

Research on the Evaluation Index System of Urban Competitiveness in Nanjing Metropolitan Circle

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Abstract: The analysis of the level of urban competitiveness in the Nanjing metropolitan area can effectively promote the healthy, sustainable and higher-quality development of the metropolitan area. Based on the basic connotation of urban competitiveness, this paper constructs the urban competitiveness index system of Nanjing metropolitan area under the new development concept from five dimensions of innovation, coordination, greenness, openness and sharing. Combined with the data of the member cities of Nanjing Metropolitan Circle, use the AHP method to conduct empirical analysis. The study found that Nanjing has the highest level of urban competitiveness in the Nanjing metropolitan area, followed by Yangzhou and Zhenjiang, the level of competitiveness of the two cities is comparable. While the overall competitiveness of the four cities in Anhui Province is relatively low, of which Xuancheng has the lowest overall competitiveness.

Keywords: City competitiveness, Evaluation index, AHP method.

1. Introduction

As an important regional unit for the development of new urbanization, metropolitan area is becoming an important space carrier for accelerating regional integration construction. With the coordinated development of regions, the process of regional integration and development is gradually accelerating, and the research on the development competitiveness of metropolitan circles is becoming the focus of attention. There are still development gaps among the cities within the Nanjing metropolitan area, and the problem of unbalanced and insufficient urban development still exists.

The comprehensive competitiveness of metropolitan areas is an important focus of regional economic development and an important measure of the level of regional economic development. The planning scope of the Nanjing Metropolitan Area has been expanded to include Nanjing, Zhenjiang, Yangzhou, Huai'an, Wuhu, Ma'anshan, Chuzhou, Xuancheng 8 cities, as well as Jintan District of Changzhou and Liyang City, with a total area of 66,000 square kilometers and a permanent population of about 35 million by the end of 2020. , the GDP of the metropolitan area is 4175.078 billion yuan, accounting for 4.1% of the national proportion. The economic data of each member city and the data of the three industries are shown in Table 1 and Figure 1.

Table 1. Main economic data of Nanjing metropolitan area in 2020

City	Permanent population (10,000 people)	GDP (100 million yuan)	Per capita production Gross value (yuan)	Urbanization rate (%)	Proportion of GDP in total metropolitan area (%)
Nanjing	931.97	14 818	159322	86.8	35.5
Yangzhou	456.10	6 048	132784	71.0	14.5
Zhenjiang	321.10	4220	131580	79.5	10.1
Huaian	455.92	4025	87507	65.7	9.6
Chuzhou	398.71	3032	76048	61.8	7.3
Ma'anshan	216.50	2187	101011	54.1	5.2
Xuancheng	250.00	1608	64301	57.0	3.9
Wuhu	364.58	3753	102964	63.8	9.0
Jintan District	58.52	973	166294	65.8	2.3
Liyang	78.55	1072	137457	62.9	2.6

Wu Fuxiang[1] and others believe that cities at all levels in the Yangtze River Delta should promote complementary advantages and coordinated development according to their own development characteristics, and realize the dynamic allocation of industrial resources in the urban agglomeration under the condition of free flow of factors. There are not many domestic studies on the evaluation index of the five major development concepts. Yi Changliang (2016) [2] compiled a development index report with five core concepts as the evaluation system on the basis of benchmarking

analysis. Yang Xinhong[3] constructed a statistical evaluation index system from five parts of the new development concept, and only analyzed the economic and social development of Shenzhen in the past five years. Based on the perspective of competitiveness, Ni Pengfei and Xu Haidong (2019) [4] predicted the future trend and pattern of national central cities from the perspectives of economic competitiveness, sustainable competitiveness, business competitiveness, and livable competitiveness. Li Jiaqi (2020) [5] conducts research on the coordinated development competitiveness of five

development concepts based on Delphi and AHP methods. Based on the previous research results, this study intends to use the AHP method to discuss the evaluation index system of urban competitiveness in Nanjing metropolitan area, in order to put forward relevant suggestions for the high-quality development of Nanjing metropolitan area.

