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Evaluation of ecological environment governance quality in the top ten cities of Zhejiang province using entropy weight method and rank-sum ratio method: A case study of air quality indicators

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Abstract. All In this study, we focused on evaluating the quality of ecological environment m governance in eleven cities within Zhejiang Province. We employed a comprehensive set of key indicators, including the proportion of days with air quality meeting or exceeding Grade II standards, annual average concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter with a diameter of 10 micrometers or less (PM10), the 95th percentile daily concentration of carbon monoxide (CO), and the 90th percentile 8-hour maximum concentration of ozone (O_3). We utilized methods such as entropy values, information utility values, and weight allocation techniques to conduct a holistic assessment of urban ecological environment governance.Our findings revealed significant advantages in terms of Ritchie's fitting values (RSR fitting values) for Zhoushan and Lishui cities, ranking them in the third tier. This underscores the commendable efforts of these two cities in improving air quality. Simultaneously, Huzhou city, while displaying relatively lower fitting values, demonstrates substantial potential in ecological environment governance. Additionally, key indicators such as the 90th percentile 8-hour maximum concentration of ozone (O_3) and annual average concentration of particulate matter (PM10) play pivotal roles in the overall evaluation.The comprehensive assessment framework presented in this study offers a thorough and accurate perspective on urban ecological environment governance. This approach can guide policy formulation and environmental management, albeit requiring further refinement and practical implementation. In summary, our research provides valuable insights for advancing ecological civilization construction through an in-depth analysis of urban ecological environment governance in Zhejiang Province.

Keywords: Urban Evaluation, Rank-Sum Ratio Method, Horizontal and Vertical Index Comparison

1. Introduction

Zhejiang Province is situated along the eastern coast of China, characterized by a topographical pattern of elevated terrain in the southwest and lower terrain in the northeast [1], gradually sloping from the southwest to the northeast, creating a cascading descent of landforms. The southwestern region comprises mountainous areas with an average elevation of 800 meters, and most peaks exceeding 1500 meters are concentrated in this area. Notably, Huangmaojian, located within Longquan County, stands as the highest peak in the province, reaching an elevation of 1929 meters [2].

The central region primarily consists of hilly terrain, interspersed with both small and large basins nestled between the hilly landscapes. In contrast, the northeastern part of the province features expansive alluvial plains characterized by flat terrain, deep soil layers, and a dense network of rivers. These mountain ranges extend continuously to the East China Sea, with some peaks protruding above the water's surface, forming peninsulas and islands. The coastal region of Zhejiang boasts over 2000 islands, making it one of the provinces in China with the highest number of islands.

Zhejiang Province and its cities have consistently maintained high levels of prominence and exerted a significant influence and leadership role in China. Analyzing cities within Zhejiang can provide valuable insights due to their representative nature [3].

2. Introduction to the Rank-Sum Ratio Method

2.1. Description of Data Structure

The data in this study were obtained from the Zhejiang Provincial Bureau of Statistics. Through normalization and weight calculation, ecological environment governance quality was assessed, using the example of seven air quality indicators.

Table 1. Evaluation Framework for Ecological Environment Governance in Zhejiang.

Level 1 Indicators	Level 2 Indicators
Ecological Environment Governance Quality	Annual Average Concentration of Sulfur Dioxide (SO_2) in Micrograms per Cubic Meter
	Annual Average Concentration of Nitrogen Dioxide (NO_2) in Micrograms per Cubic Meter
	Annual Average Concentration of Inhalable Particulate Matter (PM10) in Micrograms per Cubic Meter
	95th Percentile Daily Concentration of Carbon Monoxide (CO) in Milligrams per Cubic Meter
	Maximum 8-Hour 90th Percentile Concentration of Ozone (O_3) in Micrograms per Cubic Meter
	Annual Average Concentration of Fine Particulate Matter (PM2.5) in Micrograms per Cubic Meter
	Percentage of Days with Air Quality Meeting or Exceeding Grade II

2.2. Rank-Sum Ratio Method

Rank-sum ratio (RSR) is a statistical analysis method that combines the advantages of classical parametric statistics and modern nonparametric statistics [4].Positive indicators will be ranked in descending order, while negative indicators will be ranked in ascending order. In case of tied values, average ranks will be assigned. This process results in obtaining rank values denoted as R, which will replace the original evaluation indicator values.

