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Comprehensive risk assessment of the Luojiang River basin water environment in Western Guangdong Province

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ABSTRACT

To evaluate the comprehensive risk to the Luojiang River Basin water environment in western Guangdong, China, a comprehensive risk assessment system was constructed based on three aspects: the water environment hazard, the water environment vulnerability and the ability of regional governance. The data for 2004 and 2014 were selected, and the comprehensive risk to the water environment in the Luojiang River basin was evaluated using the water pollution risk index and analytic hierarchy process, Additionally the spatial risk distribution map of the Luojiang River Basin in western Guangdong was drawn and the spatial variation of water environment risk was analysed. The results show that from 2004 to 2014, the risk and vulnerability of the water environment in the watershed decreased, the regional governance ability increased, and the risk to the water environment gradually decreased, among which, Shiwan town was in the high risk level, and Jianghu town was in the low risk level.

Keywords: Watershed risk management; Water environment; Risk assessment; Analytic hierarchy process

1. Introduction

Water resources are key to human survival. With the development and utilization of water resources in agricultural irrigation, industrial water use, domestic water use, freshwater farming, urban construction, tourism and so on, the water pollution problem is becoming increasingly serious, and the types and quantities of water pollution sources are increasing. Water environmental risk has become a problem that cannot be ignored. With the acceleration of urbanization and the gradual development of industry and agriculture, the waste produced by human activity will pollute groundwater to different degrees [1], and have an impact on the health of residents, resulting in increased morbidity and death. The state of the watershed water environment is closely related to the life of the people. Human beings need to use water for life and production [2]. How to scientifically evaluate the possible risks to the watershed water environment has become a hot issue that needs to be solved urgently.

Watershed water environmental risk assessment is the basis of water environmental pollution prevention and control. The research on water environmental risk in foreign countries includes two aspects: (1) to avoid risks by establishing early warning systems, such as the water pollution early warning system of the Rhine River Basin with continuous water quality monitoring , that effectively avoids the risk of accidental pollution such as leakage, industrial accidents, transportation accidents, etc. [3], (2) and by risk assessment of the pollutants in a water body.

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Tornqvist et al. [4] monitored the water environment in the Amu River Delta region, and analysed the possible water pollution health risks in a large area. The risk assessment of surface water and sediment polluted by heavy metals released by a municipal solid waste composting plant was carried out by Sharifi et al. [5]. The risk assessment of water environmental pollution in China is mainly based on the analysis of the influence of the concentration of various pollutants on the water quality, and on the basis of which, the risk assessment and the construction of he water pollution risk assessment system are carried out. Liu Xiaohui et al. [6] identified the risk sources and their influencing factors based on watershed characteristics, and discussed watershed risk assessment methods from 3 aspects including water eutrophication, organic matter and heavy metals. It is suggested that we should increase the intensity of water pollution control. Li Guowei et al. [7] based on geographical data, risk sources and sensitive targets of The three Gorges Reservoir area, constructed a risk assessment system for area water pollution that realizes the basic functions of GIS and risk assessment. It has good feasibility and practicability. On the basis of the water pollution risk assessment index system designed by Shi [8], the relative weight of each risk index is determined by analytic hierarchy, and the water pollution risk assessment model is established, and applied to the early warning of water environment safety in the Three Gorges Reservoir area.

Based on a comprehensive analysis in the Luojiang River Basin from the point of view of environmental disaster risk, three factors affecting water environmental risk, such as risk, vulnerability and regional governance ability, are determined. AHP and the water pollution risk index method were used to study the watershed water environmental risk, and were combined with GIS technology to draw the water environmental risk map for each town of Huazhou City in the Luojiang River Basin of western Guangdong Province in 2004 and 2014. Vulnerability and regional governance capacity indicators are comprehensively assessed and their spatial changes are analysed. The research method can provide the basis for water environmental risk management, and can effectively reduce the water environmental risk by adjusting it, along with the vulnerability and regional governance capacity. It provides a reference for the prevention of water environmental risk in the Luojiang River Basin in the future.

