Compound effects of climate change on future transboundary water issues in the Middle East

Amin Dezfuli[1,2,*], Saman Razavi[3], and Benjamin F. Zaitchik[4]

[1] *Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, MD, USA*
[2] *Science Systems and Applications, Inc., Lanham, MD, USA*
[3] *School of Environment and Sustainability, University of Saskatchewan, Saskatoon, Canada*
[4] *Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD, USA*

**Corresponding author (amin.dezfuli@nasa.gov)*

Key Points:

- The Tigris-Euphrates headwaters is identified as the hotspot of future compound effects of climate change in the Middle East.
- The adverse impacts of the Southeastern Anatolia Project (in Turkish, GAP) may outnumber its benefits in coming decades.
- GAP may exacerbate environmental, agricultural, water conflict, and public health issues in the region.

Abstract

The Middle East is one of the world's most vulnerable areas to climate change, which has exacerbated environmental, agricultural, water conflict, and public health issues in the region. Here we analyze the latest climate model projections of precipitation and temperature for the very high emissions scenario, SSP5-8.5, to detect potential future changes in this region. A baseline period (1981-2010) is compared with the middle (2040-2069) and end (2070-2099) of the 21st century. The results, representing the worst-case scenario, identify the Tigris-Euphrates headwaters as the hotspot of future compounding effects of climate change in the Middle East. Those effects result from the coincidence of elevated temperature, reduced precipitation, and enhanced interannual variability of precipitation. The hotspot overlays the location of the Southeastern Anatolia Project (in Turkish, GAP) irrigation initiative. In this climate context, risks to GAP viability and downstream water security, and associated potential for water-related conflicts and migration are considerable and demand a reconsideration of the risk-benefit assessment of GAP. This need has become more urgent after the recent widespread and deadly climate-related conflicts and wildfires in summer 2021 across the Middle East that further underlined vulnerability of the region to climate extremes.

Plain Language Summary

The Middle East, one of the world's most vulnerable regions to climate change, has experienced a growing number of severe extreme events in recent decades. These events not only have imposed irreversible socio-environmental impacts locally but have contributed to transboundary water conflicts with implications for regional and global security. Climate model projections show that the adverse effects of such events will likely be exacerbated over riparian countries of the Tigris-Euphrates basin in coming decades. This conclusion is drawn because concurrent extreme hot and dry conditions and enhanced precipitation variability are projected over the Tigris-Euphrates headwaters, where the Southeastern Anatolia Project (in Turkish, GAP) is located. As a result, the negative impacts of GAP may outnumber its benefits, and this study attempts to warn decision-makers of the urgent need to integrate these trends to water resource planning and international negotiations.

1. Introduction

Specific natural and geopolitical characteristics of the Middle East have made this region one of the world's most vulnerable areas to climate change (Sowers et al. 2011; World Bank 2014; Barlow et al. 2016). Heavy floods, prolonged droughts, drying lakes, extreme heat waves, intense dust storms, and domestic and transboundary water tensions are some of the climate-related issues that have been exacerbated in recent decades across the region (Pal and Eltahir 2016; Soltani et al. 2016; Dezfuli et al. 2017; Alizadeh-Choobari and Najafi 2018; Dezfuli 2020; Dezfuli et al. 2021). Unsustainable land use practices, including agricultural expansion and urban development, have triggered or further intensified the adverse effects of extreme events (Waha et al. 2017; World Bank 2019). While these recent trends are indicative of growing environmental crises in the region, projection of what the future holds is challenging and deeply uncertain.

Middle East climate studies based on global climate model (GCM) realizations from previous phases of the Coupled Model Intercomparison Project (CMIP) suggest that magnitude and spatio-temporal patterns of hydroclimatic variables are to change (Evans 2009; Tabari and Willems 2018; Rahimi et al. 2019; Vaghefi et al. 2019). The possible future changes reported in these studies include spatial variability in precipitation trend, expansion of torrid-arid climate zone, and increase in dry and hot periods in parts of the region. Here, we apply CMIP Phase 6 (CMIP6) GCM outputs (Eyring et al. 2016) to: (1) expand upon previous CMIP analyses of the Middle East, with a focus on detecting hotspots of compound hot-dry extremes and regions with enhanced changes in interannual variability of precipitation; (2) cast light onto the implications of those anticipated impacts for water security in the transboundary Tigris-Euphrates basin, with specific consideration of the Southeastern Anatolia Project (in Turkish: Güneydoğu Anadolu Projesi, GAP, Fig. 1a).

Envisioned initially in the 1970s, GAP consists of 22 dams on headwaters of the Tigris-Euphrates Basin, the largest hydro-development project ever built in the region (Unver 1997; Bilgen 2019). The main aims of this project include generating hydroelectric power, expanding modern irrigation to an area of 1.7 million hectares, and improving infrastructure and economy in the poorest part of Turkey. From its beginning, GAP has been controversial both domestically—due to its impacts on the environment, historical sites and development-induced displacement—and internationally, due to downstream impacts on Syria and Iraq (Morvaridi 2004; Harris 2009; Berkun 2010). These countries heavily rely on the Tigris and Euphrates rivers and have already attributed the recent decrease in their water resources and the associated socio-economic consequences to GAP (Feitelson and Tubi 2017). The lack of a multilateral agreement and the fact that downstream countries view the project as politically-motivated, may elevate the future tensions between the riparian countries (Daoudy 2009; Jongerden 2010; Rougé et al. 2018). Thus, it would be crucial for decision-makers to know the possible changes in future climate of the Middle East and particularly the GAP region.