The RSR value is calculated using the following formula:

$$RSR_i = W'_i \sum_{j=1}^{m} w_j R_{ij}, i = 1,2,\cdots,n, j = 1,2,\cdots,m$$

Wherein, n: Number of cities being evaluated; m: Rank of evaluation indicators for the cities; w_j: Weight of the j-th indicator; R_{ij}: Corresponding values in the n-by-m ranked matrix; W'_i: City weight. In this study, it is assumed that the weights for the eleven cities are equal and are represented as 1/n. Consequently, the simplified formula for calculating the RSR value is as follows:

$$RSR_i = \frac{1}{n} \sum_{j=1}^{m} w_j R_{ij}, i = 1,2,\cdots,n, j = 1,2,\cdots,m$$

Create the RSR frequency distribution table in ascending order, listing the frequency (fi) of each group, calculate the cumulative frequency for each group $\sum f_i$, calculate the cumulative frequency$p_i = \sum f_i / n$, and adjust the last term by (1−1/4n)×100%. Then, convert pi to probability units using the percent and probability unit conversion table Probit.

Calculate the regression equation. Use Probit values (probability units corresponding to cumulative frequencies) as independent variables and RSR values as the dependent variable. Calculate the linear regression equation to fit the corresponding RSR estimates.

Sort the fitted RSR values and categorize them into different levels.

3. Comparative Analysis of Longitudinal Variations in Ecological Environment Governance Quality Among Cities

3.1. Entropy Weight Calculation Method

Table 2. Entropy Weighting Method.

Item	Information Entropye	Information Utility Value	Weight (%)
Percentage of Days with Air Quality Meeting or Exceeding Grade II (%)	0.932	0.068	9.74
Annual Average Concentration of Sulfur Dioxide (SO_2) (Micrograms per Cubic Meter)	0.949	0.051	7.275
Annual Average Concentration of Nitrogen Dioxide (NO_2) (Micrograms per Cubic Meter)	0.837	0.163	23.46
Annual Average Concentration of Inhalable Particulate Matter (PM10) in Micrograms per Cubic Meter	0.858	0.142	20.347
95th Percentile Daily Concentration of Carbon Monoxide (CO) in Milligrams per Cubic Meter	0.957	0.043	6.102
Maximum 8-Hour 90th Percentile Concentration of Ozone (O_3) in Micrograms per Cubic Meter	0.918	0.082	11.811

The Entropy Weight Method [5] was employed to ascertain the weights for each indicator in Table 2. The weights assigned to the following air quality indicators are as follows: the percentage of days with air quality meeting or exceeding Grade II (%) is 9.74%, the annual average concentration of sulfur dioxide (SO_2) (micrograms per cubic meter) is 7.275%, the annual average concentration of nitrogen dioxide (NO_2) (micrograms per cubic meter) is 23.46%, the annual average concentration of inhalable particulate matter (PM10) (micrograms per cubic meter) is 20.347%, the 95th percentile daily concentration of carbon monoxide (CO) (milligrams per cubic meter) is 6.102%, the 8-hour maximum 90th percentile concentration of ozone (O_3) (micrograms per cubic meter) is 11.811%, and the annual average concentration of fine particulate matter (PM2.5) (micrograms per cubic meter) is 21.266%. Among these indicators, the highest weight is assigned to the annual average concentration of nitrogen dioxide (NO_2) (23.46%), while the lowest weight is assigned to the 95th percentile daily concentration of carbon monoxide (CO) (6.102%).

Within the comprehensive assessment, the weights assigned to different indicators play a crucial role. For example, the weights for the 8-hour maximum 90th percentile concentration of ozone (O_3) and the annual average concentration of inhalable particulate matter (PM10) are relatively high, at 11.811% and 20.347%, respectively, indicating the significant influence of these two indicators in the evaluation process. Correspondingly, weights for other indicators are also reasonably allocated, ensuring the objectivity and comprehensiveness of the comprehensive assessment.

