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ENVIRONMENTAL PERFORMANCE OF URBAN INTEGRATION REGIONS OF CHENGDU, DEYANG, MEISHAN AND ZIYANG, BASED ON DPSIR MODEL

Evaluación del desempeño ambiental en la región de integración urbana de Chengdu, Deyang, Meishan y Ziyang con base en el modelo DPSIR

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Key words: Chengdemeizi Urban Integration, environmental performance, economic development, correlation

ABSTRACT

The paper focuses on the quantitative assessment of the environmental performance of the Urban Integration region of Chengdu, Deyang, Meishan, and Ziyang (Chengdemeizi Urban Integration) in 2015-2019, including the overall level, changing trends of the environmental performance, and the key factors that influence the environmental performance. The theme framework and driver-force-pressure-state-impact-response (DPSIR) model is used to build the evaluation indicator system, the target approximation method and the combination weighting method are adopted to calculate the environmental performance index (EPI). In addition, the Pearson correlation analysis with GDP is performed to analyze the relationship between environmental performance and the economic development level of the Urban Integration region. The results indicated that regional average scores of comprehensive environmental performances show an obvious improvement trend and had significantly positive correlation with economic level from 2015 to 2019. For the EPIs of 2nd indicators, environmental quality is the main restrictive indicator. For the EPIs of 3rd indicators, air quality, noise, and environmental management are the main restrictive indicators. Each city has different performance, and the order of EPI scores of the four cities from largest to smallest is Chengdu > Deyang > Ziyang > Meishan. Therefore, the four cities need to continuously improve their respective shortcoming environmental performance indicators and promote the balanced improvement of indicators at all levels.

Palabras clave: integración urbana Chengdemeizi, desempeño ambiental, desarrollo económico, correlación

RESUMEN

El documento se centra en la evaluación cuantitativa del desempeño ambiental de la región de Integración Urbana de Chengdu, Deyang, Meishan y Ziyang (Integración Urbana de Chengdemeizi) en 2015-2019, incluyendo el nivel general, las tendencias cambiantes del desempeño ambiental, y los factores clave que influyen en el comportamiento ambiental. El marco temático y el modelo DPSIR (Driver-force-pressure-state-impact-response) se utilizan para construir el sistema de indicadores de evaluación, el método de aproximación objetivo y el método de ponderación combinada para calcular el índice de desempeño ambiental (EPI). Además, se realiza el análisis de correlación de Pearson con el PIB para analizar la relación entre el desempeño ambiental y el nivel de desarrollo económico de la región de Integración Urbana. Los resultados indicaron que las puntuaciones medias regionales de desempeño ambiental integral muestran una tendencia de mejora obvia y tuvieron una correlación positiva significativa con el nivel económico de 2015 a 2019. Para los EPI de los segundos indicadores, la calidad ambiental es el principal indicador restrictivo. Para los EPI de los terceros indicadores, la calidad del aire, el ruido y la gestión ambiental son los principales indicadores restrictivos. Cada ciudad tiene un rendimiento diferente, y el orden de las puntuaciones EPI de las cuatro ciudades de mayor a menor es Chengdu > Deyang > Ziyang > Meishan. Por lo tanto, las cuatro ciudades necesitan mejorar continuamente sus respectivos indicadores de desempeño ambiental deficientes y promover la mejora equilibrada de los indicadores a todos los niveles.

INTRODUCTION

Environmental performance evaluation is a quantifiable environmental management tool that can evaluate environmental protection effects and provide guidance to improve government efficiency (Dias-Sardinha et al. 2001, Kolk et al. 2010, Chen et al. 2014, Zebardast et al. 2015, Avilés-Sacoto et al. 2021). Carrying out regional environmental performance research is an important way to analyze the laws of environmental development, identify key constraint factors and promote sustainable development (Somchint et al. 2017, Wu et al. 2017). In recent years, research on the applying of regional environmental performance evaluation in international level has developed mature index system construction methods and evaluation methods, and the results have been published in the form of reports or web pages (Avilés-Sacoto et al. 2021). Among them, the Environmental Performance Index jointly compiled by Yale University and Columbia University has attract much attention. This index has a global coverage of assessments and is evaluated every two years since 2006. The results of the Global Environmental Performance Index (EPI) ranking in 2020 show that China ranks 120th with a score of 37.34 among the 180 countries and regions participating in the evaluation (Wendling et al. 2020), which reflects that the ecological environment performance of China is still not optimistic to a certain extent.