2. Data and Methods

Model evaluation: We have evaluated a set of 22 models from CMIP6 (Table S1) that their monthly temperature and precipitation, needed for this study, were available at the time of this analysis. The CMIP6 data (Eyring et al. 2016) were accessed from https://pcmdi.llnl.gov/CMIP6/. Models were chosen if they had at least one ensemble member for the period 1981-2010 from the historical runs, and for the middle (2040-2069) and end

(2070-2099) of the 21st century under the high emissions scenario, SSP5-8.5. Spatial patterns of the annual mean 2-meter temperature and total precipitation were compared to their corresponding variables from the Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2, Gelaro et al. 2017) and the Global Precipitation Climatology Centre (GPCC, Schneider et al. 2015), respectively. All GCM outputs were first regridded to 0.625° × 0.5° regular longitude by latitude grids for temperature and 1° × 1° for precipitation to be consistent with MERRA-2 and GPCC, respectively. Three evaluation indices were calculated, using mean values of the baseline period (1981-2010) for land-only grids (Fig. S1). Those statistics are Pearson pattern correlation (R), root mean square difference (RMSD) and bias. However, for precipitation "relative bias" is calculated as normalized percent difference. Using these criteria collectively, three models—one based on temperature and two based on precipitation—that presented an overall low agreement with the observations were identified and excluded. All climate change diagnostics were consequently performed using the remaining 19 models. Note that for consistency in interpretation of the results, we have removed the same models for both temperature and precipitation analysis, even if their performance was not satisfactory only for one of these variables. While spatial patterns of precipitation and temperature, particularly the latter, were reasonably captured by the MME mean, these variables showed both positive and negative biases across the region (Fig. S2).

Bias correction: The MME means of the GCMs were bias-corrected for regionally-averaged (36.5-39N & 37-44E) diagnostics (e.g., Fig. 2 and Fig. 3), so that temperature and precipitation values of the models would match the observations. For this purpose, a simple delta approach was used to preserve the original GCM properties and facilitate interpretation of the results (Graham et al. 2007; Watanabe et al. 2012). For temperature, the difference between historical MME mean and MERRA-2 data was subtracted from both historical and future simulations. For rainfall, that adjustment was based on the ratio rather than difference. For the annual cycle, the corrections were applied for each month separately (Fig. S3). However, for annual precipitation totals, used in the histograms, the coefficient is calculated based on the ratio of annual totals of GPCC and historical MME mean.

Diagnostics for future changes: Three different types of plots were used to investigate the future changes. The first one presents differences between the 30-year MME mean of future and the baseline period (e.g., Fig. 1**b**, **c**). For a variable like coefficient of variation (CV), which has a nonlinear formula, the percent difference between future and historical periods is first calculated for each individual model, then the average of all GCMs is computed as the MME mean (e.g., Fig. 1**c**). Histograms are the second type of plots, which were made for each period separately, using annual values averaged over the GAP region. The data from all 19 models over the 30-year periods were included, therefore each histogram was based on 570 data points. All models are first bias-corrected, using the same delta computed from the MME mean. The third type of plots is annual cycle that simply shows the bias-corrected MME mean of all twelve months (Figs. 3 and S5). The model spread is shown for each month by the 10th percentile, median and 90th percentile of the 19 GCMs.

3. Temperature and precipitation changes across the region

GCM projections from a set of 19 CMIP6 models are used to examine future changes for the middle (2040-2069) and end (2070-2099) of the 21st century under the high emissions scenario, SSP5-8.5 (see Data and Methods and Figs. S1 and S2). To assess future changes, projections over land are compared with the historical simulations over the baseline period 1981-2010. Multi-model ensemble (MME) means show a regional 5.5 °C warming for the late 21st century. The temperature increase ranges between ~3.9 °C in the coastal areas to ~6.4 °C over the Tigris-Euphrates headwaters and the Northern and Central Arabian Peninsula (Fig. 1b). For the mid-21st century, this figure is about 2.3 °C lower than the late century but with quite similar spatial patterns (Fig. 4a). The projected warming is overall larger in CMIP6 than in CMIP5 as reported by other studies (Almazroui et al. 2020; Bağçaci et al. 2021). However, the spatial pattern of precipitation changes, that is a decrease in the northern part and an increase in the southern part of the domain (Fig. 5), remains broadly consistent with the previous versions of CMIP models, when a similar approach has been utilized (Evans 2009; Rahimi et al. 2019; IPCC 2021).