2. Methods and Materials

The AHP method [6], also known as the Analytic Hierarchy Process, was proposed by the American operations researcher T.L.Saaty in the 1970s. The principle is to classify the research problems into different levels according to different principles, and then construct a judgment matrix according to the logical relationship of each level, and calculate the single-ranking structure of the factors of a certain level relative to the factors of the previous level and relative to the upper level.

One-level total ranking weight, this method is a decision analysis method that combines qualitative and quantitative analysis.

Step1: Build a hierarchical model, that is, the classification of each influencing factor at the next level.

Step2: Construct judgment matrix. The matrix is constructed according to the consistency matrix check method, but all matrix elements are compared pairwise, and finally the consistency check is used to determine whether the matrix construction is correct. Construct the judgment matrix A (a_{ij} is the element of the matrix, i represents the row, j represents the column), the value of each element in the judgment matrix reflects the importance judgment of one element to another element, and the value method is innovative, a_{ij} is not mandatory. Select the data in Table 2, and can use any score between the above data to judge, each value represents a different relationship between them, see Table 1.

Table 1. AHP Assignment Meaning Table

assignment	explanation
1	Both are equally important
3	i is slightly more important than j
5	i is important than j
7	i is more important than j
9	i is definitely more important than j
2,4,6,8	The median value of two adjacent judgments Further subdivision is required between two adjacent judgments
reciprocal	If the ratio of the importance of i to j is a_{ij} , then the ratio of the importance of j to i is $\frac{1}{a_{ij}}$

Step3: Weight vector and consistency indicator

The judgment matrix A obtained by pairwise comparison is not necessarily consistent.

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \quad (1)$$

Assuming $W = (w_1, w_2 \cdots w_n)^T$ is the sorting weight vector of the n -order judgment matrix A, when A is the consistency matrix, there are obviously:

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \cdots & w_2/w_n \\ \cdots & \cdots & \cdots & \cdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \begin{bmatrix} 1 & 1 & \cdots & 1 \\ w_1 & w_2 & \cdots & w_n \end{bmatrix} \quad (2)$$

This shows that $W = (w_1, w_2, \cdots, w_n)^T$ is the eigenvector of A, and the eigenvalue is n . That is to say, for a consistent judgment matrix, the sorting vector W is the eigenvector of A. Conversely, if A is a consistent inverse matrix, then:

$$\text{When } a_{ii} = 1, a_{ij} = a_{ji}^{-1}, a_{ij} \cdot a_{jk} = a_{ik}, A = (a_{ij})_{n \times n} = \begin{bmatrix} a_{11}^{-1} \\ a_{12}^{-1} \\ \vdots \\ a_{1n}^{-1} \end{bmatrix} [a_{11} \ a_{12} \ \cdots \ a_{1n}] \quad (3)$$

$$\text{So, } A \begin{bmatrix} a_{11}^{-1} \\ a_{12}^{-1} \\ \vdots \\ a_{1n}^{-1} \end{bmatrix} = \begin{bmatrix} a_{11}^{-1} \\ a_{12}^{-1} \\ \vdots \\ a_{1n}^{-1} \end{bmatrix} [a_{11} \ a_{12} \ \cdots \ a_{1n}] \begin{bmatrix} a_{11}^{-1} \\ a_{12}^{-1} \\ \vdots \\ a_{1n}^{-1} \end{bmatrix} = \begin{bmatrix} a_{11}^{-1} \\ a_{12}^{-1} \\ \vdots \\ a_{1n}^{-1} \end{bmatrix} n = n \begin{bmatrix} a_{11}^{-1} \\ a_{12}^{-1} \\ \vdots \\ a_{1n}^{-1} \end{bmatrix} \quad (4)$$

So this shows that $W = (a_{11}^{-1}, a_{12}^{-1}, \cdots, a_{1n}^{-1})^T$ is the feature vector of A, and since A is a relative vector of judgment W about the target Z matrix, then W is an ordering of the values of specific indicators under the criteria at all levels.

