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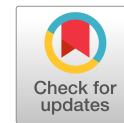
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Impacts of Climate Change on the Conflict between Water Resources and Agricultural Water Use

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Increasing CO₂ emissions most likely will impact the Earth's climate so as to produce adverse human and environmental impacts. Many regions appear vulnerable to human-induced climate change phenomena. Water resources may be particularly vulnerable to climatic change. Water use is divided among sectors including agricultural, industrial, and municipal. Most water use is by agriculture. The world's average water use in this sector is about 70% of the total. Therefore, research of climate-change effects on water resources is essential to assess the likely future of agriculture. The Aidoghmosh irrigation network is one of the largest irrigation networks in Iran. It is herein shown that this irrigation network could serve a prototypical example of the conflicts emerging between water resources and water uses under climate change.

Climate and Future Hydroclimatic Changes

One must understand the roles of hydroclimatic variables and human phenomena (such as population growth, agricultural development, land-use changes, the creation of water-resource projects) on the hydrological regime to assess the sustainability of regional water resources management, something that has not been fully addressed in several recent studies (Ahmadi et al. 2015, 2014; Akbari-Alashti et al. 2014; Ashofteh et al. 2013a, b, 2015a, b, c; Beygi et al. 2014; Bolouri-Yazdali et al. 2014; Bozorg-Haddad et al. 2013, 2014, 2015b, a; Farhangi et al. 2012; Fallah-Mehdipour 2013c, b, a, 2014; Jahandideh-Tehrani et al. 2015; Orouji et al. 2013, 2014b, a; Shokri et al. 2013, 2014; Soltanjalili et al. 2013). One approach to this assessment is by evaluating the trend of climatic variables (Huo et al. 2008). Table 1 lists the Mann-Kendall (Z_M) and Spearman (Z_S) nonparametric test statistics for the slope of the trend (either positive or negative) of time series of

hydroclimatic variables. It is seen in Table 1 that the values of the statistics show decreasing trends for rainfall and runoff variables, and increasing trend for temperature in the observed period. These observed changes on hydroclimatic variables may be due to climatic shifts. Yet, human phenomena could also play a role in the observed trends, which bodes ill for water resources management by the implied temporal decline of precipitation and runoff and increased potential evapotranspiration by rising temperature.

The curve of annual cumulative runoff changes relative to annual cumulative climatic variability (CRCCV) in each region of interest provides clues about the juxtaposition of effects affecting its hydroclimatic variables. The nonlinearity of the CRCCV curve indicates the presence of hydrological instability, most likely due to factors other than the climate factor, such as human activities (including agriculture) in each region (Raghunath 2006; Ashofteh et al. 2016). Analyses of the CRCCV curve may reveal a change in its slope over time, and appears to be increasing due to human activities such as agricultural development (Ashofteh et al. 2016). It is concluded from the analysis of the CRCCV curve that changes in hydrologic processes and changes in human activities accounted for 80 and 20% of the runoff reduction of runoff, respectively (Ashofteh et al. 2016).

It is anticipated that agricultural development will increase in the future, and this could in turn lead to further change in the hydrological regime, and in the regional water availability. Climate predictions were performed to investigate these future changes by implementing seven atmospheric ocean general circulation models (AOGCMs) (HadCM3, CCSR-NIES, CSIRO MK2, CGCM2, GFDL R30, NCAR DOE PCM, and ECHAM4) under the emission scenarios A2 (high greenhouse gas emissions). Monthly input climatic data to the AOGCM were obtained from the IPCC's site (IPCC-DDC 1988) for the baseline period (1971–2000), and first (2010–2039), second (2040–2069), and third (2070–2099) future periods, applying the method of proportional downscaling with the GCM-Retrieve Data Program. Fig. 1(a) shows the range of the difference between the long-term average monthly temperature in the future periods and in the baseline period calculated with the seven AOGCMs. Fig. 1(b) represents the range of the difference between the percentage change in the long-term average monthly rainfall in the future periods and in the baseline period calculated with the AOGCMs. It is seen in Fig. 1(a) that the temperature in the third future period is higher than the temperature in the first and second future periods, so that the temperature change in winter, spring, summer, and autumn ranges from 0.01 to 2.2°C, 0.2 to 2.6°C, 0.6 to 3.1°C, and 0.3 to 2.5°C, respectively, in the first future period; it ranges from 0.6 to 4.3°C, 0.9 to 4.6°C, 1.9 to 5.9°C, and 0.8 to

