Evaluation of Liao River estuary with cumulative and sudden risk assessment methods

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Abstract. In order to strengthen the management of water environment, cumulative and sudden risks were integrated into risk assessment of water environment. Analytic hierarchy process (AHP) was used to empower the index system. The cumulative and sudden risks of water environment were divided into five levels. The zoning matrix of risk level was applied to evaluate Liao River estuary area. The evaluation results were basically consistent with the field survey results. Although the cumulative risk of Liaoning province in 2011-2017 showed a downward trend, it is still in a high-risk state. The investment in water treatment, the number of water treatment equipment and water quality were the major factors that affect the cumulative risk, and the critical enterprises around the Liao River estuary are the main factors that affect the sudden risk. The above indicators were controlled can reduce the water environment risk.

Keyword. Risk Assessment; Liao River; Analytic Hierarchy Process; Partition Matrix

1. Introduction
The risk of water environment is affected by many factors, with many kinds of risk sources; complex spatial distribution and easy to be affected by upstream and downstream cumulative transport substances [1]. The impact of different risk sources on the water environment is different. In order to quantitatively analyze the impact, it is necessary to evaluate the risk of water environment. The risk of water environment mainly consists of two parts: sudden environmental risk and cumulative environmental risk. The final water environment risk assessment result is obtained by combining the two parts with the risk level matrix, which provides sufficient auxiliary conditions for decision-making on water environment protection and water environment issues [2].

From the time point of view, the early research was more focused on a single receptor and risk source. In the actual research, it was found that the pollution of any environmental medium did not affect human life from a single way, but through a complex way. Since the end of 1990s, scientists had tried to conduct health risk assessment research on multiple exposure pathways of different receptors [3]. In 2003, the national environmental protection administration of the United States (EPA) issued the cumulative environmental risk assessment framework [4]. In 2004, European scientists launched the Sixth Framework integrated research project [5]. In 2010, Ken Sexton [6] proposed that cumulative risk assessment can provide a kind of systematic and fair environmental assessment information for policy-making, which showed that cumulative environmental risk research played an indispensable role in human life. In 2012, World Wide Fund for Nature or World Wildlife Fund...
(WWF) and Deutsche Investitions- und Entwicklungsgesellschaft mbH (DEG) jointly released the global water risk filter [7]. In 2013, the watershed accumulating environmental risk assessment were summarized by Wang [8]. Xie [9] built a source-acceptor-response framework to assess the risk of river basins. Wang [10] based on the management platform and control unit to assess the risk of river basins.

The cumulative risk assessment of water environment was based on the method proposed by EPA and the cumulative environmental risk assessment framework issued by WWF and DEG. The sudden risk assessment of water environment was based on the Pressure-State-Response (PSR) model and the risk level matrix was used to combine the assessment results [11].

2. Materials and Methods

2.1. Evaluation index system of cumulative risk of water environment

The EPA cumulative environmental risk assessment method and WWF water risk assessment tool was used to determine the cumulative risk indicators (Figure 1).

Physical risks were analyzed, including four categories: water scarcity, water pollution, and water environment ecosystem monitoring. In order to evaluate the cumulative risk of water environment, the WWF’s index conditions were investigated, and the index is modified and corrected reasonably.

To consider the factors of water scarcity, two basic indicators were selected in this paper: per capita water shortage rate and climate impact. The index meaning of per capita water shortage was the ratio between the difference between water consumption per capita and water resources per capita and water resources per capita. The specific formula is as follows:

$$\text{per capita water shortage rate} = \frac{\text{per capita water capacity} - \text{per capita water use}}{\text{per capita water capacity}}$$

(1)

The index meaning of climate effect was the change degree of temperature in this area compared with the average temperature in recent ten years. The specific formula is as follows:

$$\text{climate effect} = 1 - \frac{\text{the yearly mean temperature}}{\text{mean temperature over the past ten years}}$$

(2)

In terms of the factors of water pollution, when considering the cumulative risk, four basic indicators were selected in this paper: water quality status, dissolved oxygen (DO), the content of ammonia nitrogen (NH$_3$-N), permanganate index (COD$_{Mn}$).

