Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2019.24163

158 (2019) 33–40
August

Water environmental risk assessment and regionalization in southeast coastal basins of China

Wenting Zhang[a,b,*], Yongzhi Liu[c,d]

[a]*College of Hydrology and Water Resource, Hohai University, Nanjing, China, Tel. +86 02583786609; Fax: +86 02583786606; email: zwt@hhu.edu.cn*
[b]*The State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China*
[c]*Hydrology and Water Resources Department, Nanjing Hydraulic Research Institute, Nanjing, China, Tel. +86 02585829772; email: yzliu@nhri.cn*
[d]*The State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing Hydraulic Research Institute, Nanjing, China*

Received 9 May 2018; Accepted 23 March 2019

ABSTRACT

Recent years, water pollution accidents have happened frequently in China. The safety of drinking water is attracting more and more attention. Most of the Beijiang River Basin is in Guangdong province of China. It flows through Shaoguan, Qingyuan and Foshan cities, which take it as their source water. The three cities not only have a large population density but also have well-developed industry and agriculture as well as many factories and mines, and the pollution accidents of water source occur easily. Risk assessment of watershed water quality is very important not only for drinking water safety but also for basin environmental management policy. Based on the analytic hierarchy process and fuzzy logic, the environmental risk assessment index system of the Beijiang River Basin is constructed, and the environmental risk status of the Beijiang River Basin is evaluated. The results show that the comprehensive risk level of Beijiang River Basin is at a medium level, and the pressure of pollutant emission is relatively high. Among the Beijiang River Basin, the environmental risk assessment values of Xinan street in Sanshui District and Jiujiang town in Nanhai District are at comparatively high level.

Keywords: Basin risk management; AHP; Water environment pollution

1. Introduction

Since we entered into the 21st century, with the economy going through a period of transition to middle stage of industrialization, traditional polluting industry and the proportion of heavy chemical industry has been rising constantly. At the same time, incoordination between extensive economy-growth mode and resources environment has been increasingly outstanding. What's worse, climate change also plays a significant role. Under those factors, water pollution incidents went into a period of high incidence, and the risk of water quality pollution has become more obvious, which makes large influence on basin economy and people's security of drinking water. Under the new situation, water ecological security has become the important content of the national security system. What's more, the control and management of the risk of water quality pollution needs to be improved.

Risk evaluation index system means making evaluation of damage of human health, social economy and environment caused by natural disasters which are induced by human collective economic activities. We can get basin environmental

* Corresponding author.

risk evaluation based on quantitative evaluation of several indexes in basin, which is essential for Integrated River Basin Management [1,2]. Currently, researches on basin's environmental risk evaluation are mainly divided into two types at home and abroad. One is using qualitative analysis namely comprehensive evaluation of environmental risk, which means making comprehensive evaluations of basin's environmental risk by using a certain evaluation method based on indexes of environmental risk evaluations [3]. The other is using quantitative analysis that implies using a certain model or calculation method to calculate content of some pollutant which represents environmental risk in water environment [4].

In order to comprehensively evaluate the water environmental risk of the river basin, the first we need to do is determining the evaluation index system. Jaimes et al. [5] and Fan et al. [6] pointed out that it can not only enhance the scientificalness and reliability of the evaluation system but also ensure the efficiency of the evaluation results, if we guide the selection process of index on the basis of the specific characteristics of research area.

In this paper, we use analytic hierarchy process (AHP) to construct evaluation index system based on the research results we already have, and guide the selection process of the indexes according to the risk characteristics of the basin. Meanwhile, we divide risk evaluation value into three categories including social and economic pressure, resource carrying pressure and pollutant emission pressure, by which we construct a comprehensive evaluation index system of the Beijiang River Basin.

2. General situation of the study area

The Beijiang River is the second biggest river of the Pearl River. Its upstream Zhenjiang River originates from Shi jie in Jiang xi and joins Wushui River, and then we call it the Beijiang River. After that, it joins the West River in Sanshui city and flows into river network of the Pearl River Delta. The main tributary flows into the sea in Hu Men. Most of the Beijiang River Basin are in Guangdong and it flows through Shaoguan, Qingyuan and Foshan. The three cities not only have a large population density but also have well-developed industry and agriculture as well as many factories and mines, which contribute to water pollution. In this paper, we mainly select part of the Beijiang River Basin in Foshan City as study area. Foshan city is situated in the northwest of Pearl River Delta and southern region of Guangdong. Its geographical position is for the east longitude 112°22′–113°23′. Its east is linked to Guangzhou and south is linked to Jiangmen and Zhongshan. Its west near Zhaoqing city and its north is next to Qingyuan city. The city's span length from east to west is 103 km and span length from south to north is 110 km. Its area is 3,848.49 km^2. Foshan city contains four districts, which are ChanCheng district, Nanhai district, Shunde district and Sanshui district. Each district contains numerous towns. Nanhai district contains Shishan town, Danzao town, Xiqiao town and Jiujiang town. Shunde district contains Longjiang town, Lecong town and Leliu street. Chancheng district contains Nanzhuang town. Sanshui district contains Xinan street. The topographical position of the basin can be seen in Fig. 1.

