Science for resilient livelihoods in dry areas

Climate Dynamics of the Arabian Peninsula

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SUGGESTED CITATION

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1. Introduction

The Arabian Peninsula (AP) in Southwest Asia at the junction of Africa and Asia is mainly a desertic arid climate. The area is an important part of the Middle East and plays an important geopolitical role because of its vast reserves of oil and natural gas. The coasts of the peninsula are, on the west, the Red Sea and the Gulf of Aqaba, on the southeast, the Arabian Sea (part of the Indian Ocean), and on the northeast, the Gulf of Oman, the Strait of Hormuz, and the Persian Gulf. Its northern limit is defined by the Zagros collision zone (Iraq-Iran border), a mountainous uplift where a continental collision between the Arabian Plate and Asia is occurring. Geographically, the AP includes parts of Iraq and Jordan. Politically, however, the peninsula is separated from the rest of Asia by the northern borders of Kuwait and Saudi Arabia. Nevertheless, we use the current extend as shown in Fig 1 for climate change analysis of the AP.

Geographically, the terrain of the AP consists of a large central plateau, a variety of deserts, marshy coastlands, and stretches of mountains. The main feature of the peninsula is the central plateau, which reaches a height of 2,500 feet. Unlike many plateaus, the central plateau of the AP is not flat; it gently slopes towards the Persian Gulf. The region as a whole is distinguished by a large variety of geographic variance, ranging from the central plateau to the stony deserts in the north, and the coastlands. The AP also has the largest uninterrupted dune in the world, called the Empty Quarter. The Empty Quarter runs for 40 kilometers and features linear dunes.

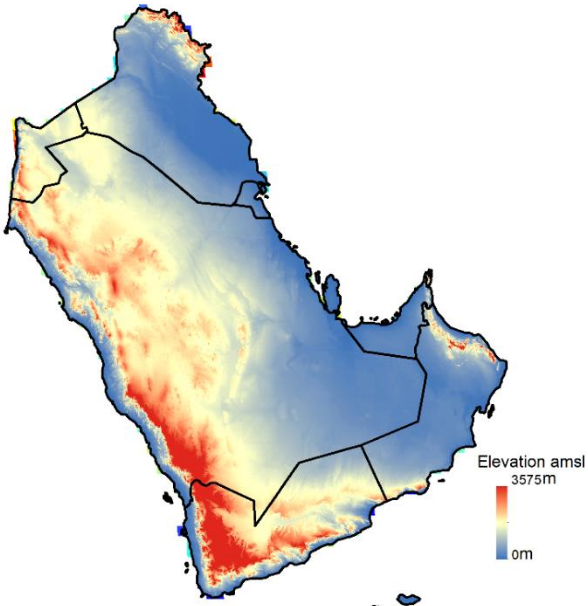

Fig.1 The physiography of the AP. This is a large plateau that gently slopes to the Persian Gulf. Western and Southern Saudi Arabia and Yemen are mountaineous.

The climate of the AP is extremely dry and arid. The AP, the region is mainly characterized by a desert-type climate with extreme day-time heat and infrequent low rainfall in about 80% of the area (Patlakas et al., 2019). According to the Koeppen–Geiger classification, the climate can be classified as Hot Desert Climate (BWh). The southwestern part features a mild steppe climate, due to higher precipitation that is spread throughout the year. Four climatological seasons are found in the AP, representing different climatological regimes, the northeast monsoon (December–March), the spring transition (April–May), the southwest monsoon (June–September), and the fall transition (October–November). Compounding the lack of precipitation, the AP also has few lakes or permanent rivers, two facts which combine to produce an extremely dry landscape that is not conducive to agriculture. The few rivers that do exist in the (wadis) are full during the wet seasons. During any other period, the wadis are dry. The dry climate, combined with lack of available water, does not permit large scale agricultural development.

ICARDA has been doing research in the global dry regions (especially in the MENA and AP) since the 70s to enhance the agricultural sustainability focusing on enhancing the livelihoods of people in dry regions. In these regions, issues such as climate change, land degradation, lack of quality water for irrigation play strong roles in limiting agricultural productivity. ICARDA’s focus has been on a multi scale approach focusing on the four main agroecosystems (irrigated, rainfed, agro-sylvo-pastoral and desert farming). Climate change in the AP is very complex and its trends are quite speculative, warranting an in-depth analysis to prepare to take necessary action plans.

ICARDA has been very keen on the theme of climate change which is a main item in ICARDA's strategic plan, and its flagship vision for the AP under the multi-CGIAR centers framework for the global drylands called the DryArc initiative.

2. Climate Change in the Arabian Peninsula

The Arab region contributes less than 5 percent to global greenhouse gas emissions but is one of the most vulnerable to the potential ravages of climate change. In recent years, the region has suffered from rising average temperatures, leading to hotter summers and more frequent heatwaves. The possible reduced rainfall in the coming years will further exacerbate regional water shortages. Weather patterns are becoming more unpredictable, and the region is subject to growing extremes in terms of unusual meteorological events, droughts and floods, shifts in seasons, and growing variability of river flows and recharge rates of groundwater aquifers.

