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Abu Dhabi Global Environmental Data Initiative

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Environment Agency - ABU DHABI

LOCAL, NATIONAL, REGIONAL CLIMATE CHANGE PROGRAMME

AL AIN WATER RESOURCES

- Atmospheric Modelling
- Arabian Gulf Modelling
- Terrestrial Ecosystems
- Marine Ecosystems
- Transboundary Groundwater
- Water Resource Management
- Al Ain Water Resources
- Coastal Vulnerability Index
- Desalination & Climate Change
- Food Security & Climate change
- Public Health Benefits of GHG Mitigation
- Sea Level Rise

Executive Briefing

Climate Change Research Group

NCAR

SEI

The authors of this report are Francisco Flores (co-Principal Investigator) and Stephanie Galaitsi from the Stockholm Environment Institute – US Center and David Yates (co-Principal Investigator) from the National Center for Atmospheric Research.

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Local, National and Regional Climate Change Programme 2013-2016

Socioeconomic Systems	Regional Climate Change	Environment	Coastal Zones	Water Resources
Public Health Benefits of GHG Mitigation (L)	Atmospheric Modelling (R)	Terrestrial Ecosystems (R)	Coastal Vulnerability Index (N)	Al Ain Water Resources (L)
Food Security (N)	Arabian Gulf Modelling (R)	Marine Ecosystems (R)	Sea Level Rise (R)	Water Resource Management (N)
Desalinated Water Supply (R)				Transboundary Groundwater (R)

L=Local N=National R=Regional

5 Thematic Areas 3 Spatial Regions 12 Sub-projects

12 Sub-projects
Assess the Impacts, Vulnerability & Adaptation to Climate Change in the Arabian Peninsula

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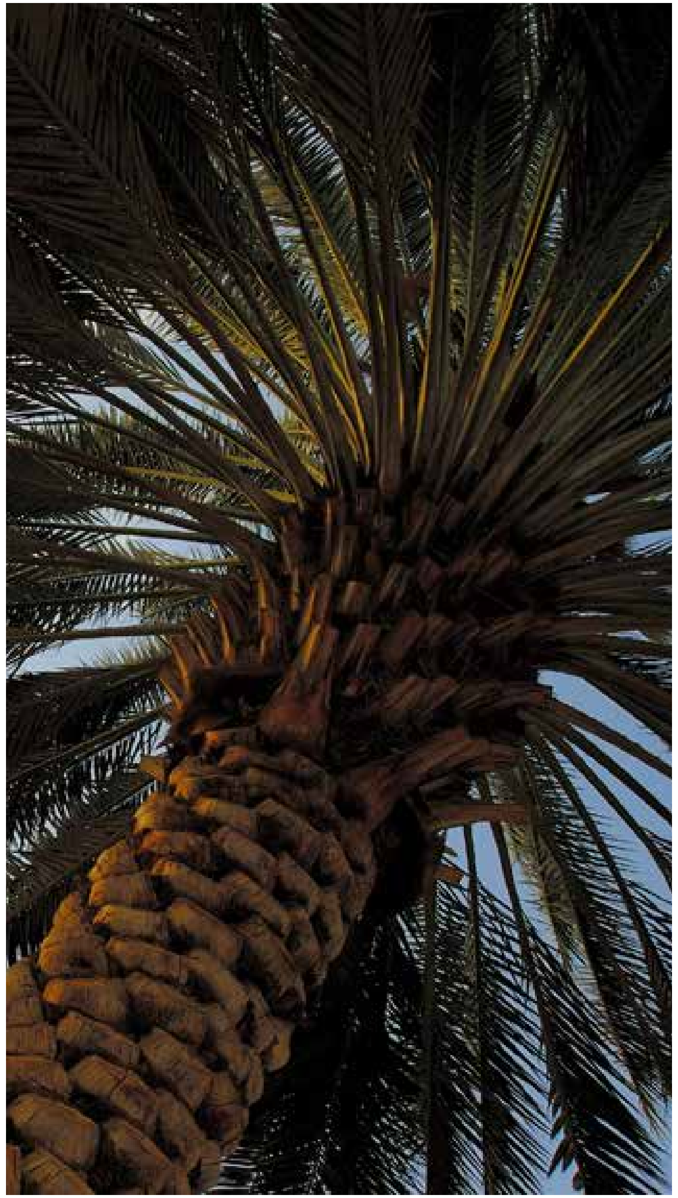
1. Introduction

Climatically sensitive eco and climatic zones, such as those on climatic margins, could be particularly vulnerable to future climate change.

