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Original Research

Research on Comprehensive Assessment of Effect on Environmental Pollution Collaborative Treatment: Taking China's Yangtze River Delta Urban Agglomeration as an Example

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Abstract

To explore an effective method for comprehensive assessment of the effect of collaborative treatment on environmental pollution in the Yangtze River Delta urban agglomeration, this paper selects four categories of 22 assessment indicators: the driving force of collaborative treatment, the pressure of collaborative treatment, the synergy degree of collaborative treatment, and the result of collaborative treatment to construct an assessment indicator system. Based on the technical treatment of the assessment indicators, the absolute niche suitability (ANS) model, the relative niche suitability (RNS) model and the spatial niche suitability (SNS) model were constructed, and the research on the effect of environmental pollution treatment in the Yangtze River Delta was applied. The assessment results were discussed in depth to verify the effectiveness of the assessment models. The study found that the spatial niche suitability assessment model has the best assessment effect. The assessment result obtained by the SNS model increased from 0.7989 in 2012 to 0.9186 in 2020, the effect of environmental pollution collaborative treatment increased from Level III in 2012 to Level I in 2020. The research results of this paper provide theoretical support for guiding the collaborative treatment of environmental pollution in the Yangtze River Delta urban agglomeration and for local governments to formulate corresponding environmental pollution collaborative treatment polices.

Keywords: collaborative treatment, environmental pollution, effect assessment, Yangtze River Delta urban agglomeration; spatial niche suitability model

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Introduction

The Yangtze River Delta urban agglomeration is the most economically developed and largest urban agglomeration in China, and it is also the sixth-largest urban agglomeration in the world. According to the "Yangtze River Delta Urban Agglomeration Development Plan" issued by the State Council of China in 2016, the Yangtze River Delta urban agglomeration consists of 26 prefecture-level cities, including Shanghai, nine cities in Jiangsu Province, eight cities in Zhejiang Province, and eight cities in Anhui Province [1], later, in 2018, Wenzhou City in Zhejiang Province was supplemented. The rapid development of the Yangtze River Delta urban agglomeration, while continuing to create gross domestic product （GDP), is also producing environmental pollution. With the integrated construction of the Yangtze River Delta urban agglomeration, the issue of environmental pollution collaborative treatment has been raised [2, 3]. According to the requirements of urban environmental pollution collaborative treatment, the air and water pollution and domestic sewage between adjacent cities need to be collaboratively treated to maximize the effectiveness of environmental pollution treatment [4, 5]. After more than six years of environmental pollution collaborative treatment practice, the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration has achieved noticeable results [6]. However, there are still problems such as asynchrony, lack of unified command, and inefficiency in dealing with emergencies regarding time arrangement, action plan, investment scale, and collaborative treatment policies for environmental pollution collaborative treatment [7]. In order to promote the continuous improvement of the effect of collaborative treatment of environmental pollution in the urban agglomeration in the Yangtze River Delta and solve the problems existing in the environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, the issue of the comprehensive assessment of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration is proposed. By comprehensively assessing the effect of collaborative environmental pollution treatment in the Yangtze River Delta urban agglomeration, clarifying the responsibilities and existing problems of cities in collaborative environmental pollution treatment, and minimizing the problems of uneven interests and disputes among cities in regional environmental pollution collaborative treatment, so as to promote the sustainable development of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration [8, 9]. Therefore, it is of particular importance and urgency to study the comprehensive assessment method and its application of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration.

The collaborative treatment of environmental pollution first originated in China. Qin et al. (1990) studied the economic environment of China's urban regulation system and two-way collaborative treatment, and advocated that cities should strengthen collaborative treatment [10]. Wilder (1993) studied the collaborative treatment of oil and gas leakage in US maritime, and mainly analyzed collaborative treatment policies and management measures. For the research on this issue, developed countries and developing countries have different opinions [11]. In the process of environmental pollution treatment in developed countries, they have experienced the initial stage of environmental pollution, which makes them have a high degree of recognition for the collaborative treatment of environmental pollution. Most scholars and practitioners agree with the practice of collaborative treatment of environmental pollution, and they also implement research and practice on collaborative treatment in their respective positions [12, 13]. On the issue of regional environmental pollution treatment, due to basically the same environmental pollution loss [14], the relevant personnel have high enthusiasm for the collaborative treatment of environmental pollution and have also achieved certain good results [15]. However, due to the drawbacks of the supremacy of interests in the private ownership society, it is difficult to achieve the authentic collaborative treatment of environmental pollution. Even if it is forced to participate in collaborative treatment due to the requirements and pressures of collaborative treatment of environmental pollution, the effect of collaborative treatment is relatively poor [16, 17]. In the process of environmental pollution treatment in developing countries, since most countries are in the stage of severe environmental pollution [18, 19] and the interests of the private institutions are paramount, most developing countries have not yet carried out collaborative environmental pollution treatment [20]. Even if individual countries have carried out collaborative treatment of environmental pollution, the efficiency of regional collaborative treatment inevitably coexists with the low efficiency of collaborative treatment among cities [21]. China is a socialist country, a centralized system is implemented, and the country undertakes the main task of environmental pollution treatment. Therefore, China's environmental pollution collaborative treatment has unique characteristics [22-24], and because of the same economic interests among regions and between regions and the country, it has a good effect on environmental pollution collaborative treatment. The Yangtze River Delta urban agglomeration is China's largest urban agglomeration and one of China's urban agglomerations that implement collaborative environmental pollution treatment, its environmental pollution collaborative treatment is at the forefront of China and the world [25]. The collaborative treatment of environmental pollution in cities in the Yangtze River Delta mainly focuses on collaborative treatment of water pollution [26, 27], collaborative treatment of air pollution [28, 29], and collaborative treatment of soil pollution [30, 31]. In addition, there are some special issues of collaborative treatment of pollutant emissions, such as collaborative treatment of waste pollution in the process of logistics and transportation [32], collaborative treatment of waste pollution from tourist passenger transport [33], and other collaborative treatment of environmental pollution issues caused by cross-regional movements.

