

Variation Characteristics and Driving Factors of Grey Water Footprint in Gansu Province: Post-print

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Date: 2023-01-17T00:00:00+00:00

Abstract

The STIRPAT model was employed to analyze the driving factors of grey water footprint, and the changes in grey water footprint in Gansu Province from 2011 to 2020 were investigated. The results indicate that during this decade, the overall grey water footprint decreased by $378.53 \times 10^8 \text{ m}^3$, with a maximum reduction of 81%. Specifically, the proportions of domestic grey water footprint, agricultural grey water footprint, and industrial grey water footprint were 43%, 38%, and 19%, respectively. The grey water footprint of crop farming exceeded that of animal husbandry. The overall grey water footprint intensity exhibited a downward trend, indicating that water resource utilization efficiency improved year by year. From the perspective of water pollution degree and residual grey water footprint, the water pollution level in Gansu Province was greater than 1 from 2011 to 2016, indicating relatively severe water resource pollution. The residual grey water footprint showed negative values from 2017 to 2020, indicating an improving trend in water quality, amelioration of water environmental issues, and increasing sustainability of water resources. Regarding the driving factors of grey water footprint in Gansu Province, urbanization level, per capita GDP, output values of the primary, secondary, and tertiary industries, grey water footprint intensity, and total retail sales of consumer goods all promoted the increase of grey water footprint, with influence coefficients of 0.142, 0.126, 0.052, 0.382, 0.132, 0.916, and 0.1, respectively. Based on the magnitude of the influence coefficients, relevant policies can be formulated to reduce the grey water footprint of Gansu Province, thereby alleviating water environmental pressure.

Full Text

Analysis of Characteristics and Driving Factors of Grey Water Footprint Changes in Gansu Province

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Abstract

This study utilizes the STIRPAT model to analyze the driving factors of grey water footprint changes in Gansu Province from 2011 to 2020. The results indicate that the total grey water footprint exhibited an overall declining trend during this period, decreasing by 378.53×10^3 units, with a maximum reduction rate of 81%. The domestic, agricultural, and industrial grey water footprints accounted for 43%, 38%, and 19% of the total, respectively. The planting industry's grey water footprint exceeded that of animal husbandry. The intensity of the grey water footprint showed a consistent downward trend, demonstrating improving water resource utilization efficiency. Analysis of water pollution degree and residual grey water footprint reveals that Gansu's water pollution level exceeded critical thresholds from 2011 to 2016, indicating severe pollution and substantial ecological pressure. However, the residual grey water footprint turned negative after 2017, suggesting improving water quality, enhanced water environmental conditions, and increased water resource sustainability. Regarding driving factors, urbanization level, per capita GDP, output values of the primary, secondary, and tertiary industries, grey water footprint intensity, and total retail sales of consumer goods all promote increases in the grey water footprint, with impact coefficients of 0.142, 0.126, 0.052, 0.382, 0.132, 0.916, and 0.100, respectively. Based on the magnitude of these coefficients, targeted policies can be formulated to reduce Gansu Province's grey water footprint and alleviate water environmental pressure.

Keywords: Gansu Province; grey water footprint; driving factors; STIRPAT model; ridge regression

1 Introduction

Water resources are essential for human survival and serve as a critical foundation for societal development. Currently, global water demand continues to grow, and due to the deteriorating water environment, increasing attention is being paid to water resource protection and efficient utilization. The concept of grey water footprint was first proposed by Hoekstra, defined as the volume of freshwater required to dilute pollutants to harmless concentrations based on water quality standards. Most research has focused on large-scale regions such

as provinces and river basins, primarily examining industrial, agricultural, and domestic water use.

Gansu Province faces severe water scarcity. In 2020, the province's total water resources amounted to $410.88 \times 10^8 \text{ m}^3$, representing an increase of $272.15 \times 10^8 \text{ m}^3$ compared to 2011. However, due to the imbalance between water supply and demand, the province still faces a water shortage of $10.88 \times 10^8 \text{ m}^3$, with a shortage degree of 6.97%. The total wastewater discharge reached $6.97 \times 10^8 \text{ m}^3$. Water resource shortages significantly constrain Gansu's development, and economic growth continues to increase water demand. Given the current situation of water scarcity and pollution in Gansu Province, the primary task is to improve water environmental quality through pollution prevention and quantitative assessment of water pollution.

