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Simulation-Prediction Dataset of Annual Irrigation Water Requirement of Cotton and Winter Wheat in Five Central Asian Countries under RCP2.6 and RCP4.5 Scenarios (2020–2100)

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Abstract: Central Asia is one of the largest arid and semi-arid regions in the world. The region is currently facing significant shortage of water resources for agricultural irrigation. Agricultural irrigation is the largest water consumer and hence understanding the water requirement of the main crops is important for planning of agricultural water resources. The study presented in this paper was based on the Representative Concentration Pathway RCP2.6 and RCP4.5 climate change scenarios of Coupled Model Intercomparison Project Phase 5 (CMIP5). The water requirements of cotton and winter wheat in five Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan and Turkmenistan) in 2020–2100 were estimated using the crop coefficient approach. The dataset is archived in .shp and .tif formats in 332 data files, with the data size of 4.65 MB (compressed to 2.16 MB in one file).

Keywords: Central Asian countries; cotton and winter wheat; future irrigation water requirement; RCP2.6 scenario; RCP4.5 scenario

Dataset Available Statement:

The dataset supporting this paper was published at: Tian, J. Irrigation water requirement for cotton and winter wheat in five Central Asian countries under RCP2.6 and RCP4.5 scenarios (2020–2100) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2020. DOI: 10.3974/geodb.2020.01.04.V1.

1 Introduction

The five countries located in Central Asia include Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan and Turkmenistan. Central Asia is one of the largest arid and semi-arid regions in the world, with scarce precipitation, intensive evaporation and a serious shortage of water resource. According to World Bank's Monthly Rainfall Database (https://climateknowled-

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[2] Tian, J. Irrigation water requirement for cotton and winter wheat in five Central Asian countries under RCP2.6 and RCP4.5 Scenarios (2020–2100) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2020. DOI: 10.3974/geodb.2020.01.04.V1.

geportal.worldbank.org/), the average rainfall in 2000–2016 was 523 mm in Tajikistan, 414 mm in Kyrgyzstan, 270 mm in Kazakhstan, 211 mm in Uzbekistan, and 155 mm in Turkmenistan. In addition to the energy sector, agriculture occupies an important position in the economic development of the five Central Asian countries.

Irrigated farmlands in the five Central Asian countries are mainly distributed in the south and southeast of the entire region. According to the land use data of European Space Agency (ESA, https://www.esa-landcover-cci.org/) Climate Change Initiative (CCI) in 2015, the area of irrigated farmland was 86,269 km^2 in Kazakhstan, 81,198 km^2 in Uzbekistan, 40,233 km^2 in Turkmenistan, 32,178 km^2 in Kyrgyzstan and 14,283 km^2 in Tajikistan. In terms of crop production, the planting area of wheat and cotton in the five Central Asian countries accounted for 93% of the total area cultivated in 2015 based on the statistics of Food and Agriculture Organization (FAO, http://www.fao.org/faostat/en/#data). Irrigation is the most important means of agricultural production, and the most important consumer of water resources in Central Asia[1]. The agricultural irrigation water requirements in Central Asia exceed 90% of all water withdrawals of the two major rivers, the Amu Darya and the Syr Darya[2–3]. Therefore, the changes in agricultural irrigation have significant impacts on the water resources in this region. The crop water requirement is the key to determining the water requirement of agricultural irrigation[4].

In the present study, which is based on the Representative Concentration Pathway RCP2.6 and RCP4.5 climate change scenarios of Coupled Model Intercomparison Project Phase 5 (CMIP5), the water requirements of cotton and winter wheat in the five Central Asian countries in 2020–2100 were estimated using the crop coefficient approach. This will provide guidance for the exploration of the development of agricultural water resources in Central Asia in the future. This is also expected to facilitate the future agricultural cooperation between China and the five Central Asian countries under the strategic initiative of the "the Belt and Road Initiative".

2 Metadata of the Dataset

The name, author, geographical region, temporal resolution, spatial resolution, data format, data publisher, and data sharing policy of the dataset[5] are shown in Table 1.