2. General situation of the study area

The Luojiang River is a tributary of the Jian River, originating in the Guangxi Zhuang Autonomous Region Beiliu City, with a head on the slope in Huazhou City. Flowing through Wenlou, Pingding, Hejiang, Rianghu, Forest Dust, Guanqiao and other towns to Huazhou City and into the Jianjiang River, the total length is 143 km, and the catchment area of 2618 km^2. The Luojiang River peripheral tributaries are the Jianjiang, Guanqiao, and Shiwan Rivers, as well as the Zhongdong water. The northern and eastern regions of the basin are high mountain areas, and the middle west is a hilly platform, the middle and lower reaches of the river are a wider plain.

The Luojiang River flows through Guangdong and Guangxi, and its water pollution has recently received widespread attention. According to the environmental function zoning table for surface water in Guangdong Province, the water quality target of the lower reaches of Huazhou from the Hejiang Estuary to Huazhou County in the Luojiang section is part of second class water divided into three kinds of water. The State Environmental Protection Administration (SEPA) recommends surface water standards of less than 150 mg per litre of suspended matter. The main pollutants in the Luojiang River are suspended solids. At worst, the pollutants per litre of water reach 5000 to 6000 mg, and at the lowest, 200 to 300 mg per litre, exceeding the national standard. This paper selects Jianghu Town, Lin Ji Town, Guanqiao Town, the Shiwan District and the Hexi District on both banks of the lower Luojiang River (Fig. 1) to comprehensively assess the water environmental risk in each region.

3. Research methodology and assessment framework

3.1. Analytic hierarchy process (AHP)

The AHP is a method for qualitative and quantitative analysis of indicators through one-to-one comparisons. In this study, the AHP method is used to analyse and determine the weight of each water environmental risk assessment index. The specific method [9,10] to determine the weight is as follows:

Construct a judgment matrix to represent the target by A,U_i, U_j (i, j = 1, 2, ..., n). Factor , U_{ij} represents the relative

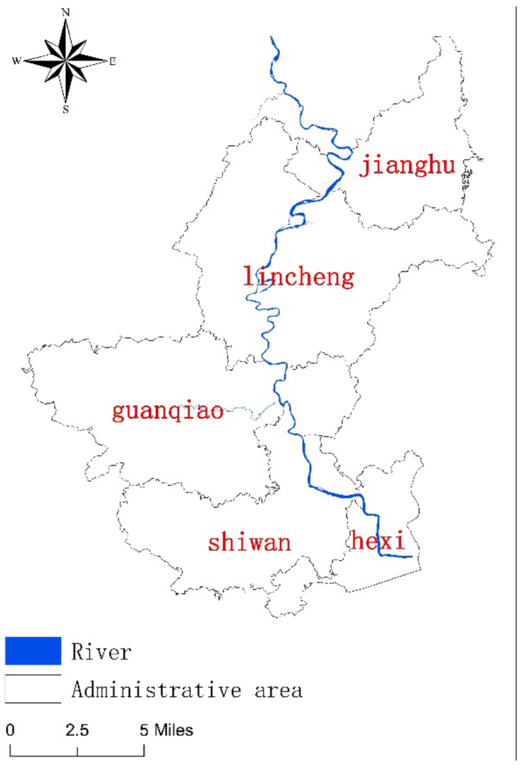


Fig. 1. The diagrammatic sketch of the research area.

importance of U_i to U_j ,The A-U judgment matrix P consists of U_{ij}.

$$P= P = \begin{bmatrix} U_{11}U_{12}.....U_{1n} \\ U_{21}U_{22}.....U_{2n} \\ .... \\ U_{n1}U_{n2}.....U_{nn} \end{bmatrix}$$

Calculate the weight distribution, and use the square root method to solve, the specific process: Calculate the product of each row element of the judgment matrix M_i, and calculate the nth power root of M_i: A normalized treatment of $\overline{W} = \left(\overline{W}_1, \overline{W}_2, \overline{W}_3, ..., \overline{W}_n\right)$, and $W_i = \overline{W}_i / \sum_{i=1}^{n} \overline{W}_i$, W_i is the allocation of weights for each indicator.

