO WHICH INCLUDES THE POTENTIAL IMPACT OF DEEPLY UNCERTAIN ICE SHEET PROCESSES, ABOUT WHICH THERE IS CURRENTLY A LOW LEVEL OF AGREEMENT AND LIMITED EVIDENCE (SEE FUTHER DESCRIPTION IN THE TEXT). THE CROSS MARKER SHOWS THE MEDIAN ESTIMATE, BRACKETED WITH THE 5, 17, 83 AND 95 QUANTILES AS TRIANGLES. FOR THE MEDIUM CONFIDENCE SCENARIO, THE 17TH-83RD PERCENTILE RANGES ARE INTERPRETED AS *LIKELY* RANGES, OR A PROBABILITY OF AT LEAST 66%; NOTE THIS INTERPRETATION DOES NOT APPLY TO THE LOW CONFIDENCE SCENARIO.

¹⁹https://coastal.climatecentral.org/map/8/48.1675/30.6524/?theme=water_level&map_type=water_level_above_mhbw&basemap=roadmap&contiguous=true&elevation_model=best_available&refresh=true&water_level=0.0&water_unit=m

a) SLR = 0 m b) SLR = 1 m c) SLR = 2 m d) SLR = 3 m

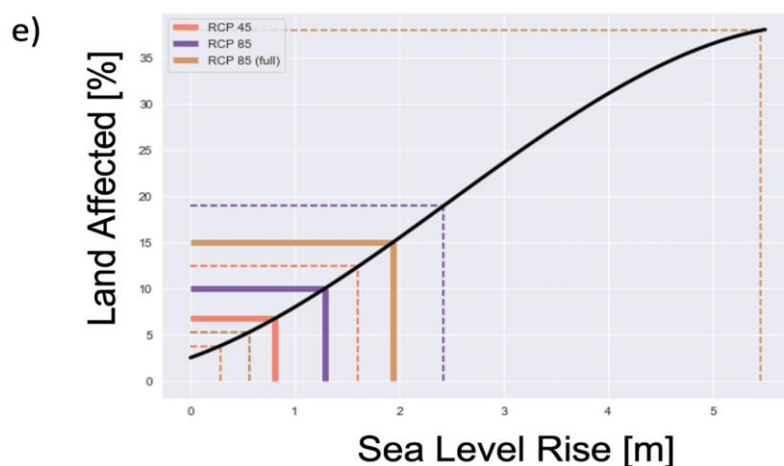
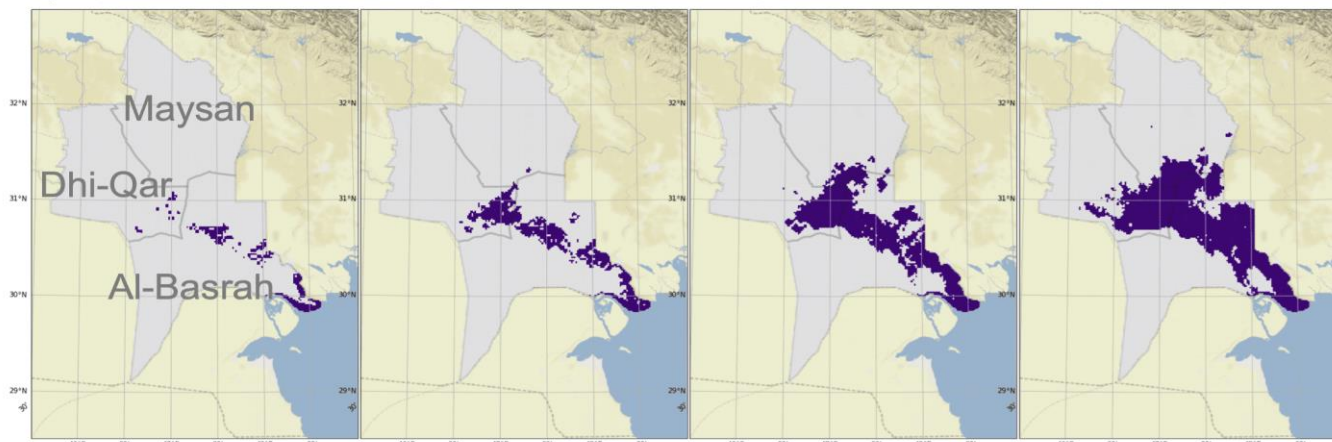


FIGURE 7: (A-D) AREA POTENTIALLY EXPOSED TO SEA LEVEL RISE FOR 0, 1, 2 AND 3 METERS OF INCREASED SEA LEVEL COMPARED TO 1995-2014 LEVEL. THE GOVERNORATE OF AL BASRAH, DHI-QAR AND MAYSAN ARE HIGHLIGHTED. (E) PERCENTAGE OF TOTAL AREA OF THE THREE GOVERNORATES UNDER A GIVEN VALUE OF SLR. THE MEDIAN (LINE) AND 5,95 PERCENTILES (DASHED LINES) OF PROJECTED SLR UNDER THE RCP4.5 MEDIUM CONFIDENCE (ORANGE), RCP8.5 MEDIUM CONFIDENCE (PURPLE) AND RCP8.5 LOW CONFIDENCE (BROWN) BY 2150 ARE MARKED IN THE PLOT TO SHOW THE CORRESPONDING PERCENTAGE OF AREA AFFECTED.

Annual Precipitation Distribution (SPI12)

The change in frequency of years wetter than average (SPI12>1) is shown in Figure 8, where RCP4.5 projections are in the bottom row (RCMs selected labelled as SOM S1 and S2) and RCP8.5 are in the upper row (RCMs labelled SOM S1, S2 and S3). Areas where frequency of wet years increase are shown in purple, and where it decreases are shown in orange.

The maps show no clear and consistent trends across SOMs. For RCP4.5, both S1 and S2 show a common signal of less wet years in the centre of the country. For RCP8.5, S1 and S2 show an overall trend of fewer wet years in the central and north-east Iraq, while S3 shows a generalised wetting. In the very south-east, over the Al Basrah governorate and the Southern Marshes, the change is less strong and overall weak, although suggests a potential wetting. As mentioned in 'Assumptions and Limitations', RCP8.5 S3 is regarded as low confidence scenario since it produces what is considered unrealistic wet conditions, also in the historical period.

The change in frequency of years drier than average (SPI12<-1) is shown in Figure 9, where RCP4.5 is the bottom row and RCP8.5 top row. Areas with more dry years are shown in orange, and with less dry years in purple. In RCP4.5, S1 and S2 show opposite trends across the whole country. In RCP8.5, S1 and S2 shows a tendency for drier years in the mountain regions in the very north-east, close to the border with Turkey. The drying signal is much less strong in RCP8.5 S3. In central and south Iraq, all the RCP8.5 SOMs show a weak signal of fewer years with dry conditions, suggesting a slight wetting in the south of the country.

Taken together Figure 8 and Figure 9 suggest high uncertainty in future average precipitation change. This result could be expected given that SOMs are selected to cover the range of different projections for precipitation across global climate models (CMIP5), which are known to project different precipitation changes in this region, as reported in numerous analyses including from IPCC. The few common signals across SOMs and RCPs seems to suggest a decrease in the frequency of wetter years in the

mountains in the north-east and in central Iraq while possibly a bit more frequent wet years in the southeast (SPI12>1, Figure 8). Dry conditions seem to increase especially in the north but may decrease a little in the centre and south (SPI12<-1, Figure 9).

Change in frequency of wet years (SPI12 > 1)

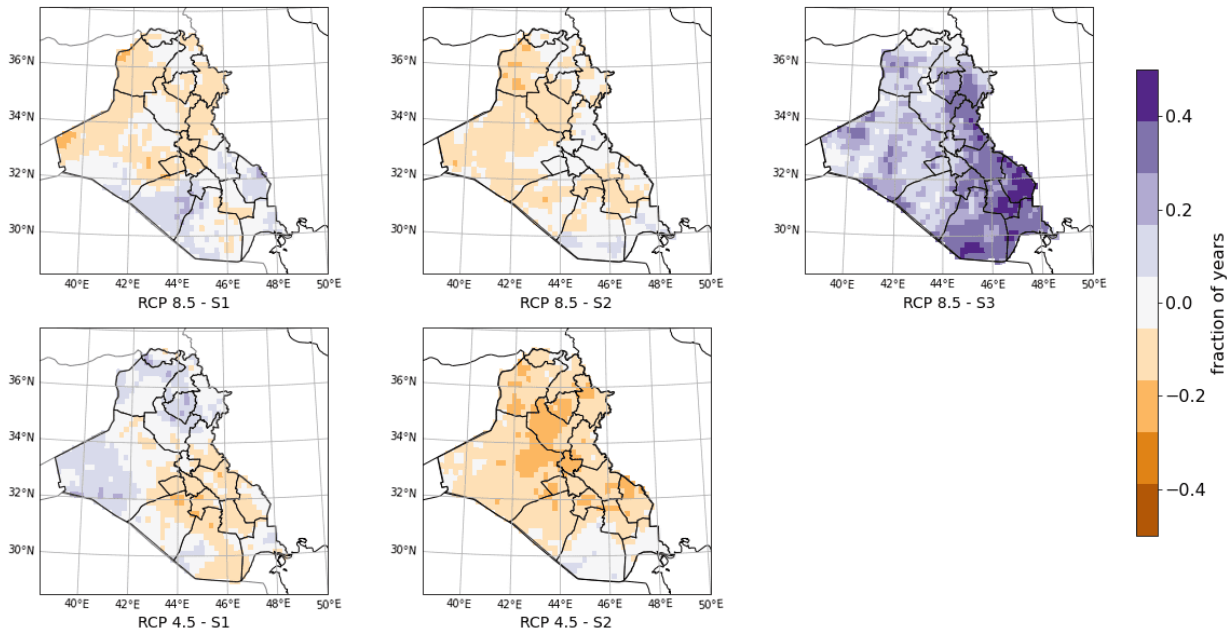


FIGURE 8: CHANGE IN FREQUENCY OF WET YEARS (SPI12 > 1) BY 2085 COMPARED TO HISTORICAL, IN THE REGIONAL CLIMATE MODELS (SOMS) SELECTED FOR RCP8.5 (TOP ROW) AND RCP4.5 (BOTTOM ROW).

Change in frequency of dry years (SPI12 < -1)

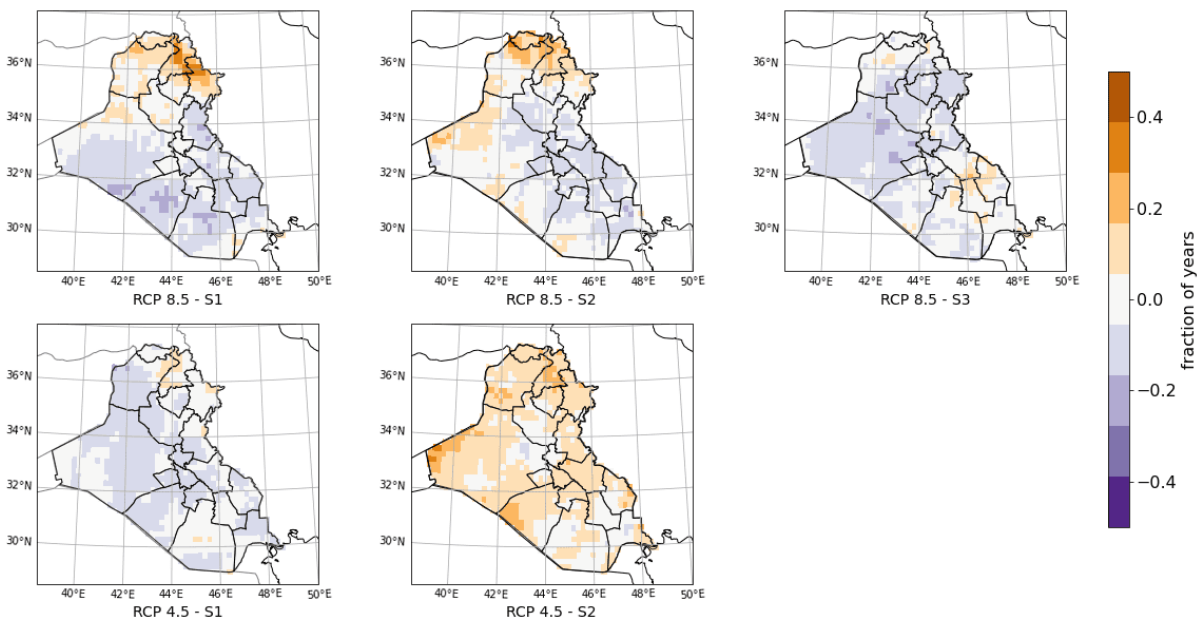


FIGURE 9: CHANGE IN FREQUENCY OF DRY YEARS (SPI12 < -1) BY 2085 COMPARED TO HISTORICAL, IN THE REGIONAL CLIMATE MODELS (SOMS) SELECTED FOR RCP8.5 (TOP ROW) AND RCP4.5 (BOTTOM ROW).

Hot and Humid Extremes

The number of days in a year with HI above 32°C was computed, and the change compared to the historical yearly mean is shown in Figure 10 for RCP4.5 (bottom row) and RCP8.5 (top row). To correct for potential bias in the historical representation of the likelihood of exceeding the 32°C level, a quantile-based bias correction on the historical run is performed. As presented in

Table 2, a HI of 32°C is considered a condition for heat stress to be treated with ‘extreme caution’, where heat stroke, heat cramps, or heat exhaustion are *possible* with prolonged exposure and/or physical activity (Blazejczyk et al., 2012). An increase in annual days with heat index above 32°C is shown in orange, a decrease in purple.

RCP4.5 and RCP8.5 both show an increase in days with HI above 32°C. This signal is consistent across all SOMs. The increase is more severe under RCP8.5 (up to +80 days per year) but is already strong under RCP4.5 (up to + 50 days per year). The largest increase is concentrated in a western south-north region, from the desert in the south up to the north not far from Mossul. Note that the historical number of annual days with HI above 32°C in the south-east of the country is already 100 (see Table 6), therefore under RCP8.5 this increase may lead to more than half of the year above this threshold of heat stress.

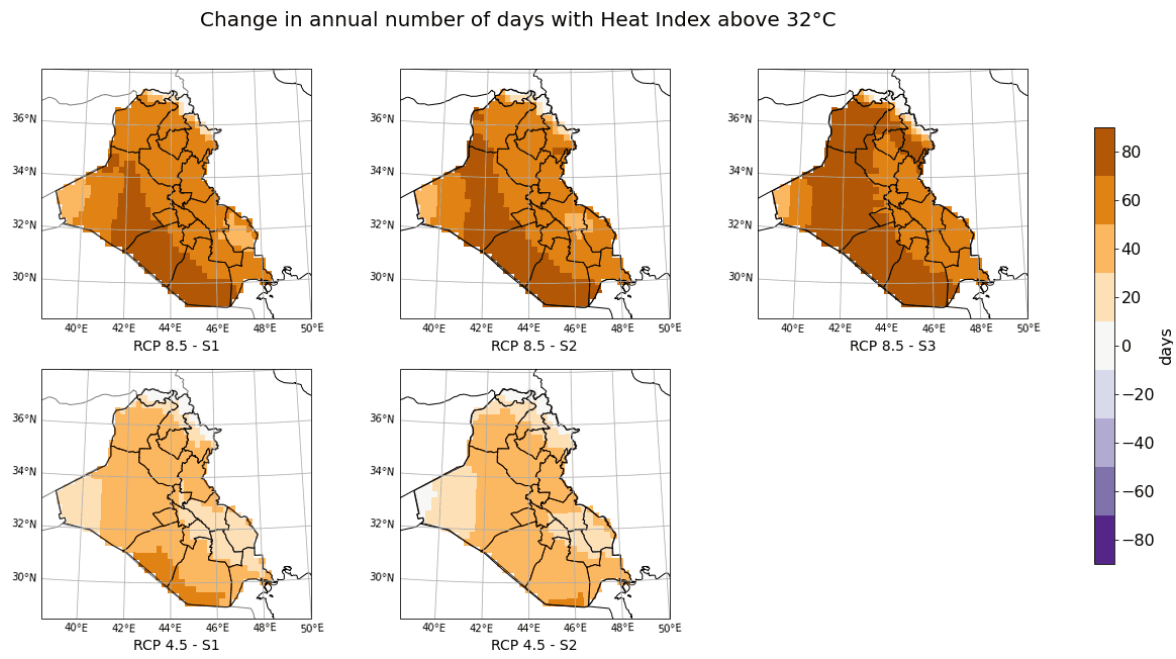


FIGURE 10: CHANGE IN ANNUAL NUMBER OF DAYS WITH HEAT INDEX ABOVE 32°C BY 2085 IN THE REGIONAL CLIMATE MODELS (SOMs) SELECTED FOR RCP8.5 (TOP ROW) AND RCP4.5 (BOTTOM ROW).

WARM AND DRY DAYS

The change in annual number of warm and dry days compared to the historical mean is shown in Figure 11 for RCP4.5 (bottom row) and RCP8.5 (top row). An increase in annual warm and dry days is shown in orange, a decrease in purple. As for HI, also for warm and dry days clearly increases for all SOMs. RCP8.5 showing a much higher increase (+40 to 60 days per year) compared to RCP4.5 (+20 to 40 days per year). The spatial pattern is of a larger increase in the south of the country compared to the north.

Overall, this analysis has also shown that projection of changes in precipitation-based hazards have a large uncertainty, meaning different models project even opposite changes (see SPI12 in Figure 8 and Figure 9). On the other hand, temperature-based hazards show a consistent pattern of change across models which is exacerbated by higher emission scenarios (Figure 10 and Figure 11). The storylines of future climate change developed in Sections 8 and 9 provide a framework that allows to contemplate different futures to plan for adaptation in the face of deep uncertainty.

Change in annual number of warm and dry days

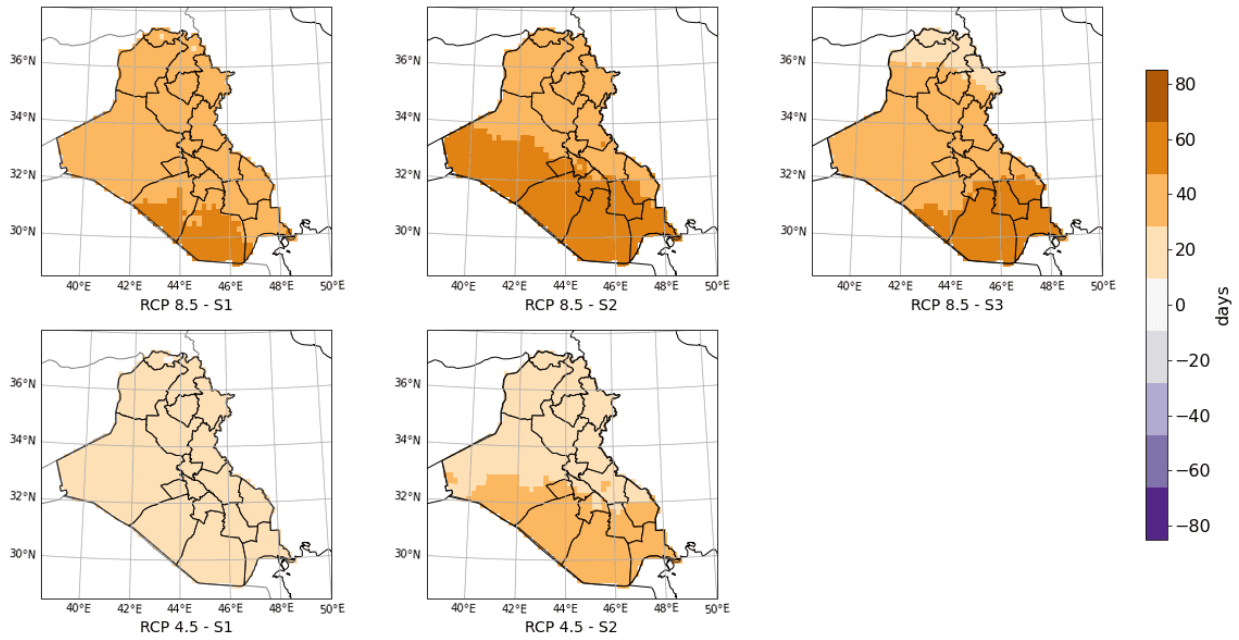


FIGURE 11: CHANGE IN ANNUAL NUMBER OF WARM AND DRY DAYS BY 2085, IN THE REGIONAL CLIMATE MODELS (SOMS) SELECTED FOR RCP8.5 (TOP ROW) AND RCP4.5 (BOTTOM ROW).

Exposure

Finally, some elements of exposure to the hazard presented in this section are analysed. Figure 12 shows the distribution of Iraqi population (right) and location of all settlements and Southern Marshes (left). Contrasted with SLR maps in Figure 7(b) for example, these maps show that a high number of people and settlements are at risk of 1m of SLR. A more detailed quantitative analysis of the number of people and villages potentially affected by the hazards presented in this section is beyond the scope of the present analysis but can be expanded in future work on adaptation.

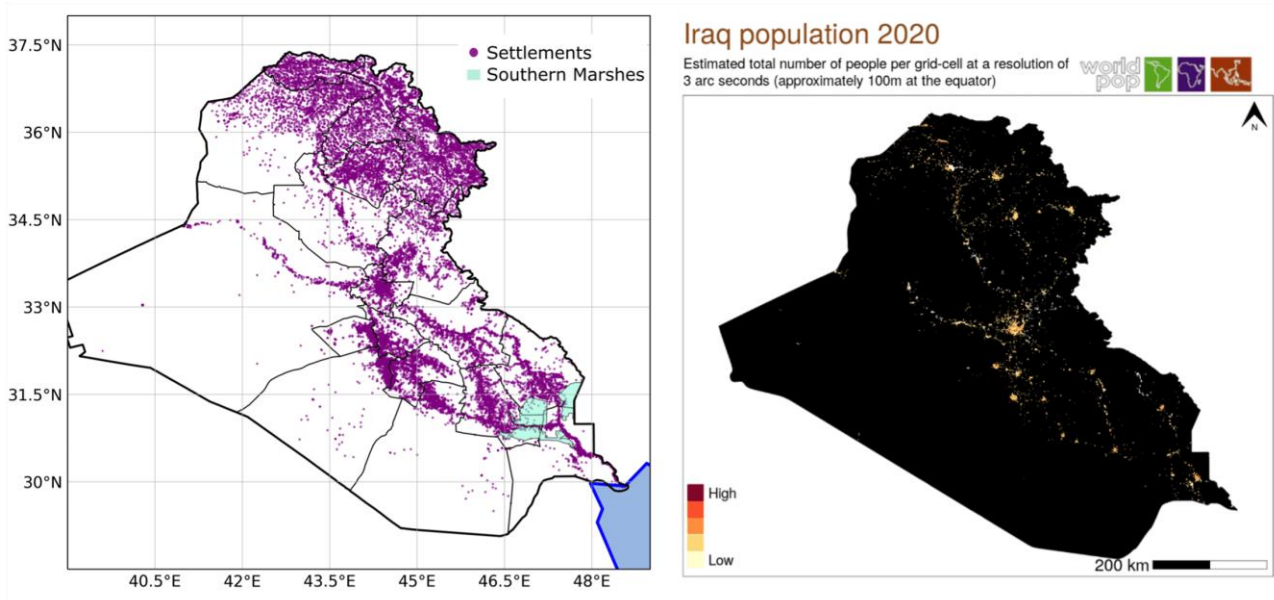


FIGURE 12: (LEFT) MAP OF IRAQ WITH GOVERNORATES (GREY LINES), SETTLEMENTS LOCATIONS IN IRAQ (PURPLE DOTS) AND THE THREE SOUTHERN MARSHES ANALYSED IN THIS REPORT (LIGHT GREEN). (RIGHT) POPULATION MAP FROM WORLDPOP.ORG.