3. Research methodology

3.1. Using AHP to construct an index system

AHP was developed by Thomas L. Saaty of United States in the middle of the 1970s. It is a combination of qualitative and quantitative and a systematic and hierarchical analysis method. It has practicality and efficiency on treating complex decision problems. Because it has concise thought and is linked tightly with decision maker's subjective judgments and make quantitative description of the decision maker's inference, then it can avoid the decision maker's mistakes in logical reasoning when the structure is complex and there are many factors [7,8]. This paper uses AHP to construct evaluation index system constructed and divide risk evaluation values into three categories including social and economic pressure, resource carrying pressure and pollutant emission pressure, and establishes the comprehensive evaluation index system of the Beijiang River Basin.

The construction principle of index system should persist in the combination of comprehensiveness and generality, systematises and hierarchy, feasibility and operability, comparability and problem-oriented principles [9]. Combining the specific risk characteristics of Beijiang River Basin, risk evaluation index system in this paper consists of a target layer, a comprehensive risk value, three criterion layers, a

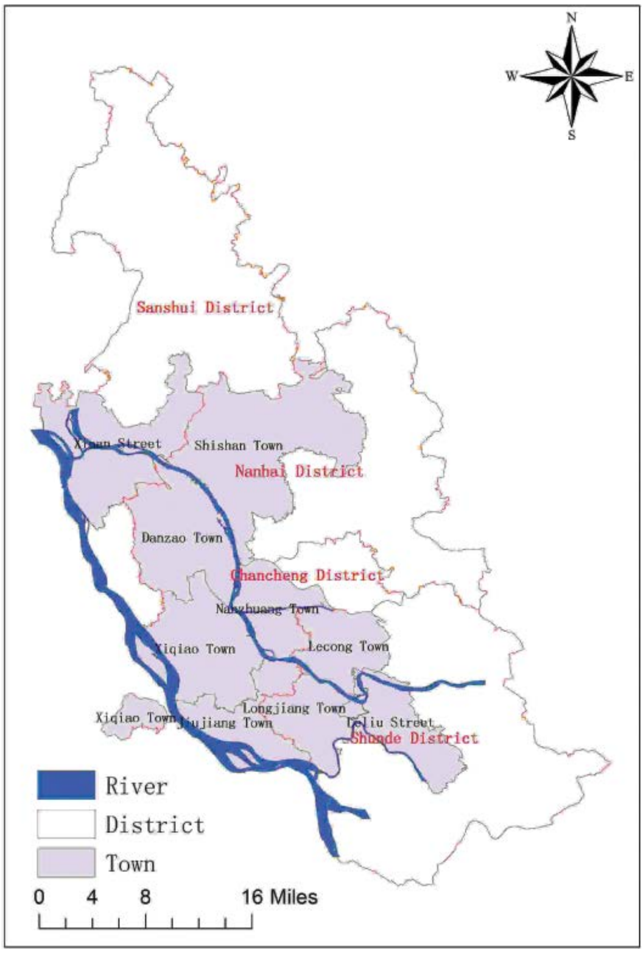

Fig. 1. Diagrammatic sketch of research area.

social economic pressure layer, a resource carrying pressure layer, a pollutant emission pressure layer and 17 indexes.