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) was an important project that made a focused study on the long term climate in the Arab region. It was a collaborative effort between the United Nations and the League of Arab States (LAS) and their respective specialized organizations to respond to the request of the Arab Ministerial Water Council and the Council of Arab Ministers Responsible for the Environment to deepen the understanding of the impact of climate change on water resources and its associated implications for socio-economic vulnerability in the Arab region. The RICCAR Initiative aimed at assessing the impact of climate change on freshwater resources in the Arab Region through a consultative and integrated assessment that seeks to identify the socio-economic and environmental vulnerability caused by climate change impacts on water resources in the Arab region. The main outcome of this project was a long term record of simulated and bias-corrected climate product (hereafter called the RICCAR data). ICARDA has been studying the dynamics of climate in the MENA region under its DryArc agenda in many parts of the dry regions and particularly the AP using a diverse set of climate products. Primarily we use the RICCAR climate product, which is focused on the MENA, which consists of the outputs of three GCMS (CNRM, GFDL and EC-EARTH) that were downscaled and bias-corrected (1980-2100) for different climate change scenarios (RCP 4.5 and RCP 8.5). In this study, these climate products were strategically analyzed, and the climate change dynamics of the AP were studied.

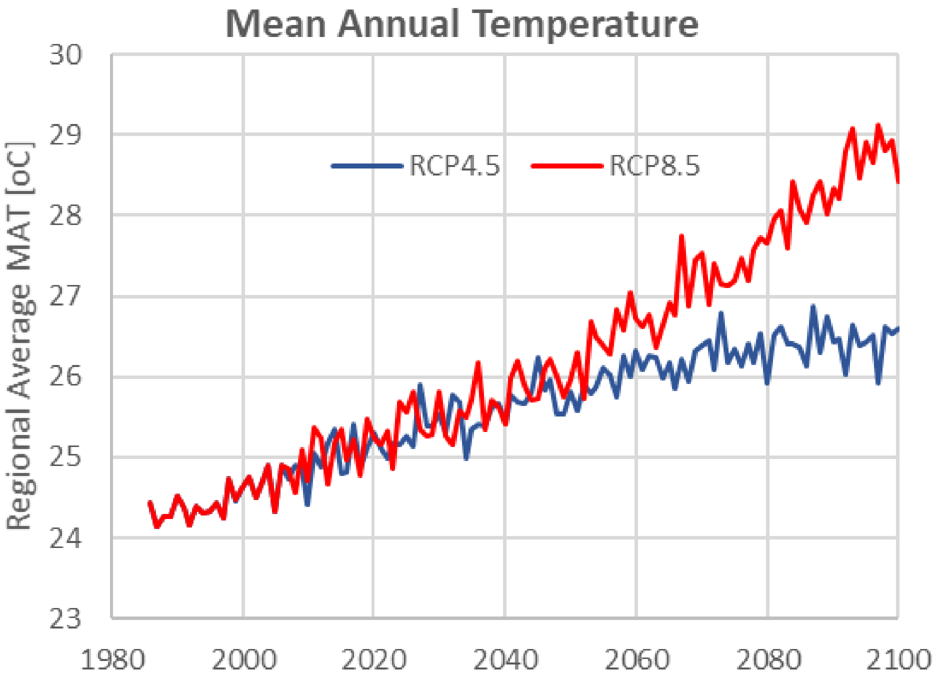

Fig.2 Temporal pattern of the Mean Annual Temperature (MAT) over the whole AP under the two IPCC scenarios. The take-home message is that the MAT can increase up to 2-4 degrees by the end of the century.

3. Climate Change in the Present (1980-2019)

To study the climate change in the current climate (1980-2019), we analyzed a climate product called the ERA5 of the ECMWF (European Centre for Medium-Range Weather Forecasting). ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset. ERA5 MONTHLY provides aggregated values for each month for seven ERA5 climate reanalysis parameters such as the 2m Air Temperature, 2m Dewpoint Temperature (a good proxy for Relative Humidity), Total precipitation. Additionally, monthly Minimum and Maximum Air Temperature at 2 m are also available. We mapped the temporal trends of these variables by calculating the slope of the linear regression with time to see the temporal trends. They are displayed below in Figure 3. The main result is the presence of intense warming hot-spots in Northern Saudi Arabia and Northern Iraq. In case of precipitation, relatively humid the mountainous Southwest AP (SouthWest Saudi Arabia and Yemen) and the mountainous section of North East Iraq shows a a strong declining trends of annual precipitation. The central desertic areas show an increasing trend of precipitation.