From the above literature review, it is obvious that there are great differences in the collaborative treatment of environmental pollution in different countries and regions [34]. In developed countries, the importance of collaborative environmental pollution treatment has been recognized, and the practice of environmental pollution collaborative treatment has also begun. However, due to the influence of the private institution, the scope of environmental pollution collaborative treatment is limited to a relatively small area, and it is difficult to form an environmental pollution collaborative treatment system within a scope of a country or a large urban agglomeration. Most developing countries have not yet implemented environmental pollution collaborative treatment. Even if some of them have begun to implement it, it is not easy to achieve satisfactory results under the private ownership system. China is at the forefront of the world's collaborative treatment of environmental pollution and has made outstanding achievements. However, the current system of environmental pollution collaborative treatment within urban agglomerations is not perfect, the efficiency of collaborative treatment is relatively low, and there are differences, contradictions and huge environmental pollution losses in the process of collaborative treatment. Therefore, in this case, it is of particular importance and urgency to study the comprehensive assessment method and its application of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, explore the effective methods of the environmental pollution collaborative treatment of the mega-urban agglomeration, and promote the continuous improvement of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration.

Materials and Methods

Research Areas

The Yangtze River Delta urban agglomeration is located in the alluvial plain before China's Yangtze River Estuary. It was founded in the "Yangtze River Delta Regional Planning" approved by the State Council in 2010. It only included Shanghai city, Jiangsu province and Zhejiang province in the early stage. In 2014, the State Council proposed the integrated development of the Yangtze River Delta to build a world-class urban agglomeration with international competitiveness. On May 11, 2016, the State Council adopted the "Yangtze River Delta Urban Agglomeration Development Plan". According to this plan, the Yangtze River Delta Urban Agglomeration includes Shanghai city; Nanjing city, Wuxi city, Changzhou city, Suzhou city, Nantong city, Yancheng city, Yangzhou city, Zhenjiang city, and Taizhou city in Jiangsu Province; Hangzhou city, Ningbo city, Jiaxing city, Huzhou city, Shaoxing city, Jinhua city, Zhoushan city, Taizhou city and Wunzhou city in Zhejiang Province; Hefei city, Wuhu city, Ma'anshan city, Tongling city, Anqing city, Chuzhou city, Chizhou city and Xuancheng city in Anhui Province, and there are 27 cities in total. The Yangtze River Delta urban agglomeration accounts for only 2.3% of China's total area, with a population of 225 million, contributing about 1/4 of the country's GDP. It is the fastest growing and largest urban agglomeration in China. With the integrated construction of Yangtze River Delta urban agglomeration, the theory of collaborative treatment of environmental pollution has gradually developed. After more than ten years of integrated construction and collaborative treatment of environmental pollution, apparent collaborative treatment effects have been achieved, which has promoted the evident improvement of environmental quality and ecological status in the Yangtze River Delta urban agglomeration.

Construction of Assessment Indicator System and Data Collection

The comprehensive assessment of effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration is a very complex work. To realize the effective assessment, we need to learn from the latest research results and fully consider the actual situation of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration to build an effective environmental pollution collaborative treatment effect assessment indicator system. Based on a comprehensive analysis, this paper selects 22 assessment indicators from the four categories of the driving force, pressure, synergy degree, and direct results of collaborative treatment of environmental pollution, and constructs the assessment indicator system. The detailed contents are shown in Table 1.

The assessment indicator system comprehensively reflects the situation of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. It is necessary to collect the historical data of these assessment indicators to realize a comprehensive assessment of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. This paper mainly carries out a comprehensive assessment of the overall effect on environmental pollution collaborative treatment in the Yangtze River Delta

Table 1. Assessment indicator system for EPCT in the Yangtze River Delta urban agglomeration.

Goal	Criterion layer	Indicator symbol	Measure layer	Unit	Indicator properties
Comprehensive assessment of the effect on EPCT in the Yangtze River Delta urban agglomeration	The driving force of EPCT (X_1)	X_{11}	Per capita GDP	10^2 yuan/ person	Forward pointer
		X_{12}	Per capita disposable income	yuan/person	Forward pointer
		X_{13}	Urbanization level	%	Forward pointer
		X_{14}	Employment rate of urban population	%	Forward pointer
		X_{15}	EPCT compliance rate	%	Forward pointer
		X_{16}	Average life expectancy of urban residents	year	Forward pointer
	The pressure of EPCT (X_2)	X_{21}	Water pollution indicator	%	Contrary indicator
		X_{22}	Air pollution indicator	%	Contrary indicator
		X_{23}	Soil pollution indicator	%	Contrary indicator
		X_{24}	Urban MV emission non-compliance rate	%	Contrary indicator
		X_{25}	The unqualified rate of UCP management	%	Contrary indicator
		X_{26}	EC and carbon emission intensity	ton/10^2 yuan	Contrary indicator
	The synergy degree of EPCT (X_3)	X_{31}	Policy synergy of EPT	%	Forward pointer
		X_{32}	Action synergy of EPT	%	Forward pointer
		X_{33}	Time synergy of EPT	%	Forward pointer
		X_{34}	Investment synergy of EPT	%	Forward pointer
		X_{35}	The synergy of urban EES	%	Forward pointer
	The result of EPCT (X_4)	X_{41}	The compliance rate of water CT	%	Forward pointer
		X_{42}	The compliance rate of atmosphere CT	%	Forward pointer
		X_{43}	The compliance rate of soil CT	%	Forward pointer
		X_{44}	EPT investment as a percentage of GDP	%	Forward pointer
		X_{45}	Public satisfaction with environmental CT	%	Forward pointer

