# Water scarcity, climate change and potential collaboration in water management in the Middle East

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## 1. Introduction

The Middle East is one of the most water-scarce regions in the world (Rosegrant et al., 2013). The gap between the demand and supply of water has significantly increased over time across this region and is expected to get wider. The annual average of precipitation in this region is usually very low, less than 200 mm (Taheripour et al., 2020). In the future, this region will face major water scarcity induced by climate change and rapid water demand expansion (Chenoweth et al., 2011; Rosegrant et al., 2013).

Water is largely used for irrigation in the Middle East. For example, the share of irrigation in total water withdrawal in Iran, Iraq, Jordan, Lebanon, Saudi Arabia, Syria, and Turkey are currently about 92.2%, 91.5%, 53.1%, 38%, 79.2%, 87.5%, and 87.1%, respectively (FAO, 2022). Due to climate conditions and the low productivity of rainfed cropping, crop production relies heavily on irrigation in the region. This suggests that a reduction in the water supply to irrigation would harm agricultural activities in the Middle East.

The adverse consequences of water scarcity induced by climate change will not be limited to the losses in crop production. With no proper mitigation policies in place and without an effective water management plan, reductions in agricultural output would negatively affect the whole food supply chain and associated economic activities. It would lead to less demand for labor and increased unemployment in the region, reduced productivity of capital assets (machinery and infrastructure), and generate idle capacities across both agricultural and non-agricultural sectors. With the reduced availability of water for irrigation, a portion of agricultural production capacity will be lost, and people will leave rural areas. With reduced water supply, the entire water infrastructure will become less efficient, a portion of hydroelectricity will be lost, and water-intensive industries will not operate at full capacity or may not be able to produce at all.

As a result of the economic impacts of the water scarcity in the region, there have been major surges in water withdrawal from unsustainable resources such as deep groundwater. In Iran, the largest water user in the region, water withdrawal from unsustainable resources (such as over-withdrawal from the surface water and depletion of groundwater) has increased from about 48 billion $m^3$ per year in the early 1970s to more than 93 billion $m^3$ per year in 2020 (FAO, 2022). In Turkey, the second largest water user in the region, water withdrawal has increased from about 32 billion $m^3$ per year in early 1990 to more than 59 billion $m^3$ in recent years (FAO, 2022). Increases in water withdrawal have also been observed in smaller economies in the region. For example, water withdrawal in Jordan, a very water-scarce country, has increased from less than 0.6 billion $m^3$ per year in the early 1980s to more than 1 billion $m^3$ in recent years (FAO, 2022).

Under water scarcity conditions, shared water sources can be a source of conflict between riparian nations. Tigris and Euphrates rivers and their tributaries flow through the countries of Turkey, Syria, Iraq, and Iran. Turkey has control over the flow to downstream Iraq and Syria due to the construction of dams (Shamout and Lahn, 2015). Transboundary water resources management in the basin is particularly difficult due to weak cooperation among riparian countries, intensive hydropower development, inefficient agricultural practices, and political instability (Shamout and Lahn, 2015). The Tigris-Euphrates (TE) river basin gets the lowest score across seven transboundary river basins ranked by how well water resources are managed (Economist Intelligence Unit, 2020). Moreover, climate change may result in a 20% reduction in rainfall over the basin by the midcentury (IPCC, 2013). By the end of this century, substantial decreases in the mean annual water discharge are expected for the two rivers, ranging between 19% and 58% (Bozkurt et al., 2015), and water availability for irrigation in the region is projected to decline between 25% and 55% (Bozkurt and Sen, 2013).

Another example of shared water resources in the Middle East is Saq-Ram Aquifer System (SRAS), a fossil transboundary aquifer containing water that accumulated thousands of years ago. Jordan and Saudi Arabia, two of the most water-scarce countries in the world[1], benefited from this water resource on their shared border. Groundwater abstraction has rapidly increased from SRAS in both Jordan and Saudi Arabia since the early 1980s, soon after its discovery (UN-ESCWA and BGR, (2013)). Both countries developed groundwater withdrawal from this aquifer to support domestic, agricultural, and industrial water uses. Agricultural activities consume a large portion of the extracted water from this aquifer in each of these countries. In 2015, an agreement was signed between Jordan and Saudi Arabia to manage the shared groundwater of this aquifer. The agreement requires elimination of all activities which depend on the extraction of groundwater in the Protected Area of the aquifer and limiting groundwaters extraction in the managed area of the aquifer to municipal uses. Adopting these restrictions will have economic implications for the economies of Jordan and Saudi Arabia.