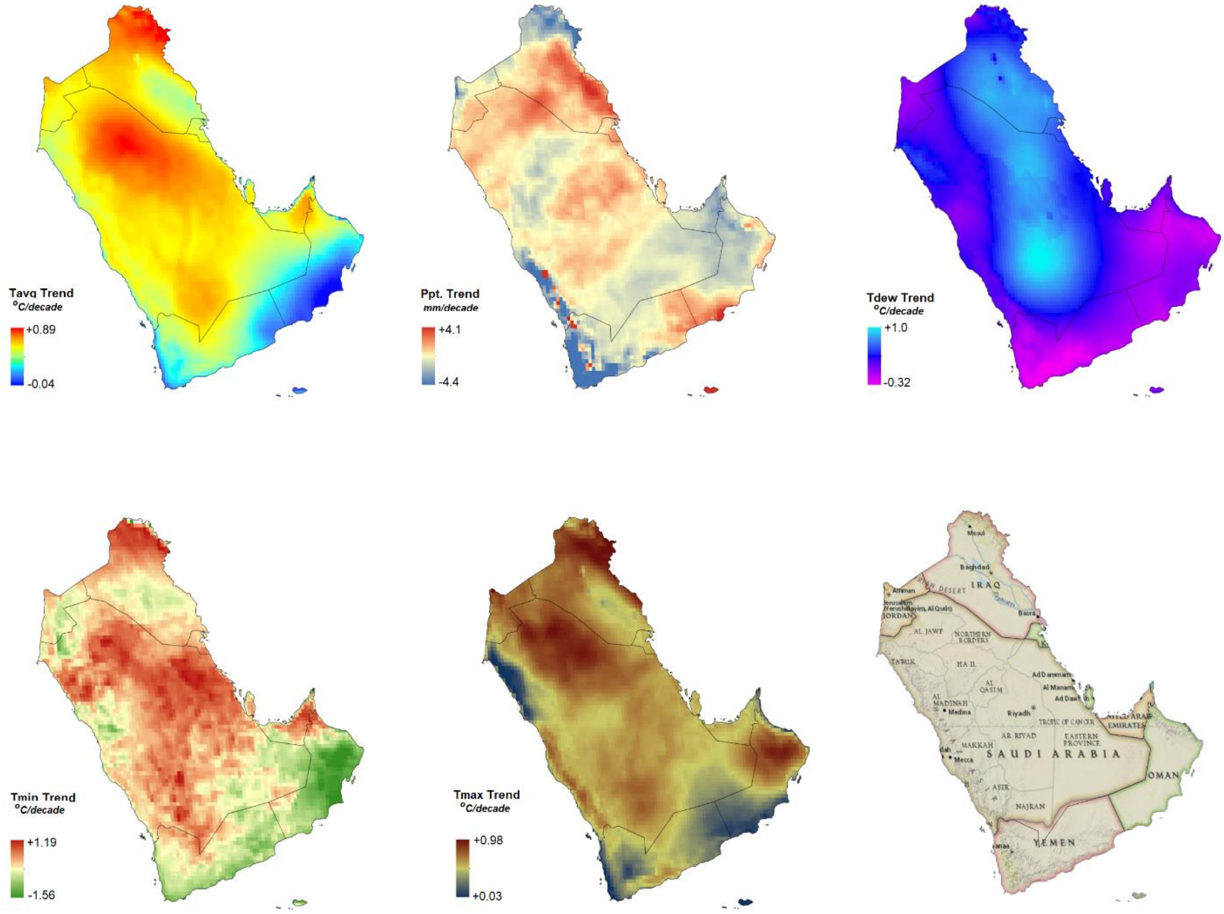

Fig. 3 Spatial Patterns of the Temporal Trends (slope of the linear regression of the parameter with time 1980-2019) of some of the key meteorological factors over the AP to show how climate change has occurred in the present climate (1980-2019). The ECMWF (European Centre for Medium-Range Weather Forecasting) ERA5 data has been used to do this analysis. The panels show from the top left spatial pattern of temporal trends in [a] Mean Annual Average Temperature, [b] Annual Precipitation, [c] Mean Annual Dew Point Temperature (Relative Humidity), [d] Mean Annual Minimum Temperature, [e] Mean Annual Maximum Temperature and [f] Map of the AP with the important cities.

4. Climate Change in the Future (2020-2100)

To understand how climate will change in the future spatially and temporally in the AP, the RICCAR climate data were analyzed (both IPCC scenarios RCP 4.5 and RCP 8.5) until the end of the century from the present for Temperature and Precipitation. We have bias-corrected 50 km climate datasets from three GCMs within the RICCAR database. Figures 4 and 5 show the temporal trends of how temperature and precipitation will change in the AP respectively for the two scenarios. Rigorous statistical tests were conducted and only the statistically significant results were plotted. It is clear the temperature increases in a statistically significant manner across the AP, although their magnitudes may vary across the region. The precipitation, on the other hand, follows a complex pattern and the statistical confidence is rather poor. This is because of the complexity of the precipitation process in an already dry environment that has huge orographic variabilities along with complex synoptic-scale maritime influence (especially in the Red Sea and Oman sea area).

Regarding the temperature trends, what can be generalized is that the Iraqi highlands (Zagros mountain ranges) that overlaps with the provinces of Al Sulaymaniyah (Slêmanî), Arbil and Kirkuk are warming at rather high rates (+0.3-+0.53 C/decade). Secondly, the Saudi Arabian provinces of Qassim, Ha'il, Madinah is the second hot spot of warming in the AP where the warming trends are at the rate of +0.2-+0.35 C/decade. The Saudi province of Najran and Riyadh are warming but at a much slower rate. Although the Yemeni and Omani highlands are topographically prone to enhanced warming, the data shows that the warming trends are rather low. Similarly, the Jordanian lowlands (not Jordan as a whole) are also warming at a much slower rate in the future.