EPCT: Environmental pollution collaborative treatment; UCP: urban construction project; EPT: environmental pollution treatment; MV: motor vehicle; CT: collaborative treatment; EC: energy consumption; EES: ecological economic system.

urban agglomeration. Each assessment indicator is collected according to 26 cities. Then the average value of 22 assessment indicators of these 26 cities is calculated respectively, which is the actual assessment indicator of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. Since China has only had statistical data on environmental pollution since 2012, the data of this paper is from 2012 to 2020. Due to the differences in statistical data caliber among cities and the complexity of the actual situation, the author corrected the individual indicators with differences and eliminated the uncertain or wrong data in data collection and analysis. In addition, due to different calculation methods, there may be some differences in the calculated assessment indicator data. The basic data of the assessment indicators of effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration collected in this paper are shown in Table 2.

Construction of Niche Suitability Assessment Model

Common Niche Suitability Model

The niche, also known as shrine, refers to the temporal and spatial position of the population in the natural ecosystem and the functional relationship and role between the related populations in an environment without human damage. It represents the minimum threshold of habitat necessary for the survival of every organism in the ecosystem (Poche Ville A., 2015). If there are n ecological factors in a region, the quantized values of these ecological factors are represented by X_i, and the ecological factor matrix can be expressed as $X_i = \{X_1, X_1, ..., X_n\}$. The ecological factors of m regions can form the $n \times m$ dimensional quantized value matrix, which is represented by EFM, and the specific expression is as follows:

Table 2. Basic data for assessing the effect on EPCT in the Yangtze River Delta urban agglomeration.

Indicator	2012	2013	2014	2015	2016	2017	2018	2019	2020
X_{11}	6.84	7.61	8.07	8.78	9.04	9.72	10.06	10.57	11.65
X_{12}	4.68	4.86	5.06	5.53	5.86	6.27	6.86	7.13	7.85
X_{13}	75.24	75.82	76.51	77.73	78.47	79.36	79.46	81.27	82.63
X_{14}	79.13	79.62	81.05	81.72	82.45	83.47	84.51	85.27	86.36
X_{15}	87.62	88.46	89.66	90.79	91.48	92.63	93.47	94.61	95.02
X_{16}	84.81	85.01	85.42	85.82	86.14	86.86	87.63	88.15	88.91
X_{21}	150.37	146.28	135.28	125.37	121.27	116.56	108.64	99.56	96.47
X_{22}	184.52	167.42	154.21	148.52	142.38	139.51	132.58	121.47	108.32
X_{23}	141.27	138.24	132.35	128.42	125.36	121.27	118.52	116.47	112.25
X_{24}	2.1624	2.0647	1.9741	1.8752	1.7213	1.5251	1.4637	1.3225	1.2115
X_{25}	3.3126	3.2651	3.0416	2.9625	2.7525	2.6427	2.5415	2.4517	2.3121
X_{26}	3.2146	3.1427	3.1327	3.0851	3.0217	2.9726	2.9125	2.8327	2.7826
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}	85.89	86.28	86.85	87.41	87.84	88.21	88.67	89.15	89.89
X_{35}	85.46	85.93	86.26	86.78	87.04	87.36	87.85	88.06	88.94
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}	89	90	91	92	92	93	94	95	96

$$EFM = \begin{pmatrix} x_{1(t_1)} & x_{2(t_1)} & \cdots & x_{n(t_1)} \\ x_{1(t_2)} & x_{2(t_2)} & \cdots & x_{n(t_2)} \\ \vdots & \vdots & \vdots & \vdots \\ x_{1(t_m)} & x_{2(t_m)} & \cdots & x_n(t_m) \end{pmatrix} \tag{1}$$

In the formula: $f(E) = (X_i) = [x_1(t_j), x_2(t_j), ..., x_n(t_j)]$ is a subset of the n-dimensional ecological factor spatial E^n at time t_j, $i = 1, 2, ..., n$, $j = 1, 2, ..., m$. Then the non-negative function $f(E)$ represents the niche of the environmental pollution collaborative treatment system at time t_j, and the closeness between the actual value X_i of the ecological factor and the optimum value is called the niche suitability, which is represented by NS_t. Then, there are: $NS_t = \tau\ (X_i, X_\alpha)$, the niche suitability model can usually be expressed as follows using the distance formula:

$$NS_t = \sum_{i=1}^{n} \frac{\delta_{min} + \lambda\delta_{max}}{\delta_{it} + \lambda\delta_{max}} = \sum_{i=1}^{n} \frac{min\left[\left|x_i'\left(t_j\right) - x_i'\left(\alpha\right)\right|\right] + max\,\lambda\left[\left|x_i'\left(t_j\right) - x_i'\left(\alpha\right)\right|\right]}{\left|x_i'\left(t_j\right) - x_i'\left(\alpha\right)\right| + max\,\lambda\left\{\left|x_i'\left(t_j\right) - x_i'\left(\alpha\right)\right|\right\}} \tag{2}$$

In the formula: $\delta_{it} = |x_i(t_j) - x_i(\alpha)|$, $\delta_{max} = max\{\delta_{it}\} = max\ \{|x_i(t_j) - x_i(\alpha)|\}$, $\delta_{max} = max\{\delta_{it}\} = min\{|x_i(t_j) - x_i(\alpha)|\}$; $i = 1, 2, ..., m$; $t = 1, 2, ..., n$; λ is the model parameter ($0 \leq \lambda \leq 1$), in the average case $\lambda = 0.5$.