Traditional water pollution assessment methods include neural networks, comprehensive pollution indices, and fuzzy mathematics. However, these methods cannot comprehensively describe the relationship between water pollution and water resources. As a novel water pollution calculation method, grey water footprint can effectively quantify the relationship between water quality and quantity, offering advantages in rapidly and intuitively calculating the degree of water pollution impact on water resources across large study areas.

Domestic scholars have conducted extensive research on grey water footprint. For instance, Shen et al. studied the grey water footprint of Shandong Province from an equilibrium perspective, finding significant regional variations in grey water footprint intensity and water environmental pressure. Fu et al. conducted spatiotemporal analysis of nitrogen and phosphorus grey water footprints in Jiangxi Province's farmland, revealing that phosphorus fertilizer grey water footprints exceeded those of nitrogen fertilizer, with higher values in central-northern regions. Luo Yong examined the spatiotemporal evolution characteristics of grey water footprints in river basins from economic and technological perspectives. However, most studies have focused on eastern and southern China, with relatively limited research on driving factors of grey water footprints in northwestern and arid regions.

This study selects Gansu Province as the research object. As an arid region with perennial water shortages, historically severe water quality pollution, and low water resource utilization efficiency, analyzing grey water footprint changes and their driving factors can not only elucidate the relationship between water quantity and quality but also provide a basis for efficient water resource utilization and water security, thereby promoting Gansu's economic development and livelihood improvement.

2 Study Area

Gansu Province is located in northwestern China, between 92°–109°E and 32°–43°N. It borders Shaanxi, Qinghai, Xinjiang, Sichuan, Ningxia, and Inner Mongolia. The province has a temperate monsoon climate characterized by dryness and low rainfall. The average annual precipitation is 317.6 mm. By the end of 2020, Gansu's permanent population reached 25.02 million, with a GDP of 1024.33 billion yuan. The province's water resources primarily consist of three major river systems. Total water supply in 2020 was $109.9 \times 10^8 \text{ m}^3$, with per capita water consumption of 438.7 m^3 . Industrial, agricultural, domestic, and ecological water consumption accounted for $83.7 \times 10^8 \text{ m}^3$, $3466.6 \times 10^8 \text{ m}^3$, $5412.0 \times 10^8 \text{ m}^3$, and $9.3 \times 10^8 \text{ m}^3$, respectively.

3 Methods

3.1 Agricultural Grey Water Footprint Calculation

Agricultural grey water footprint is divided into planting and livestock components to improve calculation accuracy.

3.1.1 Planting Industry Grey Water Footprint The primary pollutant from planting industry is chemical fertilizer, including nitrogen, phosphorus, and potassium fertilizers. Nitrogen fertilizer is selected as the representative pollutant for planting industry grey water footprint calculations. However, not all nitrogen fertilizer enters water bodies; fertilizer pollution is non-point source pollution requiring consideration of nitrogen leaching rates. Since leaching rates vary, regional geographic conditions, pollutant types, and crop varieties must be considered.

The calculation formula is:

$$WF_{\text{grey,plant}} = \max \left(\frac{Appl \times \alpha}{C_{\text{max}} - C_{\text{nat}}} \right)$$

where $WF_{\text{grey,plant}}$ represents the planting industry grey water footprint, α denotes nitrogen leaching rate, $Appl$ represents nitrogen fertilizer application amount, C_{max} is the maximum pollutant discharge concentration in water bodies, and C_{nat} is the natural concentration of pollutants in water.

3.1.2 Livestock Breeding Grey Water Footprint Pollutants from pig, cattle, sheep, and poultry manure are selected for calculation. The key pollutants in manure are total nitrogen (TN) and chemical oxygen demand (COD). The maximum value of these two pollutants is used as the livestock breeding grey water footprint.

The calculation formula is:

$$WF_{\text{grey, live}} = \text{MAX} \{ WF_{\text{grey, live}}^{\text{TN}}, WF_{\text{grey, live}}^{\text{COD}} \}$$

$$WF_{\text{grey, live}}^{\text{pollutant}} = \frac{L \times \beta}{C_{\text{max}} - C_{\text{nat}}}$$

where $WF_{\text{grey, live}}$ is the livestock breeding grey water footprint, C_{max} is the maximum allowable discharge concentration in water, C_{nat} is the natural concentration of pollutants in water, L is the pollutant content in livestock excrement, β is the loss rate of pollutants entering water bodies, and the calculation uses year-end inventory for livestock with feeding periods of one year and year-end slaughter volume for those with shorter periods.