In terms of the factors of water environment ecosystem health, when considering the cumulative risk, three aspects were considered in this paper: risk, exposure and vulnerability. The risk was mainly evaluated in four aspects: Industrial wastewater discharge, domestic wastewater discharge, fertilizer use intensity and urban sewage treatment rate. The exposure mainly analysis agriculture, industry, population and health environment, four basic indicators were selected: population density, irrigation area, number of industrial enterprises, and the prevalence of rural sanitary toilets. The threat of water biodiversity, water quality evaluation results of water system, and annual growth rate of gross domestic product (GDP) was used to assess vulnerability. The threat of water biodiversity was assessed by the method of freshwater biodiversity threat index mentioned by Vorosmarty et al. [12].

Regulatory risk was studied from four perspectives. The investment of water environment was analyzed by analyzing the percentage of environmental protection investment in GDP and the number of wastewater treatment facilities. The analysis of the complexity and transparency of water related laws and regulations system was mainly evaluate the results of laws and regulations system in different regions and the measures taken in the implementation process. The implementation of water related laws and regulations were mainly considered in the whole basin, and the results were analyzed and evaluated. And this paper evaluate and investigated the existence of water conservancy forums, online interviews, online letters and visits, and supervision and complaints related websites of each river basin.
Figure 1. Cumulative risk comprehensive indicator system.
The reputation risk was studied from two aspects. One was to analyze the importance of water in local culture. It mainly analyzed the importance of local traditional culture to water environment protection and water saving. The other was to analyze the reports of domestic and foreign media on the basin water problems, through the collection of domestic mainstream media to evaluate the reports of the basin water problems.

2.2. Evaluation index system of sudden risk of water environment

Index system of water environment emergency risk was established by the stress-state-response (PSR) model, a framework system of environmental research (Figure 2). The essence of PSR model is that hazards exert pressure on the environment, cause changes in the natural environment, and lead to human response [13].

The pressure system mainly included four aspects: the industry categories, the number of key enterprises that pollute the water environment, and the annual maximum monthly rainfall. The industry category was used to identify the magnitude of the risk of hazards to the source. The amount of key enterprises that pollute the water environment was determined to analyze the number of specific risk sources that may cause harm to the water environment of the basin. And the maximum monthly precipitation during the year was used to assess the possible damage to the water environment caused by sudden heavy precipitation.

The state system investigated the acceptability of the receptor when the risk occurs. The effect on human life, agriculture and fishery production was far greater than that on industrial production. In the basin, the main use of water was considered, so four subsystems are selected: irrigation area, population density, basin characteristics and fishery output value.

Figure 2. Sudden risk comprehensive indicator system.
The response system studied emergency response capabilities when risks occur. The more income people have, the stronger their ability to resist risks. The ability of emergency response after a risk occurs and the ability of the medical system to accept patients were directly related to the scale of the impact of the risk. Therefore, it mainly evaluated per capita GDP, the number of beds in medical institutions, and the risk control ability of risk sources.

2.3. Weight distribution of each index

In this paper, Analytic hierarchy process (AHP) was used to empower indicators. AHP is a subjective qualitative and quantitative analysis method that compares indicators one by one through expert opinions [14,15]. The specific implementation methods are as follows.

The judgment matrix is constructed. The target U_i, U_j (i, j = 1, 2, 3,...) are represented by B, the factor U_j represents the relative importance value of U_i to U_j, and the B-U judgment matrix P is composed of U_j. Then we use the square root method to solve the problem. The specific process is: calculating the product M_i of each row of elements in the judgment matrix P; calculating the n-th power root of M_i; for \( \hat{W} = (\hat{W}_1, \hat{W}_2, \hat{W}_3, ..., \hat{W}_n) \) After normalization, \( W_i = \frac{\hat{W}_i}{\sum_{i=1}^{n} \hat{W}_i} \) is the weight distribution value of each index. In order to test whether the weight distribution is reasonable, it is necessary to test the consistency of the judgment matrix. Test formula:

\[
CR = \frac{CI}{RI}
\]

Where, Cr is the random consistency ratio of the judgment matrix, CI is the general consistency index of the judgment matrix, and RI is the average random consistency index of the judgment matrix.

\[
CI = \frac{\lambda_{max} - n}{(n-1)}
\] (4)

\[
\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{PW_i}{W_i}
\] (5)

In formula 4 and 5, \( \lambda_{max} \) is the largest eigenvalue and PW is the combined weight of the target. When the CR value of the judgment matrix P is less than 0.1, P is considered to have satisfactory consistency; otherwise, the elements in P need to be adjusted to have satisfactory consistency. The matrix P was constructed by referring to certain literature and consulting relevant experts. [16] In this paper, MATLAB software was applied to weight calculation, and the weight calculation results were shown in Figure 3 and Figure 4.

