Research on the comprehensive evaluation of collaborative governance effect of environmental pollution in the Yangtze River Delta urban agglomeration based on low-carbon constraints

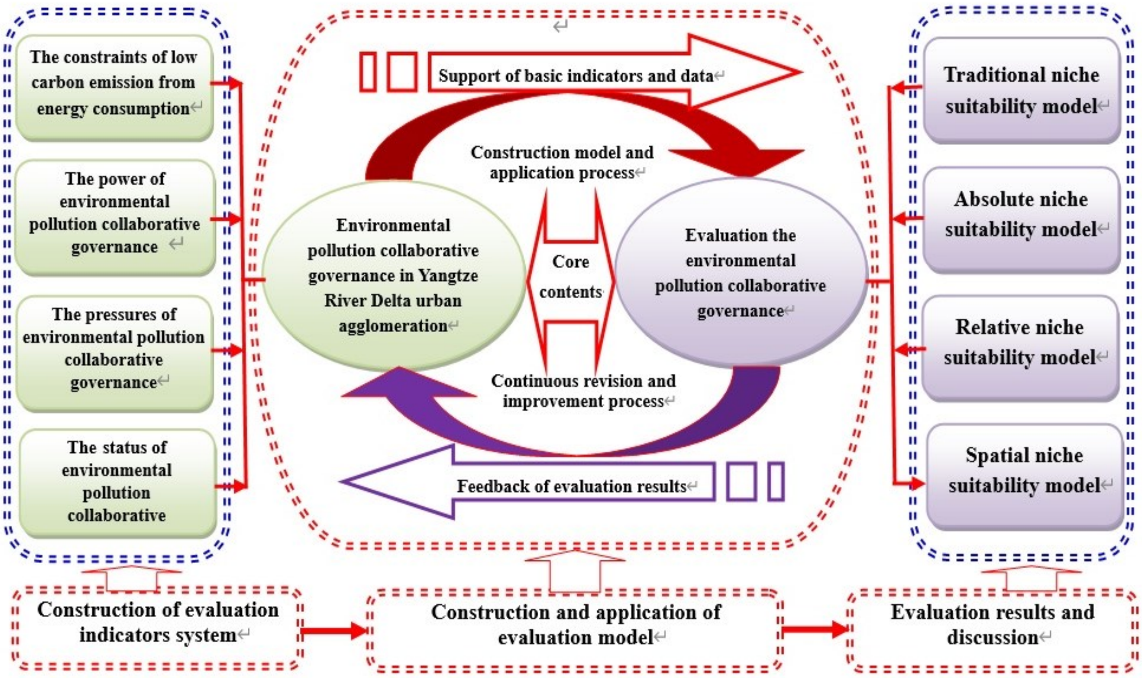
Zhentao Zhu [1]*, Juan Sun [2]

[1] School of Economics and Management, Nanjing University of Engineering, Nanjing, Jiangsu 211167 China

[2] Tai'an Hydrological Center, Taian Shandong 271000 China

* Correspondence: zztnit@njit.edu.cn

Graphical abstract



Abstract

This paper selects a total of 24 evaluation indicators, including the low carbon constraint, the driving force, the pressure, and the status of collaborative governance, to build an evaluation index system. On the basis of low carbon constraints, a spatial niche fitness model was constructed by using the weighted average method of absolute niche fitness and relative niche fitness, and applied research was conducted on 27 cities in the Yangtze River Delta urban agglomeration. The study found that the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration were "Level II" between 2013 and 2017, and its evaluation results were "good"; The period from 2018 to 2021 is " Level I", and the evaluation result is

"Excellent". According to the comparative analysis of different niche suitability evaluation methods and their evaluation results, the efficiency of its collaborative governance still has great room for improvement.

Keywords: collaborative governance; environmental pollution collaborative governance; the evaluation of collaborative governance effect; Yangtze River Delta urban agglomeration; low carbon constraint

1. Introduction

The Yangtze River Delta urban agglomeration is a state-level urban agglomeration approved by the State Council of China. It is the largest and most developed urban agglomeration in China and the sixth-largest urban agglomeration in the world. The rapid economic development of the Yangtze River Delta urban agglomeration has continuously made great contributions to China's economic development, but also caused a certain degree of environmental pollution (Han and Cao, 2022). In order to strengthen the environmental pollution governance of the Yangtze River Delta urban agglomeration and maximize the effect of environmental pollution governance, the exploration of environmental pollution collaborative governance began with the establishment of the Yangtze River Delta urban agglomeration (Zhao et al., 2016). The initial environmental pollution collaborative governance of the Yangtze River Delta urban agglomeration was a spontaneous action, mainly to strengthen the collaborative governance of water and air pollution (Sun and Zhou, 2022; Yu and Zou, 2022). This spontaneous collaborative governance of environmental pollution has gradually achieved obvious governance results, and also improved people's understanding of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration (Tan and Jiang, 2022). Since the integrated construction of the Yangtze River Delta urban agglomeration in China rose to the national strategy in 2019, the government has started to participate in the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, and the collaborative governance of environmental pollution has gradually achieved remarkable results (Yang and Horvath, 2019). On September 22, 2020, President Xi Jinping put forward the "double carbon" goal at the seventy-fifth United Nations General Assembly, raising China's "low carbon" development goal (Liu et al.2022). Due to the lack of an effective evaluation method for the effectiveness of environmental pollution collaborative governance in the process of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration, there is no way to achieve a comprehensive evaluation of the implementation effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration (Wang and Zhao,2021). In this case, the evaluation method of the collaborative environmental effect of environmental pollution has become a bottleneck issue affecting the performance in the Yangtze River Delta urban agglomeration. Therefore, it is of special importance and urgency to study the comprehensive evaluation method and its application of the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration with low carbon constraints.

Environmental pollution governance originated in developed countries. In the 1960s, the United States Committee on Environmental Hazards the current situation of water pollution in the United States and put forward the requirements for environmental pollution governance (Committee on environmental hazards, 1964); Purdom (1967) analyzed the current situation of air pollution in Oklahoma, the United States, and emphasized that the management of air pollution governance projects of the state government should be strengthened, and the control degree of environmental pollution should be strengthened; Hilbert (1967) analyzed the situation of environmental pollution within the US state government, and emphasized strengthening the management of milk and food hygiene within the state government, strengthening the management of hygiene plans and improving the quality of food hygiene environment. However, there is little research on the collaborative governance of environmental pollution abroad, and only a few stakeholders participate in the cooperative governance, the developed countries rarely study the collaborative governance of environmental pollution, which is mainly determined by foreign private ownership system (Wilder,1993). In recent years, with the upsurge of research on collaborative governance of environmental pollution in China, there are also some sporadic research results abroad. According to Taylor et al. (2020) 's research, due to the impact of western economic austerity policies, some countries that implement the environmental pollution collaborative governance have gradually formed a shrinking profile in the process of the environmental pollution governance; Sabrina et al (2021) analyzed the current situation of moose management in Sweden, put forward the idea of the environmental pollution collaborative governance in moose habitat, and analyzed the social and ecological effects of the collaborative governance; Jones and White (2022) analyzed the problem of environmental pollution governance in Phoenix city, Arizona, USA, and believed that there were obstacles to cooperative governance in the governance of the food-energy-water relationship, and advocated that the cooperative governance of this environmental pollution governance chain should be strengthened to promote the gradual improvement of the governance effect； Hnohuaan et al. (2022) analyzed the antibody map characteristics of vibrio species recovered from surface water in southwestern Uganda, and believed that collaborative governance would improve the governance effect; Yandisia et al. (2022) analyzed Thailand's food marketing policy, and believed that the impact of policy governance should be strengthened, and the implementation of cooperative marketing would improve synergy. Nicola et al. (2023) analyzed collaborative governance in environmental pollution control cases in Australia and believed that collaborative governance of environmental pollution played an important role in improving the effectiveness of environmental pollution control. It can be seen that there are relatively few studies on the collaborative governance of environmental pollution abroad. In recent years, due to the influence of China's research on this issue, some research results have been published in succession, reflecting the Chinese characteristics of collaborative governance of environmental pollution.