Consistency check. To check whether the weight distribution is reasonable, we need to check the matrix consistency using the following test formula:

$$CR = \frac{CI}{RI} \quad (1)$$

The random consistency ratio CR is the judgement matrix, and CI is the general consistency index of the judgment matrix;

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (2)$$

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(pw)_t}{W_t} \quad (3)$$

RI is the average random consistency index of the judgment matrix. When the judgment matrix p has a CR < 0.1, it is considered that P has satisfactory consistency. Otherwise, the elements in P need to be adjusted to make it have satisfactory consistency.

3.2. Water environmental risk assessment framework

The risk to the water environment is composed of three main factors: risk, vulnerability and regional management ability; the magnitude of water environmental risk in the basin is the result of the comprehensive action of these three factors. Each factor is affected by different indices. The danger refers to the possible harm caused by water pollution, such as eutrophication of water bodies, excessive organic matter, heavy metal and so on. Vulnerability refers to farmland and populations affected by water pollution. The above three factors affect the risk to the water environment. The water environmental risk assessment framework is shown in Fig. 2.

4. Construction of a water environmental risk assessment model

4.1. Water environmental risk index model

Referring to the theory of natural disaster risk, water environmental risk is the result of the comprehensive action of risk, vulnerability and regional governance ability on the water environment. Considering three factors of water environmental risk formation and their corresponding indices synthetically, and using the analytic hierarchy process to determine the weight of each index, the water environmental risk index model is established.

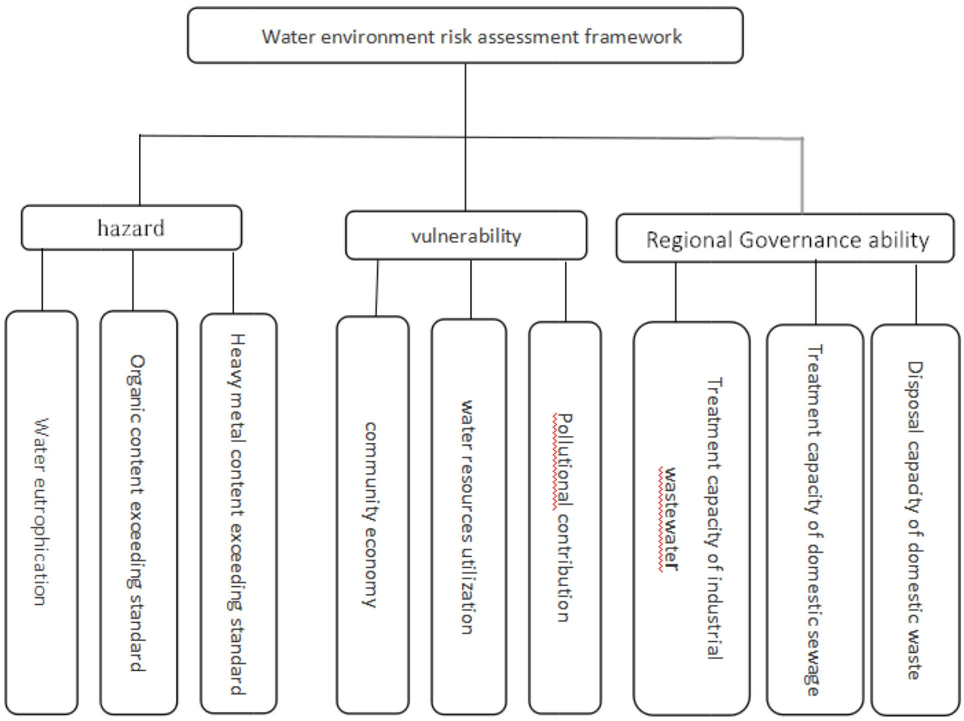


Fig. 2. The framework of water environment risk assessment.

$$RISK = H^{WH} \times V^{WV} \times (1-G)^{WG} \quad (4)$$

$$H(V,G) = \sum_{i=1}^{n} X_i \times W_i \quad (5)$$

RISK is the index indicating the water environmental risk magnitude. H, V, and G, respectively indicate the corresponding water environmental risk, vulnerability and regional governance capacity factor index. WH, WV, and WG represent the weight value of each factor. *i* is the weight value of each evaluation index, and W_i is the index weight value that indicates the relative importance of each index to the factors forming water environmental risk. X_i is the quantitative value of each evaluation index.