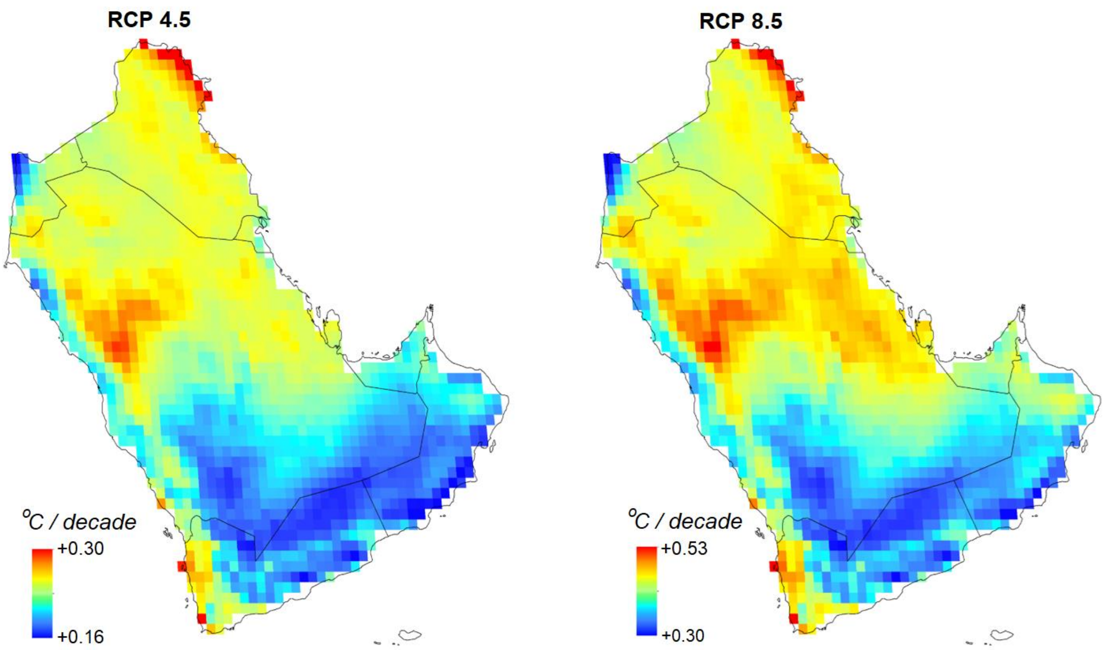

Fig. 4 Climate Change in the Future. Spatial Patterns of the Temporal Trends (slope of the linear regression with time 2020-2100) of Mean Annual Temperature over the AP for the two main IPCC climate change scenarios (RCP 4.5 and RCP 8.5). The slopes showed here have high statistical confidence ($p<0.05$) across all the locations of the AP. It can be concluded that the hot spots of warming are the Iraqi highlands and the North-Western regions of Saudi Arabia (Madinah, Hail, Qasim). It can be seen that the rate of warming is +0.30 C/decade (RCP 4.5) to +0.53 C/decade (RCP 8.5) in these locations.

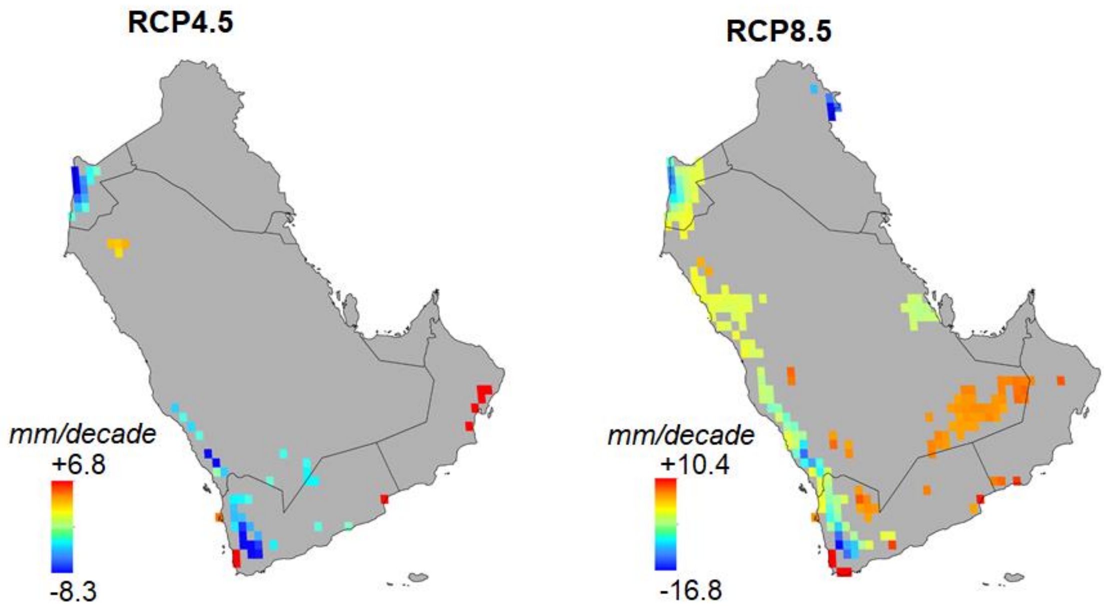

Fig. 5 Climate Change in the Future. Spatial Patterns of the Temporal Trends (slope of the linear regression with time 2020-2100) of Annual Precipitation over the AP for the two main IPCC climate change scenarios (RCP 4.5 and RCP 8.5). The slopes showed here have high statistical confidence ($p<0.05$) only for some places in the AP rest, all the places do not show any statistically significant trends. It can be concluded that the hot spots of drying are Jordan, Yemenite highlands where the rate of annual precipitation decline ranges from -8.3-16.8 mm per decade ($p<0.05$). It can also be seen that some locations show some statistically significant increase in precipitation. These locations are mostly located in Eastern and South-Eastern parts of the AP (Oman and Eastern Province of Saudi Arabia). For the rest of the peninsula, no statistically significant trend exists ($p>0.05$), however there are trends but not shown in this figure.

