Evaluation Of Ecological Environment Development in The Yangtze River Delta Urban Agglomeration

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Abstract. Ecological environment development is the foundation of the high-quality development of Yangtze River Delta integration. Using the R language, this study applied factor analysis and cluster analysis to 12 indicators to evaluate the ecological environment development of 41 cities in the Yangtze River Delta urban agglomeration in 2022. Through factor analysis, three main factors—ecological restoration, ecological resources, and ecological development—were extracted. Comprehensive scores and rankings for the 41 cities were obtained, revealing that Shanghai held a dominant position. Cluster analysis, based on the comprehensive scores, categorized the cities into three types: those with superior, good, and less developed ecological environments. Finally, targeted suggestions for ecological development are provided for each category of city, along with proposals for the coordinated governance of ecological integration in the Yangtze River Delta.

Keywords: Yangtze River Delta, Ecological Environment Development, Factor Analysis, Cluster Analysis.

1. Introduction

The Yangtze River Delta urban agglomeration is a crucial juncture between China's Belt and Road Initiative and the Yangtze River Economic Belt. As the leading development area within the economic belt, it holds a pivotal strategic position in China's modernization and the formation of a new pattern of comprehensive opening-up [1]. In 2019, the State Council issued the Outline of the Plan for the Integrated Development of the Yangtze River Delta Region, which expanded the planning scope of the urban agglomeration from the original 26 cities (1 in Shanghai, 9 in Jiangsu, 8 in Zhejiang, and 8 in Anhui) to include the entire provinces of Jiangsu, Zhejiang, and Anhui and the entirety of Shanghai, encompassing a total of 41 cities across an area of 358,000 square kilometers. The report to the 20th National Congress of the Communist Party of China explicitly called for promoting coordinated regional development, the Yangtze River Economic Belt, and the integrated development of the Yangtze River Delta [2].

In recent years, ecological governance in the Yangtze River Delta region has achieved initial results, yet certain persistent problems remain, which seriously constrain the sustainable and high-quality integrated development of the urban agglomeration's economy and society [3]. In July 2023, the "Yangtze River Delta Eco-Green Integrated Development Demonstration Zone Industrial Development Plan (2021-2035)" was issued, outlining the goal of becoming an internationally influential "green innovation industry center" by 2035. Therefore, this paper takes the Yangtze River Delta (YRD) urban agglomeration as a case study. By selecting a set of urban ecological evaluation indicators and applying factor analysis and cluster analysis, it explores the ecological development status of the YRD cluster in 2022. The paper aims to provide specific suggestions for different types of cities, offering valuable insights for promoting ecological integration within the YRD. This research is of great practical significance for guiding the region's high-quality and coordinated development.

A significant body of research on urban ecological development has focused on constructing evaluation indicator systems. Bi and Ma (2008) developed an evaluation index system for urban ecologicalization. Applying a combination of factor analysis and analytic hierarchy process (AHP), they assessed the ecosystem development of eight representative cities in the Yangtze River Delta

(YRD), ranking their ecological levels as follows: Suzhou, Shanghai, Ningbo, and Nanjing. Ma and Yang (2016) identified ten major factors influencing the ecological environment and performed an exploratory factor analysis to categorize and rank China's provincial capitals. They concluded that Hohhot had the poorest environmental conditions, whereas Haikou ranked the highest, a result they attributed to its unique geographical advantages and strong environmental protection awareness. Liang and Tong (2016) measured the ecological civilization development level within the Yangtze River Delta municipality using 18 indicators across three dimensions: ecosystem pressure, excellence, and management effectiveness. By employing principal component analysis, they scored 25 prefecture-level cities. Their findings indicated a continuous improvement in Shanghai's development level and noted a degree of homogeneity in the development patterns between Jiangsu and Zhejiang provinces. Chen, Wei, and colleagues (2006) built an eco-city evaluation system from economic, environmental, and social perspectives. They comprehensively evaluated the ecological construction level of 34 cities across three major economic zones: the West Coast of the Taiwan Straits, the Yangtze River Delta, and the Pearl River Delta, using factor and cluster analysis. Their study concluded that Shanghai, Ningbo, Guangzhou, and Shenzhen ranked as the top four cities in terms of ecological development.

In summary, while extensive literature exists on the construction of ecological evaluation indicator systems, few studies have specifically employed factor analysis to assess the ecological development status of the Yangtze River Delta region. This study aims to address this research gap and contribute to the existing body of knowledge.

