Risk Assessment of Water Resources Shortage in Sanjiang Plain

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Abstract. In view of the problems existing in the development and utilization of water resources in Sanjiang Plain, this paper made a study on the risk assessment of water resources shortage in Sanjiang Plain. From the perspective of water resources shortage risk, analytic hierarchy process was applied to establish assessment index system and evaluation criteria, and then make a comprehensive assessment and regional difference analysis of water resources shortage risk in Sanjiang Plain. Research results showed that Shuangyashan City belonged to high degree of water resources shortage risk, while Jixi, Hegang, Jiamusi, Qitaihe, Muling and Yilan belonged to extremely high water resources shortage risk, which provided a theoretical principle for sustainable and efficient utilization of regional water resources.

Keywords: water resources; shortage risk; analytic hierarchy process; Sanjiang Plain

1 Introduction

Water resources are the natural resources for human survival, but also an important resource for the economic development of a country or a region. However, China is a drought and water shortage nation in the world. Fewer amounts, uneven space distribution and serious pollution of water resources make water resources shortage in China more serious. The shortage of water resources in a certain extent has seriously restricted the sustainable development of social economy in China [1]. Therefore, the identification of water resources shortage risk factors, evaluation of its degree to reduce economic losses caused by the shortage, and the optimal allocation of water resources have important practical significance for achieving water resources sustainable utilization.

Water shortage risk assessment is a comprehensive evaluation of multiple factors. Currently, the evaluation methods include analytic hierarchy process (AHP), fuzzy mathematics method, projection pursuit clustering, etc. The calculation process and the advantages and disadvantages of various methods were studied and compared by many former scholars [2-3]. Due to the impact of many uncertainties, any single method is difficult to evaluate comprehensively. If AHP was combined with fuzzy mathematical method, it could make the abstract evaluation process and algorithm specific, and the evaluation results would be distinct. Therefore, based on the use of AHP to identify the source of water resources shortage risk, membership function was used to evaluate the risk degree of each index, and realize the risk assessment of regional water resources shortage.

2 Research area

Sanjiang Plain lies in the northeast region of Heilongjiang Province, China, including the triangle confluence region of the Heilongjiang, Songhua and Wusuli Rivers, and Woken River and Muling River Basin and Xingkai Lake Plain. Geographical position of Sanjiang Plain is 43°49′55″~48°27′20″ north latitude, 129°11′20″~135°5′10″ east longitude, north to the Heilongjiang River, south to the Xingkai Lake, east to the Wusuli River, west to the southeast part of Xiaoxinganling mountains. Its east-west width is 430km, and north-south long is 520km, with a total area of 1.09×10^5 km^2 and 24% of Heilongjiang Province total area. The administrative area of Sanjiang Plain includes Hegang City, Jiamusi City, Shuangyashan City, Qitaihe City, Jixi City and Muling City and Yilan County. The Sanjiang Plain region is essential for Heilongjiang Province to ensure grain produce capacity and food security and is also a significant marketable grain base China. Low water resources pollution emissions compliance rate, unreasonable development and utilization, low industrial water reuse rate and low water resources use rate [4], coupled with increasingly severe extreme weather and water waste caused the serious shortage of water resources. Therefore, it is of great significance to construct the risk assessment model of water resources shortage, and to analyze and evaluate the situation of water shortage in Sanjiang Plain.

3 Water shortage risk assessment

3.1 Evaluation index system construction

In order to comprehensively and systematically analyze water resources shortage, risk index and main risk sources of each city in Sanjiang Plain area, and contrast risk differences in different areas, a series of evaluation index were needed to construct a unified and complete evaluation index system. Each evaluation index should reflect the water resources shortage and shortage risk from different angles. It should be able to connect with each other, complement each other, and will be independent and representative. Combined with the characteristics of resource utilization and socioeconomic development in the study area, the risk assessment index system of water resources shortage in Sanjiang Plain was constructed. The index system is made up of target layer, state layer and index layer, in which the target layer includes one target factor (I), the state layer includes five state factors (A to E), and the index layer includes 18 indicators (A1 to E3) shown in Table 1. In the risk assessment index system of water resources shortage, the state layer indicates the risk of regional water resources shortage from different angles: water resources quantity reflects the quantity and background of water resources in evaluated area; social demand mainly reflects the intensity of water demand and social economic scale born by regional water resources; water resource reserve status mainly reflects the ability of relieving regional water shortage; water supply indicators mainly reflect the regional water supply capacity; ecological environment indicators mainly reflect the status of regional ecological balance [5].