Domestic research on regional environmental performance evaluation started relatively late and more focused on the provincial level. Cao et al. (2008) based on China's national conditions and environmental characteristics, initially constructed a national and provincial environmental performance evaluation index system and evaluation methods. Dong et al. (Dong et al. 2016, Zuo et al. 2017) carried out research on the construction of indicator systems, evaluation methods and evaluation systems, adopted the theme framework method and the target approximation method to construct the indicator system, carried out multi-dimensional data mining of indicators and evaluate China's environmental performance and main characteristics at the provincial level. Zhang et al. (2021) evaluated the environmental governance performance of Anhui Province using the "pressure-state-response" model with the panel and spatial data based on the global principal component analysis method and spatial autocorrelation analysis. Environmental performance evaluation on larger geographic scale requires the selection of more macroscopic and abstract indicators, ignoring the differences between regions and unable to assess the environmental needs of each region. Therefore, focusing on smaller-scale environmental performance evaluation and establishing differences and personalized environmental performance evaluation system is of great significance (Sun et al. 2012, Wu et al. 2018).

The four cities of Chengdu, Deyang, Meishan, and Ziyang (Chengdemeizi) are located in the circle of Chengdu Plain Economic Zone, which are the important intersection of the "Belt and Road" and "Yangtze River Economic Belt", and are also important ecological barriers and water conservation areas in the upper reaches of the Yangtze River. The Urban Integration development of Chengdemeizi is a pioneer and an important starting point in implementing the national strategy of building a Chengdu-Chongqing economic circle. Therefore, this paper constructs an environmental performance evaluation index system for "Chengdemeizi Urban Integration" region, evaluates the regional environmental performance level and development trend, and also analyze the relationship between environmental performance and the economy. In addition, some policy recommendations to improve the environmental performance of each city have also been proposed, which will help improve the overall environmental performance of the "Chengdemeizi Urban Integration" area and provide basic support for environmental management in the next few years.

METHODOLOGY

Selection of indicators and data sources

Based on the existing research results (Wei et al. 2020) and indicators such as "Green Development Index System" and "Ecological Civilization Construction Assessment Target System" as well as major issues related to the ecological environment characteristics of the four cites, the thematic framework model analysis is used to identify major problems and sub-problems, and the "driver-pressure-state-impacts-response" (DPSIR) model is used to identify 4th class indicators. In accordance with the six selection principles, which are policy relevance, simplicity, representativeness, comparability, scientificity, data availability, and timeliness, the environmental performance evaluation index system has been finally determined including four 2nd class indicators, ten 3rd class indicators, and twenty-six 4th class indicators.

To maintain credibility and impartiality in our assessment, all data are derived from official authoritative data, including the "Statistical Yearbook", "Environmental Quality Report", "Environmental Statistics Annual Report" of each city, etc.

Data standardization processing and target value source

A proximity-to-target approach method is used to standardize the collected data (Wang et al. 2017, Wen et al. 2020), and we converted the original statistical (or processed) data of indicators into a comparable index score between 0 and 100. Indicators are divided into positive and negative parts, and here is the calculation method:

Standardization of positive indicators: the larger is the observed value, the better is the performance.

$$t_{ij} = \begin{cases} 100 & , a_{ij} \geq a_{\text{target value}} \\ \dfrac{a_{ij} - a_{min}}{a_{\text{target value}} - a_{min}} \times 100 & a_{ij} < a_{\text{target value}} \end{cases}$$

Standardization of negative indicators: the smaller is the observed value, the better is the performance.

$$t_{ij} = \begin{cases} 100 & , a_{ij} \geq a_{\text{target value}} \\ \dfrac{a_{ij} - a_{max}}{a_{\text{target value}} - a_{max}} \times 100, & a_{ij} < a_{\text{target value}} \end{cases}$$

In this formula, a_{ij}, a_{max} and a_{min} represent indicator value, maximum, and minimum values, respectively.