4.2. Index system for water environmental risk assessment

The selection of a risk assessment index is the premise and key of water environmental risk assessment. This study combines actual water environmental problems in the Luojiang River Basin to select indicators. According to the water environmental risk formation process of starting from the risk, vulnerability and regional governance ability, 12 indices of 3 factors listed in Table 1 are selected, and the index system is established. The weight of each factor and index is calculated synthetically using the analytic hierarchy process (AHP).

4.3. Calculation of the index value

The amount of fertilizer and pesticide, discharge of domestic sewage, discharge of industrial wastewater, cultivated land area, population density, water consumption for ten thousand yuan GDP, treatment rate of domestic sewage, and harmless disposal rate data come from the Statistical Yearbook of Huazhou City and the related water resources report.

The amount of soil erosion emission is calculated by the United States USLE, which guides people to carry out proper farming and management and appropriate conservation measures to maintain the soil by calculating the average annual soil loss. It takes into account rainfall (R), soil erosion (K), crop management (C), slope (S), slope length (L) and soil and water conservation measures (P).

$$A = R \times K \times L \times S \times C \times P \quad (6)$$

A represents the amount of soil loss per unit area of sloping land, which mainly refers to the annual average amount of soil loss caused by rainfall and its runoff caused by rill or rill erosion on the slope surface.

The carrying capacity of water resources refers to the maximum capacity to supply water for industrial and agricultural production and ecological environmental protection, as well as the number of people that water resources can sustain in a certain area under the normal social and material living standards. The larger the bearing capacity of water environment is, to the outside world, the lower its vulnerability. The DEA model is used to calculate the water resources carrying capacity [11].

The ratio of pollution to runoff refers to the ratio of sewage discharge to river runoff, and the larger the ratio of sewage to runoff is, the worse the water quality of the river. The amount of sewage discharge in this study is calculated according to the sum of the discharge of runoff sewage and industrial waste water, and the calculation of runoff and related data are referred to in the literature [12].

5. Results and analysis

5.1. Water environmental hazard analysis

The heavy use of chemical fertilizers and heavy rainfall will lead to an increase in nitrogen and phosphorus content and eutrophication of water bodies. The discharge of industrial wastewater and domestic sewage will cause heavy metals and organic pollutants to exceed the standard. The water environmental risk analysis mainly considered four indices: the amount of soil erosion, the amount of chemical fertilizer and

Table 1
The index system for water environmental risk assessment

Water environmental risk factors	Accessory factors	Index	Comprehensive weight
Hazard (0.45)	Water eutrophication	Fertilizer and pesticide use (kg)	0.22
		Soil erosion emission (kg)	0.31
	Organic matter exceeding standard	Domestic sewage discharge (kg)	0.30
	Heavy metal exceeding standard	Industrial waste water discharge (kg)	0.17
	Community economy	Density of population	0.19
		Agricultural acreage	0.17
Vulnerability (0.34)	Water resources utilization	Water resources carrying capacity	0.25
		Ten thousand yuan GDP water consumption	0.18
	Pollution contribution	Pollution diameter ratio	0.21
Regional governance capacity (0.21)	Treatment of industrial waste water	Industrial effluent (%)	0.19
	Treatment of domestic sewage	Domestic sewage treatment rate (%)	0.61
	Disposal of domestic waste	Domestic waste disposal rate (%)	0.20

pesticides, the discharge of industrial wastewater and the discharge of domestic sewage. Fig. 3 shows that the risk to the water environment decreased gradually from 2004 to 2014. In terms of spatial distribution, the main areas with higher water environmental risk were Ligang Town, Guanqiao Town and the Shiwan District. The discharge of industrial wastewater and domestic sewage is higher than that of other towns. With the development of society, increasing attention has been paid to the management of water pollution in the city. The use of chemical fertilizer, pesticides and industry, and the discharge of domestic wastewater have taken corresponding measures, resulting in the reduction of water environmental risk in 2014.