In China, the collaborative governance of environmental pollution came into being in the mid-1980s (Gao et al., 1984), while the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration did not begin until the early 21st century (Zang, 2006). Qin et al. (1990) studied the collaborative governance of urban environmental pollution in China, and believed that urban management should adopt decentralized management, so that the central and local decentralized development at the same time, which is the best choice to improve the effect of collaborative governance of urban environmental pollution. The problem of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration was not fully launched until the release of the Yangtze River Delta Regional Plan. Dong and Dai (2015) proposed specific countermeasures for collaborative governance of urban environmental pollution on the basis of analyzing the bottleneck of environmental pollution governance in the Yangtze River Delta urban agglomeration; Mao and Cao (2016) analyzed the current situation of air pollution governance in the Yangtze River Delta, studied the problem of cross-regional collaborative governance of air pollution, and believed that the core of collaborative governance was the driving force between subjects, the innovation of cooperation mechanism was the key, and the improvement of external environment was the guarantee. On November 5, 2018, the construction of regional integration in the Yangtze River Delta became a national strategy, promoting the upgrading of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration. Yang (2019) studied the current situation of ecological civilization in the Yangtze River Delta urban agglomeration and the idea of building an ecological civilization mechanism from the perspective of the Import Expo in accordance with the requirements of regional integration construction in the Yangtze River Delta; Wu et al. (2020) analyzed the collaborative governance mechanism of the Yangtze River Delta urban agglomeration and put forward specific countermeasures to promote the improvement of the effect of collaborative governance; Xu and Sun (2021), taking Jiangsu Province as an example, studied and applied the evaluation method of the effect of environmental pollution collaborative governance in the Yangtze River Delta region, providing an effective quantitative analysis method for the evaluation of the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration; Luo et al. (2022) analyzed the situation of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration, studied the specific evaluation method of the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration, and proposed specific collaborative governance countermeasures. The coordinated treatment of environmental pollution in urban agglomerations in the Yangtze River Delta of China started relatively late, and its development speed is relatively fast. (Cao et al., 2023), especially in the past five years, there has been a significant improvement. The water, atmosphere, and soil of the Yangtze River Delta urban agglomeration have achieved significant results in the coordinated treatment of environmental pollution (Li and Li, 2022). Currently, the collaborative governance of environmental pollution in urban agglomerations in the Yangtze River Delta has entered a strategic level, and the effectiveness of collaborative governance of environmental pollution has received special attention and active participation from government departments, the situation of collaborative governance of environmental pollution in China has shown a trend of rapid improvement (Li and Jiang, 2022).

From the above literature review, we can see that the collaborative governance of environmental pollution has Chinese characteristics. This topic itself originated from the Yangtze River Delta urban agglomeration. However, due to the lack of evaluation of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration in the existing research, the existing evaluation research on the environmental pollution governance effect of the Yangtze River Delta urban agglomeration has great limitations, which cannot meet the needs of the comprehensive evaluation of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration. In particular, the low carbon constraint is not considered, and the selected evaluation index is not reasonable enough to fully reflect the situation of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration. The comprehensive evaluation model is not perfect enough and needs to be revised in many ways. The existing comprehensive evaluation method of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration cannot be effectively used in a wide range. Therefore, in this case, the comprehensive evaluation method of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration with low carbon constraints is explored, which is of special importance and urgency for improving the evaluation mechanism of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration and maximizing the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration

2. Materials and Methods

2.1. Study areas

According to the Regional Plan of the Yangtze River Delta Region approved by the State Council of China on May 24, 2010, the earliest urban agglomeration of the Yangtze River Delta only includes Shanghai, Jiangsu, and Zhejiang two provinces and one city; According to the Yangtze River Delta Urban Agglomeration Development Plan adopted by the State Council on May 11, 2016, the Yangtze River Delta urban agglomeration mainly includes Shanghai; Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Zhenjiang and Taizhou in Jiangsu Province; Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Jinhua, Zhoushan and Taizhou in Zhejiang Province; Hefei, Wuhu, Ma'anshan, Tongling, Anqing, Chuzhou, Chizhou, Xuancheng and other 26 cities in Anhui Province. In 2018, Wenzhou in Zhejiang Province was added, with a total of 27 cities. Thirteen years have passed since the State Council officially approved the implementation of the Yangtze River Delta Regional Plan on May 24, 2010, the Yangtze River Delta urban agglomeration has developed from the original two provinces and one city to three provinces and one city, with a total of 27 cities.

By the end of 2021, the total area of the Yangtze River Delta urban agglomeration is about 211700 square kilometers, accounting for about 2.3% of the total area of the country; At the end of the period, the permanent population is about 225 million, accounting for 15.85% of the total population of the country; In 2021, the GDP of 27.6054 trillion yuan was created, accounting for 24.14% of the total GDP of the country, the Yangtze River Delta urban agglomeration has become the largest urban agglomeration in China and the sixth largest urban agglomeration in the world. With the integrated development of the Yangtze River Delta urban agglomeration, the effect of environmental pollution collaborative governance will also be gradually improved. After more than ten years of integrated construction of the Yangtze River Delta urban agglomeration, the environmental pollution collaborative governance of the Yangtze River Delta urban agglomeration has achieved obvious results.

2.2 Construction of evaluation index system and data collection

The evaluation of the effect of environmental pollution collaborative governance of urban agglomeration in the Yangtze River Delta is a complex systematic project, which needs to consider various environmental conditions and influencing factors and also combine the actual situation of the collaborative governance of environmental pollution of urban agglomeration. The collaborative governance of environmental pollution in the urban agglomeration of the Yangtze River Delta is gradually developed with the proposal and implementation of the regional integration strategy in the Yangtze River Delta. It has the characteristics of government participation in supervision and reflects the development direction and future trend of the research on collaborative governance of environmental pollution in the urban agglomeration of China. In order to realize the effective evaluation of the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, this paper, through the research design, has selected four categories of 24 indicators on the basis of comprehensive analysis, including the constraint of low carbon emissions of energy consumption, the power of collaborative governance of energy consumption and environmental pollution, the pressure of collaborative governance of energy and environmental pollution, and the situation of collaborative governance of energy consumption and environmental pollution, A comprehensive evaluation index system for the collaborative governance of environmental pollution in the urban agglomeration of the Yangtze River Delta was established. This indicator system comprehensively reflects the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, and fully considers the requirements of low carbon constraint, the realization of the "double carbon" goal, and the comprehensive performance evaluation of the collaborative governance of environmental pollution in the urban agglomeration. On the basis of this indicator system, this paper attempts to build a comprehensive evaluation model of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration using the evaluation indicators through the technical treatment of the evaluation indicators, and study the evaluation system of the environmental pollution collaborative governance effect that is suitable for the actual situation of the Yangtze River Delta urban agglomeration and has characteristics. See Table 1 for the specific composition of the evaluation index system for the effect of environmental pollution collaborative governance in the Yangtze River Delta.