The precipitation trends are rather highly complex under a changing climate and there seem to be far less statistically significant trends in precipitation under a changing climate in the AP. However, there are some pockets where significant trends were visible. The Jordanian lowlands show a significant drying trend (with a -9-16 mm /decade). The region overlapping Saana in the Yemeni highlands also shows a declining trend. There is a slight precipitation declining trend along the Red Sea coast of the AP. Some regions of increasing precipitation trends were also noted. This includes mostly Omani coasts and the Southern Eastern Provinces of Saudi Arabia. The general trend is declining precipitation and lowering of the distribution of rainfall. High-intensity rainfalls are common that are detrimental to agriculture and land degradation.

Figures 6 and 7 show the country-wise trends in climate change with the analysis of temperature as an example. For the analysis, we averaged the values over the geographical area of the country to arrive at national trends. As such, local heterogeneities, owing to the topography, etc are averaged out. Figure 7 shows the country-wise warming trends at the end of the century both in magnitude and percentage. This may be useful for policy purposes and other geopolitical planning. Bahrain, owing to its very small geographical area, has been kept out of this analysis.

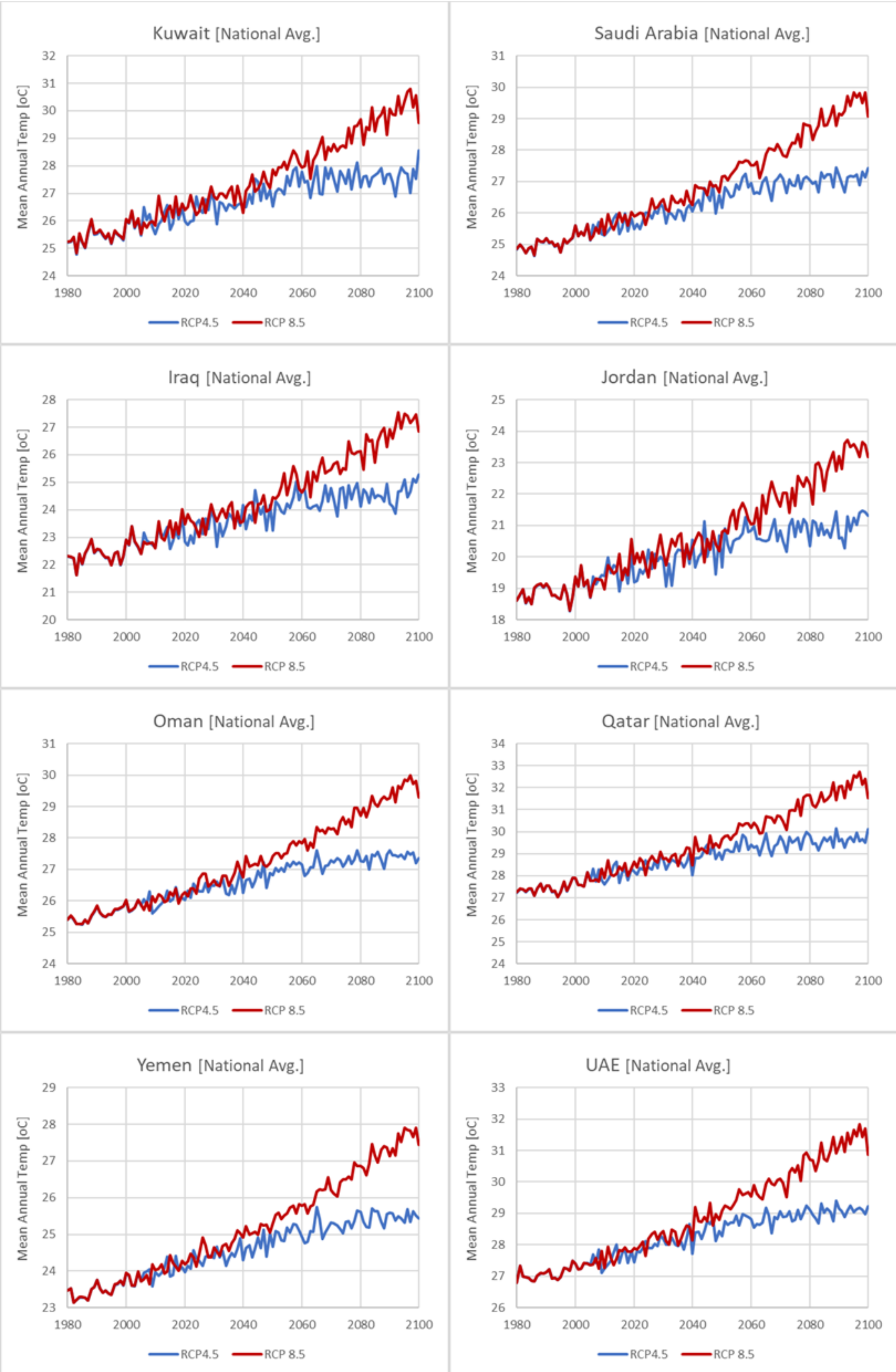

Fig. 6 Country-specific warming trends (averaged over the geographical area) under the two IPCC scenarios using the RICCAR data. This can be used to understand how much warming can be expected at the national scale.