2. Data and Methodology

2.1. Indicator Selection and Data Source

Based on the principles of systematicity, independence, simplicity, operability, and dynamic adjustability for indicator system construction [8], and with reference to existing literature [9-12], this study selected 12 indicators to evaluate the ecological development of cities in the Yangtze River Delta (Table 1). Among these, X1 to X8 are positive indicators, while X9 to X12 are negative indicators. Data were sourced from the 2022 China Urban Statistical Yearbook and the China Urban Construction Statistical Yearbook.

Table1. Urban Ecological Environment Development Indicator System

Code	Ecological Environment Development Indicators	Direction	Code	Ecological Environment Development Indicators	Direction
X1	Green space per capita (square meters)	+	X7	Total investment in water conservation measures (yuan)	+
X2	Per capita water resources (cubic meters)	+	X8	Road sweeping and cleaning area (10,000 square meters)	+
X3	Greening coverage rate of built-up areas (%)	+	X9	Per capita household domestic water consumption (cubic meters)	-
X4	Sewage treatment capacity (10,000 m3/day)	+	X10	Per capita natural gas consumption (cubic meters)	-
X5	Harmless treatment rate of domestic garbage (%)	+	X11	Number of industrial enterprises above scale (number)	-
X6	Expenditure on science and technology (million yuan)	+	X12	GDP per capita (million)	-

2.2. Research Methodology and Feasibility Analysis

This study utilized the R language to analyze the ecological environment indicators of 41 cities in the Yangtze River Delta using factor analysis and cluster analysis. Factor analysis was employed to reduce the dimensionality of the evaluation system, identify the latent factors influencing the ecological environment, and elucidate the linear relationships between the 12 indicators and these underlying factors. Cluster analysis groups samples into distinct categories based on their similarities, aiming to explore the differences between these categories. This study employed Ward's minimum variance method (based on the sum of squares) to cluster the 41 cities according to their factor scores, thereby revealing the similarities and differences in ecological environment development across the Yangtze River Delta urban agglomeration.

Factor analysis is only applicable when indicators are strongly correlated [13]. The correlation coefficient matrix and the Kaiser-Meyer-Olkin (KMO) test can be used to assess the strength of these relationships.

3. Data Analysis

3.1. Data Processing

To facilitate comparison among the 41 cities, negative indicators were positively normalized [14] by subtracting each value from the maximum value within that indicator (i.e., New_Xi = Max(Xi) - Xi). Furthermore, to eliminate the influence of measurement units, the Z-score standardization method was applied to all 12 indicators for all cities.

3.2. KMO Test and Correlation Coefficient Matrix

The Kaiser-Meyer-Olkin (KMO) test yielded a value of 0.76. Furthermore, the correlation coefficient matrix revealed that most coefficients exceeded 0.3. These results collectively indicate strong correlations among the indicators. A KMO value above 0.7 is generally considered suitable for factor analysis. Therefore, the data collected in this study are appropriate for the application of this technique.

3.3. Factor Analysis

3.3.1 Determine the number of factors

The number of factors was determined by examining the eigenvalues of the correlation matrix and the cumulative variance contribution rate (Table 2). Table 2 presents the variance contribution rates for the top five factors. As shown in Table 2, the eigenvalues for the first three factors exceeded 1, and their cumulative variance contribution rate reached 78.25%. This indicates that these three factors explain the majority of the variance in the original variables; therefore, they were retained for further analysis.

Table 2. Contribution of variance of factors

Factor	Eigenvalue	Variance contribution rate %	Cumulative variance contribution rate
1	7.01	58.42	58.42
2	1.26	10.52	68.94
3	1.12	9.32	78.25
4	0.93	7.74	86.00
5	0.58	4.83	90.83

3.3.2 Factor rotation

Following the determination of the factor number, an orthogonal rotation (varimax) was performed to extract the factors. This procedure yielded the factor loading matrix (Table 3) and the total variance explained after rotation (Table 4). As presented in Table 3, the first factor exhibits high loadings on green coverage rate of built-up areas, sewage treatment capacity, harmless treatment rate of domestic waste, expenditure on science and technology, total investment in water-saving measures, and road sweeping area. It was therefore labeled the "ecological restoration factor." The second factor, correlated with per capita green space, household water consumption, and natural gas consumption, was termed the "ecological resources factor." The third factor showed high loadings on per capita water resources, the number of large-scale industrial enterprises, and per capita GDP, leading to its definition as the "eco-development factor." (Note: In Table 3, h^2 represents the communality, indicating the variance in each variable explained by the factors. $u^2 = 1 - h^2$ denotes the unexplained variance. Values in parentheses represent negative loadings.)

Table 4 shows that the three rotated factors collectively explain 78% of the total variance, confirming that the chosen number of factors provides a reasonable explanation of the original data's variance.