Different indicator target values are identified under different standards. The priority order is defined as follows: international standard, planning target value, ideal state value, regional optimal value, and experiential target values. In this study, the basis for setting the indicator is mainly from the World Health Organization (WHO), "Sichuan Environmental Protection" The 13th Five-Year Plan, etc. Also, they are determined by the ideal state target value, the city's optimal target value, and empirical target value.

Weighting method and calculation of the EPI scores

Index weighting methods include subjective weighting method, objective weighting method, and combination weighting method (Liu et al. 2014, Zheng et al. 2014). The subjective weighting method is based on the personal experience or knowledge of the evaluator to empower indicators, which is highly subjective. While the objective weighting method is to obtain the index weight through mathematical calculation, which can better reflect the original information of the index. The combined weighting method integrates the weights obtained by different weighting methods, which can effectively avoid the defects of different weighting methods.

In order to better reflect the actual situation of the current environment and avoid the influence of subjective arbitrariness, a combination of expert judgment method and standard deviation method have been used to assign weights in this study. Calculated as follows:

$$Wi = (Wi1 * Wi2)^{1/2}$$

In this formula, w_{i1} and w_{i2} represent index weight determined by the standard deviation method and the expert evaluation method, respectively.

This study adopted EPI scores to quantify environmental performance, the higher the index, the better the overall environmental performance. The calculation formula is as follows:

$$EPI = \sum_{i=1}^{n} (w_i\, x_i/100)$$

where i represents the index number; n represents the total number of indexes; w_i represents the weight of the i-th index; x_i is the standardized value of the i-th index. Starting from the 4th-level indicators, the weighted summation is gradually obtained to obtain the scores of each indicator and the final EPI score. The performance of the 2nd, 3rd, and 4th class indicators is expressed by the proportion of the indicators that complete the target level (**Table I**).

Correlation analysis method

We conducted a normal distribution test and conversion on the environmental performance scores and GDP of a total 20 samples in various regions in Chengdu from 2015 to 2019 by using SPSS method. Then the Pearson correlation was used to perform bivariate correlations. This analysis method is used to measure whether two data sets are in a line, and the linear relationship between fixed-distance vari-

TABLE I. ENVIRONMENTAL PERFORMANCE EVALUATION INDEX SYSTEM AND WEIGHT OF FOUR CITIES.

2nd Class indicators	3rd Class indicators	4th Class indicators	Weights	Target value (basis)
Environmental quality	Air quality	Ratio of days with good air quality (S)	5.29	83.5 (The 13th Five-Year Plan of Environmental Protection in Sichuan)
		Annual concentration of $PM_{2.5}$ (S)	3.92	10 (WHO)
		Annual concentration of NO_2 (S)	4.42	40 (WHO)
		Daily maximum 8-hour average ozone concentration (S)	3.37	100 (WHO)
	Water quality	Proportion of excellent water quality (attained or better than Class III) in sections above the city control (S)	4.48	100 (Ideal value)
		Water quality compliance rate of urban and rural centralized drinking water source protection areas (S)	5.17	100 (Ideal value)
	Noise	Road traffic noise (S)	4.22	64.2 (Best in the city)
		Regional environmental noise (S)	3.76	51.5 (Best in the city)
Ecological protection	Urban greening	Public green area per capita (I)	4.53	14 (Implementation Plan for Accelerating Ecological Civilization Construction in Sichuan)
		Green coverage rate in built-up area (I)	4.01	38 (Implementation Plan for Accelerating Ecological Civilization Construction in Sichuan)
	Ecosystem	Eco-environmental status index (I)	5.12	55 (Average value)
Resources and energy utilization	Energy utilization	Total energy consumption per unit of GDP (D)	4.85	0.34 (Average value)
		Coal consumption per unit of industrial value added (D)	4.65	0.11 (Average value)
	Resources utilization	Comprehensive utilization rate of industrial solid wastes (D)	3.49	100 (Ideal value)
		Water consumption per unit of GDP (D)	4.17	40.02 (Average value)

TABLE I. ENVIRONMENTAL PERFORMANCE EVALUATION INDEX SYSTEM AND WEIGHT OF FOUR CITIES. (continued)

