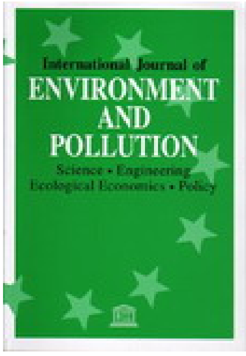

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Research on comprehensive evaluation on effects of synergistic governance on urban environmental pollution based on the evaluation model of niche suitability

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Abstract: Based on research background analysis and literature review, this paper creates an indicator system and three models of niche suitability for evaluating effects of synergistic governance on urban environmental pollution, and defines the grade standards for comprehensive evaluation results and all evaluation indicators. This paper selects the city of Wuxi, Jiangsu Province, China, as the object of case research, collects the basic data of this city, and comprehensively evaluates the effects of synergistic governance on urban environmental pollution in this city from 2012 to 2020. The evaluation results show that there had been a continuous upward trend for the effects of synergistic governance on urban environmental pollution in this city during this period. Besides, this paper analyses the differences and influencing factors of the evaluation results, demonstrates the effectiveness of the evaluation models, and puts forward some policy suggestions for Wuxi to make further improvement in urban environmental pollution governance.

Keywords: synergistic governance; effects evaluation; indicator system; the evaluation model of niche suitability; absolute niche suitability; relative niche suitability; spatial niche suitability; grade standards.

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1 Introduction

Governance on environmental pollution began in the early 1970s in China, and it has a history of more than 50 years. Although early Chinese investment in it increased year by year, due to the spatial spillover effects of environmental pollution (Chen et al., 2022), the model of solo governance could not adapt to new needs, and the actual effects of governance on environmental pollution was not optimistic in early years. Chinese government began to explore the model of joint prevention and control to govern regional air pollution in the mid to late 1990s, and gradually formed the concept of synergistic governance on environmental pollution at the beginning of this century, which has been continually deepened and developed under effective promotion of policies and regulations. After 2013, synergistic mechanism for governance on environmental pollution has been further improved with strategic advancement of regional integration in China (Yan et al., 2021). However, under the enormous environmental pressure in the middle and late stages of urbanisation and industrialisation, China is increasingly required to address more complex challenges from environmental pollution governance than ever before (Deng and Chen, 2022). Therefore, it has become an inevitable choice for China to govern environmental pollution in a synergistic model. Since cities and towns are not only the main carriers of regional economic development but also the regions with the most concentrated environmental pollution, researchers have paid high attention to effects of synergistic governance on urban environmental pollution.

Foreign researchers started to evaluate effects of governance on urban environmental pollution earlier than Chinese researchers did, and established a relatively mature and perfect theoretical system. Tyteca (1996) proposed a calculation method of environmental performance indicator, and created an indicator system of evaluation on environmental performance from three dimensions. Ritz and Ranganathan (1998) researched the process of environmental pollution, and created an indicator system of evaluation on performance of environmental pollution governance from four aspects. Esty et al. (2006) used the thematic framework model to establish an indicator system of environmental performance applicable to all countries in the world. Grilo et al. (2013) analysed problems of environmental protection in urbanisation construction, and researched methods for evaluating urbanisation level considering environmental protection. Pires et al. (2017) created a system for evaluating performance of water environment management and sustainable utilisation of water resources from three dimensions.

Chinese researchers explored methods for evaluating effects of governance on urban environmental pollution on the basis of foreign research achievements. Jiang et al. (2008) proposed principles and basic framework for designing indicator system of comprehensive evaluation on effects of urban environmental pollution governance, elaborated basic ideas and steps of applying three evaluation methods for comprehensively evaluating effects of urban environment pollution governance, and evaluated their advantages and disadvantages. Ma and Weng (2011) created an indicator system for evaluating performance of water pollution governance in urban considering the characteristics of Chinese government, determined grade standards and weights for all evaluation indicators, and conducted an empirical evaluation. Nie (2015) took synergistic governance system of urban forest as research object, created an indicator system and model for evaluating synergistic degree, and took Qingdao as the case to make an empirical analysis. Chen (2018) measured the synergistic degree of environmental pollution governance in 26 cities of Yangtze River Delta from 2007 to 2016, and believed that the synergistic degree had determined the effectiveness of environmental pollution governance to a certain extent in this region during this period. Xiong and Liu (2018) used the evaluation system of PSR to evaluate the performance of governance on air pollution in two urban agglomerations in China from 2011 to 2016, and compared the evaluation results. Yang and Huang (2019) created a model for evaluating effects of synergistic governance on environmental pollution, and used it to conduct an evaluation in the metropolitan area of Suzhou-Wuxi-Changzhou from 2006 to 2017. Huang et al. (2019) created an indicator system and model for evaluating performance of governance on regional environmental pollution, and conduct an empirical evaluation. Yu and Zhu (2019) created an indicator system for evaluating governance performance of water pollution, and took Chengdu as the case to conduct an empirical research. The latest research achievements of synergistic governance on effects of urban environmental pollution in China are as follows. Xu and Sun (2021) created an indicator system and model for evaluating effects of synergistic governance on urban environmental pollution, defined grade standards for governance effects and all evaluation indicators, and selected the city of N, China, to conduct a case research. Luo et al. (2022) selected 22 evaluation indicators, created three evaluation models of niche suitability, conducted an empirical evaluation, and discussed evaluation results to demonstrate the effectiveness of these evaluation models.