8. CLIMATE CHANGE SCENARIOS FOR PERSIAN GULF AND SHATT AL-ARAB REGION



FIGURE 13: THE PERSIAN GULF REGION AND VIEW OF SHATT AL-ARAB FROM THE NORTHERN PART OF BASRA CITY. SOURCE: AZIZ, WIKIMEDIA. [HTTPS://COMMONS.WIKIMEDIA.ORG/WIKI/FILE:SHAT_AL-ARAB-22.JPG](https://commons.wikimedia.org/wiki/File:Shatt_Al-Arab-22.jpg). ACCESSED 6 APRIL 2022

Topography and Hydrology of the Shatt Al-Arab Region

The Shatt Al-Arab delta region is formed at the confluence of the Tigris and Euphrates (T&E) rivers in the town of Al-Qurnah in the Al-Basra governorate of southern Iraq. The southern end of the river constitutes the border with Iran down to its mouth, where it discharges into the Persian Gulf. Very large quantities of silt are deposited by the T&E rivers and other smaller streams as they flow into the gulf via the Shatt Al-Arab River. The rivers reach their peak flow in spring and early summer when the snow melts in the mountains which can result in severe flooding. Surface-water temperatures range from 16 to 32 °C in the extreme northwest of the Gulf. These high temperatures and a low influx of freshwater results in high salinity due to evaporation in excess of freshwater. As a result of saltwater contamination of the Tigris, this water is unfit for human consumption, livestock and crop production (see also Section on observed changes to Water Resources). Issues of water access are further exacerbated by climate change, as the region suffers from persistent droughts, as well as upstream damming in Turkey on both the Tigris and Euphrates Rivers, which result in reduced water levels (see also Section on climate change impacts on Water Resources).

Climate

Temperatures are high along the Gulf coast, though winters may be quite cool at the north-western extremities. The sparse rainfall occurs mainly as sharp downpours between November and April and is higher in the north-east. Humidity is high. The little cloud cover is more prevalent in winter than in summer. Thunderstorms and fog are rare, but dust storms and haze occur frequently in summer when large quantities of fine dust and, in places, quartz sand, are blown into the sea by predominant north-west winds, the Shamal, from the desert areas of the surrounding lands. The shamal blows predominantly from a north-north-west direction during the summer, is seldom strong and rarely reaches gale force. Squalls and waterspouts are common in autumn when winds sometimes reach speeds of 95 miles (150 km) per hour within as short a time as five minutes. Intense heating of the land adjacent to the coasts leads to gentle offshore winds in the mornings and strong onshore winds in the afternoons and evenings.

Economics

Until the discovery of oil in Iran in 1908, the Persian Gulf area was important mainly for fishing, pearling, the building of dhows (lateen-rigged boats common in the region), sailcloth making, camel breeding, the making of reed mats, date growing, and the production of other minor products, such as red ochre from the islands in the south. The arid lands surrounding the gulf produced little else and, except for the rich alluvial lands of the Mesopotamian plain, supported only a small population of those engaged in fishing, date growing, and nomadic herding. Fishing has become highly commercialised. Yields in the north-west have been affected, however, by the construction of large dams on the rivers, which restrict the supply of nutrients into the gulf.

Since World War II the Persian Gulf and the surrounding countries have come to account for a significant proportion of the world's oil production. In addition, the area has approximately two-thirds of the world's estimated proven oil reserves and one-

third of the world's estimated proven natural gas reserves. The region thus has acquired considerable strategic significance for the world's industrialised countries. Exploration has remained active, and new reserves are continually being discovered, both on land and offshore. Large amounts of oil are refined locally, but most is exported to north-western Europe, East Asia, and other areas of the world. Petrochemical and other petroleum-based industries, as well as consumer industries, have been developing rapidly in the gulf region.

Agriculture

The Basra Governorate is rich in oil fields and used to be a major producer of date palms, wheat, barley and rice. Basra City is the governorate's main urban centre with an estimated population of more than four million inhabitants.



FIGURE 14: NEGLECTED DATE PALMS IN BASRA. SOURCE: [HTTPS://WWW.ARABNEWS.COM/NODE/1379061/MIDDLE-EAST](https://www.arabnews.com/node/1379061/middle-east). ACCESSED 6 APRIL 2022

However, increased water salinity and water shortages in Basra have adversely affected the agricultural sector, which is a major employer in rural communities and a significant income source for rural households. The area used to hold the largest date palm forest in the world. In the mid-1970s, the region included 17–18 million date palms: an estimated one-fifth of the world's 90 million palm trees. However, by 2002, more than 9 million of the palms in Iraq had been lost by the combined factors of war, salt and pests. Many of the remaining 3–4 million trees in the region are in poor health²⁰.

The livestock sector has also suffered, as a lack of animal feed and clean water has resulted in livestock deaths, particularly among buffalo. Communities reported that they can no longer sustain feeding their herds due to the prohibitively high cost of animal feed and clean water processed through reverse osmosis plants.

As a result of the water salinity issues, Basra City hosts affected agricultural and rural communities who have migrated to the city seeking alternative income opportunities. Abu Khaseeb in the south of Basra is one of the districts most adversely affected by water salinity and people are now relying on non-agricultural sources of income, which are insufficient. Al-Qurna has relatively better water quality in comparison to the rest of the governorate, and communities continue to practice agriculture on a small and medium scale. Al-Zubair has access to alternative water sources, and as such, small scale vegetable production in greenhouses is being practiced.

Areas of marshlands and fertile terrain around the Persian Gulf are further reducing, due to continued water shortages and the informal re-zoning of agricultural land to residential. According to the UN, an estimated 250 km² of fertile land is lost annually to desertification. Further development of agricultural lands will accelerate this process, as rural to urban migration increases and urban centres are forced to expand to accommodate increased populations. It is estimated that up to four million Iraqis will be forced to migrate from their homes during the next decade because of the ongoing water crisis. Meanwhile, the country is struggling to deal with the ongoing challenges of up to two million people still displaced by armed conflict (NRC, 2018).

²⁰ <https://na.unep.net/atlas/webatlas.php?id=169>. Accessed 6 April 2022.

Climate Hazards and Impacts

The primary risk factors for **Basra and the Shatt al-Arab region** in Southern Iraq are likely to be from extreme heat/humidity, combined with changes in extreme rainfall. Four narratives (i.e., 'warm-moderate', 'hot-moderate', 'warm-extreme', 'hot-extreme') will be used to evaluate impacts on human health, labour capacity, crop yields, flash flooding, and soil/water salinity.

Higher temperatures associated with global warming also imply higher sea levels with threats of erosion/flooding in the coastal zone of the Persian Gulf; more upstream saline intrusion from the estuary; and impacts on estuarine/marine eco-regions.

Potential changes in upstream regulation of inflows by dams and water diversions **will not be considered** but these conditions could amplify or dampen evaluated climate storylines (see for example, Al-Ansari et al., 2020; Al-Quraishi & Kaplan, 2021; Yasir et al., 2018).

Heat Extremes

Hot and Humid

Iraq is usually hot and dry in the summer, but at times, it experiences periods of hot and high humidity, especially close to the coast. Al Basrah is mostly under the influence of the Indian monsoon low pressure which produces easterly winds (also known as Sharje) that brings humid and hot air. In those conditions it can become hard to be comfortable or breathe for people with respiratory condition. Hot and humid extremes are analysed via the HI, as already introduced in Table 5. The number of days in a year above 32°C (level 2, extreme caution) and 41°C (level 3, danger) (Blazejczyk et al., 2012 and www.weather.gov/ama/heatindex) are analysed. These are standard impact thresholds adopted by NWS/NOAA and routinely used in literature (Schwingshackl et al. (2021), IPCC AR6, WG1, Chapter 2).

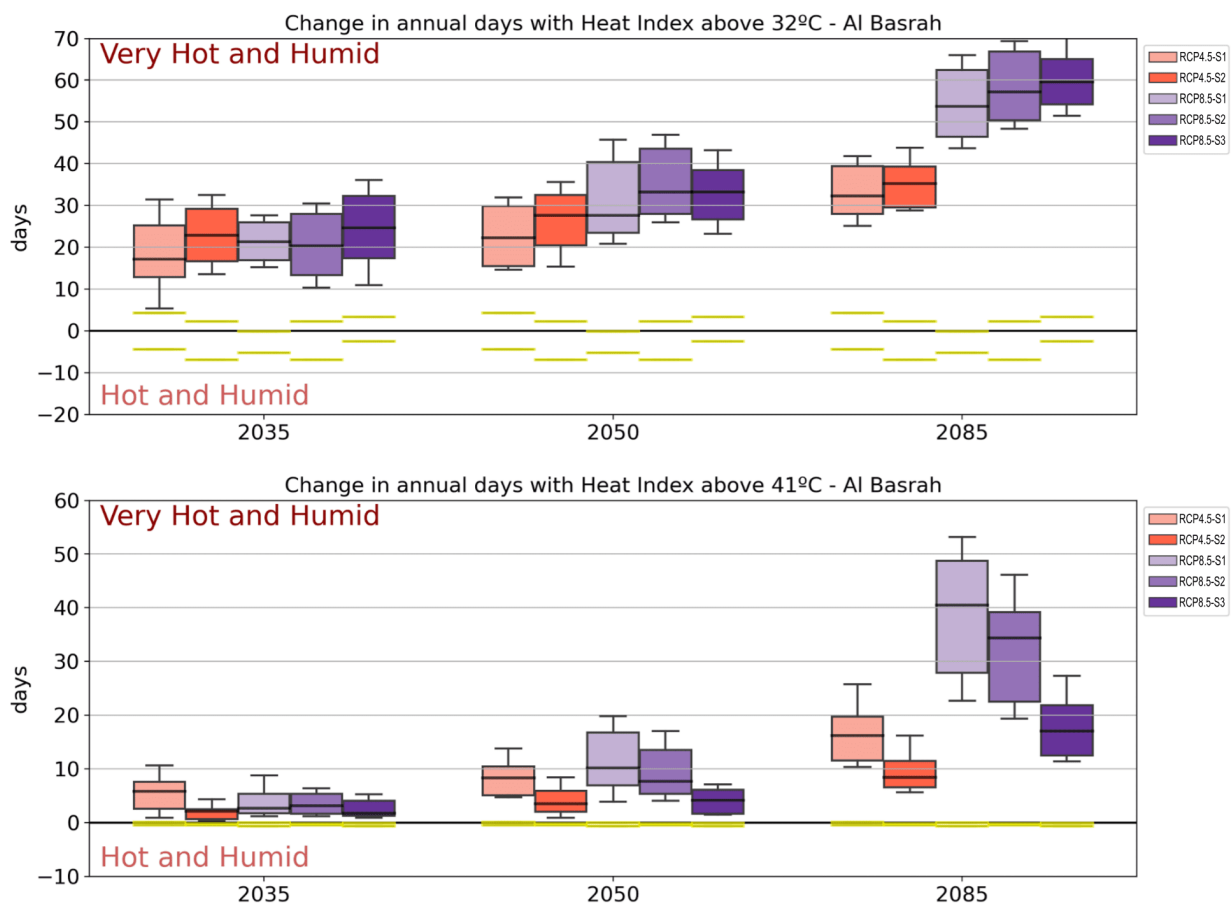


FIGURE 15: CHANGE IN ANNUAL NUMBER OF DAYS WITH HI ABOVE 32°C (TOP) AND ABOVE 41°C (BOTTOM) OVER AL-BASRAH. THE CHANGE IS WITH RESPECT TO THE HISTORICAL PERIOD (1981-2005). RCP4.5 SOMS ARE SHOWN IN ORANGE AND RCP 8.5 IN PURPLE. THE 'NOISE' LEVEL TO DETECT CHANGE IS MARKED BY YELLOW HORIZONTAL BARS, WHICH CORRESPOND TO THE HISTORICAL 25 AND 75 PERCENTILES VARIABILITY.

This analysis found that in Al Basrah the mean number of days above 32°C in the period 1981-2005 was around 100 (Table 5), hence the interest in including the higher threshold under the assumption that locals are acclimatized to some degree to the lower threshold. While 32°C represents concern for the multiple international companies and people working and living in the

area, the 41 °C constitutes a severe risk for the residents as well. In the historical period, days with HI above 41°C in a year are close to zero. The number of days above threshold are the relevant metric to estimate days where people may not be able to sustain a full day of work (or any at all) due to heat. We also compute the number of consecutive days with HI above 32°C as this quantity can also be relevant for planning (Table 6, plot not shown). For example, these persistent heat wave conditions could affect the operations in the international port of Basra and construction work, with a resulting need to stop business for several days in a row by 2050 and 2085.

The analysis shown in Figure 15 shows a marked increase in days above 32°C as well as 41°C, summarised in Table 6.

TABLE 6: HEAT INDEX IN AL BASRAH BY THE END OF THE 21ST CENTURY UNDER RCP4.5 AND RCP8.5 EMISSION SCENARIOS.

Period	HI > 32 °C (days/year)	HI > 41 °C (days/year)	Max consecutive days HI>32°C (days/year)	Comment
Historical	100	1-2	70	Already about 2 months consecutive above 32°C, of which virtually no days are above 41°C.
RCP 4.5 - 2085	130-140	10-20	120	Almost 4 months consecutive above 32°C; of which almost one above 41°C
RCP 8.5 - 2085	150-160	20-40	140	Almost 5 months consecutive above 32°C; of which about one above 41°C

Flooding

Sea-level Rise

The potential impact of SLR over Al-Basrah was presented in the Section on Hazard Maps (refer to the description of the method to estimate the area at risk, its limitations and results presented in Figure 7). SLR is increasing and is very likely to reach +0.3-0.4m by 2050s (high confidence) and then between +0.5m to +1m by 2100 depending on the emission scenario (medium confidence, as higher increase cannot be ruled out). Here we show the settlements side by side with 1m and 2m of SLR (Figure 16).

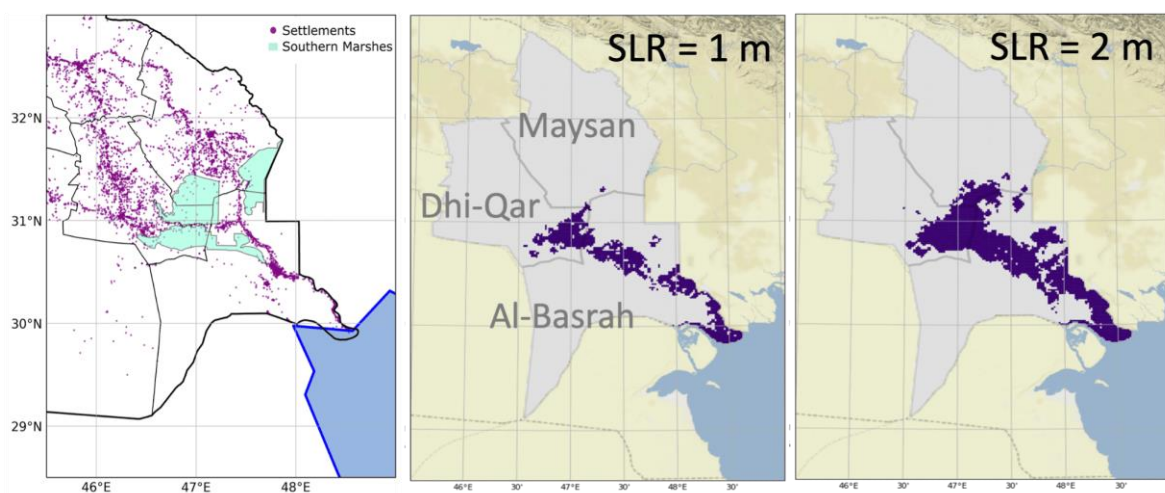


FIGURE 16: THE SETTLEMENTS AND SOUTHERN MARSHES LOCATION (LEFT). AREA POTENTIALLY EXPOSED TO 1M AND 2M OF SEA LEVEL RISE (CENTER AND RIGHT).

According to estimates, between 0 and 1m of SLR the coast, Umm Qasr and Al Faw are already threatened (likely by 2050). Umm Qasr and Al Faw support trade, shipments, and various businesses and industries (including oil production and storage). This area is very low-lying and susceptible to any amount of SLR, as well as being subjected to redistribution of coastal and marine sediments during extreme storm events, which clogs shipping channels and forces frequent dredging. Potential impacts are flooding, saltwater intrusion and potentially loss of land, especially if sea level rise is combined with changing weather patterns that may increase erosive action on the natural features of the coast, as well as infrastructure (El Raey, 2010). Sea level rise, and constant movement of the lowest low-water mark which defines the maritime borders with Kuwait and Iran, has the potential to create international conflict regarding the location of shipping (there have already been several incidents related to this in recent years – between Iran and Iraq (El Raey, 2010)).

Between 1m and 2m of sea level rise the city of Basra and the port become threatened too, as well the marshes (potentially by 2100). The potential impact may affect soil salinity by saltwater intrusion and may cause serious inundation of many parts of the region. The Shatt al-Arab River, which flows through Basra, is already suffering from salinity intrusion mostly related to lack of freshwater discharge; SLR will exacerbate this problem.

Extreme Precipitation

Heavy downpours can lead to pluvial flooding in cities, roadways, farmland, subway tunnels and buildings and can overwhelm city transportation and storm water drainage systems. Heavy rain events can directly cause leaf loss and damage or knock over crops, also driving pollutant entrainment and erosion hazards in terrestrial ecosystems and farmland with downstream ramifications for water quality (Ranasinghe et al., 2021). As suggested by climate models, precipitation may be increasing in the south of Iraq and with it potentially precipitation extremes. However, the analysis carried out in previous assignments (CCRM, 2021, Projections and Climate Change Scenarios for Iraq) suggested that there is no clear indication that rainfall extremes are greater with higher RCPs and an overall erratic behaviour.

High precipitation may lead to surface water flooding if combined with suitable conditions on the ground. However, in this analysis a hydrological model to study risk of flooding could not be carried out. The likelihood of high rainfall days, which may be one of the conditions leading ultimately to flooding and high surface runoff could however be estimated. Extreme precipitation is quantified via two indices: the annual total precipitation above the historical 90 and 99th percentiles (R90pTOT and R99pTOT) and the 30-day maximum effective precipitation.

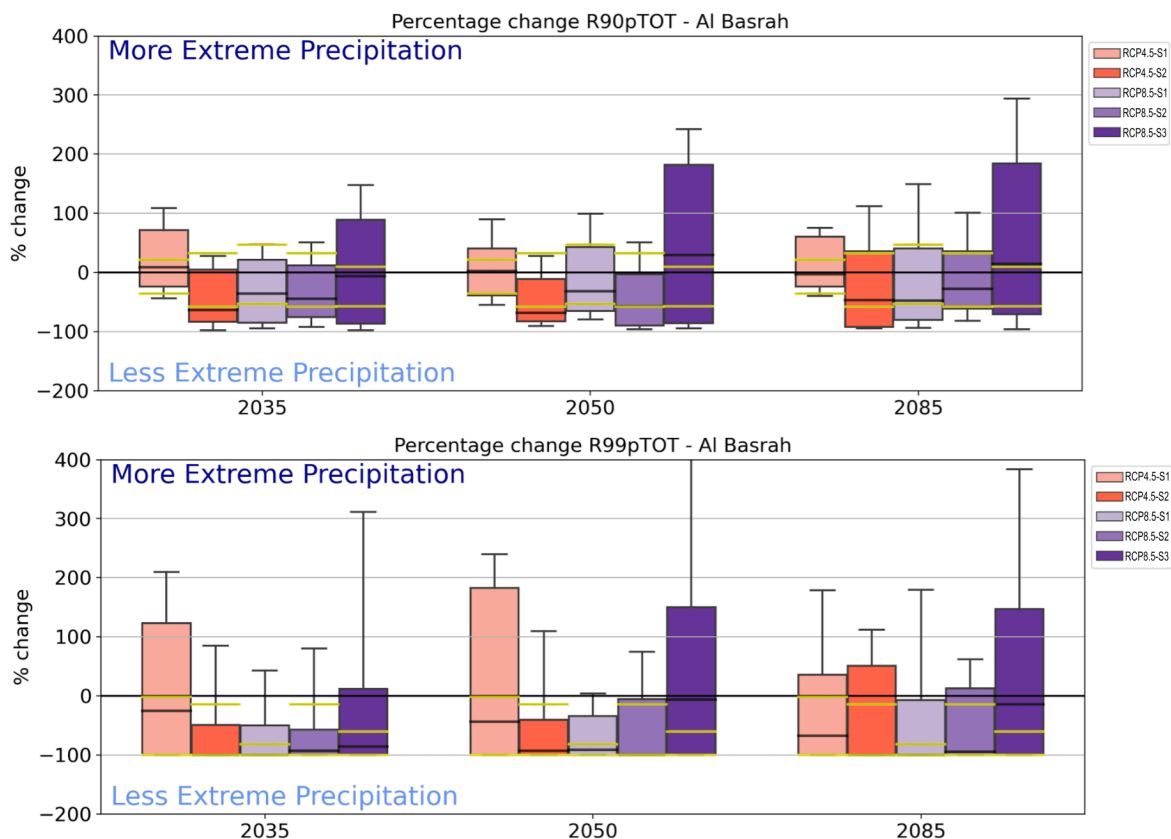


FIGURE 17: RELATIVE PERCENTAGE CHANGE IN R90pTOT (TOP) AND R99pTOT (BOTTOM) FROM HISTORICAL LEVELS. RCP4.5 SOMS ARE SHOWN IN ORANGE AND RCP 8.5 IN PURPLE. THE 'NOISE' LEVEL TO DETECT CHANGE IS MARKED BY YELLOW HORIZONTAL BARS, WHICH CORRESPOND TO THE HISTORICAL 25 AND 75 PERCENTILES VARIABILITY.

Figure 17 show the percentage change in R90pTOT (top) and R99pTOT (bottom) respectively, a change computed with respect to the historical values. A first point to note is that the RCP4.5 and RCP8.5 projections are less distinct from one another compared with the heat index: by 2085, RCP4.5 projections are very similar to RCP8.5, at least for the analysed models. This means that change in extreme precipitation signal, if any, is not clearly coupled with the warming local climate. A second point to note is that there is a decrease in the median precipitation and a general shift of the distribution towards less extreme across almost all SOMs. However, this decrease is never significantly different from the noise level (yellow horizontal lines based on historical variability). It is also worth noting that R99pTOT shows some high variability which encompasses a strong increase.