Table 1. Water resources shortage risk evaluation index

Target layer	State layer	Index layer	Index measurement method
I Water Shortage risk index	A Water resources	A1 Per capita water resources	Total water resources / total population
		A2 Per square water resources	Total water resources / land area
		A3 Surface water coefficient	Surface water resources / precipitation
	B Social needs	B1 Population density	Total population / land area
		B2 GDP per water consumptions	Gross Regional Product / total water demand
		B3 Per square water demand modulus	Water demand / land area
		B4 Per capita water demand	Total water demand / total population
	C Water source reserve	C1 Water retention coefficient	Total water resources / precipitation
		C2 Reservoir storage ratio	Reservoir water storage / total water resources
		C3 Groundwater resource coefficient	Total groundwater / total water resources
	D Water supply	D1 Per capita water supply	Total water supply / total population
		D2 Water supply rate	Water supply / total water resources quantity
		D3 Groundwater supply ratio	Total groundwater supply / total water supply
		D4 Surface water supply ratio	Total surface water supply / total water supply
	E Ecological environment	E1 Forest coverage	Forest area / total land area
		E2 Ecological water consumption rate	Ecological water consumption / annual average water resources

3.2 Calculation of index weight based on AHP

There are five steps in the weight calculation of analytic hierarchy process: systemizing problem, valuing index, constructing judgment matrix, determining index weight, and testing judgment matrix consistency [6]. The judgment matrix is an $n \times n$ comparison matrix composed by quantification of the comparison of n sub index. In this paper, the relative importance of quantitative value is obtained by using 1-5 scaling method [7], when strong factors were compared with weak factors, the numerical 1-5 were used to characterize the degree of importance, respectively, indicating equal, slightly important, obviously important, strongly important, extremely important. When weak factors were compared with strong factors, the reciprocal of the numerical 1-5 were used to represent. The judgment matrix of this study includes the target -state level (A-E), the state-index layer (A1-A3、B1-B4、C1-C3、D1-D4、E1-E2), which has 6 judgment matrixes.

The index weight was calculated by using the characteristic root of the judgment matrix, and the maximum eigenvalues and eigenvectors of the matrix were calculated by using the MATLAB software. After single ordering the 6 judgment matrix, normalized weight value was obtained by the multiply of each index weight with the corresponding state level factor. The *CR* value in consistency test of judgment matrix is calculated by the following formula [8]:

$$\begin{cases} CR = CI / RI \\ CI = (\lambda_{\max} - n)/(n-1) \end{cases} \quad (1)$$

Where *CI* is the consistency index of judgment matrix; $\lambda_{\max}$ is the maximum eigenvalue of judgment matrix; *n* is the dimensionality of judgment matrix; *RI* is the random consistency index related to the dimensionality of judgment matrix, when *n* was 3, 4, 5, 6, 7, 8, 9, 10, *RI* = 0.52, 0.90, 1.12, 1.26, 1.36, 1.41, 1.46, 1.49. When *CR* is less than 0.1, it is considered that the judgment matrix is in good agreement, and the weight is rational; elsewise it will need to adjust the judgment matrix until it is satisfied.

In this paper, the *CR* values from the consistency test of each index layer were all less than 0.1, which indicated that the judgment matrix satisfied the consistency, and the weight distribution was reasonable. The calculation results were shown in Table 2.