As can be seen from the above literature review, researchers have been conducting comprehensive evaluation on effects of governance on urban environmental pollution from various perspectives, but mainly focus on evaluation methods and their applications. Although researchers in developed countries have paid much attention to this issue for a long time, there are great differences in synergistic governance on environmental pollution in different countries and regions (Si and Pei, 2021). So, the theories and methods in this aspect from developed countries cannot be directly applied to practice in China (Han and Cao, 2022). The research on this issue has developed rapidly with its own characteristics since it started in China, but Chinese researchers are still faced with some unsolved problems and seeking satisfied solutions to them. How to combine regional integration development and synergistic factors with evaluation indicators? How to scientifically and innovatively create an evaluation model? This paper attempts to seek solutions to the above two typical and representative problems and explore an effective method for comprehensive evaluation on effects of synergistic governance on urban environmental pollution in China. As scientific and effective evaluation methods are urgently needed at present, this research is of great importance and urgency.

2 Materials and methods

2.1 Selecting evaluation indicators and creating indicator system

Selecting scientific and reasonable evaluation indicators is vital to comprehensive evaluation on effects of synergistic governance on urban environmental pollution (Xu and Sun, 2021; Luo et al., 2022). This paper draws on the latest research achievements at home and abroad, takes full account of actual situation in China (Han and Cao, 2021), and selects 22 evaluation indicators in four categories in accordance with the principles of scientific nature, completeness and operability (Zhou and Cheng, 2016). The indicator system for comprehensive evaluation on effects of synergistic governance on urban environmental pollution is created based on the selected evaluation indicators, and Table 1 shows the indicator system (Yang and Huang, 2019; Han and Cao, 2021).

Table 1 Statistical table of indicator system for comprehensive evaluation on effects of synergistic governance on urban environmental pollution

Target layer	*Criterion layer*	*Measure layer*			
		No.	*Indicator name and indicator symbol*	*Unit*	*Indicator property*
Effects of synergistic governance on urban environmental pollution	Driving force of synergistic governance	1	GDP per capita (X_1)	Yuan	Forward indicator
		2	PCDI of urban residents (X_2)	Yuan	Forward indicator
		3	Per capita fiscal revenue (X_3)	Yuan	Forward indicator
		4	Urbanisation level (X_4)	%	Forward indicator
		5	Population density (X_5)	Person/km^2	Forward indicator
		6	Average life expectancy of UR (X_6)	Year	Forward indicator
		7	SDP for environmental pollution governance (X_7)	%	Forward indicator
	Pressure of synergistic governance	8	Index of soil pollution (X_8)	%	Contrary indicator
		9	Index of water pollution (X_9)	%	Contrary indicator
		10	Index of air pollution (X_{10})	%	Contrary indicator
		11	Rate of public green travel (X_{11})	%	Forward indicator
		12	EC per unit of GDP (X_{12})	TSC/10^2 yuan	Contrary indicator
	Status and impact of synergistic governance	13	Index of Ecological environment quality (X_{13})	%	Forward indicator
		14	Rate of environmental greening (X_{14})	%	Forward indicator
		15	Public satisfaction with environment (X_{15})	%	Forward indicator
		16	Proportion of days with excellent AQ (X_{16})	%	Forward indicator
		17	Standard-reaching rate of EFZ (X_{17})	%	Forward indicator
	Response of synergistic governance	18	RHST on urban domestic waste (X_{18})	%	Forward indicator
		19	RCU of solid waste in industrial enterprises (X_{19})	%	Forward indicator
		20	Rate of water reuse in industrial enterprises (X_{20})	%	Forward indicator
		21	RCT on urban domestic sewage (X_{21})	%	Forward indicator
		22	RSP for publicity and education on EP (X_{22})	%	Forward indicator

GDP: Gross domestic product; PCDI: Per capita disposable income; UR: Urban residents; SDP: Synergistic degree of projects; EC: Energy consumption; TSC: Tons of standard coal; AQ: Air quality; EFZ: Environmental functional zone; RHST: Rate of harmless synergistic treatment; RCU: Rate of comprehensive utilisation; RCT: Rate of centralised treatment; RSP: Rate of synergistic popularisation; EP: Environmental protection.

2.2 Collecting data of evaluation indicators

This paper selects the city of Wuxi, Jiangsu Province, China, as the object of case research to illustrate the method of comprehensive evaluation on effects of synergistic governance on urban environmental pollution. By the end of 2020, the total area of this city had been 4,627.47 square kilometres, and the population of permanent residents in this city had amounted to 7.464 million. This city had five municipal districts and two county-level cities under its jurisdiction at that time, all of which participated in synergistic governance on urban environmental pollution. Table 2 shows the basic data of 22 evaluation indicators in this city from 2012 to 2020 (Wuxi Municipal Bureau of Statistics, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020).