Regarding the positive reciprocal matrix A, we have the following conclusions: Assuming A be an n -order the positive reciprocal matrix, and λ_{max} is the eigenroot with the largest modulus (norm) of A, then:

① λ_{max} must be a positive eigenroot, and its corresponding eigenvector is a positive vector;

② Any other characteristic root λ of A always has: $|\lambda| < \lambda_{max}$;

③ $\lambda_{max} = n$ is the single characteristic root of A.

Accordingly, if $\lambda_{max} > n$, the judgment matrix is inconsistent, and the feature vector W at this time cannot truly reflect the proportion of $\{y_1, y_2, \cdots, y_n\}$ in the target matrix Z. The quantitative index to measure the degree of inconsistency is called the consistency index, which is defined as:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

In fact, CI is equivalent to the average of $n-1$ eigenvalues (except the largest). Obviously, for the consistent positive

reciprocal matrix, CI=0. However, it is not enough to use CI as the criterion for judging whether the matrix A has satisfactory consistency. For this reason, the average randomness consistency index RI is introduced:

$$RI = \frac{\lambda_{max}' - n}{n-1} \quad (6)$$

Step4: Calculation of Analytic Hierarchy Process

How to judge the largest eigenroot of a matrix and its corresponding eigenvector is the fundamental problem of AHP calculation. The calculation method is as follows:

① Normalize each column of the judgment matrix:

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad (i, j = 1, 2, \dots, n) \quad (7)$$

② The normalized matrix is added row by row:

$$\overline{w_i} = \sum_{j=1}^n \overline{a_{ij}} \quad (i = 1, 2, \dots, n) \quad (8)$$

③ Normalize the vector, that is, $w_i = \frac{\overline{w_i}}{\sum_{j=1}^n \overline{w_j}}$ is the desired eigenvector.

④ Calculate the maximum eigenroot of the judgment matrix:

$$\lambda_{max} = \sum_{i=1}^n \frac{(\overline{A\overline{w}})_i}{nw_i} \quad (9)$$

In the above formula $(\overline{A\overline{w}})_i$ represents the i-th element of the vector.

Step5: Weight vector and combinatorial consistency check

The total ranking of the hierarchy is to calculate the ranking weight of the relative importance of all factors at the same level to the highest level (total target), which is carried out layer by layer from the highest level to the lowest level.

① Calculate the combined weight vector

Assume the sorting weight vector of n_{k-1} elements on the k-1 layer to the total target (the highest layer) be:

$$W^{(k-1)} = (w_1^{(k-1)}, w_2^{(k-1)}, \dots, w_{n_{k-1}}^{(k-1)})^T \quad (10)$$

The weight vector of the n_k elements on the kth layer to the jth element on the previous (k-1)

$$P_j^{(k-1)} = (p_{1j}^{(k)}, p_{2j}^{(k)}, \dots, p_{n_{kj}}^{(k)})^T, \quad j = 1, 2, \dots, n_{k-1} \quad (11)$$

Then the matrix $P^{(k)} = [P_1^{(k)}, P_2^{(k)}, \dots, P_{n_{k-1}}^{(k)}]$ is $n_k \times n_{k-1}$ matrix, represents the sorting weight vector of the elements on the kth layer to the elements of the k-1th layer. Then the total sorting weight vector of the elements on the kth layer to the target layer (the highest layer) is:

$$W^{(k)} = P^{(k)} \cdot W^{(k-1)} = [P_1^{(k)}, P_2^{(k)}, \dots, P_{n_{k-1}}^{(k)}] \cdot W^{(k-1)} = (w_1^{(k)}, w_2^{(k)}, \dots, w_{n_k}^{(k)})^T \quad (12)$$

or

$$w_i^{(k)} = \sum_{j=1}^{n_{k-1}} p_{ij}^{(k)} w_j^{(k-1)}, \quad i = 1, 2, \dots, n_k \quad (13)$$

For any $k > 2$ there is a general formula $W^{(k)} = P^{(k)} \cdot$

$P^{(k-1)} \dots \dots P^3 \cdot W^{(2)}$ ($k > 2$), and $W^{(2)}$ is the total sorting weight vector of each element on the second layer to the target layer.