2nd Class indicators	3rd Class indicators	4th Class indicators	Weights	Target value (basis)
Environmental governance	Pollution control	Emission intensity of chemical oxygen demand (P)	3.12	1.13 (Average value)
		Emission intensity of NH_3-N (P)	3.35	0.13 (Average value)
		Emission intensity of NOx (P)	2.74	0.27 (Average value)
		Emission intensity of industrial SO_2 (P)	2.69	0.23 (Average value)
		Emission intensity of industrial dust (P)	2.69	0.36 (Average value)
	Pollution treatment	Treatment rate of domestic sewage (R)	3.77	100 (Ideal value)
		Hazardous waste safe disposal rate (R)	3.04	100 (Ideal value)
		Harmless treatment rate of domestic garbage (R)	3.22	100 (Ideal value)
	Environmental management	Proportion of investment in environmental governance to GDP (R)	3.12	0.46 (Average value)
		The proportion of handling environmental petition (R)	3.59	100 (Ideal value)
		Environmental accident rate (R)	3.22	0 (Ideal value)

ables. A negative correlation coefficient shows that the two indicators are negatively correlated (high economic but low environmental performance). A positive correlation coefficient shows that the two indicators are positively correlated (high economic and high environmental performance). The closer the correlation coefficient is close to 0, the weaker the correlation is (the economic level is high but the level of environmental performance is not necessarily high).

RESULTS AND DISCUSION

Correlation analysis of comprehensive environmental performance and economy

The average scores of comprehensive environmental performance of Urban Integration region from 2015 to 2019 is shown in **figure 1 (a)**. It can be seen that an obviously rising trend exists from 2015 to 2019, and the average score in 2019 reached 73.29 points, which increases by 32.89 points comparing with 2015, indicating that the regional environmental performance of Urban Integration region is in continuous improvement. Judging from the spatial distribution map of five-year average environmental performance of four cities (as shown in **Fig. 1 (b)** and **Table II**), Chengdu performs the best with a score of 73.05 and Meishan perform the worst, with score of 56.84. The order of five-year average score of environmental performance from largest to smallest is: Chengdu > Deyang > Ziyang > Meishan. The comprehensive environmental performance level of each city is quite different, indicating that the social development and environmental conditions of various regions exist some differences, and the environmental performance needs to be further improved.

The comprehensive environmental performance and Gross Domestic Product (GDP) of the four cities are compared and analyzed. **Figure 2** compared the average annual growth rate of the EPI and GDP of four cities, a negative growth trend of EPI and GDP in other cities except for Ziyang's GDP, which perform the worst in the average annual growth rate of EPI,

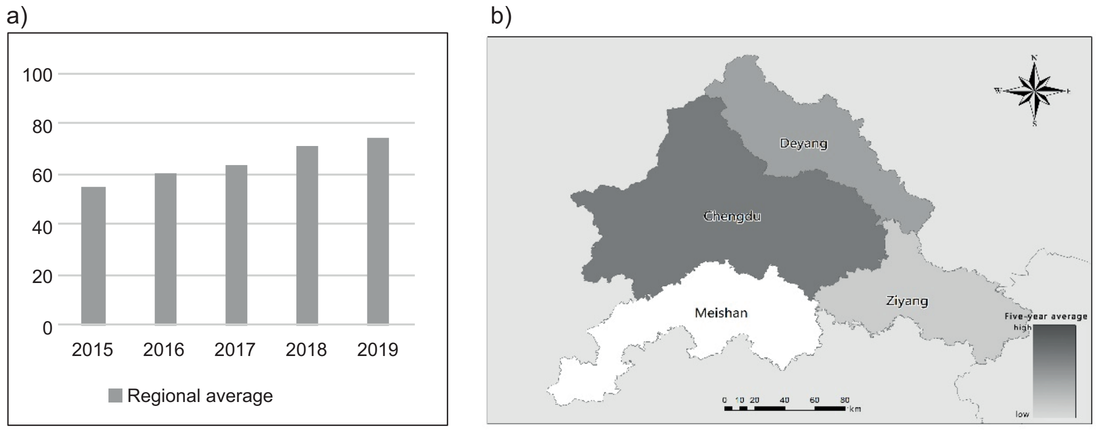

Fig. 1. Changes in Chengdu 's EPI from 2015 to 2019, (a) and spatial distribution map of five-year average environmental performance of four cities (b).

