Water Resources Shortage Risk Prediction of Shanxi Province Based on Fault Tree Analysis and Markov Chain Model

Yang Wei*

School of management, Shanghai University, Shanghai 200072, China

*Corresponding author e-mail: 17621903605@163.com

Abstract. The shortage of water resources that mankind is facing is also increasing. Shanxi province is one of the most famous traditional heavy-industry bases in China. And it is also one of the most serious water-shortage provinces in China. At present, the status of coal in the world energy structure is declined. Shanxi province is facing a critical period of transformation of industrial structure. How to solve the problem of water shortage and support the rapid development of social economy in Shanxi province is to be solved urgently in the area. Based on the specific situation of water shortage in Shanxi Province, this paper discusses the Markov prediction method and fault tree analysis model for the risk of water shortage in Shanxi Province, and we provides suggestions to prevent and solve water resources shortage in the process of economic and social development in Shanxi province.

1. Introduction

In the 21st century, water resources are showing an increasing shortage. About 1.1 billion people in the world do not have access to safe drinking water. Most rivers and lakes that breed human civilization face different levels of water shortage, pollution and even dryness. Human beings are experiencing a global water crisis.

China has proposed the “The Belt and Road Initiative” economic strategy, which aims to strengthen the resource integration and economic development of countries along the ancient Silk Road in China. Most of the provinces along the route are areas with severe water shortages. The implementation and expansion of an economic strategy. Studying the shortage of water resources in China, especially the shortage of water resources in the central and western regions, has become an important research direction in the field of water resources.

The risk of water resources is derived from the reliability theory by Hashimoto, and the risk of water resources is the probability that the water supply cannot meet the water demand situation [1]. Since then, many foreign scholars have gradually studied in this field, and the research direction mainly focuses on the risk of water resources caused by the uncertainty of hydrological model parameters. Petak [2] uses probabilistic forms to give the degree of risk to various types of natural disasters in the United States. Molostov V.S [3] studied the optimization and sufficient conditions of multi-criteria in the state of uncertainty parameters. Colorni [4] discusses the reliability optimization problem for single-objective indicators. Goicoechea [5] used the compromise method to study the multi-objective function problem under uncertainty. Haimes [6] proposed multi-objective multi-stage impact analysis and segmentation multi-objective analysis.
Since the 1990s, along with the rapid development of China’s economy, water resources have been over-exploited for a long time, resulting in different levels of water shortages in many areas and a serious imbalance in the supply and demand of water resources. The research of risk assessment has gradually become a hot spot [7]. Zhang Feng [8] discussed the factors and causes of water resources system risk, and conducted a comprehensive evaluation of regional water resources risk. Huang Mingcong and Xie Jiancang established a water resource risk assessment model based on support vector machine, and constructed an evaluation system with risk rate, vulnerability, recoverable system, accident cycle and risk as indicators. In the resource risk assessment, Luo Juingang [9] used information to quantify the uncertainty of various indicators in water resources risk assessment. Zhang Xuexia and Wu Pengfei [10] used spatial clustering method to evaluate the water resources risk status of Songqian River Basin.

2. Water shortage Fault Tree system

The research content of this paper includes the following aspects: Firstly, we construct the fault tree model of water shortage in Shanxi Province. We have established the water shortage in Shanxi Province as the top event, water resources elements, socio-economic factors and ecological environment elements as intermediate events. The fault tree system of basic events, total water resources, actual water consumption, per capita water consumption, 10,000 yuan GDP water consumption, population growth rate, and sewage discharge and forest cover rate. Then we predict the possibility of a water shortage accident in Shanxi Province in 2019. This paper uses the Markov chain prediction model to predict the probability of occurrence of various basic events, and then uses the possibility of occurrence of various basic events to predict the possibility of water shortage in Shanxi Province in 2018. Finally, the prediction results are qualitatively and quantitatively analyzed.

Establishing a scientific and rational forecast system for water shortage is the basis for predicting the shortage of water resources. We have established water in combination with the actual situation of water shortage in Shanxi Province. The resource shortage fault tree system, as shown in Figure 1, the meaning of each indicator is shown in Table 1.

![Figure 1. The Fault tree system of Shanxi Province water shortage](image_url)
Table 1. The meaning of fault tree index system of water resources shortage in Shanxi province

| Index                                      | Implication                                      |
|--------------------------------------------|--------------------------------------------------|
| The total amount of water resources        | Reflecting the availability of water              |
| Actual water consumption                   | Reflecting the demand for water resources         |
| Per capita water consumption               | Reflecting people's awareness of water saving    |
| 10,000 yuan GDP water consumption          | Reflecting water efficiency                       |
| The Population growth rate                 | Reflecting the impact of population on water scarcity |
| Sewage discharge                           | Reflecting water pollution                        |
| Forest coverage rate                       | Reflecting the state of the ecological environment|

3. Forecast of Water Resources Shortage Risk in Shanxi Province

3.1. Basic Event Analysis Based on Markov Chain

Taking data on total water resources, total water resources, actual water consumption, per capita water consumption, water consumption per 10,000 yuan of GDP, population growth rate, sewage discharge and forest coverage in Shanxi Province from 2002 to 2017 respectively. The average of each item and the range of 10% above and below the average value, so that the division status of all the above basic events can be obtained, as shown in Table 2.