While the existing literature has assessed water scarcity at the global level (Rockström et al., 2009; Rosenzweig et al., 2004; Mekonnen and Hoekstra, 2016; Liu, 2022), the extent to which climate change could affect water scarcity in the Middle East has not been fully quantified yet. Taheripour et al. (2020) have examined the impacts of water scarcity on the economies of the Middle East. However, that study did not quantify the potential impacts of climate change on water scarcity. Instead, Taheripour et al. (2020) have only considered several hypothetical water scarcity assumptions in their analyses.

The main goal of this research is to assess economic damages from reduced water supply, evaluate the extent to which potential collaboration among the riparian countries in the ET basin could help to reduce the negative impacts of climate change. Since water scarcity is expected to surge in all river basins and countries in the Middle East, and given that climate change affects crop yields and other economic activities and economies are connected through trade, this research develops a more comprehensive analysis for the entire Middle East. Specifically, the study quantifies the impacts of climate change on water scarcity in each river basin and country in the Middle East, and examines the extent to which water scarcity and changes in crop yields due to climate change could affect Middle Eastern economies. The study also quantifies the impacts of changes in water withdrawals by Jordan and Saudi Arabia from SRAS on these two economies.

## 2. Methodology

As shown Figure 1, a unique modeling framework developed in this research consists of: 1) future projections for climate variables under alternative climate scenarios and socio-economic pathways; 2) impacts of climate change on crop yields; 3) a hydrological model to project future

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[1] https://www.internationalwaterlaw.org/blog/2015/08/31/the-newest-transboundary-aquifer-agreement-jordan-and-saudi-arabia-cooperate-over-the-al-sag-al-disi-aquifer/

changes in surface water, sustainable underground water, and unsustainable underground water withdrawals at each river basin in the Middle East; and 4) a computable general equilibrium (CGE) model (GTAP-BIO-W) to quantify the economic consequences of the future changes in climate conditions. The assessments of economic damages have been examined under climate scenarios (baselines) and climate scenarios combined with policy choices (policy scenarios).

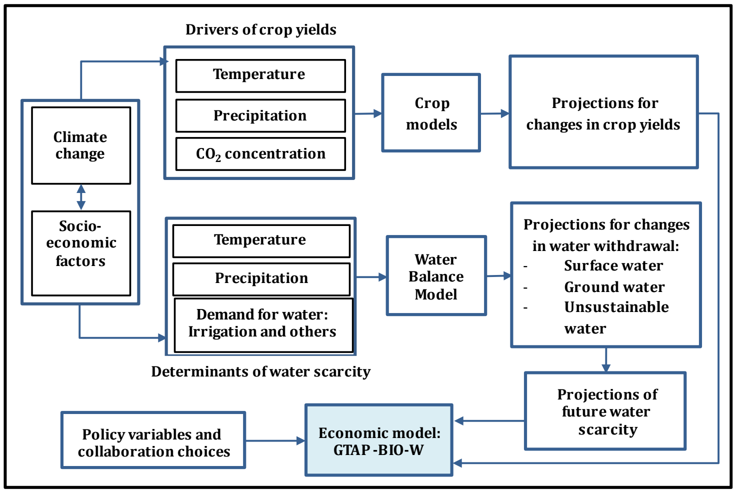


Figure 1. Modeling approach

## 2.1. Projections of Climate Variables

We use a hydrological model to quantify the impacts of future changes in climate variables on water scarcity in the Middle East under alternative climate scenarios. To accomplish this task, projections of future daily temperature and precipitation are needed. We use two alternative approaches to obtain climate projections:

- ***Approach 1.*** We use a climate dataset (Boyko, O., Reggiani, P., Todini, E. 2022) constructed using the methodology documented in (Reggiani et al. 2021). This data set is constructed using monthly temperature and precipitation time series from 1979 to 2100 produced by 19 CMIP5 models for RCP4.5 and RCP8.5 climate scenarios. These series are mutually weighted and bias-corrected using ERA5 reanalysis data (Hersbach et al. 2020) from 1979 to 2005. This method yields unbiased and sharper predictive distributions for climatological variables in comparison to using the unprocessed ensemble distribution (Reggiani et al. 2021). The monthly variables provided by this approach have been converted to daily variables using historical observations. Henceforth, we refer to these projections as ***Ensemble Average***.
- ***Approach 2.*** While climate models have some agreement regarding temperature change, there is a large disagreement regarding precipitation. It is a standard practice to take a multi-model ensemble mean for temperature in the climate impact literature. However, the ensemble means for precipitation can be misleading due to the weak performance of some climate models regarding precipitation (McMahon, Peel, and Karoly 2015). The National Aeronautics Space Administration (NASA) of the United States has developed a data set that provides gridded future projections on daily temperature and precipitation for the whole world, NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) (Thrasher, B. et al. 2021; 2022). This data set includes

downscaled climate scenarios for the globe that are derived from various General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 6. The dataset compiles climate projections from various CMIP6 GCMs for the period from 2015 to 2100. Ideally, we would like to run the hydrological model with each GCM output. However, this would require very large computing resources. Instead, we choose just one GCM model, MIROC-ES2L, from the NEX-GDDP-CMIP6 dataset.[2] We use MIROC-ES2L model daily temperature and precipitation projections for the 2016-2055 period for SSP2-RCP4.5 and SSP5-RCP8.5 climate scenarios. Henceforth, we refer to the projections provided by this model as ***Selected Model***.