Table 2 Statistical table of basic data of indicators for evaluating the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020

No.	*Indicator symbol*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
1	X_1	117,357	120,007	128,756	133,515	138,361	140,306	151,260	158,659	165,851
2	X_2	35,663	38,999	41,731	45,129	48,628	52,659	56,989	61,915	64,714
3	X_3	9528	10,135	10,700	11,464	11,964	12,588	13,632	13,903	14,411
4	X_4	72.50	73.40	74.60	76.90	78.10	79.80	80.40	82.00	82.80
5	X_5	1016	1020	1031	1039	1051	1065	1074	1087	1100
6	X_6	81.47	81.74	81.93	82.07	82.24	82.35	82.77	83.01	83.19
7	X_7	82.26	83.55	85.77	86.33	87.98	88.22	90.55	91.49	92.34
8	X_8	185.57	179.32	171.43	158.29	131.68	127.74	106.65	91.06	89.31
9	X_9	191.65	181.94	163.27	156.56	133.34	126.89	104.23	99.08	97.42
10	X_{10}	175.25	169.43	154.92	137.67	118.03	110.85	94.49	87.36	85.18
11	X_{11}	54.23	58.96	62.17	67.49	70.67	71.28	76.85	75.41	76.32
12	X_{12}	0.526	0.491	0.462	0.434	0.418	0.395	0.343	0.322	0.317
13	X_{13}	79.06	86.85	101.43	109.16	118.42	121.67	136.98	144.29	145.06
14	X_{14}	42.68	42.78	42.88	42.98	42.98	42.98	42.98	43.24	43.43
15	X_{15}	64.15	69.26	72.83	76.41	80.74	81.92	87.67	91.39	93.01
16	X_{16}	51.80	54.90	57.70	64.10	66.90	67.70	70.70	72.10	81.70
17	X_{17}	68.21	71.67	75.26	77.03	81.58	82.39	90.42	93.34	94.15
18	X_{18}	90.67	90.43	92.29	93.36	93.82	94.47	96.06	98.51	99.93
19	X_{19}	90.80	81.80	91.00	94.40	94.90	91.00	91.30	95.90	94.20
20	X_{20}	73.54	74.17	75.36	77.29	80.45	81.07	82.04	82.96	83.13
21	X_{21}	93.83	94.05	93.32	94.60	90.70	93.00	97.30	97.60	98.10
22	X_{22}	68.12	71.36	75.29	79.43	81.95	83.01	93.08	95.67	96.05

2.3 Evaluation model of niche suitability

2.3.1 Conventional evaluation model of niche suitability

American researchers first proposed the concept and analytical methods of niche to analyse ecological situation in the early last century (Barry and Moore, 1980). Niche refers to time and space positions of population in a natural ecosystem, as well as functional relationships and roles among relevant population in any environment without artificial destruction (Godsoe et al., 2017). It represents the minimum habitat threshold required for each kind of organism to survive in an ecosystem. In this paper, it is assumed that there are *m* ecological factors, that is, evaluation indicators, in an urban area. If an actual quantitative value of an ecological factor at a time is expressed as x_i $(i = 1, 2, \ldots, m.$ The same below.$)$, actual quantitative values of all ecological factors at a time can be expressed by a column vector, that is, $x = (x_1, x_2, \ldots, x_m)^T$. Therefore, actual quantitative values of all ecological factors at n times can form a matrix composed of n column vectors with m dimensions. If the matrix is represented by *EFM*, there are (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$EFM = \begin{pmatrix} x_1(t_1) & x_1(t_2) & \cdots & x_1(t_n) \\ x_2(t_1) & x_2(t_2) & \cdots & x_2(t_n) \\ \vdots & \vdots & \vdots & \vdots \\ x_m(t_1) & x_m(t_2) & \cdots & x_m(t_n) \end{pmatrix} \tag{1}$$

The non-negative function $f(E) = (x_{1(tj)}, x_{2(tj)}, \ldots, x_{m(tj)})^T$ $(j = 1, 2, \ldots, n.$ The same below.$)$ is a subset of the ecological factor space E^m with m dimensions at a time of t_j, and it represents actual niche of synergistic governance on urban environmental pollution at a time of t_j in this paper. The closeness between actual niche and optimal niche is called as niche suitability. If NS_{tj}, X_{tj}, X_α are respectively used to represent niche suitability at a time of t_j, actual niche at a time of t_j, optimal niche, there are: $NS_{tj} = \tau(X_{tj}, X_\alpha)$.