3 Methods

3.1 Algorithm Principle

The method of FAO crop water requirement (mm) was used, as shown in equation (1).

$$\text{IWR} = \frac{ET - P_e}{I_e} \tag{1}$$

Table 1 Metadata summary of the dataset

Items	Description
Dataset full name	Irrigation water requirement for cotton and winter wheat in five Central Asian countries under RCP2.6 and RCP4.5 Scenarios
Dataset short name	IrriWaterRe_CottonWheat_CenAsia_2020-2100
Authors	Tian, J. AAO-7972-2020, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, tianj.04b@igsnrr.ac.cn
Geographical region	Five Central Asian countries Year 2020–2100
Temporal resolution	Year Spatial resolution 0.5 degree
Data format	.tif Data size 2.16 MB (after compression)
Data files	Annual irrigation water requirement of cotton and winter wheat under scenarios of RCP2.6 and RCP4.5 (2020–2100)

(***To be continued on the next page***)

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Items	Description
Foundation	Chinese Academy of Sciences (XDA2004030201)
Computing environment	ENVI & IDL (5.1 & 8.3)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing &Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to cita-tion; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[6]
Communication and searchable system	DOI, DCI, CSCD, WDS/ISC, GEOSS, China GEOSS, Crossref

where P_e indicates the effective rainfall, namely the rainfall actually used by the crops and was calculated using the USDA method [see equation (2)]; ET indicates the actual crop evapotranspiration, calculated using the crop coefficient approach [equation (3)]; and I_e indicates the irrigation efficiency, namely the ratio of the irrigation water volume actually used by crops to the actual water withdrawals. According to Rost *et al.*[7], the irrigation efficiency in Central Asia is 56.6% based on a global scale.

$$P_e = \begin{cases} P \times (125 - 0.2 \times P) / 125, P < 250 \text{ mm} \\ 125 + 0.1 \times P, P \geqslant 250 \text{ mm} \end{cases} \tag{2}$$

where P represents the monthly rainfall (mm).

The actual crop evapotranspiration was calculated using the crop coefficient approach and reference evapotranspiration approach:

$$ET = K_c \times ET_0 \tag{3}$$

where K_c represents the crop coefficient. In this study, the crop coefficients of cotton and winter wheat in the four growth stages in Central Asia given by Scientific Information Centre of Interstate Commission on Water Coordination in Central Asia (SIC-ICWC) were used[8–9] (Table 2). ET_0 is the reference crop evapotranspiration (mm day^{-1}), calculated by equation (4)[10]. This method is an improved version of the original FAO method, with particular attention given to the impact of atmospheric CO_2 concentration on crop evapotranspiration.

$$ET_0 = \frac{0.408\Delta(\text{Rn} - \text{G}) + \gamma \frac{900}{\text{T} + 273} \text{U}_2(\text{e}_\text{s} - \text{e}_\text{a})}{\Delta + \gamma\left[1 + \text{U}_2\left(0.34 + 2.4 \times 10^{-4}([\text{CO}_2] - 300)\right)\right]} \tag{4}$$

where Δ indicates the slope of changes in water vapor pressure with temperature (kPa ·℃$^{-1}$), R_n indicates the net radiation (MJ m^{-2} day^{-1}), G represents the soil heat flux (MJ m^{-2} day^{-1}), γ represents the psychrometric constant (kPa ·℃$^{-1}$), T is the daily average temperature (℃), U_2 is the daily average wind velocity at a height of 2 m (m s^{-1}), e_s refers to the saturation vapor pressure (kPa), e_a refers to the actual vapor pressure (kPa), and [CO_2] refers to the atmospheric CO_2 concentration (ppm). The specific calculation method of each variable is shown in the "FAO No.56 Irrigation and Drainage Manual"[11].

Table 2 K_c values for cotton and for winter wheat at the four different growth stages

Growing stage	Planting/Harvesting (date)		Growth stages (days)		Crop coefficients (K_c)	
	Cotton	Winter wheat	Cotton	Winter wheat	Cotton	Winter wheat
Planting: initial	Early-April	Mid-October	30	30	0.55	0.65
Development phase			50	140	0.55	0.65
Mid-season			55	40	0.95–1.15	1.15
Harvest: late-season	Early-October	Early-June	45	30	0.65	0.65