5.2. Water environment vulnerability analysis

Considering The carrying capacity of a water body to the outside world, the consequences of water pollution and the socio-economic situation of water use, population density, arable land area, the carrying capacity of water resources, the ratio of sewage to the runoff, and the water consumption for a 10000 yuan GDP is considered the vulnerability analysis index. Fig. 4 shows that from 2004 to 2014, the water environmental vulnerability in the watershed gradually decreased, and the water environmental vulnerability in Shiwan and Hexi has been very high.

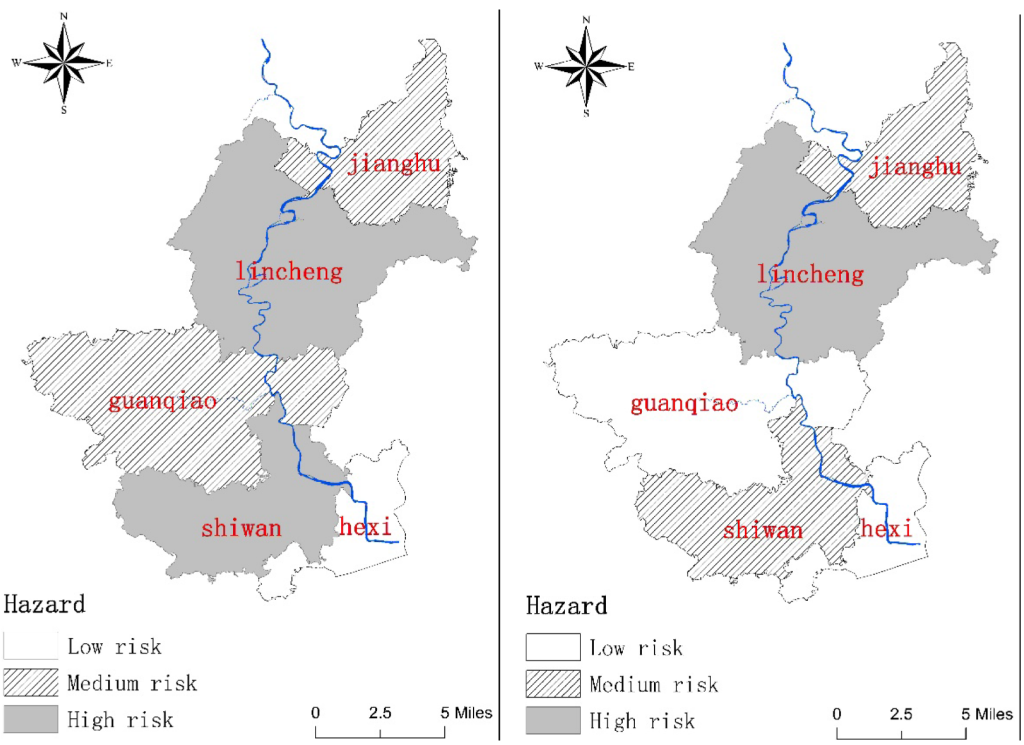
As a result of its economic development, the population scale is higher than that of other towns and townships, and the capacity of water resources to supply industrial production and human life is relatively small. Guanqiao Town is affected by upstream pollutant sludge; the sewage content in the water body is relatively high and the pollution path is relatively large. The vulnerability of these three districts and towns is higher than in tother districts.

5.3. Analysis of water environmental regional governance ability

The regional water environment treatment ability mainly analyses the region based on three aspects: industrial waste water treatment ability, domestic sewage treatment ability and domestic waste treatment ability. Fig. 5 shows that the capacity of water environment regional management was gradually strengthened in 2004 and 2014. The results show that the governments of counties and cities pay increasing attention to the problem of water environmental pollution, among which the treatment of industrial waste water is better. The treatment of domestic sewage and domestic waste should be further strengthened.