Table 1 Comprehensive evaluation indicators system for the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration

Target	Criterion	Variable	Measures	Unit	Indicators nature
Study on the comprehensive evaluation of the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration based on low-carbon constraints	The constraints of low carbon emission from energy consumption （X_1）	X_{11}	Energy consumption intensity	Ton/10000yuan	Contrary Indicators
		X_{12}	CO_2 emissions per capita	Ton / person	Contrary Indicators
		X_{13}	CO_2 emission intensity of EC	Ton/10000yuan	Contrary Indicators
		X_{14}	Satisfaction with emission reduction of EC	Score	Positive indicators
		X_{15}	The situation of "carbon peak" of EC	Score	Positive indicators
		X_{16}	Possibility of "carbon neutral" EC	Score	Positive indicators
	The power of environmental pollution collaborative governance of energy consumption （X_2）	X_{21}	Per capita GDP	10000yuan/person	Positive indicators
		X_{22}	Per capita disposable income	10000yuan/person	Positive indicators
		X_{23}	Urbanization level	%	Positive indicators
		X_{24}	Employment rate of urban population	%	Positive indicators
		X_{25}	Compliance rate of EPCG	%	Positive indicators
		X_{26}	Life expectancy of urban residents	岁	Positive indicators
	The pressures of environmental pollution collaborative governance of energy consumption （X_3）	X_{31}	Water pollution index	Index	Contrary Indicators
		X_{32}	Air pollution index	Index	Contrary Indicators
		X_{33}	Soil pollution index	Index	Contrary Indicators
		X_{34}	Comprehensive pressure index for EPCG	Index	Contrary Indicators
		X_{35}	Non-compliance rate of UMV emissions	%	Contrary Indicators
		X_{36}	Unqualified rate of municipal CP	%	Contrary Indicators
	The status of environmental pollution collaborative governance of energy consumption （X_4）	X_{41}	Compliance rate of water EPCG	%	Positive indicators
		X_{42}	Compliance rate of air EPCG	%	Positive indicators
		X_{43}	Compliance rate of soil EPCG	%	Positive indicators
		X_{44}	Proportion of investment in EPCG	%	Positive indicators
		X_{45}	Landscape index of EPCG	Index	Positive indicators
		X_{46}	Public satisfaction with EPCG	%	Positive indicators

EC: energy consumption; EPCG: environmental pollution coordinated governance; UMV: urban motor vehicle; CP: construction projects

The above evaluation indicators are calculated using the statistical data in the statistical yearbook, energy statistical yearbook and the Bulletin of Ecological Environment status of the country and the provinces and cities in the Yangtze River Delta. The energy consumption intensity is the average of the ratio of the total energy consumption of each city in the Yangtze River Delta urban agglomeration to GDP in the same period; The per capita CO_2 emission intensity is the average of the ratio between the total CO_2 emission of energy consumption of each city in the Yangtze River Delta urban agglomeration and the resident population in the same period; The proportion of petrochemical energy consumption is the average of the proportion of petrochemical energy consumption in the total energy consumption scale of cities in the Yangtze River Delta; The satisfaction degree of energy conservation and emission reduction is the average number of residents' satisfaction degree of energy conservation and emission reduction in each city obtained by questionnaire; The status of "carbon peak" of energy consumption is the average value of the scores determined by the experts of each city in the questionnaire; The possibility of "carbon neutrality" of energy consumption is also the average value of the scores determined by the experts of each city in the questionnaire; GDP per capita is the average of the ratio of GDP of each city to the permanent population at the end of the same period; Per capita disposable income is the average of the ratio of per capita disposable income of each city to the permanent population at the end of the same period; The urbanization level is the average of the ratio of the permanent population of a city to the total population of the city; The employment rate of the urban population is the average of the proportion of employed people in the urban population; The compliance rate of environmental pollution collaborative governance is the average of the ratio of compliance projects in the urban agglomeration environmental pollution collaborative governance projects; The life expectancy of urban residents is the average life expectancy of each city; The water pollution index is the average value of the water pollution index of each city; The air pollution index is the average value of the air pollution index of each city; Soil pollution index is the average of urban soil pollution index; The comprehensive pressure index of collaborative governance of environmental pollution is the average value of the pressure index of water, air and soil environmental pollution collaborative governance, and each specific pressure index refers to the average value of the relative pressure index and the absolute pressure index; The rate of substandard urban motor vehicle emissions is the average of the ratio of substandard motor vehicles in the total number of motor vehicles in each city in the same period; The unqualified rate of construction projects in inside the city is the average of the ratio of unqualified construction projects in all construction projects in each city; The compliance rate of water area collaborative governance is the average of the proportion of water area governance projects that have met the standards among the cities participating in the collaborative governance; The average proportion of the air treatment projects that have reached the standard in the air governance projects participating in the collaborative governance; The average proportion of the projects that have reached the standard in the soil governance projects participating in the collaborative treatment; The proportion of investment in environmental pollution collaborative governance is the average of the proportion of investment in environmental pollution governance in all environmental pollution collaborative governance projects that cities participate in; The landscape index of environmental pollution collaborative governance is the average value of the urban landscape index after the environmental pollution collaborative governance;

The public's satisfaction with the collaborative governance of environmental pollution is the average score of the satisfaction with the collaborative governance of environmental pollution determined by the questionnaire of urban residents. The data are mainly from the statistical yearbooks of the country and cities in the Yangtze River Delta and the author's past research accumulation. In order to maintain the basic characteristics of the original data, necessary modifications have been made to some data. In order to realize the effective evaluation of the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration, the author collected comprehensive data on the basis of the constructed evaluation index system. It mainly carries out statistical analysis on the relevant data of 27 cities in the Yangtze River Delta urban agglomeration, and collects the relevant data of 27 cities in the Yangtze River Delta urban agglomeration from 2013 to 2021. Since China began to have environmental statistics data in 2012, the starting point of this study data is 2013. In the process of collecting evaluation indicators, the data of the Yangtze River Delta urban agglomeration comes from the average value of the corresponding indicators of each major city. The specific statistical data of each evaluation index of 27 cities in the Yangtze River Delta urban agglomeration from 2013 to 2021 are shown in 2.

Table 2 Basic data for the evaluation of the effect of the coordinated treatment of environmental pollution in the urban agglomeration of the Yangtze River Delta

Indicators	2013	2014	2015	2016	2017	2018	2019	2020	2021
X_{11}	0.7216	0.7052	0.6721	0.6162	0.5724	0.5527	0.5427	0.5326	0.5218
X_{12}	6.52	6.92	7.25	7.86	8.17	8.47	8.65	8.71	8.95
X_{13}	1.4621	1.4356	1.4061	1.3372	1.2717	1.2318	1.2107	1.1753	1.1541
X_{14}	88.26	89.02	89.87	90.26	90.86	91.27	91.74	92.17	92.78
X_{15}	89.28	89.86	90.21	90.82	89.78	89.32	88.86	88.74	88.68
X_{16}	85.27	85.57	86.05	86.48	86.64	86.82	87.06	87.26	87.51
X_{21}	7.44	7.81	8.27	8.89	9.34	9.78	10.26	10.57	11.68
X_{22}	4.68	4.86	5.06	5.53	5.86	6.27	6.86	7.13	7.85
X_{23}	75.24	75.82	76.51	77.73	78.47	79.36	79.46	81.27	82.63
X_{24}	79.13	79.62	81.05	81.72	82.45	83.47	84.51	85.27	86.36
X_{25}	87.62	88.46	89.66	90.79	91.48	92.63	93.47	94.61	95.02
X_{26}	84.81	85.01	85.42	85.82	86.14	86.86	87.63	88.15	88.91
X_{31}	92.17	92.61	93.25	93.87	94.16	94.63	95.26	96.04	96.87
X_{32}	85.37	86.26	87.62	88.25	89.16	89.67	90.52	91.41	92.37
X_{33}	87.28	88.67	89.14	89.85	90.21	90.74	91.51	92.36	93.27
X_{34}	72.46	73.23	73.65	74.56	74.75	75.62	75.47	75.36	88.94
X_{35}	2.1624	2.0647	1.9741	1.8752	1.7213	1.5251	1.4637	1.3225	1.2115
X_{36}	3.3126	3.2651	3.0416	2.9625	2.7525	2.6427	2.5415	2.4517	2.3121
X_{41}	89.31	90.72	92.63	94.17	95.37	96.45	97.52	98.02	98.65
X_{42}	86.56	87.27	88.47	89.15	89.56	89.87	90.21	90.81	91.56
X_{43}	87.26	87.85	88.45	88.92	89.93	90.26	90.81	91.27	92.46
X_{44}	1.72	1.81	1.68	1.62	1.59	1.55	1.48	1.53	1.51
X_{45}	86.05	87.38	87.85	89.05	90.26	91.37	92.36	93.52	94.06
X_{46}	84.48	85.86	86.76	87.68	88.56	89.54	90.74	91.04	91.86

