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Vulnerability Assessment of Water Resources in Bayannur City based on Entropy Power Method

Xiaoying Niu*

School of Nanjing Normal University, Nanjing, China

Abstract

Water is the origin of life, agricultural production and industrial production are inseparable from water resources, in the context of climate warming, the water cycle system will be affected, therefore, the vulnerability of water resources has become the urgent need to address the sustainable use of water resources, the evaluation and analysis of the regional water resources vulnerability of Bayannur city has positive practical significance. This paper takes Bayannur city as the research object, and evaluates the water resources vulnerability of Bayannur city from 2010 to 2019 based on the research method of entropy power method, in order to provide reference significance for ecological governance and rational use of water resources. The main research conclusions are as follows: (1) Bayannur city's water resources vulnerability from 2010-2019 shows an overall trend of changing from strong to weak, and water resources vulnerability changes from extremely fragile to moderately fragile, gradually becoming weaker; (2) Bayannur city's water consumption of 10,000 yuan GDP shows a significant reduction, indicating that the overall water use efficiency of economic development has been significantly improved, which is conducive to improving the water resources carrying capacity and Reducing the vulnerability of water resources. (3) The per capita water resources and precipitation in Bayannur City are low, and it is necessary to continue to improve water use efficiency.

Keywords

Water Resources Vulnerability; Evaluation Index System; Entropy Weight Method.

1. Introduction

Water is an important natural resource and a strategic economic resource related to national livelihoods[1]. The UN World Water Development Report 2017 shows that two-thirds of the global population lives in drylands with varying degrees of water scarcity. The UN World Water Development Report 2020 further states that water security and climate change will be a continuous and profound crisis facing the world in the coming decades.

In Inner Mongolia Autonomous Region, severe water shortage is the basic regional water situation and the main bottleneck limiting the sustainable economic and social development of the region. Bayannur City is located in the western part of Inner Mongolia Autonomous Region, and the shortage of water resources is the main factor limiting its economic development. At the same time, the economic losses caused by droughts and floods are increasing due to the influence of unreasonable human activities, and these have challenged the sustainable regional development of water resources, and it is important to conduct a study on the vulnerability of water resources systems in this context.

Water resources vulnerability is defined as the change in the structure of water resources system under the effect of climate change, human activities, etc., the reduction in the quality and quantity of water resources, and the resulting changes in the supply, demand, and management of water resources and the occurrence of natural disasters such as droughts and

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floods[2]. Water resources vulnerability is an important part of the study of sustainable water resources use[3], so the evaluation of water resources vulnerability in Bayannur city is beneficial to provide reference for the subsequent water use and water conservation policies in the region. To this end, this paper conducts a dynamic evaluation of the water resources system vulnerability of Bayannur city in the last ten years from 2010 to 2019 by constructing an index evaluation system as well as the entropy weight method.

2. Literature References

2.1. Water Vulnerability Overview

The prototype of vulnerability appeared in 1945 when American geographers Gil-bert F. and White[4] first proposed the idea of "adaptation and adjustment" in their study of flood hazards, and later White[5] further defined vulnerability as the vulnerability of a system, subsystem, or system component to external disturbances and stresses due to its exposure and sensitivity, making it vulnerable to a certain extent to external disturbances and stresses. Since then, four reports of the Intergovernmental Panel on Climate Change (IPCC) have defined the meaning of vulnerability from different perspectives, and in the 21st century, vulnerability has been widely used within several disciplines, involving economics[6] and social welfare[7]. Marget in France first introduced the term "groundwater vulnerability The term "groundwater vulnerability" was first introduced by Marget in France in 1968, and subsequent studies on the vulnerability of water resources systems have emerged. Subsequent studies have also gradually extended from groundwater vulnerability to the study of the concept of water resources vulnerability, in which the requirements of water quality, water quantity, social, economic, and ecological aspects have begun to be considered simultaneously[8]. Therefore, this paper argues that water resources vulnerability means that the structure of water resources system has changed under the action of climate change and human activities, and the quality and quantity of water resources have been reduced, and the resulting changes in water resources supply, demand, management and the occurrence of natural disasters such as droughts and floods[2]. Water resources vulnerability has regional characteristics in different regions due to different water resources characteristics, natural conditions, and socioeconomic conditions; and also has stage characteristics due to being in different stages of social development and due to different levels of social productivity[8].

