Transboundary water challenges and potential collaboration in the Tigris-Euphrates river basin water management

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Introduction

Today, 47 percent of the global population live in areas that suffer water scarcity at least 1 month each year, and by 2050 this share will increase to 57 percent (*1*). Globally, transboundary rivers carry almost 60% of freshwater flows and are crucial in ensuring people have an adequate water supply (*2*). These shared resources need to be managed in a sustainable, equitable, and collaborative manner. Of the seven transboundary river systems ranked by how well countries manage transboundary water resources, the Tigris-Euphrates river basin has the lowest score (*2*). The two rivers and their tributaries run through Turkey, Syria, Iraq, and Iran. Turkey has the largest reserves of renewable water among these countries and control over the flow to the downstream Iraq and Syria due to the construction of dams (*3*). The situation in the basin is particularly difficult due to climate change, weak cooperation among riparian countries, intensive hydropower development, inefficient agricultural practices, and political instability (*3*). Ongoing construction of dams and hydropower plants and projected increase in water needs in Turkey are major concerns in Iraq and Syria. At the same time, by midcentury climate change may result in a 20 percent reduction in rainfall over the river basin (*4*) and the availability of water for irrigation may decline by 13-28 percent (*5*).

This study evaluates the economic outcomes of transboundary water allocation scenarios under alternative climate futures and considers cooperation plans that can be implemented to reduce controversies over water allocation in the Tigris-Euphrates river basin. In addition to the contribution to resource policy literature, this study offers a unique coupling of a complex economic model with a hydrological model. Transboundary water allocation scenarios are defined in terms of water withdrawals by riparian countries with and without water-sharing agreements among them. Impacts of climate change are represented by both water availability and changes in crop yields (*6*), as well as agronomic water requirements (*5*). Two types of agreements among riparian countries are considered. The first type is based on upstream countries providing compensation to the downstream countries for economic losses due to upstream countries' increased water withdrawals, while the second type is based on the maximization of overall welfare in the region. This research extends the earlier analysis in (*7*) by estimating changes in water availability with the hydrological model, and by analyzing new scenarios of water allocation and agreements among countries in the region.

Methodology

Economic model

The economic analysis is implemented using a comparative static computable general equilibrium 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 (*8–10*). 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 Rest of the World regions. The time horizon of the analysis is the middle of the 21st century. The framework is designed to examine the nexus between agricultural activities, industrial and energy sectors, and trade in the presence of climate change and water scarcity by country and on a global scale. Water is modeled as an explicit input in economic activities: irrigated agriculture, livestock, industrial sectors, and water utility services. These 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 at the river basin level by AEZ.

Hydrological model

Changes in the natural water runoff of the Tigris-Euphrates river basin due to climate change and changes in water withdrawals are quantified using a hydrological model based on the Water Balance Model (WBM) (*5*). WBM (*11*, *12*), originally developed at the University of New Hampshire, is a global model that 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) allocation of water among countries and agricultural and non-agricultural uses. The spatial scope of this study is concentrated on the Tigris-Euphrates river basin and the neighboring countries. The temporal dimension is from 2016 to 2055 to reflect the conditions around 2020 and 2050. The changes in water supply aggregated from 15 arc-min grid cells to RB-AEZs are inputs in the economic analysis with GTAP-BIO-W.