In summary, the following baseline simulations have been developed with the hydrological model:

- Impacts of moderate climate change on the surface and groundwater flows using output of:
    - Selected model with SSP2-RCP4.5 climate,
    - Ensemble average with RCP4.5 climate.
- Impacts of extreme climate change on the surface and groundwater flows using output of:
    - Selected model with SSP5-RCP8.5 climate,
    - Ensemble average with RCP8.5 climate.

In each of these simulations the area of irrigated cropland and crop mix in each grid cell are assumed to be fixed over time horizon of the analysis. It is also assumed the water withdrawal for non-agricultural uses will remain constant in each grid cell.

### 2.2. Impacts of climate change on crop yields

A large body of research has been conducted to quantify the worldwide impacts of climate change and its variability on agricultural activities (a few important examples are: Rosenzweig et al., 2002; Reilly et al., 2003; Parry et al. 2004; Fischer et al., 2005; Nelson et al. 2010, Rosegrant et al., 2013; and Rosenzweig et al. 2014). Taheripour et al (2020) studied the extent to which climate change could affect the productivity of irrigated and non-irrigated crops across the Middle East by river basin and AEZ under RCP4.5 and RCP8.5 climate scenarios. The results provided by Taheripour et al. (2020) show that yields for wheat, coarse grains, and rice are expected to drop across the Middle East at a rapid rate. On the other hand, sugar crops, vegetables and fruits, fibers, and other crops may have some yield improvements, albeit at different rates across the region. In this research, we use the results reported in Taheripour et al. (2020) to represent impacts of climate change on crop yields.

### 2.3. Economic model

The economic analysis is implemented using a CGE model (GTAP-BIO-W) that combines economic and biophysical information on land and water at the spatial resolution of River Basin–Agro-Ecological Zone (RB-AEZ) in each region of the model (Liu et al. 2014; Taheripour, Hertel, and Liu 2013; Taheripour et al., 2018). Iran, Iraq, Jordan, Lebanon, Syria, Saudi Arabia, and Turkey are separate regions in the model. Other countries are grouped into the Rest of the Middle East and the Rest of the World regions. The time horizon of the analysis is 2050. The framework

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[2] Following the approach of Abbasain et al. (2019), we systematically compared the projections of GCMs with the Modern-Era Retrospective Analysis for Research and Applications (MERRA-2) observational data for the Middle East region over the 1980-2005 period. The comparison is based on correlation coefficient, root mean square error, and extreme precipitation indices. Models in the MIROC family performed slightly better than other GCMs.

is designed to examine the nexus between agricultural activities and trade in the presence of climate change and water scarcity by country and on a global scale. In this version of the GTAP-BIO-W model, water is modeled as an explicit input in irrigated agriculture, livestock, and water utility services, with the latter supplying water to other sectors and the final demand in the model. The three activities compete for water at the river basin level, while individual crops compete for water within RB-AEZ. Irrigated crops are distinguished from rainfed. A large river basin could serve several AEZs. Thus, water consumption is traced by sector and country/region at the river basin level by AEZ.

### 2.4.Hydrological model

Changes in the natural water runoff due to climate change and changes in water withdrawals are quantified using a hydrological model (Haqiqi 2019), based on the Water Balance Model (WBM) (Vörösmarty, Federer, and Schloss 1998; D. Grogan 2016), originally developed at the University of New Hampshire. Though the hydrological model is a global model, in this analysis we focus on the Middle East region. The model simulates both the vertical exchange of water between the ground and the atmosphere and the horizontal transport of water through runoff and stream networks at the grid cell level. The model separates surface water and groundwater. It considers location-specific parameters and projects the available surface water and groundwater considering precipitation, irrigation volume, evapotranspiration, and flow routing. The hydrological model determines the annual supply of water at the 15 arc-min grid cell level based on: 1) climate scenarios, 2) the main parameters of WBM, and 3) consumption allocation of water among countries for agricultural and non-agricultural uses. Given the harvested area, which is exogenous in the model, the model produces irrigation requirements to maintain agricultural yields in future climate, and how this requirement is met by withdrawals from surface water (SW), shallow groundwater (GW), and deep or unsustainable groundwater (UGW). Deep groundwater for irrigation is more expensive than the surface and shallow groundwater due to higher pumping costs and becomes even more expensive as the water table goes down. The increase in deep groundwater use for irrigation or other uses serves as a proxy for surface and shallow groundwater scarcity. Grid cell level results are aggregated by river basin and country to calculate river basin and country specific water scarcity indices.