First of all, actual quantitative values and optimal quantitative values of all evaluation indicators should be dimensionless so that they can be transformed into comparable values. If $x_{i(tj)}$, $x_{i(t0)}$, $x'_{i(tj)}$ are respectively used for an evaluation indicator (X_i) to represent its actual quantitative value at a time of t_j, its maximum, its dimensionless quantitative value at a time of t_j, there are (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$x'_{i(tj)} = \begin{cases} x_{i(tj)} \cdot \left[x_{i(t0)}\right]^{-1} & \text{forward indicators} \\ 1 - x_{i(tj)} \cdot \left[x_{i(t0)}\right]^{-1} & \text{contrary indicators} \end{cases} \tag{2}$$

For calculation convenience in this paper, a dimensionless optimal value for an evaluation indicator is determined by the average of the standardised maximum for evaluation (The standardised maximum for evaluation is 1.) and the dimensionless quantitative maximum of the corresponding evaluation indicator. If $x'_{i(\alpha)}$ is used to represent dimensionless optimal value of an evaluation indicator (X_i), there are:

$$x'_{i(\alpha)} = \left[1 + \max(x'_{i(t1)}, x'_{i(t2)}, \ldots, x'_{i(tn)})\right] \cdot 0.5 \tag{3}$$

NS_{tj} can usually be expressed by the distance formula as follows (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$NS_{tj} = \sum_{i=1}^{m} \frac{\min\left[\left|x'_{i(tj)} - x_{i(\alpha)}\right|\right] + \max\lambda\left[\left|x'_{i(tj)} - x'_{i(\alpha)}\right|\right]}{\left|x'_{i(tj)} - x'_{i(\alpha)}\right| + \max\lambda\left[\left|x'_{i(tj)} - x'_{i(\alpha)}\right|\right]} \tag{4}$$

where λ is model parameter, then there are: $0 \le \lambda \le 1$, generally, $\lambda = 0.5$. Formula (4) is the conventional evaluation model of niche suitability, and it is the basis for creating other models of niche suitability.

2.3.2 Comprehensive evaluation model of spatial niche suitability

This paper creates the evaluation models of absolute and relative niche suitability to calculate spatial niche suitability, that is, comprehensive evaluation coefficient, so as to improve the effectiveness of applying the evaluation models based on niche suitability and meet the specific requirements of comprehensive evaluation.

Dimensionless quantitative values and dimensionless optimal values of all evaluation indicators are absolutely zeroed to create the evaluation model of absolute niche suitability. The data of each row in the two matrices respectively composed of dimensionless quantitative values and dimensionless optimal values of all evaluation indicators are respectively subtracted by the corresponding data of the first row, and then two new matrices with all data of the first row being 0 and the data of the other rows generally not being 0 are obtained. If $x'_{i(tj)}(0)$, $x'_{i(\alpha)}(0)$, $X'_{tj}(0)$, $X'_{\alpha}(0)$ are respectively used to represent quantitative value of an evaluation indicator (X_i) with dimensionless and absolutely zeroed processing at a time of t_j, optimal value of an evaluation indicator (X_i) with dimensionless and absolutely zeroed processing, actual niche with dimensionless and absolutely zeroed processing at a time of t_j, optimal niche with dimensionless and absolutely zeroed processing, there are (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$\begin{cases} X'_{tj}(0) = \left(x'_{1(tj)}(0), x'_{2(tj)}(0), \cdots, x'_{n(tj)}(0)\right)^T = \left(x'_{1(tj)} - x'_{1(tj)}, x'_{2(tj)} - x'_{1(tj)}, \cdots, x'_{n(tj)} - x'_{1(tj)}\right)^T \\ X'_{\alpha}(0) = \left(x'_{1(\alpha)}(0), x'_{2(\alpha)}(0), \cdots, x'_{n(\alpha)}(0)\right)^T = \left(x'_{1(\alpha)} - x'_{1(\alpha)}, x'_{2(\alpha)} - x'_{1(\alpha)}, \cdots, x'_{n(\alpha)} - x'_{1(\alpha)}\right)^T \end{cases} \tag{5}$$

The closeness between actual niche and optimal niche can be determined by the distance formula so as to obtain absolute niche suitability on this basis. If ANS_{tj} is used to represent absolute niche suitability at a time of t_j, there are (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$ANS_{tj} = \frac{1+|S_{\alpha}|+|S_{tj}|}{1+|S_{\alpha}|+|S_{tj}|+|S_{\alpha}-S_{tj}|} \tag{6}$$

where $|S_{\alpha}| = \left|\sum_{i=2}^{n-1} x'_{i(\alpha)}(0) + 0.5x'_{n(\alpha)}(0)\right|$, $|S_{tj}| = \left|\sum_{i=2}^{n-1} x'_{i(tj)}(0) + 0.5x'_{n(tj)}(0)\right|$, $|S_{\alpha}-S_{tj}| = \left|\sum_{i=2}^{n-1}\left[x'_{i(\alpha)}(0) - x'_{i(tj)}(0)\right] + 0.5\left[x'_{n(\alpha)}(0) - x'_{n(tj)}(0)\right]\right|$.