3.2. Rank Calculation

According to each specific evaluation criterion, rankings (R) are determined based on the magnitude of the criterion values. These rankings (R) are used to replace the original values of the evaluation criteria. A ranking matrix for each criterion is established based on the ranking results, as shown in Table 2. In Table 3, X1 represents the proportion (%) of days with air quality reaching or exceeding Level 2 standards, R1 represents the ranking for this criterion, X2 represents the annual average concentration of sulfur dioxide (SO2) in micrograms per cubic meter (μg/m³), R2 represents the ranking for this criterion, X3 represents the annual average concentration of nitrogen dioxide (NO2) in micrograms per cubic meter (μg/m³), R3 represents the ranking for this criterion, X4 represents the annual average concentration of inhalable particulate matter (PM10) in micrograms per cubic meter (μg/m³), R4 represents the ranking for this criterion, X5 represents the 95th percentile concentration of daily average carbon monoxide (CO) in milligrams per cubic meter (mg/m³), R5 represents the ranking for this criterion, X6 represents the 90th percentile concentration of maximum 8-hour ozone (O3) in micrograms per cubic meter (μg/m³), R6 represents the ranking for this criterion, and X7 represents the annual average concentration of fine particulate matter (PM2.5) in micrograms per cubic meter (μg/m³), R7 represents the ranking for this criterion.

Non-Integral Ranking Method: This method employs a technique similar to linear interpolation to assign rankings to criterion values. It is used to improve the shortcomings of the RSR method's ranking process, ensuring a quantitative linear relationship between the assigned rankings and the original criterion values. This method overcomes the limitation of losing quantitative information from the original criterion values during the ranking process.

For this study, the non-integral ranking method was adopted.

Table 3. Entropy Weighting Method.

City	X1	R1	X2	R2	X3	R3	X4	R4	X5	R5	X6	R6	X7	R7
Hangzhou	0.2288	3.2876	0.7500	8.4999	0.1177	2.1765	0.0000	1.0000	0.8181	9.1812	0.1569	2.5686	0.0000	1.0001
Ningbo	0.7516	8.5163	0.0000	1.0002	0.1177	2.1765	0.6250	7.2500	0.8181	9.1812	0.6471	7.4706	0.5385	6.3846
Wenzhou	0.9477	10.4771	1.0000	10.9998	0.1765	2.7647	0.1667	2.6667	0.0001	1.0009	0.8627	9.6274	0.2308	3.3077
Jiaxing	0.3726	4.7255	0.5000	6.0000	0.1177	2.1765	0.2500	3.5000	0.7272	8.2723	0.2745	3.7451	0.1539	2.5385
Huzhou	0.0000	1.0001	0.7500	8.4999	0.0000	1.0001	0.0833	1.8334	0.8181	9.1812	0.0000	1.0000	0.2308	3.3077
Shaoxing	0.5882	6.8823	0.5000	6.0000	0.3529	4.5294	0.2083	3.0834	0.8181	9.1812	0.4118	5.1177	0.0769	1.7693
Jinhua	0.6993	7.9934	0.7500	8.4999	0.2353	3.3530	0.2083	3.0834	0.7272	8.2723	0.4902	5.9020	0.0769	1.7693
Quzhou	0.7320	8.3202	0.7500	8.4999	0.4706	5.7059	0.1667	2.6667	0.7272	8.2723	0.5490	6.4902	0.3076	4.0770
Zhoushan	0.8954	9.9542	1.0000	10.9998	1.0000	10.9999	0.1000	11.0000	0.9090	10.0902	0.7843	8.8431	0.1000	10.9999
Taizhou	0.9673	10.6731	1.0000	10.9998	0.7647	8.6470	0.4583	5.5833	0.9999	10.9991	0.8039	9.0392	0.3846	4.8462
Lishui	1.0000	10.9999	0.7500	8.4999	1.0000	10.9999	0.6250	7.2500	0.9999	10.9991	1.0000	11.0000	0.5385	6.3846

3.3. Distribution of RSR Values

The distribution of RSR refers to the specific cumulative frequency of values expressed with probability unit Probit, as shown in Table 4.