### 2.5. Baseline and policy scenarios

To quantify the economic consequences of water scarcity and changes in crop yields induced by climate change, 8 different baseline scenarios have been examined (Table 1). These scenarios represent 4 climate scenarios of RCP4.5 and RCP8.5 with the ensemble approach and SSP2-RCP4.5 and SSP5-RCP8.5 with the selected model, combined with two assumptions about the impact of water scarcity on the productivity of capital in each country. As noted, water scarcity is expected to negatively affect the productivity of the existing capital assets (infrastructure, equipment, and machinery) -- phenomenon frequently occurs across the Middle East (Taheripour et al, 2020). However, the extent to which this phenomenon could reduce the productivity of capital assets has not been quantified yet. To take this important effect into account, we established a relationship between the index of water scarcity and the productivity of capital assets at the macro level using the following elasticity:

$$\propto = -\frac{\%\ change\ in\ productivity\ of\ captial\ in\ region\ r}{\%\ change\ in\ water\ scarcity\ in\ region\ r} \qquad (1)$$

or

$$\% \, change \, in \, productivity \, of \, captial \, in \, region \, r = -\propto * \, \% \, change \, in \, water \, scarcity \, in \, region \, r$$

We used values of 0.1 and 0.15 for this elasticity. For example, with $\propto = 0.1$, an increase in water scarcity by 5% leads to a reduction in productivity of capital by 0.5%. Henceforth, we label simulations with $\propto = 0.1$ as EOC1 and simulations with $\propto = 0.15$ as EOC2 (Table 1).

Table 1. Baseline scenarios

| Scenarios | Ensemble | | Selected Model | |
|---|---|---|---|---|
| | RCP4.5 | RCP8.5 | SSP2-RCP4.5 | SSP5-RCP8.5 |
| $\propto = 0.1$: EOC1 | B-EOC1-E1 | B-EOC1-E2 | B-EOC1-S1 | B-EOC1-S2 |
| $\propto = 0.15$: EOC2 | B-EOC2-E1 | B-EOC2-E2 | B-EOC2-S1 | B-EOC2-S2 |

The alternative policy scenarios capture the effects of the designed policies on the baseline results (Table 2). The first set of scenarios is designed to examine the implications of changes in water use efficiency (WUE) in the TE river basin riparian countries (Iran, Iraq, Syria and Türkiye). The next set of policy scenarios examines the extent to which free trade agreements among the TE river basin riparian countries could help them to use their agricultural and non-agricultural resources more efficiently. We examined two trade policies: 1) import tariff removal on agricultural and food products, and 2) import tariff removal on all goods and services. Since Türkiye has access to the headwater of ET basin, its water management plans could intensify water scarcity in Iraq, Syria, and Iran. The stylized plan considers 20% reduction in water flow from upstream to downstream in the ET basin. "No collaboration" is worst case scenario that assumes 20% reduction in water flow from upstream to downstream in the ET basin, plus reduction in WUE by 10% and 15% elasticity of the productivity of capital stock with respect to water scarcity. For "Full collaboration" scenario we aggregate the economies of Iran, Iraq, Syria, and Türkiye in CGE model. The aggregation removes all the existing barriers among these countries in resource allocation, including water, and merges their markets for all goods and services. We also assume 10% in WUE due to collaboration.

To study potential impacts of the agreement between Jordan and Saudi Arabia to manage the shared groundwater of the Saq-Ram Aquifer System and potential non-compliance with the agreement, six more scenarios have been developed. The first three experiments represent non-compliance with the agreement and assumed 10% increase in water withdrawal:

- ***Saq-Ram-I:*** An increase in the annual water withdrawal of Jordan by 10%.
- ***Saq-Ram-II:*** An increase in the annual water withdrawal of Saudi Arabia by 10%.
- ***Saq-Ram-III:*** Both countries increase withdrawal, each by 10%.

The next three scenarios represent compliance with the agreement and assumed 10% reduction in water withdrawal:

- ***Saq-Ram-IV:*** A voluntary reduction in annual withdrawal by 10% by Jordan.
- ***Saq-Ram-V:*** A voluntary reduction in annual withdrawal by 10% by Saudi Arabia.
- ***Saq-Ram-VI:*** Both countries decrease withdrawal, each by 10%.