Two climate scenarios considered in the analysis are RCP8.5 and RCP4.5. Daily temperature and precipitation projected under these scenarios are obtained from NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) (*13*, *14*). The two variables are critical inputs in the hydrological model to project the availability of water resources in the future. The NEX-GDDP-CMIP6 dataset is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 6. The Bias-Correction Spatial Disaggregation (BCSD) method used to generate the NEX-GDDP-CMIP6 dataset is a statistical downscaling algorithm developed to address limitations of global GCM outputs, such as coarse resolution grids and locally biased projections in their statistical characteristics when compared with observations. The dataset compiles climate projections from thirty-five CMIP6 GCMs and four SSP scenarios (SSP2-4.5, SSP5-8.5, SSP1-2.6, and SSP3-7.0) for the period from 2015 to 2100. In this analysis, we use SSP2-4.5 and SSP5-8.5. In addition to the NEX-GDDP-CMIP6 dataset, we also explore another climate dataset (*15*) constructed using the methodology documented in (*16*). This data set is constructed using temperature and precipitation time series from 1979 to 2100 produced by 19 CMIP5 models for RCP8.5 and RCP4.5 climate scenarios. These series are mutually weighted and bias-corrected using ERA5 reanalysis data (*17*) over 1979-2005. This method yields unbiased and sharper predictive distributions for climatological variables in comparison to using the unprocessed ensemble distribution (*16*).

Temperature and precipitation variables representing two climate scenarios from the two climate products are inputted in the hydrological model to produce changes in soil moisture, groundwater, and surface water by 15 arcmin grid cells over the first half of this century. Thus, we will consider four sets of hydrological model outputs to inform the economic model about future water availability in respective four baseline simulations.

Scenarios

The first set of experiments with GTAP-BIO-W quantifies the economic implications of changes in crop yields and water availability due to climate changes, keeping water withdrawals in each country and region at the current level.