2.3. Construction of niche suitability evaluation model

2.3.1. Conventional niche fitness model

A Niche refers to the position of the population in time and space in the natural ecosystem and the functional relationship and role between the population and the relevant population in the environment without human destruction (Xu and Sun, 2021). It represents the minimum habitat threshold required for the survival of each species in the ecosystem (Han et al, 2021). If there are m regions and each region has ecological factors, use X_{ij} refers to the j_{th} ecological factor of the i_{th} area, use NM refers to the $m \times n$ dimensional niche matrix, this NM can be expressed as:

$$NM = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix} \quad (1)$$

If δ_{it} represents the absolute value of the difference between the normalized value of the niche and the maximum value of the normalized value in the i_{th} region at time t, and NS_i represents the ecological factor suitability of the ith region, the niche suitability model is expressed as follows:

$$NS_t = \frac{1}{n}\sum_{i=1}^{n}\frac{\delta_{min}+\lambda\delta_{max}}{\delta_{it}+\lambda\delta_{max}} = \frac{1}{n}\sum_{i=1}^{n}\frac{min\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}+max\,\lambda\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}}{\left|x_i'(t)-x_i'(\alpha)+max\,\lambda\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}\right.} \quad (2)$$

$$\begin{cases} \delta_{it} = \left|x_i'(t)-x_i'(\alpha)\right|, (i=1,2,\cdots,m; t=1,2,\cdots n) \\ \delta_{max} = max\{\delta_{it}\} = max\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\} \\ \delta_{min} = min\{\delta_{it}\} = min\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\} \end{cases}$$

Where: λ Is the parameter of the model, whose value range is（$0 \leq \lambda \leq 1$）, which can be used to adjust the calculation results of niche fitness, t is the time, $x_i'(t)$ is the niche value after normalization, and $x_i'(\alpha)$ is the most suitable value of Niche value after being standardized

2.3.2. Construction of spatial niche fitness model

According to the above conventional niche model, and in combination with the requirements of the evaluation of the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, a spatial niche suitability evaluation model suitable for the comprehensive evaluation of the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration is constructed. The evaluation indicators of the collaborative governance effect of the Yangtze River Delta urban agglomeration are regarded as the niche value. If i is the ecological region and t is the time, the time series of the evaluation indicators can be expressed as: X_{i1}，X_{i2}，$\cdots$，X_{it}，among in：$i = 1,2$，$\cdots$，m；$t = 1,2$，$\cdots$，n; In order to construct a spatial niche fitness model suitable for the comprehensive evaluation of the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, this paper refers to the Xu et al. (2022) 's method, introduces the generalized grey correlation degree of the grey theory to calculate the niche of ecological factors, and uses the weighted average method of absolute niche fitness and relative niche fitness to build a spatial niche fitness evaluation model. In order to construct the spatial niche fitness model, it is necessary to normalize the evaluation introduces now, and the maximum value can be used for normalization. According to research experience, the maximum value of positive introduces normalization can use the lower boundary value of the Level I standard or a certain ratio of the lower boundary value; Due to the influence of the calculation method, the normalization calculation of the contrary indicators has its particularity. When there is a Level V upper limit, select this upper limit as the normalization maximum; If the upper boundary tends to infinity, more than 10 times of the lower boundary value of Level V shall be used as the maximum value (Han and Cao,2022; Cao et al.2023). If the evaluation indicators have large volatility, the evaluation indicators should be buffered at 1-2 grades. Because the basic data of the evaluation indicators in this paper have good stability, the buffer processing of the evaluation indicators is omitted.

(1) Normalization of evaluation indicators. The ratio of the quantity value of the evaluation indicators to the determined maximum value of the evaluation indicators is used for normalization. After processing, the value range of the evaluation indicators is between [0,1]. The dimensionless calculation formula is as follows:

$$\begin{cases} X'_{it} = (X_{it})/(max\, X_{it}) & (Contrary\ indicators) \\ X'_{it} = 1-(X_{it}/maxX_{it}) & (Positive\ indicators) \end{cases} \tag{3}$$

Where: X'_{it} represents the dimensionless value of the i_{th} factor in year t, $i = 1,2,\cdots,m; t = 1,2,\cdots,n$; $X_{i\alpha}$ represents the most suitable value of the i evaluation indicators, and $X'_{i\alpha}$ represents the dimensionless processing value of the most suitable value of the i evaluation indicators, then:

$$\begin{cases} X'_{i\alpha} = (X_{i\alpha})/(max\, X_{it}) & (Contrary\ indicators) \\ X'_{i\alpha} = 1-(X_{i\alpha}/max\, X_{it}) & (Positive\ indicators) \end{cases} \tag{4}$$

(2) The construction of absolute niche fitness model. In order to calculate the absolute niche suitability, it is necessary to carry out the null conversion processing on the basis of the dimensionless processing results of the evaluation indicators. The null conversion processing is also called " Zero-image" processing. This method is so named because the elements in the first row are all zero after null conversion processing. Absolute null conversion processing is the process of subtracting the quantity value of one line from the quantity value of all indicators so that the quantity value of the first line of indicators is zero, and all the other indicators are differences. The specific calculation formula of absolute null conversion processing is as follows:

$$\begin{cases} X'_{it}(0)=\left(X'_{1t}(0),\ X_{2t}(0),\cdots,\ x'_{mt}(0)\right)=x'_{it}-x'_{1t} \\ X'_{i\alpha}(0)=\left(X'_{1\alpha}(0),\ x'_{2\alpha}(0),\cdots,\ x'_{m\alpha}(0)\right)=x'_{i\alpha}-x'_{1\alpha} \end{cases} \tag{5}$$

On the basis of the absolute null conversion processing of the evaluation indicators, the absolute niche fitness model can be constructed by using the calculation results of the absolute space null conversion processing. When the evaluation indicators are discrete variables, the absolute niche fitness model ($ANM_{t\alpha}$) the specific expression of is:

$$ANM_{t\alpha}=\frac{1+|S_\alpha|+|S_t|}{1+|S_\alpha|+|S_t|+|S_\alpha-S_t|} \tag{6}$$

$$\begin{cases} |S_t|=\left|\sum_{k=2}^{n-1}X'_{kt}(0)+\frac{1}{2}X'_{mt}(0)\right| \\ |S_\alpha|=\left|\sum_{k=2}^{n-1}X'_{k\alpha}(0)+\frac{1}{2}X'_{mt}(0)\right| \\ |S_t-S_\alpha|=\left|\sum_{k=2}^{n-1}\left(X'_{i\alpha}(0)-X'_{it}(0)\right)+\frac{1}{2}\left(X'_{m\alpha}(0)-X'_{kt}(0)\right)\right| \end{cases}$$

(3) Construction of relative niche fitness model. The above formula has constructed an absolute niche fitness model to evaluate the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration. The absolute niche fitness model can be constructed using the same method. We first perform the null conversion processing of evaluation indicators, that is, divide the historical value of each evaluation indicator by the corresponding value of the first line of evaluation indicators minus 1, then the quantity values of the first line indicators are zero, and the other lines are the difference between the ratio and 1. The specific calculation formula of relative null conversion processing is as follows:

$$\begin{cases} X''_{it}(0)=\left(X''_{1t}(0),X''_{2t}(0),\cdots,X''_{mt}(0)\right)=(X''_{mt})/(X''_{1t})-1 \\ X''_{i\alpha}(0)=\left(X''_{1\alpha}(0),X''_{2\alpha}(0),\cdots,X''_{m\alpha}(0)\right)=(X''_{m\alpha})/(X''_{1\alpha})-1 \end{cases} \tag{7}$$