- Social economic pressure layer. Socioeconomic factors are the most primary driving factors of environmental risk. Accumulative environmental risk represented by non-point sources in Beijiang River Basin is significant. Population factors play an important role in the generation of pollution. For example, rural and urban domestic pollution is closely related to population. In the Beijiang River Basin, the economy is well developed and urban–rural income gap is large, and also urban and rural social structure is seriously different. It lacks a material basis for pollution mitigation. At the same time, the mining industry, planting industry and animal husbandry produce a large number of pollution, causing great risk to the environment. Social economic pressure layer chooses population density, the population ratio in urban and rural areas, the proportion of secondary and tertiary industry and per person gross domestic product (GDP) as evaluation indexes.
- Resource carrying pressure layer. Resources carrying capacity is a good reflection of a basin's anti-risk ability. If resources carrying capacity is poor, the carrying pressure of resources in the basin is high, and the risk resistance of the basin environment itself is poor, such as the low forest coverage, which leads to a higher risk level. Resource carrying pressure layer chooses farmland areas per person, water resources per person, farmland population load, rainfall and forest coverage as evaluation indexes.
- Pollutant emission pressure layer. Pollutant emission pressure is the direct factors in causing environmental risk, which is mainly reflecting in the pollution emission and accumulation in the industrial and agricultural production and urban and rural life. In the agricultural activities, poultry and livestock farming exert pressure on resources and environment. And also, energy and electric quantity consumption can produce environmental pressure during the above progress. Pollutant emission pressure layer chooses energy consumption per 10,000 Yuan GDP, electricity consumption per 10,000 Yuan GDP, beast and poultry loading per farmland, COD, TN (total nitrogen) and TP (total phosphorus) as the evaluation indexes.

3.2. Determination of index weight

Weight calculation adopts the method of constructing two - two judgment matrices. We evaluate it by comparing the importance between two indexes. The contribution of the lower index to the upper level is determined by calculating the eigenvector of the judgment matrix. Thus, the importance ranking result of the primary index to the general goal is available. Then we should check the matrix consistency. If the consistency ratio is lower than 0.1, the judgment matrix is satisfied. Table 1 is the explanation of the importance of the index.

First, starting from the index layer, the indexes belonging to the same category in each level are compared in two pairs, and the grade is assigned according to their importance. Constructing two - two judgment matrices A_{ij}.

Table 1
Explanation of the importance of the index

Index	Meanings
1	Two indexes are of equal importance
3	One index is slightly more important than the other
5	One index is obviously more important than the other
7	One index is far more important than the other
9	One index is absolutely more important than the other
2,4,6,8	Importance of the index is between the above adjacent judgments
Reciprocal	Importance of index *a* to index *b* is *c*, so the importance of index *b* to *a* is 1/*c*

$$A_{ij} = \left(a_{ij}\right)_{n\times n} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \quad a_{ij} = \frac{1}{a_{ji}} \tag{1}$$

a_{ij} indicates the importance of comparison between the two indexes. In this paper, the importance of indexes is measured according to Table 1.

Second, calculate weight vectors. The eigenvectors and the maximum eigenvalues of the judgement matrix are calculated. The eigenvector of a judgement matrix is the proportion of importance between each evaluation index.

The first step is to normalize every column of judgement matrix. $\overline{a_{ij}} = a_{ij} / \sum_{k=1}^{n} a_{kj},\ \left(i,j = 1,2,\ldots n\right)$

In the second step, each column is summed up by the normalized judgment matrix.

$$\overline{W}_i = \sum_{j=1}^{n} a_{ij},\quad \left(i,j = 1,2,\ldots,n\right) \tag{2}$$

After calculating the required eigenvectors, $\overline{W}_i = \left[\overline{W}_1, \overline{W}_2, \ldots \overline{W}_n\right]^T$, the maximum eigenvalue $\lambda_{\max}$ is obtained.

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{\left(PW\right)_i}{nW_i},\quad \left(i = 1,2,\ldots,n\right) \tag{3}$$

The third step is consistency check. To check the consistency of the judgement matrix, we need to calculate the conformance index CR:

$$\mathrm{CR} = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

3.3. Fuzzy evaluation method

During the process of basin environmental risk evaluation, we need to do dimensionless treatment of the index first. According to the influence degree of each index to environmental risk, we divide it into five levels in this paper; the higher the level, the greater the risk. We define it as I, II, III, IV and V. The meaning of ecological risk may occur at each level is LV = {low, comparatively low, medium, comparatively high, high}. The classification standard of each index is shown in Table 2. Comprehensive environmental risk value boundaries for five risk levels of comprehensive environmental risk level are $P = \{P_1, P_2, P_3, P_4, P_5\} = \{2, 2.5, 3.5, 4.5, 5\}$.

The second step is to construct the membership function of evaluation objects. $R_{ij} = [r_{ij1}, r_{ij2}, r_{ij3}, r_{ij4}, r_{ij5}]$. Among them, r_{ij} indicates the membership degree of an evaluation index for the grade. The membership function is used to quantitatively answer the question: how does the measured value of each index belong to a certain level?. The membership degree calculation is based on the following (Eqs. (5)–(7)).