Given its distinctly different climatic conditions relative to the rest of the UAE, there is no place within the country that is more climatically vulnerable than Al Ain. Also known as the Garden City due to its greenery, Al Ain is the second largest city of the Abu Dhabi Emirate and the fourth largest city in the United Arab Emirates. The region has been continuously inhabited for more than four thousand years and is considered central to the cultural heritage of the country. It is the birthplace of Shaikh Zayed bin Sultan Al Nahyan, the first president and founding father of the UAE. It is one of the only locations in the UAE with renewable groundwater, although as a percentage of overall water use, it is quite small. Water use in the region has exploded in the modern era, with the development of thousands of groundwater wells.

The socioeconomic situation in the Al Ain region has changed dramatically over the past several decades.

The population of the once small oasis has grown to roughly 570,000 in 2011. This growth has been supported through economic development, including agriculture, leading to substantial exploitation of regional water resources. Agriculture is the largest sector water user, consuming nearly 78% of all water in the eastern region, followed by amenity irrigation (7.2%), domestic water supply (7.1%), forestry, 6.9% and industry / commerce less than 1%, with an estimate of about 1,500 Mm^3/yr used annually. This is more than a threefold increase in consumption since 1994, whereas population has only increased by a factor of 1.7 (Brook et al. 2005; GOAD, 2014).



2. Approach

Due to the importance of the Al Ain region, an important question concerns future options for water resource management in the face of climate change and increasing population pressures.

Prior to rapid population growth, the local population relied on the falaj system, a type of irrigation system using surface water runoff from the Al Hajar mountains. The introduction of drilling rigs and mechanical groundwater pumps has allowed the exploitation of groundwater on a completely different scale than had been previously realized. There is now, ever intensifying water use in the region, bringing into question the viability of sustaining the greening-of-the-desert policy, whereby large tracts of trees are maintained via irrigation from brackish groundwater supplies through deep wells and pumping.

The challenge of effective water resource and agricultural management in Al Ain will be affected by climate change.

Climate change is likely to alter patterns and cycles of water supply, with profound implications for water resource management. Specifically, two key trends suggest the importance of addressing water and agricultural management in the Al Ain region in a holistic manner. First, climate change has already begun to affect rainfall and temperature patterns across the region, and while the country is characterized as a typically warm, arid region, future warming and changing rainfall, wind, humidity, cloud cover, and CO2 concentrations could change patterns of water and agricultural production. Second, socioeconomic growth patterns indicate that the population in the country's arid environment is likely to continue to increase and will require additional resource capacity to satisfy increasing water demands, with interest in increasing food security through increased local food production.

The overall goal of the sub-project is to better understand Al Ain's water and agricultural management challenges in the face of climate change and socioeconomic development.

The major research questions underlying the methodological approach were twofold. First, how will climate change affect the water resources of the Al Ain Region that support direct human use and uses for a forestry sector and an agriculture sector that have grown considerably over the past few decades, supported primarily with fossil groundwater? These sectors have an important cultural legacy and heritage, particularly surrounding the production of date palms - the region's important and productive agricultural commodity - and other agricultural products, such as water intensive fruit and vegetable production, and the production of fodder used to support a relatively large livestock sector. Second, what water management strategies could be explored - as measured in water savings associated with various scenarios - that aim to promote efficiency and conserve natural resources under climate change?

Addressing the goal and research questions required an analytical framework capable of accounting for the water and agriculture systems of the region in an integrated manner.

The Water Evaluation And Planning (WEAP) system was used for this analysis (Yates, et al. 2005). WEAP is an integrated modelling tool that can track water resource stocks and flows associated with extraction, production, and consumption, including seawater desalination, groundwater pumping, and the transmission of water. A model development period using historic data from 2005 – 2015 was used for model setup and configuration. Once the Al Ain WEAP model was calibrated and validated against the historic period, it was used to project forward into the 21st century under different assumptions of resource use and climate through 2060.

The representation of water supply and demand characteristics within the Al Ain water system model was as "granular" as possible.

While there was ample local data to construct a modestly granular water system model, there was not enough detailed data to develop a highly granular water system model. This has implications for the level of detail that could be analyzed during the policy scenario analysis. That is, the water system model was able to analyze high-level (i.e. sectoral level) policy scenarios and offer first-order impacts associated with climate change and alternative development pathways. However, the model was not sufficiently detailed to analyze the interactions between water supply/demand policies at high levels of disaggregation (e.g. level of enterprises, households, precincts).

3. Scenario framework

The structure of the Al Ain water system model accounts for the locations of all water supply sources and the magnitude of current and future demand for water.

The spatial coverage encompasses the eastern region of the Abu Dhabi Emirate, which includes Al Ain and the wadis of the Oman Mountains, reflecting the shared aquifers between the UAE and Oman, where there is some renewable fresh groundwater. A plant growth model was incorporated in order to simulate the effects of climate change and elevated atmospheric CO_2 concentrations on cultivated plant's water use and crop yields. A schematic of the model is shown in Figure 1.