**Table 2. Alternative Scenarios**

| Scenarios | | Ensemble | | Selected Model | |
|---|---|---|---|---|---|
| | | RCP4.5 | RCP8.5 | SSP2-RCP4.5 | SSP5-RCP8.5 |
| WUE* of -10% | EOC1 | W1-EOC1-E1 | W1-EOC1-E2 | W1-EOC1-S1 | W1-EOC1-S2 |
| | EOC2 | W1-EOC2-E1 | W1-EOC2-E2 | W1-EOC2-S1 | W1-EOC2-S2 |
| WUE* of 10% | EOC1 | W2-EOC1-E1 | W2-EOC1-E2 | W2-EOC1-S1 | W2-EOC1-S2 |
| | EOC2 | W2-EOC2-E1 | W2-EOC2-E2 | W2-EOC2-S1 | W2-EOC2-S2 |
| WUE* of 20% | EOC1 | W3-EOC1-E1 | W3-EOC1-E2 | W3-EOC1-S1 | W3-EOC1-S2 |
| | EOC2 | W3-EOC2-E1 | W3-EOC2-E2 | W3-EOC2-S1 | W3-EOC2-S2 |
| Food tariff removal | EOC1 | T1-EOC1-E1 | T1-EOC1-E2 | T1-EOC1-S1 | T1-EOC1-S2 |
| | EOC2 | T1-EOC2-E1 | T1-EOC2-E2 | T1-EOC2-S1 | T1-EOC2-S2 |
| Overall tariff removal | EOC1 | T2-EOC1-E1 | T2-EOC1-E2 | T2-EOC1-S1 | T2-EOC1-S2 |
| | EOC2 | T2-EOC2-E1 | T2-EOC2-E2 | T2-EOC2-S1 | T2-EOC2-S2 |
| 20% reduction in water flow | EOC1 | R1-EOC1-E1 | R1-EOC1-E2 | R1-EOC1-S1 | R1-EOC1-S2 |
| | EOC2 | R1-EOC2-E1 | R1-EOC2-E2 | R1-EOC2-S1 | R1-EOC2-S2 |
| No collaboration | NOCO-ENSEMBLE | NOCO-SELECTED | No collaboration | NOCO-ENSEMBLE | NOCO-SELECTED |
| Full collaboration | FULLCO-ENSEMBLE | FULLCO-SELECTED | Full Collaboration | FULLCO-ENSEMBLE | FULLCO-SELECTED |

**Water Use Efficiency*

## 3. Results

The results vary by climate scenario, projection method, country, and river basin. Climate change is expected to significantly increase the demand for water across the Middle East by 2050. Under the Ensemble RCP4.5 scenario, the expected increases in water withdrawal vary from 2.5% in Syria to 14% in Iran. Moreover, climate change is expected to reduce available surface water significantly. These will shift the demand for water withdrawal to unsustainable underground water resources. Under the Selected model method, the expected increases in water withdrawal from unsustainable resources vary from 6.2% in Lebanon to 17% in Iran under the moderate climate scenario. In the extreme climate scenario, water withdrawal from unsustainable resources is projected to increase in Turkey and Iran by 52% and 116%, respectively.

The index of water scarcity will increase across the Middle East by 2050. Under the Ensemble RCP8.5 scenario, at the river basin level, the projected increases in this index vary between 6% to 10%. Among the river basins in the Middle East, the index of water scarcity is expected to increase the most in the ET river basin. Across riparian countries in the basin and climate scenarios, the index will increase from 5% to 30% between 2016 and 2050. A reduction in water flow to downstream countries is expected to amplify climate change induced water scarcity in these countries. A 20% reduction of water flow to downstream countries due to changes in Turkey's water policies may double the water scarcity index in Iran, Iraq, and Syria.

Water scarcity could severely affect economies in the Middle East. The negative impacts are larger under extreme climate scenarios (RCP8.5 and SSP5-8.5). Under the Selected model RCP5-8.5 climate, the Middle East region is expected to lose $102.7 billion, or 3.11% of GDP, due to intensified water scarcity and changes in crop yields. In this baseline, about 50.4% of the economic damage is expected in Turkey, and 25.5% is in Iran. Therefore, progressive additional investments in water use efficiency and conservation practices are required to limit the economic losses.

