Investigating Response Techniques for Water Function Zones Based on the PSR Model

Yihan Bai

School of Environment, Hohai University, Nanjing, 210098, China

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Abstract: With the gradual promotion of water ecological civilization construction and the implementation of the Beijing-Tianjin-Hebei integration strategy, Zhangjiakou's capital water conservation and ecological environment support function is increasingly prominent. This study analyzes the current state of the water function zones in the Olympic core area and establishes an evaluation indicator system for the water function zones using the Pressure-State-Response (PSR) model. Based on this analysis, response technologies are proposed to address influential factors such as social and economic structure, tourist population growth, and point and non-point source pollution. The response technologies include ecological protection and restoration of water function zones, comprehensive management of point and non-point source pollution, regulating tourist population levels, and scientifically planning urban development to alleviate human development pressures. In this paper, the concept of harmony and balance is coordinated with the health of rivers and lakes to formulate treatment measures, which provides technical basis for the government functional departments to coordinate social and economic development, strengthen the management of water functional areas, implement the strictest water resources management system and other work, and has certain social, economic and ecological benefits. On the other hand, the protection of water functional zones also provides technical support for the capital's water safety, the construction of Beijing-Tianjin-Hebei ecological support zone and the construction of the capital's water conservation functional zone.

1. Introduction

As the promotion of aquatic ecological civilization and implementation of the Beijing-Tianjin-Hebei integration strategy continues, the Capital Water Source Conservation and Ecological Environment Support function in Zhangjiakou City garners increasing attention. The successful 2022 Winter Olympics provides a favorable opportunity for area development. However, the pressures brought about by Olympic venue construction and population growth in the post-Olympics era cannot be ignored. It is essential to find a balance between economic development, improved living standards, and the carrying capacity of the water environment. This study pilots the core area of the Zhangjiakou Winter Olympics, applies the Pressure-State-Response (PSR) model to analyze the main factors that affect water quality, suggests targeted response technologies, and establishes a system of water function zone protection techniques to support water environmental protection.

2. Current Situation of Olympic Core Area

2.1. Current Situation of Water Quality

The Olympic core area, including the Donggou Zhangjiakou drinking water source area, has a water quality target of Grade III according to the *Surface Water Environmental Quality Standards* (GB3838-2002) [1]. The water quality evaluation for the full year of 2021 achieved Grade III, meeting the water quality objectives of water function zones. The main control items for pollutant discharge in water function zones, including COD and ammonia nitrogen, are within required limits.

2.2. Pollution Sources

The water function zones in the Olympic core area are designated as a drinking water source, but still experiences sewage outlets whose discharge negatively affects the area. At present, sewage outlets remain in the surrounding area. During 2021 in Chongli District, industrial wastewater discharge into the river amounted to 1.7523 million tons per year, with 31.3 tons of COD and 1.1 tons of ammonia nitrogen discharged as pollutants annually, which has the potential to negatively impact the water function zone's water quality [2].

3. Developing an Indicator System to Evaluate Water Function Zones using the PSR Model

The PSR (Pressure-State-Response) model is used to construct an evaluation indicator system that comprehensively assesses the impact of human pressure on nature, the status of resources, and management response measures. The pressure variable describes the impact of human activities on the environment, while the state variable describes the physical measurable characteristics of environmental problems caused by human activities. Finally, the response variable describes the degree to which society is responding to environmental problems caused by human activities [3,4].

This paper employs the PSR model to depict the current state and changing trends of water function zones. By examining economic, social, and other pressure factors through the lens of the "natural-social" dual water cycle, this study addresses the external forces that affect the well-being of water function zones. To combat these challenges, we propose policies and institutional responses that aim to reduce such pressures, and to improve the overall condition of water function zones [5].

4. Factor Analysis of Water Function Zones Based on PSR Model

Using principal component analysis (PCA) and statistical software (SPSS), this study analyzes the data of indicators related to water function zones constructed under the PSR model. Comprehensive indicators that affect water function zones are identified, and a response analysis is conducted based on actual water function zones within the core area of the Winter Olympics [6-8].

4.1. Factor Analysis on the Present Situation of Water Function Zones in Olympic Core Area

The basic data for the comprehensive evaluation indicator constructed by the core area water function zones as the unit is processed by principal component analysis using SPSS statistical software. The related coefficient matrix, eigenvalues, and cumulative contribution rate (Table 1), and the main component loading matrix (Table 2) are obtained. The related coefficient matrix shows that there is a certain degree of correlation between these 21 indicators, which provides a necessary precondition for subsequent principal component analysis and calculations. As shown in Table 1, the eigenvalues of the main components C-F_1, C-F_2, and C-F_3 are all greater than 1, and the cumulative contribution rate is 92.0%, indicating that they are the main influencing factors. Therefore, the first, second, and third principal components can be selected to analyze the status of water function zones in the Olympic core area, as shown in Table 3.