3.2 Technical Route

The procedures of generating dataset are as follows: the monthly average daily maximum temperature, monthly average daily minimum temperature and monthly rainfall were downloaded from the outputs of 15 climate models under the CMIP5 RCP2.6 and RCP4.5 scenarios. The information about growth phases and crop coefficients of cotton and winter wheat in Central Asia were obtained through literature review. The averages of monthly average daily maximum temperature, monthly average daily minimum temperature and monthly rainfall for the 15 climate models under RCP2.6 and RCP4.5 scenarios were calculated. The effective monthly rainfall was calculated based on the monthly rainfall data. The reference evapotranspiration of cotton and winter wheat was calculated based on the monthly average daily maximum temperature and monthly average daily minimum temperature. The actual evapotranspiration of cotton and winter wheat was calculated using the crop coefficient and reference crop evapotranspiration. Finally, the crop water requirement was obtained using the actual evapotranspiration, effective rainfall and irrigation coefficient.

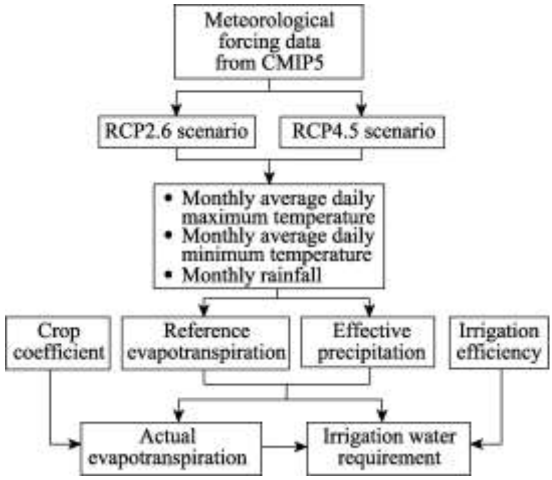

Figure 1 Technical route

An extreme and hypothetical situation was assumed in this study, that is, cotton or winter wheat is planted in the entire Central Asia. The results obtained based on such a hypothesis are helpful for analyzing the spatial pattern of the water requirements of cotton and winter wheat in Central Asia in the future. They can be combined with the prediction results of future agricultural lands to analyze the total irrigation water requirement more accurately.

4 Data Results and Verification

4.1 Dataset Composition

This dataset consisted of four parts:

(1) Annual water requirement of cotton in 2020–2100 under the RCP2.6 scenario;

(2) Annual water requirement of cotton in 2020–2100 under the RCP4.5 scenario;

(3) Annual water requirement of winter wheat in 2020–2100 under the RCP2.6 scenario;

(4) Annual water requirement of winter wheat in 2020–2100 under the RCP4.5 scenario.

The files were named in a uniform way (Table 3).

4.2 Data Results

(1) Future water requirement of cotton under the RCP2.6 and RCP4.5 scenarios

In terms of the spatial distribution, the future water requirement of cotton gradually declined from southwest to north and east under the RCP2.6 and RCP4.5 scenarios (Figure 2–3). It was the highest in Turkmenistan, followed by Uzbekistan, and it was the lowest in Tajikistan and Kyrgyzstan. The future water requirement was also lower in northern Kazakhstan. Such a spatial distribution pattern (532–2,286 mm) remained unchanged in 2020–2100. Compared with Turkmenistan and Uzbekistan, the higher rainfall during the cotton growing season in Tajikistan, Kyrgyzstan and northern Kazakhstan was the main reason for the lower water requirement of cotton. According to the calculation method of crop water requirement, the spatial characteristics of meteorological conditions (mainly including rainfall, temperature, wind velocity and radiation) basically determined the spatial characteristics of crop water requirement. The spatial distribution characteristics of meteorological conditions under the RCP2.6 and RCP4.5 scenarios were basically the same. Therefore, the spatial distribution pattern of crop water requirement remained unchanged.