Table 3. Factor loading matrix

Item	Factor 1	Factor 2	Factor 3	h2	u2
X1	0.11	0.90	0.09	0.82	0.18
X2	0.05	(0.04)	0.56	0.32	0.68
X3	(0.61)	0.12	0.46	0.60	0.40
X4	0.70	0.57	(0.35)	0.94	0.06
X5	(0.87)	(0.32)	0.04	0.87	0.13
X6	0.71	0.56	(0.33)	0.92	0.08
X7	0.82	0.18	0.05	0.72	0.28
X8	0.56	0.50	(0.55)	0.86	0.14
X9	(0.38)	(0.78)	0.41	0.92	0.08
X10	(0.50)	(0.58)	0.40	0.75	0.25
X11	(0.29)	(0.17)	0.83	0.80	0.20
X12	(0.19)	(0.62)	0.67	0.87	0.13

Table 4. Total explained variance after rotation

Factor	Factor loadings	Variance contribution %	Cumulative variance contribution %
1	3.65	30	30
2	3.20	27	57
3	2.54	21	78

3.3.3 Factor scores

According to the regression estimation method, the score function of the three factors was calculated to get the factor scores of the ecological environment status of the 41 cities in the Yangtze River Delta; and then, using the variance contribution ratio of the factors, the comprehensive evaluation score function could be obtained: the factor comprehensive score= (Factor 1*30% + Factor 2*27% + Factor 3*21%) ／78%. According to the comprehensive evaluation score function, the total factor scores of the ecological environment of 41 cities in the Yangtze River Delta in 2022 were obtained (Table 5).

From the results of factor analysis, it can be seen that Shanghai has the best ecological environment condition, followed by Huangshan City and Chizhou City. Shanghai's overall ecological environment ranked first, mainly due to the high level of ecological restoration factor, its factor score is 4.85 times higher than that of Quzhou City, which ranked second, indicating that Shanghai has an absolute advantage in ecological environment restoration investment, which gives other cities in the Yangtze River Delta region a leading role in improving the environmental conditions by increasing the level of ecological restoration. This is mainly because Shanghai has abundant economic, human resources, technology and other resources, and can improve the ecological environment efficiently by relying on advanced equipment[15] . And Jiaxing City, Zhejiang Province, the factor composite score ranking is in the 41st place, which indicates that the ecological environment of Jiaxing City is underdeveloped, especially in the two aspects of ecological resources and ecological development, firstly, the ecological resources of Jiaxing are not rich enough, and secondly, although Jiaxing is close to Shanghai, the water transportation and transportation of its main urban area does not have an advantage, compared with Suzhou and Nantong, the water transportation and transportation of Jiaxing is not developed enough, and the level of economic and social development constrains the level of economic and social development restricts the development of ecological environment.

In Factor 1 "Environmental Restoration Factor", Shanghai ranks first with absolute advantage, and Quzhou City in Zhejiang Province ranks second. Quzhou is located in the southwest of Zhejiang Province, with a forest coverage of 69.53%, and is located at the source of the Qianjiang River, which is rich in ecological resources, and what's more important is that Quzhou relies on the ecological resources to leverage the ecological industry, and increases financial investment in water conservation. Increase financial investment in water conservancy and promote water conservancy and ecological enrichment. Suzhou, which has a reputation as a paradise on earth, has a much smaller score than Quzhou and Maanshan, indicating that Suzhou's ecological environment is on a downward trend and that it has not invested enough in ecological restoration, so it needs to keep up with Shanghai and learn from Quzhou's experience in ecological environmental protection to improve the level of ecological environment restoration in the future.

Table 5. Main factor scores of ecological environment status of 41 cities in the Yangtze River Delta region