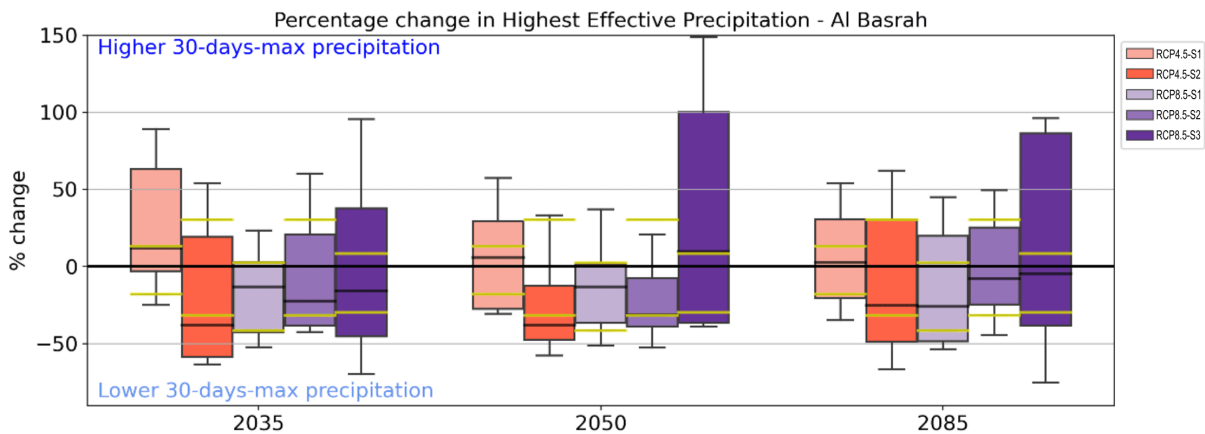


FIGURE 18: RELATIVE PERCENTAGE CHANGE IN ANNUAL 30-DAY MAXIMUM EFFECTIVE PRECIPITATION FROM HISTORICAL LEVELS. RCP4.5 SOMS ARE SHOWN IN ORANGE AND RCP 8.5 IN PURPLE. THE ‘NOISE’ LEVEL TO DETECT CHANGE IS MARKED BY YELLOW HORIZONTAL BARS, WHICH CORRESPOND TO THE HISTORICAL 25 AND 75 PERCENTILES VARIABILITY.

A very similar conclusion emerges from Figure 18 which shows the 30-day maximum effective precipitation. From this analysis, there is no clear signal of an increase in extreme precipitation, instead, the contrary is rather more likely. Nevertheless, given several of the models analysed have a positive trend in mean annual precipitation for the region (not shown), the potential for wetter conditions in the south of Iraq cannot be ruled out, and may trigger flooding. Finally, it is important to note that this type of extreme precipitation analysis is usually performed with data on (sub-)hourly time scale, however the data analysed here is of daily time scale so short and intense events cannot be assessed here. Moreover, extreme precipitation events are very uncertain across many regions of the world, not only in Iraq, as described in IPCC AR6 (Ranasinghe et al., 2021).

Climate Change and Vulnerability Storylines

The analysis of the previous sections, including hazard maps and review of the literature, gives the following general picture of the climate hazard changes that can influence the Persian Gulf region and the Al-Basrah governorate. Assessment of confidence is stated at the end of each statement (in brackets).

- **Precipitation change**

A decrease in precipitation upstream, with a resulting decrease in flow of the Tigris and Euphrates rivers and the Shatt Al-Araba and Shatt Al-Basra rivers (medium confidence).

An unclear trend in local precipitation in the Southeast of Iraq, both for the average annual and high extremes. The mean change in CMIP6 GCM models in the region is positive (more precipitation) but not statistically significant, hence there is low confidence in this increase and further analysis is needed. RCM models show divergent behaviour also in changes in extreme precipitation.

- **Sea level rise**

SLR is increasing and will reach almost certainly +0.3-0.4 m by 2050s (high confidence) and then between +0.5m to +1m by 2100 depending on the emission scenario (medium confidence, as higher increase cannot be ruled out); it would continue for centuries and millennia.

The effect on Iraqi coast is likely to be felt in the next 30-80 years with the magnitude depending on the global emissions (high confidence).

- **Temperature and humidity**

The increase in temperature and humidity, and their combined effect would result in high heat stress values. This is indicated across all RCP scenarios (even for the RCP2.6 lower concentration pathway, based on our literature review; high confidence).

Crucially, the magnitude of these positive trends vary dramatically between different scenarios, with the higher emission pathway (RCP8.5) reaching levels that threaten human and animal lives for multiple weeks in a year (e.g., see Figure 15 and Figure 10).

Given the above results, we focus on the climate impacts that can affect the region due to:

- (1) an increase in hot and humid days (different magnitudes depending on the RCP scenario), and
- (2) an increase or decrease in local precipitation extremes (as there is no agreement across the analysed SOMs/RCMs nor across GCMs).

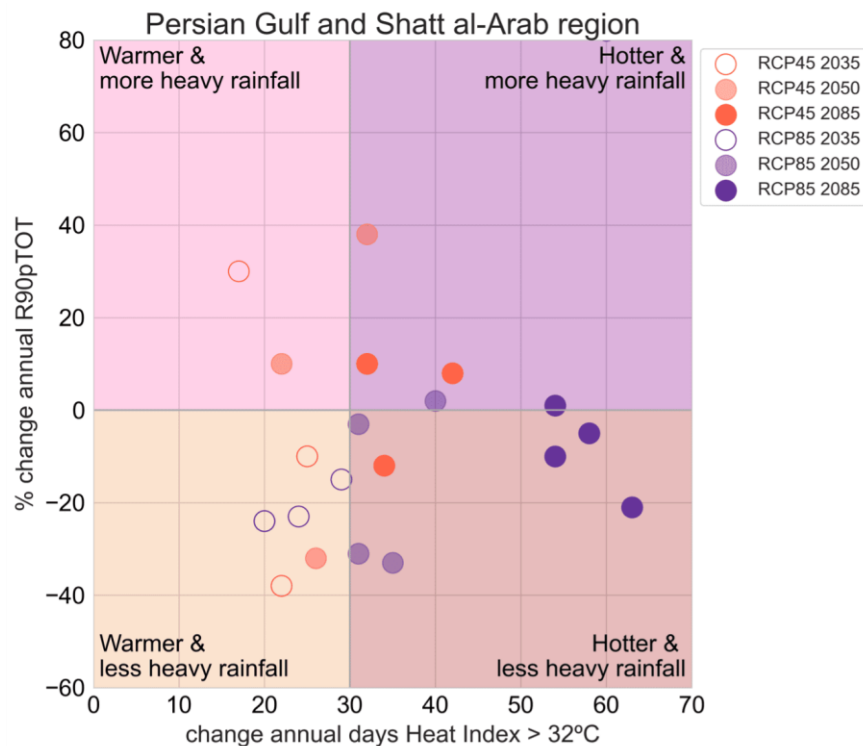


FIGURE 19: CLIMATE CHANGE AND VULNERABILITY STORYLINES FOR THE PERSIAN GULF AND SHATT AL-ARAB ECO-REGION. CHANGE IN EXTREME PRECIPITATION (VERTICAL AXIS) VERSUS CHANGE IN HEAT INDEX ABOVE 32°C (HORIZONTAL AXIS). RCP8.5 (PURPLE) AND RCP4.5 (ORANGE) MEAN ESTIMATES FOR THE 25 YEARS CENTERED AT 2035 (EMPTY DOT), 2050 (FILLED LIGHT DOT) AND 2085 (FILLED DARK DOT). THE LINES DIVIDING THE FOUR QUADRANTS REPRESENT NO CHANGE IN PRECIPITATION EXTREME (0 HORIZONTAL LINE) AND MODERATE CHANGE IN HOT-HUMID EXTREMES (+30 DAYS VERTICAL LINE; NOTE THIS THRESHOLD MAY BE ADJUSTED DEPENDING ON IMPACT ASSESSMENT).

Using these two dimensions of change, four climate change storylines have been defined, corresponding to the four quadrants in Figure 19. Because the impacts due to increasing heat stress are the same, albeit with different magnitude depending on the RCP, this report describes only two of the storylines. These are:

- **Climate Storyline 1: ‘Hot-humid and more extreme precipitation’,** and
- **Climate Storyline 2: ‘Hot-humid and less extreme precipitation’.**

These storylines reflect a common underlying trend of change with **less precipitation upstream** and **less water in rivers**, and a **range of SLR** affecting the coast (as described above).

The narrative for these storylines is presented below. They describe each possible future scenario for different sectors in the eco-regions, and the human and socio-economic impacts that might be experienced by people living in these areas. The narratives aim to stimulate discussion towards realistic adaptation policy responses and the decision support tools needed to assist future planning needs. **It is important to recognise that the scenarios do not represent every outcome projected by climate models and the resulting impacts will be further contextualised by local circumstances during the planned Capacity**

2050 Climate Storyline 1 (Persian Gulf and Shatt Al-Arab Region)

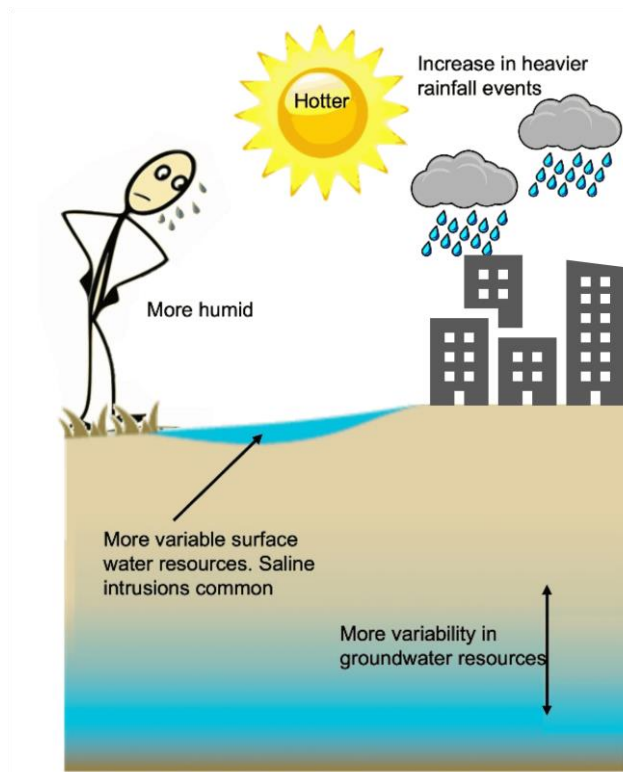


FIGURE 20: CLIMATE STORYLINE 1 - PERSIAN GULF & SHATT AL-ARAB REGION

‘Hot-humid and more extreme precipitation’

The temperature is noticeably hotter and more humid with almost 4-5 months a year of Heat Index (HI) consecutively above 32°C, compared to 100 days per year in the historical record. Of this, about 1 month the HI is above 41°C, compared to almost 0 days per year in the historical record. The higher temperature and humidity rises are felt particularly in the urban areas due to the ‘heat island’ effect.

Maximum temperatures have also increased by a similar amount and hot days are now extremely hot.

The coastal areas are experiencing a sea level rise (SLR) of around 0.5m to 1m threatening the city of Basra and the port, as well as the marshes.

With the temperature increases, there is also an increase in heavy and more intense rainfall events increasing humidity dramatically, making days very uncomfortable for working.

Despite the increases in extreme rainfall events, there is no clear trend in annual local rainfall. But there is less water available upstream from the Tigris and Euphrates. Overall, interannual recharge of water resources is more variable. The heavier rainfall and higher humidity potentially outweigh increases in evapotranspiration from the hotter climate, with the possibility of a long-term rise in groundwater levels.

Attention is required to monitor how much water is available in the first place which can offset the more extreme rainfall events.

Headline Impacts

Despite large aspects of uncertainty, this future has significant socio-economic impacts. This future raises several questions such as: **how will the uncertainty of this future be managed and supported? Is there potential for improved production in any sector?** For example, is there potential for improved production e.g., in agriculture, that can balance the higher socio-economic vulnerability linked to loss of employment under conditions of increased heat stress?

Impacts



Water

- Sea level rise is threatening the city of Basra and the port, as well as the marshes and causing serious inundation of many parts of the region. Pre-existing challenges of salinity intrusion in the Shatt al-Arab river, are significantly exacerbated.
- Sea level rise along the Gulf Coast, and the constant movement of the lowest low-water mark which defines the maritime borders with Kuwait and Iran, is creating the potential for international conflict regarding the location of shipping.
- Depending on the length and frequency of dry periods between the intense rainfall events, tensions over water access and use are rising.



Health

- People are struggling significantly with heat stress in the hotter temperatures and high humidity. This is impacting on their labour capacity.

- Poor diet due to reduced access to sources of protein through e.g., livestock raising, is exacerbating nutritional deficiencies and impacting the poorest rural communities.
- Although there is greater availability of water at different times in the year, resulting in places where overall health conditions are better, stagnant water from heavy rainfall events is increasing the incidence of water-borne diseases, cholera, gastrointestinal diseases, and typhoid fever. Increasing temperatures and precipitation can also lead to water contaminated with Vibrio bacteria or algae blooms.
- Increasing urban population is stressing the water and sanitation infrastructure and services, contaminating water with faecal bacteria (e.g. E. coli, salmonella) from run-off or sewer overflow.
- Vector borne tropical disease incidence is increasing, e.g. leishmaniasis increase due to changes in breeding patterns and distribution of sandflies (Al-Warid et al, 2017).



Agriculture

- Saltwater intrusion is affecting soil salinity, causing significant land degradation, contributing to biodiversity loss, and contributing to desertification processes. The loss of productive agricultural land due to salinisation is impacting on food security and rural livelihoods.
- In areas where there is saltwater intrusion, livestock raising, a common practice alongside inland fisheries and domestic poultry rearing in years gone by, is now declining further as livestock drinking water deteriorates. This is impacting on rural populations as these together constituted important income streams and sources of protein.
- Reduced reliability in surface water supplies and rainfed crop production leads to a greater dependency on the variable groundwater resources, especially in times of low rainfall with tensions rising over water access and use.
- Where there is more waterlogging from heavy rainfall events, communities can increase rice yields which grow better in wetter soils, as long as salinity intrusion is not an issue.
- Vegetables such as tomatoes, aubergines and potatoes are plentiful where communities optimise their use of rain-fed cropping and dry season irrigation. Communities are keen to invest at other stages in the value chain such as in soil quality and conservation.



Socioeconomic Impacts / Livelihoods

- Due to the variability of the rainfall, the resilience of communities relying mainly on agriculture is undermined, with reserves built up in good years increasingly eroded by losses during bad years. The worst affected households will seek employment in other sectors. Those with access to private wells will be more able to cope than those without which will exacerbate inequalities.
- Communities are looking for more financial support systems such as insurance as flash flooding events increase in frequency and intensity triggered by the very intense rainfall.
- Increased heat and economic pressures are reducing the availability of manual labourers to keep up with production.
- This is compounded with the loss of productive agricultural land where there is saline intrusion. Many people are migrating and there are increasing numbers of internally displaced people, resulting in significant rural-urban migration with urban infrastructure, sanitation, and housing under pressure with an increase in poor peri-urban areas.
- There is a disproportionate impact on women given the very high proportion employed in agriculture (Table 7) – though a significant proportion of men are also working in agriculture.

TABLE 7: PERCENTAGE OF MEN AND WOMEN EMPLOYED IN AGRICULTURE, INDUSTRY AND SERVICES. SOURCE: WORLD BANK (2018)

	Female (% of total Female Employment)		Male (% of total Male Employment)	
	2011	2017	2011	2017
Employment in Agriculture	49	43.7	17.2	16.1
Employment in Industry	3.5	3.9	21.3	24.2
Employment in Services	47.5	52.3	61.5	59.7

Source: World Bank. (2018). Data Bank based on ILO Modeled Estimates.

- The combined impacts of falling crop production in areas affected by saline intrusion, the loss of rural employment and falling economic productivity due to heat stress is contributing to rising inflation and significant increase in the cost of Iraq's Public Distribution System: increased cereal imports required for welfare distribution and more people are requiring assistance.

2050 Climate Storyline 2 (Persian Gulf and Shatt Al-Arab Region)

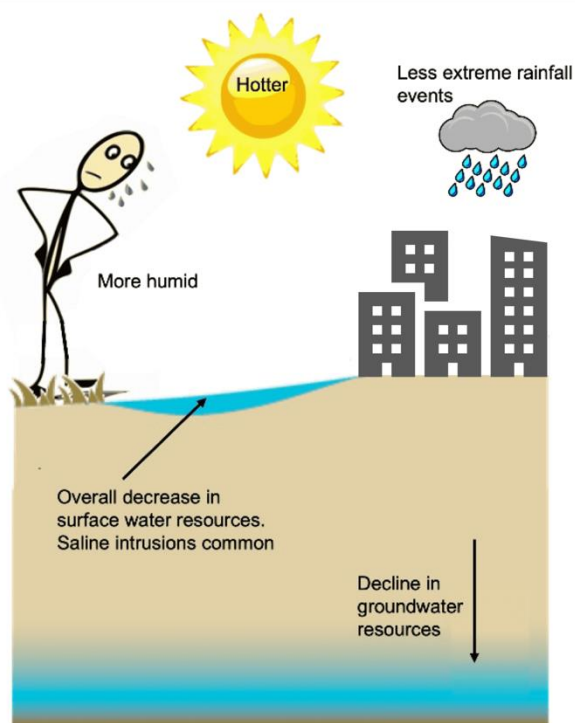


FIGURE 21: CLIMATE STORYLINE 2 - PERSIAN GULF & SHATT AL-ARAB REGION

'Hot-humid and less extreme precipitation'

The temperature is noticeably hotter and more humid with almost 4-5 months a year of Heat Index (HI) consecutively above 32°C, compared to 100 days per year in the historical record. Of this, about 1 month the HI is above 41°C, compared to almost 0 days per year in the historical record. The higher temperature and humidity rises are felt particularly in the urban areas due to the 'heat island' effect.

Maximum temperatures have also increased by a similar amount and hot days are now extremely hot.

The coastal areas are experiencing a sea level rise (SLR) of around 0.5m to 1m threatening the city of Basra and the port, as well as the marshes.

There is more erratic rainfall during the rainy seasons and a decrease in extreme rainfall events though no clear trend in local rainfall. There is also less water available upstream from the Tigris and Euphrates and an increase in the number of more severe sand and dust storms.

Inter-annual recharge of water resources is much more variable and in the long term is significantly lower than currently, due to increased evapotranspiration and reduced rainfall despite the higher humidity.

Headline Impacts

Increased poverty with potential for displacement and loss of employment, extending to urban communities as well as rural, agriculture-dependent areas. **What are the main challenges for maintaining basic living standards?** What other national **alternatives are there for supporting adaptation** when there is high socio-economic vulnerability linked to loss of employment under conditions of increased heat stress? **What are the options for managing the urban environment** (e.g., heat stress)?

Impacts



Water Resources

- Sea level rise is threatening the city of Basra and the port, as well the marshes and causing serious inundation of many parts of the region. Pre-existing challenges of salinity intrusion in the Shatt al-Arab River, are significantly exacerbated.
- Sea level rise along the Gulf Coast, and the constant movement of the lowest low-water mark which defines the maritime borders with Kuwait and Iran, is creating the potential for international conflict regarding the location of shipping.
- Use and demand of surface water is increasing, with the potential depletion of groundwater, resulting in reduced surface water resources and widespread abandonment of shallow groundwater sources.
- In the cities, urban water supplies are under pressure due to increased demand.
- Rain-fed agriculture is less viable with increasing dependency on groundwater for irrigation.
- Water quality deteriorates linked to saltwater intrusion, because of the rising sea level (see *2050 Climate Storyline 1 (Persian Gulf and Shatt Al-Arab Region)*)
- Increase of water salinity and decline in livestock drinking water means communities are keen for (i) water resource management activities and (ii) education.
- Effective irrigation systems and rainfall harvesting for irrigation and livestock are vital to support income.

- As well as agriculture, hydropower supporting increasing energy demands is driving close monitoring of water resources.
- Depending on the length and frequency of dry periods, tensions over water access and use are rising with less resilient water-dependent environments more severely affected.



Health

- People are struggling significantly with heat stress in the higher temperatures and high humidity. This is impacting on their labour capacity.
- Many more people are suffering from respiratory conditions with older people and children in particular requiring hospitalization due to the marked increase in severe sand and dust storms.
- Urban areas are particularly at risk of higher temperatures than their surroundings due to their characteristic LULC patterns contributing to higher land surface temperatures (LST) through the urban heat island (UHI) effect.
- Poor diet is exacerbating nutritional deficiencies and impacting heavily on the poorest people in the community as well as pregnant women, children, adolescent boys and the elderly.
- Incidences of water-borne diseases are rising because communities are relying on fewer groundwater sources.
- Increasing urban population is stressing the water and sanitation infrastructure and services, contaminating water with faecal bacteria (e.g. E. coli, salmonella) from run-off or sewer overflow.
- Vector borne tropical disease incidence is increasing, e.g. leishmaniasis increase due to changes in breeding patterns and distribution of sandflies (Al-Warid et al, 2017).



Agriculture

- Saltwater intrusion is affecting soil salinity, causing significant land degradation, contributing to biodiversity loss, and contributing to desertification processes. The loss of productive agricultural land due to salinisation is impacting on food security and rural livelihoods.
- In areas where there is saltwater intrusion, livestock raising, a common practice alongside inland fisheries and domestic poultry rearing in years gone by, is now declining further as livestock drinking water deteriorates. This is impacting on rural populations as these together constituted important income streams and sources of protein.
- Reduced reliability in surface water supplies and rainfed crop production leads to a greater dependency on the declining groundwater resources, especially in times of low rainfall with tensions rising over water access and use.
- Staple crop harvests are reducing due to limited water and increased incidences of pests. Some staples are failing.
- Some households are adopting more drought resistant crops despite the cultural barriers and related additional costs.



Socioeconomic Impacts / Livelihoods

- People with more power/resources are capitalising on remaining water sources increasing community tensions and the vulnerability of female headed households and those headed by people with disabilities.
- Financial stress is exacerbating food security as households have less income for additional consumption goods to compensate for the poor staple crop harvests.
- Poverty is rising as people lose vital assets and seek to diversify their livelihoods out of agriculture. There is disproportionate impact on women given the very high proportion employed in agriculture (Table 7) – though a significant proportion of men are also working in agriculture.
- Many rural communities are seeking alternative livelihoods and the rates of rural/urban migration have increased substantially. Informal settlements around urban centres are growing rapidly, putting stress on the urban infrastructure (Watsan and health), and many issues such as high disease rates are occurring.
- Industries, sectors, and workplaces where heat is generated within buildings are suffering from significant labour shortages because of the decreasing productivity from heat stress exposure of staff. Particularly vulnerable businesses include agriculture, construction, landscaping, delivery, oil and gas well operations, as well as bakeries, kitchens, laundries, (indoor heat generating appliances) fire services, iron and steel mills, foundries, manufacturing with furnaces, and warehousing.
- Aviation power generation and businesses are struggling with major disruptions due to the increased prevalence of severe sand and dust storms.