Dimensionless quantitative values and dimensionless optimal values of all evaluation indicators are relatively zeroed to create the evaluation model of relative niche suitability. The data of each row in the two matrices respectively composed of dimensionless quantitative values and dimensionless optimal values of all evaluation indicators are divided by the corresponding data of the first row, and then two new matrices with all data of the first row being 0 and the data of the other rows generally not being 0 are obtained by subtracting 1 from each corresponding ratio. If $x''_{i(tj)}(0)$, $x''_{i(\alpha)}(0)$, $X''_{i(tj)}(0)$, $X''_{i(\alpha)}(0)$ are respectively used to represent quantitative value of an evaluation indicator (X_i) with dimensionless and relatively zeroed processing at a time of t_j, optimal value of an evaluation indicator (X_i) with dimensionless and relatively zeroed processing, actual niche with dimensionless and relatively zeroed processing at a time of t_j, optimal niche with dimensionless and relatively zeroed processing, there are (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$\begin{cases} X''_{tj}(0) = \left(x''_{1(tj)}(0), x''_{2(tj)}(0), \ldots, x''_{n(tj)}(0)\right)^T = \left(x''_{1(tj)} \times \left[x''_{1(tj)}\right]^{-1} - 1, x''_{2(tj)} \times \left[x''_{1(tj)}\right]^{-1} - 1, \ldots, x''_{n(tj)} \times \left[x''_{1(tj)}\right]^{-1} - 1\right)^T \\ X''_{\alpha}(0) = \left(x''_{1(\alpha)}(0), x''_{2(\alpha)}(0), \ldots, x''_{n(\alpha)}(0)\right)^T = \left(x''_{1(\alpha)} \times \left[x''_{1(\alpha)}\right]^{-1} - 1, x''_{2(\alpha)} \times \left[x''_{1(\alpha)}\right]^{-1} - 1, \ldots, x''_{n(\alpha)} \times \left[x''_{1(\alpha)}\right]^{-1} - 1\right)^T \end{cases} \tag{7}$$

The closeness between actual niche and optimal niche can be determined by the distance formula so as to obtain relative niche suitability on this basis. If RNS_{tj} is used to represent relative niche suitability at a time of t_j, there are (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$RNS_{tj} = \frac{1+|S'_{\alpha}|+|S'_{tj}|}{1+|S'_{\alpha}|+|S'_{tj}|+|S'_{\alpha}-S'_{tj}|} \tag{8}$$

where $|S'_{\alpha}| = \left|\sum_{i=2}^{n-1} x''_{i(\alpha)}(0) + 0.5x''_{n(\alpha)}(0)\right|$, $|S'_{tj}| = \left|\sum_{i=2}^{n-1} x''_{i(tj)}(0) + 0.5x''_{n(tj)}(0)\right|$, $|S'_{\alpha}-S'_{tj}| = \left|\sum_{i=2}^{n-1}\left[x''_{i(\alpha)}(0) - x''_{i(tj)}(0)\right] + 0.5\left[x''_{n(\alpha)}(0) - x''_{n(tj)}(0)\right]\right|$.

The comprehensive evaluation model of spatial niche suitability can be created by the evaluation models of absolute and relative niche suitability. Spatial niche suitability is the weighted average of absolute and relative niche suitability. If W is used to represent relative weight of absolute niche suitability, $(1-W)$ is relative weight of relative niche suitability. If SNS_{tj} is used to represent spatial niche suitability at a time of t_j, there are (Luo et al., 2022; Xu et al., 2023; Guo et al., 2023):

$$SNS_{tj} = W \cdot ANS_{tj} + (1 - W) \cdot RNS_{tj} \tag{9}$$

where $0 \leq W \leq 1$. When relative weight of absolute niche suitability tends to 0, spatial niche suitability tends to relative niche suitability. When relative weight of absolute niche suitability tends to 1, spatial niche suitability tends to absolute niche suitability. Under the equilibrium condition, the relative weight of absolute niche suitability is equal to that of relative niche suitability, that is: $W = 0.5$. In order to improve the effectiveness of applying the comprehensive evaluation model of spatial niche suitability, relative weights of absolute and relative niche suitability should be reasonably determined on the basis of comprehensive analysis according to actual situations in an evaluation process.

2.4 Definition of grade standards for comprehensive evaluation

This paper classifies effects of synergistic governance on urban environmental pollution into five grades according to the size of comprehensive evaluation coefficient by referring to the latest research achievements at home and abroad. Grade Ⅰ is “excellent”, and the corresponding value range of comprehensive evaluation coefficient in this grade is [0.90, 1.00]. Grade Ⅱ is “good”, and the corresponding value range of comprehensive evaluation coefficient in this grade is [0.80, 0.90]. Grade Ⅲ is “medium”, and the corresponding value range of comprehensive evaluation coefficient in this grade is [0.70, 0.80]. Grade Ⅳ is “slightly poor”, and the corresponding value range of comprehensive evaluation coefficient in this grade is [0.60, 0.70]. Grade Ⅴ is “poor”, and the corresponding value range of comprehensive evaluation coefficient in this grade is [0.00, 0.60]. Since comprehensive evaluation coefficient of each evaluation object is obtained from actual quantitative values of all evaluation indicators through a series of certain calculation procedure, actual quantitative values of all evaluation indicators should also be classified according to the corresponding evaluation requirements and basic data. Table 3 shows the grade standards for classifying actual quantitative values of all evaluation indicators to evaluate effects of synergistic governance on urban environmental pollution (Han and Sun, 2016).