For the alternative policy scenarios, the impacts of changes in WUE (at -10% +10, and +20% in the ET basin), tariff removal (for food products only and for all goods and service) among the riparian countries of the ET basin) and a 20% reduction in water flow from upstream to downstream of the ET basin on the regional GDP for the ensemble average and the selected model are presented in Table 3. The policy variables have been added to the baseline changes in water scarcity and crop yields in each policy scenario. In Table 3, the first column of each panel represents the corresponding baseline results and other columns show the results of policy simulations. Accordingly, a reduction in WUE in the ET basin by 10% could significantly affect the economies of Iraq, Syria, and Türkiye and reduce their GDPs. On the other hand, improvements in WUE could largely improves these economies. For example, the results of the selected model show that the reductions in the real GDPs of Iraq, Syria, and Türkiye are about -2.9%, -3.5%, and 6% under the baseline scenario of B-EOC2-S2. Adding a 20% improvement in WUE in the ET basin alters these GDP reductions to -0.6%, -0.7%, and -4.2%. These are the major savings in the GDP losses in these countries, in particular for the economies of Iraq and Syria which mainly rely on water from the ET basin. Note that changes in WUE in the ET basin, will not significantly affect the economy of Iran, as this country has a small share in this basin. Any collaboration to enhance WUE in the ET basin will help economies of Iraq, Syria, and Türkiye to mitigate the negative impacts of the future water scarcity that could be induced due to climate change. While Iran could also get some benefits, for this country the benefits could be minor.

A 20% reduction in water flow from upstream to downstream of the ET basin could significantly damage the economies of Iraq and Suria, as these countries heavily rely on water from this basin. For example, the results of the selected model show that the reductions in the real GDPs of Iraq and Syria are about -2.9% and -3.5%, under the baseline scenario of B-EOC2-S2. A 20% reduction in water flow from upstream to downstream of the ET basin could further drop the GDPs of these countries to -4.8% and -6.4%. Finally, it is important to note that while the implemented policies directly affect the riparian countries of the ET basin, other countries are expected to experience indirect effects as well.

Table 3. Impacts of alternative policy scenarios and selected baseline scenarios on real GDP, % change

| Description | Ensemble average results | | | | | | | Selected model results | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B-EOC2-E2 | W1-EOC2-E2 | W2-EOC2-E2 | W3-EOC2-E2 | T1-EOC2-E2 | T2-EOC2-E2 | R1-EOC2-E2 | B-EOC2-S2 | W1-EOC2-S2 | W2-EOC2-S2 | W3-EOC2-S2 | T1-EOC2-S2 | T2-EOC2-S2 | R1-EOC2-S2 |
| Iran | -2.0 | -2.1 | -1.9 | -1.8 | -2.0 | -2.0 | -2.1 | -6.3 | -6.4 | -6.1 | -6.0 | -6.3 | -6.2 | -6.4 |
| Iraq | -1.7 | -3.1 | -0.5 | 0.5 | -1.7 | -1.7 | -3.3 | -2.9 | -4.3 | -1.7 | -0.6 | -2.9 | -2.9 | -4.8 |
| Jordan | -0.8 | -0.9 | -0.8 | -0.8 | -0.8 | -0.8 | -0.9 | -1.1 | -1.2 | -1.1 | -1.1 | -1.1 | -1.2 | -1.2 |
| Lebanon | -1.0 | -1.0 | -1.0 | -1.0 | -1.0 | -1.0 | -1.0 | -1.1 | -1.2 | -1.1 | -1.1 | -1.1 | -1.1 | -1.2 |
| Saudi Arabia | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.9 | -0.9 | -0.9 | -0.9 | -0.9 | -0.9 | -0.9 |
| Syria | -2.4 | -4.0 | -1.0 | 0.3 | -2.4 | -2.4 | -4.9 | -3.5 | -5.0 | -2.0 | -0.7 | -3.4 | -3.5 | -6.4 |
| Türkiye | -1.9 | -2.8 | -1.0 | -0.3 | -1.9 | -1.7 | -1.9 | -6.0 | -7.0 | -5.1 | -4.2 | -6.0 | -5.8 | -6.0 |
| RME | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -1.1 | -1.1 | -1.1 | -1.1 | -1.1 | -1.1 | -1.1 |

In the case of no collaboration in water management, the projected losses among riparian countries could mount up to 6% of the GDP in the ET basin. Overall, the Middle East region will need to import more food products due to water scarcity. This suggests a need for changes in the agricultural and food policies of the region. Our analysis also indicates that new investments in water-saving technologies could partially mitigate the negative impacts of water scarcity in the region. With full collaboration, the overall economic losses for the riparian countries in the ET river basin could turn into an economic gain of 0.9% (or $13 billion per year) of real GDP under the ensemble RCP4.5 climate (Table 4). Collaboration among the ET riparian countries also may lead to some gains for other countries in the Middle East (Table 4).