- Combined impacts of falling crop production and loss of rural employment contribute to significant increase in the cost of Iraq's Public Distribution System: increased cereal imports required for welfare distribution and more people require assistance.

9. CLIMATE CHANGE SCENARIOS FOR THE SOUTHERN MARSHES

Topography, Climate and Hydrology of the Marshes

The core of the marshes is centred around the confluence of the Tigris and Euphrates. It is usually divided into the three major areas (Figure 22): Hammar Marsh, to the south of the Euphrates; Central Marsh, between the Tigris and Euphrates; and Hawizeh Marsh, to the east of the Tigris.

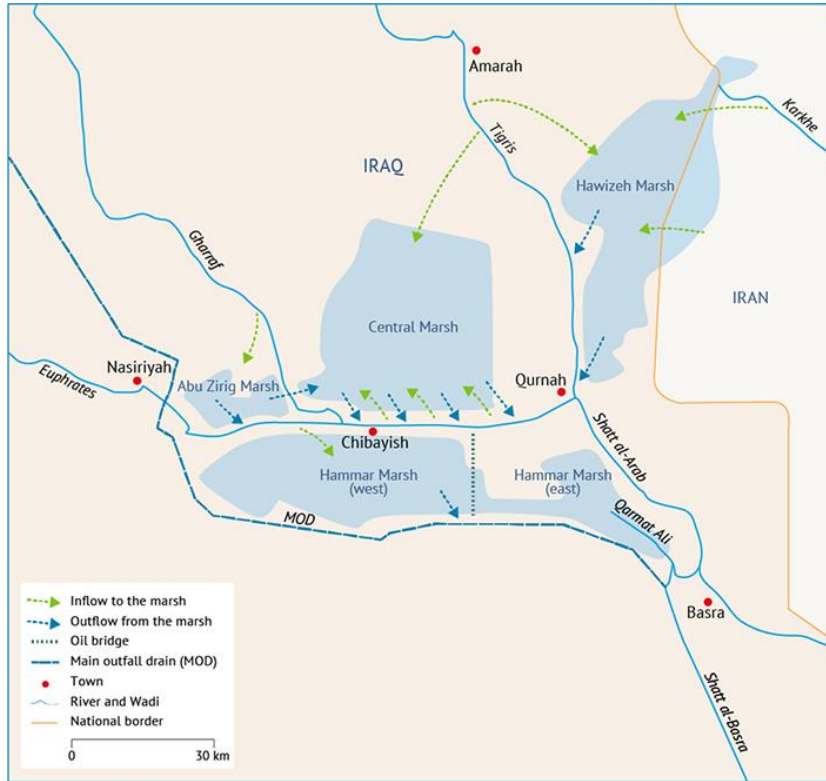


FIGURE 22: MAIN CONNECTIONS BETWEEN THE MARSHES AND THE HYDROLOGICAL NETWORK. SOURCE: [HTTPS://WATER.FANACK.COM/SPECIALS/IRAQI-MARSHES/PHYSICAL-SETTING/#_FTN1](https://water.fanack.com/specials/iraqi-marshes/physical-setting/#_FTN1). ACCESSED FEBRUARY 2022

The primary source of water in the marshlands is the Tigris and Euphrates rivers, with several major tributaries flowing from Iran towards the Tigris and Hawizeh. From the head of the Upper Mesopotamian Plain to the Gulf, the rivers meander slowly and deposit their silt, thereby building up their beds and banks above the level of the plain. This makes the rivers prone to overflow their banks seasonally and change course unpredictably. It is believed that some of the deeper portions of the marshes (lakes) were former river courses that were cut off as the rivers changed course upstream (Sanlaville, 2002). The Tigris and Euphrates split into many branches and form an interior delta which in turn split into smaller distributaries that meander and shift. The levees are smaller and lower than in the Upper Mesopotamian Plain, the groundwater is closer to the surface and depressions between the channels become marshy. Past the delta, the waters flow into the marsh and lake areas, where the land is essentially flat. At this point, the groundwater intersects the ground surface and groundwater outcrops, forming ponds.

The extent of the flooded areas is subject to variability during the year, according to the hydrological regime. Dry years lead to a reduction of the flooded areas, while wet years contribute to an increase in the extent of the marshlands. With less than 200 mm of annual rainfall, the climate in the marshlands is arid subtropical. It is characterised by hot summers (with average maximum temperatures around 43°C) and mild to cool winters (with average minimum temperatures around 4°C). In the summer, dust storms are common and heat waves can raise the temperature to 48°C. During the winter, the temperature can drop to -8°C. Humidity is low and evaporation from free water surfaces is high, causing water losses due to evaporation ten times higher than rainfall contribution over the area. (Food and Agriculture Organization of the United Nations (FAO), 2017).

Change in the 20th Century

Before the 1970s, there was a complex system of natural channels where the Tigris and Euphrates formed interior deltas upstream of the marshes, and the marshes created a highly interconnected system in which the rivers merged and disappeared. This natural system has been altered in the last century with the implementation of agricultural canals, drainage systems and hydraulic structures, which significantly impact the hydrological management of the entire system (Fanack Water, 2017).

The most important development in the 20th century was the establishment of modern water controls in the Tigris and Euphrates basins. This led to a decrease in the significant floods that affected Iraq and consequently also the marshes. In addition, local irrigation projects played an active role in determining the courses of the Tigris and Euphrates and their branches. Furthermore, the marshlands suffered large-scale destruction during the Iraq-Iran War (1980-1988). The Hawizeh Marsh was partially desiccated, and the construction of a road across the Central Marsh parallel to the west bank of the Tigris effectively bisected the marshes from north to south. This was followed in the early 1990s by a massive drainage programme through the construction of several diversion canals aimed at taking water directly to the existing channel network and finally to the sea.

A good indicator of the dramatic decrease in the water flow in southern Iraq is an evaluation of the current water use in all the riparian countries (Turkey, Syria, Iran and Iraq)²¹: of the natural annual volume of about 90 billion cubic metres available in the entire watershed, about 60% is used by agriculture, 10% is used by municipalities and industries, 15% is lost due to evaporation in lakes and reservoirs, with the remaining 15% left for environmental purposes, including the marshlands.

Impact of dams

Since the marshlands are located at the tail end of the Tigris-Euphrates watershed, water storage and control projects are the main activities impacting on the wetlands since as early as 1913. Most of the projects took place after the 1950s, when Iraq embarked on the construction of several new control infrastructure projects, including Samarra Barrage (on the Tigris) and Ramadi Barrage (on the Euphrates), which have diverted excess water towards natural depressions. Haditha Dam on the Euphrates and Mosul Dam on the Tigris were completed in the 1980s. Similarly, Turkey and Syria initiated dam construction projects in the 1960s and 1970s. In 1990, the GAP project in Turkey went online, significantly impacting the Euphrates' flow. At the same time, Iran implemented similar works on the Tigris tributaries. As a result, hydrological records of the main rivers' upstream marshlands area show a remarkable difference in flow regime before and after 1990. The post-1990 average flow through the Euphrates downstream of Hindiyah is approximately half of what it was in the past; in the Tigris, downstream of Kut, flows have decreased to almost a third of their pre-1990 discharge. Additionally, peak flows, which were used to feed the marshlands during extreme runoff events, were reduced to about 25%-30% of their pre-1990 flow. (New Eden Group, 2006). Today (July 2022), the local rural communities in the marshlands are in distress. Amongst these communities, the buffalo producers face a dire situation with the unprecedented low water levels in the areas threatening their livelihoods and communal existence (FAO, 2022).

Agriculture

A plan designed by the Ministry of Water Resources in the 1980s led to the implementation of a more modern type of irrigation and drainage. Agriculture and marshlands were viewed as antithetical, and the marshlands were drained to make way for croplands and other development projects. In subsequent years, this approach was reassessed and, today, more holistic, sustainable approaches that recognize the give and take between agricultural lands and marshlands are gaining ground. For many reasons, including groundwater recharge, microclimate effects, soil salinity and quality improvements, and expansion of future agricultural areas, marshlands have proved to be vital and complementary partners in agricultural development (New Eden Group, 2006). As a result, the plan designed in the 1980s was updated and incorporated into the Strategy for Water and Land Resources (SWLRI), which was finalized by the Ministry of Water Resources in 2015.

Impact on Petroleum Development

To date, the development of oil production facilities has necessitated the drainage of about 5%-10% of the total marshland area. Future development of oilfields within the area may necessitate additional drainage of the marshlands, and such developments should be integrated into the sustainable development strategy to allow for appropriate consideration of the land-use needs of the local inhabitants, ecosystem conservation and agriculture (Fanack Water, 2017).

Re-flooding in the 21st Century and Present Conditions

In early 2000s, the marshes started to be re-flooded by locals and through the central government's Centre for Restoration of the Iraqi Marshlands (CRIM) established in January 2004. In 2003-2005, the Iraq Marshlands Observation System (IMOS) was part of the United Nations Environment Programme's (UNEP) Support for Environmental Management of the Iraqi Marshlands project. While the remote sensing observation programme implemented by UNEP was ended in 2006, the New Eden Team

²¹Data elaborated from New Eden Group (2006); and Ministry of Water Resources (2014), Strategy for Water and Land Resources of Iraq 2015-2035.

continued the project, using similar remote-sensing methodological approaches. By 2006, roughly half the area of the marshes pre-1990 had been restored (El Raey, 2010).

Currently the marshes are managed completely differently: the presence of dams, man-made levees and embankments allows for full control of how water enters the marshes and where it flows. Dams and levees were built to enable and protect human activities. An immediate consequence of the construction of dams was the disappearance of peak flows from the rivers and the reduction of total available water for southern Iraq. At the same time, the construction of an extensive levee system imposed physical constraints on the amount of land potentially available for marshland development as well as the connectivity between marshlands and rivers. The lack of peak flows and hydro-periods, the reduction in water availability and the lack of hydrological connectivity are all contributing to the existence of an unhealthy and unstable marshland system. Recognising that both 'natural' and 'semi-natural' management is no longer feasible or adequate, the Ministry of Water Resources is currently pursuing 'controlled' management, a system where both inflows and outflows are fully controlled. Controlled management attempts to attain the necessary flow-through and water-level variations required by the ecological system to thrive. From a hydraulic standpoint, controlled management operates by preventing or limiting the water flowing out from the inundated areas.

The government has acknowledged the importance of the marshlands for both environmental conservation and water resource management. This was expressed in e.g., the New Eden Master Plan in 2006-2008 and the SWLRI strategic plan in 2015. In addition, concrete actions have been taken, such as the approval on 23 July 2013 by the Iraqi Council of Ministers for the Central Marsh to be designated as the country's first national park. The marshes perform a variety of ecosystem services, including: hospitable environment that serves communities, and reduces the occurrence of migration from the marshes to urban centres, flood hazard mitigation, groundwater recharge, water purification through wetland plant species absorbing some constituents in the marsh water, prevention of erosion, sand or dust storms and desertification, improved microclimate, including lowering local temperatures and increasing local humidity, improved soil structure through the rehydration and introduction of organic matter, increased land value and ecological tourism (Fanack Water, 2017).

Climate Hazards and Impacts

The primary climate risk factors in the **Central and Al Hammar Marshes** are linked to changed water balance, due to hydrological drought affecting inflows and heat/evaporation affecting losses to the atmosphere. Another threat is posed by sea level rise and related saltwater intrusion.

Four climate storylines (i.e., 'warm-moist', 'hot-moist', 'warm-arid', 'hot-arid') will be used to evaluate impacts on human health, crop and fisheries productivity, and water security.

Potential changes in upstream regulation of inflows by dams and water diversions **have not been considered** but these conditions could amplify or dampen the evaluated climate storylines (see for example, Al-Ansari, 2020; Al-Quraishi and Kaplan, 2021; Yasir et al., 2018).

Water Levels

The marshes are affected by both upstream recharge through the T&E and local precipitation and evaporation. Figure 23 shows the boundaries of the marshes according to the RAMSAR database and the T&E catchments.

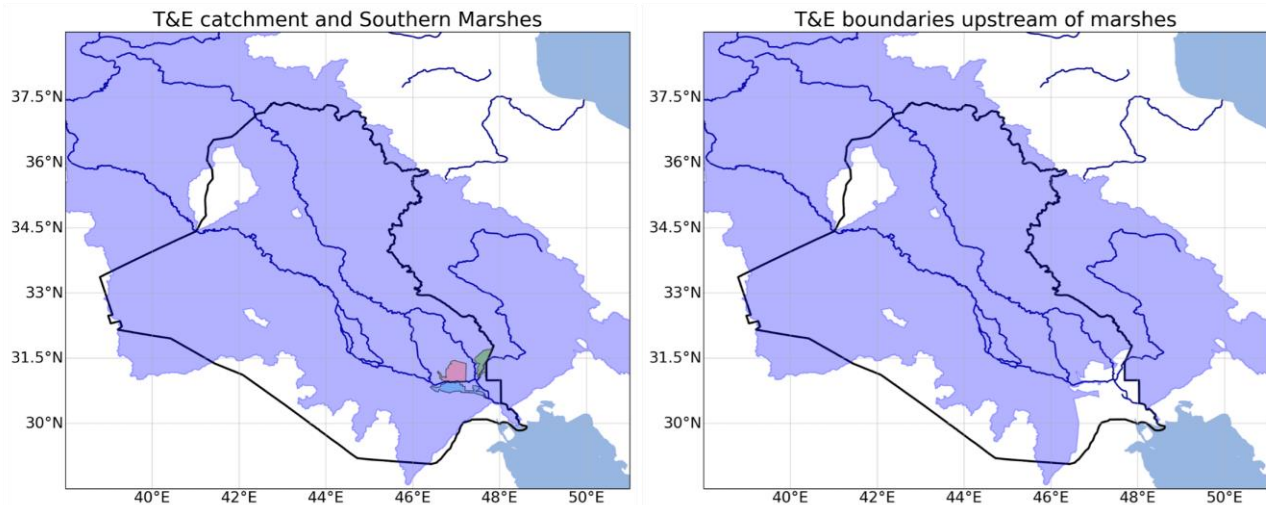


FIGURE 23: (LEFT) BOUNDARIES OF THE MARSHES ACCORDING TO THE RAMSAR DATABASE: CENTRAL (PINK), HAMMAR (LIGHT BLUE) AND HAWIZEH (GREEN). TIGRIS AND EUHRATES RIVERS CATCHMENT (PURPLE AREA) AND RIVERS (BLUE LINES). (RIGHT) T&E CATCHMENT AREA UPSTREAM OF THE MARSHES.

Surface Water

In the absence of hydrological modelling, the potential change in water balance in the marshes driven by climate change was only analysed by the effective precipitation aggregated over the T&E (to represent the inflow) and the effective precipitation over the area of the marshes (outflow). Effective precipitation is simply the difference between precipitation and evapotranspiration.

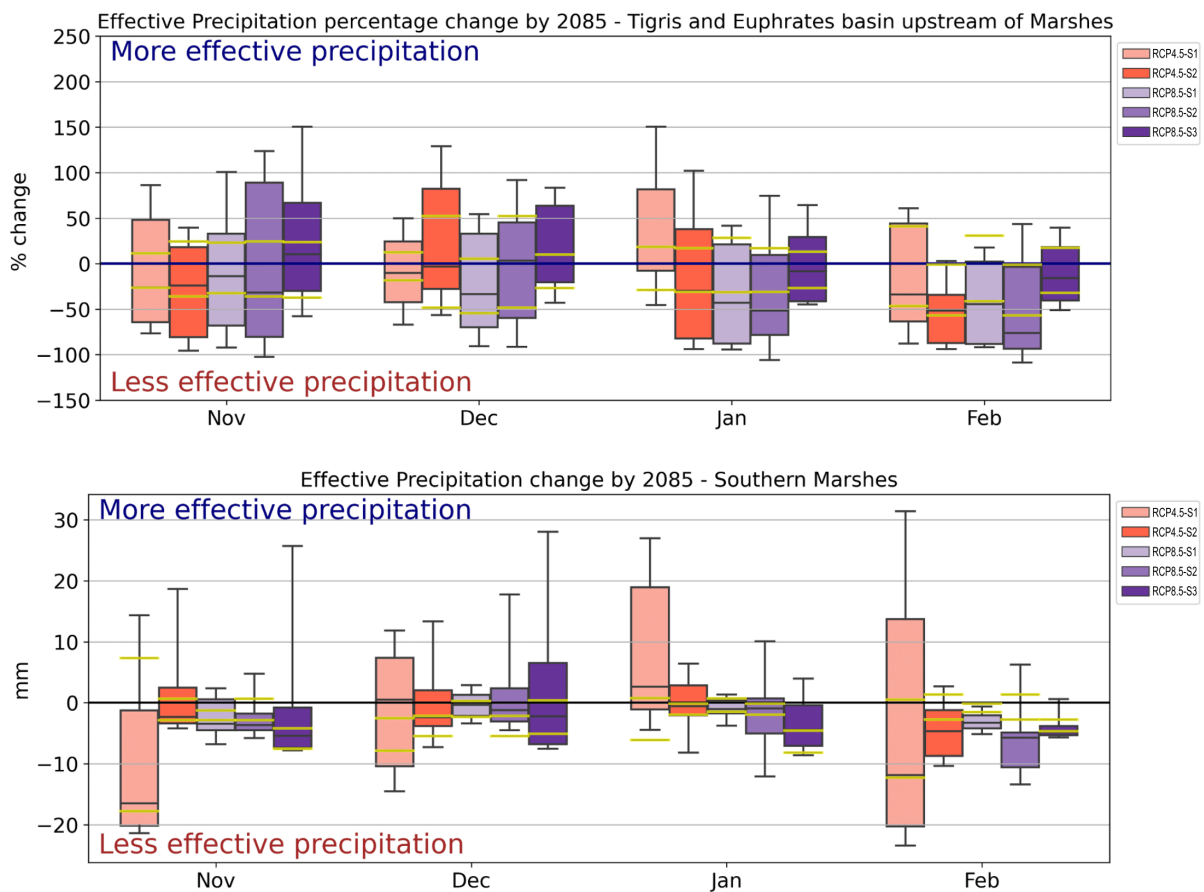


FIGURE 24: EFFECTIVE PRECIPITATION CHANGE BY 2085 (2072-2097) COMPARED TO 1981-2005 LEVEL IN THE AREA ENCOMPASSING THE TIGRIS AND EUHRATES CATCHMENT UPSTREAM OF THE MARSHES (TOP; PERCENTAGE CHANGE) AND LOCALLY IN THE SOUTHERN MARSHES (BOTTOM; CHANGE). RCP4.5 SOMS ARE SHOWN IN ORANGE AND RCP 8.5 IN PURPLE. CHANGE FOR EACH MONTH OF NOVEMBER, DECEMBER, JANUARY, AND FEBRUARY, CORRESPONDING TO THE RAINY SEASON. THE 'NOISE' LEVEL TO DETECT CHANGE IS MARKED BY YELLOW HORIZONTAL BARS, WHICH CORRESPOND TO THE HISTORICAL 25 AND 75 PERCENTILES VARIABILITY.

Figure 24 shows the percentage change in effective precipitation by the year 2085 compared to the 1981-2005 level for the months November to February. The top panel shows a diminishing inflow to the marshes in both RCP4.5 and RCP8.5, with a median of -50%. However, there is large variability, and some models have years with both positive and negative changes each year by the end of the century. Less water in the T&E is likely due to the reduction of snow and rainfall in the northern region of the T&E catchment, which includes Turkey and Syria. Note that this reduction in effective precipitation is due to climatic changes only, thus does not account for potential higher abstraction upstream of Iraq which may also be exacerbated by decreasing rainfall. The bottom panel of Figure 24 shows changes to the local effective precipitation, suggesting a tendency to reduction due to less precipitation and/or more evaporation. Note that the total annual precipitation locally is of about 200 mm/year therefore the projected relative changes are quite significant. There is also a large spread in some models.

Overall, the picture is of a negative water balance for the marshes under both RCP4.5 and RCP8.5. However, as noted above detailed hydrological modelling is needed to confirm the message emerging from this first order analysis, especially in terms of magnitude of change.

Heat

The climate in the marshes is arid subtropical. Future changes in temperature, evapotranspiration and precipitation could affect the local climate. This analysis used the De Martonne aridity index (De Martonne, 1926), which is a simple index that is a ratio between total annual precipitation (P) and annual mean temperature (T) (expressed in degrees Celsius and to which 10°C are added).²² This numerical indicator quantifies the degree of climate dryness at a given location and classifies the type of climate in relation to water availability. The higher the aridity indices of a region, the greater the water resources variability. Although it is one of the oldest aridity/humidity indices, because of its efficiency and relevance in relation to the arid/humid climate classification, it is still used worldwide with good results to identify dry/humid conditions of different regions. It has been recently used in studies of climate in southern Italy (Pellicone, 2019) and in Iran (Piri, 2016).

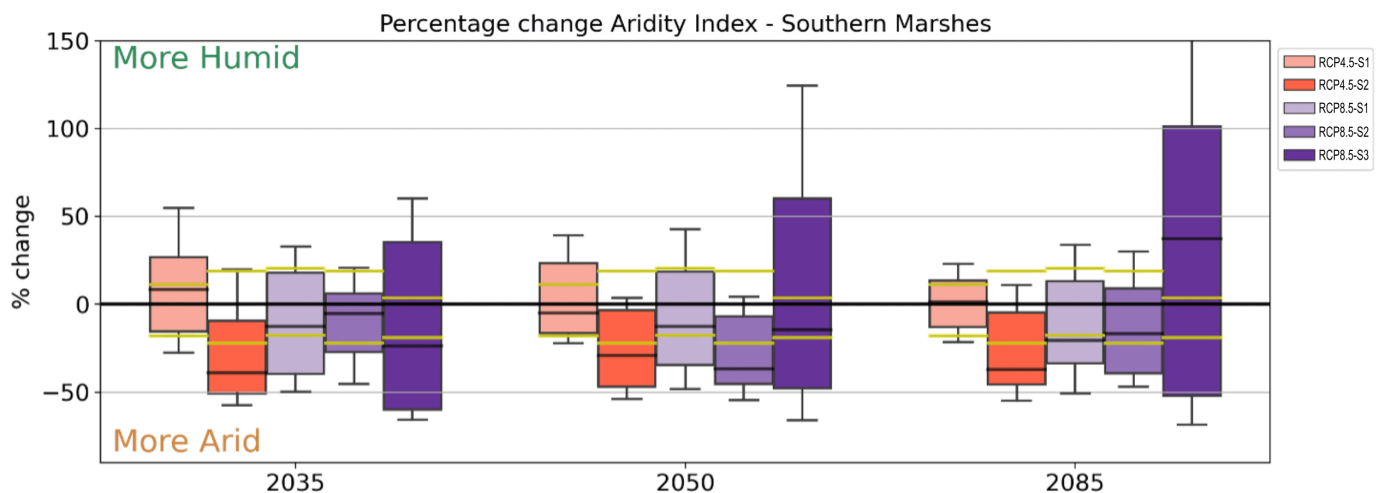


FIGURE 25 PERCENTAGE CHANGE OF THE DE MARTONNE ARIDITY INDEX. THE CHANGE IS WITH RESPECT TO THE HISTORICAL PERIOD (1981-2005). RCP4.5 SOMS ARE SHOWN IN ORANGE AND RCP 8.5 IN PURPLE. THE 'NOISE' LEVEL TO DETECT CHANGE IS MARKED BY YELLOW HORIZONTAL BARS, WHICH CORRESPOND TO THE HISTORICAL 25 AND 75 PERCENTILES VARIABILITY.