Construction of the Spatial Niche Suitability Model

To improve the effectiveness of the assessment of niche suitability models, this paper reconstructs the niche model based on the traditional niche suitability model and reconstructs the spatial niche suitability comprehensive assessment model. To facilitate the calculation of the niche suitability model, the assessment indicator should be standardized first. The normalization method is adopted in this paper, and the value range of the assessment indicator is determined between [0, 1]. The normalization process uses the maximum value of the assessment indicator. In this paper, the assessment indicator is selected as the maximum value in the assessment standard. The specific calculation formula is as follows:

$$\begin{cases} X_i'(t_j) = X_i(t_j) \cdot \left[ZXLI_X(t_j)\right]^{-1} & forward\ pointer \\ X_i'(t_j) = 1 - X_i(t_j) \cdot \left[NXLV_S(t_j)\right]^{-1} & contrary\ indicator \end{cases} \tag{3}$$

In the above formula: $ZXLI_X(t_j)$ is the maximum value of the forward pointer, $NXLV_S(t_j)$ is the maximum value of the contrary indicator, 1.05 times of the maximum indicator value is used in the normalization calculation, and the maximum value of the contrary indicator uses the 3 times the lower boundary value of the standard value Level V. If $X_i(\alpha)$ is the optimal value of the assessment indicator, and $X'_{i\alpha}$ is the optimal value after normalization, there are:

$$\begin{cases} X_i'(\alpha) = X_i(\alpha) \cdot \left[ZXLI_X(t_j)\right]^{-1} & forward\ pointer \\ X_i'(\alpha) = 1 - X_i(\alpha) \cdot \left[ZXLI_X(t_j)\right]^{-1} & contrary\ indicator \end{cases} \tag{4}$$

In the actual construction process of the niche suitability assessment model, according to the specific requirements of the comprehensive assessment of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, an absolute niche suitability model and a relative niche suitability model can be constructed respectively. Next, an absolute niche suitability measurement model is constructed based on niche theory and methods. Using the result of the assessment indicator's dimensionless processing, the assessment indicator's absolute null transformation calculation is performed using the following absolute null transformation model. Absolute null transformation is a conversion calculation method in which each row of data in the data matrix is subtracted from the data in the first row, and the difference in the first row is zero, and other differences are generally not zero. This method gets its name because the first row uses the absolute difference method to get the first row to zero. If x'_{it} represents the value of the assessment indicator after absolute null transformation, $x'_{i\alpha}$ represents the optimal value of the assessment indicator after absolute null transformation, and $X'_{it}(0)$ represents the niche value after absolute null transformation, $X'_{i\alpha}(0)$ represents the optimal niche value after absolute null transformation, and the specific calculation formula of absolute null transformation is as follows:

$$\begin{cases} X_{it}'(0) = x_i'(t_j) - x_1'(t_j) = \left(x_{1t}'(0),\ x_{2t}'(0), \cdots, x_{nt}'(0)\right) \\ X_{i\alpha}'(0) = x_i'(t_j) - x_1'(0) = \left(x_{1\alpha}'(0),\ x_{2\alpha}'(0), \cdots, x_{n\alpha}'(0)\right) \end{cases} \tag{5}$$

Based on the calculation results of the absolute null transformation formula, the distance formula is used to determine the closeness of the actual niche to the most suitable niche, that is, the absolute niche suitability ($ANS_{t\alpha}$). The specific calculation formula is as follows:

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

In the above formula:

$|S_t| = \left|\sum_{i=2}^{n-1} x'_{it}(0) + 0.5x'_{nt}(0)\right|$,

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

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

The same idea is used to construct the relative niche suitability model below. It is also necessary to calculate the relative null transformation first. The relative null transformation is to divide the data of each row of the assessment indicator by the data corresponding to the first row and then use the method of subtracting one from the corresponding ratio to obtain the difference matrix of the assessment indicator so that the data in the first row are zero. This method is named after the method of subtracting one from the ratio, and the first row is all zero, and the other rows are generally not zero. If x''_{it} represents the value of the assessment indicator after relative null transformation, $x''_{i\alpha}$ represents the optimal value of the assessment indicator after relative null transformation, and $X''_{it}(0)$ represents the value of niche after relative null transformation, $X''_{i\alpha}(0)$ represents the optimal niche value after relative null transformation, and the specific calculation formula for relative null transformation is as follows:

$$\begin{cases} X_{it}''(0) = x_i''(t_j) \times \left[x_1''(t_j)\right]^{-1} - 1 = \left(x_{1t}''(0),\ x_{2t}''(0),\ \cdots,\ x_{nt}''(0)\right) \\ X_{i\alpha}''(0) = x_i''(\alpha) \times \left[x_1''(\alpha)\right]^{-1} - 1 = \left(x_{1\alpha}''(0),\ x_{2\alpha}''(0),\ \cdots,\ x_{n\alpha}''(0)\right) \end{cases} \tag{7}$$

Based on the calculation results of the relative null transformation formula, the distance formula is used to determine the closeness of the actual niche to the most suitable niche, which is the relative niche suitability ($RNS_{t\alpha}$). The specific calculation formula is as follows:

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

Where:

$|S'_t| = \left|\sum_{i=2}^{n-1} x''_{it}(0) + 0.5x''_{nt}(0)\right|, |S'_\alpha| = \left|\sum_{i=2}^{n-1} x''_{i\alpha}(0) + 0.5\, x''_{n\alpha}(0)\right|$,

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

A comprehensive assessment model of spatial niche suitability can be constructed by using the absolute niche suitability model and the relative niche suitability model, which is the weighted average of the absolute niche suitability and relative niche suitability. If W is used to represent the weight of absolute niche suitability, then $1-W$ is the weight of relative niche suitability, and $SNS_{t\alpha}$ is used to represent spatial niche suitability, then the spatial niche suitability model is:

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

In the formula: W∈[0,1], the weight W tends to 0, and the spatial niche suitability tends to $RNS_{t\alpha}$; the weight W tends to 1, and the sapitial niche suitability tends to $ANS_{t\alpha}$; under equilibrium conditions W = 0.5, W should be reasonably determined based on comprehensive analysis according to the actual assessment, which can promote the effectiveness of the assessment results of the spatial niche suitability model.