$$y = \begin{cases} 1 & x \le f_{i1} \\ \dfrac{f_{i2} - x}{f_{i2} - f_{i1}} & f_{i2} > x > f_{i1} \\ 0 & x \ge f_{i2} \end{cases} \quad (5)$$

$$y = \begin{cases} \dfrac{x - f_{i(j-1)}}{f_{ij} - f_{i(j-1)}} & f_{i(j-1)} < x < f_{ij} \\ 0 & f_{i(j-1)} \ge x, x \ge f_{i(j+1)} \\ \dfrac{f_{i(j+1)} - x}{f_{i(j+1)} - f_{ij}} & f_{i(j+1)} > x > f_{ij} \end{cases} \quad (6)$$

$$y = \begin{cases} 1 & x \ge f_{i5} \\ \dfrac{x - f_{i4}}{f_{i5} - f_{i4}} & f_{i5} > x > f_{i4} \\ 0 & x \le f_{i4} \end{cases} \quad (7)$$

Among them, f_i is the rank value in LV corresponding to the index and x is the measured value of the index. The membership degree of each index is constructed into membership matrix R mentioned above.

On the basis of above, the evaluation formula of each level is deduced by the following (Eqs. (4)–(6)).

Risk evaluation indexes in the index layer are based on Eq. (8). Q_{ij} represents the evaluation value of each index in the index layer.

$$Q_{ij} = R_{ij} \times \begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \end{pmatrix} \quad (8)$$

$$Q_i = W_i \times R_{ij} \times \begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \end{pmatrix} \quad (9)$$

$$Q = W \times \begin{pmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \end{pmatrix}. \quad (10)$$

Table 2
Classification standard of each index

Indicator (level)	v_1 (I)	v_2 (II)	v_3 (III)	v_4 (IV)	v_5 (V)
Population density (person·km^{-2})	100	200	300	400	500
Proportion of urban and rural population (%)	10	15	20	25	30
Tertiary industry proportion (%)	50	40	30	20	10
Secondary industry proportion (%)	40	50	60	70	80
GDP per land (10,000 yuan·km^{-2})	50	100	200	400	600
Farmland areas per person (10^{-4} km^2)	8	7	6	5	4
Water resources per person (m^3)	5,000	3,000	2,000	1,000	500
Forest coverage (%)	100	80	70	60	50
Population loading per farmland (person·km^{-2})	800	1,000	1,200	1,400	1,600
Rainfall (mm)	200	400	800	1,200	1,600
Energy consumption per 10,000 Yuan GDP (t)	0.8	1.2	1.5	2.2	2.6
Electricity consumption per 10,000 Yuan GDP (kw h)	800	1,200	1,600	2,200	2,600
Beast/poultry loading per farmland (km^{-2})	50	60	100	120	160
COD (per land) (t km^{-2})	0.05	0.25	0.75	1	1.25
Ammonia nitrogen (per land) (t km^{-2})	0.05	0.25	0.75	1	1.25
TN (per land) (t km^{-2})	0.05	0.25	0.75	1	1.25
TP (per land) (t km^{-2})	0.01	0.05	0.15	0.2	0.25

Risk evaluation indexes in the criterion layer are based on Eq. (9). W_{ij} represents the feature vector of the indexes in the index layer; Q_i represents evaluation value of each index in the criterion layer.

Finally, the risk evaluation of the target layer is based on Eq. (10). W_i represents the feature vector of the indexes in the criterion layer Q represents evaluation value of the target layer.

4. Results and discussion

4.1. Weight values for each index

Table 3 shows the weight values for each index. The weight values are calculated by Eqs. (2) and (3). The CR value is calculated by Eq. (4). The consistency ratio test results of criterion layer C1 are CR = 0.008. The consistency ratio test results of criterion layer C2 are CR = 0.015. The consistency ratio test results of criterion layer C3 is CR = 0.3. The consistency ratio test results of the target layer are CR = 0.3. All of these values are lower than 0.1 and it is acceptable.

4.2. Beijiang River Basin environmental risk evaluation

According to the classification standard of fuzzy comprehensive evaluation, we rank the evaluation results of the towns in the basin. Evaluation results of the environmental risk in Beijiang River Basin are listed in Table 4.

4.2.1. Analysis of social economic pressure

Population pressure and economic development have an important impact on environmental risks, especially the accumulation of environmental risks. Table 4 shows the overall and regional results of the environmental risk evaluation in the Beijiang River Basin. The contribution of social economic factor to environmental risk in the Beijiang River Basin is at a medium level, and the grade characteristic value is 2.86.

According to the statistical yearbook of Guangdong province, the secondary industry proportion of the Sanshui district is up to 75%, which shows that industry occupies a large proportion in the economic development of the region. At the same time, because the secondary industry in the region is dominated by traditional high pollution industry and construction, which has negative impact for the environment. Among them, social economic pressure of Xinan street is at a high level. Economic development contributes greatly to environmental risks.