Table 1 Eigenvalue and cumulative contribution rate of water function zones in Olympic core area

Components	Initial eigenvalues		
	Total	Percentage of variance	Cumulative %
C-F_1	15.448	77.241	77.241
C-F_2	1.874	9.369	86.61
C-F_3	1.125	5.627	92.237

Table 2 Principal component load matrix of water function zones in Olympic core area

Variables	Principal components				
	$C\text{-}F_1$			$C\text{-}F_2$	$C\text{-}F_3$
Rainfall precipitation	-.066	.888	.159	.270	-.164
Total water use for ecological environment	-.125	-.107	.870	-.217	-.103
GDP	.397	-.263	.174	-.078	.791
Total local population	.071	-.020	-.393	.017	.606
Total tourist population	-.048	.894	-.116	-.391	-.166
Amount of agricultural chemical fertilizer applied	-.225	-.261	-.243	.831	-.186
Urbanization rate	-.282	.223	.823	.270	.224
Total amount of irrigation water for farmland	-.951	.072	.068	-.021	-.240
Total water use for forestry, husbandry, fishing and livestock	-.285	.861	-.061	-.365	-.076
Total industrial water consumption	.697	-.497	-.355	.335	.160
Total urban public water use	-.024	.314	.837	.017	-.133
Total domestic water consumption for residents	-.124	.780	.491	-.224	.230
Water consumption per ten thousand yuan of GDP	-.814	.403	.021	-.285	-.285
Total water consumption	.346	-.313	.030	.828	.119
Annual discharge of COD from waste water	.942	.035	-.266	.055	-.095
Annual discharge of ammonia nitrogen from waste water	.591	-.762	-.081	.213	.072
Total annual discharge of waste water	.364	.247	-.714	.441	.216
Proportion of primary industry GDP	.827	-.221	-.136	-.424	.179
Proportion of secondary industry GDP	.584	-.571	-.418	.115	.354
Proportion of tertiary industry GDP	-.637	.521	.536	-.039	-.059

4.2. Analysis of Comprehensive Impact Indicators

The comprehensive analysis reveals,

(1) The first principal component represents the socio-economic structure, with a contribution

rate of 77.2%, and is the most important comprehensive impact indicator affecting water quality conditions in the water function zones of the Olympic core area.

(2) The second principal component represents the agricultural structure, positively correlated with primary industry GDP and negatively correlated with the amount of agricultural fertilizers applied, suggesting that the second principal component reflects the fact that Chongli is not only a tourist area but also an agricultural region, where factors such as the use of fertilizers, agricultural water use, and wastewater discharge all affect the water quality of the water function zones.

(3) The third principal component represents human development, exhibiting strong negative correlations with GDP and the total local population. During the Winter Olympics, as a venue for snow events, the Olympic core area adhered to the concept of integrated urban-rural development, achieving complete coverage of beautiful villages. However, the development of new small towns along the river will put pressure on the water quality of the local water function zones.

The comprehensive indicators that have a significant impact on the water quality of the water function zones in Olympic core area are the social and economic structure, agricultural structure, human development, and other critical factors, as demonstrated in Table 4, based on the principal component analysis [9-11] and the preceding analysis.

Table 3: Correlation of principal components and related indicators in the Olympic core area

Principal components	Positive correlation	Negative correlation	Contribution rate (%)
Principal component 1 ($C\text{-}F_1$)	Annual discharge of COD from waste water, proportion of primary industry GDP and total industrial water consumption	Total amount of irrigation water for farmland, water consumption per ten thousand yuan of GDP, proportion of tertiary industry GDP	47.724
	Total tourist population, rainfall precipitation, total water consumption for forestry, animal husbandry, fishery and livestock, and total domestic water consumption for residents	Annual discharge of ammonia nitrogen from waste water, proportion of secondary industry GDP	15.612
	Total water consumption of ecological environment, total urban public water use and urbanization rate	Total annual discharge of waste water	13.905
Principal component 2 ($C\text{-}F_2$)	Amount of agricultural chemical fertilizer applied and total water consumption		9.369
Principal component 3 ($C\text{-}F_3$)	GDP, total local population		5.627

5. Response Techniques of Water Function Zones Based on PSR Model

Research findings indicate that the social and economic structure, agricultural structure, and human development are the main comprehensive indicators influencing the water quality of the Olympic core area water function zones. In response to the challenges posed by a growing tourist population, large waste water discharge, and significant point and non-point source pollution, five response techniques have been proposed.