The current aridity index in the Iraqi Southern Marshes is around 2-5, between the arid and hyper-arid band according to the De Martonne classification. Future changes to the index are shown in Figure 25 and indicates a tendency towards a more arid climate. However, the median change (black line in the box plot) is larger than the noise level (lower yellow horizontal bar) in only a few models, hence the change is larger than natural variability only a few SOMs. This result is likely due to the combined effect of temperature and precipitation changes: while the temperature clearly increases above natural variability levels by the end of the century (in both RCP4.5 and RCP8.5), the precipitation change is very variable, and this results in the large spread of changes in aridity index (wide boxplots in the vertical dimension). As we noted in the Section 6. Data and Information Sources, the representation of precipitation in some models (for example RCP8.5 S3) is considered unrealistic in comparison with historical period, hence results must be taken with a degree of caution as the overall change in aridity may be underestimated by some models.

²² Aridity index = $P / (T+10)$ [mm/C].

Climate Change and Vulnerability Storylines

The analysis of the previous section, the analysis of hazard maps and review of the literature give the following general picture of the climate hazard changes that can influence the southern marshes. We state our assessment of confidence at the end of each statement (in brackets).

- **Effective precipitation change**

A decrease in effective precipitation over the Tigris and Euphrates rivers catchment upstream of the marshes in the rainy months, resulting in a likely decreasing inflow of water into the marshes themselves. This can potentially reduce the ability of the marshes to recharge in autumn and winter (medium confidence).

An unclear trend in local effective precipitation change in the Southern Marshes, likely linked to the uncertain precipitation trends in Southeast Iraq noted also for the Al-Basrah governorate.

- **Sea level rise**

As noted in the analysis of the Iraqi Persian Gulf region, sea level is increasing and is very likely to reach between +0.5m to +1m by 2100 depending on the emission scenario (note that higher increase cannot be ruled out).

The southern Iraqi marshes may directly feel the effect under high sea level rise, given the possibility that the marshes are likely to be inundated by sea water under the 1 to 2m of sea level rise²³ conditions. The marshes may also be impacted through intrusion of saltwater via the Shatt al-Arab river into portions of the Hammar Marshes and Central Marshes. This effect may significantly affect their water salinity in the next 30-80 years (medium confidence in the scale of hazard, high confidence in the increase in probability of the hazard).

- **Aridity change**

The local climate is likely to become more arid, driven both by an increase in temperature and in the number of warm and dry days. The uncertain precipitation change (with potential for higher precipitation that cannot be ruled out) may still not be able to counterbalance the temperature-driven and evaporation-driven increase in aridity.

- **Temperature and humidity**

As seen in the Al-Basrah region, the temperature will increase together with humidity, and their combined effect will result in high heat stress values. The increase in heat stress is seen across all RCP scenarios (even for the RCP2.6 lower concentration pathway, based on our literature review; high confidence).

Crucially, the magnitude of these changes can vary dramatically between different scenarios, with the higher emission pathway (RCP8.5) reaching levels that threaten human and animal lives (e.g., see Figure 15 and Figure 10).

Given the above results, key climate impacts that can affect the marshlands due to:

- (1) **A decrease in water inflow from upstream** of the marshes (different magnitudes not clearly depending on the RCP scenario, likely due to uncertain precipitation changes);
- (2) **An increase in aridity levels** (different magnitudes not clearly depending on the RCP scenario, likely due to uncertain precipitation changes); and
- (3) **An increase in hot and humid days** (different magnitudes depending on the RCP scenario).

²³ Note there is large uncertainty in the estimates of area under a given amount of sea level, due both to vertical uncertainty in the elevation dataset used and to our method simplified calculation method, as explained in the sea level rise hazard map section.

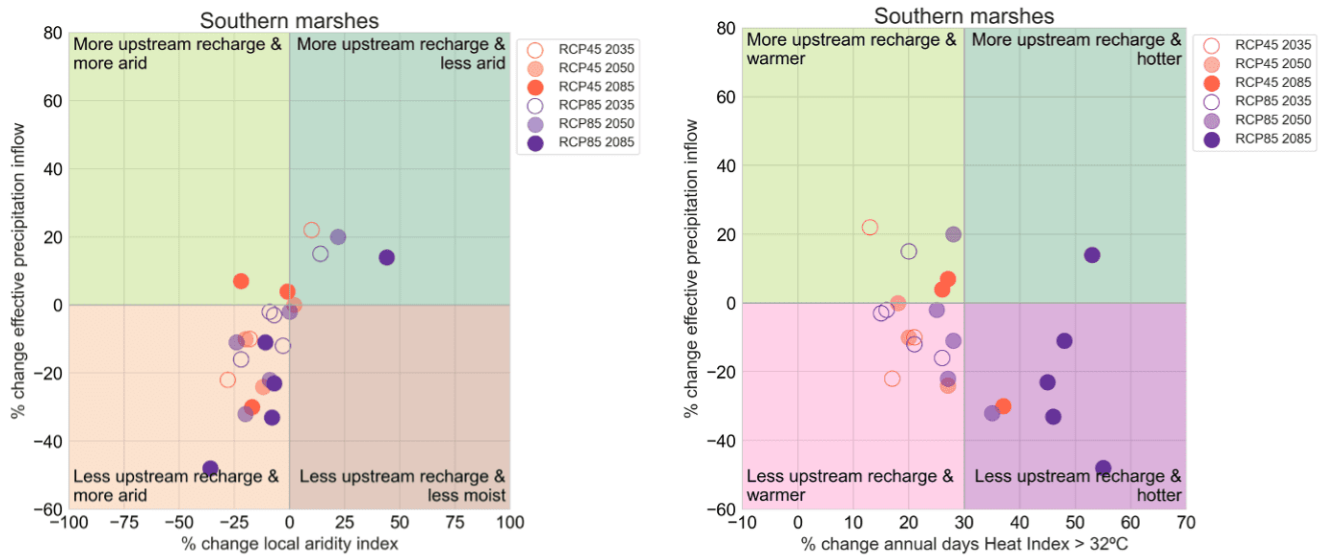


FIGURE 26: CLIMATE CHANGE AND VULNERABILITY STORYLINES FOR THE SOUTHERN MARSHES. (LEFT) CHANGE IN INFLOW (VERTICAL AXIS) VERSUS CHANGE IN LOCAL ARIDITY (HORIZONTAL AXIS); (RIGHT) CHANGE IN INFLOW (VERTICAL AXIS) VERSUS CHANGE IN LOCAL HEAT INDEX (HORIZONTAL AXIS). RCP8.5 (PURPLE) AND RCP4.5 (ORANGE) MEAN ESTIMATES FOR THE 25 YEARS CENTRED AT 2035 (EMPTY DOT), 2050 (FILLED LIGHT DOT) AND 2085 (FILLED DARK DOT). THE LINES DIVIDING THE FOUR QUADRANTS REPRESENT NO CHANGE (0 LINE).

Using these three dimensions of change, eight climate change storylines have been defined corresponding to the four quadrants of each of the two diagrams in Figure 26.

The left diagram (key climate impacts 1 vs 2) shows that most of the models at different points in time in the 21st century fall in the ‘more arid and less upstream recharge’ quadrant (bottom-left), with only a few points showing increase in upstream recharge and moister climate. Given our physical understanding of the system and the added water management pressures to the T&E rivers, we decide to focus only on the storyline of ‘more arid and less upstream recharge’.

The right diagram (key climate impacts 1 vs 3) shows that most of the models at different points in time in the 21st century fall in the two bottom quadrants of ‘warm (hot)-humid and less upstream recharge’, and we will focus on this as a second storyline which is useful to talk about human health impacts as well. Overall, the two storylines are:

- **Climate Storyline 1: ‘more arid and less upstream recharge’, and**
- **Climate Storyline 2: ‘hot-humid and less upstream recharge’**

These storylines reflect a common underlying trend of change with less precipitation upstream and less water in rivers, and a more arid climate driven by higher temperature and higher evapotranspiration but also with increasing numbers of hot and humid days. Note that these storylines are not mutually exclusive. In addition, different ranges of sea level rises are affecting the marshes (as described above). **It is important to recognise that the scenarios do not represent every outcome projected by climate models and the resulting impacts will be further contextualised by local circumstances during the planned *Capacity Building & Consultation Workshop* in Summer 2022. The results of the workshop’s consultation activities on these storylines are summarised in Appendix F.**

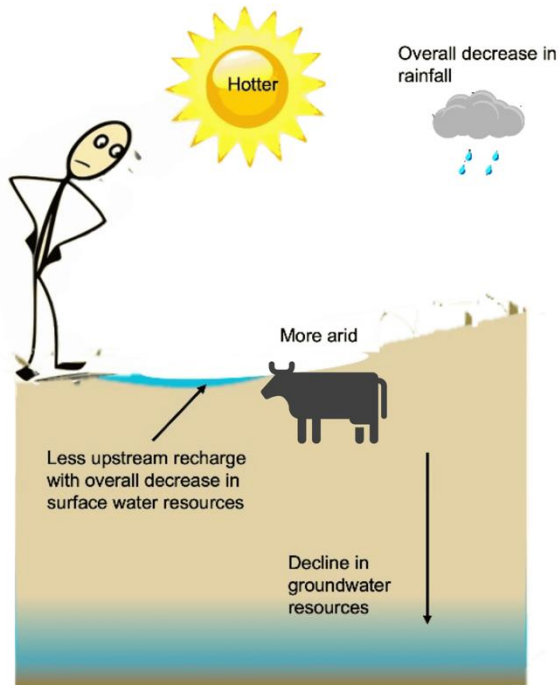


FIGURE 27: CLIMATE STORYLINE 1 - SOUTHERN MARSHES

‘More arid and less upstream recharge’

The temperature is noticeably hotter and more humid with almost 4-5 months a year of Heat Index (HI) consecutively above 32°C, compared to 100 days per year in the historical record. Of this, about 1 month the HI is above 41°C, compared to almost 0 days per year in the historical record.

Maximum temperatures have also increased by a similar amount and hot days are now extremely hot.

The coastal areas are experiencing a sea-level rise of around 0.5m to 1m with saltwater intrusions threatening the marshes.

Rainfall has decreased over the Tigris and Euphrates Basin upstream of the marshes in the rainy months. Less water now flows into the marshes reducing recharge in the autumn and winter seasons.

The local climate is now more arid, driven both by the hotter temperatures and an increase in the number of warm and dry days. The uncertain precipitation change (with potential for higher precipitation that cannot be ruled out) may still not be able to counterbalance the temperature-driven and evaporation-driven increase in aridity

Headline Impacts

Despite large uncertainty in the water balance relating to abstraction upstream and hydropower, this future has significant socio-economic impacts. This includes increased poverty with impact extending to urban communities through significant increases in urban migration from rural, agriculture-dependent areas. What investments might be targeted to increase community, regional and national **hydrological infrastructure** (e.g., deeper groundwater sources, improved abstraction technology)? What are the **challenges for supporting populations whose livelihoods have been disrupted**? What are the challenges for maintaining a healthy urban environment while population grows?

Impacts



Water Resources

- Inter-annual recharge of water resources in the marshes has decreased and in the long term is significantly lower than currently, due to increased evapotranspiration and reduced rainfall both upstream in the Tigris and Euphrates rivers catchment as well as locally.
- The southern marshes are beginning to feel the effect of the 0.5m to 1m high SLR with the intrusion of saltwater via the Shatt al-Arab River into portions of the Hammar Marshes and Central Marshes. This is leading to biodiversity loss and contributing to desertification of the marshes.
- Abstraction upstream of Iraq is exacerbated by decreasing rainfall and may also be contributing to a reduction in river levels.
- Use and demand of surface water is increasing, with the depletion of groundwater, resulting in reduced surface water resources and widespread abandonment of shallow groundwater sources.
- Where available, more emphasis on groundwater for irrigation, livestock, and other productive uses, is causing tension over water access and conflict with domestic users.



Health

- Increasing water salinity and the decline in livestock drinking water means communities have reduced access to sources of protein through e.g., livestock raising.
- Poor diet is exacerbating nutritional deficiencies and impacting the poorest rural communities.
- Incidences of water-borne diseases are rising because people/livestock are concentrated around fewer water sources.

- Vector borne tropical disease incidence is increasing, e.g. leishmaniasis increase due to changes in breeding patterns and distribution of sandflies (Al-Warid et al, 2017).



Agriculture

- Staple crop harvests are reducing due to increasing aridity and increased incidences of pests. Some staples are failing completely.
- The increasing saltwater inundation due to rising sea levels combined with the increasing aridity are detrimental to agricultural practices in the marshes.
- Cash crops are difficult to produce, and livestock are dying due to lack of water and fodder.
- Financial stress is exacerbating food security as households have less income for additional purchase of staple foods in the market to compensate for poor staple crop harvests.
- The loss of productive agricultural land due to salinisation is impacting on food security and rural livelihoods, and disproportionately affecting women (see Table 7).
- Poverty is rising as people lose vital assets and seek to diversify their livelihoods out of agriculture.



Socioeconomic Impacts / Livelihoods

- As the productive land decreases, people are moving away from the marshes and migrating towards the cities, increasing the number of internally displaced people and rural-urban migration.
- Combined impacts of falling crop production and loss of rural employment contribute to significant increase in the cost of Iraq's Public Distribution System and increasing inflation: increased cereal imports are required for welfare distribution and more people require assistance through other forms of social protection.
- Socio-economic opportunities exist for supporting biodiversity and the management of marshland restoration processes.
- Rehydration efforts in the Southern Marshes do not yet equate with restoration of local livelihoods. Ecological recovery and sustainability of marshlands depends on simultaneous restoration of marshland flora and fauna (reed bed products, fishing, agriculture, and livestock). Alternative livelihood options need to be explored if restoration process continues to plateau or reverses with hotter and drier conditions.

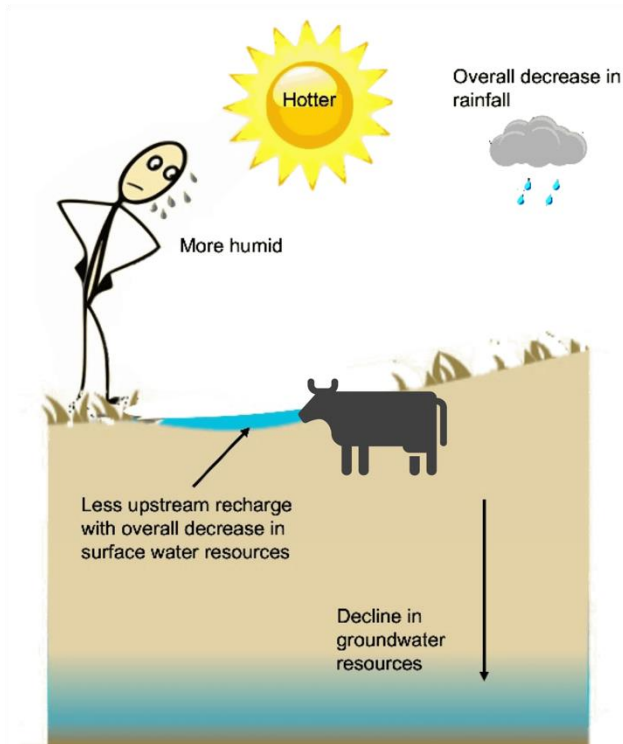


FIGURE 28: CLIMATE STORYLINE 2 - SOUTHERN MARSHES

‘Hot-humid and less upstream recharge’

The temperature is noticeably hotter and more humid with almost 4-5 months a year of Heat Index (HI) consecutively above 32°C, compared to 100 days per year in the historical record. Of this, about 1 month the HI is above 41°C, compared to almost 0 days per year in the historical record.

Maximum temperatures have also increased by a similar amount and hot days are now extremely hot, but also have high humidity, making working very uncomfortable.

The coastal areas are experiencing a sea-level rise of around 0.5m to 1m with saltwater intrusions threatening the marshes.

Rainfall has decreased over the Tigris and Euphrates Basin upstream of the marshes in the rainy months. Less water now flows into the marshes reducing recharge in the autumn and winter seasons.

The local climate is now driven both by the hotter temperatures and an increase in the number of hot and humid days. The uncertain precipitation change (with potential for higher precipitation that cannot be ruled out) may still not be able to counterbalance the temperature-driven and evaporation-driven increase in aridity.

Headline Impacts

Increased poverty in rural, agriculture-dependent areas in the marshes with impact extending to urban communities, including through rural to urban migration. **What are the risks to health in this environment?** How can the higher socio-economic vulnerability linked to loss of rural employment under conditions of increased heat stress and failing be supported? What policies are in place to ensure sustainable development of water-related livelihoods and the sustainable exploitation of water resources? Are there **new skills and jobs** needed to support communities in both rural and urban environments?

Impacts



Water Resources (as Storyline 1)

- Inter-annual recharge of water resources in the marshes has decreased and in the long term is significantly lower than currently, due to increased evapotranspiration and reduced rainfall both upstream in the Tigris and Euphrates rivers catchment as well as locally.
- The southern marshes are beginning to feel the effect of the 0.5m to 1m high sea level rise with the intrusion of saltwater via the Shatt al-Arab River into portions of the Hammar Marshes and Central Marshes. This is leading to biodiversity loss and contributing to desertification of the marshes.
- Abstraction upstream of Iraq is being exacerbated by decreasing rainfall and may also be contributing to a reduction in river levels.
- Use and demand of surface water is increasing, with the depletion of groundwater, resulting in reduced surface water resources and widespread abandonment of shallow groundwater sources.
- Where available, more emphasis on groundwater for irrigation, livestock, and other productive uses, is causing tension over water access and conflict with domestic users.



Health

- People are struggling much more with heat stress. This is impacting on their labour capacity.
- Incidences of water-borne diseases are rising because people/livestock are concentrated around fewer sources.

- Vector borne tropical disease incidence is increasing, e.g. leishmaniasis increase due to changes in breeding patterns and distribution of sandflies (Al-Warid et al, 2017).
- Rural communities have seen a big decrease in their incomes due to water constraints and reduced yields with a poor diet due to reduced access to food, exacerbating nutritional deficiencies and stunting in children. This is impacting the poorest most.



Agriculture

- The increasing saltwater inundation due to rising sea levels combined with the increasing aridity are detrimental to agricultural practices in the marshes.
- Staple crop harvests are reducing due to increasing aridity and increased incidences of pests. Some staples are failing completely.
- Cash crops are difficult to produce, and livestock are dying due to lack of water and fodder.
- Financial stress is exacerbating food security as households have less income for additional purchase of staple foods in the market to compensate for the poor staple crop harvests.
- The loss of productive agricultural land due to salinisation is impacting on food security and rural livelihoods, and disproportionately affecting women (see Table 7).
- Poverty is rising as people lose vital assets and seek to diversify their livelihoods out of agriculture.



Socioeconomic Impacts / Livelihoods

- Migration increases into the urban centres as people turn away from agriculture and look for cash work and temporary labour. Urban infrastructure, sanitation and housing are under pressure with an increase in poor peri-urban areas.
- Migration south to wetter lands is increasing tensions and water competition. Concern increases for people entering the informal economy which lacks social safety nets.
- Tensions rise with the competing water demands and increased migration leading to breakdown of cultural and social systems.
- Financial constraints limit people's ability to adapt and increase reliance on social protection strategies.
- Marginalised rural communities are experiencing greater poverty and the number of ultra- poor are increasing dramatically.
- Combined impacts of falling crop production and loss of rural employment contribute to significant increase in the cost of Iraq's Public Distribution System: increased cereal imports required for welfare distribution and more people require assistance.

10. COMMON IMPACTS ACROSS STORYLINES

Despite uncertainties in the climate projections, it is expected there will be common impact across different storylines. These high likelihood impacts can provide the basis for identifying low regret adaptation options. This section provides a summary of the common impacts described across the two storylines for the Persian Gulf and Shatt Al-Arab region (Section 8) and for the Southern Marshes region (Section 9).

Persian Gulf and Shatt Al-Arab Region

For the two storylines, ‘Hot-humid and less extreme precipitation’ and ‘Hot-humid and more extreme precipitation’, common climatic hazards are:

- increased temperature and humidity levels
- higher sea level
- very likely decreased precipitation in the North of Iraq, with a resulting decrease in flow of the Tigris and Euphrates rivers and the Shatt Al-Araba and Shatt Al-Basra rivers.

As a result, both climate storylines will likely lead to the following sectoral impacts:

Water

- Sea level rise threatens the city of Basra and the port.
- Pre-existing challenges of salinity intrusion in the Shatt al-Arab river, are significantly exacerbated. Water quality deteriorates.
- Sea level rise along the Gulf Coast, and the constant movement of the lowest low-water mark which defines the maritime borders with Kuwait and Iran, creates the potential for international conflict regarding the location of shipping.
- Use and demand of surface water is increasing, with the potential depletion of groundwater, resulting in reduced surface water resources and widespread abandonment of shallow groundwater sources.
- Increase of water salinity and decline in livestock drinking water means communities are keen for (i) water resource management activities, (ii) support from extension services, and (iii) education.
- Effective irrigation systems and rainfall harvesting for irrigation and livestock are vital to support income.

Health

- People struggle significantly with heat stress in the hotter temperatures and high humidity. This is impacting on their labour capacity and productivity.
- Poor diet due to reduced access to sources of protein through e.g., livestock raising decreased due to too hot conditions and reduced water quality in rivers and streams, is exacerbating nutritional deficiencies and impacting the poorest rural communities.
- Many more people are suffering from respiratory conditions with older people and children in particular requiring hospitalization due to the marked increase in severe sand and dust storms.
- Urban areas are particularly at risk of higher temperatures than their surroundings due to their characteristic land use and land cover (LULC) patterns contributing to higher land surface temperatures (LST) through the urban heat island (UHI) effect.
- Water borne diseases increase due to inadequate clean water supply and sanitation, especially in overcrowded cities receiving rural migration.
- Vector borne tropical diseases increase, e.g. incidence of leishmaniasis increase due to changes in breeding patterns and distribution of sandflies (Al-Warid et al, 2017).



Agriculture

- Saltwater intrusion affects soil salinity, causing significant land degradation, contributing to biodiversity loss, and contributing to desertification processes. The loss of productive agricultural land due to salinisation impacts on food security and rural livelihoods.
- In areas where there is saltwater intrusion, livestock raising, a common practice alongside inland fisheries and domestic poultry rearing in years gone by, is now declining further as livestock drinking water deteriorates. This is impacting on rural populations as these together constituted important income streams and sources of protein.