Social economic pressure of Nanzhuang town in Chancheng district is at a low level. The population factor in this area has less pressure on the environment. Meanwhile, the proportion of tertiary industry in the whole region reached 54%, which is higher than that of secondary industry. This data indicated that the production of high-contaminated traditional industries in the region has been gradually reduced, and the tertiary industry of light-polluting has gradually developed. As a result, economic development contributes less to environmental risk.

The proportion of secondary and tertiary industries in the GDP of Nanhai district and Shunde district is basically the same. This phenomenon shows that these two regions are no longer blindly emphasizing traditional industries, but gradually expanding to the tertiary industry in the economic model. Therefore, the pressure of economic development on the environment has been reduced. However, it is worth noting that the population density is high in

Table 3
Beijiang River Basin environmental risk

Target layer (O)	Weight	Criterion layer (C)	Weight	Index layer (I)
	0.32	Social economic pressure C1	0.33	Population density
			0.05	Proportion of urban and rural population
			0.12	Tertiary industry proportion
			0.16	Secondary industry proportion
			0.34	GDP per land
Environment risk comprehensive assessment (O)	0.14	Resources carrying pressure C2	0.33	Farmland areas per person
			0.29	Water resources per person
			0.08	Forest coverage
			0.15	Population loading per farmland
			0.15	Rainfall
	0.54	Pollutants emission pressure C3	0.16	Energy consumption per 10,000 Yuan GDP
			0.21	Electricity consumption per 10,000 Yuan GDP
			0.13	Beast/poultry loading per farmland
			0.12	COD (per land)
			0.12	Ammonia nitrogen(per land)
			0.13	TN (per land)
			0.13	TP (per land)

Table 4
Results of the environmental risk assessment in the Beijiang River Basin

District	Grade characteristic			Comprehensive environmental risk value	Comprehensive environmental risk level
	Social economic pressure	Resources carrying pressure	Pollutants emission pressure		
Basin	2.86	3.15	3.64	3.41	III
Nanhai district					
Shishan town	2.73	2.43	2.14	2.51	III
Danzao town	2.81	2.35	2.41	2.63	III
Xiqiao town	2.91	2.11	2.35	2.58	III
Jiujiang town	3.67	3.64	3.77	3.69	IV
Chancheng district					
Nanzhuang town	2.34	2.66	2.16	2.31	II
Shunde district					
Longjiang town	1.96	2.98	2.39	2.51	III
Lecong town	3.23	3.12	2.41	3.02	III
Leliu street	3.51	3.22	3.17	3.32	III
Sanshui district					
Xinan street	3.86	4.11	3.79	3.97	IV

these regions, and the contribution of population factors to environmental risk is great. As a result, the social economic pressure in most towns in the two districts is at a medium and comparatively high level (Fig. 2).

4.2.2. Analysis of resources carrying pressure

Evaluation results of resources carrying pressure layer (Table 4) indicate that the Beijiang River Basin is at a medium level in resources carrying pressure layer, and the fuzzy characteristic value of resources for carrying pressure is 3.15.

The resources carrying pressure of Shishan, Xiqiao and Danzao in Nanhai district are comparatively low but are comparatively high in the case of Jiujiang. Comparing with the data of Foshan Statistical Yearbook [10], it is found that the main reason is that Jiujiang town has a large population, but the area is small, and the water resources per person are lower than that of Shishan, Xiqiao and Danzao town.

The fuzzy characteristic value of resources carrying pressure of Lecong town, Longjiang town and Leliu street in Shunde district and Nanzhuang town in Chancheng district are 3.12, 2.98, 3.22 and 2.66, respectively, which indicate that the risk are all at the medium level, an acceptable range. Based on the data of population, natural resources and land information in Foshan Statistical Yearbook, it is found that due to the less farmland area, the population factor put more pressure on farmland resources, and the bearing capacity of agriculture and animal husbandry is poor. However, water resources per person in the region are relatively high and the forest area is relatively large. Therefore, the overall environmental capacity is acceptable for industrial development within the planning scope.