Determination of Assessment Standard

The assessment standard is the direct basis for assessing the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. This paper referred to China's "Surface Water Quality Standards (GB3838-2012)", "Environmental Air Quality Standards (GB3095-2012)", "Soil Environmental Quality Standards (GB36600-2018)" and the environmental quality standards of cities in the Yangtze River Delta urban agglomeration, and formulated the assessment standard for the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. The specific contents are shown in Table 3.

In addition to formulating standards for assessment indicators, it is also necessary to formulate standards for assessment objectives, that is, the overall assessment standards for the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. Since the value range of the assessment model is between [0, 1], the assessment grade standard for the effect of collaborative environmental pollution treatment in the Yangtze River Delta urban agglomeration can be determined as: $NS_{t\alpha}$ = [0.90, 1.00]∈Level I, the assessment result is excellent; $NS_{t\alpha}$ = [0.80, 0.90)∈Level II, the assessment result is good; $NS_{t\alpha}$ = [0.70, 0.80)∈Level III, the assessment result is medium; $NS_{t\alpha}$ = [0.70, 0.80)∈Level IV, the assessment result is qualified; $NS_{t\alpha}$ = [0, 0.60) ∈Level V, the assessment result is unqualified.

Results and Discussion

Assessment Results

To use the niche suitability model to assess the effect of environmental pollution collaborative treatment

Table 3. Assessment standard for the effect of environmental pollution collaborative treatment.

Indicator	Level I	Level II	Level III	Level IV	Level V
X_{11}	>15	10-15	7.5-10	5-7.5	<5
X_{12}	>8	6-8	4-6	2-4	<2
X_{13}	>80	60-80	50-60	40-50	<40
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}	0-70	70-150	150-200	200-300	>300
X_{22}	0-70	70-150	150-200	200-300	>300
X_{23}	0-70	50-150	150-200	200-300	>300
X_{24}	<1	1-2	2-3	3-4	>4
X_{25}	<1	1-3	3-5	5-7	>7
X_{26}	<2	2-3	3-4	4-5	>5
X_{31}	90-100	80-90	70-80	60-70	<60
X_{32}	90-100	80-90	70-80	60-70	<60
X_{33}	90-100	80-90	70-80	60-70	<60
X_{34}	90-100	80-90	70-80	60-70	<60
X_{35}	90-100	80-90	70-80	60-70	<60
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}	<2	1.5-2	1-1.5	0.8-1	<0.8
X_{45}	90-100	80-90	70-80	60-70	<60

Table 4. Dimensionless results of assessment indicators for the effect of environmental pollution collaborative treatment.

Indicator	2012	2013	2014	2015	2016	2017	2018	2019	2020	$x'_{i\alpha}$
X_{11}	0.5437	0.6049	0.6415	0.6979	0.7186	0.7727	0.7997	0.8402	0.9261	0.9259
X_{12}	0.5519	0.5731	0.5967	0.6521	0.6910	0.7394	0.8090	0.8408	0.9257	0.9259
X_{13}	0.8338	0.8402	0.8479	0.8614	0.8696	0.8794	0.8805	0.9006	0.9157	0.9259
X_{14}	0.8484	0.8537	0.8690	0.8762	0.8840	0.8949	0.9061	0.9142	0.9259	0.9259
X_{15}	0.8538	0.8620	0.8737	0.8847	0.8914	0.9027	0.9108	0.9219	0.9259	0.9259
X_{16}	0.8833	0.8853	0.8896	0.8938	0.8971	0.9046	0.9126	0.9180	0.9260	0.9259
X_{21}	0.8329	0.8375	0.8497	0.8607	0.8653	0.8705	0.8793	0.8894	0.8928	0.8928
X_{22}	0.7950	0.8140	0.8287	0.8350	0.8418	0.8450	0.8527	0.8650	0.8796	0.8796
X_{23}	0.8430	0.8464	0.8529	0.8573	0.8607	0.8653	0.8683	0.8706	0.8753	0.8753
X_{24}	0.8198	0.8279	0.8355	0.8437	0.8566	0.8729	0.8780	0.8898	0.8990	0.8990
X_{25}	0.8423	0.8445	0.8552	0.8589	0.8689	0.8742	0.8790	0.8833	0.8899	0.8899
X_{26}	0.7857	0.7905	0.7912	0.7943	0.7986	0.8018	0.8058	0.8112	0.8145	0.8145
X_{31}	0.8810	0.8852	0.8913	0.8972	0.9000	0.9045	0.9105	0.9180	0.9259	0.9259
X_{32}	0.8558	0.8647	0.8783	0.8846	0.8937	0.8989	0.9074	0.9163	0.9259	0.9259
X_{33}	0.8665	0.8803	0.8849	0.8920	0.8956	0.9008	0.9085	0.9169	0.9259	0.9259
X_{34}	0.8847	0.8888	0.8946	0.9004	0.9048	0.9086	0.9134	0.9183	0.9259	0.9259
X_{35}	0.8897	0.8945	0.8980	0.9034	0.9061	0.9094	0.9145	0.9167	0.9259	0.9259
X_{41}	0.8383	0.8515	0.8694	0.8839	0.8952	0.9053	0.9153	0.9200	0.9259	0.9259
X_{42}	0.8754	0.8826	0.8947	0.9016	0.9057	0.9089	0.9123	0.9184	0.9260	0.9259
X_{43}	0.8738	0.8797	0.8857	0.8904	0.9006	0.9039	0.9094	0.9140	0.9259	0.9259
X_{44}	0.8821	0.9282	0.8615	0.8308	0.8154	0.7949	0.7590	0.7846	0.7744	0.9259
X_{45}	0.8584	0.8681	0.8777	0.8873	0.8873	0.8970	0.9066	0.9163	0.9259	0.9259