If the evaluation indicators are continuous variables, the relative niche fitness can be calculated using the integral method. The specific relative niche fitness model ($RNM_{t\alpha}$) can be expressed as follows:

$$RNM_{t\alpha}=\frac{1+|S'_\alpha|+|S'_t|}{1+|S'_\alpha|+|S'_t|+|S'_\alpha-S'_t|} \tag{8}$$

$$\begin{cases} |S'_t|=\left|\sum_{k=2}^{m-1}X''_{kt}(0)+\frac{1}{2}X''_{mt}(0)\right| \\ |S'_\alpha|=\left|\sum_{k=2}^{m-1}X''_{k\alpha}(0)+\frac{1}{2}X''_{m\alpha}(0)\right| \\ |S'_t-S'_\alpha|=\left|\sum_{k=2}^{n-1}\left(X''_{k\alpha}(0)-X''_{kt}(0)\right)+\frac{1}{2}\left(X''_{m\alpha}(0)-X''_{kt}(0)\right)\right| \end{cases}$$

(4) Construction of spatial niche fitness model. If the relative weight of absolute niche fitness and relative niche fitness is ξ, the spatial niche fitness model ($SNM_{t\alpha}$) can be expressed as follows:

$$SNM_{t\alpha}=\xi ANM_{t\alpha}+\left(1-\xi\right)RNM_{t\alpha} \tag{9}$$

Where: $0 \leq \xi \leq 1$ is the relative weight value, which can be reasonably selected according to the actual situation of the importance of absolute niche fitness and relative niche fitness. When the relative weight value tends to 1, the magnitude of spatial niche fitness tends to the magnitude of absolute niche fitness; When the relative weight tends to 0, the magnitude of spatial niche fitness tends to the magnitude of relative niche fitness.

2.3.3. Determination of the evaluation standard of collaborative treatment effect of environmental pollution

The comprehensive evaluation of the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration should adopt the method of combining the relevant national standards with the experience of collaborative governance in the Yangtze River Delta. During the research, this paper mainly based on the Ambient Air Quality Standard (GB3095-2012), the Surface Water Quality Standard (GB3838-2012) and the Soil Environmental Quality Standard (GB36600-2018), and drew on the research results of Xu and Sun (2021), and Luo et al.(2022). The evaluation standards of evaluation indicators and the evaluation objectives are determined as five levels. In full consideration of the actual situation of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, the evaluation standards for the effect of the collaborative governance of environmental pollution in the Yangtze River Delta are determined on the basis of comprehensive analysis, as shown in Table 3.

Table 3 Comprehensive evaluation standards for the effect of collaborative governance of environmental pollution in urban agglomeration of the Yangtze River Delta

Indicators	Level Ⅰ	Level Ⅱ	LevelⅢ	LevelⅣ	Level Ⅴ
X_{11}	<0.55	0.55-0.60	0.60-0.70	0.70-0.80	>0.80
X_{12}	<7.5	7.5-9.0	9.0-10.5	10.5-12	>12
X_{13}	<1.10	1.10-1.40	1.40-1.60	1.60-1.80	>1.80
X_{14}	>90	80-90	70-80	60-70	<60
X_{15}	>90	80-90	70-80	60-70	<60
X_{16}	>90	80-90	70-80	60-70	<60
X_{21}	>12	10-12	8-10	6-8	<6
X_{22}	>8	6-8	4-6	2-4	<2
X_{23}	>80	60-80	50-60	40-50	<40
X_{24}	>90	80-90	70-80	60-70	<60
X_{25}	>90	80-90	70-80	60-70	<60
X_{26}	>90	80-90	70-80	60-70	<60
X_{31}	0-70	70-150	150-200	200-300	>300
X_{32}	0-70	70-150	150-200	200-300	>300
X_{33}	0-70	50-150	150-200	200-300	>300
X_{34}	0-70	70-120	120-170	170-200	>200
X_{35}	<1	1-2	2-3	3-4	>4
X_{36}	<1	1-3	3-5	5-7	>7
X_{41}	90-100	80-90	70-80	60-70	<60
X_{42}	90-100	80-90	70-80	60-70	<60
X_{43}	90-100	80-90	70-80	60-70	<60
X_{44}	<1.7	1.5-1.7	1-1.5	0.8-1	<0.8
X_{45}	90-100	80-90	70-80	60-70	<60
X_{46}	90-100	80-90	70-80	60-70	<60

To comprehensively evaluate the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration, in addition to determining the standards of evaluation indicators, the standards of evaluation objectives should also be determined. Since the evaluation indicators have been normalized in this paper, the value range of the evaluation results is between [0,1]. Regarding the national standards and the latest research results of domestic scholars, the evaluation level of the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration is determined as Level V, Level I is the best, and Level V is the worst. The specific standards are determined as follows: $SNM_{t\alpha}$ =[0.90,1.00], the evaluation grade is Level I, and the evaluation result is excellent; $SNM_{t\alpha}$=[0.80,0.90], the evaluation grade is Level II, the evaluation result is good, $SNM_{t\alpha}$=[0.70,0.80], the evaluation grade is Level III, the evaluation result is medium, $SNM_{t\alpha}$=[0.60,0.70], the evaluation grade is Level IV, the evaluation result is qualified; $SNM_{t\alpha}$=[0,0.60], the evaluation grade is Level V, and the evaluation result is unqualified. The above determination of the evaluation criteria for the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration is mainly based on relevant standards formulated by the national and provincial governments in the Yangtze River Delta region. These standards are current standards and have strong reliability (Guo et al., 2022); based on this, this paper also draws on the latest standards for the evaluation of the effectiveness of environmental pollution collaborative governance by domestic and foreign scholars. These are identified in the paper through document labeling.

3. Results and discussion

3.1 The evaluation results

(1) Normalization results of evaluation indicators. To effectively evaluate the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, according to the above research design, the evaluation indicators are first normalized, and the basic data of each evaluation indicator in Table 1 are processed dimensionless by using formula (7-8). The maximum value is selected according to the research design standards, the membership degree of the positive indicators whose value is greater than the determined maximum value is 1, and the subordinate degree of the contrary indicator is 1 if it is less than the determined maximum value, the other subordinate degree of the evaluation indicators is calculated and determined by the subordinate function. The specific dimensionless processing results are shown in Table 4.

Table 4 Normalized results of evaluation indicators for the effect of environmental pollution collaborative governance in urban agglomeration of the Yangtze River Delta