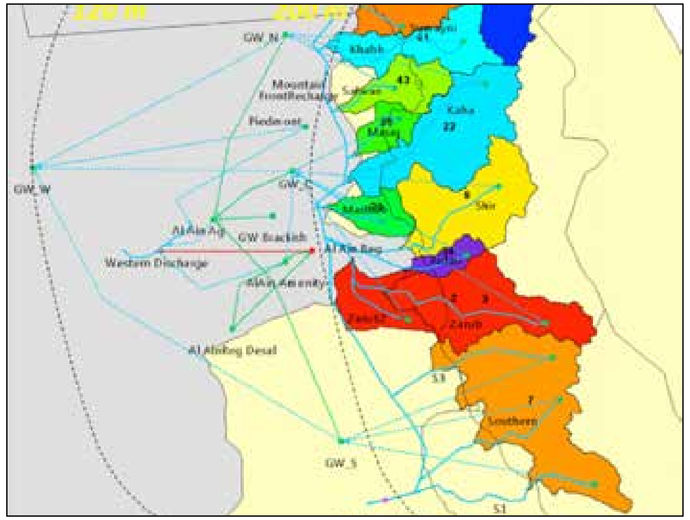
The regional alluvial aquifer is the only renewable water supply in the region.

It has shown considerable heterogeneity in terms of groundwater levels, with some regions exhibiting dramatic drawdown of groundwater levels, while others have revealed local phenomena, such as elevated groundwater levels that have caused local problems to infrastructure. While the reason for these elevated groundwater levels are not precisely known, the fact that hundreds of millions of cubic meters of desalinated and brackish water are used in a region with a relatively shallow alluvium, suggests that groundwater levels can fluctuate significantly and could be the cause of local groundwater problems.

The ability of the Al Ain water system model to capture the dynamics of the alluvial groundwater system was made possible by simulating pre-development, steady-state conditions, before modern pumping began.

The model was calibrated using manual calibration techniques, with the goal of establishing a set of realistic model parameters that simulate the steady-state elevations on the eastern boundary and a constant flux boundary on the western boundary of the modeled domain. The three alluvial aquifers depicted in Figure 1 are GW_N, GW_C and GW_S. Each of these groundwater systems is hydrologically connected to each of the 15 wadis, which pass their flux to these three groundwater objects. The results of the model calibration process indicated that the model adequately reproduced historical conditions for water supply and demand, hence was a reliable basis on which to project the impacts of future climate change and sustainable development scenarios.

Figure 1: Schematic representation and spatial extent of the Al Ain water system model.



The validated water system model for the Al Ain region was used to analyze the impacts of policy scenarios aimed at promoting resilience of water and agriculture systems under climate change.

Two Business-as-usual (BAU) scenarios were considered - one with climate change (hereafter "BAU"); the other without climate change (hereafter "BAU-RCP8.5"). Two policy scenarios were considered - one focused on climate-resilient agriculture (hereafter "FallowFF"); the other focused on maximizing groundwater storage (hereafter "GWStabilize").

Both Business-As-Usual scenarios included population and climatic assumptions that also applied to the policy scenarios.

The future population forecasts were taken from projections made by the United Nations (UNDESA, 2015) and included a single population growth rate projection for the region over time. The UAE's population was estimated at about 9,300,000 in 2015 and projected to grow to 13,500,000 by 2060 (1.8% per year), with Al Ain growing from 700,000 to about 1.2 million by 2060. Future climate forecasts (i.e. total precipitation, average annual temperature) were taken from the outputs of the LNRCCP's regional atmospheric modelling sub-project (Yates, et al. 2015), which projected future climatic conditions in the Al Ain region using a high-resolution (i.e. 4 km) regional climate model (Yates, et al. 2015). The BAU scenario without climate change assumed an extension of climatic trends for the 1985-2004 period through 2060. The BAU scenario with climate change assumed was based on a regional dynamic downscaling of the IPCC's RCP8.5 scenario. Both BAU scenarios continue past resource use with respect to water and consumption on a per-capita basis, and the technologies associated with their production and delivery through 2060, with no new policies that would influence water supply/demand

The two policy scenarios were constructed to illustrate the stakes for socioeconomic development in the Al Ain region under climate change.

Summary details for each policy scenario are offered in Table 1. The FallowFF scenario explores a future in which the use of water for irrigation of forestry and fodder plantations decrease. In this scenario, production activities would decline linearly from their current levels to zero by 2060. The total water savings are then made available for the cultivation of higher valued agricultural products (i.e. Date Palms, vegetables, and fruits).

The GWStabilize scenario explores the evolution of the Al Ain alluvial aquifer over the coming decades, within the context of regional population growth, water demand growth, and climate change.