in the Yangtze River Delta urban agglomeration, it is necessary to use formulas (7-8) to perform dimensionless processing on the basic data in Table 1. The maximum value is 1.5 times the lower limit of the V level, and the assessment value of the indicator greater than this value is determined to be zero. The specific dimensionless processing results are shown in Table 4.

Based on dimensionless processing of assessment indicators, formula (5) is used to calculate the result of absolute null transformation of assessment indicators. Then the data of absolute null transformation and formula (6) are used to calculate the absolute niche suitability of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration and fill in the first row of Table 5. Next, use the formula (7) to calculate the relative null transformation results of the assessment indicators, and then use the calculation results of the relative null transformation and formula (8) to calculate the relative niche suitability of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration and fill in the third row of Table 5. Finally, use the calculation results of $ANS_{t\alpha}$ and $RNS_{t\alpha}$, the pre-determined relative weight W and formula (9) to calculate the spatial niche suitability of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration and fill in the sixth row of Table 5. The specific calculation results are shown in Table 5.

According to Table 5, the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration has shown a rapid upward trend from 2012 to 2020. The effect of environmental pollution collaborative treatment has increased from Level III in 2012 to Level I in 2020. From the analysis of the specific assessment results of Level I, the assessment value is still at the lower boundary of Level I, and there is still much space for improvement.

Discussion on the Differences in the Assessment Results of Different Niche Suitability Models

To assess the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, this paper constructs an absolute

Table 5. Assessment results of different niche suitability models.

	2012	2013	2014	2015	2016	2017	2018	2019	2020
$ANS_{t\alpha}$	0.8060	0.8170	0.8518	0.8750	0.8855	0.9076	0.9143	0.9177	0.9259
Level	II	II	II	II	II	I	I	I	I
$RNS_{t\alpha}$	0.7883	0.8062	0.8141	0.8302	0.8557	0.8703	0.8826	0.8972	0.9076
Level	III	II	II	II	II	II	II	II	I
W	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
$SNS_{t\alpha}$	0.7989	0.8127	0.8367	0.8571	0.8736	0.8927	0.9016	0.9095	0.9186
Level	III	II	II	II	II	II	I	I	I

niche suitability model, a relative niche suitability model and a spatial niche suitability model [35], and uses them to conduct applied research on the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, which verifies the effectiveness of the assessment model. To compare the differences in the assessment results of the three niche suitability models, the author used a pyramid diagram to draw the assessment results in the rectangular coordinate system. The specific composition and differences are shown in Fig. 1.

It can be seen from Fig. 1 that the assessment results of the spatial niche suitability model are between the assessment results of the absolute niche suitability model and relative niche suitability model, which have a correction effect. The actual control process can be realized by adjusting the weight coefficient [36]. Therefore, the spatial niche suitability model combines the advantages of the absolute niche suitability model and the relative suitability model [37]. It is an ideal assessment model for the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration.

Discussion on Influencing Factors of Assessment Results

According to the research design of this paper, 22 specific assessment indicators were selected to construct an assessment indicator system to assess the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. These assessment indicators are the essential influencing factors on the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. In order to analyze the degree of influence of these assessment indicators on the assessment object, this paper uses the curve graph in the rectangular coordinate system to reflect the change of each assessment indicator, as shown in Fig. 2.

Fig. 2 shows the specific influencing situation of 22 assessment indicators on the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration from 2012 to 2020. The combination of the influencing degree of these assessment indicators ultimately determines the assessment result of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration.

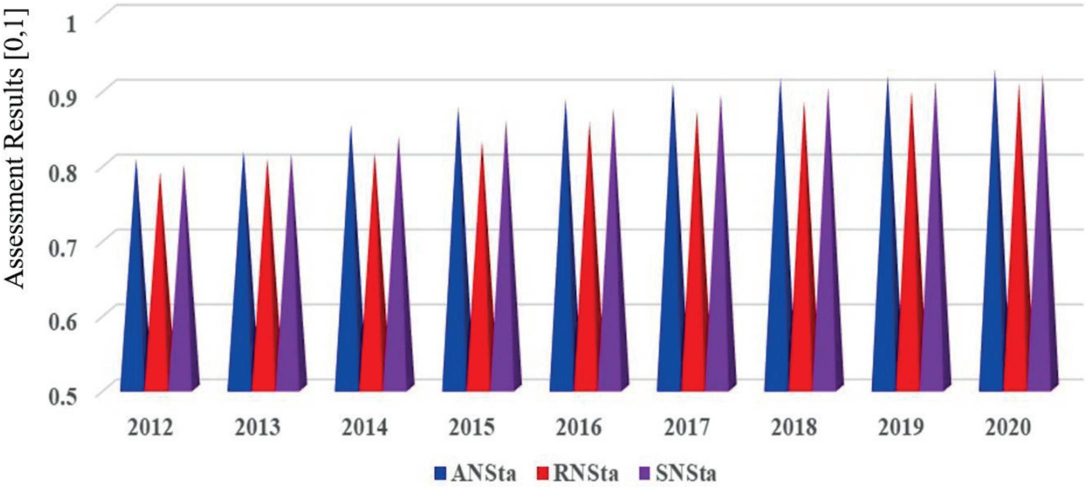

Fig. 1. Comparison of assessment results of three niche suitability models.