The procedure of applying the comprehensive evaluation model of spatial niche suitability to evaluate effects of synergistic governance on urban environmental pollution can be summarised as follows. Firstly, dimensionless quantitative values and dimensionless optimal values of all evaluation indicators are absolutely and relatively zeroed so as to calculate absolute and relative niche suitability. Secondly, relative weights of absolute and relative niche suitability are determined. Thirdly, spatial niche suitability determined by absolute niche suitability, relative niche suitability and their relative weights is calculated so as to obtain comprehensive evaluation coefficient. Since all values of spatial niche suitability range from 0 to 1, all grades for effects of synergistic governance on urban environmental pollution can be determined by spatial niche suitability and the corresponding grade standards, and finally a comprehensive evaluation result can be obtained.

Table 3 Statistical table of the grade standards for classifying quantitative actual values of all evaluation indicators to evaluate effects of synergistic governance on urban environmental pollution

No.	*Indicator symbol*	*Grade standards*					*Maximum*
		Grade I	*Grade II*	*Grade III*	*Grade IV*	*Grade V*	
1	X_1	>120,000	100,000~120,000	80,000~100,000	50,000~80,000	<50,000	240,000
2	X_2	>60,000	48,000~60,000	36,000~48,000	24,000~36,000	<24,000	80,000
3	X_3	>10,000	8000~10,000	6000~8000	4000~6000	<4000	20,000
4	X_4	70~100	60~70	50~60	40~50	<40	100
5	X_5	>1400	1200~1400	1000~1200	800~1000	<800	1 800
6	X_6	>85	80~85	75~80	70~75	<70	100
7	X_7	90~100	80~90	70~80	60~70	<60	100
8	X_8	0~70	70~150	150~200	200~300	>300	900
9	X_9	0~70	70~150	150~200	200~300	>200	600
10	X_{10}	0~70	50~150	150~200	200~300	>300	900
11	X_{11}	80~100	75~80	70~75	65~70	<65	100
12	X_{12}	<0.5	0.5~1	1~1.5	1.5~2	>2	3
13	X_{13}	>200	150~200	100~150	50~100	<50	210
14	X_{14}	>45	40~45	35~40	30~40	<30	60
15	X_{15}	90~100	80~90	70~80	60~70	<60	100
16	X_{16}	90~100	80~90	70~80	60~70	<60	100
17	X_{17}	90~100	80~90	70~80	60~70	<60	100
18	X_{18}	80~100	70~80	60~70	50~60	<50	100
19	X_{19}	90~100	80~90	70~80	60~70	<60	100
20	X_{20}	90~100	80~90	70~80	60~70	<60	100
21	X_{21}	90~100	80~90	70~80	60~70	<60	100
22	X_{22}	90~100	80~90	70~80	60~70	<60	100

3 Results and discussion

3.1 Evaluation results

Firstly, the dimensionless processing is carried out for the actual quantitative values and the optimal quantitative values of all evaluation indicators in Table 2 by formula (2) and formula (3). Table 4 shows the results of dimensionless processing.

Secondly, the absolutely zeroed processing is carried out by formula (5), and the absolute niche suitability in each year is calculated by formula (6) and the results of absolutely zeroed processing.

Thirdly, the relatively zeroed processing is carried out by formula (7), and the relative niche suitability in each year is calculated by formula (8) and the results of relatively zeroed processing.

Fourthly, formula (9), the absolute niche suitability, the relative niche suitability and the relative weights are used to calculate the spatial niche suitability in each year.

Table 4 Statistical table of the results of dimensionless processing for the actual quantitative values and the optimal quantitative values of all indicators for evaluating the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020

