Analysis of Spatiotemporal Variation in Water Resource Security Based on Agricultural Water Footprint: A Case Study of Hotan Region, Xinjiang (Postprint)

Authors: Zhang Lili, Deng Xiaoya, Long Aihua

Date: 2022-03-28T12:47:04+00:00

Abstract

The Hotan region is a typical inland arid area, and studying regional water resource security is of great significance for guiding water resource development and utilization, and promoting the sustainable development of socio-economy and water resources. Based on the water footprint theory, this paper investigates the composition and spatiotemporal variation of agricultural production water footprint for crop production and animal product production in the Hotan region from 1989 to 2018, and analyzes and evaluates the spatiotemporal variation of water resource security status from the two perspectives of water resource consumption and pollution through water footprint intensity and water resource pressure indicators. The results show that: the agricultural production water footprint in the Hotan region has experienced three stages of rapid growth, slow growth, and significant decline, composed of a ratio of approximately 8:2 between crop production water footprint and animal product production water footprint. The changes in each stage are dominated by the increase or decrease of blue water footprint in crop production, showing a spatial distribution pattern of high in the west and low in the east; water footprint intensity exhibits a logarithmic decreasing trend, shrinking to 1/19 of its original value by 2018. The water resource pressure values in the Hotan region fluctuate below 1, with water resources remaining in a safe state for many years, although the degree of water resource pressure has been relatively high in the recent 10 years. Over the years, the agricultural production water footprint in the Hotan region has grown fluctuatingly over time, water resource utilization efficiency has significantly improved, while water resource pressure has also increased synchronously, continuously threatening regional water resource security.

Full Text

Spatial-Temporal Assessment of Water Resource Security Based on Agricultural Water Footprint: A Case Study of Hotan Prefecture, Xinjiang

ZHANG Lili[1,2], DENG Xiaoya[2], LONG Aihua[1,2], GAO Haifeng[3], REN Cai[1,2], LI Zhiyun[1,2]

[1]College of Water & Architectural Engineering, Shihezi University, Shihezi, Xinjiang 832000, China
[2]State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[3]Satellite Application Center for Ecology and Environment, Ministry of Ecology and Environment, Beijing 100094, China

Abstract

Hotan Prefecture represents a typical inland arid region where investigating regional water resource security holds significant importance for guiding water resource development and utilization while promoting sustainable socioeconomic and water resource development. Based on water footprint theory, this study examines the composition and spatiotemporal dynamics of agricultural production water footprints in Hotan from 1989 to 2018, encompassing both crop production and animal product production. Water resource security status is then analyzed and evaluated through water footprint intensity and water resource pressure indicators from the perspectives of water consumption and pollution. The results demonstrate that agricultural production water footprints in Hotan experienced three distinct phases: rapid growth, slow growth, and significant decline, composed at an approximate 8:2 ratio between crop production and animal product production water footprints. Stage-specific variations were dominated by fluctuations in the blue water footprint of crop production, exhibiting a spatial pattern of high values in the west and low values in the east. Water footprint intensity decreased logarithmically, shrinking to 1/19 of its original value by 2018, while water resource pressure values remained below 1 for many years, indicating a secure water resource status, though pressure has been relatively high in the past decade. Overall, agricultural production water footprints in Hotan have shown fluctuating growth over time, water use efficiency has improved significantly, yet water resource pressure has increased simultaneously, continuously threatening regional water resource security.

Keywords: crop production water footprint; animal product production water footprint; grey water footprint; water resource security; Hotan Prefecture

1. Study Area and Methods

1.1 Study Area Overview

Hotan Prefecture is located in the hinterland of the Eurasian continent at the southernmost tip of Xinjiang Uygur Autonomous Region (77°20 ~85°E, 34°~39°30 N), covering a total area of 24.78×10^{4} km^2 and jurisdiction over 24 counties and townships (Fig. 1). The region represents a typical inland arid zone characterized by scarce annual precipitation, abundant sunlight, rich heat resources, long frost-free periods, and large diurnal temperature variations. With average annual precipitation of 35 mm, surface runoff replenishment primarily depends on melted glaciers and snowpack plus some alpine precipitation, resulting in substantial interannual variability in river runoff fluctuating by 20%~40% annually. The area contains 74 rivers of varying sizes with total annual runoff of 73.4×10^{8} m^3, among which the Yulong Kashi River and Kara Kashi River account for 85.94% of the region' s total water volume. These two rivers converge near Koshlash to form the Hotan River, which serves as a crucial ecological corridor preventing the eastern and western halves of the Taklimakan Desert from merging.