Table 1. Calculated Nonparametric Test Statistics (with a Confidence Level of 99%) of Hydro-Climatic Variables

Variable	Mann-Kendall trend test	Spearman trend test
	Z_M	Z_S
Temperature	0.25	0.26
Rainfall	−0.20	−0.23
Runoff	−0.07	−0.10

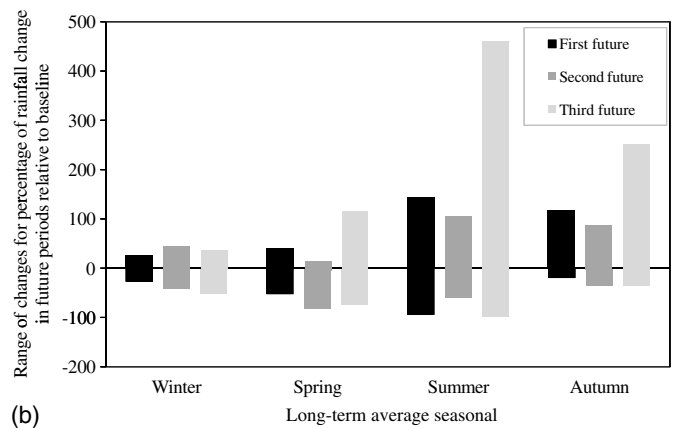
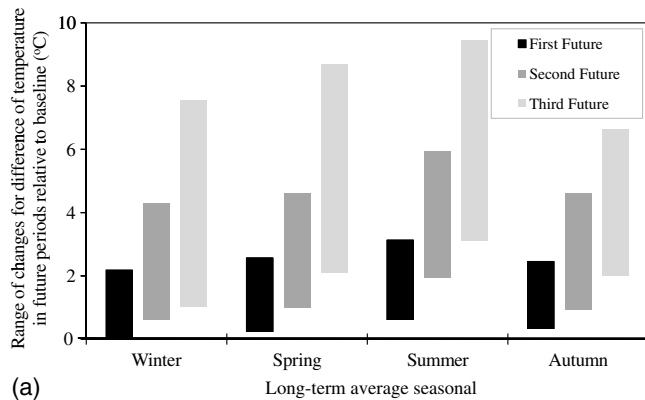


Fig. 1. (a) Range of differences between temperature in the future periods and in the baseline period; (b) range of differences between rainfalls in the future periods and in the baseline period from different AOGCMs

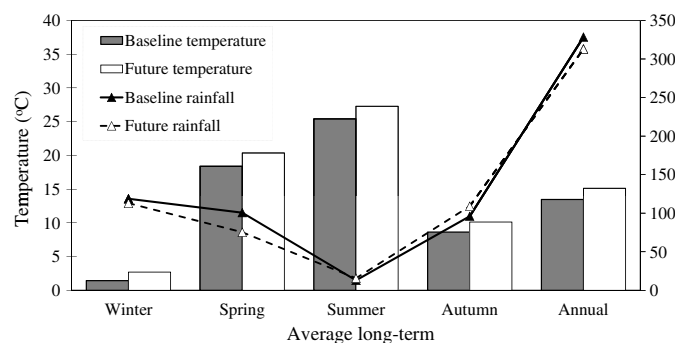


Fig. 2. Comparison of the long-term average of climatic variables

4.6°C, respectively, in the second period, and it ranges from 1.0 to 7.5°C, 2.1 to 8.7°C, 3.1 to 9.4°C, and 2.0 to 6.6°C, respectively, in the third period. The rainfall results depicted in Fig. 1(b) indicate that the rainfall change in winter, spring, summer, and autumn ranges from −27 to 27%, −52 to 37%, −94 to 140%, and −19 to 119%, respectively, in the first future period; it ranges from −41 to 51%, −81 to 20%, −59 to 108%, and −35 to 94%, respectively, in the second future period; and it ranges from −51 to 38%, −74 to 118%, −98 to 464%, and −35 to 254%, respectively, in the third future period.