In order to understand which part of the Middle East would likely be hit hardest by climate change impacts, regions with projected concurrent extreme annual hot and dry conditions are detected. For each condition, a percentile threshold is defined using the MME means of all grids in the domain. Consequently, those regions are located where an increase in annual temperature greater than the 85th percentile may simultaneously occur with a percent difference of annual precipitation (Fig. 5) lower than the 15th percentile of the entire domain. Such compound hot-dry conditions appear to be strongest over the Tigris-Euphrates headwaters, including the GAP region (Fig. 1b). The results are generally consistent with recent studies, which analyzed daily temperature and precipitation from CMIP6 models at the global scale and rather qualitatively found the Mediterranean as a hotspot of future hot-dry conditions (Vogel et al. 2020; Almazroui et al. 2021).

In addition to the percent difference between historical and future simulations, changes in coefficient of variation (CV) of annual precipitation are compared. That allows us to identify the hotspots of maximum increase in interannual variability, which is an indicator of escalated uncertainty that authorities in those regions will face when planning strategies for water resources management (Fig. 1c). The regions of enhanced interannual variability span the northwestern part of the domain, within several hundred kilometers from the Mediterranean Sea, covering the headwaters of the Tigris-Euphrates Basin. The changes over this region are even more distinctly evident in the mid-21st century (Fig. 4).

These findings lead us to further focus on the GAP region, including the development itself and its headwaters. Frequency analysis of MME mean annual temperature averaged over the GAP region shows an increase of 3.4 °C ($p < 0.0001$) and 6.1 °C ($p < 0.0001$) for the middle and end of the 21st century, respectively (Fig. S4 and Fig. 2a). The annual precipitation total, meanwhile, decreases from 502 mm for the historical simulations to 473 mm ($p < 0.001$) and 438 mm ($p < 0.0001$) for the two future periods. Despite the significant shift in the means, the skewness of the distribution for historical and future projections remains qualitatively quite comparable for both temperature and precipitation.

At the monthly scale, the sign of future changes in temperature is consistently positive and across all models, with some differences between their magnitudes (Fig. 3a and Fig. S5a). That is the temperature increase is highest during the summer and fall seasons and lowest in March and April for both future periods. In the case of precipitation, the model spread is larger than that for temperature, and the vast majority of models (~81%) agree on decreasing trends all year round. In particular, during the main rainy season (November through April), when the GAP region receives ~80% of its annual precipitation, the percent difference in precipitation in late century varies from 10% in November to 17% in April. The decrease is also high for JAS, but that season includes only ~2% of the annual precipitation.

4. Impacts on the GAP region

Potential impacts of the projected climate changes extend to societal issues, environment, health, and agricultural practices. The water loss through evapotranspiration from landscapes and evaporation from the many reservoirs in the GAP region will increase due to significantly higher air temperatures. Projected decreases in annual precipitation over the region would further reduce water availability. These conditions would be exacerbated by coincidence with increases in interannual precipitation variability that has been shown to have adverse socio-economic effects, particularly in developing countries (Brown and Lall 2006). These compound effects, along with the anticipated population growth and the associated increase in future demands (Droogers et al. 2012; Rougé et al. 2018), would impose enormous challenges on downstream countries to meet their water needs for irrigation and urban uses.

A possibly major societal impact of decrease in water supply would be an increased risk of climate-related migration, although further research is needed on the associated geopolitical consequences such as violence and civil wars (Selby et al. 2017; Ide 2018; Helman et al. 2020). Our results also have several health and environmental implications. The projected lower water flow from the Tigris and Euphrates rivers would threaten wetland ecosystems of Southern Iraq (Richardson and Hussain 2006; Albarakat et al. 2018). Drying conditions over these wetlands and an emerging dust source located just to the south of Tigris-Euphrates headwaters (Nabavi et al. 2016) would potentially increase dust emissions and the associated risk of respiratory diseases locally and for the downwind countries like Iran (Khaniabadi et al. 2017).

In addition to the impacts on downstream countries, the future compound changes found in this study would have local adverse effects on people within the GAP region. One of the main objectives of the project is to stabilize current and attract new residents to the region by expanding the irrigation network and creating new jobs (Bilgen 2019). However, future reduction in water supply along with potential international pressure from other riparian countries could restrict farming, which may result in new societal issues such as reverse migration. Also, increases in malaria cases have been reported during anomalously warm years and attributed to high temperatures and relative humidity, the latter caused by development of irrigated areas in previously drylands within the GAP region (Aksoy et al. 1995; Şeker et al. 2020). Rapid warming, combined with continued irrigation, will likely lead to more frequent malaria outbreaks in the region.

5. Conclusions and future directions

In sum, CMIP6 results reinforce and intensify concerns about climate change in the Tigris-Euphrates headwaters, including the GAP region. The hotspot analysis performed here emphasizes that this area is likely to see the most dramatic compound changes of any area in the Middle East, with rapid warming, increased interannual precipitation variability, and decreased precipitation all coinciding in an area of massive irrigation development and known transboundary water tension. This brief note attempts to warn decision-makers of these trends, which may mean that the adverse impacts of GAP will outnumber its benefits in coming decades.