2.2. Factors Influencing Regional Water Vulnerability

In the development of the concept and connotation of water resources vulnerability, domestic scholars were more influenced by the early foreign concept of groundwater vulnerability, and believed that its influencing factors were only related to water quality[8]. Yang Yanmai et al. believe that the natural environment determines its own vulnerability and human social activities determine its exogenous vulnerability[9]; Yu Cuisong et al. believe that water quality, water quantity, and even resources, ecology, environmental economy and other aspects have an impact on it[10].

The most widely used method in water resources vulnerability evaluation is the comprehensive index method, which constructs a corresponding index system by analyzing the main factors that lead to water resources vulnerability, with specific applications such as hierarchical analysis (AHP)[11]. In addition, some scholars have adopted GIS and other methods for groundwater vulnerability evaluation, Yang Guomin et al. used DRASTIC and combined with GIS geographic analysis function to evaluate the groundwater vulnerability of Fuxin basin[12]. In addition Data Envelopment Approach (DEA) is also its common application method[13]. And Liu et al.[14] applied entropy method to select the evaluation index system including three aspects of water resources system, socio-economic system, and ecosystem.

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3. Overview and Construction of the Research Model

3.1. Indicator System Construction

Table 1. Bayannur city water resources vulnerability evaluation index system

Guideline layer	Indicator layer	Calculation method	Meaning	Nature of Indicator
Water Systems	B1: Water resources per capita(m3/ person)	Total water resources/total population	Reflects per capita water availability	Cost
	B2: Groundwater resources per capita(m3/ person)	Total regional groundwater resources/total population	Reflects per capita possession of groundwater resources	Cost
	B3:Water production modulus(104 m3/km2)	Total water resources/area area	Reflecting the regional water resources	Cost
	B4: Water supply modulus(104 m3/km2)	Water supply/area area	Reflecting the regional water supply	Beneficial
	B5: Rainfall(mm)	Statistics	Reflecting the amount of rainfall	Cost
	B6: Water Resources Development and Utilization(%)	Water supply/total water resources	Reflects the extent of water resources development and utilization	Beneficial
Socio-economic system	B7: Water consumption of 10,000 Yuan GDP(m3/ million yuan)	Water consumption / 10,000 Yuan GDP	Reflects water consumption per unit of GDP	Beneficial
	B8:Population density(person/km2)	Total population/area area	Reflects regional population	Beneficial
	B9: GDP per capita(yuan/ person)	GDP / Total population	Reflects economic development per capita	Cost
	B10: Water use rate for agricultural irrigation(%)	Agricultural irrigation water consumption/total water consumption	Reflecting the efficiency of irrigation water use on farmland	Beneficial
Ecosystem	B11: Water consumption per capita(m3/ person)	Water consumption / total population	Reflects per capita water consumption	Beneficial
	B12:Ecological water use rate(%)	Ecological water consumption/total water consumption	Reflecting the construction of ecological environment	Cost

The annual average precipitation in Bayannur City in 2019 was 98.9 mm, which translates into a total precipitation of 6.51 billion cubic meters, a 49.6% decrease in precipitation compared to 2018 and a 41.3% decrease compared to the multi-year average. Total water resources of 5,318.1 million cubic meters, of which 4,865.8 million cubic meters of surface water resources, including the net diversion of 4,738.2 million cubic meters of water from the Yellow River and 127.6 million cubic meters of surface runoff in the city; underground water resources of 1,976.4 million cubic meters, the duplication between surface water and underground water resources of 1,524.1 million cubic meters. Bayannur city water resources use a total of 4,989.1 million cubic meters, the total water consumption of 3,434.8 million cubic meters.