In this scenario, the alluvial groundwater levels in and around the Al Ain region are stabilized by managing the mix of water resources to meet the demands of productive activities. Specifically, the GWStabilize scenario explored the level of groundwater use of and corresponding decrease in imported desalinated water that would maintain the groundwater level in a steady state condition (i.e. constant groundwater levels).

Table 1:

Policy Objective	**Policy Objective**
FallowFF	Reduction in these subsidized water sectors which are using fossil groundwater well below the market value. Date Palm, vegetable and fruit production are substituted such that the water saved in the forestry and fodder sector is used by the agricultural sector. Reduction in Forestry and Fodder and an increase in higher valued crops under irrigation.
GWStabilize	Maintaining groundwater levels in a near steady-state condition over a prolonged period of time, by finding the level of imported desalinated water and amenity and outdoor water use that tends to maintain groundwater levels at a constant elevation; while simultaneously strategically using the desalinated water that becomes recharge to this alluvial aquifer system.

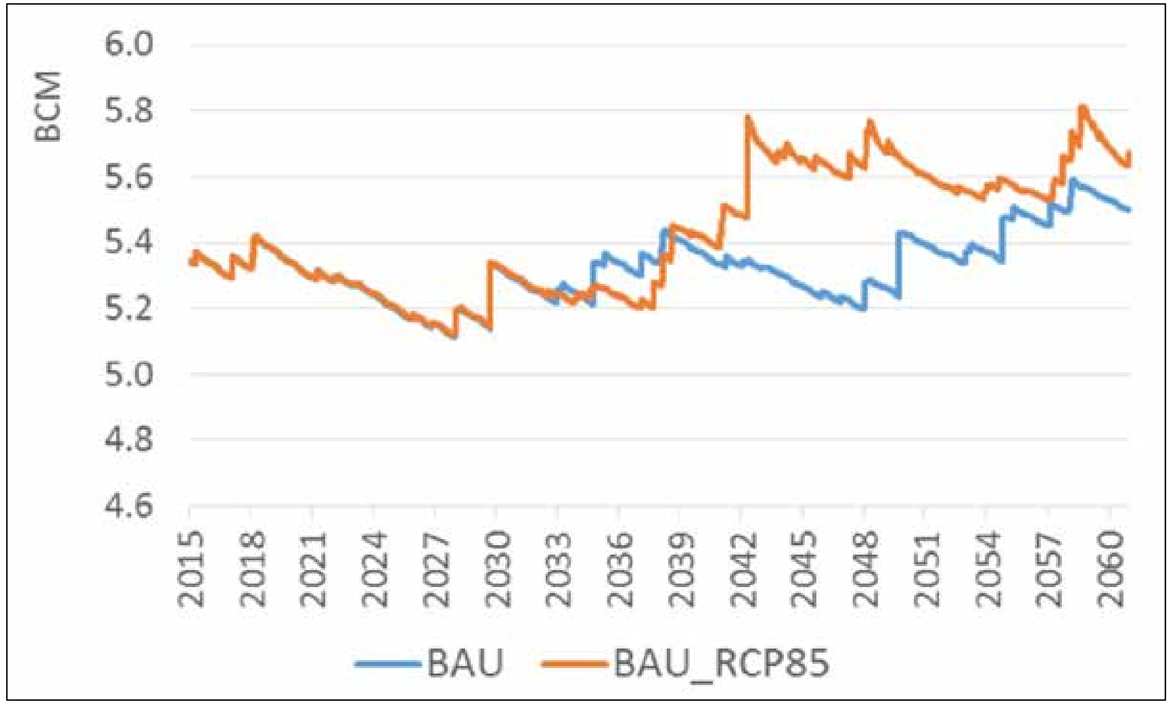
4. Impact of climate change

The impact of climate change on the water and agricultural systems of the Al Ain Region can be seen by comparing the BAU-RCP8.5 scenario with the BAU scenario.

Several conclusions may be offered as outlined in the bullets below.

- **Water supply:** Future groundwater storage of the three alluvial aquifers for the Al Ain region is projected to increase slightly under climate change (see Figure 2). This is primarily driven by the wetter conditions projected by the regional climate model under climate change leading to enhanced groundwater recharge.
- **Water consumption:** If practices and methods of irrigation remain the same, climate change will cause annual increases in water use for the forestry, amenity, and outdoor water use sectors. Increases are on the order of 5% by 2060, as warming conditions create slightly greater demand for water. However, agricultural water use does not increase due to efficiencies from CO2 fertilization effects, which lead to more production over a shorter growing season. The new water use in the region is about 1.35 BCM in the BAU and BAU-RCP8.5 scenario.

Figure 2: Total Al Ain groundwater storage for the BAU and BAU-RCP8.5 scenarios.