![Figure 3. Cumulative risk weight of water environment.](image-url)
2.4. Risk classification of water environment

Five level scoring was used in the scoring standard of cumulative and sudden risk level of water environment. The indicator level was divided into five levels [17]: no risk or acceptable risk, low risk or binding risk, medium risk, high risk and extremely high risk, in Table 1.

Table 1. Water environment risk rating.

| Risk level                        | Grade | Risk description                                           |
|-----------------------------------|-------|-----------------------------------------------------------|
| no risk or acceptable risk (0.1)  |       | The probability of risk generation is very low or the damage is very weak |
| low risk or binding risk (1.2)    |       | To prevent risks by restricting water use                 |
| medium risk (2.3)                 |       | Damage caused by risk occurrence or potential existence   |
| high risk (3.4)                   |       | Risk is very easy to occur and cause great damage         |
| extremely high risk (4.5)         |       | Frequent occurrence of risk and non-recoverable damage    |

The following methods were used to determine the grading standards of indicators [18]:

1. The indicators were divided the specified grade classification value, with national or local standards.
2. For the indicators with references, the evaluation and grading standards listed were used in the literature;
3. Statistical yearbook of the index data of all provinces in China from 2011 to 2017, rank them, select the 5th and 95th percentages as the best or worst value, according to the best and worst values It can be divided into five levels;
4. Delphi method is used for subjective indicators. expert experience values were counted for classification of cumulative risk assessment index of water environment.

Classification standard of cumulative and sudden risk level are shown in Table 2 and Table 3

Table 2. Classification standard of cumulative risk level

| Risk grade | 1 | 2 | 3 | 4 | 5 |
|------------|---|---|---|---|---|
| per capita water shortage | 0.9 | 0.6 | 0.3 | 0 | -0.3 |
| climate effect(%) | 2% | 5% | 10% | 15% | 18% |
|------------------|----|----|-----|-----|-----|
| Water quality    | ClassI<sup>a</sup> | ClassII<sup>a</sup> | ClassIII<sup>a</sup> | ClassIV<sup>a</sup> | ClassV and poor ClassV<sup>a</sup> |
| NH<sub>3</sub>-N (mg·L<sup>-1</sup>) | 0.15 | 0.5 | 1 | 1.5 | 2 |
| COD<sub>Mn</sub> (mg·L<sup>-1</sup>) | 2 | 4 | 6 | 10 | 15 |
| DO (mg·L<sup>-1</sup>) | 20~7.5 | 6 | 5 | 3 | 2 |
| Industrial wastewater discharge (10<sup>5</sup> t) | 2000 | 5000 | 8000 | 10000 | 13000 |
| Domestic wastewater discharge (10<sup>4</sup> t) | 5000 | 20000 | 40000 | 60000 | 80000 |
| the amount of fertilizer applied (10<sup>5</sup>t) | 5 | 10 | 20 | 30 | 40 |
| wastewater treatment rate | 0.95 | 0.9 | 0.85 | 0.8 | 0.75 |
| Population density (cap/km<sup>2</sup>) | 100 | 300 | 500 | 700 | 900 |
| Irrigated area (1000hm<sup>2</sup>) | 50 | 100 | 150 | 200 | 250 |
| Number of industrial enterprises | 200 | 500 | 800 | 1000 | 1500 |
| Prevalence of rural sanitary toilets | 95 | 90 | 80 | 70 | 65 |
| Biodiversity threat | 0.2 | 0.2~0.4 | 0.4~0.6 | 0.6~0.8 | 0.8 |
| Assessment results of water quality in the basin | Proportion of class I and class II water quality in the basin>0.5 | Proportion of class I and class II water quality in the basin>0.4 | Proportion of class I and class II water quality in the basin>0.3 | Proportion of class I and class II water quality in the basin>0.2 | Proportion of class I and class II water quality in the basin>0.1 |
| growth rate of GDP | 0.25 | 0.14 | 0.03 | -0.09 | -0.2 |
| Proportion of environmental protection investment in GDP | 1 | 0.8 | 0.6 | 0.4 | 0.2 |
| Number of wastewater treatment facilities | 500 | 400 | 300 | 200 | 100 |
|------------------------------------------|-----|-----|-----|-----|-----|
| Complexity and transparency of water related laws and regulations | 1 level | 2 level | 3 level | 4 level | 5 level |
| Implementation of water related laws and regulations system | 1 level | 2 level | 3 level | 4 level | 5 level |
| Stakeholders discuss relevant water issues in official forums or platforms | 1 level | 2 level | 3 level | 4 level | 5 level |
| The importance of water in local culture and religion | 1 level | 2 level | 3 level | 4 level | 5 level |
| Media reports on water environment problems in river basins at home and abroad | None | Rarely (> once a year) | Occasionally (> every 6 months) | Frequently (> once a month) | always (> once a week) |