Table 2. State division of basic events

| Status                                           | Data division   |
|--------------------------------------------------|-----------------|
| The total amount of water resources decreased     | X<90.73         |
| The total amount of water resources is flat       | 90.73<X<110.82  |
| The total amount of water resources increased     | X>110.82        |
| Actual water consumption decreased                | X<60.58         |
| Actual water consumption is flat                  | 60.58<X<66.96   |
| Actual water consumption increased                | X>66.96         |
| 10,000 yuan GDP water consumption decreased      | X<109.8         |
| 10,000 yuan water consumption is flat             | 109.8<X<134.2   |
| 10,000 yuan GDP water consumption increased      | X>134.2         |
| Higher population growth rate                     | X<4.95          |
| The population growth rate is flat                | 4.95<X<6.05     |
| Lower population growth rate                      | X>6.05          |
| Per capita water consumption decreased            | X<174.4         |
| Per capita water consumption is flat              | 174.4<X<192.76  |
| Per capita water consumption increased            | X>192.76        |
| Increased forest coverage                         | X<14.63         |
| Forest coverage is flat                           | 14.63<X<17.79   |
| Reduced forest cover                              | X>17.79         |
| Sewage discharge decreased                        | X<13252         |
| Sewage discharge is flat                          | 13252<X<13599   |
| Sewage discharge increased                        | X>13599         |

Then we analyze the state transition matrix of all basic events, as shown in Table 3.
Table 3. State transition matrix of basic events

\[
\begin{pmatrix}
3/4 & 2/5 & 1/4 \\
1/4 & 0 & 1/2 \\
0 & 3/5 & 1/4 \\
\end{pmatrix}
\times
\begin{pmatrix}
1 & 1 & 0 \\
0 & 0 & 1/6 \\
0 & 0 & 5/6 \\
\end{pmatrix}
\times
\begin{pmatrix}
5/6 & 0 & 0 \\
1/12 & 1/2 & 0 \\
1/12 & 1/2 & 1 \\
\end{pmatrix}
\]

\[
\begin{pmatrix}
2/3 & 2/3 & 0 \\
1/3 & 1/3 & 1/6 \\
0 & 0 & 5/6 \\
\end{pmatrix}
\times
\begin{pmatrix}
3/4 & 0 & 1/6 \\
0 & 1 & 1/6 \\
1/4 & 1/8 & 2/3 \\
\end{pmatrix}
\times
\begin{pmatrix}
3/5 & 1/3 & 2/7 \\
1/5 & 1/3 & 1/7 \\
1/5 & 1/3 & 4/7 \\
\end{pmatrix}
\]

3.2. Minimum cut set

According to the fault tree model of water shortage in Shanxi Province, this paper considers that the changes of single basic elements in socio-economic factors and eco-environmental factors have limited impact on the changes of the whole system, so the system pays more attention to the middle-level elements caused by the changes of multiple factors. The impact of changes on the occurrence of top events. The minimum cut set is only five:

\[
\{X_1, X_2, X_3, X_4X_5, X_6X_7\}
\]

3.3. Structural importance

The structural importance indicates the size of the influence of each element in the fault tree system on the water shortage in Shanxi Province. We use FreeFta software to calculate:

\[
I(X_2)>I(X_3)>I(X_4)=I(X_5)=I(X_6)=I(X_7)
\]

3.4. Top event probability

From the above prediction of the possibility of occurrence of water shortage in Shanxi Province in 2019, the probability of occurrence of each basic event is shown in Table 4.

Table 4. The probability of each basic event of the water resources shortage in Shanxi province

| Basic events                              | Probability |
|-------------------------------------------|-------------|
| The total amount of water resources decreased | 0.45        |
| Actual water consumption increased        | 0.69        |
| Per capita water consumption increased    | 0.69        |
| 10,000 yuan GDP water consumption increased | 0.19        |
| Higher population growth rate             | 0.33        |
| Sewage discharge increased                | 0.43        |
| Reduced forest cover                      | 0.014       |

Using the FreeFta software to calculate the data in Table 4, the probability of water shortage in Shanxi Province in 2019 is about 0.95.