City	Factor 1		Factor 2		Factor 3		Composite Score	Ranking
	Score	Rank	Score	Rank	Score	Ranking		
Shanghai	5.44	1	2.02	3	(0.25)	25	2.74	1
Nanjing	(1.01)	40	3.00	1	(0.23)	24	0.56	5
Wuxi	(0.58)	35	0.69	8	(1.60)	40	(0.42)	36
Xuzhou	(0.23)	25	(0.50)	29	(0.09)	23 (0.28)	(0.28)	29
Changzhou	(0.60)	36	0.97	7	(1.02)	34	(0.18)	23
Suzhou	0.10	13	0.40	11	(2.49)	41	(0.50)	38
Nantong	(0.41)	30	(0.43)	25	(1.13)	36	(0.61)	40
Lianyungang	0.13	12	(0.24)	20	0.25	18	0.04	15
Huaian	(0.26)	26	(0.30)	22	(0.04)	22	(0.21)	26
Yancheng	(0.21)	23	(0.73)	33	(0.32)	27	(0.42)	34
Yangzhou	(0.65)	37	(0.17)	19	(0.41)	32	(0.42)	35
Zhenjiang	(0.54)	33	0.25	13	(0.41)	32	(0.24)	27
Taizhou	(0.31)	28	(0.35)	24	(0.34)	29	(0.33)	32
Suqian	(0.19)	20	(0.46)	27	0.20	19	(0.18)	21
Hangzhou	0.42	8	1.43	5	(1.30)	37	0.30	9
Ningbo	(0.22)	24	0.46	10	(1.48)	38	(0.33)	31
Wenzhou	0.65	4	(1.49)	41	(1.13)	36	(0.56)	39
Jiaxing	(0.03)	17	(1.04)	38	(1.50)	39	(0.77)	41
Huzhou	(0.44)	32	(0.14)	18	(0.34)	29	(0.31)	30
Shaoxing	0.45	7	0.17	14	(0.03)	21	0.23	10
Jinhua	0.05	15	(0.95)	36	(0.55)	33	(0.45)	37
Quzhou	1.12	2	(1.11)	40	0.96	5	0.32	8
Zhoushan	(1.39)	41	2.49	2	1.23	4	0.64	4
Taizhou	(0.21)	23	(0.65)	31	(0.31)	26	(0.39)	33
Lishui	0.62	5	(0.73)	33	1.57	3	0.42	6
Hefei	(0.31)	28	1.10	6	(0.34)	29	0.16	11
Wuhu	(0.44)	32	0.48	9	0.13	20	0.03	16
Bengbu	0.03	16	(0.49)	28	0.35	14	(0.06)	17
Huainan	(0.58)	35	(0.13)	17	0.49	11	(0.14)	19
Maanshan	0.74	3	(0.31)	23	0.86	7	0.42	7
Huaibei	0.27	9	(0.44)	26	0.71	8	0.15	12
Tongling	(0.40)	29	0.30	12	0.50	10	0.08	14
Anqing	0.08	14	(0.91)	35	0.31	16	(0.19)	24
Huangshan	(0.74)	39	1.69	4	2.65	1	1.00	2
Chuzhou	(0.67)	38	(0.11)	16	0.32	15	(0.21)	25
Fuyang	(0.18)	19	(0.76)	34	0.26	17	(0.26)	28
Suzhou	0.18	11	(0.99)	37	0.45	12	(0.14)	20
Luan	(0.16)	18	(0.63)	30	0.67	9	(0.10)	18
Bozhou	0.20	10	(1.06)	39	0.39	13	(0.18)	22
Chizhou	0.48	6	(0.09)	15	2.08	2	0.72	3

3.4. Cluster Analysis

We performed a cluster analysis on the ecological status of the 41 cities using Ward's method (based on minimizing within-cluster sum of squares). To better reflect the actual conditions, the factor scores derived from the factor analysis were used as inputs for the clustering [16], resulting in the dendrogram shown in Figure 1. The dendrogram in Figure 1 suggests that the 41 cities can be categorized into three distinct groups based on their ecological status: those with superior, good, and poor ecological environments. Shanghai was the only city classified as having a superior ecological environment. Fifteen cities, including Huangshan, Chizhou, Nanjing, Zhoushan, Hangzhou, and Quzhou, were grouped as having a good ecological environment. The remaining 25 cities were categorized as having a less developed ecological environment.

Shanghai has an absolute advantage in terms of ecological environment development and is alone in the first echelon. Shanghai is not only the fastest growing economy and the most urbanized region in the Yangtze River Delta, but also the city with the best ecological and environmental development, thanks to the development of high-tech industries, the continuous improvement of ecological and environmental development by eliminating outdated production capacity that endangers the environment, and the replacement of traditional energy with clean energy.

There are 15 cities in the second echelon, including 8 in Anhui, 5 in Zhejiang and 2 in Jiangsu, indicating that Anhui is overall better than Jiangsu and Zhejiang in terms of ecological and environmental development. Jiangsu has experienced rapid economic development in recent years, and environmental conflicts have become increasingly prominent. How to weigh economic development and environmental protection is a topic to be further addressed in Jiangsu[17] . Anhui is located in the hinterland of the Yangtze River Delta, and its economic development is relatively lagging behind, but its rich natural resources bring advantages to the development of Anhui's ecological environment. The second echelon of Anhui cities includes Huangshan, Chizhou, Maanshan, Hefei, Huaibei, Tongling, Xuancheng, and Wuhu, of which four cities are near the Yangtze River.