Table 4. RSR Distribution Table.

RSR	Frequency	Cumulative Frequency Number of Σf	Evaluation of Rank Number	Evaluation Rank Number / n * 100%	Probit
0.24592132733474506	1	1	1	9.090909090909092	3.664822263881063
0.248082424535606	1	2	2	18.181818181818183	4.091542131462615
0.32785676601470826	1	3	3	27.27272727272727	4.395414653416763
0.3943365984665313	1	4	4	36.36363636363637	4.6512443044829554
0.3989956971554752	1	5	5	45.45454545454545	4.8858147056785715
0.44667316491115305	1	6	6	54.54545454545454	5.1141852943214285
0.49529153023162126	1	7	7	63.63636363636363	5.3487556955170446
0.5171189783262166	1	8	8	72.72727272727273	5.604585346583237
0.7067004850476519	1	9	9	81.81818181818183	5.908457868537385
0.8248663791997944	1	10	10	90.9090909090909	6.335177736118936
0.9625297067573818	1	11	11	97.72727272727273	7.00042356910598

3.4. Linear Regression Analysis

The analysis results of this model are presented in Table 5, including the standardization coefficient, t value, VIF value, R^2, adjusted R^2, etc., are used to test the model and analyze the formula of the model.

From the analysis of the results of F test, we can see that the significance P value is 0.000 * * *, the level is significant, and the null hypothesis of regression coefficient of 0 is rejected. At the same time, the goodness of fit of the model R^2 is 0.951, and the model performance is excellent, so the model basically meets the requirements. For variable collinearity performance, the VIF is all less than 10, so the model does not have multicollinearity problems and the model is well constructed. For variable collinearity performance, the VIF is all less than 10, so the model does not have multicollinearity problems and the model is well constructed.

The formula of the model is as follows:

$$y = -0.681 + 0.229 * Probit$$

Table 5. Results of the linear regression analysis.

Linear regression analysis resulted in n=11									
	Non-standardized coefficients		Standardization coefficient	t	P	VIF	R^2	adjust R^2	F
	B	standard error	Beta						
constant	-0.681	0.092	-	-7.44	0.000***	-	0.951	0.945	F=173.879 P=0.000***
Probit	0.229	0.017	0.975	13.186	0.000***	1			
dependent variable: RSR									

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10%, respectively

3.5. *Table of Critical Values for Tiered Sorting*

The objective of this step is to generate Tiered Sorting Threshold Table 6, with a particular focus on the RSR threshold values (fitted values) corresponding to the Probit threshold values.

First: the percentile critical value and Probit critical value change according to the number of classification levels, the two items are fixed values and completely one to one.

Second: the RSR criticality (fitted value) in the table above, is calculated by substituting the regression model based on the Probit critical value.

Table 6. Ssorting critical value table.

Stile sorting critical value table			
level	The percentile cut-off value	Probit	RSR cut-off value (fitted value)
The first gear	<15.866	<4	<0.2355
The second gear	15.866 ~	4 ~	0.2355 ~
The third gear	84.134 ~	6 ~	0.6936 ~

3.6. *Summary of Tiered Rating Results in Academic Paper*

The classification level is obtained by interval comparing the RSR fit values, and the RSR criticality (fitted values) in the previous table, Table 7.

The larger the number of grade Level, the higher the level, that is, the better the effect.

Table 7. Classification and Grade.

Index of Matrix	RSR ranking	Probit	RSR Fitting Values	Classification level
Zhoushan	1	7.00042356910598	0.9228334308886679	3
Lishui	2	6.335177736118936	0.7704314539982711	3
Hangzhou	10	4.091542131462615	0.2564342448222702	2
Ningbo	4	5.604585346583237	0.6030591549996118	2
Wenzhou	6	5.1141852943214285	0.4907128106470737	2
Jiaxing	9	4.395414653416763	0.3260487704188322	2
Shaoxing	8	4.6512443044829554	0.38465709629830824	2
Jinhua	7	4.8858147056785715	0.4383951147713705	2
Quzhou	5	5.3487556955170446	0.5444508291201358	2
Taizhou	3	5.908457868537385	0.6726736805961739	2
Huzhou	11	3.664822263881063	0.15867647142017283	1

The ranking summary is presented in Table 8.

