Postprint: Analysis of the Spatial Relationship between Crop Water Footprint and Economic Growth in Xinjiang over the Past 25 Years

Authors: Wang Jie, Long Aihua, Yang Guang, Deng Xiaoya, Zhang Pei, ocean, Li Yang, Long Aihua

Date: 2019-06-13T00:00:00+00:00

Abstract

The water-economy spatial relationship constitutes a key research focus in water resources studies of arid and semi-arid regions. Elucidating the evolution patterns and causal relationships of water–economy spatial distribution can provide theoretical and decision-making references for optimizing rational water resources allocation and formulating industrial restructuring policies. This study applies water footprint theory to calculate the crop water footprint of various prefectures and autonomous prefectures in Xinjiang from 1991 to 2015, and integrates information entropy theory to analyze the spatial evolution patterns and causal relationships of entropy values for crop water footprint, gross domestic product, and primary industry added value across Xinjiang' s prefectures and autonomous prefectures. The results demonstrate that: the spatial evolution of crop water footprint, primary industry added value, and gross domestic product in Xinjiang is progressing toward equilibrium and order overall, with the spatial imbalance of water–economy gradually diminishing; the crop water footprint in Xinjiang significantly influences the spatial evolution of its primary industry added value, with an impact period of 1–5 years, and the spatial distribution of the agricultural economy is constrained by the spatial distribution of agricultural water use in the long term; no causal relationship in spatial evolution exists between crop water footprint and gross domestic product, the economic development of the entire region is transitioning toward the secondary and tertiary industries, and the agricultural economy no longer exerts significant influence on the overall economic development of Xinjiang.

Full Text

Preamble

DOI: 10.12118/j.issn.1000-6060.2019.03.08
Journal: ARID LAND GEOGRAPHY

Authors: WANG Jie[1], LONG Ai-Hua[1,2], YANG Guang[1], DENG Xiao-Ya[2], ZHANG Pei[2], HAI Yang[2], LI Yang[2]
[1]Shihezi University Water Conservancy and Construction Engineering College, Shihezi 832000, Xinjiang, China
[2]China Institute of Water Resources and Hydropower Research, Beijing 100038, China

Funding: National Natural Science Foundation of China (51476209, 51609260); National Key Research and Development Program (2017YF0404301)

Abstract: The spatial relationship between water and economy represents a critical research frontier in arid and semi-arid regions. Understanding the evolution patterns and causal mechanisms of water-economic spatial distributions provides theoretical and decision-making support for optimizing water resource allocation and adjusting industrial structures. This study employs water footprint theory to calculate crop water footprints across Xinjiang's prefectures from 1991 to 2015, and analyzes their spatial evolution and economic relationships using information entropy theory in conjunction with primary industry value-added, GDP, and crop entropy values. Results demonstrate that the spatial evolution between crop water footprint and primary industry value-added/GDP exhibits a balanced, well-organized trend with gradually deflating spatial disequilibrium. Crop water footprint significantly influences the spatial evolution of primary industry value-added with a 1-5 year lag period, indicating that agricultural economic distribution is chronically constrained by agricultural water resource distribution. No causal relationship exists between crop water footprint and GDP, suggesting Xinjiang' s economic development is transitioning toward secondary and tertiary industries, with agriculture no longer significantly affecting overall economic growth.

Keywords: water resources; spatial analysis; cointegration equation; crop water footprint; lag period; Xinjiang

---

2 Data and Methods

2.1 Data Sources and Processing

Meteorological data (1991–2015) including precipitation, temperature, humidity, sunshine hours, and wind speed were obtained from the Xinjiang Meteorological Bureau. Crop data comprising planting area, yield, and growth period were sourced from the Xinjiang Statistical Yearbook and Bureau of Statistics.

Economic data including primary industry value-added and GDP were derived from the Xinjiang Statistical Yearbook and regional statistical databases. The CROPWAT model was utilized to calculate reference evapotranspiration (ET) and crop water requirements.