According to the *Xinjiang Water Resources Bulletin*, Hotan Prefecture' s average annual agricultural water consumption exceeds 95% of total water use, comprising crop irrigation water and animal husbandry water at approximately a 6:1 ratio. The *Hotan Statistical Yearbook* indicates the prefecture currently has 133 irrigated areas above designated size, predominantly small-scale irrigation districts, with two districts exceeding 3.33×10^{3} hm^2. Major crops include wheat, coarse grains, and cotton.

1.2 Data Sources

Data required for calculating agricultural production water footprints were obtained from the *Xinjiang Statistical Yearbook* (1990–2019) and *Xinjiang Production and Construction Corps Statistical Yearbook* (1990–2019) for crop planting area, fertilizer use, animal headcounts, and water footprint efficiency indicators. Available water resources data for water resource pressure calculations were sourced from the *Xinjiang Water Resources Bulletin* (2004–2019). Meteorological data needed for calculating crop evapotranspiration—including annual rainfall, average wind speed, relative humidity, maximum temperature, and minimum temperature from Hotan meteorological stations—were obtained from the National Meteorological Science Data Sharing Service Center (http://data.cma.cn). To assess overall regional water resource security, this study includes the 14th Division of the Xinjiang Production and Construction Corps within the research scope, incorporating various regiments into their respective jurisdictions for calculation and analysis of agricultural production water footprints without separate analysis.

1.3 Calculation Methods

1.3.1 Agricultural Production Water Footprint Calculation Based on water footprint theory, this study calculates blue, green, and grey water footprints for agricultural production in Hotan from the producer perspective. Considering pollutant emissions, environmental sensitivity, and data availability, the primary pollutants selected for grey water footprint analysis were ionic chemical oxygen demand (COD), total nitrogen (TN), and ammonia nitrogen (NH_3-N). Agricultural production water footprints are represented by crop production and animal water footprints using the formula:

$$WF_{agr} = WF_{cul} + WF_{ani}$$

where WF_{agr} is agricultural production water footprint; WF_{cul} is crop production water footprint; and WF_{ani} is animal product production water footprint.

1.3.2 Crop Production Water Footprint Crop production water footprint refers to water resources consumed during crop growth, which can be further divided into blue, green, and grey water footprints based on water resource type and environmental impact. The calculation method is:

$$WF_{cul} = WF_{blue} + WF_{green} + WF_{grey}$$

where WF_{cul} is crop production water footprint ($\mathrm{m}^3 \cdot \mathrm{yr}^{-1}$); WF_{blue}, WF_{green}, and WF_{grey} are blue, green, and grey water footprints of crop production, respectively ($\mathrm{m}^3 \cdot \mathrm{yr}^{-1}$).

Blue and green water footprints are calculated as:

$$WF_{blue} = \frac{CWU_{blue}}{Y} = \frac{10 \times \sum d_{blue}}{Y}$$

$$WF_{green} = \frac{CWU_{green}}{Y} = \frac{10 \times \sum d_{green}}{Y}$$

where CWU_{blue} and CWU_{green} are crop blue and green water requirements ($\mathrm{m}^3 \cdot \mathrm{hm}^{-2}$); Y is crop yield per unit area ($\mathrm{kg} \cdot \mathrm{hm}^{-2}$); d_{blue} and d_{green} are daily crop blue and green water use (mm); the coefficient 10 is a constant factor; and the summation represents accumulation from planting date to harvest date.