② Combination consistency test

Assume the consistency index of layer k is $CI_1^{(k)}, CI_2^{(k)}, \dots, CI_{n_{k-1}}^{(k)}$, The random consistency index is: $RI_1^{(k)}, RI_1^{(k)}, \dots, RI_{n_{k-1}}^{(k)}$. Then the combined consistency index of the kth layer to the target layer (the highest layer) is:

$$CI^{(k)} = (CI_1^{(k)}, CI_2^{(k)}, \dots, CI_{n_{k-1}}^{(k)}) \cdot W^{(k-1)} \quad (14)$$

The combined random consistency index is:

$$RI^{(k)} = (RI_1^{(k)}, RI_1^{(k)}, \dots, RI_{n_{k-1}}^{(k)}) \cdot W^{(k-1)} \quad (15)$$

The combined consistency ratio indicator is:

$$CR^{(k)} = CR^{(k)} + \frac{CI^{(k)}}{RI^{(k)}} \quad (k \geq 3) \quad (16)$$

When $CR^{(k)} < 0.10$, the comparison judgment matrix of the whole level is considered to pass the consistency test. The corresponding RI numbers see Table 2.

Table 2. Average random consistency index RI

n	1	2	3	4	5	6	7	8	9
R	0	0	0	0	1	1	1	1	1
I		.52	.89	.12	.26	.36	.41	.46	

Data normalization: In order to facilitate the comparison and analysis of the data, standardization processing is required. This paper adopts the range standardization method. The calculation formula of the factor with positive correlation in the final score is (16), and the calculation formula of the factor with negative correlation is (17)

$$X'_{ij} = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \quad (17)$$

$$X'_{ij} = \frac{\max\{x_{ij}\} - x_{ij}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \quad (18)$$

Step6: Adjust and recalculate the situation that does not meet the consistency check.

When using the AHP method to construct the matrix, the Delphi method is used for comprehensive decision-making. Experts evaluate and score the importance of the indicators, and multiple experts adjust the influencing factors. On the basis of the AHP method, the original matrix is normalized to obtain the results of each judgment matrix, and the consistency test (CI/RI) is carried out to confirm that the matrix is valid, and the final index weight result is obtained[7].

Data sources: There are 30 indicators at the indicator level in this article. The data are all obtained from the statistical yearbooks officially released by the cities in 2021 and the statistical bulletins of national economic and social development, and are obtained directly or indirectly. Due to the limitation of data samples, the analysis of Nanjing metropolitan area in this paper is limited to prefecture-level cities, and Liyang and Jintan in Changzhou are not included in the scope of data analysis.

3. Results and Discussion

3.1. Evaluation System

The connotation of urban competitiveness is relatively rich. Before evaluating urban competitiveness, it is necessary to build a relatively complete evaluation index system for urban

competitiveness, and try to select all indicators that can reflect the connotation of urban competitiveness. There are 3 levels in the evaluation index system of city competitiveness which belongs to the index weight determination, namely the target level (A), the criterion level (B) and the index level (C), see Table 3. Criterion layer weights and Index layer weights are shown in Table 4 and Table 5.