2.2 Research Methods

2.2.1 Water Footprint Calculation

Following the Water Footprint Assessment Manual framework, crop water footprint (WF) comprises green water footprint (WF_green) and blue water footprint (WF_blue):

$$WF = WF_{\text{green}} + WF_{\text{blue}}$$

where WF_green represents rainwater consumption and WF_blue represents irrigation water consumption, both in $\mathrm{m}^3 \cdot \mathrm{kg}^{\ 1}$.

The calculation formulas are:

$$WF_{\text{green}} = \frac{CWU_{\text{green}}}{Y} = \frac{10 \times ET_{\text{green}}}{Y}$$

$$WF_{\text{blue}} = \frac{CWU_{\text{blue}}}{Y} = \frac{10 \times ET_{\text{blue}}}{Y}$$

where CWU_{blue} and CWU_{green} are crop water use ($\mathrm{m}^3 \cdot \mathrm{hm}^{\ 2}$), Y is crop yield ($\mathrm{kg} \cdot \mathrm{hm}^{\ 2}$), and the factor 10 converts mm to $\mathrm{m}^3 \cdot \mathrm{hm}^{\ 2}$.

Green and blue evapotranspiration are calculated as:

$$ET_{\text{green}} = \min(ET_c, P_e)$$

$$ET_{\text{blue}} = \max(0, ET_c - P_e)$$

where ET_c is crop evapotranspiration (mm) and P_e is effective precipitation (mm). ET_c is computed using:

$$ET_c = K_c \times ET_0$$

where K_c is the crop coefficient and ET_0 is reference evapotranspiration (mm), calculated via the CROPWAT model.

Effective precipitation P_e is determined using the USDA SCS method:

$$P_e = \begin{cases} P_{\text{dec}} \times (125 - 0.6 \times P_{\text{dec}}) & \text{if } P_{\text{dec}} \leq \frac{250}{3} \\ 125 + 0.1 \times P_{\text{dec}} & \text{if } P_{\text{dec}} > \frac{250}{3} \end{cases}$$

where P_{dec} is monthly precipitation in mm.

2.2.2 Entropy Model

Information entropy measures system disorder. For crop water footprint and economic indicators, entropy values (H) are calculated as:

$$H = -\sum_{i=1}^{n} P_i \ln(P_i)$$

where P_i represents the proportion of region i' s water footprint or economic value.

2.3 Spatial Relationship Analysis

The spatial evolution between crop water footprint and economic growth was analyzed through:

1. **Unit Root Testing**: Augmented Dickey-Fuller (ADF) tests verified stationarity of time series data (Tables 1-3).
2. **Cointegration Analysis**: The long-term equilibrium relationship was examined using cointegration equations.
3. **Lag Period Analysis**: Lag periods of 1-6 years were tested to identify causal relationships.

Table 1 Unit root test results of crop water footprint and primary industry added value and GDP entropy

Variable	ADF Statistic	1% Critical Value	5% Critical Value	10% Critical Value	Stationarity
Crop WF entropy	-1.242903	-5.135672	-3.103043	-2.991878	Non-stationary
Primary industry VA entropy	-8.167465	-3.868873	-3.612199	-3.243079	Stationary**
GDP entropy	-3.752946	-3.737853	-2.991878	-2.635542	Stationary*

Variable	ADF Statistic	1% Critical Value	5% Critical Value	10% Critical Value	Stationarity
Crop WF entropy residual	-4.394309	-3.752946	-2.998064	-2.635542	Stationary**

*Significant at 5% level; **Significant at 1% level

Table 2 1991–2015 annual unit root test results of crop water footprint and primary industry added value entropy residuals

Lag Period	ADF Statistic	1% Critical Value	5% Critical Value	10% Critical Value
1 year	-4.336742	-2.664853	-1.955681	-1.608793
2 years	-4.294781	-4.394309	-3.612199	-3.243079
3 years	-4.241212	-3.737853	-2.991878	-2.635542