Table 3 Data files of the dataset

Fold name	Nomination	Description	Format	Number	Data size
CottonRCP26	CA_yearly_CottonIWR_CO2_RCP26_yeaer_NAN.tif	WGS84: NAN	.tif	81	1.1 MB
CottonRCP45	CA_yearly_CottonIWR_CO2_RCP45_year_NAN.tif	WGS84: NAN	.tif	81	1.1 MB
WheatRCP26	CA_yearly_WheatIWR_CO2_RCP26_year_NAN.tif	WGS84: NAN	.tif	81	1.1 MB
WheatRCP45	CA_yearly_WheatIWR_CO2_RCP45_year_NAN.tif	WGS84: NAN	.tif	81	1.1 MB

(2) Future water requirement of winter wheat under the RCP2.6 and RCP4.5 scenarios

Under the RCP2.6 and RCP4.5 scenarios, the spatial distribution of future water requirement of winter wheat was the same as that of cotton, and also gradually declined from southwest to north and east (Figure 3–4). It was the highest in Turkmenistan, followed by Uzbekistan, and it was the lowest in Tajikistan and Kyrgyzstan. Such a spatial distribution pattern (−329–1,440 mm) remained unchanged in 2020–2100. The negative value indicated the higher effective rainfall than the crop water requirement, that is, rainfall can meet the requirement of crop growth. Obviously, the water requirement of winter wheat was lower

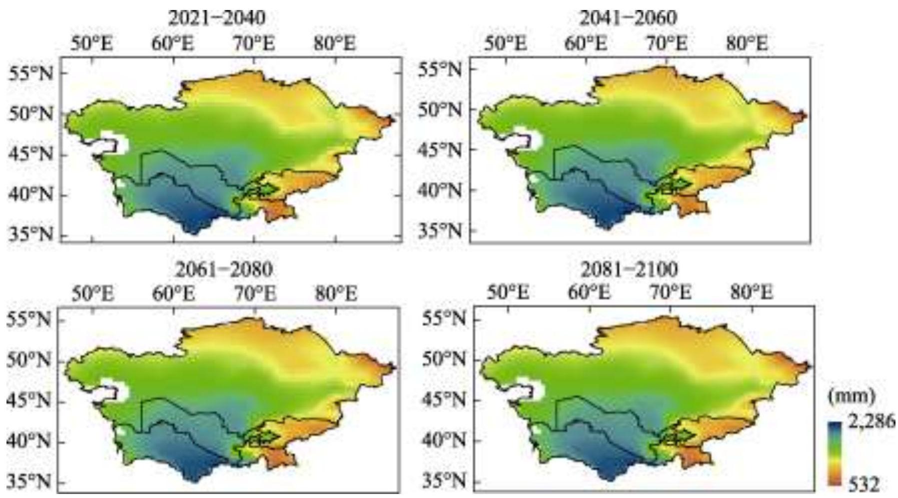

Figure 2 Spatial distribution of water requirement of cotton in five Central Asian countries in four periods under the RCP2.6 scenario

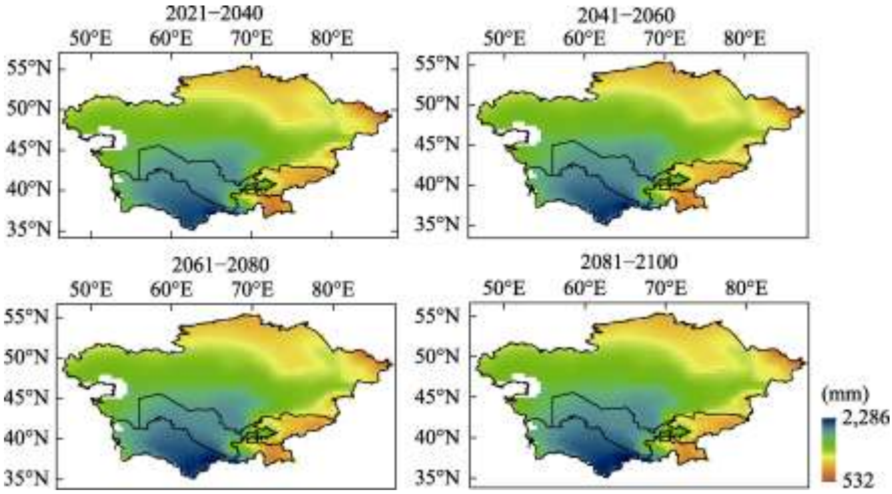

Figure 3 Spatial distribution of water requirement of cotton in five Central Asian countries in four periods under the RCP4.5 scenario