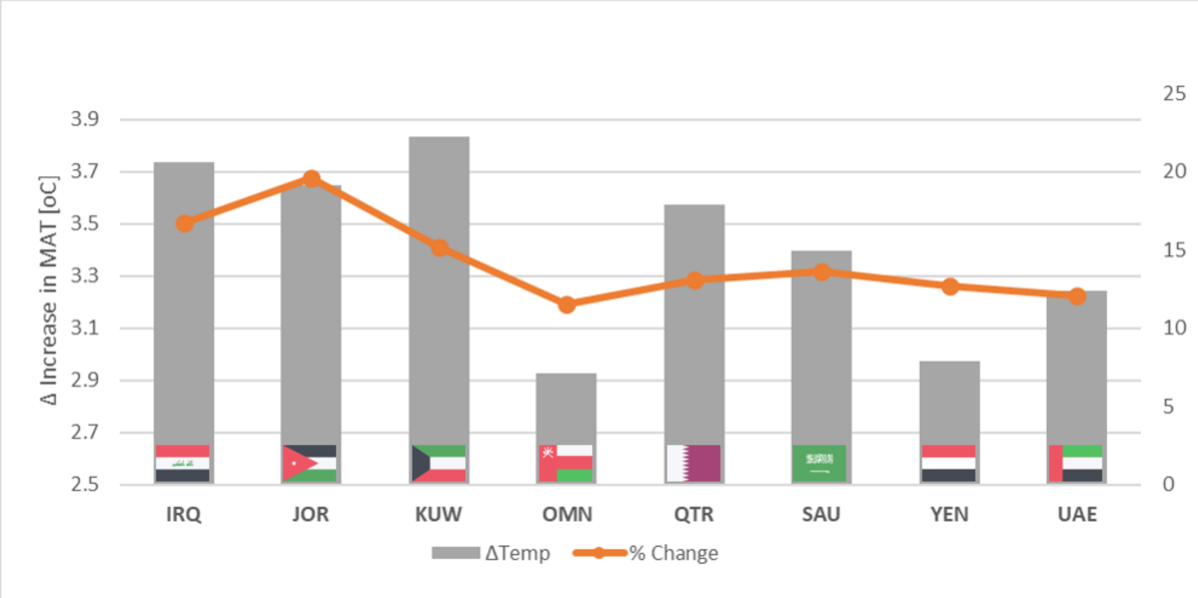

Fig. 7 The magnitudes of increase in the Mean Annual Temperature from the present for the different countries of the AP. The figure shown here is the average of the two IPCC scenarios, RCP 4.5 and RCP 8.5 and nationally averaged based on the geographical area. Bahrain is a very small country and is not shown. The percentage of warming from the baseline is shown in the secondary right axis using the orange line. It can be seen that Kuwait warms up the most in terms of magnitude, however, Jordan experiences the maximum warming effect. Among the countries, Oman experiences the least warming both in terms of magnitude and effect.

5. Climate Downscaling Activities for Climate Adaptation Studies

Climate change adaptation research is a fundamental part of understanding how large scale (regional) climate change affects various sectors such as agriculture, water resources, etc. Studying climate change adaptation is conducted using Soil-Vegetation-Atmosphere Transfer (SVAT) models [1] Crop Model (APSIM) for the agriculture sector and [2] Ecohydrological model (e.g. SWAT, Soil Water Assessment Tool, STEPS). This needs even higher resolution climate products at more local scales (e.g. <1 km). The ICARDA team has been doing spatial downscaling of bias-corrected climate products to run the SWAT model for different countries of the AP (e.g. Iraq, UAE). Because these models need various datasets in specific formats, we are now engaged in preparing the data accordingly. We employ two approaches [1] to use the high-resolution CGIAR-CCAFS downscaled product based on the Delta approach that uses thin-plate spline spatial interpolation and [2] employ a high-resolution downscaling strategy based on the Gradient plus Inverse Distance Squared method of the USGS.

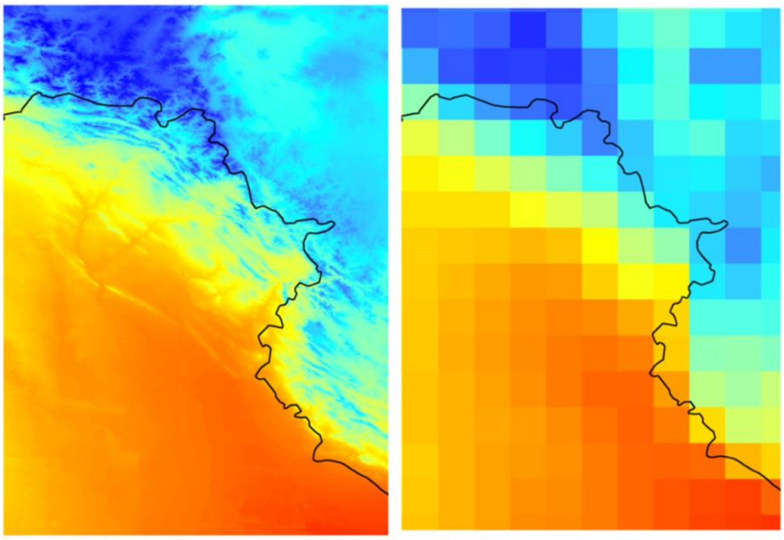

Fig.8, A zoomed-in comparison of the GIDS-based downscaled climate product (1 km, daily) vis-à-vis the RICCAR product (50 km, daily) over a complex topography in North-Eastern Iraq. An example is shown here for Air Temperature on the day of the year 195 for 2018. Note the high-resolution variability in the downscaled product (left) that captures the topographic variability and its impact on microclimate.