Indicators	2013	2014	2015	2016	2017	2018	2019	2020	2021	$x'_{i\alpha}$
X_{11}	0.9098	0.9119	0.9160	0.9230	0.9285	0.9309	0.9322	0.9334	0.9348	0.9348
X_{12}	0.9457	0.9423	0.9396	0.9345	0.9319	0.9294	0.9279	0.9274	0.9254	0.9457
X_{13}	0.9188	0.9202	0.9219	0.9257	0.9294	0.9316	0.9327	0.9347	0.9359	0.9359
X_{14}	0.9006	0.9084	0.9170	0.9210	0.9271	0.9313	0.9361	0.9405	0.9467	0.9467
X_{15}	0.9110	0.9169	0.9205	0.9267	0.9161	0.9114	0.9067	0.9055	0.9049	0.9267
X_{16}	0.8701	0.8732	0.8781	0.8824	0.8841	0.8859	0.8884	0.8904	0.8930	0.8930
X_{21}	0.6200	0.6508	0.6892	0.7408	0.7783	0.8150	0.8550	0.8808	0.9733	0.9733
X_{22}	0.6012	0.6085	0.6325	0.6913	0.7325	0.7838	0.8575	0.8913	0.9813	0.9813
X_{23}	0.7920	0.7981	0.8054	0.8182	0.8260	0.8354	0.8364	0.8555	0.8698	0.8698
X_{24}	0.8329	0.8381	0.8532	0.8602	0.8679	0.8786	0.8896	0.8976	0.9091	0.9091
X_{25}	0.8941	0.9027	0.9149	0.9264	0.9335	0.9452	0.9538	0.9654	0.9696	0.9696
X_{26}	0.8927	0.8948	0.8992	0.9034	0.9067	0.9143	0.9224	0.9279	0.9359	0.9359
X_{31}	0.9386	0.9383	0.9378	0.9374	0.9372	0.9369	0.9365	0.9360	0.9354	0.9386
X_{32}	0.9431	0.9425	0.9416	0.9412	0.9406	0.9402	0.9397	0.9391	0.9384	0.9431
X_{33}	0.9418	0.9409	0.9406	0.9401	0.9399	0.9395	0.9390	0.9384	0.9378	0.9418
X_{34}	0.9275	0.9268	0.9264	0.9254	0.9253	0.9244	0.9245	0.9246	0.9111	0.9275
X_{35}	0.9459	0.9484	0.9506	0.9531	0.9570	0.9619	0.9634	0.9669	0.9697	0.9697
X_{36}	0.9527	0.9534	0.9565	0.9577	0.9607	0.9622	0.9637	0.9650	0.9670	0.9670
X_{41}	0.8931	0.9072	0.9263	0.9417	0.9537	0.9645	0.9752	0.9802	0.9865	0.9865
X_{42}	0.8833	0.8905	0.9028	0.9097	0.9139	0.9170	0.9205	0.9266	0.9343	0.9343
X_{43}	0.8904	0.8964	0.9026	0.9073	0.9177	0.9210	0.9266	0.9313	0.9435	0.9435
X_{44}	0.9053	0.9526	0.8842	0.8526	0.8368	0.8158	0.7789	0.8053	0.7947	0.9526
X_{45}	0.8781	0.8916	0.8964	0.9087	0.9210	0.9323	0.9424	0.9543	0.9598	0.9598
X_{46}	0.8620	0.8761	0.8853	0.8947	0.9037	0.9137	0.9259	0.9290	0.9373	0.9373

(2) The evaluation results of the three niche fitness models. After completing the above technical processing of the evaluation indicators, the absolute niche suitability evaluation results can be calculated using formula (6) according to the research design; Use formula (9) to calculate the evaluation results of relative niche suitability; Use formula (11) to calculate the evaluation results of spatial niche suitability. The specific evaluation process and results are shown in Table 5.

Table 5 Comprehensive evaluation results of three niche suitability models

Indicators	2013	2014	2015	2016	2017	2018	2019	2020	2021
$ANM_{t\alpha}$	0.8261	0.8525	0.8758	0.8946	0.9076	0.9136	0.9187	0.9286	0.9347
Level	II	II	II	II	I	I	I	I	I
$RNM_{t\alpha}$	0.8035	0.8257	0.8346	0.8526	0.8767	0.8965	0.9015	0.9082	0.9146
Level	II	II	II	II	II	II	I	I	I
ξ	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
$SNM_{t\alpha}$	0.8171	0.8418	0.8593	0.8778	0.8952	0.9068	0.9118	0.9204	0.9267
Level	II	II	II	II	II	I	I	I	I

It can be seen from Table 5 that the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration has shown an upward trend from 2013 to 2021. From the evaluation results of three different niche fitness models, the evaluation results of the absolute niche fitness model are significantly higher than the evaluation results of the relative niche fitness model. The evaluation results of the spatial niche fitness model are located between the evaluation results of the two models and have the function of smoothing. The evaluation results of the spatial niche model also take into account the advantages of the absolute niche fitness model and the relative niche fitness model; From the evaluation results of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration, the evaluation results of the three evaluation models are basically the same, and the evaluation results of the three models have great differences between 2013 and 2018. In 2019 and 2021, although the evaluation coefficients have some differences, the evaluation results of the three models are the same, and the evaluation results of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration are all "Level I", The effect of collaborative governance of environmental pollution is "excellent" grade.

3.2 Discussion on the difference of evaluation results of different niche fitness models

In order to effectively evaluate the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration, the author, based on comprehensive analysis and the traditional niche model, reconstructs the absolute niche model, the relative niche fitness model, and the spatial niche fitness model, and uses the basic data of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration. Three niche fitness models were used to study the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, and the effectiveness of the evaluation model was verified. To analyze and compare the differences and effectiveness of the evaluation results of the three niche fitness models, the evaluation results of the three niche fitness models are drawn by a radar chart. The composition and differences of the evaluation results of the three niche fitness models are shown in Figure 1.

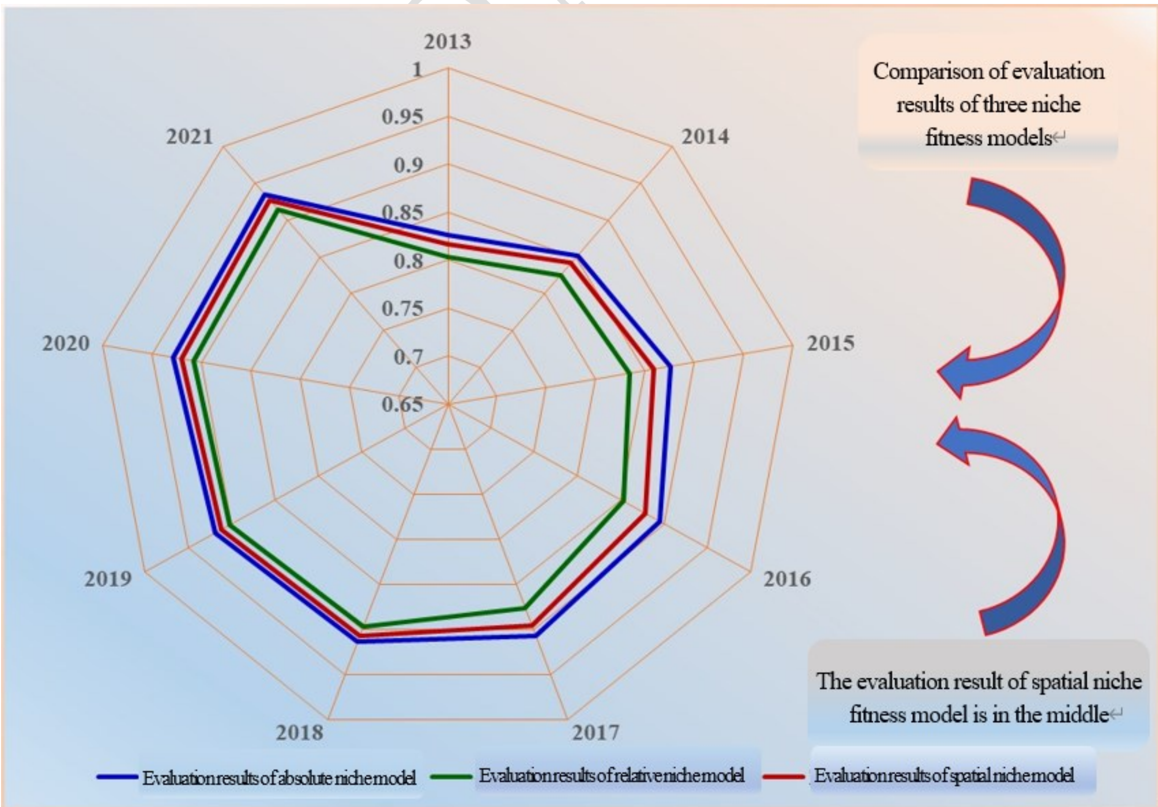


Figure 1. Comparison of evaluation results of three niche fitness models

It can be seen from Figure 1 that the evaluation results of the spatial niche fitness model lie between the evaluation results of the absolute niche fitness model and the evaluation results of the relative niche fitness model, and the evaluation results of the spatial niche fitness model can be adjusted by using the change of the relative weight value to consciously bias the evaluation results of the absolute niche fitness model or the evaluation results of the relative niche fitness model. Therefore, the spatial niche index model has a wide range of application and regulation, a wide range of suitable evaluation, and a wide range of applications, which has a good effect on smoothing and regulation of evaluation results. The process of application test proved that the niche fitness model is suitable for the evaluation of the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, and the spatial niche model has a wider application range.