- **Water consumption:** If practices and methods of irrigation remain the same, climate change will cause annual increases in water use for the forestry, amenity, and outdoor water use sectors. Increases are on the order of 5% by 2060, as warming conditions create slightly greater demand for water. However, agricultural water use does not increase due to efficiencies from CO2 fertilization effects, which lead to more production over a shorter growing season. The new water use in the region is about 1.35 BCM in the BAU and BAU-RCP8.5 scenario.

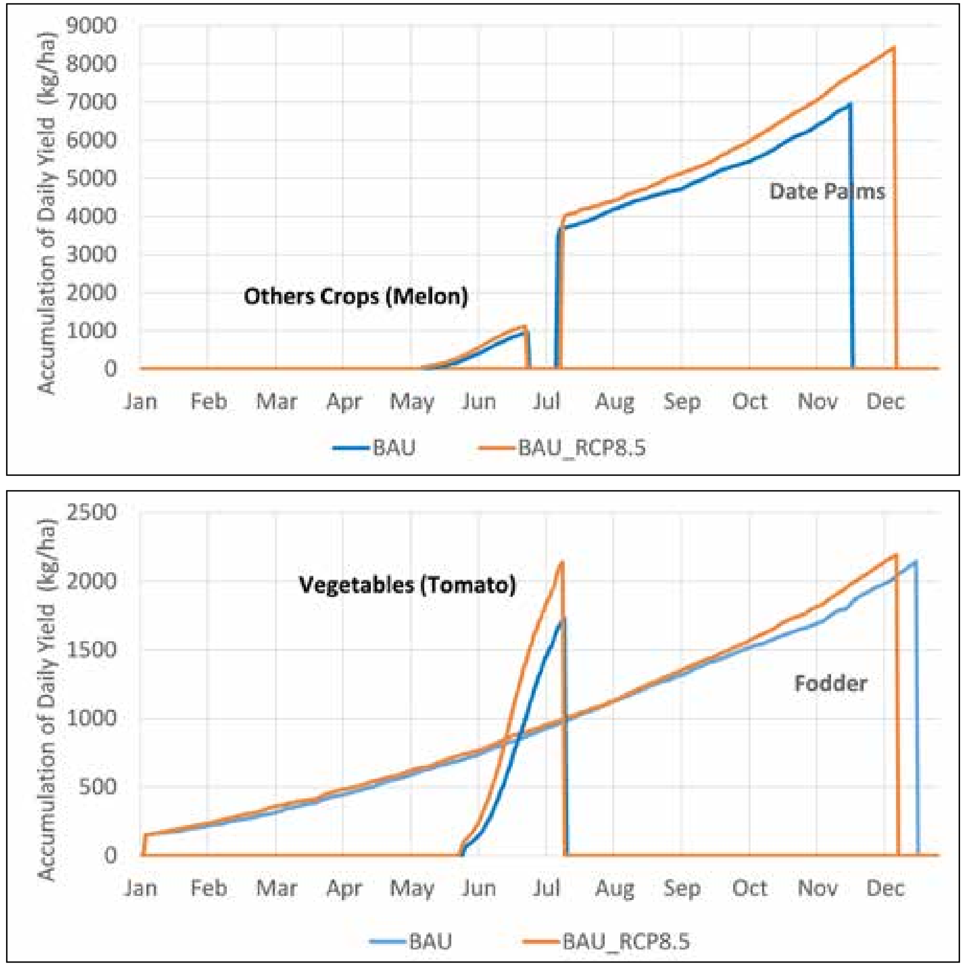


Figure 3: Accumulation of daily crop yields in kilograms per hectare for date palms, fodder, vegetables and other crops under two BAU scenarios.

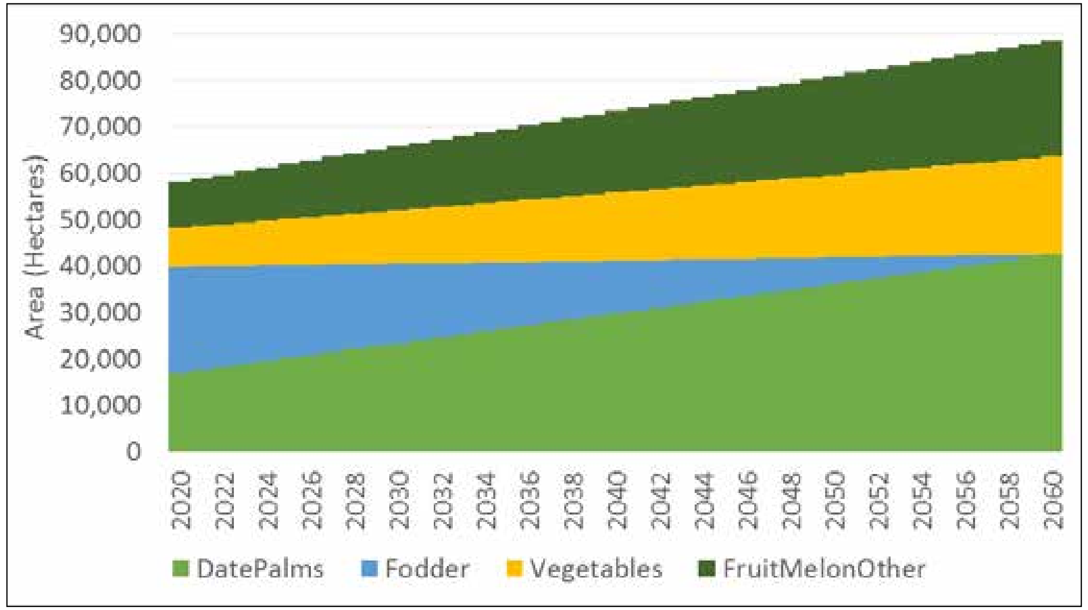
5. Impact of policies to fallow fodder and forests