Table 3. Urban Competitiveness Index System

City Competitiveness A	Economic Coordination Competitiveness B1	GDP per capita C1 GDP growth rate C2 Total GDP C3 Urbanization rate C4 Income ratio of urban and rural residents C5 Total investment in fixed assets C6 The output value of the secondary industry accounts for the proportion of GDP C7 The output value of the tertiary industry accounts for the proportion of GDP C8 Ratio of consumption expenditure of urban and rural residents C9
	Innovation Ability Competitiveness B2	R&D expenditure C10 R&D spending as a percentage of GDP C11 Number of patent applications C12 Number of patents granted C13 The number of ordinary colleges and universities C14
	Openness Competitiveness B3	Total Import and Export C15 The proportion of total imports and exports to GDP C16 Total actual utilization of foreign capital C17 Tourism Income C18 Total freight volume C19 Passenger volume C20
	Green Development Competitiveness B4	Park green space per capita C21 Green coverage in built-up areas C22
	Shared level competitiveness B5	Population density C23 Urban registered unemployment rate C24 Local fiscal revenue per capita C25 Local fiscal expenditure per capita C26 Urban road area per capita C27 Rail transit mileage C28 Number of beds in hospitals C29 Number of public libraries C30

Table 4. Criterion layer weights of urban competitiveness evaluation index system

Index	B1	B2	B3	B4	B5
Weights	0.3521	0.2358	0.0946	0.1082	0.2093

Table 5. Index layer weights of urban competitiveness evaluation index system

Index	Weights	Index	Weights	Index	Weights	Index	Weights	Index	Weights
C1	0.2091	C7	0.0391	C13	0.3042	C19	0.0824	C25	0.0445
C2	0.1538	C8	0.0734	C14	0.4627	C20	0.1123	C26	0.3327
C3	0.1223	C9	0.0937	C15	0.1242	C21	0.0901	C27	0.0482
C4	0.0751	C10	0.0157	C16	0.1089	C22	0.5351	C28	0.1021
C5	0.086	C11	0.0457	C17	0.3498	C23	0.4649	C29	0.2065
C6	0.0553	C12	0.0308	C18	0.3654	C24	0.0537	C30	0.2123

3.2. Indicator Description

By measuring the spatial distribution of the industrial structure in the region by the location entropy, it is found that in the Nanjing metropolitan area, only Nanjing is dominated

by the tertiary industry, and other cities are mainly concentrated in the primary or secondary industry. see Figure1 and Figure2. The formula for calculating location entropy is: $LQ_{ij} = \frac{G_{ij}/G_j}{G_i/G}$, Among them, G_{ij} represents the output value of

industry j in city i , G_j represents the output value of industry j in the metropolitan area, G_i represents the total output value of city i , G represents the total output value of metropolitan

area, and LQ_{ij} represents the location entropy. The evaluation results are shown in Table 5 and Figure 3.

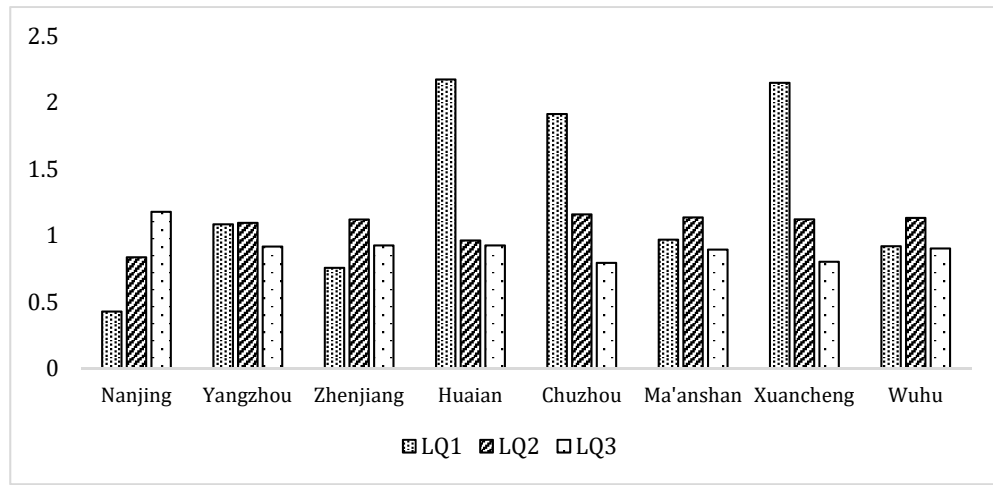


Figure 1. Location entropy of three industries in Nanjing metropolitan area in 2020