The water disputes among riparian countries of the Tigris and Euphrates rivers have a long history and have grown over the past several decades. The downstream countries have been particularly affected during periods when Turkey was filling major reservoirs like the Ataturk Dam over the Euphrates River and the Ilisu Dam over the Tigris River, completed in 1990 and 2019, respectively (Olson 1997; Warner 2012; Al-Madhhachi et al. 2020). The latter preceded the unprecedented dry and hot conditions in 2021 that led to significant reduction in water flow from Turkey to Iraq. The resulting water and energy crises downstream led to violent protests in Iraq (PRI 2021). Therefore, the water conflicts in the region should be regarded in the context of combined effects of GAP and climate change and variability. As presented here, the chance of occurrence of compound extreme events is projected to increase, therefore climate-related crises similar to those in 2021 are expected to happen more frequently in the future. Quantitative approaches such as structural equation modeling (Helman et al. 2020) could help gaining more insight into the causes and interrelationship between different components of the conflicts.

While the risks associated with this project are often viewed through the lens of transboundary conflict, we note that the hotspot over GAP is also cause for significant concern domestically for Turkey (Berkun 2010). Interestingly, Lake Urmia in Northwestern Iran lies in the hotspot area as well, which is relevant to high-profile domestic environmental management strategies in Iran (AghaKouchak et al. 2015). Further work is urgently needed to integrate the latest climate projections to water resource planning and international negotiations; analyses of GAP and other major development projects that fail to account for the changing climate reality of the region will underestimate risk and could lead to dangerously optimistic decision making.

In this study, we have used a suite of state-of-the-art GCM projections from CMIP6 archive. Better process representation and higher resolution in these models have led to more realistic simulation of large-scale climate modes of variability (Orbe et al. 2020). However, differences have been reported in the ability of the models in capturing the magnitude and details of tropical teleconnection, suggesting caution when using these GCMs for regional impact analysis (Barlow et al. 2021). Other potential issues may arise from the tendency of these models to underestimate the amplitude of the seasonal cycle in the region (Kelly et al. 2012; Rahimi et al. 2019). We also recognize that our results are based on the very high emissions scenario, SSP5-8.5, which represents the worst-case outcome. However, similar spatial patterns with smaller magnitude in the future changes are expected for lower emissions scenarios such as SSP2-4.5 (Almazroui et al. 2021; IPCC, 2021; Carvalho et al. 2021). The issues discussed above should be taken into consideration when interpreting the CMIP6 simulations for regional long-term planning.

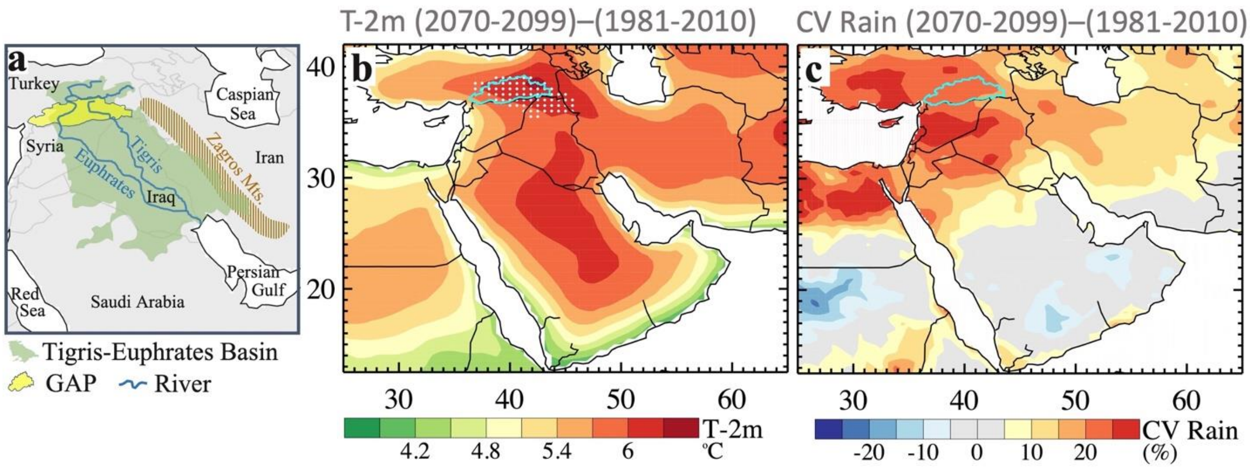

Figure 1. (**a**) Location of major geographical features in the Middle East. (**b**) Difference between multi-model ensemble (MME) mean of annual temperature of 2070-2099 and that of 1981-2010. The white dots mark the region of compound hot-dry extremes, where an increase in annual temperature greater than the 85th percentile is projected to occur along with a decrease in percent difference of annual precipitation to a level lower than the 15th percentile of the entire domain (see Data and Methods). (**c**) The same as **b** but for percent difference of coefficient of variation of annual rainfall, which is indicative of larger interannual variability in the future. Borders of the GAP region are shown with cyan line in **b**, **c**.