Through a comprehensive analysis of the RSR fit values of 11 cities in Zhejiang Province, we can objectively measure the relative performance of different cities in ecological environment governance. The results show that Zhoushan city and Lishui City showed excellence in RSR fitting value, ranking the third grade respectively, which indicates that these two cities have made significant progress in the improvement of ecological environment quality. This achievement is closely consistent with the policy goal of actively promoting the construction of ecological civilization.

From the perspective of urban grade, different cities are divided into different grades on the basis of RSR fitting values. This stratification can help us to have a clearer understanding of the ecological environment quality of each city and provide an important reference for policy makers. For example, although Huzhou city is low in the fitting value, this does not mean that its efforts are insufficient. Instead, this can be seen as an opportunity for the city to further increase its environmental governance efforts to reach a higher urban level.

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The city ranking provides us with the relative location of the cities throughout Zhejiang province. The top cities, such as Zhoushan and Lishui, show their outstanding position in ecological and environmental governance. Such ranking can not only promote competition among cities, but also provide experience for other cities and accelerate the improvement of overall ecological and environmental quality.

Table 8. Summary Table of the Ranking.

City	RSR Fitting Values	City Grade	City Ranking
Zhoushan	0.922833	The third gear	1
Lishui	0.770431	The third gear	2
Taizhou	0.672674	The second gear	3
Ningbo	0.603059	The second gear	4
Quzhou	0.544451	The second gear	5
Wenzhou	0.490713	The second gear	6
Shaoxing	0.384657	The second gear	7
Jinhua	0.438395	The second gear	8
Jiaxing	0.326049	The second gear	9
Hangzhou	0.256434	The second gear	10
Huzhou	0.158676	The first gear	11

In general, the RSR fitting value, city grade and city ranking are closely related to each other, which together constitute a comprehensive ecological and environmental governance evaluation system. Through this system, we can accurately capture the differences of different cities in air quality governance, find their advantages and disadvantages, and provide a scientific basis for the future environmental governance strategies of Zhejiang Province. However, it should be noted that this evaluation system still needs to be improved. In the future, more dimensional data and indicators can be combined to further improve the accuracy and practicability of the evaluation.

4. Comparative Analysis of Lateral Variations in Urban Ecological Environment Governance Quality

As shown in Figure 1, Hangzhou City: Over the three years from 2019 to 2021, Hangzhou City exhibited a certain level of stability and improvement in air quality. The concentration of nitrogen dioxide (NO_2) decreased year by year, and the maximum 8-hour 90th percentile concentration of ozone (O_3) also decreased, indicating the effectiveness of measures taken to address these pollutants. The annual average concentration of fine particulate matter (PM2.5) remained relatively low, reflecting positive achievements in controlling fine particulate matter. Furthermore, the proportion of days with air quality reaching or exceeding the second-level standard remained high, indicating the consistent good air quality in Hangzhou City.

Ningbo City: Over the past three years, Ningbo City has maintained stable and excellent air quality. The concentrations of various pollutants have remained low, especially the annual average concentration of inhalable particulate matter (PM10). The proportion of days with air quality reaching or exceeding the second-level standard is close to perfection, demonstrating significant success in air quality management in the city.

Wenzhou City: In the last three years, Wenzhou City has maintained overall stable air quality. The daily 95th percentile concentration of carbon monoxide (CO) has decreased, indicating improvements in traffic and industrial emissions control. The proportion of days with air quality reaching or exceeding the second-level standard is relatively high, indicating positive progress in maintaining fresh air quality.

Jiaxing City: The governance effectiveness in Jiaxing City has been more pronounced over the past three years. Carbon monoxide (CO) and ozone (O_3) concentrations are relatively low, and the air quality compliance rate is high, indicating significant achievements in governance. The annual average concentration of fine particulate matter (PM2.5) remains at a low level, indicating good progress in controlling fine particulate matter pollution.