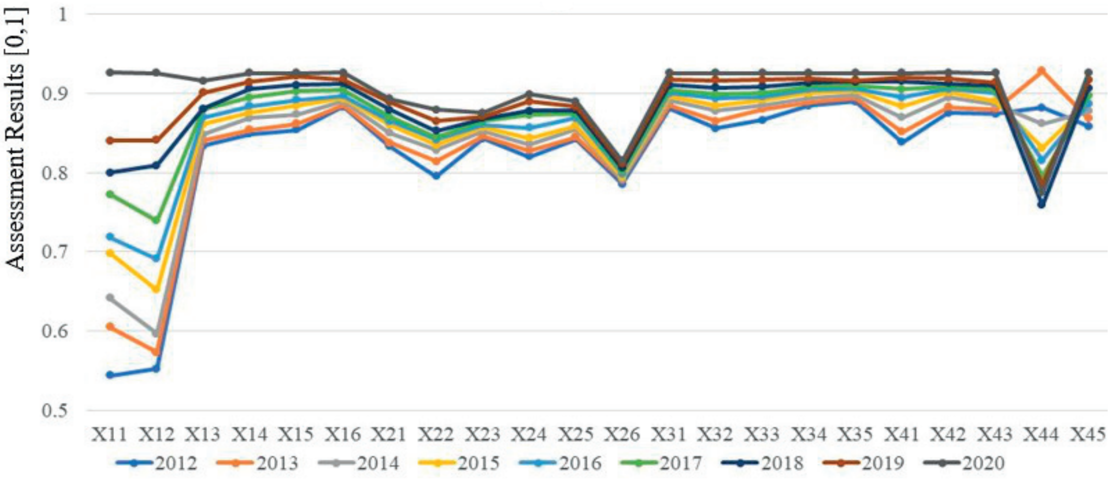

Fig. 2. Influencing factors of the effect on environmental pollution collaborative treatment.

Conclusion

The comprehensive assessment of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration is a crucial research topic. In order to explore an effective method for comprehensive assessment of the effect on environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, this paper selects four categories of 22 assessment indicators that can reflect the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, constructs an assessment indicator system, and formulates corresponding assessment standards based on the research background analysis, literature review and research area analysis. By analyzing the status quo of the environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration, the paper reconstructs the absolute niche suitability model, the relative niche suitability model, and the spatial niche suitability model. Finally, the constructed three niche suitability models are applied to assess the effect of environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration. The application test is carried out, proving the validity of the assessment model. The study found that the spatial niche suitability assessment model has the best assessment effect. The assessment results using the spatial niche suitability model are: the assessment result in 2012 is 0.7989, and the effect of environmental pollution collaborative treatment is Level III, which belongs to the medium level; in 2020, the assessment result rises to 0.9186, and the effect of environmental pollution collaborative treatment is Level I, which is an excellent level. This paper provides theoretical support for guiding the environmental pollution collaborative treatment in the Yangtze River Delta urban agglomeration and for local governments to formulate related policies of environmental pollution collaborative treatment.

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Conflict of Interest

The authors declare no conflict of interest.

Reference

1. WANG J.J., LU X.M., YAN Y.T., ZHOU L.G., MA W.C. Spatiotemporal characteristics of $PM_{2.5}$ concentration in the Yangtze River Delta urban agglomeration, China on the application of big data and wavelet analysis. Science of the Total Environment **724**, 138134, **2020**.
2. 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 **7** (03), 81, **2015**.
3. SUO L.M., LI X. Regional Governance, Beyond the Limits of Single Administrative Boundary, A Case Study on Interlocal Collaboration in Air Pollution Control in the Yangtze River Delta. Chinese Public administration **428** (2), 92, **2021**.
4. EBENSTEIN A., FAN M.Y., GREENSTION M., HE G.J., YIN, P., ZHOU M. G. Growth, Pollution, and Life Expectancy, China from 1991-2012. American Economic Review **105** (5), 226, **2015**.
5. LIU J., TU Y.R., DUAN Y.P., ZHI W.D., TANG Y., ZHANG H. System and mechanism construction of collaborative transboundary water pollution control in Yangtze River Delta region. Environment and Sustainable Development **46** (03), 153, **2021**.
6. XU D.Y., TAO S. Research on comprehensive assessment of synergistic governance effect of urban environmental pollution. Environmental Science and Management **46** (12), 176, **2021**.