The green water footprint is calculated as $d_{green} = \min(ET_c, P_e)$, and the blue water footprint as $d_{blue} = \max(0, ET_c - P_e)$, where ET_c is crop evapotranspiration ($\mathrm{mm} \cdot \mathrm{d}^{-1}$) and P_e is effective rainfall (mm). ET_c is calculated using the FAO-56 standard crop coefficient and correction formula, adjusted according to study area climate, soil, crop, and irrigation conditions. ET_0 is reference crop evapotranspiration ($\mathrm{mm} \cdot \mathrm{d}^{-1}$) calculated using the Penman-Monteith formula.

The grey water footprint of crop production primarily refers to water resources required to dilute pollution ions from unused fertilizers leached into rivers by irrigation or rainfall to standard concentrations. This study analyzes nitrogen and phosphorus fertilizers—the most widely applied in Hotan—as primary pollution sources. Since the same water body can dilute multiple pollutants simultaneously, the grey water footprint is determined by the maximum water requirement among pollutant ions. The calculation formula is:

$$WF_{grey} = \max(WF_{grey,N}, WF_{grey,P})$$

$$WF_{grey,N} = \frac{L_N \times A}{C_{max,N} - C_{nat,N}}$$

$$WF_{grey,P} = \frac{L_P \times A}{C_{max,P} - C_{nat,P}}$$

where α_N and α_P are fertilizer leaching coefficients for nitrogen and phosphorus fertilizers, respectively, taken from the *First National Pollution Source Census Coefficient Manual*; A is fertilizer application amount (kg); $C_{max,N}$ and $C_{max,P}$ are maximum pollutant concentrations under environmental water quality standards, with $C_{max,N} = 0.01\ \mathrm{kg \cdot m^{-3}}$ and $C_{max,P} = 0.005\ \mathrm{kg \cdot m^{-3}}$ from the *Integrated Wastewater Discharge Standard* (GB8978-2002); and $C_{nat,N}$ and $C_{nat,P}$ are natural background concentrations of receiving water bodies, assumed to be 0.

This study focuses on major crops in Hotan, including grain crops (rice, wheat, coarse grains, beans), economic crops (cotton, oil crops, sugar beets, vegetables, melons, potatoes, alfalfa), and fruits (grapes, apples, pears, dates, other fruits), analyzing water footprint variation patterns across counties and crops from 1989 to 2018.

1.3.3 Animal Product Production Water Footprint Animal product production water footprint refers to the water footprint throughout an animal' s entire lifecycle from birth to slaughter, including virtual and direct water consumption for growth, feed processing, drinking water, cleaning service water, and grey water footprint primarily from animal excreta. The calculation formula is:

$$WF_{ani} = WF_{feed} + WF_{drink} + WF_{serve} + WF_{grey}$$

where WF_{feed}, WF_{drink}, WF_{serve}, and WF_{grey} represent feed water, drinking water, service water, and grey water footprints, respectively ($\mathrm{m^3 \cdot yr^{-1}}$).

The feed water footprint is calculated as:

$$WF_{feed} = \sum_i SWC_i \times C_{mix,i} + \sum_i \int_{birth}^{death} C_{ij} dt$$

where $C_{mix,i}$ is water required for mixed feed ($m^3 \cdot yr^{-1}$); C_{ij} is the weight of feed j consumed by animal i ($kg \cdot d^{-1}$); and SWC_i is the virtual water content of feed i ($m^3 \cdot kg^{-1}$). Virtual water content of feed crops is calculated using the crop production water footprint method, weighted according to different feed crop ratios (by weight).

Drinking and service water footprints are calculated as:

$$WF_{drink} = \int_{birth}^{death} Q_i^d dt$$

$$WF_{serve} = \int_{birth}^{death} Q_i^s dt$$

The grey water footprint is calculated as:

$$WF_{grey} = \max_k \left(\frac{P_k \times \beta_k}{C_{max,k} - C_{nat,k}} \right)$$

where P_k is the annual amount of pollutant k generated in animal urine and feces ($kg \cdot yr^{-1}$); β_k is the loss rate of pollutant k from animal excreta into water bodies, taken from the *National Large-scale Livestock and Poultry Breeding Industry Pollution Survey Technical Report*; $C_{max,k}$ is the environmental water quality standard value for pollutant k, with $C_{max,COD} = 0.06$ $kg \cdot m^{-3}$ and $C_{max,NH_3-N} = 0.015$ $kg \cdot m^{-3}$ from GB8978-2002; and $C_{nat,k}$ is the natural background concentration of the receiving water body.