(1) Ecological protection and restoration technique specific to water function zones

By adjusting the river channel at the confluence of tributaries and highlighting the water landscape features of Chongli tourism development nodes, three artificial wetlands were built in places such as Shangliangjianfang Village, Batu Bay, and Shangxinying Village to store and hold rainwater resources and enhance the ecological landscape.

Table 4 Comprehensive indicators of water function zones in Olympic core area

Objective layer	Principal components	Comprehensive	Indicator layer	Criterion layer
Evaluation indicator system of water function zones in Zhangjiakou area in preparation for Winter Olympics	(C-F_1) Principal component 1	Social and economic structure	Total amount of irrigation water for farmland (10,000 m^3)	P
			Total industrial water consumption(10,000 m^3)	
			Water consumption per ten thousand yuan of GDP	S
			Annual discharge of COD from waste water (t)	
			Proportion of primary industry GDP (10,000 yuan)	R
			Proportion of tertiary industry GDP(10,000 yuan)	
			Total tourist population (10,000 people)	P
			Total domestic water consumption for residents (10,000 m^3)	
			Total water consumption for forestry, animal husbandry, fishery	
			Rainfall precipitation (mm)	S
			Annual discharge of ammonia nitrogen from waste water (t)	S
			Proportion of secondary industry GDP (10,000 yuan)	R
			Total annual discharge of waste water (10,000 t)	P
			Total water consumption of ecological environment (10,000	
			Total urban public water use (10,000 m^3)	
			Urbanization rate (%)	S
	(C-F2) Principal component 2		GDP (10 million yuan)	P
			Total local population (10,000 people)	
	(C-F3) Principal component 3		Amount of agricultural chemical fertilizer applied (t)	P
			Total water consumption (10,000 m^3)	

(2) The technique to accelerate comprehensive treatment of point sources and non-point sources, along with strict control of river pollution

This involves identifying the commonalities of point and non-point source pollution, carrying out an evaluation of the carrying capacity of the water function zones, and implementing integrated treatment measures to promote watercourse development and ecological restoration. The primary technical measures include

A: Source reduction: adopting clean production technologies and processes, adjusting the industrial product structure, and reducing the generation of pollutants from the source;

B: Process blockage: blocking the path of transfer and transformation from social water cycle to natural water cycle layer by layer, establishing a closed-loop circulation system, implementing the reuse of recycled water and the recycling of nutrients, to achieve the goal of blocking pollutants from entering the water body.

C: Terminal treatment, includes comprehensive treatment of sewage, sludge disposal and reuse, and restoration of water ecological systems. The primary response is that sewage treatment should shift from centralized and large-scale to decentralized, small-scale, and ecological.

(3) The technique to control the number of tourists and provide efficient water supply and drainage facilities

The local government should scientifically assess the tourism reception capacity, control the number of tourists, and enable the tourism industry to follow a development path that is coordinated with the local ecological environment and is sustainable. At the same time, the government should increase the promotion of water-saving facilities, and enhance the capacity and efficiency of sewage treatment systems.

(4) The technique to scientifically plan the scale of urban development to alleviate the pressure of human development

To address the pressure of human development on the water function zones, it is recommended that the local government scientifically plan the local urban development scale from the perspective of social management. Multiple aspects, such as urbanization construction, talent attraction, and supporting infrastructure construction, should be considered, and overall coordination should be carried out from legal, policy, economic, and ecological protection aspects, to alleviate the ecological pressure caused by urban development on the water function zones.

(5) The technique of comprehensive planning, scientific management and comprehensive control of agricultural non-point source pollution

To address the pressure that agricultural activities impose on water function zones, it is necessary to accelerate the pace of economic transformation by promoting the transformation of the “agricultural town” into an “ice and snow tourism town” and reducing the impact of non-point source pollution on water quality in water function zones. To achieve this, comprehensive planning and scientific management of the Olympic core area are required, which should involve changing the agricultural planting structure and management methods, reducing the use of pesticides and fertilizers, and managing the impact of agricultural wastewater on water function zones. It is also important to establish a buffer zone with water and land interfaces for restoration and utilization, and to construct ecological wetlands before the agricultural wastewater enters the river to prevent agricultural non-point source pollution.

6. Conclusions

This paper delves into an extensive exploration of the response technologies for water function ones using the PSR model. In light of the impact reaction factors that afflict water function zones, governance measures have been devised, taking into account the principles of harmonious balance and coordination with river and lake healthy development. These effective measures extend unparalleled technical support to government functional departments to facilitate social and economic development and enforce the strictest water resources management framework, while strengthening governance of water function zones. This study’s ramifications are manifold, encompassing social, economic, and ecological benefits. Furthermore, the protection of water function zones provides essential technical support for ensuring water security in the capital, constructing an ecological support zone for the Beijing-Tianjin-Hebei region, and building a functional area for water source conservation in the capital.

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