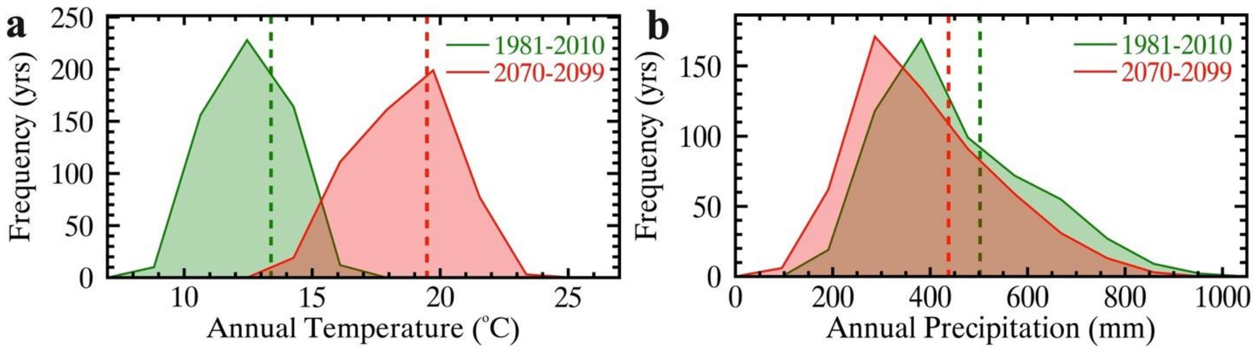

Figure 2. (**a**) Histogram of MME mean of annual temperature over the GAP region for the baseline period and the end of the 21st century. Note that the 30 years data of all individual GCMs are included. (**b**) The same as **a** but for annual precipitation totals.

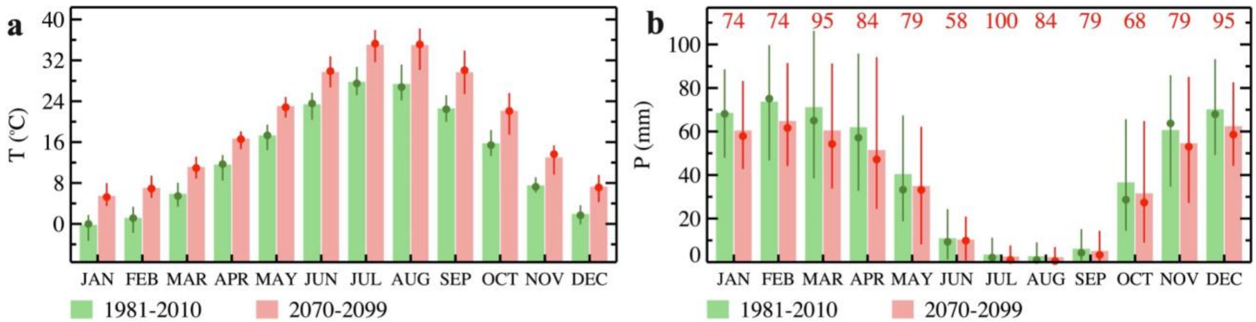

Figure 3. (**a**) Annual cycle of MME mean of temperature, averaged over the GAP region for the baseline period and the end of the 21st century. Vertical lines show the 10th, median and 90th percentiles of the 19 GCMs used for each month. (**b**) The same as **a** but for precipitation amount. The red numbers show the percentage of GCMs for each month that project a decrease in future precipitation.

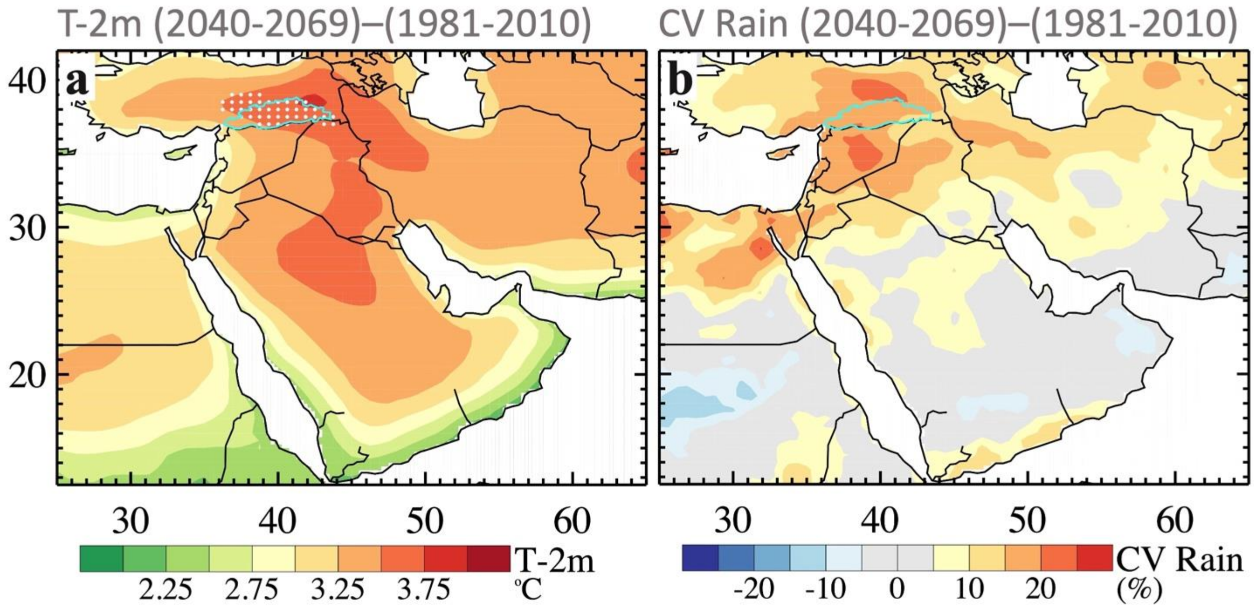

Figure 4. The same as Fig. 1**b** and **c**, but for the middle of the 21st century (2040-2069).