This study uses live animal data, excluding feed crop production water footprints that overlap with crop production water footprints in growth and feed processing water use, to calculate animal water footprints for five major livestock types (cattle, horses, pigs, donkeys, sheep) in Hotan from 1989 to 2018.

1.4 Water Resource Security Evaluation Indicators

This study employs water footprint intensity and water resource pressure indicators to analyze and evaluate water resource security status in Hotan (Table 1). The *Water Footprint Assessment Manual* defines a product' s water footprint as the sum of water used throughout its entire production supply chain—a multi-dimensional indicator reflecting water consumption volume, water source type, pollution amount, and pollution type. Blue and green water footprints primarily reflect consumed water volume and source type, while grey water footprints reflect pollution amount and type. To facilitate evaluation indicator calculation and result analysis, this study categorizes water footprints consumed in virtual and direct water forms as non-grey water footprints of agricultural production (WF_{con}), and the remainder as grey water footprints of agricultural production (WF_{grey}). Thus, WF_{agr} can be expressed as:

$$WF_{agr} = WF_{con} + WF_{grey}$$

where WF_{con} is agricultural production non-grey water footprint ($\mathrm{m}^3 \cdot \mathrm{yr}^{-1}$) and WF_{grey} is agricultural production grey water footprint ($\mathrm{m}^3 \cdot \mathrm{yr}^{-1}$).

Water resource security evaluation indicators include water footprint intensity and water resource pressure indicators. Water footprint intensity reflects water resource utilization efficiency, expressed as agricultural production water footprint per unit of GDP. Smaller values indicate higher water resource utilization efficiency. The calculation formula is:

$$WFS = \frac{WF_{agr}}{GDP}$$

Water resource pressure indicators reflect water resource pressure status and utilization security degree, expressed as the ratio of agricultural production water footprint to available water resources (Q). The calculation formula is:

$$WFP = \frac{WF_{agr}}{Q}$$

When $WFP < 1$, available water resources can meet consumption demand and regional water resources are secure; when $WFP = 1$, water resources are at critical security with available resources equal to consumption demand; when $WFP > 1$, consumption exceeds available resources and water resource utilization is insecure.

To better evaluate water resource pressure status in Hotan, this study classifies water resource pressure indicators into levels following reference [24] (Table 2).

2. Results

2.1 Composition and Spatiotemporal Changes of Agricultural Production Water Footprint

2.1.1 Crop Production Non-Grey Water Footprint The crop production non-grey water footprint ($WF_{con,cul}$) comprises the sum of crop production green water footprint ($WF_{green,cul}$) and blue water footprint ($WF_{blue,cul}$), reflecting water resource consumption during crop production. Across Hotan from 1989 to 2018, $WF_{con,cul}$ for different crop types (grain crops, economic crops, fruits) showed fluctuating growth trends, dominated by grain crop consumption followed by economic crop consumption. Except for Minfeng County, all counties and cities exhibited $WF_{con,cul}$ growth, with wheat, coarse grains, cotton, and alfalfa—the four most extensively planted crops—accounting for 59%~96% of county-level $WF_{con,cul}$. Due to policy-guided planting area fluctuations, $WF_{con,cul}$ for wheat and coarse grains showed irregular large-amplitude changes. As a characteristic economic crop in Hotan, $WF_{con,cul}$ for red dates increased rapidly, closely related to the promotion of red date industry and policy encouragement for planting [29]. In regional red date cultivation, Hotan City showed no significant growth, while Minfeng County exhibited the most remarkable increase. From 2009, Minfeng County' s economic crops, dominated by red date water consumption, exceeded grain crops and fruits in production water consumption, reaching 46.3% of crop production non-grey water footprint by 2018, becoming an important crop for local farmers' income and county-wide per capita income improvement.