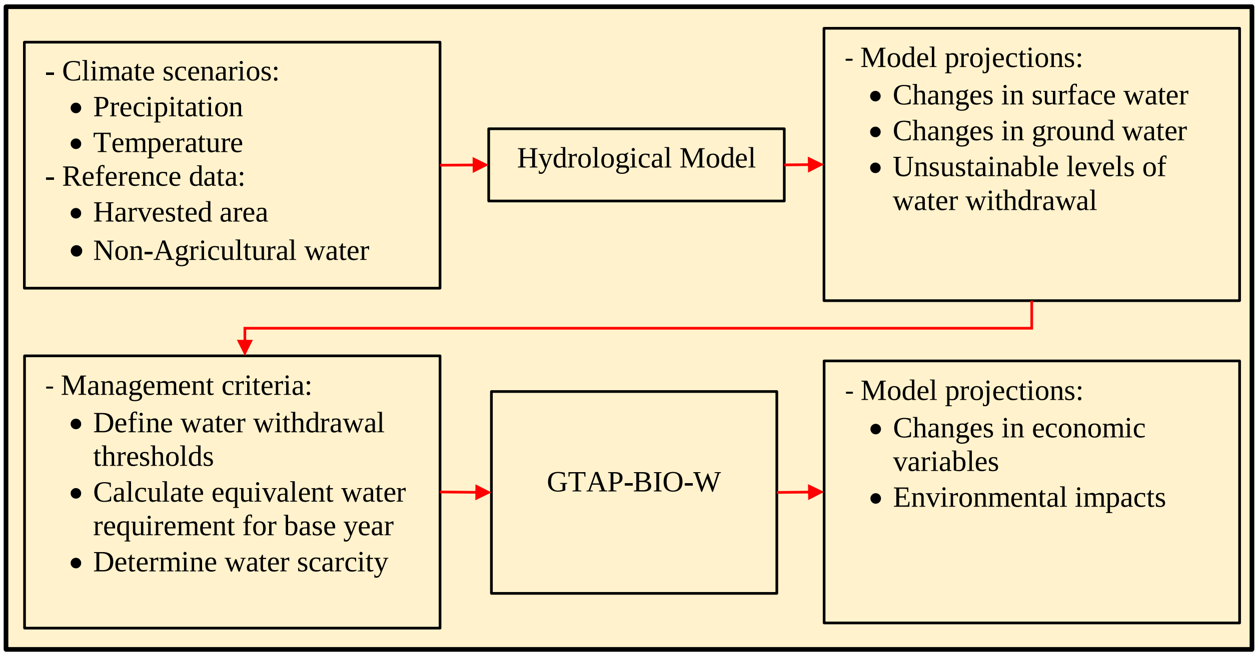

Figure 1. Baseline scenarios

The projections for future changes in precipitation and temperature plus data on harvested area and non-agricultural water uses of the base year are introduced into the hydrological model to determine future changes in the surface water and underground water. The model also suggests the sustainable water withdrawals by river basin in each riparian country in the Tigris-Euphrates river basin. Using these outputs, we determine an index of water scarcity by river basin for each region using the concept of *climate-adjusted equivalent water requirement*. These calculated water scarcity measures will be introduced into the CGE model to determine the economic and environmental impacts of climate change for each baseline scenario.

The second set of scenarios combines climate impacts with increases in upstream countries' water withdrawals (*3*) and reduced water availability in the downstream countries. These simulations allow for the evaluation of different water allocation plans in the region. The third set of scenarios evaluates potential agreements among countries that aim to redistribute gains and losses due to water withdrawals. The scenarios consider general-purpose monetary transfers from upstream to downstream countries, as well as transfers to subsidize food consumption and transfers to pay for improvements in water use efficiency (WUE). The improvements in WUE require more capital inputs in agricultural sectors and may offset the negative impact of reduced water supply on food production in downstream countries. In the final set of scenarios, overall welfare in the region is maximized under RCP8.5 and RCP4.5 climate futures (SSP2-4.5 and SSP5-8.5 scenarios in the NEX-GDDP-CMIP6 dataset). These scenarios show changes in the location of agricultural production and other activities within the Tigris-Euphrates river basin that maximize overall welfare in the region.

Preliminary results

The simplified Water Balance Model (*5*) takes the conditions of the state variables in the initial period (December 31, 2015, in this analysis). The state variables are the water stored in different forms and locations at one point in time. This includes volumetric soil moisture levels in mm, shallow groundwater depth in mm, reservoir storage in m3, and initial snowpack in mm. These conditions are calculated following (*18*) based on MERRA-2 observations (*19*). Figure 1 illustrates the average reservoir storage in the Tigris-Euphrates river basin and the larger Middle East region simulated by the model given current climate conditions.

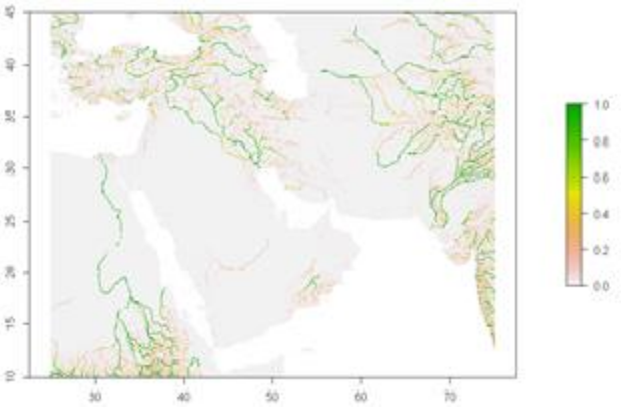

Figure 1. Average monthly reservoir storage up to 1 million m3 over period from January 2012 to December 2018 in the Middle East region (units are in million m3).

The hydrological model runs based on total daily precipitation (in mm day-1) and near-surface daily average air temperature (in °C) from the first day of 2016 to the last day of 2055. In this draft, we use projected precipitation and temperature in the NEX-GDDP-CMIP6 dataset. The dataset includes outputs of many GCM models. 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. Precipitation for selected countries based on the daily output of the MIROC-ES2L model with SSP5-8.5 climate is shown in Figure 2. In addition, in the future, we will also use climate data product (*15*) constructed using the methodology in (*16*).