* An official water quality classification standard in China

**Table 3.** Classification standard of sudden risk level.

| Risk grade | 1 | 2 | 3 | 4 | 5 |
|------------|---|---|---|---|---|
| Industry category | Agricultur al and sideline food manufacturing and others | Pesticide and fertilizer manufacturing industry, | Paper industry, metal processing industry, | Electroplating industry, printing and dyeing industry, pharmaceutical manufacturing industry, ferrous metal refining and rolling processing industry, coal | Petrochemical industry, chemical raw materials and chemical products manufacturing industry, nonferrous metal mining |

| Industry category | Agricultur al and sideline food manufacturing and others | Pesticide and fertilizer manufacturing industry, | Paper industry, metal processing industry, | Electroplating industry, printing and dyeing industry, pharmaceutical manufacturing industry, ferrous metal refining and rolling processing industry, coal | Petrochemical industry, chemical raw materials and chemical products manufacturing industry, nonferrous metal mining |
|                          | non-metallic mineral products industry | mining and washing industry | and processing industry, nuclear industry |
|--------------------------|----------------------------------------|----------------------------|------------------------------------------|
| Number of key sewage enterprises that pollute the water environment | <10 | 10~20 | 20~30 | 30~40 | 40~50 |
| Maximum monthly rainfall during the year | 200 | 300 | 400 | 500 | 600 |
| Irrigation area | 50 | 100 | 150 | 200 | 250 |
| Population density | 1000 | 2000 | 3000 | 4000 | 5000 |
| Watershed characteristics | Industrial water area | Agricultural water area | Basin buffer zone | Fishery water area, Nature Reserve | Drinking water source area |
| Fishery output value | 25 | 50 | 100 | 200 | 300 |
| GDP per capital | 120000 | 100000 | 70000 | 40000 | 20000 |
| Number of beds per thousand people in hospital | 8 | 7 | 6 | 5 | 4 |
| Risk emergency response | 1 level | 2 level | 3 level | 4 level | 5 level |

Figure 5. Risk degree partition matrix.
2.5. Risk degree partition matrix
Risk assessment is an important and complex scientific problem. In order to compare the magnitude of risk, people often use expected value to replace probability distribution, or select some operator or some operator to make mathematical combination of relevant quantities. "Add" and "multiply" are the two operators with the highest frequency. The definition and general expression of natural disaster risk adopted in this paper are as follows:

\[ \text{Risk} = \text{cumulative risk} + \text{sudden risk} \]  

(6)

In practical analysis and application, risk assessment is to determine the relative size of risk, mostly qualitative and semi quantitative risk assessment model. Taking the county as the basic unit, the risk degree of each evaluation unit can be calculated according to formula 7. The risk level is generated by cumulative risk and sudden risk. The cumulative risk level and sudden risk level are divided into five levels, and the risk level zoning matrix is obtained [19] (Figure 5).

3. Results and discussion

3.1. Study area
Liao River Basin is one of the seven major basins in China (Figure 6). It is located in the southwest of Northeast China, with a total length of 1345 kilometers. It runs through the middle of Liaoning Province from north to south, and finally enters the sea in Liaodong Bay. Liao River estuary in Panjin of Liaoning Province is selected for analysis. It is located in the south end of Liao Delta, where there are a large number of oil fields.

![Figure 6. Topographic map of Liao River in Liaoning Province.](image)

3.2. Data sources
The data included the regional social and economic development data, meteorological data, social basic situation data, government supervision data and media data which were looked up from ‘China Statistical Yearbook’, ‘China Meteorological Yearbook’, ‘China Meteorological Disaster Yearbook’, ‘China Water Conservancy Yearbook’, ‘China Health Statistics Yearbook’, ‘China Environmental Statistics Yearbook’, ‘Liaoning statistical yearbook’, etc. And the other of data came from relevant websites of relevant departments, activities in water culture construction, collection of domestic mainstream paper, network media reports on water issues and other network information.
3.3. Risk analysis
According to the above data sources, find the index parameters of Liaoning Province in 2011-2017, determine the index scores according to table 1, and substitute the weights determined in Table 2 to get the specific comprehensive evaluation index, as shown in Table 4.