Table 2. Calculation results and consistency test of the weight of the index system

State factor weight	Conformance test（CR）	Index factor weight				Conformance test（CR）
		w1	w2	w3	w4	
A 0.4082	0.0498	0.1750	0.1750	0.0582	-	0
B 0.2562		0.0202	0.0349	0.0639	0.1372	0.0258
C 0.1048		0.0419	0.0419	0.210	-	0
D 0.1860		0.0700	0.0700	0.0230	0.0230	0
E 0.0448		0.0075	0.0373	-	-	0

3.3 Membership evaluation construction

After the establishment of the risk evaluation index system of water resources shortage, we need to connect each index value with water resource shortage risk index, and the common method solving this problem is fuzzy mathematics evaluation method. By dividing the numerical interval, the index value was converted into the risk degree, and the relationship between the index value and risk index was established. By transforming the measured values of each and every index in evaluation area into the risk degree, risk index was obtained by weighted sum of the risk of all the indexes in the evaluation area [9]. In this paper, the membership of risk is 1~8, the higher the number, the higher the membership of risk. Based on water resources shortage risk level, the membership degree is divided into 5 levels (V_1~V_5) as shown in Table 3.

Table 3. Grade standard of risk membership degree of water resources shortage index system

Status factor	Index factor	Unit	Risk membership				
			V_1(1)	V_2(2~3)	V_3(4~5)	V_4(6~7)	V_5(8)
A Water resources	A1 Per capita water resources	m^3	>2000	2000~1600	1600~1200	1200~800	<800
	A2 water resources per square	m^3	>4.5	4.5~3.5	3.5~2.5	2.5~1.5	<1.5
	A3 Surface water coefficient		>0.4	0.4~0.3	0.3~0.2	0.2~0.1	<0.1
B Social needs	B1 Population density	capita/km^2	<25	25~50	50~100	100~300	>300
	B2 GDP per water consumptions	yuan/m^3	>120	120~100	100~60	6	<20
	B3 Per square water modulus	m^3	<2	2~5	5~10	10~20	>20
	B4 Per capita water demand	m^3	<300	300~400	400~500	500~600	>600
C Water source reserve	C1 Water retention coefficient	-	>0.6	0.6~0.45	0.45~0.3	0.3~0.1	<0.1
	C2 Reservoir storage ratio	-	>0.8	0.8~0.5	0.5~0.3	0.3~0.1	<0.1
	C3 Groundwater resource coefficient	-	>0.4	0.4~0.35	0.35~0.3	0.3~0.25	<0.25
D Water supply	D1 Per capita water supply	m^3	>800	800~600	600~400	400~200	<200
	D2 Water supply rate	%	>0.6	0.6~0.4	0.4~0.2	0.2~0.1	<0.1
	D3 Groundwater supply ratio	%	>0.05	0.05~0.01	<0.01	-	-
	D4 Surface water supply ratio	%	>0.95	0.95~0.9	-	-	-
E Ecological environment	E1 Forest coverage	%	>50	50~40	40~20	20~10	<10
	E2 Ecological water consumption rate	%	<1	1~2	2~3	3~5	>5

3. 4 Evaluation results and analysis

In accordance with the above evaluation process, the water resources shortage risk assessment of Jixi City, Hegang City, Shuangyashan City, Jiamusi City, Qitaihe City, Muling City, Yilan County and the whole Sanjiang Plain was conducted. The risk membership of index in each city was shown in Table 4, and the comprehensive risk index and risk level were shown in Table 5.

Table 4. Index risk membership of evaluation area

City	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	D1	D2	D3	D4	E1	E2
Jixi	1	8	1	5	7	1	8	2	8	3	1	1	1	1	4	1
Hegang	1	8	1	4	8	1	8	1	8	8	1	1	1	1	2	1
Shuangyashan	1	8	1	4	7	1	8	1	8	1	1	1	1	1	4	1
Jiamusi	1	8	3	4	8	1	8	3	8	3	1	1	1	1	6	1
Qitaihe	6	8	4	6	7	1	8	5	8	3	6	1	1	1	3	1
Muling	1	8	4	3	8	1	8	4	8	3	7	1	1	1	1	1
Yilan	1	8	3	5	8	1	8	5	8	6	1	1	1	1	4	1
Sanjiang Plain	1	8	8	5	7	1	8	8	8	4	1	1	1	1	4	1

The evaluation index in target layer of water resources shortage risk are between 1~8. According to the cluster analysis of risk value, the water resources shortage risk was divided into 4 levels: extremely high risk (>4.0), high risk (4.0~3.75), medium risk (3.75~3.5), low risk (<3.5).