5.4. Water environmental risk assessment

According to the conceptual framework of water environment risk assessment and GIS technology, the water environmental risk index (RISK) is calculated according to the assessment model. To determine the optimal classification and threshold of water environmental risk in the Luojiang River Basin, the optimal



(a) 2004 (b) 2014

Fig. 3. The variation of the water environment hazard.

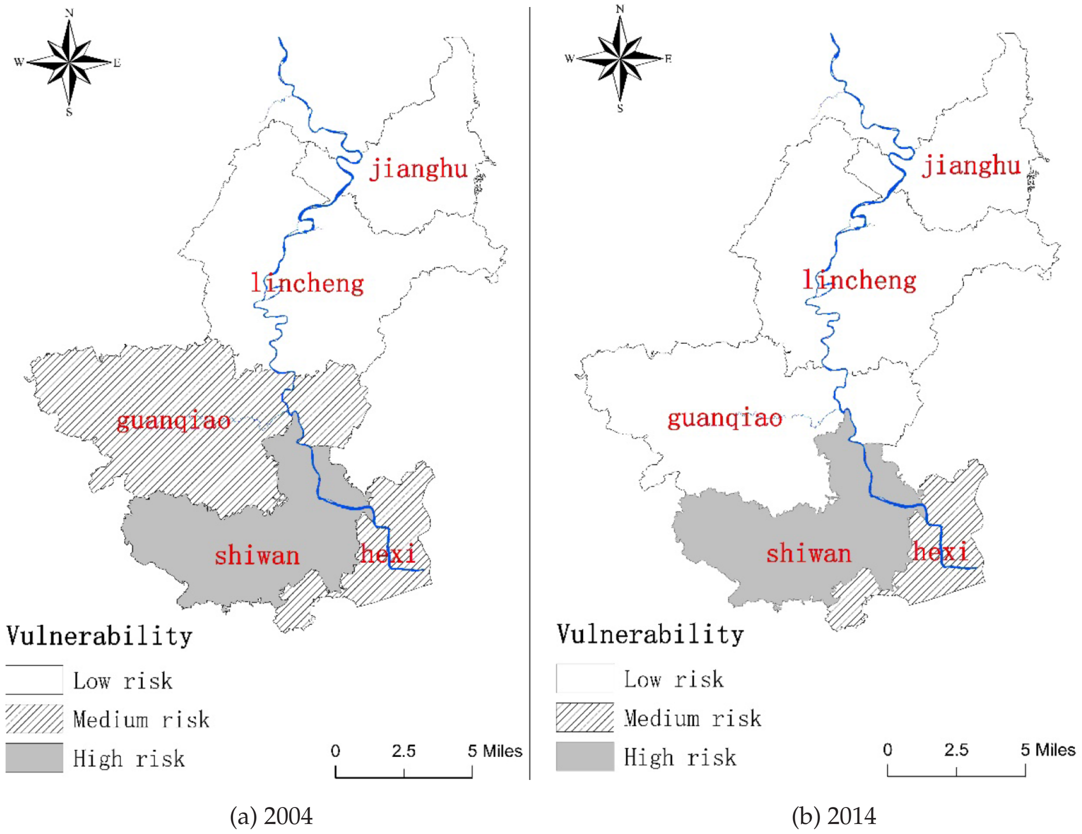


Fig. 4. The variation of water environmental vulnerability.