According to the characteristics of water resources utilization in Bayannur city, and under the condition that the indicators are representative and available, the indicator system of national water resources supply and demand analysis and evaluation [15] and other water resources evaluation indicator systems [16] are referred to, 12 evaluation indicators including 3 aspects of water resources system, socio-economic system and ecosystem are selected. By calculating the vulnerability of water resources to evaluate the vulnerability of water resources in Bayannur city, it is considered that the larger the value of vulnerability, the higher the vulnerability, that is, the more vulnerable the water resources in Bayannur city. Therefore, the evaluation indicator that the greater the value of the indicator causes the higher the vulnerability is set in the model as the benefit type indicator, and the evaluation indicator that the smaller the value of the indicator causes the lower the vulnerability is the cost type indicator. The meaning of each indicator is shown in Table 1.

3.2. Data Standardization for Each Indicator

The evaluation model chosen for this study is the entropy weight assessment model. The entropy weight criterion was proposed by E.T. Jaynes and applied in information theory. Since each evaluation index has different magnitudes, the indexes are first dimensionless according to their characteristics.

(1) For the benefit-based indicators, Vij is obtained after processing:

$$V_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{1}$$

(2) For cost-based indicators, Vij is obtained after processing:

$$V_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_j) - \min(x_j)} \tag{2}$$

3.3. Entropy Weighting Method to Calculate Index Weights

Entropy weighting method is an objective weighting method that determines the weight through information entropy according to the dispersion degree of the original data of each index. It can effectively avoid the bias caused by subjective factors and improve the credibility and accuracy of index weight values.

Measure the jth indicator of the object to be evaluated, the weight of the characteristics of the ith object to be evaluated:

$$P_{ij} = \frac{V_{ij}}{\sum_{i=1}^{m} V_{ij}}, 0 \le V_{ij} \le 1, 0 \le P_{ij} \le 1 \tag{3}$$

Calculate the entropy value of the jth indicator using the measured characteristic weight of the indicator:

$$e_j = -\frac{1}{lnm} \sum_{i=1}^{m} P_{ij} lnP_{ij} \tag{4}$$

When $P_{ij} = 0$, or $P_{ij} = 1$, $P_{ij} lnP_{ij} = 0$

Calculate the entropy weight of the jth indicator:

$$w_j = \frac{(1 - e_j)}{(n - \sum_{j=1}^{n} e_j)} \tag{5}$$

Determine the composite score of each evaluation subject:

$$Z_i = \sum_{j=1}^{n} w_j V_{ij} \tag{6}$$

3.4. Water Vulnerability Assessment

Table 2. Classification of vulnerability levels [17]

Vulnerability	Grade
$0 \le Z_i < 0.25$	Not fragile
$0.25 \le Z_i < 0.45$	Weak fragile
$0.45 \le Z_i < 0.6$	Medium fragile
$0.6 \le Z_i < 0.72$	Strong fragile
$0.72 \le Z_i < 1$	Extremely fragile

According to the comprehensive evaluation value calculated by the linear weighting method, the vulnerability of water resources in Bayannur City is classified into vulnerability levels with reference to the classification range in Table 2.

4. Results and Analysis

4.1. Bayannur City Water Resources Evaluation Index Value

In this part, we selected the data of Bayannur City for the decade 2010-2019 as the evaluation object, and for the above sorted indicators, we accurately identified these data in the water resources bulletin of Inner Mongolia Autonomous Region and the statistical bulletin of national economic and social development of Bayannur City for evaluation.

After the attribute weights were known, the attribute weights were ranked and used to calculate the final evaluation score, as shown in Table 3.