The resources carrying pressure characteristics of Xinan street in Sanshui district are at a high level. The fuzzy characteristic value of resources carrying pressure value

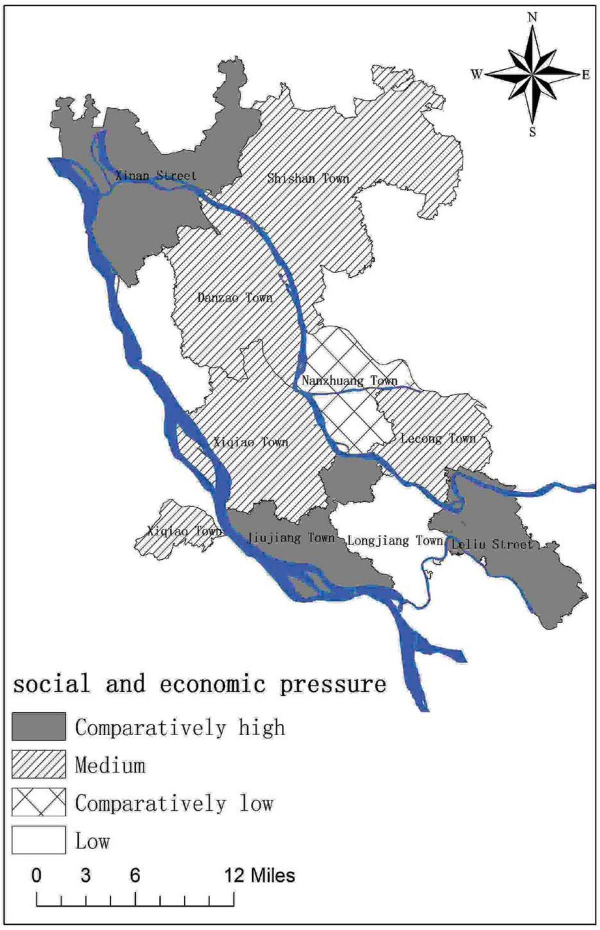

Fig. 2. Spatial distribution of social economic pressure.

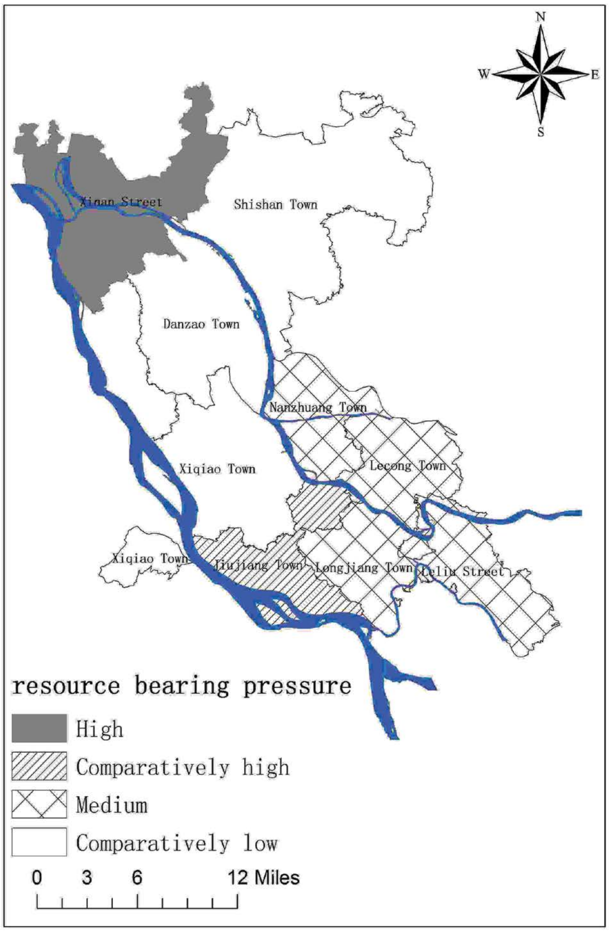

Fig. 3. Spatial distribution of resources carrying pressure.