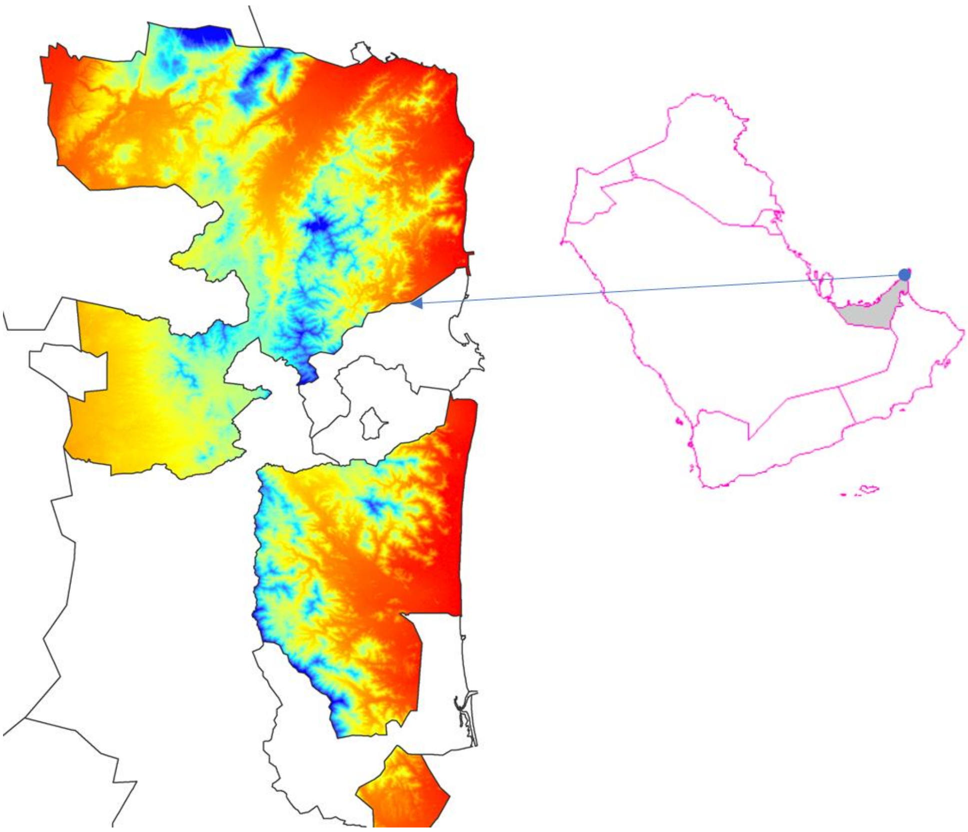

Fig.9 An example of a high resolution downscaled (RICCAR-based) climate product developed over Fujairah, UAE for future climate adaptation studies.

6. Climate Adaptation Research in the Arabian Peninsula under ICARDA's DryArc Agenda

ICARDA's climate change adaptation research in the AP aligns nicely with its DryArc agenda. DryArc agenda is a multi-CGIAR centers vision that ICARDA is leading to support systemic innovation in agri-food systems of the global dry areas. This region extends from Africa to East Asia (including MENA), a vast region expected to be among the worst affected by climate change. In the DryArc mandate regions, a complex set of challenges such as water scarcity, land degradation, drought, and temperature extremes, threaten rural livelihoods and the viability of agriculture is prevalent. This is exacerbated by rising population, migration and geopolitics resulting in poverty, malnutrition, rising unemployment, human displacement, and increasing competition over scarce natural resources.

Solving this complex problem requires new research strategies to strengthen the resilience of rural communities and food systems in drylands. 'DryArc' plans to harness the knowledge and expertise of eight CGIAR centers (including ICARDA) to mobilize a rich diversity of technological, managerial, socio-economic, institutional, and policy innovations tailored to major agroecosystems of the drylands (irrigated, rainfed, agro-sylvo-pastoral and desert farming). Solutions target higher land, water, and labor productivities, all of which are strongly related to climate factors, directly or indirectly. This holistic approach will lead to sustainability, and food and nutritional security, and alleviate some of the underlying causes driving human displacement and the socio-political fragility that affects many dryland countries.

Innovations and strategies are evaluated according to the following criteria: 1) their ability to foster climate change adaptation and sustainable intensification; 2) their ability to generate new employment opportunities for the rural poor; 3) their affordability and context-specificity, and 4) whether they demonstrate the potential to reduce conflict and involuntary displacement. The trans-boundary approach of DryArc encourages the linking policies, mechanisms, governments, the public and private sector that are needed to streamline the breadth and depth of knowledge already in existence to address the challenges highlighted above, as a means to test innovations and drive knowledge sharing across the DryArc.

Thus, all the climate change analytics of ICARDA will be integrated into the Dry Arc interface (and connected to national and regional CC networks and tools) to support projects of adaptation in the AP. For example, ICARDA has active projects that have climate change elements in several countries in the AP (e.g. Iraq, Jordan, UAE, Saudi Arabia). With the climate change theme within the DryArc framework, ICARDA will also embark on the CGIAR's Two Degree Special Climate Change Initiative and lead its MENA component where the AP will be a major component partnering with other agencies in the region. As such, ICARDA's interest in climate adaptation research is significant. Some examples of Climate Adaptation research that ICARDA is fostering are.