Significant spatial differences in $WF_{con,cul}$ resulted from combined effects of water resource spatial distribution and inter-regional crop development. Among Hotan counties, Moyu, Hotan, and Luopu counties—located along the Hotan River with large populations, extensive crop planting areas, high agricultural output values, and relatively developed agricultural economies—showed significantly higher $WF_{con,cul}$ than other counties and cities, supported by water resources from the Hotan River despite large water consumption demands from extensive crop cultivation.

2.1.2 Animal Product Production Non-Grey Water Footprint Animal product production non-grey water footprint ($WF_{con,ani}$) includes water for growth, feed processing, drinking, and cleaning services, reflecting water resources consumed from birth to slaughter. Hotan $WF_{con,ani}$ showed unsteady growth over time, increasing by 381.78% from 1989 to 1999, then decreasing by 32.8% from 1999 to 2009, followed by another increase. The number of animals directly impacted $WF_{con,ani}$ changes. With relatively stable feed structure and service/drinking water consumption, large livestock numbers decreased from 9.71$×10^{6}$ heads in 1999 to 7.58$×10^{6}$ heads in 2009, causing $WF_{con,ani}$ reduction. County-level contributions to Hotan' s animal water consumption were largest from Moyu County and smallest from Minfeng County. Moyu County' s $WF_{con,ani}$ reached its historical maximum of 1.09$×10^{8}$ m^3 in 1999, accounting for 29.3% of Hotan' s $WF_{con,ani}$ that year. As the main contributor to animal water consumption in Hotan, Moyu County' s changes significantly influenced regional $WF_{con,ani}$ dynamics.

2.2 Analysis of Agricultural Production Water Footprint Change Process

From 1989 to 2018, Hotan' s agricultural production water footprint (WF_{agr}) experienced three stages: rapid growth (1989–1999), slow growth (1999–2009), and obvious decline (2009-2018). Stage-specific WF_{agr} changes were dominated by crop production blue water footprint ($WF_{blue,cul}$) fluctuations, corresponding to $WF_{blue,cul}$ increase, basic stability, and decrease in the three stages, respectively.

Continuously expanding crop planting areas increased water consumption for crop growth. Under Hotan' s arid climate, this intensified demand for blue water resources, creating the rapid growth stage of agricultural production water footprint. During 1989-1999, WF_{agr} increased from 5.94×10^{8} m^3 to 17.45×10^{8} m^3, with an average annual growth rate of 10.36%. The slow growth stage (1999-2009) featured relative stability of $WF_{blue,cul}$. WF_{agr} increased from 17.45×10^{8} m^3 to 19.36×10^{8} m^3, with $WF_{blue,cul}$ increasing by only 182.13% and WF_{ani} increasing by 91.83%. The obvious decline stage (2009-2018) showed clear decreasing trends, with WF_{agr} decreasing from its peak of 19.36×10^{8} m^3 to 14.17×10^{8} m^3, and $WF_{blue,cul}$ decreasing from its peak of 7.69×10^{8} m^3 to 5.68×10^{8} m^3, representing reductions of 26.93% and 32.12%, respectively.

Spatially, WF_{agr} showed an overall pattern of high values in the west and low values in the east, with Moyu County as the highest value in the west and Hotan City as a low-value enclave. In the east, Yutian County served as a high-value area separating Cele and Minfeng counties. The western region, as the origin and flow path of the Hotan River, has abundant water resources that greatly satisfy water demands along the route, creating high-value areas. The eastern region shows low values, with Cele and Minfeng counties maintaining relatively low water consumption levels for planting and animal husbandry.

In composition, agricultural production non-grey water footprint (WF_{con}) dominated WF_{agr}, accounting for over 97.61%. The proportion of WF_{con} in WF_{agr} first decreased then increased, reaching its highest proportion of 99.39% in 2018. Crop production and animal product production water footprints composed Hotan' s WF_{agr} at a ratio of 88.16%~95.71%. The increase in WF_{grey} proportion in 1999 resulted from substantial increases in nitrogen fertilizer use during crop production, making agricultural production grey water footprint (WF_{grey}) rise to 2.38% of WF_{agr}. Chemical oxygen demand (COD) was the main pollution source in WF_{grey}, accounting for 50.82% of WF_{grey} in various years, but its small proportion indicated no significant impact on Hotan' s water resource security.