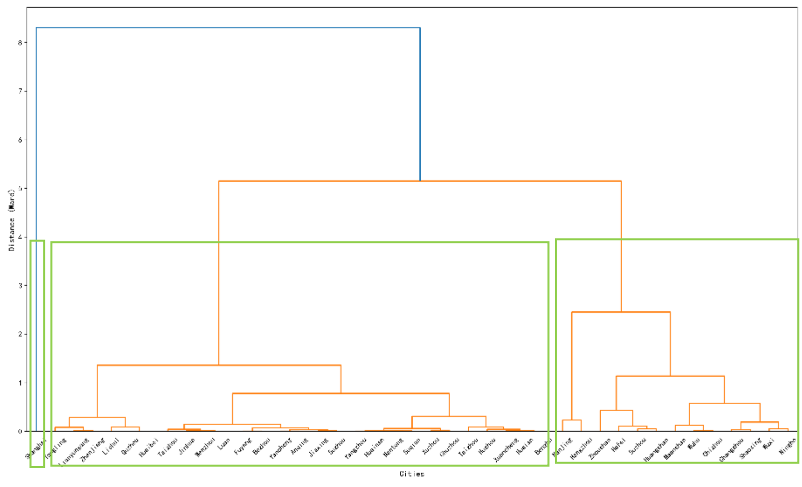

Fig.1 Spectral clustering diagram

There are 25 cities in the third echelon, 9 in Anhui, 8 in Jiangsu and 8 in Zhejiang, indicating that each province has cities with poor ecological development. The third echelon cities have an arduous task of ecological environment development, and they should actively learn from the ecological development experience of the first and second echelon cities. In addition, the first and second echelon cities should play their own leading role to promote the integrated development of ecological environment in the Yangtze River Delta region.

4. Conclusion and Outlook

4.1. Conclusions and Recommendations

This study evaluated the ecological development status of 41 cities in the Yangtze River Delta (YRD) in 2022. Through factor analysis, three principal factors—ecological restoration, ecological resources, and ecological development—were extracted, providing a basis for ranking the cities. Subsequent cluster analysis, informed by the factor scores, categorized the cities into three tiers: superior, good, and less developed ecological environments. The characteristics of each tier were analyzed, and targeted recommendations are proposed below.

As the sole city with a superior ecological environment, Shanghai should continue increasing investment in ecological restoration. It must actively leverage its advantages in talent, technology, and capital to foster high-tech industries, initiate the establishment of resource-saving and recycling systems across various sectors, and steadily promote the continuous improvement of its urban ecological quality.

Cities with good ecological environments, such as Quzhou, Huangshan, and Nanjing, should strive to maintain their inherent resource and geographical advantages. They should further study advanced green technologies, enhance their capacity for independent innovation, and actively engage with Shanghai, the central hub of the YRD, to absorb successful experiences through continuous exchange and integration. This will accelerate the ecological development of their respective regions.

For cities with less developed ecological environments, the immediate priorities are to enhance awareness of ecological protection and focus on transforming traditional development models. Simultaneously, these cities should learn from the ecological management practices of neighboring high-performing cities. This will enable them to gradually optimize their local ecological development strategies based on their specific conditions.

Coordinated governance and protection of the ecological environment are the foundation for realizing integrated development within the YRD urban agglomeration and a prerequisite for sustainable, high-quality development [18]. Internally, the region must further utilize the radiating influence of ecologically advanced cities like Shanghai. This involves strengthening the integration of environmental protection systems, technologies, and evaluation standards across the region. Active exploration of a collaborative legislative mechanism for ecological environment protection, joint cultivation of green high-tech industrial clusters, and standardization of urban statistical data calibers are essential steps to escort the sustainable development of the entire region. Secondly, cities with relatively backward ecological development should further explore their comparative advantages, leveraging their strengths while mitigating weaknesses. They must proactively learn from neighboring cities and intensify efforts in ecological civilization construction. The more advanced cities should play a leading role by creating innovative and open platforms. This will accelerate the flow and integration of knowledge, information, talent, and technology within the YRD city cluster, ultimately promoting the realization of environmental protection integration and high-quality development.

4.2. Future Prospects

As China's primary economic development zone and financial center, the Yangtze River Delta also grapples with a mismatch between economic growth and ecological civilization, alongside a relative lag in the latter's development [19][20]. Future research should be extended to evaluate the level of coordinated development between the ecological environment and the socio-economic system within the YRD. Exploring the coupling relationship between these two systems from a high-quality development perspective will provide valuable insights and policy recommendations for the coordinated and high-quality advancement of the YRD urban agglomeration. This effort is crucial for realizing the strategic goal of building a world-class city cluster at an early date.

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