7. HU B. Research on Regional Collaborative treatment of Yangtze River Delta under the Perspective of Double Circulation Development Strategy. Regional Economic Review (06), 46, **2020**.
8. ZHU J.Q. Study on Performance Assessment of Regional Intergovernmental Cooperative Governance of Air Pollution, Empirical Analysis Based on Beijing, Tianjin and Hebei. Environmental Science and management **46** (01), 13, **2020**.
9. XIAO P., SU J., DONG S.J. Study on the current situation and Countermeasures of cross regional ecological environment collaborative treatment. Social Sciences in Hunan (05), 92, **2021**.
10. QIN R.S., CHEN S.Z., LIU Z.F. Establishing urban regulation system and two-way coordinated governance of economic environment. Urban Problems (01), 23, **1990**.
11. WILDER R.J. Cooperative governance, environmental policy, and management of offshore oil and gas in the United States. Ocean Development & International Law **24** (01), 41, **1993**.
12. SHI J.G., XU S., DUAN K.F. Investigating the intention to participate in environmental governance during urban-rural integrated development process in the Yangtze River Delta Region. Environmental Science & Policy **128**, 132, **2022**.
13. BARRUTIA J.M., ECHEBARRIA C. Comparing three theories of participation in pro-environmental, collaborative treatment networks. Journal of Environmental Management **240**, 108, 2019.
14. SABRINA D., ANNELIE S.L., MARIA J., GÖRAN E., CAMILLA S. Achieving Social and Ecological Outcomes in Collaborative Environmental Governance, Good Examples from Swedish Moose Management. Sustainability **13** (04), 2329, **2021**.
15. WANG Y., HE Y. Environmental Regulations, Relocation of Heavy Polluting Enterprises and Collaborative treatment Effect, Evidence Based on the Establishment of Subsidiaries in Different Places. Economic Science (05), 130, **2021**.
16. WANG Y., ZHAO H. Is collaborative treatment effective for air pollution prevention? A case study on the Yangtze River delta region of China. Journal of Environmental Management **292**, 112790, **2021**.
17. AN B.Y., TANG S.Y., LEACH W.D. Managing environmental change through inter-agency collaboration, Protective governance in mandated sustainability planning. Environmental Science & Policy **125**, 146, **2021**.
18. JONES J.L., WHITE D.D. Understanding barriers to collaborative treatment for the food-energy-water nexus, The case of Phoenix, Arizona. Environmental Science & Policy. **127**, 111, **2022**.
19. 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 **807** (02), 150706, **2022**.
20. TAYLOR N.K., RUSSEL D., WINTER M. The Contours of State Retreat from Collaborative Environmental Governance under Austerity. Sustainability **12** (07), 2761, **2020**.
21. YANDISA S.P., COLIN N.J., THOW A.M., SCHRAM A., SCHNEIDER C.H., FRIEL S. Moving from silos to synergies, strengthening governance of food marketing policy in Thailand. Global Health **18** (01), 29, **2022**. doi, 10.1186/s12992-022-00825-5
22. TANG X.J., CHEN X.X. From Coordination to Synergy, Reform and Path of Regulatory System in Cross-Regional Environmental Governance, From the Perspective of Wanda Planning Demonstration Area for Sichuan and Chongqing. Chinese Journal of Environmental Management **13** (02), 72, **2021**.
23. XU P., WU S.S. Research on Environmental Governance by Central Government and Local Government Under the Environment Decentralization System Research on Economics and Management **41** (12), 124, **2020**.
24. ZHANG Y.N., SUN L., ZHANG H.M., SUN N. Research on Collaborative treatment Path of Cross Regional Pollution in Urban Agglomeration under Decentralized Environmental Regulation. Resources and Environment in the Yangtze Basin **30** (12), 2925, **2021**.
25. DING T.H., CHEN J.F., FANG Z., CHEN J.Y. Assessment of coordinative relationship between comprehensive ecosystem service and urbanization, A case study of Yangtze River Delta urban Agglomerations, China Author links open overlay panel. Ecological Indicators **133**, 108454, **2021**.
26. LUO Z., QI B.C. The Effects of Environmental Regulation on Industrial transfer and upgrading and Banking Synergetic Development evidence from Water Pollution Control in the, Evidence from water pollution control in the Yangtze River Basin. Economic Research Journal **56** (02), 174, **2021**.
27. LI H.S., WANG L.J., ZHANG Z.Q., DENG C.N. Theoretical thought and practice of eco-environment synergistic management in the Yangtze River. Journal of Environmental Engineering **11** (03), 409, **2021**.
28. YI L., ZHAO W., YANG L. Innovation of collaborative treatment mechanism on air pollution and climate change control. Science Research Management **41** (10), 134, **2020**.
29. LI J., BAO X.B. The Practical Dilemma and Solution Path of Collaborative treatment of Air Pollution in Beijing-Tianjin- Hebei Region. Reform (02), 146, **2021**.
30. WANG X., LI Z., MENG L. Improving the Effectiveness of Soil Environmental Management, Promoting the Coordinated Governance of Soil-Water-Air Pollution. Chinese Journal of Environmental Management **8** (05), 36, **2016**.
31. LI W.Q. The Superfund act Enlightenment of soil pollution coordinated control in China, Economic perspective of environmental management. Legality Vision (22), 16, **2021**.
32. ZHANG Y.C. Evolution and development of intelligent logistics ecosystem, from the perspective of multi center collaborative treatment. Journal of Commercial Economics (06), 96, **2021**.
33. MA H.Y., WU N. Research on the Cooperative Governance Mechanism of Cross-departmental Tourism under the Background of All-area Tourism-based Development. Tourism Forum **12** (03), 22, **2019**.
34. SI L.B., PEI S.Y. The Process and Reference of the Performance Accountability of Cross-administrative Region Eco-environment Synergy-governance, Based on the Comparative Analysis of Typical Environmental Governance Events in Foreign Countries. Journal of Henan Normal University (Philosophy and Social Sciences Edition) **48** (02), 16, **2021**.
35. HAN X.Y., CAO T.Y. 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, **2022**.

36. HAN X.Y., CAO T.Y. Study on ecological environment quality evaluation of the energy consumption pollution treatment in industrial parks. Environmental Science and Pollution Research **28**, 28038, **2021**.

37. HAN X.Y., CAO T.Y., YAN X.Y. 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 **23**, 7581, **2021**.