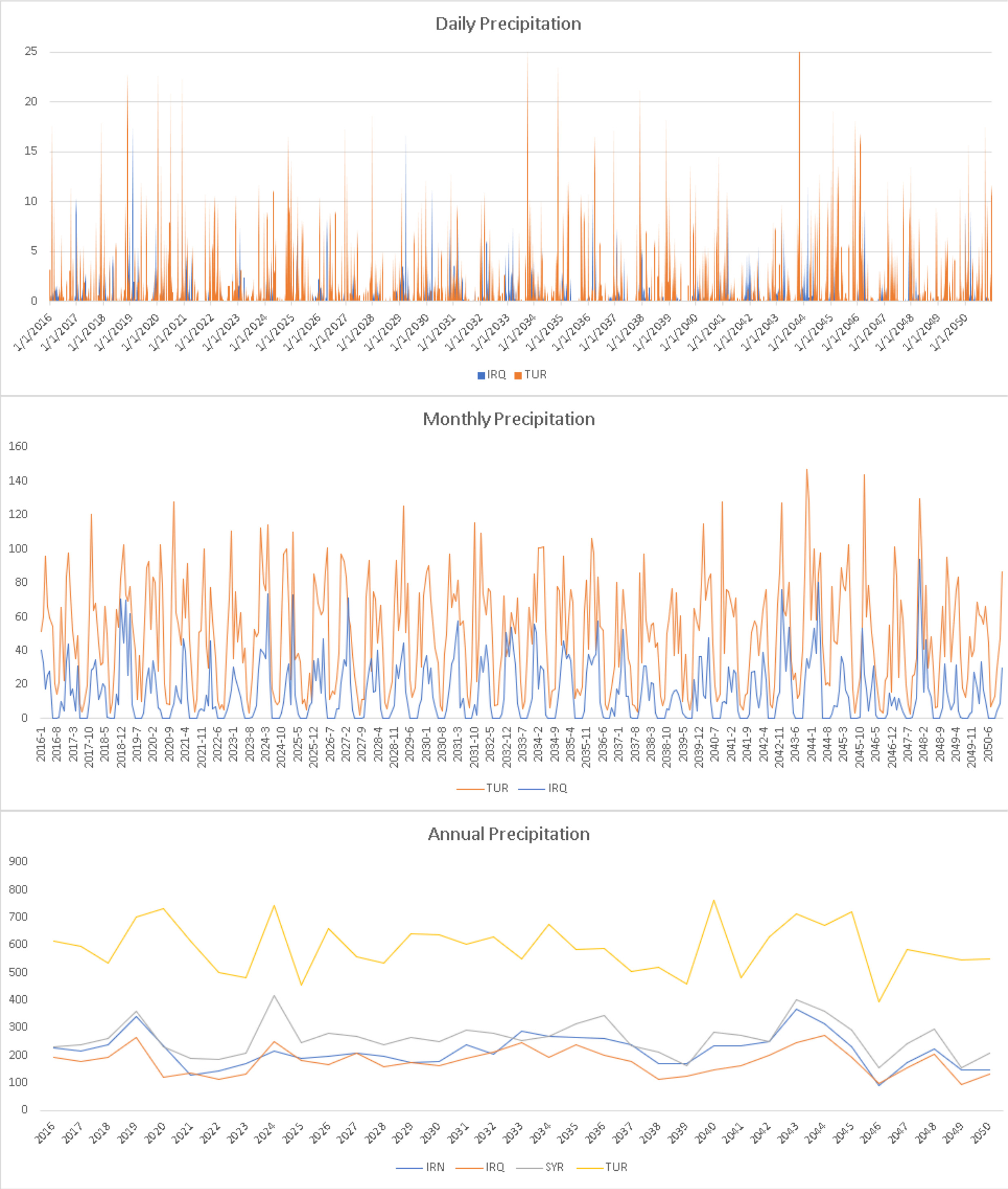

Figure 2. Precipitation for selected countries based on the daily output of the MIROC-ES2L model from NEX-GDDP-CMIP6 with SSP5-8.5

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