3.3 Discussion on influencing factors of evaluation results

According to the research design, on the basis of comprehensive analysis, this paper selected four types of 24 evaluation indicators to evaluate the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration. The selected 24 evaluation indicators are the main driving factors that affect and determine the effect of the collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration. In order to further analyze the impact of these influencing factors on the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration, the membership degrees of 24 driving factors are drawn in the rectangular coordinate diagram, and the specific changes of the driving factors are shown in Figure 2.

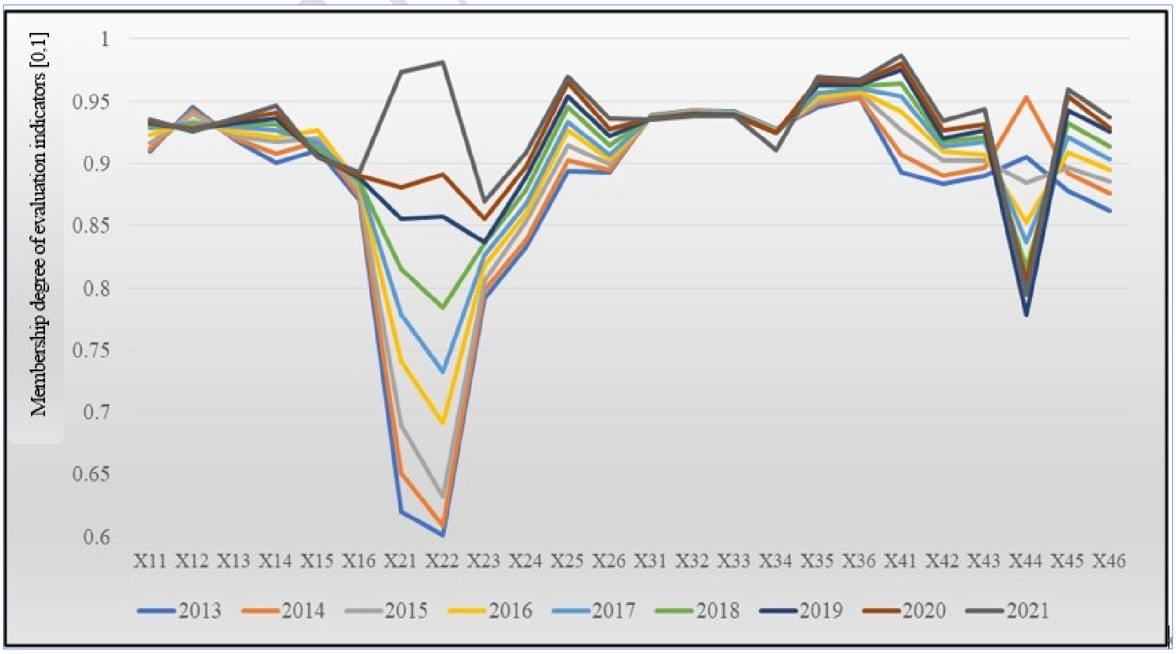


Figure 2. Diagram of factors affecting the effect of coordinated treatment of environmental pollution in the Yangtze River Delta urban agglomeration

It can be clearly seen from Figure 2 that the changes of 24 evaluation indicators during 2023-2021 are very uneven, and the impact of evaluation indicators is also very different. The membership of most evaluation indicators is relatively high, and only a few indicators such as X_{21} and X_{22} are relatively small. However, the comprehensive effect of 24 evaluation indicators has made the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration reach a better level. However, the comprehensive functions of 24 evaluation indicators have made the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration reach a better level. To improve the effect of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration, improving the subordination of these relatively low indicators is a good way to improve the effect of environmental pollution collaborative governance. The main indicators to be improved include X_{15}-X_{23}, X_{43} and X_{44}. In the process of specific improvement and improvement, specific adjustment objects should be determined through comparison. Only according to the changes of these driving factors, the managers continuously pay attention to the relatively low indicators and continuously improve these relatively low indicators, can they continuously promote the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration

5. Conclusions

The comprehensive evaluation of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration is a complex research topic. Due to the influence of the complex environment and many factors, the selection of evaluation indicators, basic data processing, model construction and the evaluation of the environmental pollution collaborative governance effect all show complexity. Based on the analysis of the results of the environmental pollution collaborative governance and its effect evaluation of the Yangtze River Delta urban agglomeration, this paper has selected the evaluation indicators, processed the evaluation indicators, and combined with the situation of the environmental pollution collaborative governance of the Yangtze River Delta urban agglomeration, constructed three comprehensive evaluation models: absolute niche fitness model, relative niche fitness model and spatial niche fitness model. Based on the comparison and analysis of the three evaluation models, the spatial niche suitability evaluation model is selected as the main model for the comprehensive evaluation of the effect of collaborative governance of environmental pollution in the Yangtze River Delta urban agglomeration. The evaluation results show that the comprehensive evaluation results of the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration are "Level II" in the period of 2013-2017, the evaluation results are “Good" grade; The period from 2018 to 2021 are “Level I", and the evaluation results are "Excellent" grade. Especially in 2021, the collaborative governance effect is the best, and the comprehensive evaluation coefficient is 0.9267. Although the evaluation result is "excellent", the comprehensive evaluation coefficient is lower in the excellent grade, and there is still a long distance from the best evaluation coefficient 1. This requires all cities in the Yangtze River Delta urban agglomeration to step up their efforts and make continuous efforts to improve the effects of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration. Based on the above research results, the following policy recommendations are proposed:

(1) Improve the environmental pollution collaborative governance effect of the Yangtze River Delta urban agglomeration by maximizing the relatively weak evaluation indicators. According to the basic evaluation data of the paper, the power (X_2) indicators for collaborative governance of energy consumption environmental pollution are relatively weak, which is the key factor for improving the effectiveness of environmental pollution collaborative governance in the Yangtze River Delta urban agglomeration in this paper. Grasping these indicators can achieve twice the result with half the effort;

(2) Make full use of the differences shown by spatial niche evaluation methods to enhance the collaborative treatment effect of environmental pollution in the Yangtze River Delta urban agglomeration. According to the characteristics of the spatial niche evaluation method, the results displayed by the spatial niche evaluation method should be used to improve the collaborative governance effect of environmental pollution in the Yangtze River Delta urban agglomeration. In this paper, the main membership and relative weights are used to improve the collaborative governance effect of environmental pollution;

(3) Make full use of the differences shown in the evaluation results to improve the collaborative treatment effect of environmental pollution in the Yangtze River Delta urban agglomeration. Although the evaluation results in the paper have been relatively high, from the perspective of the evaluation results, the evaluation results have not reached the optimal level, and there is still much room for improvement. This is a breakthrough for improving the effectiveness of coordinated environmental pollution control in the Yangtze River Delta urban agglomeration in the future.

Availability of data and materials

Not applicable.

Ethical Approval,

Not applicable.

Consent to Participate,

Not applicable.

Consent to Publish,

All the authors agree to publish this paper in this journal.

Authors Contributions,

This paper was written by two authors, associate professor Zhentao Zhu completed the first draft and conducted a comprehensive examination. Master Juan Sun participated in data collection, model calculation and paper translation， the authors ranked according to their contributions.

Competing Interests,

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This work has received funding from the general project of national social science foundation of China: "Research on the new division of labor and regional coordinated development mechanism of manufacturing industry in the Yangtze River Economic Belt" (Approval number: 19BJL052).

Acknowledgements

This work has received funding from the general project of national social science foundation of China， the author thanks the National Office for philosophy and Social Sciences for this study support and thanks for the Constructive modification suggestions put forward by the reviewers.