|                      | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   |
|----------------------|--------|--------|--------|--------|--------|--------|--------|
| per capita water shortage | 0.1979 | 0.1322 | 0.1443 | 0.2670 | 0.2843 | 0.1754 | 0.2558 |
| climate effect (%)  | 0.0776 | 0.0084 | 0.0494 | 0.0737 | 0.0438 | 0.0930 | 0.0532 |
| Water quality       | 0.5385 | 0.5385 | 0.4308 | 0.4308 | 0.4308 | 0.5385 | 0.4308 |
| NH$_3$-N (mg·L$^{-1}$) | 0.0442 | 0.0603 | 0.0998 | 0.0790 | 0.0977 | 0.0804 | 0.0625 |
| COD$_{Mn}$ (mg·L$^{-1}$) | 0.1122 | 0.0952 | 0.1113 | 0.1113 | 0.1113 | 0.0557 | 0.0928 |
| DO (mg·L$^{-1}$)    | 0.0718 | 0.1303 | 0.0689 | 0.0327 | 0.0313 | 0.0855 | 0.0311 |
| Industrial wastewater discharge ($10^5$ t) | 0.0429 | 0.0445 | 0.0472 | 0.0489 | 0.0479 | 0.0345 | 0.0271 |
| Domestic wastewater discharge ($10^5$ t) | 0.0359 | 0.0366 | 0.0365 | 0.0370 | 0.0370 | 0.0370 | 0.0372 |
| the amount of fertilizer applied ($10^5$ t) | 0.0285 | 0.0268 | 0.0268 | 0.0268 | 0.0268 | 0.0268 | 0.0265 |
| wastewater treatment rate | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Population density(cap/km$^2$) | 0.0558 | 0.0551 | 0.0551 | 0.0551 | 0.0552 | 0.0553 | 0.0554 |
| Irrigated area(10$^4$hm$^2$) | 0.0332 | 0.0338 | 0.0291 | 0.0291 | 0.0293 | 0.0299 | 0.0300 |
| Number of industrial enterprises | 0.0181 | 0.0181 | 0.0181 | 0.0246 | 0.0236 | 0.0211 | 0.0157 |
| Prevalence of rural sanitary toilets | 0.0851 | 0.0851 | 0.0786 | 0.0735 | 0.0633 | 0.0563 | 0.0524 |
| Biodiversity threat | 0.1192 | 0.1192 | 0.1192 | 0.1192 | 0.1192 | 0.1192 | 0.1192 |
| Assessment results of water quality in the basin | 0.1299 | 0.0736 | 0.0629 | 0.0684 | 0.0788 | 0.0779 | 0.0970 |
| growth rate of GDP | 0.0190 | 0.0296 | 0.0386 | 0.0464 | 0.0466 | 0.0649 | 0.0341 |
| Proportion of environmental protection investment in GDP | 0.1427 | 0.1164 | 0.1354 | 0.1174 | 0.1343 | 0.1421 | 0.1416 |
| number of wastewater treatment facilities | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 | 0.3000 |
| Complexity and transparency of water related laws and regulations | 0.1500 | 0.1500 | 0.1500 | 0.1500 | 0.0750 | 0.0750 | 0.0750 |
| Implementation of water related laws and regulations system | 0.1500 | 0.1500 | 0.1500 | 0.1125 | 0.1125 | 0.0750 | 0.0750 |
| Stakeholders discuss relevant water issues in official forums or platforms | 0.1800 | 0.1800 | 0.1200 | 0.1200 | 0.1200 | 0.1200 | 0.1200 |
| The importance of water in local culture and religion | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 |
| Media reports on water environment problems in river basins at home and abroad | 0.1600 | 0.1600 | 0.1600 | 0.1600 | 0.1600 | 0.1600 | 0.1600 |
| Total | 2.7925 | 2.6437 | 2.5320 | 2.5834 | 2.5185 | 2.5235 | 2.3908 |

From Table 4, it can be seen that the cumulative risk of water environment in 2011-2017 is in medium risk, and the trend is to reduce year by year, and the proportion of various risks is basically stable. This is closely related to the active management of Liaoning Province and the country.
the upgrading of technology, the supervision of water environment has been strengthened year by year, and the cumulative risk of water environment has been decreasing year by year. However, the basin continues to be at medium risk, and the water quality situation in the basin is still severe. The shortage of water treatment equipment is also the main reason that affects the risk of water environment. It will take some time to improve the water quality.