Table 5. Risk index and risk rank of evaluation area

City	A	B	C	D	E	Total risk index	Risk level
Jixi	1.6332	1.5068	1.0490	0.1860	0.0673	4.4423	Extremely high risk
Hegang	1.6332	1.5215	2.0571	0.1860	0.0523	5.4501	Extremely high risk
Shuangyashan	1.6332	1.4866	0.5871	0.1860	0.0673	3.9602	High risk
Jiamusi	1.7496	1.5215	1.0909	0.1860	0.0823	4.6303	Extremely high risk
Qitaihe	2.6828	1.5270	1.1747	0.5360	0.0598	5.9803	Extremely high risk
Muling	1.8078	1.5013	1.1328	0.6060	0.0448	5.0927	Extremely high risk
Yilan	1.7496	1.5417	1.8047	0.1860	0.0673	5.3493	Extremely high risk
Sanjiang plain	2.0406	1.5068	1.5104	0.186	0.0673	5.3111	Extremely high risk

The results showed that the whole area of Sanjiang Plain had extremely high risk. Water resources shortage risk mainly came from three aspects: small amount of water resources, high social demand and shortage of water reserves. Low risk of water supply and water environment eased the water shortage risk level to a certain extent. The water shortage risk rank of seven administrative regions in Sanjiang Plain from high to low was as follows: Qitaihe City, Hegang City, Yilan County, Muling City, Jiamusi City, Jixi City, Shuangyashan City.

Jixi City, Hegang City, Qitaihe City, Jiamusi City, Muling City and Yilan County belonged to extremely high water resources shortage risk, and the main reasons were small amount of water resources, high social demand and shortage of water reserves. Shuangyashan City belonged to high water shortage risk and the risk index was close to the extremely high risk, and the main reason was that the region had less rainfall, less reservoir storage and high industrial water consumption. Therefore, the shortage of water resources in Sanjiang Plain is very serious.

4 Conclusions

In order to make risk assessment of water resources shortage in Sanjiang Plain, the study made full use of the uncertainty information contained in the object of study, used numbers to process and express, and quantified decision makers' subjective identification and judgment to simplify complex problem and to analyze the details by hierarchy method. Combining quantitative and qualitative analysis with quantitative data, simply calculating, judging and comparing various factors in each level were carried out, and the weight value of each factor was obtained. By calculating the ordering weights of individual factors relative to the overall goal of the whole system, the overall risk condition of these factors was analyzed, namely, regional water resources shortage risk level. The model constructed in this paper based on AHP, with the advantages of simple structure, simple calculation, clear concept, easy operation, simple and effective modeling method could be applied to regional natural resources shortage risk grade evaluation.

After the evaluation of the analytic hierarchy process, the results showed that Jixi City, Hegang City, Qitaihe City, Jiamusi City, Muling City, Yilan County belonged to the extremely highly water shortage risk, the main reasons were small amount of water resources, high social demand and shortage of water reserves. Shuangyashan City belonged to high water shortage risk and the risk index was close to the extremely high risk. According to the evaluation results，for the region with both extremely high and high shortage risk, the demand of water resources will increase along with population growth and economy development. Therefore it is necessary for us to integrate regional characteristic, make full use of the rich water resources of Heilongjiang River and Xingkai Lake, strengthen water resources management, improve water use efficiency, and then as soon as possible to realize the transformation of economic structure from water-intensive economic structure to water-saving economic structure. At the same time, the government needs to increase investment in water conservancy projects, pay attention to the deep development of water resources, and then guarantee the sustainable water supply ability to socioeconomic development in Sanjiang Plain.

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