Agricultural pollution is non-point source pollution. The agricultural grey water footprint is obtained by summing the maximum values from planting and livestock components:

$$\text{GWF}_{\text{grey, agri}} = \text{MAX} \{ WF_{\text{grey, plant}}, WF_{\text{grey, live}} \}$$

3.2 Industrial Grey Water Footprint

Industrial pollution is point source pollution. Based on literature references, industrial grey water footprint is determined by the maximum value of ammonia nitrogen or COD pollution footprints:

$$WF_{\text{grey, ind}} = \text{MAX} \{ WF_{\text{grey, ind}}^{\text{NH}_3\text{-N}}, WF_{\text{grey, ind}}^{\text{COD}} \}$$

$$WF_{\text{grey, ind}}^{\text{pollutant}} = \frac{L}{C_{\text{max}} - C_{\text{nat}}}$$

where $WF_{\text{grey, ind}}$ represents industrial grey water footprint, C_{max} is the maximum pollutant discharge concentration in water, C_{nat} is the natural concentration of pollutants, and L is industrial pollutant discharge amount.

3.3 Domestic Grey Water Footprint

Domestic grey water footprint is also point source pollution, with COD and ammonia nitrogen as primary pollutants:

$$WF_{\text{grey, lif}} = \text{MAX} \{ WF_{\text{grey, lif}}^{\text{COD}}, WF_{\text{grey, lif}}^{\text{NH}_3\text{-N}} \}$$

where $WF_{\text{grey, lif}}$ represents domestic grey water footprint.

3.4 Regional Grey Water Footprint

Regional grey water footprint equals the sum of agricultural, industrial, and domestic grey water footprints:

$$WF_{\text{grey,area}} = WF_{\text{grey,lif}} + WF_{\text{grey,ind}} + WF_{\text{grey,agri}}$$

3.5 Grey Water Footprint Intensity

Grey water footprint intensity is the ratio of regional grey water footprint to gross domestic product, serving as an indicator of water resource utilization efficiency. Smaller values indicate higher efficiency:

$$\text{GWFI} = \frac{WF}{\text{GDP}}$$

where GWFI denotes grey water footprint intensity, WF represents the study area's grey water footprint, and GDP is the regional gross domestic product.

3.6 Water Pollution Degree

Water pollution degree, also called water ecological pressure index, is expressed as the ratio of grey water footprint to annual available water resources. When the coefficient is less than 1, the water environment is safe; equal to 1 indicates balance; greater than 1 signifies danger:

$$\text{WPL} = \frac{WF}{R}$$

where WPL represents water pollution degree and R is annual available water resources.

3.7 Residual Grey Water Footprint

Residual grey water footprint is the difference between grey water footprint and regional water resources, evaluating water resource sustainability. When grey water footprint exceeds water resources (positive difference), water pollution is severe, indicating insufficient water to dilute pollutants to national standards. Conversely, a negative value indicates adequate dilution capacity:

$$\text{RGWF} = WF - R$$

where RGWF is residual grey water footprint.

3.8 STIRPAT Model

The STIRPAT model is an extension of the Ehrlich model, developed to address energy and environmental issues. The original IPAT model's three factors (population, affluence, technology) proved insufficient for complex research questions, leading Dietz and Rosa to propose the stochastic impacts by regression on population, affluence, and technology (STIRPAT) model. This extension allows for adding and modifying influencing factors, overcoming IPAT limitations through stochastic regression.

The basic expression is:

$$I = aP^b A^c T^d e$$

where I is environmental pressure, a is a constant, P is population, A is affluence, T is technology, b , c , d are elasticity coefficients, and e is the error term.

For computational convenience, the logarithmic form is used:

$$\ln I = \ln a + b \ln P + c \ln A + d \ln T + \ln e$$

Considering Gansu's specific development context, key influencing factors were selected. Population size is a primary driver of social development, increasing water demand, agricultural output, and fertilizer use. Urbanization level also drives grey water footprint, as urban consumption patterns utilize more public resources and water. Per capita GDP, as a main socioeconomic indicator, correlates with environmental pressure. Additionally, output values of the primary, secondary, and tertiary industries, grey water footprint intensity, and total retail sales of consumer goods were included as influencing factors.