Table 5. Sudden risk assessment.

|                    | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   |
|--------------------|--------|--------|--------|--------|--------|--------|--------|
| Industry category  | 0.6321 | 0.6321 | 0.6321 | 0.6321 | 0.6321 | 0.6321 | 0.6321 |
| Number of key sewage enterprises that pollute the water environment | 0.6373 | 0.6373 | 0.6373 | 0.6373 | 0.6373 | 0.6373 | 0.6373 |
| Maximum monthly rainfall during the year | 0.1765 | 0.2174 | 0.1750 | 0.1427 | 0.1390 | 0.3633 | 0.1379 |
| Irrigation area    | 0.0958 | 0.0974 | 0.0839 | 0.0839 | 0.0845 | 0.0863 | 0.0863 |
| Population density | 0.2046 | 0.2018 | 0.2017 | 0.2020 | 0.2023 | 0.2027 | 0.2029 |
| Watershed characteristics | 0.2156 | 0.2156 | 0.2156 | 0.2156 | 0.2156 | 0.2156 | 0.2156 |
| Fishery output value | 0.1021 | 0.1104 | 0.1151 | 0.1163 | 0.1190 | 0.1191 | 0.0960 |
| GDP per capita     | 0.2396 | 0.2173 | 0.1965 | 0.2067 | 0.2166 | 0.2668 | 0.2513 |
| Number of beds per thousand people in hospital | 0.1125 | 0.1218 | 0.1116 | 0.1032 | 0.0989 | 0.0778 | 0.0592 |
| Risk emergency response | 0.1720 | 0.1720 | 0.1720 | 0.1720 | 0.2150 | 0.2150 | 0.2150 |
| Total              | 2.5881 | 2.6232 | 2.5408 | 2.5119 | 2.5604 | 2.8160 | 2.5337 |

From Table 5, the risk of water environment emergencies fluctuated in 2011-2017, reaching the maximum value of water environment risk in 2016. Through the analysis of the data, it is found that the increase of precipitation in 2016 increases the possibility of water environment emergencies, increases the risk, and the reduction of Panjin’s per capita GDP due to the economic environment and other factors reduces the response capacity, but the main reason is that many industrial enterprises, such as oil fields, are established in the estuary area, which will affect the water environment, increase the risk sources and improve the level of water environment emergency risk. According to the risk level zoning matrix, we get the final risk assessment results as shown in Table 6.

Table 6. Risk assessment.

|                     | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   |
|---------------------|--------|--------|--------|--------|--------|--------|--------|
| Cumulative risk assessment | 2.7925 | 2.6437 | 2.5320 | 2.5834 | 2.5185 | 2.5235 | 2.3908 |
| Sudden risk assessment    | 2.5881 | 2.6232 | 2.5408 | 2.5119 | 2.5604 | 2.8160 | 2.5337 |
| Total                | 5.3806 | 5.2669 | 5.0728 | 5.0953 | 5.0788 | 5.3395 | 4.9245 |

4. Conclusions

Based on the cumulative environmental risk assessment framework proposed by EPA, combined with the water environmental risk model framework of WWF and DEG, this paper evaluates the cumulative risk and applies the stress state response model to analyse the sudden risk, and based on this, uses the “plus” operator. The comprehensive risk assessment results of water environment in Liao River estuary are obtained. Due to the complexity of risk formation and many influencing factors, it is difficult to analyse the risk completely and quantitatively. The evaluation of this paper is only a preliminary exploration in this respect.
The results of cumulative risk assessment show that the supervision of Liao River estuary area has been strengthened year by year, but the impact of water treatment investment and water treatment equipment is greater, and the poor water quality in this area is also the main source of risk, but the trend of cumulative risk is decreasing year by year, which shows that the environmental governance work in China in the past 10 years is effective.

The results of sudden risk assessment show that the main risk sources of Liao River estuary are the number of enterprises that are dangerous to the water environment and the highly dangerous industry nearby, Liao Oilfield. At the same time, it is found that the risk of 2016 is the highest. Through analysis, it is found that the precipitation in 2016 is significantly higher than that in previous years, which is also the reason for the increased risk of emergencies.

The evaluation results are basically consistent with the field investigation of the author. The evaluation results have certain practical application value, which can provide the basis for the environmental related departments in the macro decision-making. When evaluating the water environment risk, more factors should be considered, such as pollutant diffusion speed, water environment capacity, etc., which will be further studied in the future.

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