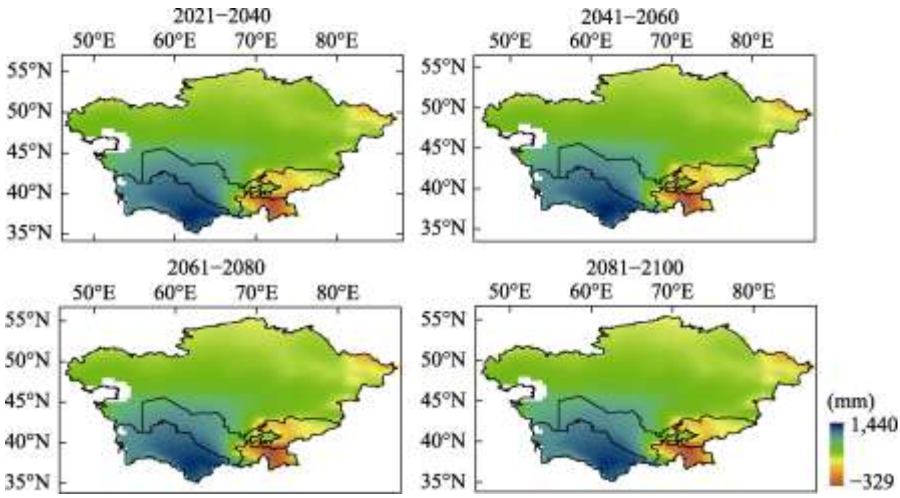

Figure 4 Spatial distribution map of water requirement of winter wheat in five Central Asian countries in four periods under the RCP2.6 scenario

than that of cotton. In Tajikistan, the rainfall during the winter wheat growing season was even higher than the crop water consumption, and hence the crop water requirement was negative. The spatial distribution characteristics of meteorological conditions were basically the same under the RCP2.6 and RCP4.5 scenarios, and therefore the spatial distribution pattern of crop water requirement basically remained unchanged.

(3) Future change trends of water requirements of cotton and winter wheat under the RCP2.6 and RCP4.5 scenarios

The future change trends of water requirements of cotton and winter wheat in 2020–2100 were analyzed using the Mann-Kendall test. The slope of change trends at the 0.05 level is shown in Figure 6. Under the RCP2.6 scenario, the water requirement of cotton displayed a significant downward trend in mid-eastern and northeastern Kazakhstan, and in eastern Turkmenistan. There was insignificant change in cotton water requirement in other regions. Under the RCP4.5 scenario, the water requirement of cotton increased in the entire Central

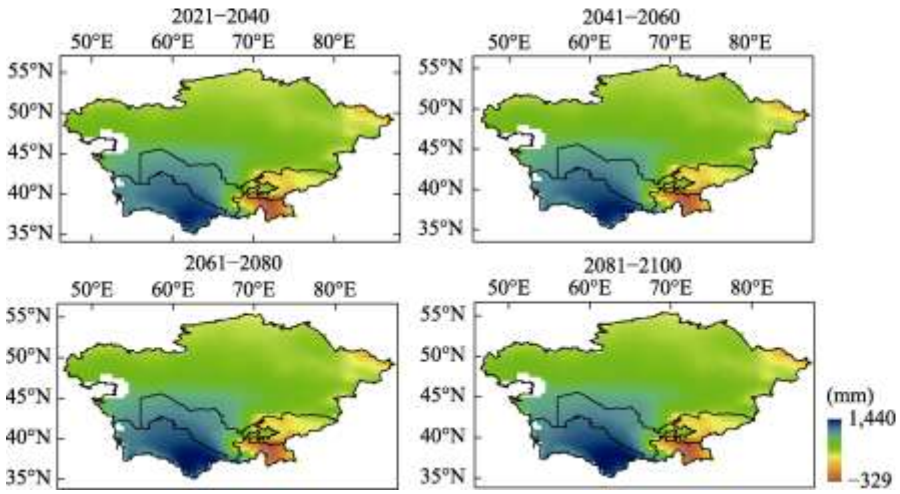

Figure 5 Spatial distribution map of water requirement of winter wheat in five Central Asian countries in four periods under the RCP4.5 scenario