No.	*Indicator symbol*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	$x_i'(\alpha)$
1	X_1	0.4890	0.5000	0.5365	0.5563	0.5765	0.5846	0.6303	0.6611	0.6910	0.8455
2	X_2	0.4458	0.4875	0.5216	0.5641	0.6079	0.6582	0.7124	0.7739	0.8089	0.9045
3	X_3	0.4764	0.5068	0.5350	0.5732	0.5982	0.6294	0.6816	0.6952	0.7206	0.8603
4	X_4	0.7250	0.7340	0.7460	0.7690	0.7810	0.7980	0.8040	0.8200	0.8280	0.9140
5	X_5	0.5644	0.5667	0.5728	0.5772	0.5839	0.5917	0.5967	0.6039	0.6111	0.8056
6	X_6	0.8147	0.8174	0.8193	0.8207	0.8224	0.8235	0.8277	0.8301	0.8319	0.9160
7	X_7	0.8226	0.8355	0.8577	0.8633	0.8798	0.8822	0.9055	0.9149	0.9234	0.9617
8	X_8	0.7938	0.8008	0.8095	0.8241	0.8537	0.8581	0.8815	0.8988	0.9008	0.9504
9	X_9	0.6806	0.6968	0.7279	0.7391	0.7778	0.7885	0.8263	0.8349	0.8376	0.9188
10	X_{10}	0.8053	0.8117	0.8279	0.8470	0.8689	0.8768	0.8950	0.9029	0.9054	0.9527
11	X_{11}	0.5423	0.5896	0.6217	0.6749	0.7067	0.7128	0.7685	0.7541	0.7632	0.8843
12	X_{12}	0.8247	0.8363	0.8460	0.8553	0.8607	0.8683	0.8857	0.8927	0.8943	0.9472
13	X_{13}	0.3765	0.4136	0.4830	0.5198	0.5639	0.5794	0.6523	0.6871	0.6908	0.8454
14	X_{14}	0.7113	0.7130	0.7147	0.7163	0.7163	0.7163	0.7163	0.7207	0.7238	0.8619
15	X_{15}	0.6415	0.6926	0.7283	0.7641	0.8074	0.8192	0.8767	0.9139	0.9301	0.9651
16	X_{16}	0.5180	0.5490	0.5770	0.6410	0.6690	0.6770	0.7070	0.7210	0.8170	0.9085
17	X_{17}	0.6821	0.7167	0.7526	0.7703	0.8158	0.8239	0.9042	0.9334	0.9415	0.9708
18	X_{18}	0.9067	0.9043	0.9229	0.9336	0.9382	0.9447	0.9606	0.9851	0.9993	0.9997
19	X_{19}	0.9080	0.8180	0.9100	0.9440	0.9490	0.9100	0.9130	0.9590	0.9420	0.9795
20	X_{20}	0.7354	0.7417	0.7536	0.7729	0.8045	0.8107	0.8204	0.8296	0.8313	0.9157
21	X_{21}	0.9383	0.9405	0.9332	0.9460	0.9070	0.9300	0.9730	0.9760	0.9810	0.9905
22	X_{22}	0.6812	0.7136	0.7529	0.7943	0.8195	0.8301	0.9308	0.9567	0.9605	0.9803

Fifthly, the corresponding grades of the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020 can be determined according to the results of spatial niche suitability and the grade standards for comprehensive evaluation on governance effects. Table 5 shows the results of comprehensive evaluation.

As can be seen from Table 5, there had been a continuous upward trend for the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020.

3.2 Discussion on evaluation results

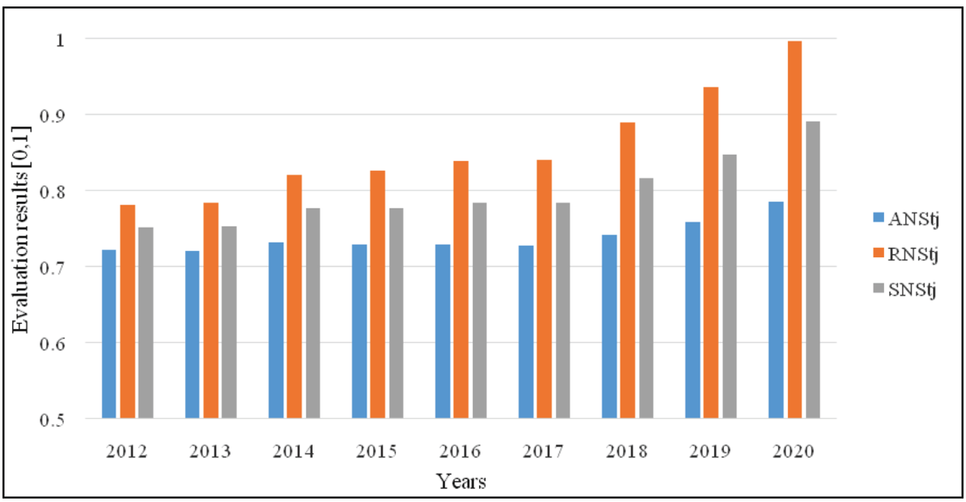
3.2.1 Discussion on the different evaluation results based on the different evaluation models

This paper applies three evaluation models of niche suitability to comprehensively evaluate the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020 to demonstrate their effectiveness, and Figure 1 shows the different evaluation results based on the different evaluation models by the histogram in the rectangular coordinate system for comparison.