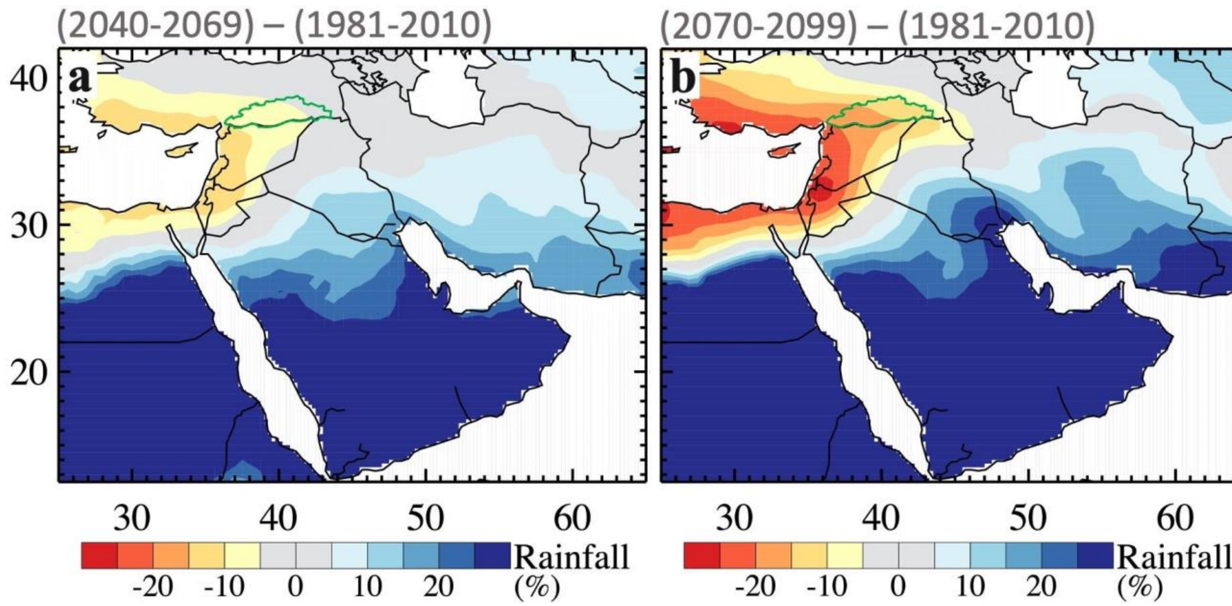

Figure 5. Percent difference of annual precipitation between future and historical GCM simulations. The MME mean is used for (**a**) the middle and (**b**) end of the century.

Acknowledgments
This study was partially supported by the Global Modeling and Assimilation Office (GMAO) Core funding, provided under NASA's Modeling, Analysis and Prediction (MAP) program and Razavi's Natural Sciences and Engineering Research Council (NSERC) Discovery Grant. The authors would also like to appreciate constructive comments from the two anonymous reviewers and the associate editor.

Data Availability Statement
All data used here are publicly available as described in Data and Methods: CMIP6 at https://pcmdi.llnl.gov/CMIP6/, MERRA-2 at https://doi.org/10.5067/KVIMOMCUO83U, and GPCC at DOI: 10.5676/DWD_GPCC/FD_M_V2020_100.

References:

AghaKouchak, A., Norouzi, H., Madani, K., Mirchi, A., Azarderakhsh, M., Nazemi, A., Nasrollahi, N., Farahmand, A., Mehran, A. and Hasanzadeh, E., 2015. Aral Sea syndrome desiccates Lake Urmia: call for action. *Journal of Great Lakes Research*, *41*(1), pp.307-311.

Aksoy, S., Ariturk, S., Armstrong, M.Y., Chang, K.P., Dörtbudak, Z., Gottlieb, M., Ozcel, M.A., Richards, F.F. and Western, K., 1995. The GAP project in southeastern Turkey: the potential for emergence of diseases. *Emerging infectious diseases*, *1*(2), p.62.

Alizadeh-Choobari, O. and Najafi, M.S., 2018. Extreme weather events in Iran under a changing climate. *Climate Dynamics*, *50*(1), pp.249-260.

Al-Madhhachi, A.S.T., Rahi, K.A. and Leabi, W.K., 2020. Hydrological impact of ilisu dam on Mosul Dam; the river Tigris. *Geosciences*, 10(4), p.120.

Almazroui, M., Saeed, F., Saeed, S., Islam, M.N., Ismail, M., Klutse, N.A.B. and Siddiqui, M.H., 2020. Projected change in temperature and precipitation over Africa from CMIP6. *Earth Systems and Environment*, *4*(3), pp.455-475.