3.5. Probability importance

The probability importance of the basic events reflects the influence of basic events on the water shortage fault tree system in Shanxi Province from a quantitative perspective, and brings the probability of the top event and the probability of each basic event into the software. We obtain the probability importance of the basic event, as shown in Table 5.
Table 5. The basic events probability importance of water resources shortage in Shanxi province

| Basic events                                              | Probability importance |
|-----------------------------------------------------------|------------------------|
| The total amount of water resources decreased              | 0.083                  |
| Actual water consumption increased                         | 0.148                  |
| Per capita water consumption increased                     | 0.148                  |
| 10,000 yuan GDP water consumption increased               | 0.016                  |
| Higher population growth rate                              | 0.009                  |
| Sewage discharge increased                                 | 0.008                  |
| Reduced forest cover                                       | 0.016                  |

In 2019, Shanxi Province will have a higher probability of water shortage, with a probability of 95%, and the risk of water shortage is serious. Among the seven basic events selected in the paper that affect the water shortage in Shanxi Province, the actual water consumption and per capita water consumption are both in the qualitative analysis of structural importance and in the quantitative analysis of probability importance. The biggest basic event. Therefore, the possibility of reducing the actual water consumption can effectively reduce the probability of water shortage risk in Shanxi Province. Secondly, the total amount of water resources has a greater impact on the system than on the system. When the risk of water shortage occurs, priority should also be given to reducing the probability of failure.

4. Conclusion

In this paper, the method of fault tree is introduced into the risk assessment of water resources, and the risk of water shortage in Shanxi Province is analyzed and calculated. Systematically classify the main influencing factors affecting water shortage into the fault tree model, and use the Markov chain model to calculate the corresponding basic event probability, which can not only qualitatively and quantitatively analyze the system, but also according to the events in the system. The situation of change quickly gives the corresponding treatment, making the whole system more orderly. The research results and conclusions obtained in the thesis are as follows:

Establishing the top of the water shortage in Shanxi Province, taking water resources, social and economic factors and ecological environment as the middle-level events, with total water resources, actual water consumption, per capita water consumption, water consumption per 10,000 yuan of GDP, and population growth. Rate, sewage discharge and forest cover are the fault tree systems for basic events. In 2019, the probability of water shortage in Shanxi Province is 95%, and the risk of water shortage is serious.

In the basic incidents affecting the water shortage in 2019 Shanxi Province, the actual water consumption and per capita water consumption in Shanxi Province will increase the maximum in 2019, which is 69%. Therefore, the actual use of water resources in Shanxi Province should be strict in 2019. Control to avoid waste of water resources.

Through the analysis of the probability importance of the basic events affecting the shortage of water resources in Shanxi Province, the results show that the actual water consumption and per capita water consumption are the basic events with the highest impact on the system, and its importance is 0.148, followed by the importance of total water resources. The probability of occurrence of the above basic events is 0.083, which can effectively prevent the shortage of water resources in 2019 Shanxi Province.

References

[1] T.Hashimot, J.Stedinger, D.Loucks. Reliability,Resilien and Vulnerability Criteria for Water Resource System Performance Evaluation. Water Resources Research, Vo118, No1(1982)
[2] J.Petak William, A.Atkisson Arthur.Natural hazard risk assessment and public policy. NewYork: Springer-Verlag, (1982)109-138.
[3] V.S.Mloostvov. Multiple-criteria optimization under uncertainty: concept of optimality and
sufficient conditions. In: Theory and Practice of Multiple Criteria Decision Making New York: North-Holland, Iss: 9, (1983) 1-105.

[4] A. Colomn, G. Fronza. Reservoir management via reliability programming. Water Resources Research, Vol: 12, Iss: 1 (1976) 85-88.

[5] A. Goicoechea, L. Duckstein. Multiple objective under uncertainty: an illustrative application of procedure. Framwork. New York: McGraw Hill, (1985)

[6] Y.Y. Haimes, Risk-benefit analysis in a multiobjective. Framwork. New York: McGraw Hill, (1985)

[7] S.F. Zhang. Risk Composition and Assessment of Water Resources System: A Case Study of Beijing. Journal of Natural Resources, Iss: 11 (2010) 1855-1863.

[8] M.C. Huang. Fuzzy comprehensive evaluation of water shortage risk. Journal of Hydraulic Engineering, Vol: 38, Iss: 3 (2005) 906-912.

[9] J.G. Luo, J.C. Xie. Fuzzy comprehensive evaluation model for water shortage risk based on expropriation and its application. Journal of Hydraulic Engineering, Vol: 39, Iss: 3 (2008) 1092-1097.

[10] X.X. Zhang, P.F. Wu. Risk Assessment of Water Resources Utilization in Songliao River Basin Based on Spatial Cluster Analysis. Progress in geography, Vol: 29, Iss: 9 (2010) 1032-1040.