The impact of policies that would seek to fallow fodder and forests in the Al Ain Region can be seen by comparing the FallowFF scenario with the BAU-RCP8.5 scenario.

This offers an estimate of the impact of this policy scenario net of any climate change impacts. Several conclusions may be offered as outlined in the bullets below.

- **Area under cultivation:** The fallowing of fodder and forests can be offset by an increase in the cultivatable area for Date Palms, Vegetables, and Fruit. The net planted area increases from about 60,000 ha to 90,000 ha, while the forested area under irrigation decreases from 100,000 hectares in 2015 to being fully fallowed by 2060 (see Figure 4).
- **Water savings:** The fallowing of forests and fodder results in about 12 BCM of water savings over the full 40-year analysis period. With these water savings, the total area in production of higher valued agricultural commodities, including date palm, vegetables, and other crops can grow by 2.5 times over the 40-year period, as shown in Figure 4. By using the water savings from the fallowing of fodder and forests, the production of date palms increases by 75%, vegetable and fruits and other commodities production by 73% in terms of production in units of metric tonnes.

Figure 4: Planted area evolution in the FallowFF Scenario for date palms, fodder, vegetables and other crops.



6. Impact of policies to stabilize groundwater levels

The impact of policies that would seek to stabilize groundwater levels in the Al Ain Region can be seen by comparing the GWStabilize scenario with the BAU-RCP8.5 scenario.

This offers an estimate of the impact of this policy scenario net of any climate change impacts. Several conclusions may be offered as outlined in the bullets below.

- **Desalinated water use:** To stabilize groundwater levels, the total annual desalinized use in the region would decline relative to historical trends. Figure 5 shows the annual desalinated water use for all agriculture, amenity, indoor and outdoor uses for the business as usual scenarios and the GWStabilize scenario. In all years, the total amount of desalinated water use is between 8 and 12 MM3 less than the amount needed in the BAU-RCP8.5 scenario, or roughly 400 MM3 of saved water over the 45 year planning horizon for stabilizing groundwater levels.
- **Groundwater use:** To stabilize groundwater levels, the total annual groundwater use in the region would need to increase relative to historical trends. Figure 6 shows the corresponding increase in pumping from the alluvial groundwater aquifer, noting an annual pumping of about 6 MM3 around 2020, which grows to about 10 MM3 by 2060. In other words, stabilizing groundwater levels in the Al Ain region requires an increase in pumping and is virtually independent of the role of climate change.

Figure 5: Annual production and use of desalinated water for agriculture, amenity, indoor, and outdoor use

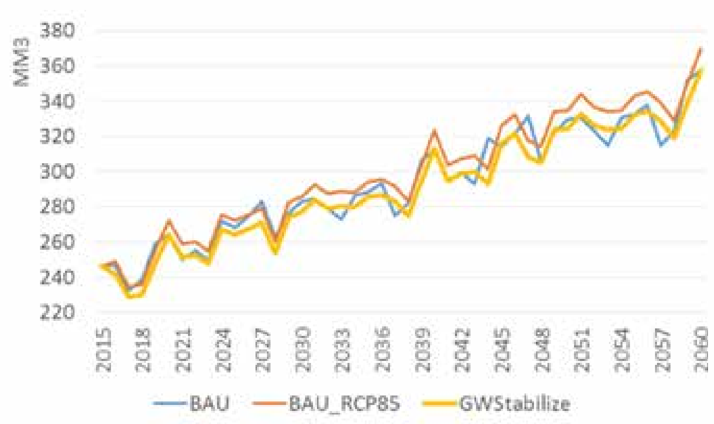
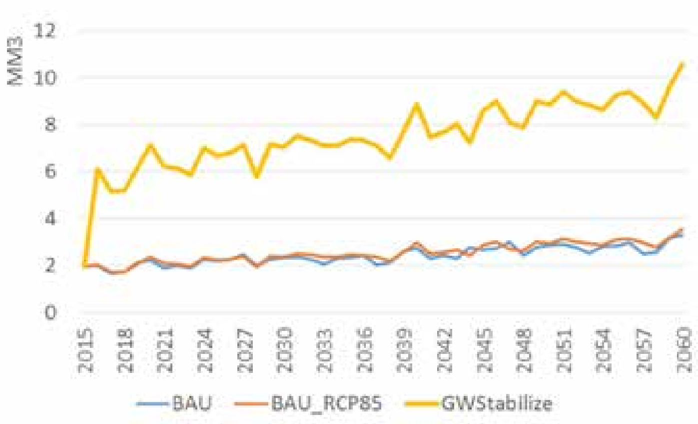