2.3 Water Resource Security Assessment Based on Agricultural Production Water Footprint

Based on agricultural production water footprint calculations, water resource security status was analyzed using water footprint intensity (WFS) and water resource pressure (WFP) indicators. As shown in Fig. 6, WFS showed a near-logarithmic decreasing trend, with 2009 as a sudden increase point. Water footprint consumption intensity (WFS_{con}) dominated WFS changes, showing a consistent logarithmic decrease, while grey water footprint intensity (WFS_{grey}) played a secondary role, also decreasing logarithmically. WFS decreased from 1.86 $m^3 \cdot yuan^{-1}$ to 0.10 $m^3 \cdot yuan^{-1}$, indicating that water resources consumed per unit GDP decreased by 94.44%, demonstrating significant improvement in water use efficiency. However, compared to economically developed regions, Hotan' s water resource utilization efficiency remains relatively low. Compared with Beijing' s WFS of 0.0028 $m^3 \cdot yuan^{-1}$ in 2015 and Shaanxi Province' s WFS of 0.0224 $m^3 \cdot yuan^{-1}$, Hotan' s WFS was 35.7 times and 4.5 times higher, respectively, indicating substantial potential for improvement.

Hotan' s water resource pressure (WFP) showed fluctuating upward trends over time, with a slow decreasing trend after 2009, but values remained below 1, indicating persistent water resource security. According to water resource pressure level classification, WFP can be divided into two stages: 1989-2009 with medium-low water resource pressure, and 2009-2018 with basically high and very high pressure states. This aligns with Wu Xuemei et al.' s [31] research results on water resource pressure status in Hotan from 2000 to 2013 through indicator system evaluation, reflecting secure water resource status.

Spatial distribution analysis (Fig. 7) revealed that in 1999, WFS showed a pattern of "one high, one low," with Hotan City as the lowest (0.03 $m^3 \cdot yuan^{-1}$) and Minfeng County as the highest (10.93 $m^3 \cdot yuan^{-1}$), while other counties ranged between 1.17-4.90 $m^3 \cdot yuan^{-1}$. Compared with 1999, Hotan's water resource utilization efficiency improved significantly by 2018, with Minfeng County showing the most remarkable reduction of 10.63 $m^3 \cdot yuan^{-1}$. Spatially, the contiguous area along the Hotan River (Hotan City, Moyu County, Hotan County, Luopu County, and Cele County) demonstrated higher water resource utilization efficiency than other counties.

Spatial patterns of WFP showed that in 1999, the county with highest pressure was Moyu County (WFP = 0.86), representing medium-high water resource pressure status, while Minfeng County had the lowest pressure (WFP = 0.25) with very low pressure status. By 2018, water resource pressure across Hotan counties generally increased, with only Minfeng County at medium status. Moyu, Hotan City, Hotan County, and Cele counties showed WFP values between 0.86-0.90, indicating very high water resource pressure status.

These results indicate that while counties like Moyu, Hotan City, and Cele showed smaller water footprint intensity values and higher water resource utilization efficiency, they were also high water resource pressure areas. Higher water resource utilization efficiency generates greater economic benefits but also demands more water resources, demonstrating the inevitable link between economic development and water resource demand. Better economic development requires certain water resource support.

3. Conclusion

Based on agricultural production water footprints in Hotan from 1989 to 2018, this study analyzed and evaluated regional water resource security status, yielding the following main conclusions:

1) Agricultural production non-grey water footprint accounted for over 97.61% of regional agricultural production water footprint. County-level crop production non-grey water footprint ($WF_{con,cul}$) showed fluctuating growth trends, dominated by grain crop consumption followed by economic crop consumption. Spatially, Moyu County showed the largest water resource consumption with an annual average $WF_{con,cul}$ of 3.80$\times10^{8}$ m^3, while Minfeng County showed the smallest at 0.76$\times10^{8}$ m^3.