3.9 Data Sources

Required data including wastewater discharge, pollutant emissions, water resources, and economic indicators were obtained from the *Gansu Provincial Statistical Yearbook* (2011–2020). Livestock manure pollutant loss rates into water bodies were derived from the *National Survey on Pollution from Large-Scale Livestock and Poultry Breeding and Prevention Countermeasures*. Nitrogen leaching rate was determined as $1 \text{ mg} \cdot \text{L}^{-1}$ based on the *First National Pollution Source Census – Agricultural Pollution Source Fertilizer Loss Coefficient Manual*. Pollutant concentration standards followed the *Surface Water Environmental Quality Standard* (GB3838-2002) Class III water quality standard, with natural background pollutant concentrations set at $20 \text{ mg} \cdot \text{L}^{-1}$ and $10 \text{ mg} \cdot \text{L}^{-1}$ for respective pollutants.

4 Results

4.1 Temporal Changes in Gansu's Grey Water Footprint

As shown in [Figure 1: see original paper], Gansu Province's grey water footprint exhibited an overall declining trend from 2011 to 2020, decreasing by 378.53×10^3 units. The maximum reduction occurred in 2013, with a decrease of 106.14×10^3 units. The average annual grey water footprint was 373.05×10^3 units, with the highest value reaching 572.75×10^3 units. The decline was relatively gradual from 2011 to 2015, but steeper from 2016 to 2020. Per capita grey water footprint changes mirrored total grey water footprint trends, with an average annual per capita grey water footprint of 1473.28 m^3 [Figure 2: see original paper].

From the perspective of China's economic and social development five-year plans, the 12th Five-Year Plan period (2011–2015) represented a slow decline phase, during which water conservancy economic development planning began emphasizing environmental issues and reducing arbitrary wastewater discharge. The 13th Five-Year Plan period (2016–2020) marked a rapid decline phase, during which national policies, water management system reforms, water-saving society promotion, increased environmental pollution control investment, and ecological civilization construction initiatives led to effective pollution control and improved water ecological protection awareness, driving the significant reduction in grey water footprint.

4.2 Grey Water Footprint Structure

The grey water footprint structure [Figure 3: see original paper] shows that domestic grey water footprint is the largest component, followed by agricultural and industrial grey water footprints. Domestic grey water footprint exhibited a declining trend with fluctuations, while agricultural grey water footprint showed a decreasing trend overall, corresponding to reduced fertilizer use. The planting industry's grey water footprint consistently exceeded that of animal husbandry, indicating that Gansu's agricultural economy relies primarily on crop cultivation. Industrial grey water footprint also declined due to improved production technology, modified production methods, and the transformation of polluting enterprises.

4.3 Grey Water Footprint Intensity

Grey water footprint intensity [Figure 4: see original paper] decreased from 1004 m^3 per 10,000 yuan GDP in 2011 to 215 m^3 per 10,000 yuan GDP in 2020, a reduction of 78.6%. This decline indicates improving water resource utilization efficiency. Two main factors contributed to this improvement: first, continuous reduction in industrial grey water footprint alongside larger industrial output value compared to agriculture; second, industrial structure adjustments, reduced environmental pollutant emissions, and enhanced wastewater treatment technology.

4.4 Water Pollution Degree and Residual Grey Water Footprint

As shown in [Figure 5: see original paper], Gansu's water pollution level exceeded 1 from 2011 to 2016, indicating severe pollution and substantial water ecological pressure. The residual grey water footprint [Figure 6: see original paper] was positive before 2017, meaning annual water resources were insufficient to dilute pollutants to national standards. However, from 2017 onward, residual grey water footprint became negative, indicating improving water quality, enhanced water environmental conditions, and increased water resource sustainability.

4.5 Driving Factor Analysis

4.5.1 Multicollinearity Issues Multivariate linear regression analysis was conducted with urbanization level, per capita GDP, primary/secondary/tertiary industry output values, grey water footprint intensity, and total retail sales of consumer goods as independent variables (X_1 – X_7) and grey water footprint as the dependent variable (Y). However, all variance inflation factor (VIF) values were large, indicating severe multicollinearity among variables.