Table 3. Bayannur city water resources vulnerability evaluation index weights and comprehensive score ranking table

Property Name	Attribute weights	Sort by	Year	Overall Score	Sort by
B1	0.07	9			
B2	0.08	6			
B3	0.07	10	2010	0.85	1
B4	0.06	12	2011	0.64	3
B5	0.09	5	2012	0.31	10
B6	0.07	7	2013	0.51	8
B7	0.12	1	2014	0.54	6
B8	0.11	2	2015	0.59	5
B9	0.10	4	2016	0.53	7
B10	0.07	8	2017	0.67	2
B11	0.10	3	2018	0.43	9
B12	0.07	11	2019	0.64	4

As can be seen from Table 3, the weights of the water resources vulnerability evaluation indicators of Bayannur city from 2010 to 2019 are higher for the water consumption of 10,000 Yuan GDP (B7), population density (B8), per capita water consumption (B11), per capita GDP (B9), and rainfall (B5) compared with other indicators; the weights of the water production modulus (B3), ecological environment water use rate (B12), and water supply modulus (B4) are lower compared with other The weights of water production modulus (B3), ecological environment water use rate (B12) and water supply modulus (B4) are lower than other indicators.

Table 4. Bayannur city water resources vulnerability evaluation results

2010	2011	2012	2013	2014
0.85	0.64	0.31	0.51	0.54
Extremely fragile	Strong fragile	Weak fragile	Medium fragile	Medium fragile

Continued from Table 4

2015	2016	2017	2018	2019	2020
0.59	0.53	0.67	0.43	0.64	0.59
Medium fragile	Medium fragile	Strong fragile	Weak fragile	Strong fragile	Medium fragile

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(3) After calculating the weights and comprehensive evaluation values of water resources vulnerability evaluation indicators in Bayannur city, the water resources vulnerability of Bayannur city from 2010 to 2019 was obtained according to the vulnerability classification in Table 2 as shown in Table 4.

4.2. Analysis of Research Findings

(1) B7>B8>B11>B9>B5>B2>B6>B10>B1>B3>B12>B4. Among them, the water resources vulnerability evaluation indicators of Bayannur city from 2010 to 2019 are water consumption per 10,000 Yuan GDP (B7), population density (B8), water consumption per capita (B11), GDP per capita (B9), rainfall (B5) The weights of water production modulus (B3), ecological environment water use rate (B12), and water supply modulus (B4) are higher compared with other indicators; the weights of these indicators are lower compared with other indicators. It can be seen that socio-economic system factors have more significant influence than water resources system factors and ecosystem factors.

(2) For the comprehensive water resources vulnerability score of Bayannur City from 2010 to 2019, it can be seen that the overall water resources vulnerability shows a decreasing trend from high to low, which reflects the effectiveness of the implementation of relevant water conservation policies. 2019 The increase in water resource vulnerability is mainly affected by the sudden decrease in precipitation, and facing the uncertainty of climate change, it is more important to take appropriate management measures to improve the vulnerability of water resources. It is also important to recognize that Bayannur City, as a representative region of relatively abundant water resources in the northwest, water resources vulnerability is still generally above the medium vulnerability, and the task of water conservation and environmental protection it faces is still very difficult.

5. Conclusion

From the above analysis, it can be seen that the overall water resources vulnerability in Bayannur city from 2010 to 2019 shows a trend from strong to weak. The vulnerability of water resources in Bayannur city changes from extremely vulnerable to moderately vulnerable and gradually becomes weaker. The water consumption per 10,000 yuan of GDP in Bayannur city shows a significant trend of reduction, indicating that the overall water use efficiency of economic development has been significantly improved, which is conducive to improving the water resources carrying capacity and reducing water resources vulnerability.

The per capita water resources and precipitation in Bayannur City are low and need to continue to improve water use efficiency. The water consumption rate of agricultural irrigation remains above 80%, and the proportion of agricultural water consumption is high. Therefore, the water consumption of agricultural irrigation is controlled through the use of engineering water conservation techniques such as college farm irrigation techniques, agricultural water conservation measures such as adjusting planting structures, and management measures such as regulating agricultural water prices to further reduce agricultural water consumption and improve agricultural water use efficiency.

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