- Reduced reliability in surface water supplies leads to a greater dependency on the variable groundwater resources, especially in times of low rainfall with tensions rising over water access and use.
- Staple crop harvests, such as wheat, barley, rice, vegetables and dates, are reducing due to limited water and increased incidences of pests. Some staples are failing.
- Some households are adopting more drought resistant crops despite the cultural barriers and related additional costs.



Socioeconomic Impacts / Livelihoods

- Due to the variability of the rainfall, the resilience of communities relying mainly on agriculture is undermined, with reserves built up in good years increasingly eroded by losses during bad years. The worst affected households will seek employment in other sectors. Those with access to private wells will be more able to cope than those without which will exacerbate inequalities.
- Increased heat and economic pressures are reducing the availability of manual labourers to keep up with production.
- Also due to the loss of productive agricultural land where there is saline intrusion, many people are migrating and there are increasing numbers of internally displaced people.
- Significant rural-urban migration is putting pressure on urban infrastructure, sanitation, and housing with the peri-urban areas experiencing higher levels of disruption.
- There is a disproportionate impact on women given the very high proportion employed in agriculture – though a significant proportion of men are also working in agriculture.
- The combined impacts of falling crop production in areas affected by saline intrusion, the loss of rural employment and falling economic productivity due to heat stress is contributing to rising inflation and significant increase in the cost of Iraq's Public Distribution System: increased cereal imports required for welfare distribution and more people are requiring assistance.
- Industries, sectors, and workplaces where heat is generated within buildings are suffering from significant labour shortages because of the decreasing productivity from heat stress exposure of staff. Particularly vulnerable businesses include agriculture, construction, landscaping, delivery, oil and gas well operations, as well as bakeries, kitchens, laundries, (indoor heat generating appliances) fire services, iron and steel mills, foundries, manufacturing with furnaces, and warehousing.

Southern Marshes Region

For the two storylines, '**More arid and less upstream recharge**' and '**Hot-humid and less upstream recharge**', common climatic hazards are:

- increased temperature and humidity levels
- higher sea level
- likely increased local aridity (e.g. decrease soil moisture)
- very likely decreased effective precipitation over the Tigris and Euphrates rivers catchment upstream of the marshes in the rainy months, resulting in a likely decreasing inflow of water into the marshes themselves.

As a result, both climate storylines will likely lead to the following sectoral impacts:



Water Resources

- Inter-annual recharge of water resources in the marshes has decreased and in the long term is significantly lower than currently, due to increased evapotranspiration and reduced rainfall both upstream in the Tigris and Euphrates rivers catchment.
- The southern marshes are beginning to feel the effect of the 0.5 m to 1 m higher sea level, with the intrusion of saltwater via the Shatt al-Arab River into portions of the Hammar Marshes and Central Marshes. This is leading to biodiversity loss and contributing to desertification of the marshes.
- Abstraction upstream of Iraq is exacerbated by decreasing rainfall and may also be contributing to a reduction in river levels.
- Use and demand of surface water is increasing, with the depletion of groundwater, resulting in reduced surface water resources and widespread abandonment of shallow groundwater sources.

- Where available, more emphasis on groundwater for irrigation, livestock, and other productive uses, is causing tension over water access and conflict with domestic users.



Health

- Increasing water salinity with the resulting decline in livestock drinking water means communities have reduced access to sources of protein through e.g., livestock raising. Poor diet is exacerbating nutritional deficiencies and impacting the poorest rural communities.
- Incidences of water-borne diseases are rising because people/livestock are concentrated around fewer water sources.
- Vector borne tropical disease incidence is increasing, e.g. leishmaniasis increase due to changes in breeding patterns and distribution of sandflies (Al-Warid et al, 2017).
- People are struggling much more with heat stress. This is impacting on their labour capacity.



Agriculture

- The increasing saltwater inundation due to rising sea levels combined with the increasing aridity are detrimental to agricultural practices in the marshes: from growing crops to fishing and livestock raising.
- Staple crop harvests, such as rice and vegetables, are reducing due to increasing aridity and increased incidences of pests. Some staples are failing completely.
- Cash crops, such as palm dates, are difficult to produce.
- Livestock, such as water buffaloes, are dying due to lack of (and poor quality of) water and fodder. Fishing is also becoming less productive.
- Financial stress is exacerbating food security as households have less income for additional purchase of staple foods in the market to compensate for poor staple crop harvests.
- The loss of productive agricultural land due to salinisation is impacting on food security and rural livelihoods, and disproportionately affecting women.
- Poverty is rising as people lose vital assets and seek to diversify their livelihoods out of agriculture.



Socioeconomic Impacts / Livelihoods

- As the productive land decreases, people are moving away from the marshes and migrating towards the cities, increasing the number of internally displaced people and rural-urban migration.
- Combined impacts of falling crop production and loss of rural employment contribute to significant increase in the cost of Iraq's Public Distribution System and increasing inflation: increased cereal imports are required for welfare distribution and more people require assistance through other forms of social protection.
- Socio-economic opportunities exist for supporting biodiversity and the management of marshland restoration processes.
- Rehydration efforts in the Southern Marshes do not yet equate with restoration of local livelihoods. Ecological recovery and sustainability of marshlands depends on simultaneous restoration of marshland flora and fauna (reed bed products, fishing, agriculture, and livestock). Alternative livelihood options need to be explored if restoration process continues to plateau or reverses with hotter and drier conditions.
- Financial constraints limit people's ability to adapt and increase reliance on social protection strategies.
- Marginalised rural communities are experiencing greater poverty and the number of ultra-poor are increasing dramatically.

11. FINAL REMARKS

The overall aim of this work was to present first- and second-order climate level risks, informed by Iraqi stakeholders, to help build climate resilience in two eco-regions. The objectives were to engage with Iraq decision-makers in a participatory way to improve the understanding of climate change projections and impacts in selected eco-regions of Iraq, specifically the Southern Marshes and the Persian Gulf and Shatt Al-Arab eco-regions and provide Iraq decision-makers with impact analyses and data to incorporate in their decision-making processes. This is vital to equip Iraq in identifying and planning for technical support activities and multi-sectoral cooperation to formulate and implement the NAP process. It is anticipated that this technical report may serve as the analytical underpinning for ongoing discussions taking place within the Iraq government, including the Ministries of Health and Environment and the Iraq General Authority for Meteorology and Seismic Monitoring of the Ministry of Transport, on how to best move forward in building climate resilience to climate change.

Throughout the assignment, consultative processes have been maximised where possible with the alignment of the approach to good practice used by the wider community of UN stakeholders in supporting National Adaptation Planning for other countries and linked UNFCCC programmes (e.g., UNFCCC Nairobi Work Programme) that similarly aimed to engender ownership of the process and results. The stepwise consultation “knowledge-to-action” approach was adopted for gathering stakeholder views on priority knowledge gaps in existing climate modelling capacity, and the mandate and operational model for the proposed Iraq Climate Modelling Unit, with the culmination of the consultation involving the government officials, stakeholders and scientific communities (the expert group), informing the development of the climate risk in first order and second-order risk domains. This expert group provided inputs to the methodological paper which underpinned the climate risk assessment and identified the eco-regions of interest. The expectation is that this identified expert group will now continue to collaborate in developing future actions to address identified risks.

The culmination of the detailed climate risk assessment was the description of two plausible climate storylines for each of the two eco-regions prioritised by the Iraq government – the **Basra and the Shatt al-Arab region** in Southern Iraq, and the **Central and Al Hammar Marshes**. The four climate storylines were used to evaluate impacts on human health, crop and fisheries productivity, and water security. Each storyline reflected a common underlying trend of change with less precipitation upstream and less water in rivers, and a more arid climate driven by higher temperature and higher evapotranspiration but also with increasing numbers of hot and humid days. Note that these storylines are not mutually exclusive. Furthermore, different ranges of sea level rises are affecting both the Gulf region and the Southern Marshes. The introduction of the climate storylines recognised that in the production of these climate risk assessments, there is a cascade of uncertainty.

Different data sets, parameters and models may be more appropriate at the local scale or may give slightly different quantifications of the effects of climate change. There are also many potential variations on indicators for each eco-region, and the projected impacts are likely to be sensitive to the precise definitions of the climate indices used.

Precipitation is a particularly complicated process to model due to the many components that can affect it, some of which are described differently across models. As a result, some models cannot reproduce the past precipitation climatology satisfactorily. The appropriate way to handle these biases, and still make reasonable inferences about the future changes in precipitation, is to quantify *the change compared to the model’s representation of the past* i.e., by looking only at changes and not interpreting the projected absolute values. Similarly, only an analysis with detailed hydrological modelling can properly quantify the risk to surface water flooding for the Gulf eco-region (since extreme precipitation does not necessarily result in flooding) and can properly quantify the actual change in water balance for the marshes, only approximated with change in effective precipitation inflow and outflow in this assessment. It is also important to note that potential changes in upstream regulation of inflows by dams and water diversions were not considered in the risk assessment, but these conditions could amplify or dampen the climate storylines.

Currently, this deep uncertainty cannot be resolved other than considering the different scenarios as plausible and, in the context of planning for adaptation, consider which effects these may have and if, for example, there are common strategies to mitigate them. This is one of the key reasons for introducing the storylines of future climate for Iraq.

This work has also exposed some data constraints. Due to a lack of quantitative data on exposure and the short timeframe for this analysis, the potential impacts have been described only qualitatively. Future work will be devoted to quantifying the potential socio-economic impacts.

Finally, whilst the ultimate objective is a robust integration of first- and second-order climate level risks into the Iraq NAP, in the short term, it is expected that this analysis can be used to support and encourage engagement of the governorates with climate risks within the NAP development window of opportunity. Further refinement and closure of the adaptation knowledge gaps that still exist can be achieved through the implementation and then long-term operationalisation of the proposed **Iraq Climate Modelling Unit**. The reader is referred to the **Climate Modelling Unit Strategy Guide** (Cornforth et al., 2022b) and the recommendations therein, that link back to the results presented here. For ease of reference, these are reproduced here in Appendix G.

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APPENDIX A

Guidance to Representative Concentration Pathways

The RCP pathways represent a broad range of climate outcomes and are neither forecasts nor policy recommendations. They include a wide range of assumptions regarding population growth, economic development, technological innovation, and attitudes to social and environmental sustainability. Each pathway can be met by a combination of different socioeconomic assumptions. More information on RCPs is available in van Vuuren et al (2011).

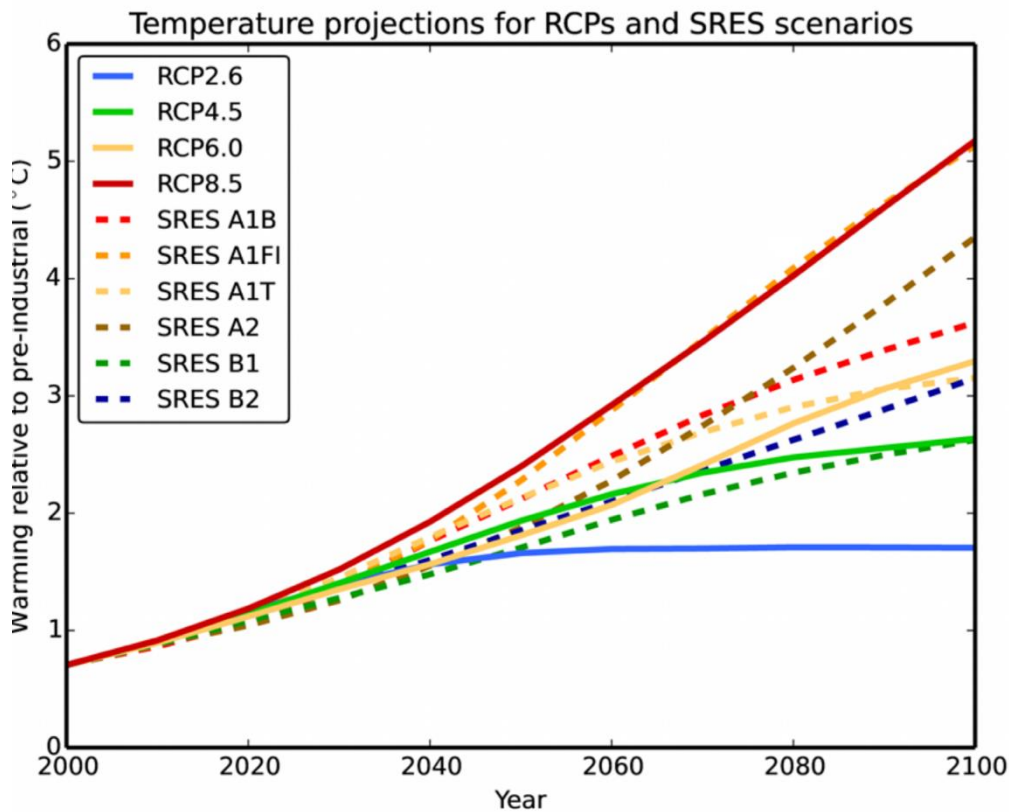


FIGURE 29: GLOBAL MEAN TEMPERATURE PROJECTIONS FROM A CLIMATE MODEL (CALLED MAGICC6) RELATIVE TO A PRE-INDUSTRIAL AVERAGE (1850-1900) FOR RCP2.6 (BLUE), RCP4.5 (GREEN), RCP6.0 (YELLOW) AND RCP8.5 (RED) AND THE OLDER SRES SCENARIOS (DASHED COLOURED LINES). SOURCE: [HTTPS://WWW.METOFFICE.GOV.UK/BINARIES/CONTENT/ASSETS/METOFFICEGOVUK/PDF/RESEARCH/UKCP/UKCP18-GUIDANCE---REPRESENTATIVE-CONCENTRATION-PATHWAYS.PDF](https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---representative-concentration-pathways.pdf)

RCP2.6 (blue line in Figure 29) represents a pathway where greenhouse gas emissions are strongly reduced, resulting in a best estimate global average temperature rise of 1.6°C by 2100 compared to the pre-industrial period. RCP8.5 (red line in Figure 29) is a pathway where greenhouse gas emissions continue to grow unmitigated, leading to a best estimate global average temperature rise of 4.3°C by 2100. RCP4.5 and RCP6.0 are two medium stabilisation pathways, with varying levels of mitigation.

The increase in the global mean surface temperature averaged over 2081-2100 for each RCP is summarised in Table 8.

RCP	Change in Temperature (deg C) by 2081-2100
RCP2.6	1.6 (0.9-2.3)
RCP4.5	2.4 (1.7-3.2)
RCP6.0	2.8 (2.0-3.7)
RCP8.5	4.3 (3.2-5.4)

TABLE 8: THE INCREASE IN GLOBAL MEAN SURFACE TEMPERATURE AVERAGED OVER 2081-2100 COMPARED TO THE PRE-INDUSTRIAL PERIOD (AVERAGE BETWEEN 1850-1900) FOR THE RCP PATHWAYS (BEST ESTIMATE, 5-95% RANGE). FROM IPCC AR5 WG1 TABLE 12.3

APPENDIX B

Background to the Self-Organising Maps (SOMs) Approach

Dr. Mike Harrison, Climate Change Risk Management [(CCRM), part of the Wood Consortium.

Edited by Prof. Rosalind Cornforth, Walker Institute.

Extensive discussions followed the Day 1 (26th July) presentations on climate change projections at the UNEP project workshop in Beirut (26-28th July 2022), regarding the non-deterministic nature of the projections and the fact that some of the pathways identified suggest an increase in rainfall over Iraq.

Two issues are considered in more detail here:

1. The background to the self-organising maps (SOMs) approach, and the reasons for probabilistic projections, some of which included increased rainfall,
2. Further analyses possible using the downscaled data.

Much of the succeeding information might be followed up by the proposed Iraq Climate Modelling Unit. The Consortium would be willing to assist the CMU on request as required.

B1. The background to the self-organising maps approach, and the reasons for probabilistic projections, some of which included increased rainfall

Climate change projection is not a deterministic process but one in which the objective is to identify all possible futures, given current climate modelling capabilities and uncertainties over future atmospheric greenhouse gas concentrations. To achieve this a large ensemble of projections from different models (CMIP) is used under a range of emissions scenarios (RCPs and SSPs). If the ensemble is “proper” then all possible outcomes are covered in their correct likelihoods, but we know this is unlikely to be the case – evidence suggests the atmosphere is warming faster than many models indicate – but this is the best information available.

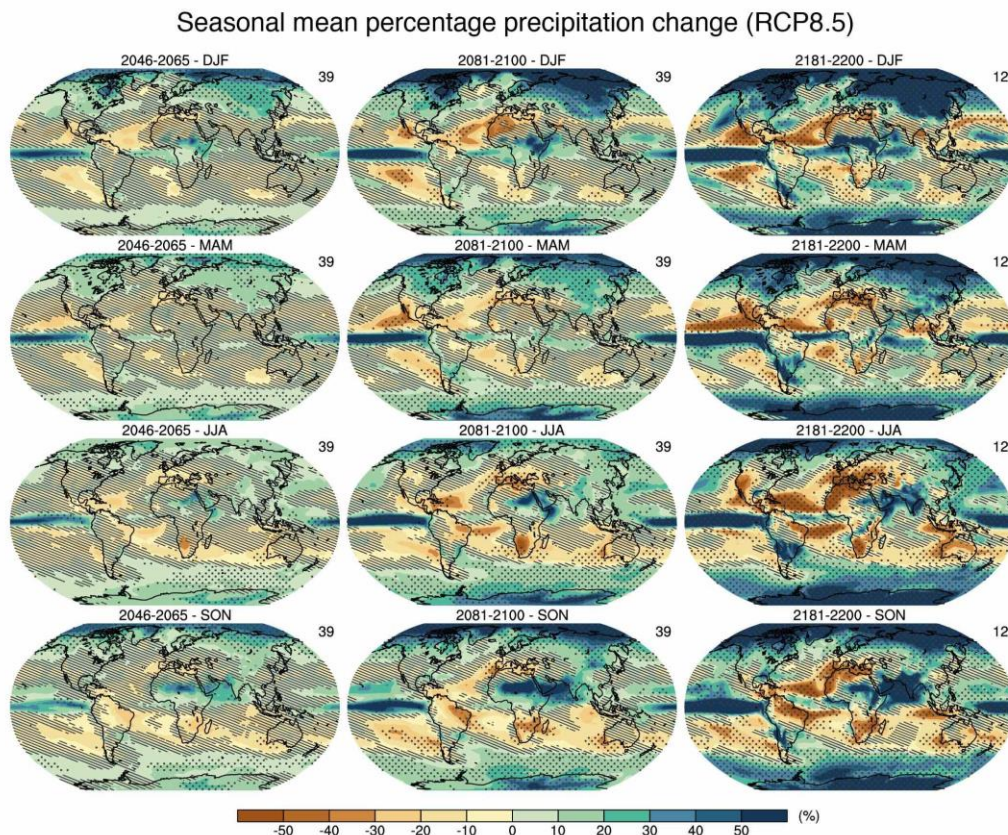


FIGURE 30 ENSEMBLE MEAN RAINFALL CHARTS UNDER RCP8.5. SOURCE: WGI CHAPTER 12 OF IPCC AR5 (FIGURE 12.22, P.1078)

Part of the issue is that much of the information in the IPCC AR5 might be seen on a brief glance as deterministic. Thus, it is easy to gain the impression from the ensemble mean rainfall charts under RCP8.5 on p.1078 of WGI Chapter 12 of the AR5 in Figure 12.22 that rainfall over Iraq is likely to decline. For ease of reference, this figure is reproduced in Figure 30 above.

However, in the perhaps less-visited pages of Annex I of the AR5 there exists the possibility, typically exceeding 25% of increased rainfall under all emissions scenarios. Similarly the presentation in WGI Chapter 4 of the AR6 (Figure 4.24) might suggest a decrease over Iraq (although there appears more chance compared to the AR5 of an increase, an issue mentioned in the technical report), but the following diagram in Figure 31, from the AR6 Interactive Atlas, indicates, for an area that includes but extends beyond Iraq, that while the mean is close to zero change, some projections are for both significant increases and significant decreases (the red average projection line runs approximately along zero change, with increased projections above (to over +60% in some cases) and decreased projections below (to almost -50% in some cases)).

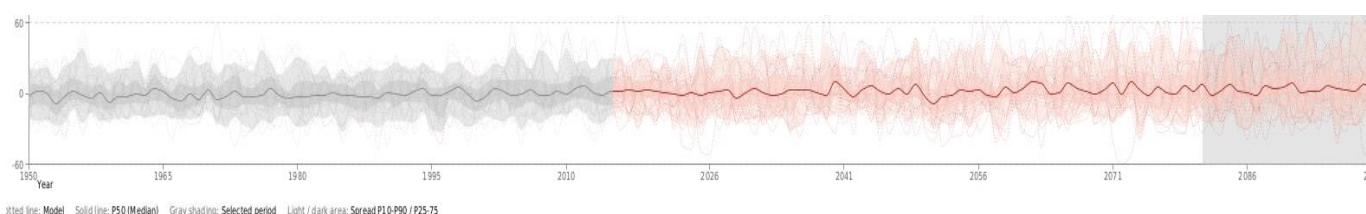


FIGURE 31 PRECIPITATION CHANGE EXPRESS IN PERCENTAGE (WITH RESPECT TO THE PERIOD 1950-2015) UNDER RCP8.5 FOR AN AREA THAT INCLUDES IRAQ, FROM IPCC AR6 INTERACTIVE ATLAS.

The self-organising maps (SOMs) approach is a technique to simplify the complex projection information by seeking out pathways that are supported by the majorities of the models, an approach consistent with predictability theory. Assuming the ensembles are proper, then it is also possible to estimate likelihoods for each pathway. An example is given below in Table 9 taken from the technical report submitted under the UNEP Iraq project.

TABLE 9: LIKELIHOOD OF RAINFALL CHANGES FROM RCP2.6 FROM THE 4 SOMS, AND FOR THE ENSEMBLE UPPER AND LOWER EXTREMES (UE AND LE)

RCP2.6 November to April using 4 soms				
Likelihood	som	2035	2060	2080
45%	1	1.0/1.00	1.0/1.00	1.0/1.00
20%	2	1.0/1.25	1.5/1.30	1.5/1.25
20%	4	2.0/0.95	2.0/1.00	2.0/0.85
15%	3	0.5/0.80	0.5/0.80	0.5/0.80
UE		1.0/1.35	1.5/1.40	2.0/1.25
LE		1.0/0.80	1.0/0.75	2.0/0.70

In this case, for RCP2.6, four pathways were identified, that with highest estimated likelihood, 45%, indicating little, if any, change, in rainfall, the second with 20% likelihood suggesting increased rainfall of order 25%, then two final pathways with a combined likelihood of 35% looking towards rainfall decreases. Strictly these changes apply only over central Iraq, with likelihoods of increases higher in the south and lower in the north, according to the AR5 and AR6.