Figure 6: Groundwater use needed to maintain a relatively constant groundwater levels over time



7. Conclusions and recommendations

Major highlights of the study results are briefly summarized in the bullets below.

- Groundwater in the region is dominated by non-renewable, fossil sources mainly serving the agriculture and forestry sectors, while the bulk of municipal and industrial water is supplied through desalinization. Historically, most seawater desalinization has been made using energy intensive, fossil fuel based technologies, although it is commonly co-generated at power plants whose priority is to first generate electricity, but the waste heat is then used to produce water.
- Renewable groundwater supply is very marginal in the Al Ain region relative to total water demand. While changes in policy around the forestry and agricultural sectors could have impacts on the brackish groundwater supplies, the only way for the freshwater system to be sustained is through more targeted actions at the local level.
- While the future viability of the forestry and fodder sectors in the harsh desert climate of the UAE is one that is commonly debated, alternative uses of water can be readily assessed within a water and climate change modelling framework. The integrated model developed has the capability for evaluating alternatives in terms of water savings and the equivalent production of higher valued commodities such as date palms.
- It is highly likely that the importation of desalinated water causing elevated groundwater levels due to municipal and industrial uses, perhaps even from water leaks from the distribution system. This water can be exploited locally to serve agricultural interest and perhaps lead to reduced groundwater levels in places where elevated water tables are actually a threat to infrastructure.
- There are 'win-win' outcomes in terms of stabilizing the local groundwater system by conjunctively using it along with desalinated water. Future climate change shows more wet conditions, which could be used to strategic advantage to periodically reduce desalinated water imports in favour of local alluvial groundwater.

Key knowledge gaps are summarized in the bullets below.

- The data are generalized and could be further developed and explored and the analysis and results analyzed with greater scrutiny. Data regarding indoor use is assumed on a per-capita basis, and the area irrigated for outdoor and amenity uses was approximated from aerial maps and images, and could be further corroborated.
- The groundwater model applies simple first principles of groundwater flow, making use of Darcy's law to characterize the near surface alluvial aquifer that was considered in this study. More detailed groundwater modelling could add credibility to the simplified groundwater modelling assumptions.
- The sensitivity of the crops grown in the region to elevated CO2 in field conditions is not known with certainty. Plant growth model does exhibit sensitivity to elevated CO2 in in terms of yield, particularly for date palms. This sensitivity could be studied in greater detail in subsequent studies.
- The study represents a first-order representation of the overall water supply and demand for the Al Ain region, and demonstrates how detailed modelling of agricultural commodities can be used to better understand the water supply-demand balance.

Key recommendations are summarized in the bullets below.

- To ensure the stability and sustainability of groundwater resources, a restructured monitoring programme would be helpful in managing these shared resources under climate change. The results of the study demonstrate that by actively monitoring groundwater levels, building the infrastructure to take advantage of the near surface alluvial aquifers, these aquifers could act as a strategic reserve or serve to reduce the imports of desalinated water.
- Sensitivity analysis should be conducted to explore a greater range of relevant policy scenarios for the region. It would be very useful to continue to develop the water and climate change modelling capabilities with a broader array of stakeholders, where the tools could be used to explore additional targeted questions and regional differences.

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About

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Under the guidance and patronage of His Highness Sheikh Khalifa bin Zayed Al Nahyan, President of the United Arab Emirates, the Abu Dhabi Global Environmental Data Initiative (AGEDI) was formed in 2002 to address responses to the critical need for readily accessible, accurate environmental data and information for all those who need it.

With the Arab region as a priority area of focus, AGEDI facilitates access to quality environmental data that equips policy-makers with actionable, timely information to inform and guide critical decisions. AGEDI is supported by Environment Agency – Abu Dhabi (EAD) on a local level, and by the United Nations Environment Programme (UNEP), regionally and internationally.