Table 3 1991–2015 unit root test results of crop water footprint and GDP entropy residuals

Lag Period	ADF Statistic	1% Critical Value	5% Critical Value	10% Critical Value
1 year	-2.402516	-2.664853	-1.955681	-1.608793
2 years	-2.228529	-4.394309	-3.612199	-3.243079
3 years	-2.356243	-3.737853	-2.991878	-2.635542

The entropy evolution trend (Figure 2) shows that crop water footprint entropy decreased from 2.325 in 1991 to 2.224 in 2015, indicating improved spatial equilibrium. Primary industry value-added entropy remained relatively stable, while GDP entropy exhibited slight fluctuations.

[Figure 2: see original paper]

Figure 2 Evolution trend of entropy values (1991–2015)

Cointegration analysis reveals a significant causal relationship between crop water footprint and primary industry value-added at 1–5 year lags (Table 2), but no significant relationship with GDP (Table 3). This confirms that agricultural water resources constrain agricultural economic development, while the overall economy has decoupled from agricultural water consumption.

References

[1] QIU Hanxue, WANG Binchen. Water resources development and utilization and sustainable development in arid areas[J]. Marine Geology and Quaternary Geology, 1998(4): 97-108.

[2] YANG Shuying, ZHANG Zengqiang. Problems and countermeasures of water resources in China[J]. Environmental Protection, 1997(11): 6-8.

[3] WU Dan. Evaluation and prospect of decoupling situation of China' s economic development and water resources utilization[J]. Journal of Natural Resources, 2014(1): 46-54.

[4] ZHAO Liangshi, SUN Caizhi, ZHENG Defeng. Spatial econometric analysis of interprovincial water footprint intensity convergence in China[J]. Acta Zoology Sinica, 2014, 34(5): 1085-1093.

[5] XU Changxin, LIN Janting, SONG Min. Soil and water matching, spatial effect and regional agricultural economic growth: Based on China' s 2003-2013 experience analysis[J]. Chinese Journal of Population, Resources and Environment, 2016, 26(7): 153-158.

[6] WANG Xinhua, XU Zhongmin, LONG Aihua. Preliminary analysis of water footprint of China in 2000[J]. Journal of Glaciology and Geocryology, 2005, 27(5): 774-781.

[7] SUN Caizhi, LIU Yuyu, CHEN Lixin, et al. Spatial and temporal variation pattern of Chinese water footprint based on Gini coefficient and SIL index[J]. Acta Ecologica Sinica, 2010, 30(5): 1312-1321.

[8] ZHAO Liangshi, SUN Caizhi, ZHENG Defeng. Spatial econometric analysis of interprovincial water footprint intensity convergence in China[J]. Acta Zoology Sinica, 2014, 34(5): 1085-1093.

[9] WU Pute, SUN Shikun, WANG Yubao, et al. Quantitative method and evaluation of water footprint in crop production[J]. Journal of Hydraulic Engineering, 2017, 48(6): 651-660.

[10] CHEN Weijun, CHANG Jianjun. Research on water resources utilization and economic growth based on decoupling index in China[J]. China Rural Water and Hydropower, 2016(10): 116-118.

[11] WU Dan, XU Zhongmin, UPMANU Lall, et al. Water footprint evaluation and economic growth decoupling analysis in China[J]. Journal of Hunan Normal University (Natural Science), 2015, 38(4): 37-44.

[12] HOEKSTRA AY, CHAPAGAIN AK, ALDAYA MM, et al. The water footprint assessment manual: Setting the global standard[M]. 2011.

[13] CHEN Wei, SUN Caizhi, ZHENG Defeng. Spatial econometric analysis of water footprint and economic growth coupling relationship in China[J]. Journal of Hydraulic Engineering, 2014, 45(6): 673-681.

[14] WANG Jie, LONG Aihua, YANG Guang, et al. Spatial relationship between crop water footprint and economic growth in Xinjiang in recent 25 years[J]. Arid Land Geography, 2019, 42(3): 1-8.

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