Fig. 2 shows that the calculated future temperature is higher than the baseline temperature. However, the calculated future rainfall is

less than the baseline rainfall in winter and spring by about 5 and 25%, respectively, whereas it is larger than the baseline rainfall in the summer and autumn by about 19 and 12%, respectively. The results shown in Fig. 2 correspond to the first future period and were obtained with the HadCM3 model, which has been found to produce reliable climatic predictions (Ashofteh et al. 2015b).

Conflicts from the Effects of Climate Change on Water Resources

The irrigation requirement might increase in the future (Ashofteh et al. 2015c). This means that crops under changing climatic conditions will have larger irrigation requirements. This in turn will further stress the agricultural water supply system and worsen food security. The rise in the irrigation requirement for crops such as walnuts, alfalfa, and potatoes will be the largest, amounting to about 20, 16, and 19% annually, respectively, in the first future period compared to the baseline period. The largest increase in agricultural water use is predicted to occur during the summer. A 20% increase in average annual agricultural water use is expected in the first future period given the current area under cultivation.

To compound matters, water availability for agriculture would decrease in the future period. Fig. 3(a) depicts the conflict emerging from the effects of climate change on the temporal distribution of water resources and water uses. Fig. 3(b) represents the crisis severity (expressed as a percentage deficit) resulting from this conflict between climate change and water needs. Comparison of

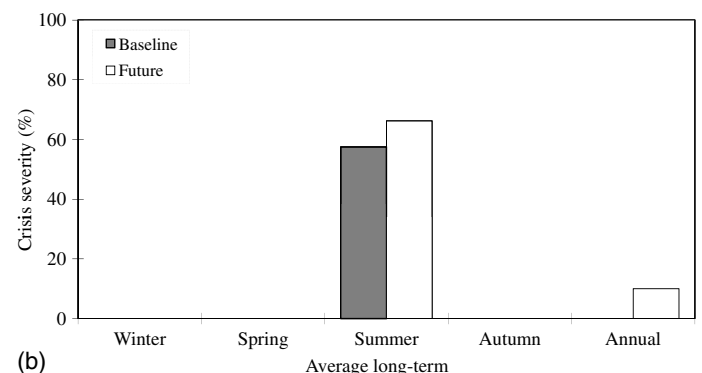
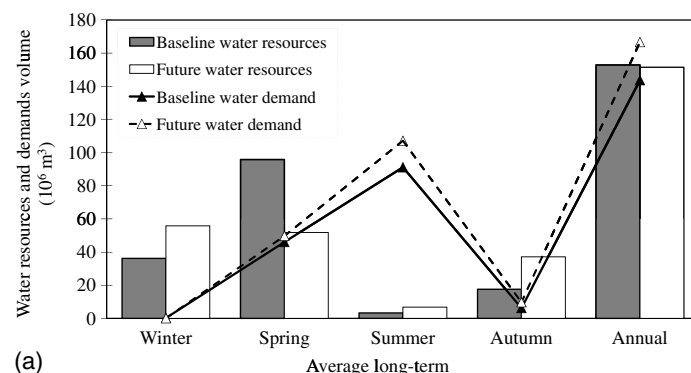


Fig. 3. Comparison of the long-term average of (a) water sources and water uses; (b) the crisis severity, for the baseline and future periods

the long-term average monthly availability of water resources and water demand shows that the volume of future water resources in the spring (wet season) will decline significantly (about 46%). This is most likely due to significant rainfall reduction in the spring relative to the baseline rainfall (about 25%, compared to other seasons (Fig. 2). On the other hand, increases in the volume of water resources in future periods in autumn and winter seasons will be about 53 and 35%, respectively, while water demand is low in the latter two seasons. There will be high water demand in the summer precisely when water availability would be low. The water crisis severity will be highest in the summer in the study region [Fig. 3(b)]. It is seen in Fig. 3(b) that the future crisis severity will increase 13% relative to the baseline for this season. It should be noted that the volume of future water demand in all seasons exceeds the volume of the baseline water demand, and the difference between the baseline and future water demand volumes will be largest in the summer, becoming about 15% larger in the future relative to the baseline.

This paper's analysis indicates a growing mismatch between agricultural water demand and available water resources under future climatic conditions. The awareness about this impending crisis might encourage planners and decision-makers to reduce the volume of network water demand in their long-term plans. This could be realized through adaptation strategies such as delaying the planting date, increasing the irrigation efficiency, changing system management practices, or resorting to other adaptive strategies.

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