Table 5 Statistical table of the results of comprehensive evaluation on the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020

No. (year)	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
ANS_{tj}	0.7230	0.7207	0.7323	0.7288	0.7291	0.7278	0.7422	0.7589	0.7853
Grade	III	III	III	III	III	III	III	III	III
RNS_{tj}	0.7818	0.7847	0.8211	0.8270	0.8385	0.8409	0.8898	0.9366	0.9969
Grade	III	III	II	II	II	II	II	I	I
W	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
SNS_{tj}	0.7524	0.7527	0.7767	0.7779	0.7838	0.7843	0.8160	0.8478	0.8911
Grade	III	III	III	III	III	III	II	II	II

Figure 1 Statistical chart of the different evaluation results based on the different evaluation models for evaluating the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020 (see online version for colours)

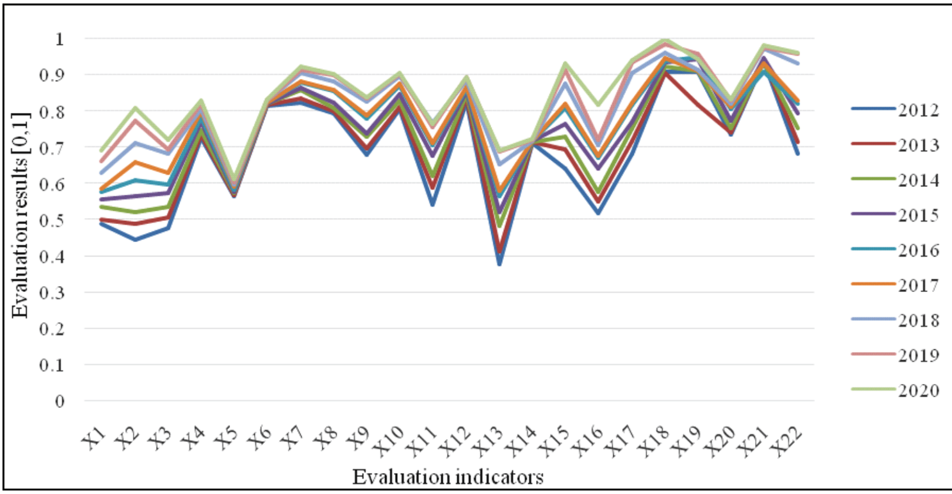


As can be seen from Figure 1, spatial niche suitability is between absolute niche suitability and relative niche suitability in each year. The comprehensive evaluation model of spatial niche suitability not only has a correction effect for evaluation, but also combines the advantages of the other two evaluation models. Therefore, this evaluation model is more suitable for comprehensive evaluation on effects of synergistic governance on urban environmental pollution than the other two evaluation models.

3.2.2 Discussion on the factors influencing evaluation results

This paper selects 22 evaluation indicators to create the indicator system for evaluating effects of synergistic governance on urban environmental pollution according to the corresponding evaluation requirements. These evaluation indicators are the important factors influencing the comprehensive evaluation results, and Figure 2 shows the degrees of influence that these evaluation indicators had made on the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020 by the broken line diagram in the rectangular coordinate system for comparison.

Figure 2 Statistical chart of the factors and degrees influencing the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020 (see online version for colours)



4 Conclusion

Based on research background analysis and literature review, this paper selects 22 evaluation indicators that can reflect effects of synergistic governance on urban environmental pollution, creates the evaluation indicator system and three evaluation models of niche suitability, and defines the grade standards for comprehensive evaluation results and all evaluation indicators. This paper applies the evaluation models of absolute, relative and spatial niche suitability to comprehensive evaluation on the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020, so as to conduct an application test to demonstrate their effectiveness. It is found that the comprehensive evaluation model of spatial niche suitability has the best evaluation effects among the above three ones.

The evaluation results show that there had been a continuous upward trend for the effects of synergistic governance on urban environmental pollution in Wuxi from 2012 to 2020. The suggestions for this city to improve the effects of synergistic governance on urban environmental pollution are as follows.

Firstly, this city should strengthen air quality monitoring and air pollution prevention. As can be seen from the analysis results, there is still significant room to improve air quality in this city. Air quality monitoring and air pollution prevention play a crucial role in synergistic governance on urban environmental pollution. On the one hand, indicators related to air quality have a relatively high weight in the indictor system for evaluating effects of synergistic governance on urban environmental pollution. On the other hand, the issue of air pollution in urban areas involves a wide range of uncertain factors that are difficult to deal with, and the importance of synergistic governance is fully reflected in a governance process.

Secondly, this city should strive to create a resource-saving society, especially to strengthen water resource management. As can be seen from the analysis results, the instability of RCT on urban domestic sewage in this city had affected the overall effects of synergistic governance on urban environmental pollution during this period. So, this city should take measures to protect its existing water resources, and vigorously promote water-saving efficiency improvement and water recycling through management and technology. Only in this way can this city avoid the negative influence on the effects of synergistic governance on urban environmental pollution.

Thirdly, this city should increase investment in synergistic governance on urban environmental pollution and improve investment performance to provide effective and efficient financial support. The problems arising from insufficiency and poor performance of investment in governance on urban environmental pollution will become increasingly apparent with the rapid development of economy, because this city is located in the economically developed region of Yangtze River Delta in China.

Comprehensive evaluation on effects of synergistic governance on urban environmental pollution is a very important research topic. This paper aims to make up for many defects in existing research (Xu and Sun, 2021), explores an effective method for comprehensive evaluation, provides a scientific basis for local governments to formulate effective policies, and therefore scientifically promotes the process of synergistic governance on urban environmental pollution in China.

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Conflict of interest

The authors declare no conflict of interest.

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