Table 4. Changes in real GDP under the examined collaboration scenarios

| Description | | Ensemble average results under RCP4.5 | | Selected model results under SSP5-RCP8.5 | |
|---|---|---|---|---|---|
| | | No collaboration | Full collaboration | No collaboration | Full collaboration |
| Change in real GDP (%) | ET countries | -2.18 | 0.88 | -6.85 | -2.88 |
| | Jordan | -0.62 | -0.46 | -1.23 | -1.13 |
| | Lebanon | -0.50 | -0.39 | -1.17 | -1.13 |
| | Saudi Arabia | -0.50 | -0.48 | -0.89 | -0.90 |
| | RME | -0.55 | -0.51 | -1.11 | -1.11 |
| | Total | -1.27 | 0.12 | -3.64 | -1.86 |
| Change in real GDP ($ million) | ET countries | -29,132 | 13,034 | -101,141 | -42,700 |
| | Jordan | -240 | -178 | -476 | -436 |
| | Lebanon | -257 | -201 | -603 | -583 |
| | Saudi Arabia | -3,271 | -3,140 | -5,801 | -5,909 |
| | RME | -5,923 | -5,492 | -11,992 | -11,914 |
| | Total | -38,823 | 4,022 | -120,012 | -61,541 |

Table 5 shows the economic consequences of Saq-Ram-I to Saq-Ram-III scenarios:

- A 10% more withdrawal by Jordan increases the real GDP of this country by $116 million leading to a reduction in the real GDP of Saudi Arabia by $172.7. In this case, the real GDP increases in other countries of the Middle East by small values as well. In this scenario the overall GDP of the Middle East decreases by $46.5 million, mainly due to the reduction in the GDP of Saudi Arabia.

- A 10% more withdrawal by Saudi Arabia increases the real GDP of this country by $233.7 million leading to a reduction in the real GDP of Jordan by $174.5. In this case, the real GDP decreases in other countries of the Middle East by small values as well. In this scenario the overall GDP of the Middle East increases by $43.2 million, mainly due to the increase in the GDP of Saudi Arabia. The next section which provides some sectoral results explains this finding.

- A 10% increase in withdrawal by Saudi Arabia generates more GDP than a 10% increase in withdrawal by Jordan. That is because Saudi Arabia withdraws more water than Jordan from the aquafer according to the data imbedded in the WBM model.

- When both countries withdraw more water, each by 10%, the real GDP goes up in Jordan and Saudi Arabia by $116.1 million and $238.3 million, respectively. The real GDP increases slightly in other countries of the Middle as well. In this scenario the overall GDP of the Middle East increases by $374.7 million. However, this is not a sustainable scenario, as it ends with a more rapid depletion of the aquafer.

- In the absence of collaboration between Jordan and Saudi Arabia, these countries may gain short term unsustainable GDP increases due to more water withdrawal for the Saq-Ram Aquafer. However, collaborations on the aquafer water management could provide gains in the long run.

Table 5. Real GDP changes due to water withdrawal from Saq-Ram Aquafer under no collaboration ($ million)

| Country | *Saq-Ram-I* | *Saq-Ram-II* | *Saq-Ram-III* |
|---|---|---|---|
| Iran | 2.7 | -4.1 | 2.4 |
| Iraq | 2.9 | -4.4 | 2.5 |
| Jordan | 116.0 | -174.5 | 116.1 |
| Lebanon | 0.5 | -0.7 | 0.7 |
| Saudi Arabia | -172.7 | 233.7 | 238.3 |
| Syria | 0.3 | -0.5 | 0.4 |
| Türkiye | 0.7 | -1.2 | 2.8 |
| RME | 3.1 | -4.9 | 5.0 |
| Total | -46.5 | 43.2 | 368.2 |

Table 6 shows the results of the defined compliance with agreement scenarios. A voluntary 10% reduction in water withdrawal by Saudi Arabia drops the GDP of this country by $235.3 million. Assuming no change in total water withdrawal from the aquafer, less water withdrawal by Saudi Arabia opens the room for Jordan to withdraw more water and expand its real GDP by $156.3 million. On the other hand, a voluntary 10% reduction in water withdrawal by Jordan drops the GDP of this country by $126.1 million. That opens the room for Saudi Arabia to withdraw more water and expand its real GDP by $171.8 million. When both countries voluntarily withdraw less water from the aquafer, each by 10%, the real GDP in Jordan and Saudi Arabia will drop by $126.2 million and $239.8 million, respectively. However, that increases the aquafer life time.