Almazroui, M., Saeed, F., Saeed, S., Ismail, M., Ehsan, M.A., Islam, M.N., Abid, M.A., O'Brien, E., Kamil, S., Rashid, I.U. and Nadeem, I., 2021. Projected changes in climate extremes using CMIP6 simulations over SREX regions. *Earth Systems and Environment*, 5(3), pp.481-497.

Bağçaci, S.Ç., Yucel, I., Duzenli, E. and Yilmaz, M.T., 2021. Intercomparison of the expected change in the temperature and the precipitation retrieved from CMIP6 and CMIP5 climate projections: A Mediterranean hot spot case, Turkey. *Atmospheric Research*, *256*, p.105576.

Barlow, M., Zaitchik, B., Paz, S., Black, E., Evans, J. and Hoell, A., 2016. A review of drought in the Middle East and southwest Asia. *Journal of climate*, *29*(23), pp.8547-8574.

Barlow, M., Hoell, A. and Agel, L., 2021. An evaluation of CMIP6 historical simulations of the cold season teleconnection between tropical Indo-Pacific sea surface temperatures and precipitation in Southwest Asia, the coastal Middle East, and Northern Pakistan and India. *Journal of Climate*, 34(16), pp.6905-6926.

Berkun, M., 2010. Hydroelectric potential and environmental effects of multidam hydropower projects in Turkey. *Energy for Sustainable Development*, *14*(4), pp.320-329.

Bilgen, A., 2019. The southeastern anatolia project (GAP) in Turkey: an alternative perspective on the major rationales of GAP. *Journal of Balkan and Near Eastern Studies*, *21*(5), pp.532-552.

Brown, C. and Lall, U., 2006, November. Water and economic development: The role of variability and a framework for resilience. In *Natural resources forum* (Vol. 30, No. 4, pp. 306-317). Oxford, UK: Blackwell Publishing Ltd.

Carvalho, D., Cardoso Pereira, S. and Rocha, A., 2021. Future surface temperatures over Europe according to CMIP6 climate projections: an analysis with original and bias-corrected data. *Climatic Change*, 167(1), pp.1-17.

Daoudy, M., 2009. Asymmetric power: Negotiating water in the Euphrates and Tigris. *International Negotiation*, 14(2), pp.361-391.

Dezfuli, A.K., Zaitchik, B.F., Badr, H.S., Evans, J. and Peters-Lidard, C.D., 2017. The role of low-level, terrain-induced jets in rainfall variability in Tigris–Euphrates headwaters. *Journal of hydrometeorology*, *18*(3), pp.819-835.

Dezfuli, A., 2020. Rare atmospheric river caused record floods across the Middle East. *Bulletin of the American Meteorological Society*, *101*(4), pp.E394-E400.

Dezfuli, A., Bosilovich, M.G. and Barahona, D., 2021. A Dusty Atmospheric River Brings Floods to the Middle East. *Geophysical Research Letters*, p.e2021GL095441.

Droogers, P., Immerzeel, W.W., Terink, W., Hoogeveen, J., Bierkens, M.F.P., Van Beek, L.P.H. and Debele, B., 2012. Water resources trends in Middle East and North Africa towards 2050. *Hydrology and Earth System Sciences*, *16*(9), pp.3101-3114.

Evans, J.P., 2009. 21st century climate change in the Middle East. *Climatic Change*, *92*(3-4), pp.417-432.

Eyring, V., Bony, S., Meehl, G.A., Senior, C.A., Stevens, B., Stouffer, R.J. and Taylor, K.E., 2016. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development*, *9*(5), pp.1937-1958.

Feitelson, E. and Tubi, A., 2017. A main driver or an intermediate variable? Climate change, water and security in the Middle East. *Global environmental change*, *44*, pp.39-48.

Gelaro, R., McCarty, W., Suárez, M.J., Todling, R., Molod, A., Takacs, L., Randles, C.A., Darmenov, A., Bosilovich, M.G., Reichle, R. and Wargan, K., 2017. The modern-era retrospective analysis for research and applications, version 2 (MERRA-2). *Journal of climate*, *30*(14), pp.5419-5454.

Graham, L.P., Andréasson, J. and Carlsson, B., 2007. Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods–a case study on the Lule River basin. *Climatic Change*, *81*(1), pp.293-307.

Harris, L.M., 2009. Contested sustainabilities: Assessing narratives of environmental change in southeastern Turkey. *Local Environment*, *14*(8), pp.699-720.

Helman, D., Zaitchik, B.F. and Funk, C., 2020. Climate has contrasting direct and indirect effects on armed conflicts. *Environmental Research Letters*, *15*(10), p.104017.

Ide, T., 2018. Climate war in the Middle East? Drought, the Syrian civil war and the state of climate-conflict research. *Current climate change reports*, *4*(4), pp.347-354.

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press.

Jongerden, J., 2010. Dams and politics in Turkey: utilizing water, developing conflict. *Middle East Policy*, *17*(1), pp.137-143.

Khaniabadi, Y.O., Daryanoosh, S.M., Amrane, A., Polosa, R., Hopke, P.K., Goudarzi, G., Mohammadi, M.J., Sicard, P. and Armin, H., 2017. Impact of Middle Eastern Dust storms on human health. *Atmospheric pollution research*, *8*(4), pp.606-613.