2) Hotan' s agricultural production water footprint (WF_{agr}) experienced three stages: rapid growth, slow growth, and obvious decline, primarily influenced by crop production blue water footprint fluctuations, peaking at 19.36$\times10^{8}$ m^3 in 2009. Spatially, WF_{agr} showed a west-high, east-low distribution pattern, with Moyu County as the highest value in the west and Yutian County as a high-value area separating Cele and Minfeng counties in the east.

3) Hotan' s water resource status was secure from 1989 to 2018. Over time, regional water footprint intensity (WFP) decreased logarithmically, while water resource pressure (WFS) showed unsteady slow increase, indicating significant improvement in water resource utilization efficiency alongside increasing threats from water resource shortages.

Under policy support for "Comprehensive Paired Assistance to Xinjiang" and economic development opportunities from the "Belt and Road" strategy, Hotan will inevitably face further development challenges regarding whether regional water resources can meet economic development demands and how to resolve development-water demand conflicts. Future efforts should fully exploit water resource development potential, promote economic development in counties with lower water resource pressure and lagging development like Minfeng and Pishan, and seek balanced socioeconomic development across Hotan. Simultaneously, Hotan should actively respond to regional policies of farmland reduction and water-saving irrigation, reduce agricultural water use, strictly implement the "Three Red Lines" of water resource development and utilization, appropriately promote industrial development, and encourage low water-consuming, low energy-consuming agricultural product processing industries to improve economic benefits from agricultural production and further enhance water resource utilization efficiency and socioeconomic benefits, achieving synchronized improvement in water resource utilization efficiency and economic benefits.

References

[1] Li Li, Liu Shiqi, Wang Ping, et al. Evaluation of water resource exploration potential of the China Mongolia Russia Economic Corridor based on carrying capacity[J]. Arid Zone Research, 2021, 38(4): 910-918.

[2] Sithirith Mak. Downstream state and water security in the Mekong Region: A case of cambodia between too much and Too little water[J]. Water, 2021, 13(6): 802-814.

[3] Tursunmo Maimaitiming. How to utilize water resources in Hotan Region[J]. Journal of China Hydrology, 2015, 35(3): 92-95.

[4] Hu Xu, Nie Yong, Xu Xia, et al. Monitoring land use change in Hetian area of the southern Tarim Basin, China using satellite remote sensing observation between 1990 and 2016[J]. Progress in Geography, 2020, 39(4): 577-590.

[5] Ambrosio E, Ricci F G, Gentile F, et al. Using water footprint concepts for water security assessment of a basin under anthropogenic pressures[J]. Science of the Total Environment, 2020, 748: 141352.

[6] Jia Shaofeng, Zhang Junyan, Zhang Shifeng. Regional water resources stress and water resources security appraisement indicators[J]. Progress in Geography, 2002, 21(6): 538-545.

[7] Liu J L, Chen J, Yuan Z, et al. Water resource security evaluation of the Yangtze River Economic Belt[J]. Water Supply, 2020, 20(4): 1386-1397.

[8] Gong Qiaoling, Guan Dongjie. Study on water resources security evaluation of Chongqing section of three gorges reservoir based on BP neural network[J]. Research of Soil and Water Conservation, 2017, 24(6): 292-299.

[9] Chang Yuting, You Bing. Evaluation of water resources carrying capacity of Xinjiang based on water footprint method[J]. Arid Environmental Monitoring, 2019, 33(4): 150-154.

[10] Liu Liying, Zhang Yichi, Su Xiaoling. Spatial evaluation and sensitivity analysis of water resource security in Guizhou Province under climate change[J]. Carsologica Sinica, 2020, 39(5): 714-723.

[11] Hoekstra Y A. Water footprint assessment: Evolvement of a new research field[J]. Water Resources Management, 2017, 31(10): 3061-3065.

[12] Falkenmark M. Freshwater as shared between society and ecosystems: From divided approaches to integrated challenges[J]. Philosophical Transactions of the Royal Society B: Biological Sciences, 2003, 358(1440): 2037-2046.

[13] Veettil V A, Mishra K A. Water security assessment using blue and green water footprint concepts[J]. Journal of Hydrology, 2016, 542(32): 589-602.