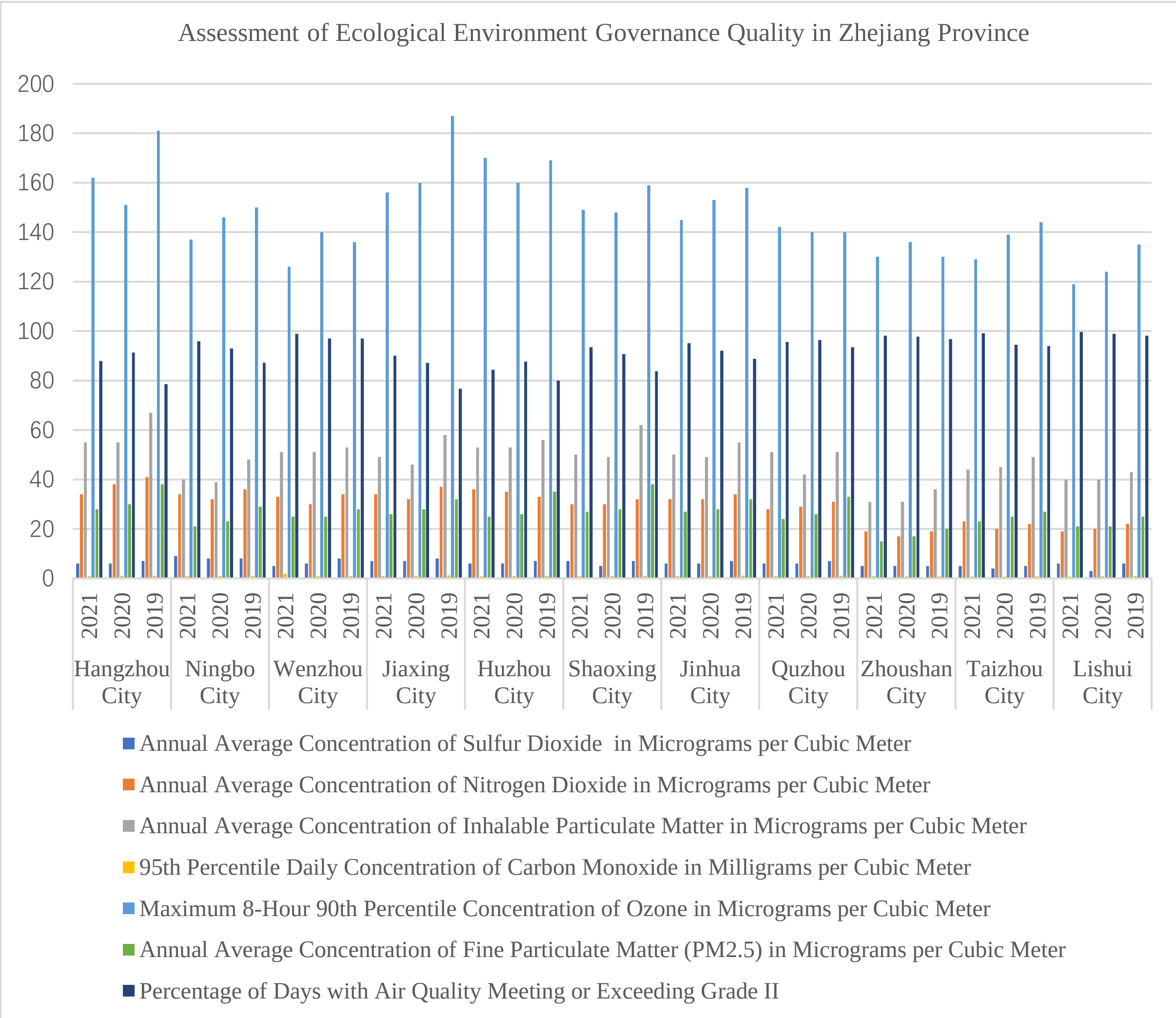

Figure 1. Assessment of Ecological Environment Governance Quality in Zhejiang Province

Huzhou City: Over the past three years, Huzhou City has shown relatively high concentrations of ozone (O_3), which requires further attention. Nevertheless, the annual average concentration of fine particulate matter (PM2.5) remains relatively low, and the air quality compliance rate is high, indicating the city's efforts in pollution control.