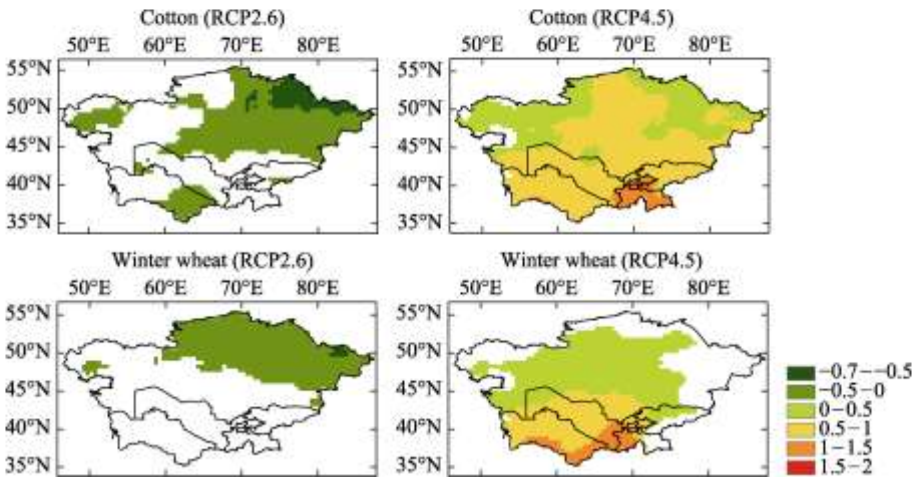

Figure 6 Slope of change trends of water requirements of cotton and winter wheat under the RCP2.6 and RCP4.5 scenarios in 2020–2100 (at the 0.05 level)

Asia, especially in Tajikistan. Besides, under the RCP2.6 scenario, the water requirement of winter wheat showed a significant downward trend in northeastern Kazakhstan, while it had no obvious trend in other regions. Under the RCP4.5 scenario, except a few regions in eastern, southeastern and northern Central Asia, the water requirement of winter wheat almost increased in the entire Central Asia. This increase was more pronounced in the south of Central Asia. It can be seen that the change trends of water requirements of cotton and winter wheat under the RCP2.6 and RCP4.5 scenarios have great differences, which is mainly due to the differences in the two climate change scenarios. RCP2.6 is a scenario where the radiative forcing first rises to 3.1 W m^{-2} by the middle of the 21st century and then gradually declines, and reaches 2.6 W m^{-2} by 2100. RCP4.5 is a scenario where the radiative forcing gradually rises and reaches 4.5 W m^{-2} by 2100. Therefore, the change trends of meteorological elements vary with time under the two scenarios, leading to different change trends of crop water requirement.

5 Discussion and Conclusion

The water requirements of cotton and winter wheat in five Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan and Turkmenistan) in 2020–2100 were estimated through the crop coefficient approach. The attributes of the datasets generated set as follows time span: 2020–2100, temporal resolution: year, spatial resolution: 0.5 degrees, and data format: .tif. It is worth noting that the crop water requirement was estimated under an extreme and hypothetical situation, which assumed that cotton or winter wheat is planted in the entire Central Asia. The main reason for this assumption is that it is difficult to predict the specific planting of cotton and winter wheat in the next few decades. The hypothesis used in this paper is more helpful for analyzing the changes in crop water requirement in the entire Central Asia. The dataset reflected the temporal-spatial patterns and change pattern of the water requirements of cotton and winter wheat in the five Central Asian countries in the next 80 years.

According to the data analyzed, it was found that: (1) Under the RCP2.6 and RCP4.5 scenarios, it was the highest in Turkmenistan, followed by Uzbekistan. The future water requirement was the lowest in Tajikistan and Kyrgyzstan, and also lower in northern Kazakhstan. (2) Under the RCP2.6 and RCP4.5 scenarios, it was the highest in Turkmenistan, followed by Uzbekistan, and it was the lowest in Tajikistan and Kyrgyzstan. (3) The spatial distribution patterns of cotton and winter wheat remained basically unchanged under the RCP2.6 and RCP4.5 scenarios in 2020–2100. (4) The change trends of water requirements of cotton and winter wheat under the RCP2.6 and RCP4.5 scenarios varied significantly. Under the RCP2.6 scenario, the water requirements of cotton and winter wheat displayed significant downward trends only in the northeast of Central Asia, while there were no major changes in other regions. Under the RCP4.5 scenario, the water requirements of cotton and winter wheat remarkably increased almost in the entire Central Asia.

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