Morvaridi, B., 2004. Resettlement, rights to development and the Ilisu Dam, Turkey. *Development and Change*, *35*(4), pp.719-741.

Nabavi, S.O., Haimberger, L. and Samimi, C., 2016. Climatology of dust distribution over West Asia from homogenized remote sensing data. *Aeolian Research*, *21*, pp.93-107.

Olson, R., 1997. Turkey- Syria Relations since the Gulf War: Kurds and Water. *Middle east policy*, 5(2), pp.168-193.

Orbe, C., Van Roekel, L., Adames, Á.F., Dezfuli, A., Fasullo, J., Gleckler, P.J., Lee, J., Li, W., Nazarenko, L., Schmidt, G.A. and Sperber, K.R., 2020. Representation of modes of variability in six US climate models. *Journal of Climate*, 33(17), pp.7591-7617.

Pal, J.S. and Eltahir, E.A., 2016. Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nature Climate Change*, *6*(2), pp.197-200.

PRI, 2021. https://www.pri.org/stories/2021-09-10/drought-iraq-and-syria-could-totally-collapse-food-system-millions-aid-groups

Rahimi, J., Khalili, A. and Butterbach‐ Bahl, K., 2019. Projected changes in modified Thornthwaite climate zones over Southwest Asia using a CMIP5 multi‐ model ensemble. *International Journal of Climatology*, 39(12), pp.4575-4594.

Richardson, C.J. and Hussain, N.A., 2006. Restoring the Garden of Eden: an ecological assessment of the marshes of Iraq. *BioScience*, *56*(6), pp.477-489.

Rougé, C., Tilmant, A., Zaitchik, B., Dezfuli, A. and Salman, M., 2018. Identifying key water resource vulnerabilities in data‐ scarce transboundary river basins. *Water Resources Research*, *54*(8), pp.5264-5281.

Şeker, M. Koyuncu, I., and Öztürk, I. Eds. 2020. Climate Change and Public Health in Turkey. *Akademisi, Türkiye Bilimler*.

Selby, J., Dahi, O.S., Fröhlich, C. and Hulme, M., 2017. Climate change and the Syrian civil war revisited. *Political Geography*, *60*, pp.232-244.

Schneider, Udo; Becker, Andreas; Finger, Peter; Meyer-Christoffer, Anja; Rudolf, Bruno; Ziese, Markus (2015): GPCC Full Data Monthly Product Version 7.0 at 1.0°: Monthly Land-Surface Precipitation from Rain-Gauges built on GTS-based and Historic Data. DOI: 10.5676/DWD_GPCC/FD_M_V7_100

Soltani, M., Laux, P., Kunstmann, H., Stan, K., Sohrabi, M.M., Molanejad, M., Sabziparvar, A.A., SaadatAbadi, A.R., Ranjbar, F., Rousta, I. and Zawar-Reza, P., 2016. Assessment of climate variations in temperature and precipitation extreme events over Iran. *Theoretical and Applied Climatology*, *126*(3), pp.775-795.

Sowers, J., Vengosh, A. and Weinthal, E., 2011. Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. *Climatic Change*, *104*(3), pp.599-627.

Tabari, H. and Willems, P., 2018. More prolonged droughts by the end of the century in the Middle East. *Environmental Research Letters*, *13*(10), p.104005.

Unver, I.O., 1997. Southeastern Anatolia Project (GAP). *International Journal of Water Resources Development*, *13*(4), pp.453-484.

Vaghefi, S.A., Keykhai, M., Jahanbakhshi, F., Sheikholeslami, J., Ahmadi, A., Yang, H. and Abbaspour, K.C., 2019. The future of extreme climate in Iran. *Scientific reports*, *9*(1), p.1464.

Vogel, M.M., Hauser, M. and Seneviratne, S.I., 2020. Projected changes in hot, dry and wet extreme events' clusters in CMIP6 multi-model ensemble. *Environmental Research Letters*, 15(9), p.094021.

Waha, K., Krummenauer, L., Adams, S., Aich, V., Baarsch, F., Coumou, D., Fader, M., Hoff, H., Jobbins, G., Marcus, R. and Mengel, M., 2017. Climate change impacts in the Middle East and Northern Africa (MENA) region and their implications for vulnerable population groups. *Regional Environmental Change*, *17*(6), pp.1623-1638.

Warner, J., 2012. The struggle over Turkey's Ilısu Dam: domestic and international security linkages. International Environmental Agreements: Politics, *Law and Economics*, 12(3), pp.231-250.

Watanabe, S., Kanae, S., Seto, S., Yeh, P.J.F., Hirabayashi, Y. and Oki, T., 2012. Intercomparison of bias- correction methods for monthly temperature and precipitation simulated by multiple climate models. *Journal of Geophysical Research: Atmospheres, 117*(D23).

World Bank Publications, 2014. *Turn down the heat: confronting the new climate normal*. World Bank Publications.

World Bank, 2019. Sustainable Land Management and Restoration in the Middle East and North Africa Region: Issues, Challenges, and Recommendations. (2040-2069).