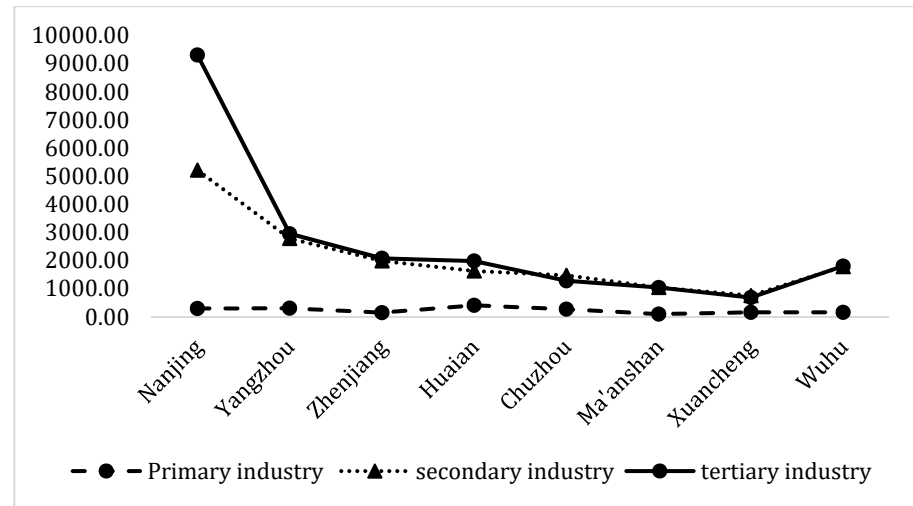


Figure 2. Three industries in Nanjing metropolitan area

Table 5. Criterion layer index score and competitiveness index of city competitiveness in Nanjing metropolitan area

City	Nanjing	Zhenjiang	Yangzhou	Huaian	Chuzhou	Ma'anshan	Wuhu	Xuancheng
B1	0.2749	0.1853	0.1899	0.1693	0.1092	0.1185	0.1349	0.0862
B2	0.2963	0.1734	0.1921	0.1576	0.0548	0.0461	0.0812	0.0554
B3	0.1325	0.0921	0.1254	0.1164	0.0564	0.0794	0.1187	0.0441
B4	0.0654	0.0215	0.0403	0.0321	0.0167	0.0221	0.0376	0.0067
B5	0.0745	0.0436	0.0564	0.0322	0.0195	0.0396	0.0412	0.0074
Total score	0.8436	0.5159	0.6041	0.5076	0.2566	0.3057	0.4136	0.1998
Sort	1	3	2	4	6	7	5	8