No SOMs results were provided for RCP6.0 as there are no CORDEX downscaled projections available and note that RCP2.6 was not used in the production of the storylines, but all results are available in the report. In the above table there are also pathways that reasonably represent the outer parts of the full ensemble, the Upper and Lower Extremes (UE and LE); these are available for all RCPs but were not used later in the project.

B2. Further analyses possible using the downscaled data.

Based on the CMIP pathways as discussed above, the closest CORDEX RCM to each pathway was then identified (see the ellipse diagrams in the technical report). These RCMs replicate closely the average changes in temperature and rainfall through the century as determined through the SOMs, but do not necessarily replicate smaller-scale details in a consistent manner. So, if

two RCMs were similar in replicating a particular SOM pathway it does not follow necessarily that they would simulate changes in, say, heavy rainfall events comparably.

Many data were supplied from the identified RCMs for the three RCPs, but resource limitations dictated that not all were used. Thus, it is possible to investigate these data in much more detail to gain insight into parameters such as: lengths of heatwaves, periods of drought and heavy rain, etc. The following is a list of the data downscaled under the project; further data are available from the models and additional indices could be calculated from these data (in addition data were supplied that included simulations over a historic period and from ERA5).

Please note that **in any additional analyses using the RCMs the objective is not to identify a 'preferred' model**, or even a 'preferred' emissions scenario, but to review all the available information, taking into consideration the suggested likelihoods, to gain an overall view in similar manner to the way in which the storylines were developed.

- Daily average temperature
- Daily maximum temperature
- Daily minimum temperature
- Daily rainfall total
- Daily surface evaporation
- Daily average relative humidity
- Daily average surface wind speed
- Daily maximum 3-hour surface wind speed
- Daily maximum gust speed
- Daily surface snow amount
- Daily snow depth
- Daily surface snow melt
- Daily surface air pressure
- Daily sunshine duration
- Daily surface runoff
- Daily short-wave downwelling radiation
- Daily long-wave downwelling radiation
- Daily short-wave upwelling radiation
- Daily long-wave upwelling radiation
- Daily east-west average wind
- Daily north-south average wind

The following were proposed to be calculated separately either from the RCM data and/or from other sources:

- Precipitation intensity
- 3-month SPI
- Number of warm days >90th percentile
- Number of warm nights >90th percentile
- Daily temperature range
- Length of periods with daily rainfall ≤1mm
- UTCI (Universal Thermal Climate Index)
- MTR (Mean Radiant Temperature)
- Days with snow cover
- Flooding index
- Sea level rise
- Water scarcity index
- Atmospheric CO₂ concentration
- Solar elevation angle
- Daily dew-point temperature

APPENDIX C

Indices produced from the downscaling

The indices listed below in Table 10 are available for each of the RCPs and SOMs.

TABLE 10: TEMPERATURE-BASED INDICES AVAILABLE FOR EACH RCP AND SOM (CORDEX DATA).

Climate variable / hazard	Climate index	Definition	units
Temperature	Mean Temperature	Mean daily air temperature	°K
Temperature	Temperature Range	Daily air temperature range: Tmax - Tmin	°K
Temperature	Low Temperature	Minimum daily air temperature	°K
Temperature	High Temperature	Maximum daily air temperature	°K
Temperature	Warm Days	Annual number of Days when Tmean > 90th percentile	Days
Temperature	Warm Nights	Annual number of Nights when Tmin > 90th percentile	Days
Temperature	Warm Spells	Annual number of days with at least 6 consecutive days when Tmax > 90th percentile	Days

TABLE 11: PRECIPITATION-BASED INDICES AVAILABLE FOR EACH RCP AND SOM (CORDEX DATA).

Climate variable / hazard	Climate index	Definition	units
Precipitation	Annual Simple Precipitation Intensity Index	The annual average amount of daily precipitation received on wet days (days with > 1 mm).	mm
Precipitation	Daily Precipitation	Daily precipitation during different precipitation types (e.g., liquid, solid) and scale (e.g., global, synoptic, meso, micro)	kg m ⁻² s ⁻¹
Precipitation	Wet Spells	Annual maximum number of consecutive wet days (R >= 1.0 mm)	days
Precipitation	Effective Precipitation	Annual highest effective precipitation during a continuous 30-day period	kg m ⁻² s ⁻¹

TABLE 12: ICE AND SNOW-BASED INDICES AVAILABLE FOR EACH RCP AND SOM (CORDEX DATA).

Climate variable / hazard	Climate index	Definition	units
Ice / snow	Daily Snowfall	Daily Surface Snow Amount	kg m ⁻² s ⁻¹
Ice / snow	Snow Depth	Daily snow on ground	m
Ice / snow	Snow Cover	Annual total number of days with snow cover	day
Ice / snow	Surface snow melt	Daily surface snow melt	mm

TABLE 13: WIND-BASED INDICES AVAILABLE FOR EACH RCP AND SOM (CORDEX DATA).

Climate variable / hazard	Climate index	Definition	units
Winds	Daily Maximum Surface Wind	Maximum value of daily maximum wind speed	m/s
Winds	Daily Mean Surface Wind Mean of daily mean wind strength (m/s)	Mean of daily wind surface	m/s
Winds	Daily Maximum gust Daily maximum near surface wind speed of gust	Maximum value of daily maximum wind gust	m/s
Winds	Eastward Near-Surface Wind	Daily mean of eastward winds	m/s
Winds	Northward Near-Surface Wind	Daily mean of northward winds	m/s

TABLE 14: RADIATION-BASED INDICES, SEA LEVEL PRESSURE AND HUMIDITY AVAILABLE FOR EACH RCP AND SOM (CORDEX DATA).

Climate variable / hazard	Climate index	Definition	units
Pressure	Sea Level Pressure (SLP)	Daily mean sea level pressure	Pa
Radiation	Duration of Sunshine	Daily sunshine hours	s
Radiation	Surface downwelling Longwave/shortwave radiation	Daily mean of downwelling longwave/shortwave flux in the air	W m ⁻²
Radiation	Surface Upwelling Longwave/shortwave Radiation	Daily mean of upwelling longwave/shortwave flux in the air	W m ⁻²
Humidity	Near surface relative humidity	Daily mean relative humidity	%

TABLE 15: DERIVED INDICES (CORDEX DATA).

Climate variable / hazard	Climate index	Definition	units
Hot-humid	Heat index (HI)	Daily NOAA HI based on combination of temperature and relative humidity	°C
Cold-wet	Cold-Wet Days	Annual number of days with Tmean < 25th percentile of daily mean air temperature; and with precipitation > 75th percentile of daily amounts	days
Hot-dry	Warm-dry days	Annual number of days with Tmean > 75th percentile of daily mean air temperature; and with precipitation < 25th percentile of daily amounts	days
Drought / low precipitation	Standardized Precipitation Index (SPI)	A statistical indicator that compares the total precipitation at a location during a 12-month period with the long-term rainfall distribution for the same period of time at that location. Annual value. Negative/positive SPI indicates below/above normal standard deviation.	no units, is a standardized coefficient
Humidity	Near surface relative humidity	Daily mean relative humidity	%
Drought / low precipitation	Dry Spells	Annual maximum number of consecutive dry days (R < 1.0 mm)	days
Drought / low precipitation	Evaporation	Daily land evaporation from surface and subsurface mas	kg m ⁻² s ⁻¹

APPENDIX D

Changes in Maximum Annual Number of Consecutive Dry Days and Annual Average Intensity of Precipitation by 2085

Change in maximum annual number of consecutive dry days

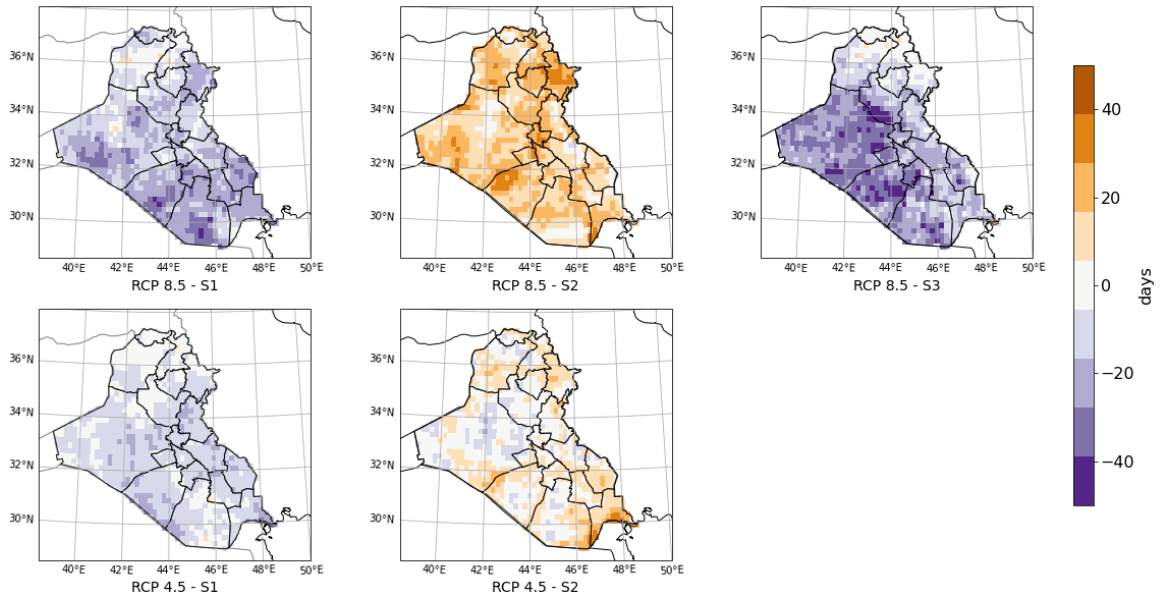


FIGURE 32: CHANGE IN MAXIMUM ANNUAL NUMBER OF CONSECUTIVE DRY DAYS BY 2085 COMPARED TO HISTORICAL, IN THE REGIONAL CLIMATE MODELS (SOMS) SELECTED FOR RCP8.5 (TOP ROW) AND RCP4.5 (BOTTOM ROW).

Figure 32 shows the change in the maximum length of a dry spell (consecutive days with precipitation <1mm): S1 and S3 show a that the length of dry spells decreases to 10-30 days, meaning the stretch of consecutive dry days decreases; S2 shows an opposite picture with longer dry spells across the country.

Change in annual average intensity of rain during wet days

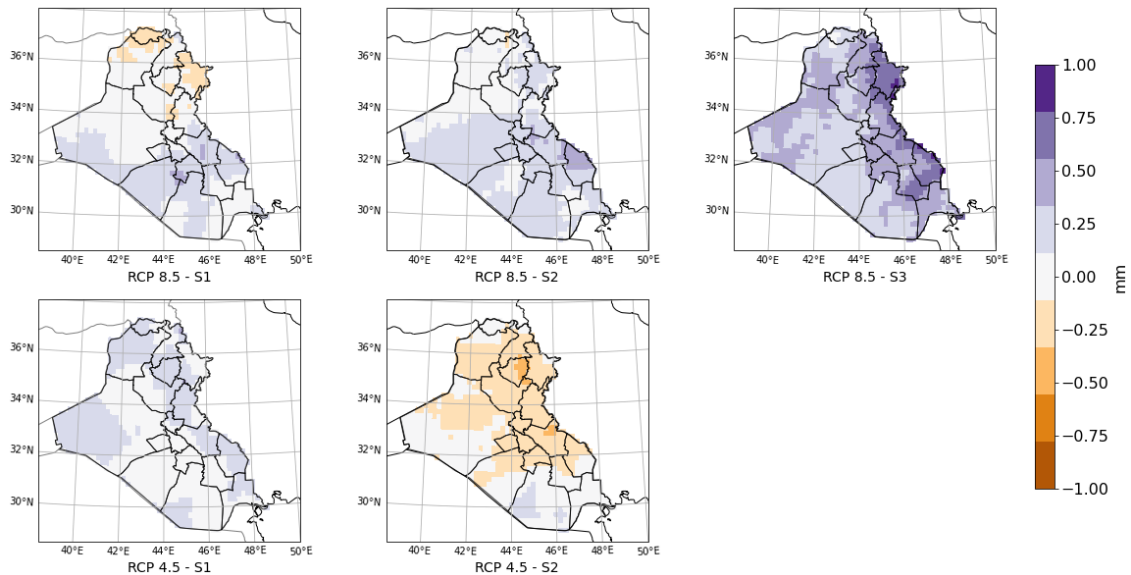


FIGURE 33: CHANGE IN ANNUAL AVERAGE INTENSITY OF RAIN DURING WET DAYS BY 2085 COMPARED TO HISTORICAL, IN THE REGIONAL CLIMATE MODELS (SOMS) SELECTED FOR RCP8.5 (TOP ROW) AND RCP4.5 (BOTTOM ROW).

Figure 33 shows the change in average annual intensity of rainy days. Across most of the SOMs, a slight increase in intensity seems to emerge in the south part of the country.

APPENDIX E

Workshop consultation on the storylines for the Persian Guld and Shatt Al-Arab ecoregion

Climate Storyline 1: Hot-humid and more extreme precipitation (with underlying increase in SLR and low availability of water resources)

Group 2			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Saltwater intrusion Crop damage Land degradation Biodiversity Displacement 	<ul style="list-style-type: none"> Water treatment Crop management Land use good practice Protected area Increased resilience to enhance farmers' livelihoods 	<ul style="list-style-type: none"> Governmental actions to increase water supply for these areas. Plant rice and other crops that needs wet soil Raise awareness among the farmers to plant suitable crops Land reclamation Raise awareness among the farmers and habitants to collect information about Biodiversity of the area Increase support for the people
Water resource management	<ul style="list-style-type: none"> Chemical and industrial water pollution Saltwater intrusion Drought 	<ul style="list-style-type: none"> Emergency plans for contamination Rainwater draining 	<ul style="list-style-type: none"> Raise awareness
Health	<ul style="list-style-type: none"> Communicable diseases Heat stress 	<ul style="list-style-type: none"> Heath Institutions that are specialised in climate related diseases Emergency Plan 	<ul style="list-style-type: none"> Cooperation between the Governments Institutions Raise awareness

Group 4			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Food security Low productivity Loss in the Agricultural areas Over saturated Soil Soil erosion Soil salinity Displacement of farmers New types of pests 	<ul style="list-style-type: none"> Smart Agriculture Plant selectivity Regular inspection Preventing land change 	<ul style="list-style-type: none"> Reviewing of our legislation Monitoring stations Infrastructure rehabilitation Motivate investment (green financial resources availability)
Water resource management	<ul style="list-style-type: none"> Water quality changes Costly treatment Water scarcity Conflict Invasive species appear 	<ul style="list-style-type: none"> Water harvesting Reservoirs Development of a water management system Wave breaker 	<ul style="list-style-type: none"> Monitoring systems Building capacity Early warning systems Raising awareness Assets conservation
Health	<ul style="list-style-type: none"> Emergence of new diseases Pressure on health facilities Malnutrition Increasing disease transmission 	<ul style="list-style-type: none"> Building capacity of health staff Changing the lifestyle 	<ul style="list-style-type: none"> Build new smart health facilities Raising awareness Early warning systems

Climate Storyline 2: Hot-humid and less extreme precipitation (with underlying increase in SLR and low availability of water resources)

Group 1			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Lack of water to irrigate agricultural lands and livestock needs. This causes a shortage of land and loss in economic diversification. Ecosystems change, species extinction and emergence of new species. A threat to Food Security, farmers migration. Increasing rates of poverty and unemployment. 	<ul style="list-style-type: none"> Use modern technologies for desalination of sea water and grey wastewater treatment Use of salinity resistant crops Modern techniques to reduce water wastage during irrigation. 	<ul style="list-style-type: none"> Increasing financial allocations to ministries to design adaptation measures to reduce risk. Building the resilience of the health sectors and providing the necessary infrastructure to absorb risks for the health sector Increase international technical and financial support from UNFCCC (United Nations Framework Convention on Climate Change) to establishing giant projects such as building irrigation networks, dams and sea water treatment. Early warning and technology transfer Building capacity for Government and Community institutions and benefit from non-governmental organisations to implement current and proactive treatment and initiatives
Water resource management	<ul style="list-style-type: none"> Severe shortage of drinking water, industrial, energy facilities. Deterioration of groundwater quality and increase the pressure on the use of backup. The possibility of clan conflicts occurring in the region due to the lack of water and threat to security. 	<ul style="list-style-type: none"> Construction of dams to prevent sea water from extending into the Shatt al – Arab river Use of salinity resistant crops Modern techniques to reduce water wastage during irrigation 	
Health	<ul style="list-style-type: none"> Diseases due to climate change Increasing burden on health centres Possibility of water pollution causing water-related diseases and malnutrition 	<ul style="list-style-type: none"> Providing health centres and homes for treating the poorest and most vulnerable groups. Provide clear water for poor families and most vulnerable people 	

Group 3			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Land degradation, loss in crops Food insecurity Increasing poverty Displacement 	<ul style="list-style-type: none"> Climate smart agriculture Crops resistant to drought and salinity Building resilience Use of irrigation techniques 	<ul style="list-style-type: none"> Reduce the change in type of agricultural land Raise awareness among farmers Reduce water wastage Support women to reach to financial and technical resources
Water resource management	<ul style="list-style-type: none"> Increased salinity that can be damaging for agriculture Displacement Drinking water Tourism Economy (e.g. imports) 	<ul style="list-style-type: none"> Water harvesting Water tanks Groundwater management Irrigation techniques 	<ul style="list-style-type: none"> Plans and studies Policy with upstream countries and regions
Health	<ul style="list-style-type: none"> New diseases (e.g. dengue fever) Heat stroke Typhoid and allergic skin diseases Increasing rates of existing disease 	<ul style="list-style-type: none"> Field teams to provide assistance Reduce in water waste Building resilience 	<ul style="list-style-type: none"> Early warning Building resilience among vulnerable people

APPENDIX F

Workshop consultation on the storylines for the Southern Marshes ecoregion

Climate Storyline 1: More arid and less upstream recharge (with underlying increase in SLR)

Group 1			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Drought Loss of Agricultural lands Poverty of famers, displacement Biodiversity loss Crop damage 	<ul style="list-style-type: none"> Employ modern techniques for irrigation Good practices of land use management Support the tourism Financial support and product marketing Employ modern agricultural techniques 	<ul style="list-style-type: none"> Capacity building Value the knowledge of local people Strengthen the marketing of local cultured products and activities Develop species list Plant suitable crops
Water resource management	<ul style="list-style-type: none"> Droughts Exacerbated water pollution Aquatic species loss 	<ul style="list-style-type: none"> Dams and artificial lakes Water treatment plants Increased water supplies 	<ul style="list-style-type: none"> Water use rationing Capacity building and technology transformation
Health	<ul style="list-style-type: none"> Water borne diseases Heat stress 	<ul style="list-style-type: none"> Health Care specialised for Climate related diseases 	<ul style="list-style-type: none"> Raise awareness among local people Research Research of stations Mobile hospitals

Group 3			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Droughts Dust storms Increased aridity resulting in low productivity Tourism impact Unemployment 	<ul style="list-style-type: none"> Effective irrigation Engagement with marshland populations Tourism conservation Genetic crops planting 	<ul style="list-style-type: none"> Early warnings Financial resource availability Technology transfer
Water resource management	<ul style="list-style-type: none"> Low water supplies Strikes and conflicts Degraded water quality Decreasing in the groundwater level 	<ul style="list-style-type: none"> Increasing resilience of hydrological infrastructure 	<ul style="list-style-type: none"> Awareness Support traditional practices Support green jobs Monitoring systems
Health	<ul style="list-style-type: none"> Pandemics Toxicity Pollutions Heat strokes Malnutrition 	<ul style="list-style-type: none"> Improvement of Health facilities Enhance drinking water availability 	<ul style="list-style-type: none"> Deploy renewable energy Regular inspection teams Environmental inspection Monitoring of industrial service activities

Climate Storyline 2: Hot and humid and less upstream recharge (with underlying increase in SLR)

Group 2			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Land degradation and less crop, livestock Food insecurity Displacement of the indigenous people Change in conditions for growing crops 	<ul style="list-style-type: none"> Building resilience for indigenous people Feed livestock 	<ul style="list-style-type: none"> Feed livestock Provide livelihood
Water resource management	<ul style="list-style-type: none"> Drought Displacement Tourism Livelihood Livestock and fisheries 	<ul style="list-style-type: none"> Building resilience for indigenous people 	<ul style="list-style-type: none"> Water recycling Plans and studies Policy with upstream Awareness for people
Health	<ul style="list-style-type: none"> Increase cases of heat exhaustion Increase in cases of communicable diseases New diseases Respiratory problems 	<ul style="list-style-type: none"> Building resilience for the health sector for vulnerable people 	<ul style="list-style-type: none"> Early warnings Health field teams

Group 4			
Sector	Relevant climate Impacts	Adaptation options	What to do now to prepare?
Agriculture	<ul style="list-style-type: none"> Lack of water for human and agricultural and livestock needs. This causes shortage of land and Marshes and loss in economic diversification. Ecosystem change, species extinction and emergence of new species A threat to food security farmers migration Increasing rates of poverty and unemployment loss of unique ecosystem in Iraq 	<ul style="list-style-type: none"> Use of Modern technologies for desalination of water and grey wastewater treatment Use of salinity resistant hybrid crops 	<ul style="list-style-type: none"> Increasing financial allocations to ministries to develop adaption measures and reduce risks Building the resilience of the health sectors and providing the necessary infrastructure to absorb risks for the health sector.
Water resource management	<ul style="list-style-type: none"> Severe shortage of water Possibility of conflicts occurring in the region due to the lack of water and threat to the societal security file. Environmental displacement of indigenous people 	<ul style="list-style-type: none"> Use of Modern technologies for desalination of water and gray wastewater treatment Use of salinity resistant crops Provide sufficient water for the survival and sustainability of the marshlands as a unique ecosystem in Iraq. Take urgent measure to treatment and the risk of losses from Climate change 	<ul style="list-style-type: none"> Increase international technical and financial support from UNFCCC to establishing large projects such as building irrigation networks, dams and sea water treatment Early warning systems Technology transfer Increase the knowledge among policy maker and Iraqi people about the threat of climate change in the area
Health	<ul style="list-style-type: none"> Diseases due to Climate Change that are related with high 	<ul style="list-style-type: none"> Providing Health Centre and homes to treat the poorest and most vulnerable groups 	<ul style="list-style-type: none"> Building capacity of Government and Community institutions and benefit from non-governmental organisations

	humidity and temperature increase <ul style="list-style-type: none"> • Possibility of water pollution causing diseases • Malnutrition • Respiratory diseases 	<ul style="list-style-type: none"> • Provide clear water for poor families and more vulnerable people 	to implement current and proactive treatment and initiatives
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APPENDIX G

Executive Summary from the Iraqi Climate Modelling Unit - Strategy Guide (2022)

G.1 Challenges to Implementation of a Fully Functional National Climate Service in Iraq

The primary aim of this assignment is to analyse gaps in terms of existing climate modelling capacity within relevant academic institutions and develop a strategy for implementing functional climate services in Iraq. This will be achieved through conducting in depth interviews with key national stakeholders using a novel interview protocol that directly aligns to the WMO standard for development planning and the Enabling Environmental Framework. The organization and implementation of these interviews has been challenging; however, a national consultant has conducted several preliminary interviews with relevant stakeholder to identify preliminary obstacles that various climate institutions face.