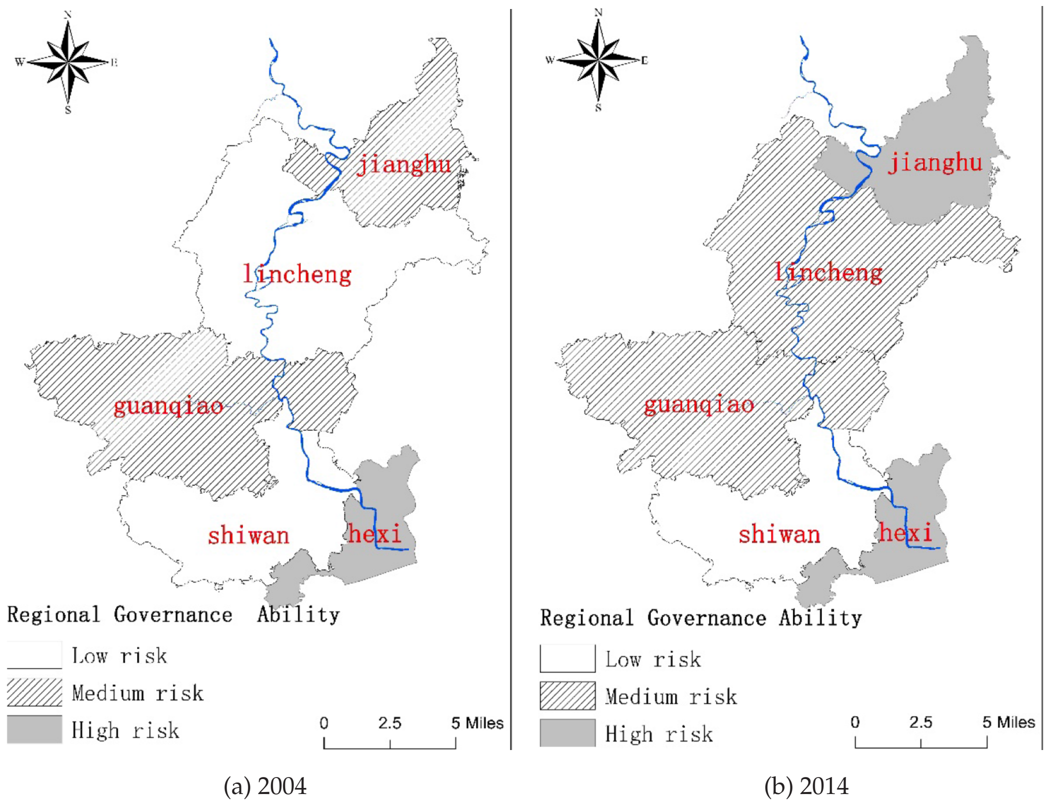


Fig. 5. The variation of water environment regional governance ability.

segmentation method is applied to the risk index. For the analysis of the optimal segmentation scatter plot, 5 segments is good, so the water environmental risk of the Luojiang River Basin is determined to have 5 grades: low risk, lower risk, medium risk, high risk and higher risk (Table 2). The risk zoning is carried out with this threshold to obtain the water environmental risk zoning map of the Luojiang River Basin in different years (Fig. 6). As seen in Tables 3 and Fig. 6, from 2004 to 2014, the overall trend of water environmental risk in the basin is decreasing. Shiwan has been at a high risk level, and Jianghu Town has been at a low risk level. This is related to the social and economic development of counties and cities. From the analysis of various indicators, from 2004 to 2014, the risk and vulnerability of the water environment gradually decreased, the capacity of regional governance continuously improved, and the weight of each index was synthesized. The proportion of water environmental risk is the largest, and it depends on change to a great extent, so it decreases gradually.

Table 2
The grade division of water environment risk

Water environmental risk index	Low risk	Medium risk	High risk
2004	<263	263–1500	>1500
2014	<230	230–460	>460

6. Conclusion

Based on the hazard, vulnerability and regional ability to control water environmental risk, this paper analysed the watershed risk using the water pollution risk index method, which is a comprehensive consideration of water environmental risk. However, there are many factors involved in water environmental risk, and the risk development process is complex. Therefore, in future research, we should consider not only the risk formation mechanism but also transmission. The sensitivity of the risk receptor and the three factors mentioned in the study that affect the risk to the water environment should also be analysed, and the corresponding risk prevention measures should be put forward on the basis of loss to the social economy and harm to human health caused by the risk receptor, effectively controlling the risk to the watershed water environment.

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(a) 2004

(b) 2014

Fig. 6. The variation of risk to the water environment.

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