- Establishing a platform of collective intelligence for climate change action. This includes accumulating a set of ground data on meteorological, hydrological, agronomic and land degradation factors. These warrants establishing and growing a network of ground observation sites and linking it with Earth Observation and digital augmentation of agriculture.
- Establishing agronomic experiments towards enhancing water use efficiencies techniques.
- Establishing and implementing action plans on climate change-induced land degradation in the rangelands of the drylands.
- Establishing early warning systems and climate/weather-related agrometeorological advisories.
- Establishing climate-smart plant breeding methods and scaling up the seed systems.

* Establishing climate-smart value chains in the agriculture sector.
* Identification of location-specific Best Climate Adaptation Practices (BCAP) using modeling techniques using downscaled climate data.
* Fostering sustainable land management that integrates sustainable crop and animal husbandry (small ruminants) in the rangelands.

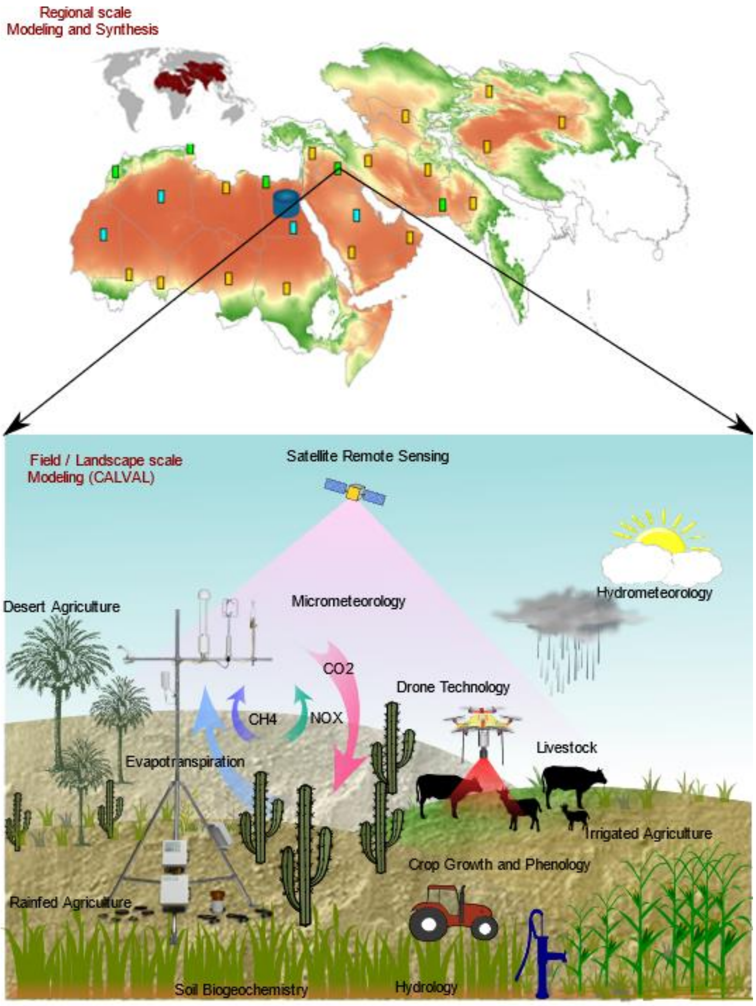

Fig.10, A conceptual framework of the collective intelligence vision of enhancing climate change knowledge in the DryArc framework.

7. Conclusions.

The nature of climate change in the already dry and resource-limited AP is alarming. The ICARDA team has analyzed the present and future trends of climate change over the AP using the standard datasets and have identified the hot-spots within the Region. Based on this, ICARDA and the CGIAR alliance is looking forward to fostering various R4D projects in the Agrifood sector to make the region more climate-smart and resilient to climate change and the shocks due to extreme weather events. These climate smart research endeavors are strategically planned along with parallel changes in the economy (that warrants a change in the food systems, dietary trends and partnerships) and the adequate mix between crop-livestock. The AP has a unique combination of the typical four agroecosystems prevalent in the MENA (viz. Rangelands, rainfed, irrigated, and desertic systems). We also look into various aspects of Date Palm cultivation and its performance under a changing climate. Thus, agroecosystem-specific climate-smart R4D will be implemented in the AP. In addition to the basic climate research that deals with understanding the regional climate dynamics, extreme weather and hydrometeorology and the development of various agrometeorological Early warning and Advisories, our R4D climate change endeavors revolve around various issues such as [1] Enhancing Water Productivity, including on-farm water management and lowering evapotranspiration [2] Climate-smart plant breeding (including cereals, legumes and forage crops) targeting abiotic and biotic stresses, [4] Enhancing the rangeland resilience and sustainable crop-livestock combination under a changing climate will be targeted, [5] Systems agronomy research to explore the prospects of conservation tillage as a climate-smart solution for mitigation n/r adaptation endeavors will be carried out using observations, experiments and modeling. All these research directions will come under ICARDA's DryArc agenda. The R4D outcomes will be part of DryArc's major modules that will be used to disseminate the results to the end-user and stakeholders. These modules include the [1] Knowledge Management Tool, [2] the Multicriteria Assessment Tool (MAT), [3] The Integrated Modelling Framework (IMF), [4] The Mapping Tool (MT) and the [5] The Stakeholders Integration Tool (SIT).

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References

Patlakas, P.; Stathopoulos, C.; Flocas, H.; Kalogeri, C.; Kallos, G. Regional Climatic Features of the Arabian Peninsula. *Atmosphere* **2019**, *10*, 220.