Shaoxing City: Shaoxing City has achieved good ecological environment governance results over the past three years. The concentrations of various pollutants are low, and the proportion of days with air quality reaching or exceeding the second-level standard is high, especially concerning the annual average concentration of fine particulate matter (PM2.5).

Jinhua City: In the last three years, Jinhua City has achieved significant governance results. The concentrations of various pollutants are low, especially for carbon monoxide (CO) and ozone (O_3) concentrations, indicating a significant improvement in urban air quality.

Quzhou City: Over the past three years, Quzhou City has maintained a low annual average concentration of fine particulate matter (PM2.5), and the proportion of days with air quality reaching or exceeding the second-level standard is high. This suggests positive achievements in controlling fine particulate matter and other pollutants.

Zhoushan City: The governance effectiveness in Zhoushan City has been relatively good over the past three years. The annual average concentration of inhalable particulate matter (PM10) is low, and the air quality compliance rate is close to perfect, highlighting the city's advantages in air quality maintenance.

Taizhou City: Taizhou City has achieved remarkable governance results. The annual average concentration of fine particulate matter (PM2.5) is low, and the air quality compliance rate is high, indicating significant progress in controlling fine particulate matter and other pollutants.

Lishui City: Over the past three years, Lishui City has maintained a low annual average concentration of fine particulate matter (PM2.5), and the air quality compliance rate is high. This indicates the city's proactive efforts in fine particulate matter and other pollutant control.

In summary, most cities have achieved significant results in ecological environment governance, effectively controlling various pollutant concentrations and improving air quality. However, continuous efforts are still required, especially in monitoring and controlling some fluctuating indicators, to ensure the continued improvement of urban ecological environment quality.

5. Conclusion

Zhejiang Province, as one of the more economically advanced regions in China, has been experiencing rapid economic development alongside serious ecological and environmental challenges. Through the analysis of ecological and environmental data from 11 cities, various trends and governance outcomes can be observed.

Firstly, from the perspective of Ritchie Fit Values (RSR Fit Values), Zhoushan and Lishui rank highest, both reaching the third category. This indicates significant success in environmental governance in these two cities, with their measures showing notable results in improving air quality. This aligns with Zhejiang Province's policy focus on proactive ecological and environmental protection and air quality improvement. These successful experiences can provide valuable insights for other cities.

Secondly, Huzhou ranks relatively low in both Ritchie Fit Values and Probit values, falling into the first category. This might suggest that there is room for improvement in controlling certain pollutants in this city. The Zhejiang provincial government has explicitly set the goal of "resolutely winning the battle against pollution prevention and control to fundamentally improve environmental quality" in its ecological civilization construction, so Huzhou City is expected to further enhance its ecological environment quality by formulating more refined governance strategies.

Additionally, cities like Hangzhou, Ningbo, and Wenzhou are showing positive trends in air quality, indicating some degree of improvement. This is closely related to the Zhejiang provincial government's policies aimed at intensifying environmental protection efforts and promoting green development. However, among cities where air quality still needs further improvement, Jiaxing, Shaoxing, and Jinhua are also intensifying their governance efforts, making positive contributions to the overall improvement of ecological environment quality in Zhejiang Province.

In conclusion, the Zhejiang provincial government has been actively responding to the promotion of ecological civilization construction, and various cities have achieved certain results in ecological and environmental governance. However, it is important to note that different cities have distinct characteristics and issues, so governance strategies should be tailored to local conditions. In the future, Zhejiang Province can enhance cooperation among different cities while intensifying environmental protection efforts, facilitating experience sharing and collaboration, and collectively moving towards a fresher and more livable ecological environment.

In summary, through data analysis and policy integration, this study has delved into the ecological and environmental governance status of various cities in Zhejiang Province. The research findings indicate that some cities have achieved significant results in governance but still have areas for improvement. Based on these conclusions, this study provides valuable references for the future ecological and environmental governance in Zhejiang Province, aiming to achieve coordinated economic and environmental development. However, it is important to note that this study is still limited by the scope of data, and future research can incorporate data from more dimensions to further refine

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the analytical model for a more accurate assessment of the ecological and environmental governance quality of each city.

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