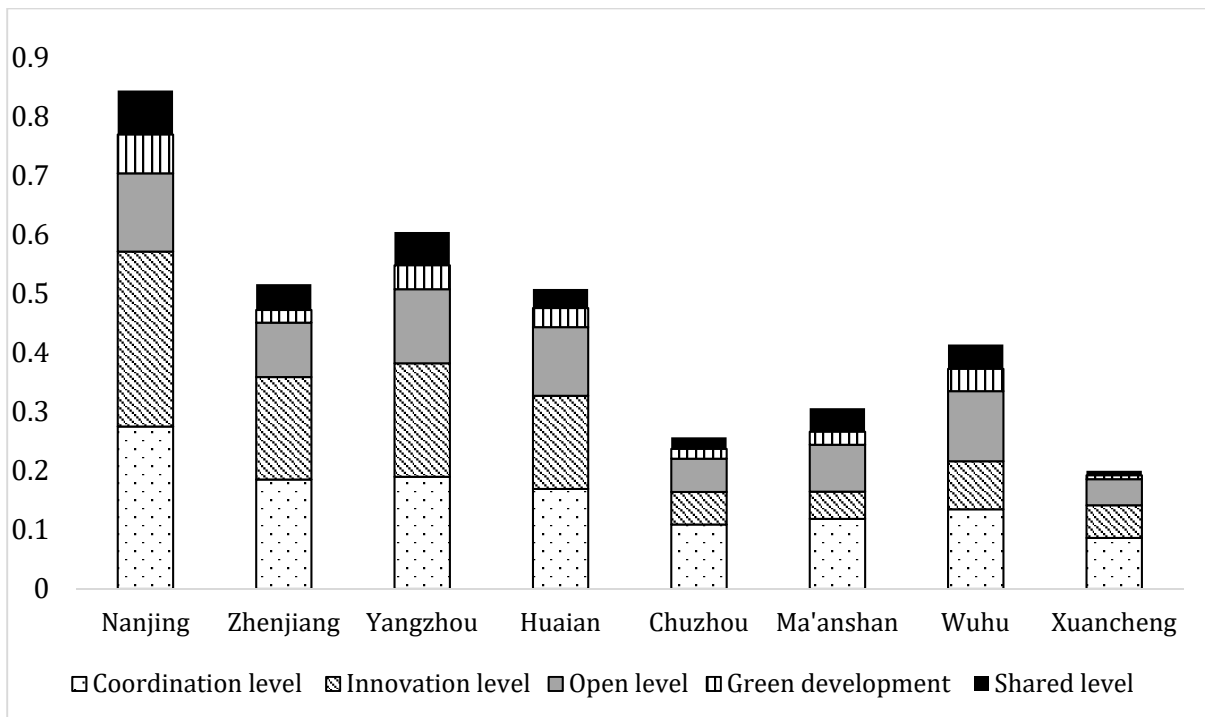


Figure 3. Evaluation results of urban competitiveness in Nanjing metropolitan area

The indicator system includes innovation, coordination, green, openness and sharing 5 parts, and a total of 30 indicators are set up, the coordinated development and shared development parts set 9 and 8 indicators respectively. Taking into account the particularity of the development orientation of the Nanjing metropolitan area. In order to build a national model area for the development of the same city, 5 indicators are set for the development of innovation capability, 6 indicators are set for the openness level, and 2 indicators are set for the green development part.

4. Conclusions

Based on the AHP method, this paper obtains the competitiveness ranking of cities in the Nanjing metropolitan area, and puts forward specific ideas and innovative measures for the development of the metropolitan areas under the new requirements of high-quality and integrated development, so as to enhance the overall strength and competitiveness of the metropolitan area.

(1) As the core city in the metropolitan area, Nanjing has leading advantages in terms of industrial development, innovation level, coordinated development and public service sharing. Compared with other cities, Nanjing has the highest level of urban competitiveness. In terms of economic strength, Nanjing has an absolute advantage, and its total scale is 9 times that of the lowest Xuancheng city. Therefore, it is necessary to give full play to the leading and leading role of Nanjing's central city. The advantages of Nanjing's innovation primacy should be fully amplified, the integration of innovation resources should be deepened, the R&D platform should be jointly built in the metropolitan area, and the technological breakthroughs of major projects should be coordinated to form a cross-regional industry-university-research innovation complex.

(2) Overall, Nanjing, Yangzhou, Zhenjiang and Huai'an of the 4 cities in Jiangsu Province are more competitive than the adjacent 4 cities in Anhui Province. Among them, Yangzhou

ranks second in city competitiveness, and Zhenjiang and Huai'an are comparable in competitiveness, ranked third and fourth respectively. The overall competitiveness of Chuzhou and Xuancheng is relatively low. Because Xuancheng is relatively far away from Nanjing, it is limited in accepting the radiation power of core cities, resulting in the lowest level of urban competitiveness. In the future, it is even more necessary to break down the administrative barriers between regions, and at the same time, further strengthen collaborative innovation and industrial cooperation.

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