The obstacles identified can be grouped under four discrete themes: Regulatory Frameworks/Institutions; Data and Technology; Capacity Building and Research.

1. Regulatory Frameworks/Institutions

Institutional structures must be in place to ensure that adaptation planning and projects address the needs of the vulnerable now, which are resilient to the large uncertainty inherent to projections of future regional climate. Ongoing challenges include:

- **Competing priorities** due for example, to ongoing security issues and economic instability in Iraq, have typically led to a lack of investment by policymakers in a fully functioning national climate service with improved research tools, infrastructure (e.g., irrigation), technological innovation, institutional strengthening, knowledge strengthening and policy reform (see Verner 2012). This has critical implications for policy direction, priorities and budgetary allocation going forwards to support, for example, the implementation of the Iraq National Adaptation Plan to build the country's resilience to climate change, including a national climate change strategy; changes to land-use laws to foster land-use changes; the operationalising of agricultural risk management strategies through agricultural insurance schemes.
- **Coordination and engagement of institutions** that need to be involved, including,
 - The *General Authority for Meteorology and Seismic Monitoring (IMSO)* of the *Ministry of Transport* (the official body responsible for meteorology).
 - The *Ministry of Health and Environment / the National Center for Climate Change* (responsible for decision-making regarding Disaster Management and Disaster Risk Reduction and Climate Change services)
 - The *Joint Coordination and Monitoring Centre (JCMC) /Prime Minister*
 - The *Permanent National Committee on Climate Change* which works with the *Ministry of Health and Environment / the National Center for Climate Change* to coordinate issues and the participation of all relevant institutions in climate change services.
 - *Ministry of Planning*.
 - The *Agricultural Meteorological Centre* in the *Planning and the Follow-up Department of the Ministry of Agriculture* (with responsibility for agriculture).
 - *Partnerships with Higher Education Institutions*, those related to climate modelling and climate services, in addition to specialized technical departments and colleges such as the Department of Atmospheric Sciences.
 - It is reported that there is a poor connection between governmental institutions, and coordination is limited to specific issues. It also noted that there is poor decision making structures, and a disjoint between research groups and other industries.

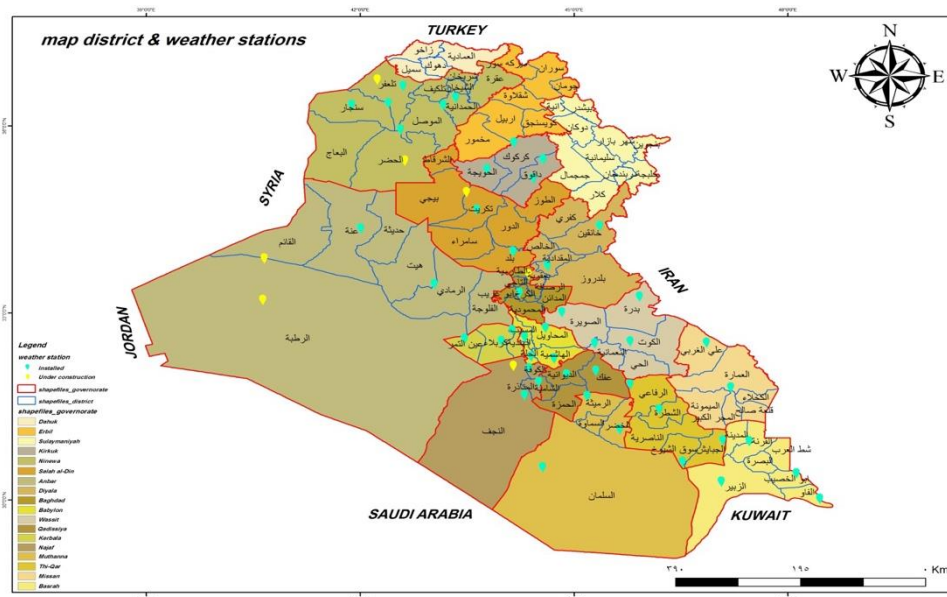


FIGURE 34: ADMINISTRATIVE BOUNDARIES OF THE AGRO-METEOROLOGICAL NETWORK. SOURCE: FIG. 1 FROM THE CMU STRATEGY GUIDE (CORNFORTH ET AL., 2022).

2. Data and technology

Improved integration of climate risk information within the adaptation and development programmes of Iraq will depend on greater access and uptake of high-quality meteorological data characterising climate variability and change.

- **Climate information services are very limited**, extending only as far as daily weather bulletins which are announced through the official satellite TV channels such as Al-Iraqiya, in addition to the official website of the General Authority for Meteorology and Seismic Monitoring (IMSO).
- **The IMSO relies heavily on world weather centres** as well as satellite information for short-term forecasts (up to 5 days). There are no operational Early Warning Systems for flooding, severe weather (heavy thunderstorms), or dust storms. Long term forecasts for drought monitoring are also unavailable in-country, severely limiting the deployment of disaster responses systems in time to support those most affected.
- **The infrastructure**, e.g., weather stations, being used to collect climate and weather data are largely outdated, damaged and many stations are not adequately maintained and/or provide adequate coverage of the country. Weather stations operate only in the following governorates at the time of writing: Nineveh, Baghdad, Kirkuk, Basra, Dhi Qar, Salah al-Din, Anbar, Wasit and Qadisiyah. This lack of infrastructure impacts the reliability, longevity and geographical extent of data collected, leaving key response institutions without the information needed to support early warning systems and adaptation efforts to build climate resilience. In addition, this information is not available to the general public and beneficiaries at this time
- **Data is not centralized** and does not meet the diverse needs of all stakeholders.
- **There is no operational early warning system** in Iraq for slow- or fast-onset disasters such as droughts, floods, heatwaves, coldwaves, thunderstorms, dust storms etc., with a corresponding lack of information available for responder organizations.

3. Research and Capacity building research

Sufficient technical capacity is needed to undertake vulnerability assessment, options appraisal, and adaptation planning.

- **There is a considerable shortage of staff** working in climate services and climate change impact modelling as well as difficulties for staff in accessing specialist training, including in the areas of monitoring, analysis, and forecasting. This is exacerbated by a lack of specialist research centres focusing on weather, climate/climate change and adaptation, and hydrological research, despite the size of the challenges facing Iraq. It is reported that capacity building on climate information services is conducted on small scales and in specific institutions, and that such training is not benefiting from research produced by educational institutions.
- **Lack of models and predictive scenarios** for climate change at the national level.
- **In scientific research**, researchers are forced to choose simple research projects for postgraduate students due to the high financial costs needed by studies related to climate models. This limits new research and data production that would support the future direction of climate policy and actions.

- **Limited partnerships between the IMSO and the higher education institutions** in Iraq are reported, and largely focus on data sharing. It is also noted that such relationships belong to the Ministry of Higher Education and Scientific Research. Job progression from education institutions into the Met Office is difficult due the ongoing financial crisis, lack of job grades, and policies.

These preliminary findings indicate that there is a need for political investment into climate information services which could provide the necessary priority of financing vital infrastructure, equipment, capacity building and research.

G.2 Evidence Synthesis and Co-Production to Build Climate Resilience

Arming the next generation of climate researchers with ‘climate to policy and impact’ literacy is vital to better support improved adaptation decision making to build climate resilience. This requires:

- A system thinking approach to understand the complex interconnections across the components of the climate system and the multiple hazards people face, and
- Learning to co-produce solutions to strengthen engagement with decision-makers and users, both the process and principles of co-production.

Critical to both are putting in place, mechanisms to ensure participatory approaches. These can be used to “ground truth” climate trends, alongside perceived and actual impacts of climate change on different sectors in different locations (Heinke et al., 2006). Furthermore, engagement with communities creates opportunities to improve decision-making through the uptake of ‘actionable climate knowledge’. Ideally, any engagement and/or data collection campaigns that bring in the expert inputs of local stakeholders, would be aligned with other initiatives that are already underway in Iraq, as well as the recommended Communities of Practice at the governorate level.

G.3 Increased Access to Timely Meteorological Information is for the Implementation of Early warning Systems that can Build Resilience

Bridging the Gaps to Bring the Iraqi Agro-Meteorological Network up to WMO Standard for Adaptation Planning in the agricultural sector

Iraq should work to improve climate projection information. In the short- and medium-term, the collection and monitoring of climate data could be improved by:

- Continuing the investment in the Agro-meteorological network maintenance and expansion of weather stations, in particular for the eastern governorates (e.g., Nineveh and Anbar) where data scarcity is a significant constraint on model calibration and confidence. In addition, such extension of the network will (1) provide more information on trends and natural variability to act as a backdrop for understanding the climate-socio-economic links and support adaptation planning; and (2) improve reanalysis (e.g., ERA 5) and model validation.
- Developing and field-testing different alternatives for remotely sensed indices of drought and integrated water resource management (surface and groundwater).
- Collaborating with other countries in the region to improve coverage and data comparability.
- Using TRMM (Tropical Rainfall Measuring Mission) data to extend the potential for hydrological modelling and impact assessment at locations without meteorological observations.

These should be combined with a push to **link climate data with impact analyses and quantitative livelihoods information** by making climate data available to policymakers and researchers. We recognise that some efforts in this direction have already begun. For example, Iraq is part of the European Climate Assessment and Dataset (ECA&D) project. This aims to combine the collation of a daily series of observations at meteorological stations with quality control, an analysis of extremes and the dissemination of both the daily data and the analysis results. This effort to improve climate projection information is gradually being extended across the Middle East (e.g., Jordan, Syria, Turkey).

The accessibility of climate data should be improved in Iraq by:

- Digitalizing historical data that may only be available as hard copies which are likely to be damaged or difficult to access.
- Increasing access to data through implementing appropriate regulatory frameworks that enable civil authorities to make data available to users.
- Setting up websites to provide public access to older data (for example one month or one year) at daily or sub-daily temporal resolution, in the absence of current weather information, which may be restricted for other reasons (e.g., security).

- Ensuring information is provided on the availability, conditions for use, and procedures to access data and keep this updated (Verner 2012).

Establishing a technological platform on the Internet for all stakeholders and beneficiaries to access climate information and to support the long-term modelling and prediction of climate change.

Bridging the Gaps in Human Capacity and Institutional Systems Support

- There is a considerable shortage of specialised staff reported, in particular, those with expertise in climate information services, climate change and adaptation.
- There is a shortage of capacity building training reported in the areas of monitoring, surveying, and forecasting.
- There is only one specialized department in climatic and atmospheric sciences, including climate change (Department of Atmospheric Sciences at the Al-Mustansiriya University in the College of Science). The vast majority of graduates of this department are appointed directly to the General Authority for Meteorology and Seismic Monitoring (IMSO), in addition to the Civil Aviation Authority and Military Aviation, Ministry of Environment and Ministry of Science and Technology. Consequently, the Ministry of Higher Education has provided scientific and academic support to these institutions through graduates whose academic education matches the needs of these institutions.

This could be improved by targeted training provided to government employees at the National Centre for Climate Change, on the use of climate change modelling and climate risk assessments, as well as other government agencies and institutions and relevant authorities. This is covered under the proposed Foundation Stones for the new Iraqi CMU.

G.4 The Foundation Stones of the New Iraqi Climate Modelling Unit for Building Resilience

We believe that the most important ‘foundation stones’ upon which rigorous and useful climate change research should be undertaken could be summarized under three priority actions: (i) improved access to data and information, (ii) enhanced research capacity; and (iii) enhancing the impacts of research.

We also believe that it is the degree to which planned initiatives and the proposed Climate Modelling Unit can assist in laying these foundation stones that long-term success towards adaptation efforts for building resilience should be assessed.

We summarise here three recommendations under each of the foundation stones that the Iraqi government, donors, and grant recipients might wish to consider in below.

Foundation Stone 1: Improved Access to Information

Many of the scientists currently engaged in climate change research have been trained in various disciplines of agriculture or the social sciences and do not have a fundamental knowledge of the climate sciences. Yet the onus is upon them to plan and execute relevant and innovative research targeted towards helping stakeholders cope better with current climate-induced risk and to adapt to climate change. For them to successfully address this challenge, it is imperative that they have easy access to:

- Published and unpublished information contained in the literature that is related to their field of enquiry.
- Information about both completed and on-going projects addressing climate risk management and adaptation to climate change in Iraq, and other global studies.
- Long-term daily weather datasets collected from an enhanced Iraqi Agro-meteorological network (maintained by the Iraqi Ministry of Agriculture) with stations close to the location where adaptation interventions will be based, without which ‘hard’ climate risk and climate change research is very difficult, or indeed, near impossible.

Without access to such information there is a real danger that the research undertaken will fail to be well prioritized, rigorous, relevant, and non-repetitive of that already undertaken or currently on-going.

In addition, it is equally, if not more important that the next generation of scientists who undertake such research will have had a much more substantive exposure to climate science in their graduate and postgraduate training than is currently the case. This will require the building of specific and up-to-date teaching material into their curricula and providing them with specialized and intensive training courses with specialized technical departments in Iraqi universities, such as the Department of Atmospheric Sciences.

1. **Literature review** – We recommend that the unit considers supporting a dedicated review of the literature and the production of an easily accessible annotated appendix of up-to-date climate risk management and adaptation literature.
2. **Database of Projects** - Given the real danger of precious financial resources being used to support research that has already been undertaken, or is on-going elsewhere in the region, the unit together with donor agencies should play a coordinating

role in ensuring that the information about previous or on-going projects that is held by individual institutions and donor agencies is collated, made easily accessible and shared more widely.

3. **Access to data** - Access to high quality and long-term daily weather data is crucial for a critical analysis of climate-induced risk and climate change research. We believe that influential scientists, donor agencies and research institutions should continue their advocacy that such data is too important to be considered the property of a single institution and should be viewed as a public good.
4. **Curriculum development and professional training** - Given the importance of establishing a critical mass of research personnel for the future, we recommend that priority be given to:
 - Providing dedicated funding to support the required follow up to the current work of the Universities that is targeted towards building a *comprehensive and integrated curriculum on climate change* that feeds relevant capability into the CMU and other key institutions in future.
 - *Installing fully operational meteorological stations at the universities*, and in particular, the College of Science at Al-Mustansiriya University (given it hosts the Department of Atmospheric Sciences) and the Iraqi Climate Modelling Unit and using the resource to teach field techniques and climate data analysis. Other universities as resource allows.
 - We also recommend the establishment of the *Strengthening the role of the Department of Atmospheric Sciences in the Ministry of Higher Education and Scientific Research as a national training Institution* for the provision of Diploma, Certificate, and professional Operational Training Course (OTC) in meteorology and related sciences in Iraq.

Foundation Stone 2: Enhanced Research Capacity

1. **Building rigorous scientific methods and interdisciplinary approaches** – We recommend that dedicated funding should be made available for courses that promote rigorous scientific research design and interdisciplinary approaches to make sure that research on climate change adaptation is conceived and undertaken in the correct context of the impacts of other important drivers of change.
2. **Developing conceptual frameworks for the impact pathways of change** – Being able to develop a conceptual framework that situates a hypothesis in the context of related impact pathways of human and animal population growth, for example, is critical. Unless researchers are trained to undertake this type of analysis, misinterpretation of results could well lead to quite serious consequences. We believe that putting climate change in the context of other drivers of change e.g., through the generation of plausible climate storylines and application of causal networks, is essential in order that researchers and decision-makers may have confidence that the processes, impacts and research innovations under investigation are properly focussed on climate-induced risk and change and are not in response to other, possibly more important, drivers of change.
3. **Technical training on climate risk analysis** (hot spot analysis, risk analysis, trend analyses) - We recommend that donor agencies consider providing funding for training, both in climate risk analysis and adaptation research including for example, in the use of weather-driven crop growth simulation models (such as the Decision Support System for Agricultural Technology (DSSAT) and the Agricultural Production Systems Simulator (APSIM), both part of the Agricultural Model Intercomparison and Improvement Project (AgMIP), a global project on crop and economic modelling to estimate the impacts of climate change on agricultural production and water resource management into the future. This training should extend to the use, manipulation and post-processing of climate change projections provided by international and regional climate modelling groups including recent bias corrected climate change projections provided by ESCWA.
4. **Analyses of impacts of climate variability and projected climate changes for different sectors** e.g., *Integrated Water Resource Management (surface water and groundwater) Agricultural Production, Health and Energy Production*. In addition to the climatic analyses above, it is important that the CMU researchers have the capacity to use a range of models to analyse the impacts of variable weather on many aspects of critical services such as health, energy production, agricultural production (including crop, livestock, pastures and trees and shrubs) and integrated (surface and groundwater) water resource management using simulation models. Such modelling must be integrated with a rigorous and disaggregated analysis of the **livelihood impacts**. By way of example, recent international research conducted by the members of this project's team (Walker Institute) has improved understanding of how water moves through catchments, and when combined with output from land surface and groundwater models, scientific knowledge can genuinely support planning from basin-scale, to seasonal community management of groundwater supplies and emergency planning (see <https://upgro.org/category/final-report/upgro-project/brave/>). We would argue strongly a rigorous analysis of the livelihood impact of changes in access to or availability of water should be included as an integral part of water security research that the CMU conducts. This would complement e.g., work on institutional analysis (The **Critical Institutional Analysis and Development (CIAD) framework** etc.) and will provide quantitative information on the social and economic impacts of infrastructure investments, governance changes, local financing arrangements etc. A disaggregated livelihoods impact metric provides a crucial link between water security and issues driving conflict, migration, access to education and health services. This will also provide additional insight to qualitative work on issues of gender inequality and other forms of discrimination and exclusion. **This feedback needs to be at the heart of future work of the CMU to support transformational change** (see also the section on Customised Capacity Building below and Element 2).
5. **Focal Research Areas for the CMU**

- (i) **Climate Modelling, Scenarios and Downscaling to:**
 - Identify gaps in the development of national and sub-national climate scenarios, including the need for, and the availability and applicability of, climate models, and the options to fill these gaps.
 - Identify practical opportunities to improve access to, and use of outputs of different models, including assessment of their applicability, and training opportunities.
 - Analyse means to improve the availability and applicability of climate change modelling and downscaling data to support policy makers at all levels and optimize resource management.
 - (ii) **Climate Risk Services** – in particular upscaling of skills to conduct national-scale, hot-spot analyses to identify regions and vulnerable groups that are potentially sensitive to changing patterns of rainfall and temperature, including support to optimise water resource management e.g., rain harvesting methods, cutting edge irrigation techniques, and build early warning capacity, particularly in anticipating extreme weather events. Such high-level screenings can provide a focus for more detailed assessment and field survey of high-risk areas to support adaptation and potential migration issues. The information might also be used to prioritise extensions of observing networks into regions with high vulnerability but low intensities of data collection and contribute to developing strategic plans for the country relating to drought and flood management in particular.
 - (iii) **Nature-Based Solutions (NBS)** – develop research capacity to protect Iraq from climate change impacts through, for example, nature-based solutions (NBS) while slowing further warming and combating desertification, supporting biodiversity, and securing ecosystem services. This is particularly important with respect to the two ecoregions identified by the MoHE in this study (the Iraqi coasts of the Persian Gulf and Shatt al-Arab region in the city of Basra, southern Iraq; and the Iraqi marshes declared as World Heritage Sites in southern and central Iraq - The Hawizeh marsh and the Central and Hammar marshes), in addition to the natural reserves in Iraq.
6. **Customised Capacity Building** - Building the capacity of multiple climate response stakeholder and devolving capacity to CMU personnel as well as Governorates to respond more effectively to the development challenges of climate is central to this stream and its focus on Training of the Trainers approach. The capacity development will: nurture systems-based thinking and inter-disciplinary research leadership to ensure that national- and governorate-level risks and needs are understood and can be addressed; include training for sustainable data and knowledge management over the long term; building knowledge of, and capacity to access, financial support from global funding sources and implement adaptation and mitigation projects. We would recommend five training streams under this tier:
- (i) Enhance governorate level capacity to undertake long term monitoring of the quantitative impacts of climate and environmental change on livelihoods to track evolving climate hazards and population exposure.
 - (ii) **Provide Evidence Synthesis Training** to deliver practical, real-world experience in the synthesis of evidence from climate information and other data across a range of sectors (e.g., disaster, integrated water resource management, agriculture, health, and energy production) to support improved policy and business decision-making in the field of climate resilience and support key personnel in the preparation of national communications, adaptation and mitigation plans on a regular basis.
 - (iii) **Enhance farmer capacity to demand and use information** covering water, agriculture, livestock (e.g., water buffalo), weather and climate, health and nutrition and market information through innovative methodologies e.g., radio and listening groups.
 - (iv) Establish a vibrant Women’s **Leadership Training and Mentoring** network.
 - (v) Build capacity for researchers to **access global funding mechanisms** and upskill in climate modelling, and building climate scenarios.
7. **Improved Working Practices** - The recommendations above have been for the provision of resources for training. However, individual training courses should not be funded in isolation, but rather as an agreed capacity development program for the Iraqi CMU and Academic Institutes to develop the improved working practices of their staff and of their institutes in this complex area of climate variability and change. The Director of the Iraqi CMU and the VCs of linked Academic Institutions must also recognize their responsibilities to ensure that the new skills are fully used so that the outputs of such training are data being more thoroughly processed and reports being better written, rather than just of ‘staff being trained’.

Foundation Stone 3: Enhancing the Impacts of Research

1. **Written and visual reports** - Good reporting, both written and visual, is critical for ensuring research outputs deliver the maximum impact possible. We recommend that when researchers have results to report from their work and presentations to make, provision and attendance of additional training in external scientific communication would be highly beneficial and by extension warrants greater government and donor support. In some instances, such expertise does exist ‘in house’ in Iraqi organizations, but often it does not. In the latter case, we propose that donors should support outside help from some of the many well-established external science communication courses that already exist internationally.
2. **Archiving and sharing data** - Too often, primary research data that have been collected using public funds are unavailable to others or, worse still, has become lost. We recommend that the Unit and key stakeholders including the government and donors who support sectoral adaptation to climate change research should work together in ensuring that primary datasets

that are developed using their funds are properly archived and are made publicly available once the researchers have completed their analyses and reporting.

In the concluding section of the Iraqi CMU Strategy Guide (Section 6 therein), several recommendations towards the implementation of the CMU are outlined.

This report is part of the “Building Capacity to Advance National Adaptation Plan (NAP) Process in Iraq” project under ‘Provision of Consultancy Services Related to Producing Climate Change Scenarios and Risk assessments for Asia- Pacific’ programme funded by the United Nations Environment Programme (Contract No. UNEP/2019/008 (4700016597)).

To cite this report

Cornforth, R. J., Saggiaro, E., Petty, E. C., Pope, H., Tarnavsky, E. (2022). ‘ Climate Risk Assessments for Iraq: Southern Marshes and Persian Gulf & Shatt Al-Arab’, *Briefing Note WIBN0222/01*, Walker Institute, University of Reading, 12 December 2022

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