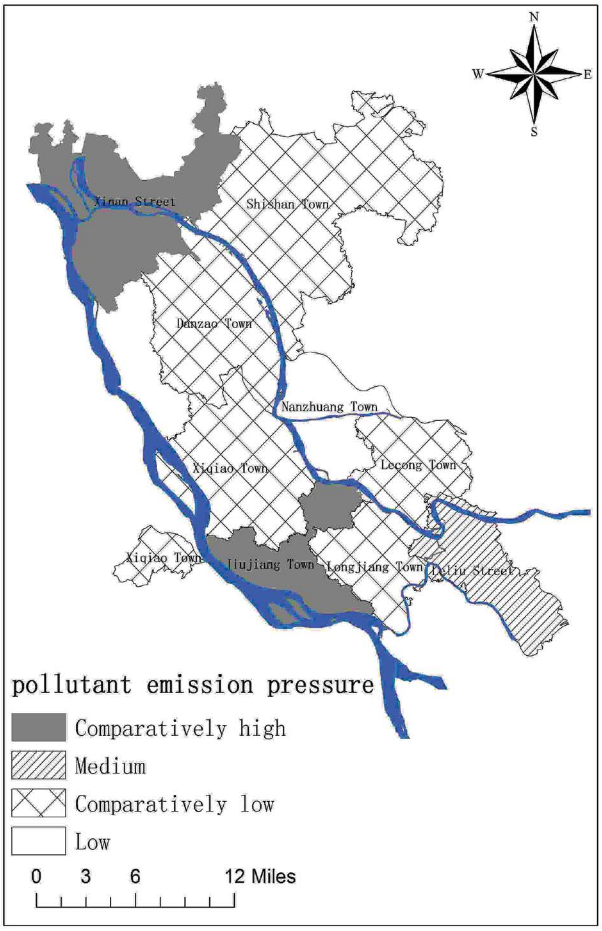

Fig. 4. Spatial distribution of pollutants emission pressure.

is up to 4.11, which is due to the large population density in the region, less farmland area and low forest coverage, resulting in greater resources carrying pressure (Fig. 3).

4.2.3. Analysis of pollutants emission pressure

As Table 4 shows, pollutants emission pressure of the Beijiang River Basin is at a relatively high level, and the fuzzy characteristic value is 3.64. The degree of its contribution to environmental risk is a little high yet (Fig. 4).

The main reason is that the Xinan street of the Sanshui district is one of China's Top 100 public-listed counties. However, its industrial development mainly depends on traditional industries such as cement and hardware, which bring high energy consumption and pollution. High emission of pollutants results in more contribution to accumulated environmental risks, such as COD, ammonia nitrogen, TP and TN, which mean higher potential risk of environment. The fuzzy characteristic value of pollutant emission pressure is 3.79, which is ranked in the comparatively high level.

Three towns in Nanhai district including Shishan, Xiqiao and Danzao, and two towns of Shunde district including Lecong and Longjiang, in which cultivated area is less and agriculture is underdeveloped as well as animal husbandry. Daily life and agriculture activities make less contributions to pollutant emission pressure. Meanwhile, the proportions of tertiary industry in the five counties are all over 35%, According to the analysis of the corresponding data in Foshan Statistical Yearbook in recent years, the increase of the proportion of tertiary industry reflects the decrease of the secondary industry of high-polluting industries and mines in the regions, which means that the contribution to the emission pressure of pollutants has been reduced. Therefore, the fuzzy characteristic values of pollutant emission pressure in these towns are all lower than 2.5. However, because Leliu district has high urban population and produce huge living pollution, leading to the huge production quantity of COD, ammonia nitrogen, TN and TP. What's worse, it causes great environmental risk and pollutant emission pressure eigenvalue is higher than 3.0, which is the medium level.

Nanzhuang town in Chancheng district, whose proportion of tertiary industry is up to 54% has less industrial and mining enterprises, it contributes slightly to the pollutant emission pressure and the fuzzy characteristic value of pollutant emission pressure is lower than 2.5.

4.2.4. Comprehensive analysis of basin environmental risk

Synthesizing evaluation results and index weight of every layer, we can get comprehensive results of environment risk

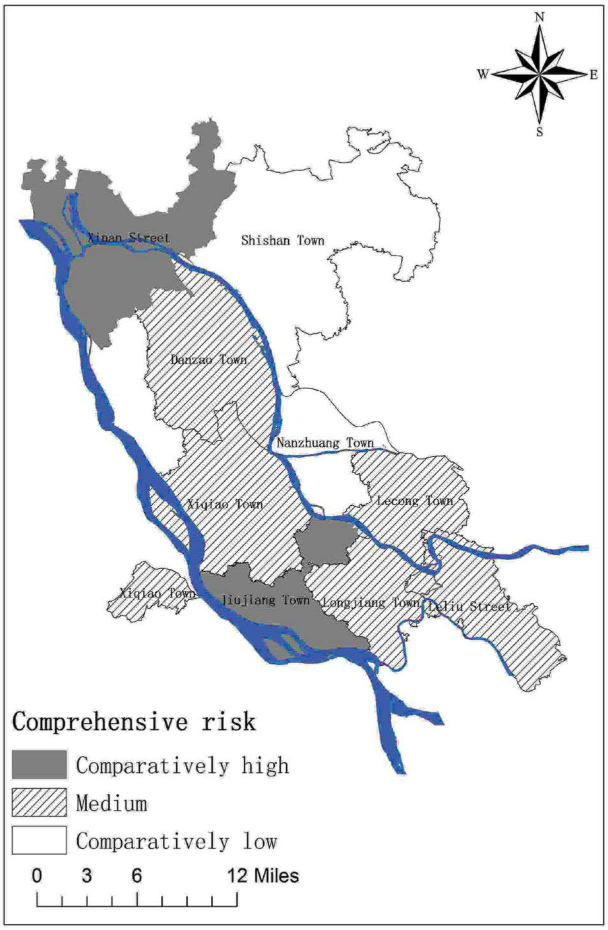

Fig. 5. Spatial distribution of environmental risk.

evaluation of the North River (Fig. 5) on the whole, the basin is at an acceptable risk level, but local areas' risk value is high, for example, most of the southwest street of Sanshui district and Jiujiang town of Nanhai district are at middle or higher risk level, which need to be treated with emphasis.