4.5.2 Ridge Regression Analysis To address multicollinearity, ridge regression was employed as an improved least squares method. After logarithmic transformation of the data, SPSSAU software was used for ridge regression analysis. When the K -value reached 0.7, standardized regression coefficients stabilized, making $K = 0.7$ the optimal value. The model achieved $R^2 = 0.9987$, indicating excellent fit.

ANOVA testing (essentially an F-test) showed the model was statistically significant ($F = 217.867$, $P = 0.005 < 0.05$), confirming that at least one independent variable significantly affected the dependent variable. The ridge regression equation is:

$$\ln Y = 7.829 + 0.142 \ln X_1 + 0.126 \ln X_2 + 0.052 \ln X_3 + 0.382 \ln X_4 + 0.132 \ln X_5 + 0.916 \ln X_6 + 0.1 \ln X_7$$

4.5.3 Regression Results The model reveals that all independent variables positively influence grey water footprint. Grey water footprint intensity (X_6) has the greatest impact (coefficient = 0.916), followed by secondary industry output value (X_4 , coefficient = 0.382). Tertiary industry output value (X_5 , coefficient = 0.132) and urbanization level (X_1 , coefficient = 0.142) also show substantial effects. Primary industry output value (X_3 , coefficient = 0.052) and per capita GDP (X_2 , coefficient = 0.126) have moderate impacts, while total retail sales of consumer goods (X_7 , coefficient = 0.1) has the weakest effect.

Among the three industries, secondary industry output value most significantly affects grey water footprint, indicating that industrial development has the greatest impact on water pollution. The results demonstrate that accelerated

urbanization and development across the three industries are the main factors driving changes in Gansu's grey water footprint.

5 Conclusions

From 2011 to 2020, Gansu Province's grey water footprint showed an overall declining trend, decreasing by 378.53×10^3 units, though with a slight increase in 2019. Per capita grey water footprint changes aligned with total grey water footprint trends, averaging 1473.28 m^3 annually. Domestic pollution represents the primary environmental pollution source in Gansu, followed by agricultural pollution. The overall decline in grey water footprint indicates effective pollution control and improved water ecological environmental quality.

Grey water footprint intensity decreased from 1004 m^3 to 215 m^3 per 10,000 yuan GDP, a 78.6% reduction, indicating significantly improved water resource utilization efficiency, though agricultural grey water footprint intensity declined more slowly. Water pollution levels exceeded critical thresholds from 2011 to 2016, but residual grey water footprint became negative after 2017, indicating improving water quality and enhanced water resource sustainability.

Analysis of driving factors shows that accelerated economic development and urbanization in Gansu Province, particularly growth in the three industries, significantly influence grey water footprint changes. Secondary industry development and industrial sectors have the most substantial impact. Based on these findings, policy recommendations include: (1) Promoting green and characteristic agriculture tailored to Gansu's geographic conditions while strictly controlling fertilizer application; (2) Strengthening wastewater discharge controls and environmental supervision in industrial sectors; (3) Improving urban domestic wastewater treatment capacity, advancing water conservation, and enhancing water-saving supervision and management.

The STIRPAT model effectively evaluates grey water footprint from multiple dimensions, clearly identifying primary influencing factors and providing valuable insights for reducing regional grey water footprints.

References

- [1] Shen Manhong, Chen Qingneng. Water Economics[M]. Beijing: China Environmental Press, 2008.
- [2] Wang Ya, 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.