[14] Feng H Y, Sun F Y, Liu Y Y, et al. Mapping multiple water pollutants across China using the grey water footprint[J]. Science of the Total Environment, 2021,

785: 147255.

[15] Cao Jianting, Li Yuanyuan, Zhang Wengshen, et al. Research background, methodological issues and significance on virtual water of crop and livestock production[J]. Advances in Water Science, 2004, 15(6): 829-834.

[16] Zhao Rui, Li Hong, He Hualing, et al. Assessment of water footprint of animal products in Leshan City[J]. Ecological Science, 2017, 36(2): 93-99.

[17] Garfin M G, Scott A C, Wilder M, et al. Metrics for assessing adaptive capacity and water security: Common challenges, diverging contexts, emerging consensus[J]. Current Opinion in Environmental Sustainability, 2016, 21(662): 86-89.

[18] Hao Shuai, Sun Caizhi, Song Qiangmin. Study on the competitive relationship between energy and food production for water resources in China: From a perspective of water footprint[J]. Geographical Research, 2021, 40(6): 1565-1581.

[19] Chapagain K A, Hoekstra Y A. Virtual Water Flows Between Nations in Relation to Trade in Livestock and Livestock Products[M]. Netherlands: UNESCO-IHE, 2003.

[20] Yu Po, Shang Manting, Yao Mei, et al. Water resources carrying capacity evaluation based on water footprint and principal component analysis in Xinjiang[J]. Journal of China Hydrology, 2021, 41(1): 49-54.

[21] Jin Qian, Gui Dongwei, Gao Xiaopeng, et al. Water footprints of primary crop production in Xinjiang[J]. Agricultural Research in the Arid Areas, 2018, 36(6): 243-249.

[22] Yu J W, Long A H, Deng X Y, et al. Incorporating the red jujube water footprint and economic water productivity into sustainable integrated management policy[J]. Journal of Environmental Management, 2020, 269: 110828.

[23] Cui S B, Dong H J, Wilson J. Grey water footprint evaluation and driving force analysis of eight economic regions in China[J]. Environmental Science and Pollution Research, 2020, 27(16): 20380-20390.

[24] Wang Yaqing, Xian Chaofan, Ouyang Zhiyun. Integrated assessment of sustainability in urban water resources utilization in China based on grey water footprint[J]. Acta Ecologica Sinica, 2021, 41(8): 2983-2995.

[25] Wang Ning, Li Zhaoyao, Tian Xiaofei, et al. Water footprint intensity and spatial association analysis of the Yellow River Basin: Based on ESDA model[J]. Environmental Science & Technology, 2021, 44(2): 196-202.

[26] Zhang Cheng, Li Jing, Zhou Zixiang. Water resources security pattern of the Weihe River Basin based on spatial flow model of water supply service[J]. Scientia Geographica Sinica, 2021, 41(2): 350-359.

[27] Hong Chuanchun, Liu Moucheng, Zhang Yajing, et al. Analysis on the intensity and efficiency of agricultural grey water footprint in Beijing Tianjin Hebei Region under the perspective of spatial-temporal patten[J]. Journal of Hebei Agricultural University, 2021, 44(2): 128-135.

[28] Wang Lichuan, Hou Baodeng, Zhou Yuyan, et al. Evaluation of water resources utilization in Beijing based on water footprint theory[J]. South North Water Transfers and Water Science & Technology, 2021, 19(4): 680-688.

[29] Zhang Pei, Long Aihua, Hai Yang, et al. Spatiotemporal variations and driving forces of agricultural water consumption in Xinjiang during 1988-2015: Based on statistical analysis of crop water footprint[J]. Journal of Glaciology and Geocryology, 2021, 43(1): 242-253.

[30] Wu Xuemei, Tashpolat Tiyip, Mamat Sawut, et al. Evaluation research for the carrying capacity of water resources in Hotan Based on the POS-PPE model[J]. Agricultural Research in the Arid Areas, 2014, 32(2): 228-233.

[31] Editorial Board of Hotan Yearbook. Hotan Yearbook[M]. Hotan: Xinjiang People' s Publishing House, 2016.

Note: Figure translations are in progress. See original paper for figures.