5. Conclusion

- An index system for environmental risk assessment of Beijiang River Basin has been established on basis of the analysis of the specific pollution characteristics of the pollution in the Beijiang River Basin. Moreover, an AHP-based environmental risk assessment method combining with the fuzzy comprehensive evaluation method has been constructed in the risk evaluation.
- Through the comprehensive evaluation of basin environmental risk based on AHP, the results shows that a comprehensive risk condition of the basin is at the medium level, but there are great geographical differences, which is closely related to the imbalance of region's socio-economic development. At the same time, risk ratings are made on social economic pressure level, resource carrying pressure level and pollutant discharge pressure level. Result shows that the risk levels of social and economic pressure and resources carrying pressure in Beijiang River Basin are all at medium level. The suggestion for improvement is that different regions should develop their economy according to local conditions and adjust the second and third industrial structures reasonably. The risk of pollutants emission pressure level is at a comparatively high level, which is related to the large number of factories and mines in the upstream areas and the dense population. Suggestions are to close or relocate high-polluting industries and mines and raise public awareness of environmental risks.

Acknowledgements

The authors would like to acknowledge the Fundamental Research Funds for the Central Universities (Grant: 2019B10714), the National Natural Science Foundation of China (Grant nos: 41471427, 41101504), Special Basic Research Key Fund for Central Public Scientific Research Institutes (Y517017, Y517018).

References

[1] S. Bagnis, M. Fitzsimons, J. Snape, A. Tappin, S. Comber, Sorption of active pharmaceutical ingredients in untreated wastewater effluent and effect of dilution in freshwater: Implications for an "impact zone" environmental risk assessment approach, Sci. Total Environ., 624 (2018) 333–341.
[2] I. Zimoch, J. Paciej, Spatial risk assessment of drinking water contamination by nitrates from agricultural areas in the Silesia province, Desal. Wat. Treat., 57 (2016) 1084–1097.
[3] H. Di, X.P. Liu, J.Q. Zhang, J. Qu, Q.Y. Ma, Temporal and spatial distribution of water environmental comprehensive risk in Yinma River Basin, Res. Environ. Sci., 31 (2018) 496–506.
[4] L. Lijó, N. Frison, F. Fatone, S.G. García, G. Feijoo, M.T. Moreira, Environmental and sustainability evaluation of livestock waste management practices in Cyprus, Sci. Total Environ., 634 (2018) 127–140.
[5] J.A. Jaimes, C. Postigo, R.M. Alemán, J. Aceña, D. Barceló, M.L. Alda, Study of pharmaceuticals in surface and wastewater from Cuernavaca, Morelos, Mexico: Occurrence and environmental risk assessment, Sci. Total Environ., 613 (2018) 1263–1274.
[6] M. Fan, H. Shibata, L. Chen, Environmental and economic risks assessment under climate changes for three land uses scenarios analysis across Teshio watershed, northernmost of Japan, Sci. Total Environ., 599 (2017) 451–463.
[7] M. Mishra, S. Chatterjee, Application of Analytical Hierarchy Process (AHP) algorithm to income insecurity susceptibility mapping - A study in the district of Purulia, India, Socio-econ. Plan. Sci., 62 (2018) 56–74.
[8] R. Mosadeghi, J. Warnken, R. Tomlinson, H. Mirfenderesk, Comparison of Fuzzy-AHP and AHP in a spatial multi-criteria decision making model for urban land-use planning, Comput. Environ. Urban, 49 (2015) 54–65.
[9] C. Mupenzi, L.H. Li, L. Nahayo, A.C. Amanambu, A. Kayiranga, F. Karamage, F. Ndayisaba, E.M. Nyesheja, J.B. Nsengiyumva, Spatial pattern assessment of Lake Kivu basin rivers water quality using National Sanitation Foundation Water Quality and Rivers Pollution Indices, Desal. Wat. Treat., 95 (2017) 118–127.
[10] Foshan Statistical Yearbook, Available at: http://www.shujuku.org/statistical-yearbook-of-foshan.html.