References

Cao, T.Y., Sun, F.Q., Han X.Y* and Xia Y.T. Study on treatment effect assessment of heavy metal pollution in Taihu lake sediments based on the rapid development of Yangtze River delta urban agglomeration in China. Global NEST Journal, 2023, 25:141-150.

Cao T.Y., Sun F.Q., Sun T. 2023. Spatial test of collaborative treatment efficiency measurement and driving factors of air pollution in China's Yangtze River Delta urban agglomeration. Urban Climate,49: 101454.

Committee on environmental hazards. Committee on environmental hazards: present status of water pollution control. Pediatrics, 1964, 34 (3): 431-433.

Dong, X., Dai, X.Y. The Root of Pollution in Yangtze River Delta and the Collaboration of Regional Environmental Governance. Chinese Journal of Environmental Management,2015, 7, (3):81-85.

Gao, J.T., Lei, D.P., Xu, J.T. Work together for comprehensive governance. Soil and Water Conservation in China, 1984, (10):44-44. DOI: 10.14123/j.cnki.swcc.1984.10.023

Guo P.Y., Sun F.Q., Xiuyan Han X.Y. 2022. Study on comprehensive evaluation of environmental pollution treatment effect in coal mine subsidence area: taking Xinglongzhuang mining area of Yanzhou energy as an example. Environmental Science and Pollution Research, 111: 22532-9.

Han, X.Y., Cao, T.Y. 2022. Study on the evaluation of ecological compensation effect for environmental pollution loss from energy consumption: Taking Nanjing MV Industrial Park as an example Environmental Technology & Innovation, 27:102473.

Han, X.Y., Cao, T.Y. Urbanization level, industrial structure adjustment and spatial effect of Urban Haze pollution: Evidence from China's Yangtze River Delta Urban Agglomeration. Atmospheric Pollution Research, 2022， 13(6): 101427.

Han, X.Y., Cao, T.Y.， Yan X.L. 2021. Comprehensive evaluation of ecological environment quality of mining area based on sustainable development indicators: a case study of Yanzhou Mining in China. Environment, Development and Sustainability,2021, 23: 7581–7605.

Hnohuean, H., Okoh, A.I., Nwodo, U.U. Antibiogram signatures of Vibrio species recovered from surface waters in South Western districts of Uganda: Implications for environmental pollution and infection control. Science of The Total Environment,2022, 807(02): 150706.

Hibert, M.S. Administration of environmental health programs within the state government: II. Administration of water supply and pollution control within the state government. American Journal of Public Health and the Nation’s Health,1967, 57, (2): 275-280.

Jones, J.L., White, D.D. Understanding barriers to collaborative governance for the food-energy-water nexus: The case of Phoenix, Arizona. Environmental Science & Policy, 2022, 127: 111-119.

Li Y.L., Li Z.C. 2022. Intergovernmental Cooperation, Financial Autonomy, and Regional Environmental Governance Performance: An Analysis Based on Urban Agglomeration in Beijing, Tianjin, Hebei, and the Yangtze River Delta. Urban Problems, (2): 13-22.

Li J.M., Jiang S.S. 2022. How can governance strategies be developed for marine ecological environment pollution caused by sea-using enterprises? — A study based on evolutionary game theory. Ocean & Coastal Management, 232: 106447.

Liu, X.J., Song, L.F., Li, Q.F., Huang, Y. Challenges and Suggestions of Green Low Carbon in The Yangtze River Delta Waterway under “Double Carbon” Background. Shanghai Energy Saving, 2022, (2): 130-134.

Luo, Y.N., Sun, F.Q., Yan, X.L., Sun, T. Research on Comprehensive Assessment of Effect on Environmental Pollution Collaborative treatment: Taking China’s Yangtze River Delta Urban Agglomeration as an Example. Polish Journal of Environmental Studies, 2022, 31, (6): 5151-5162.

Mao, C.H., Cao, X.F. Research into Cross-Regional Collaborative Governance of Pollution: Taking the Yangtze River Delta for Example. Journal of Hohai University (Philosophy and Social Sciences) ,2016, 18, (5): 46-51+91.

Nicola U., Mark T.I., Saba S., Hayley H. 2023. Drivers and Dynamics of Collaborative Governance in Environmental Management. Environmental Management, 71(3): 495-504.

Purdom, P.W. Administration of environmental health programs within the state government: 3. Administration of air pollution control programs within the state government. American Journal of Public Health and the Nation's Health, 1967, 57, (2): 281-286.

Qin, R.S., Chen, S.Z., Li, Z.F. Establishment of urban regulation system and two-way coordinated governance of economic environment. Urban Problems,1990, (1): 23-25.

Sabrina, D., Annele, S.L., Maria, J., Göran, E., Camilla, S. Achieving Social and Ecological Outcomes in Collaborative Environmental Governance: Good Examples from Swedish Moose Management. Sustainability, 2021, 13 (4): 2329-2329.

Sun, Y.M., Zhou, C.Y. The spatio-temporal evolution characteristics and influencing factors of collaborative governance of air pollution in the Yangtze River Delta region. Geographical Research, 2022, 41, (10): 2742-2759.

Sirinya P., Yandisa N., Jeff C., Marie T.A., Ashley S., Carmen Huckel S.C., Sharon F. (2022). Moving from silos to synergies: strengthening governance of food marketing policy in Thailand. Global and Health, **18**(1): 29-39.

Taylor, N.K., Russel, D., Winter, M. The Contours of State Retreat from Collaborative Environmental Governance under Austerity. Sustainability,2020, 12(7): 2761-2761.

Tan, J., Jiang, Z. Mechanism and Empirical Test of Collaborative Environmental Governance in the Yangtze River Delta Region. Ecological Economy,2022, 38, (6): 192-199+224.

Wang, Y., Zhao, Y.H. Is collaborative governance effective for air pollution prevention? A case study on the Yangtze River delta region of China. Journal of Environmental Management, 2021,292: 112709-112709.

Wilder, R.J. Cooperative governance, environmental policy, and management of offshore oil and gas in the United States. Ocean Development & International Law,1993, 24 (1): 41-62.

Wu, J.N., Liu, Q.Q., Chen, Z.T., Qin, C. How does the Regional Collaborative Governance Mechanism of Air Pollution in China Operate Well? Evidence from the Yangtze River Delta. Chinese Public Administration, 2020, (05): 32-39.

Xu, D.Y., Sun, T. Research on Comprehensive Evaluation of Synergistic Governance Effects of Urban Environmental Pollution. Environmental Science and Management, 2021, 46(12):176-181, 2021.

Xu, L.J., Liu, Y.J., Zhang, X.Y. Study on Comprehensive Assessment of Air Quality of Energy Consumption in Industrial Parks: Take Nanjing HX Industrial Park in China as an Example. Polish Journal of Environmental Studies, 2023,32, (1): 387-397.

Yandisa, S.P., Colin, N.J., Thow, A.M., Schram, A., Schneider, Zhao, Y.B., Wang S.J., Zhou, C.S. Understanding the relation between urbanization and the eco-environment in China's Yangtze River Delta using an improved EKC model and coupling analysis. Science of The Total Environment, 2016, 571: 862-875.

Yu, M.J., Zou, F. Stimulating Social Vitality: The Construction of an Activist Network in the Coordinated Governance of Water Environment in the Yangtze River Delta. Jiangsu Social Sciences, 2022, (1): 43-51+242.

Yang, C.M. Research on the coordinated governance of ecological civilization in the Yangtze River Delta urban agglomeration from the perspective of the Import Expo. Journal of Suzhou University of Science and Technology (Social Science Edition), 2019, 9,36(2):43-46.

Yang, C.M., Horvath, G. Study on Dynamic Associative Network and Collaborative Governance of Haze Pollution in Yangtze River Delta Urban Agglomeration Based on Spatiotemporal Interaction Perspective. Soft Science, 2019, 33(12):114-120.

Zang, N.K. Multi-center theory and the cooperation mechanism of public governance in the Yangtze River Delta region. Chinese Public Administration,2006, (5):83-87.