Table 6. Real GDP changes due to water withdrawal from Saq-Ram Aquafer under collaboration ($ million)

| Country | *Saq-Ram-IV* | *Saq-Ram-V* | *Saq-Ram-VI* |
|---|---|---|---|
| Iran | 3.6 | -3.0 | -2.7 |
| Iraq | 3.9 | -3.2 | -2.8 |
| Jordan | 156.3 | -126.1 | -126.2 |
| Lebanon | 0.6 | -0.5 | -0.7 |
| Saudi Arabia | -235.3 | 171.8 | -239.8 |
| Syria | 0.5 | -0.4 | -0.4 |
| Türkiye | 0.8 | -0.9 | -3.1 |
| RME | 4.1 | -3.6 | -5.5 |
| Total | -65.4 | 34.2 | -381.1 |

## 4. Conclusion

The Middle East is one of the most water-scarce regions in the world. The gap between the demand for and supply of water has significantly increased over time across this region and is expected to get wider in the future. This research develops a coupled hydro-economic framework to quantify the extent to which climate change could limit the supply of water in the Middle East by 2050 and examine if collaboration in transboundary water management can reduce the adverse economic impacts from water scarcity. The results show that collaboration in the ET basin can eliminate all or a portion of the adverse economic impacts. This highlights that countries need to collaborate to tackle emerging challenges such as the impact of climate change on water availability. The water scarcity and resulted economic implication vary across climate scenarios and climate products used to project future temperature and precipitation. The use of a broader range of climate products will help to narrow this uncertainty.

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## References

- Abbasian, Mohammadsadegh, Sanaz Moghim, and Ahmad Abrishamchi. 2019. "Performance of the General Circulation Models in Simulating Temperature and Precipitation over Iran." Theoretical and Applied Climatology 135 (3–4): 1465–83.
- Boyko, O., Reggiani, P., Todini, E. 2022. Temperature and Precipitation in the Middle East 1979-2100 Constructed Using CMIP5 Outputs.
- Bozkurt, D., & Sen, O. L. (2013). Climate change impacts in the Euphrates–Tigris Basin based on different model and scenario simulations. Journal of hydrology, 480, 149-161.
- Bozkurt, D., Sen, O. L., & Hagemann, S. (2015). Projected river discharge in the Euphrates-Tigris Basin from a hydrological discharge model forced with RCM and GCM outputs. Climate Research, 62(2), 131-147.
- Chenoweth et al. (2011). Impact of Climate Change on the Water Resources of the Eastern Mediterranean and Middle East region: Modeled 21st Century Changes and Implications. AGU Publications.
- Economist Intelligence Unit. 2020. "The Blue Peace Index 2020."
- FAO (2022) "AQUASTAT dataset", Available online: http://www.fao.org/nr/water/aquastat/About_us/index.stm.
- Haqiqi, Iman. 2019. "Irrigation, Water Scarcity, and Adaptation. Ph.D. Dissertation, Purdue University, West Lafayette, IN." Dissertation. Purdue University.
- IPCC. 2013. "Climate Change 2013: The Physical Science Basis." In Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Liu, X., Liu, W., Tang, Q., Liu, B., Wada, Y., & Yang, H. (2022). Global agricultural water scarcity assessment incorporating blue and green water availability under future climate change. Earth's Future, 10(4), e2021EF002567.

- Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. Science advances, 2(2), e1500323.
- Reggiani, Paolo, Ezio Todini, Oleksiy Boyko, and Roberto Buizza. 2021. “Assessing Uncertainty for Decision-making in Climate Adaptation and Risk Mitigation.” International Journal of Climatology 41 (5): 2891–2912.
- Rockström, J., Falkenmark, M., Karlberg, L., Hoff, H., Rost, S., & Gerten, D. (2009). Future water availability for global food production: The potential of green water for increasing resilience to global change. Water resources research, 45(7).
- Rosegrant M. et al. (2013) “Water and food in the bioeconomy: Challenges and opportunities for development,” Agricultural Economics, 44(s1), 139–150.
- Rosenzweig, C., Strzepek, K. M., Major, D. C., Iglesias, A., Yates, D. N., McCluskey, A., & Hillel, D. (2004). Water resources for agriculture in a changing climate: international case studies. Global Environmental Change, 14(4), 345-360.
- Shamout, Nouar, and Glada Lahn. 2015. “The Euphrates in Crisis: Channels of Cooperation for a Threatened River.” Research Paper. Chatham House. https://www.chathamhouse.org
- Taheripour, Farzad, Wallace E. Tyner, Ehsanreza Sajedinia, Angel Aguiar, Maksym Chepeliev, Erwin Corong, Cicero Z. De Lima, and Iman Haqiqi. Water in the Balance: The Economic Impacts of Climate Change and Water Scarcity in the Middle East. World Bank, 2020.
- Thrasher, B., Wang, W., Michaelis, A., and Nemani, R. 2021. “NASA Earth Exchange Global Daily Downscaled Projections - CMIP6.” NASA Center for Climate Simulation. https://doi.org/10.7917/OFSG3345
- Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., and Nemani, R. 2022. “NASA Global Daily Downscaled Projections, CMIP6.” Nature Scientific Data (in review).
- UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). (2013). Inventory of Shared Water Resources in Western Asia. Beirut.