- [3] Xu Chengcheng. Research on Evaluation of Water Resources Carrying Capacity in Gansu Province[D]. Lanzhou: Lanzhou University of Finance and Economics, 2021.
- [4] Li Xiang, Guan Tao, Xu Qing. The evaluation of soil heavy metal pollution based on the BP neural network: Taking soil environmental quality assessment in Baotou as an example[J]. Chinese Agricultural Science Bulletin, 2012, 28(2): 250-256.
- [5] Jing Zhaoxia, Xia Jun, Zhang Xiang, et al. Spatial and temporal distribution and variation of water quality in the middle and downstream of Hanjiang River[J]. Research of Environmental Sciences, 2019, 32(1): 104-115.
- [6] Wu Gang, Cai Jingwei, Fu Haiwei, et al. Application of fuzzy comprehensive assessment in risk assessment of water pollution conditions in downriver area of Dahuofang Reservoir[J]. Environmental Science, 2007, 11(3): 2438-2441.
- [7] Qian Xiuhong. Investigation, Evaluation and Control Countermeasures of Agricultural Non-point Source Pollution in Hangjiahu Plain[D]. Hangzhou: Zhejiang University, 2001.
- [8] Li Fei, Dong Suocheng. Pollution from livestock and poultry and its resource strategy in West China[J]. Resources Science, 2011, 33(11): 2204-2211.
- [9] Hoekstra A Y, Chapagain A K. Globalization of Water: Sharing the Planet's Freshwater Resources[M]. Oxford: Wiley Blackwell, 2008.
- [10] Hoekstra A Y, Chapagain A K, Aldaya M M, et al. The Water Footprint Assessment Manual: Setting the Global Standard[M]. London: Earthscan, 2011: 30-40.
- [11] Fu Chun, Chen Yudi, Liu Yezhong, et al. Temporal and spatial analysis of grey water footprint in Jiangxi Province farmland[J]. Journal of Agro-Environment Science, 2022, 41(7): 1501-1508.
- [12] Luo Yong. Study on the Temporal and Spatial Evolution Characteristics of Grey Water Footprint in Ganjiang River Basin[D]. Nanchang: Nanchang University, 2021.
- [13] He Zhiwen, Xiang Pingan. An analysis of the variations and driving factors of grey water footprint in Hunan Province[J]. China Rural Water and Hydropower, 2018(10): 19-26.
- [14] Department of Natural Ecology Protection, State Environmental Protection Administration. Investigation on the Pollution Situation of National Large-scale Livestock and Poultry Breeding Industry and Countermeasures for Prevention and Control[M]. Beijing: China Environmental Press, 2002.
- [15] National Pollution Source Census Aquaculture Industry Pollution Source Production and Discharge Coefficient Calculation Project Team. The First National Pollution Source Census Aquaculture Industry Pollution Source Produc-

tion Sewage Coefficient Manual[M]. Beijing: Chinese Academy of Fishery Sciences, 2009.

[16] Li Zhonggui, Gao Lizhen. Water footprint assessment in wastewater treatment plants[J]. Chinese Journal of Environmental Engineering, 2017, 11(3): 1599-1604.

[17] Wang Xiaomeng, Huang Kai, Yang Shunshun, et al. Temporal variability and influencing factors of sectoral water footprint in China[J]. Journal of Natural Resources, 2014, 29(12): 2114-2126.

[18] Ehrlich P R, Holden J P. Impact of population growth[J]. Science, 1971, 171: 1212-1217.

[19] Dietz T, Rosa E A. Rethinking the environmental impacts of population, affluence and technology[J]. Human Ecology Review, 1994, 1: 277-300.

[20] York R, Rosa E A, Dietz T. STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts[J]. Ecological Economics, 2003, 46(3): 351-365.

[21] Zeng Zhao, Liu Junguo. Historical trend of grey water footprint of Beijing, China[J]. Journal of Natural Resources, 2013, 28(7): 1169-1178.

[22] Sheng Hao, Chen Zhiqun, Liu Jian, et al. Analysis of the regional equilibrium of grey water footprint in Shandong Province[J]. Water Saving Irrigation, 2022(3): 1-7.

[23] Zhang Yu, Zhang Zheng, Su Mingtao. Research on grey water footprint based on chemical fertilizer use in the grain production in Heilongjiang reclamation area[J]. Journal of Arid Land Resources and Environment, 2013, 27(7): 28-32.

[24] Wu Bo, Zeng Weihua, Chen Honghan, et al. Grey water footprint combined with ecological network analysis for assessing regional water quality metabolism[J]. Journal of Cleaner Production, 2016, 112: 1274-1282.

[25] Li Y, Lu L, Tan Y, et al. Decoupling water consumption and environmental impact on textile industry by using water footprint method: A case study in China[J]. Water, 2017, 9(2): 124.

[26] Yang Nan. The unique role of ridge regression analysis in solving multicollinearity problems[J]. Statistics & Decision, 2004(3): 14-15.

[27] Zhang Lili. Analysis of Carbon Emission Factors in Construction Industry Based on STIRPAT Model[D]. Xi'an: Xi'an University of Architecture and Technology, 2020.

[28] Li Yunjie. Research on Grey Water Footprint in Hangzhou[D]. Zhejiang: Zhejiang Normal University, 2017.

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