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The Environment Agency - Abu Dhabi

The Environment Agency – Abu Dhabi (EAD) was established in 1996 to preserve Abu Dhabi's natural heritage, protect our future, and raise awareness about environmental issues. EAD is Abu Dhabi's environmental regulator and advises the government on environmental policy. It works to create sustainable communities, and protect and conserve wildlife and natural resources. EAD also works to ensure integrated and sustainable water resource management, to ensure clean air and minimize climate change and its impacts.

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CCR Group

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LNRClimateChange@ead.ae

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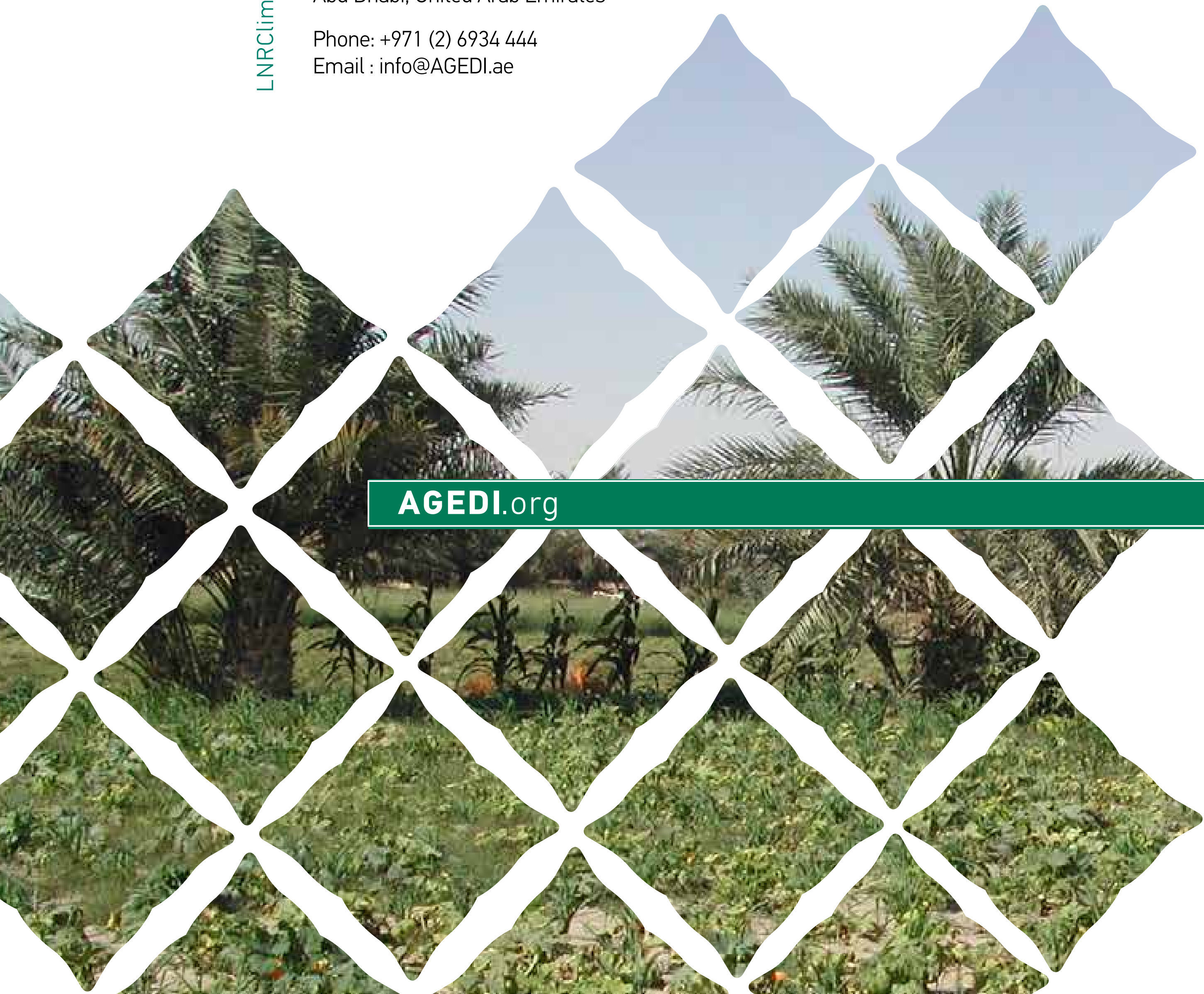
هيئة البيئة - أبوظبي
Environment Agency - ABU DHABI

Abu Dhabi Global Environmental Data Initiative (AGEDI)
P.O Box: 45553
Al Mamoura Building A, Murour Road
Abu Dhabi, United Arab Emirates

Phone: +971 (2) 6934 444
Email : info@AGEDI.ae



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