TABLE II. THE SPECIFIC SCORES OF THE COMPREHENSIVE ENVIRONMENTAL PERFORMANCE OF FOUR CITIES FROM 2015 TO 2019.

	2015	2016	2017	2018	2019
Chengdu	66.60	69.38	71.96	74.82	82.49
Deyang	53.25	64.87	67.77	76.99	81.98
Meishan	41.17	50.83	58.30	66.77	67.11
Ziyang	58.55	56.97	56.92	66.05	65.14
Regional average	54.89	60.51	63.74	71.16	74.18

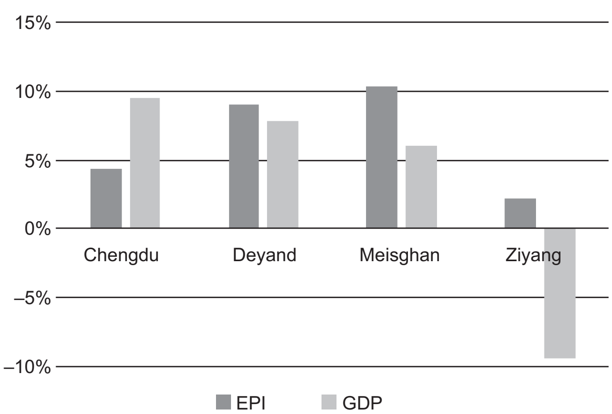

Fig. 2. Comparison of four city's annual average growth rate of EPI and GDP.

indicating that poor economic development will limit the improvement of environmental comprehensive performance to some extent.

In order to further explore the correlation between comprehensive environmental performance and the economic development level, the Pearson correlation analysis of comprehensive environmental performance and GDP was conducted and the results are shown in **table III**. It can be seen that there is a significant positive correlation between comprehensive environmental performance and GDP, which

TABLE III. PEARSON CORRELATION ANALYSIS OF ENVIRONMENTAL PERFORMANCE AND GDP

Index		N(GDP)
N (Comprehensive environmental performance)	Pearson correlation	0.728**
	Sig. (Two-tailed)	0.000
	Cases	20
Environmental quality	Pearson correlation	–0.157
	Sig. (Two-tailed)	0.510
	Cases	20
Ecological protection	Pearson correlation	0.739**
	Sig. (Two-tailed)	0.000
	Cases	20
Energy and resource utilization	Pearson correlation	0.536*
	Sig. (Two-tailed)	0.015
	Cases	20
Environmental governance	Pearson correlation	0.558*
	Sig. (Two-tailed)	0.011
	Cases	20

* At the level of 0.05 (Two-tailed, significant correlation.
** At the level of 0.01 (Two-tailed, significant correlation.
N (GDP) exhibited that the GDP indicator has undergone normalization conversion, and the following are similar.

reflects the environmental performance level and the economic development level is in the climbing period of the Kuznets curve, indicating that the regional economic and social development level is in good agreement with the environmental performance.

Analysis of the correlation between the performance of 2nd class indicators and economy

Performance of each 2nd class indicators from 2015 to 2019 are exhibited in **figure 3**, the overall performance of environmental quality indicators is relatively poor, and none of them reached 80% of the target value. There are significant differences in the performance of the ecological protection indicators, resource, and energy utilization indicators, among the four cities. Chengdu is the best one and reached 80% of the target; Ziyang and Meishan performed the worst in the performance of ecological protection indicators and resource and energy utilization, respectively. Although the overall performance of environmental governance indicators is relatively good, Meishan and Ziyang still have not reached 80% of the target level in the five years.

The correlation between the 2nd class indicator's performance and economic development is further analyzed. As shown in **Table III**, GDP has a significantly positive correlation with the performance of the three secondary indicators of ecological protection, sustainable utilization of resources and environmental governance. That is, the higher the socio-economic level is, the higher the effectiveness of ecological protection, the sustainable utilization of resources and energy and the level of environmental governance are. There is a significant positive correlation between the energy and resource utilization and economic development indicators, which indicate that areas with poor economic development may still have problems such as relying on excessive investment in resources and energy to improve economic levels. However, there is no significant correlation between GDP and environmental quality

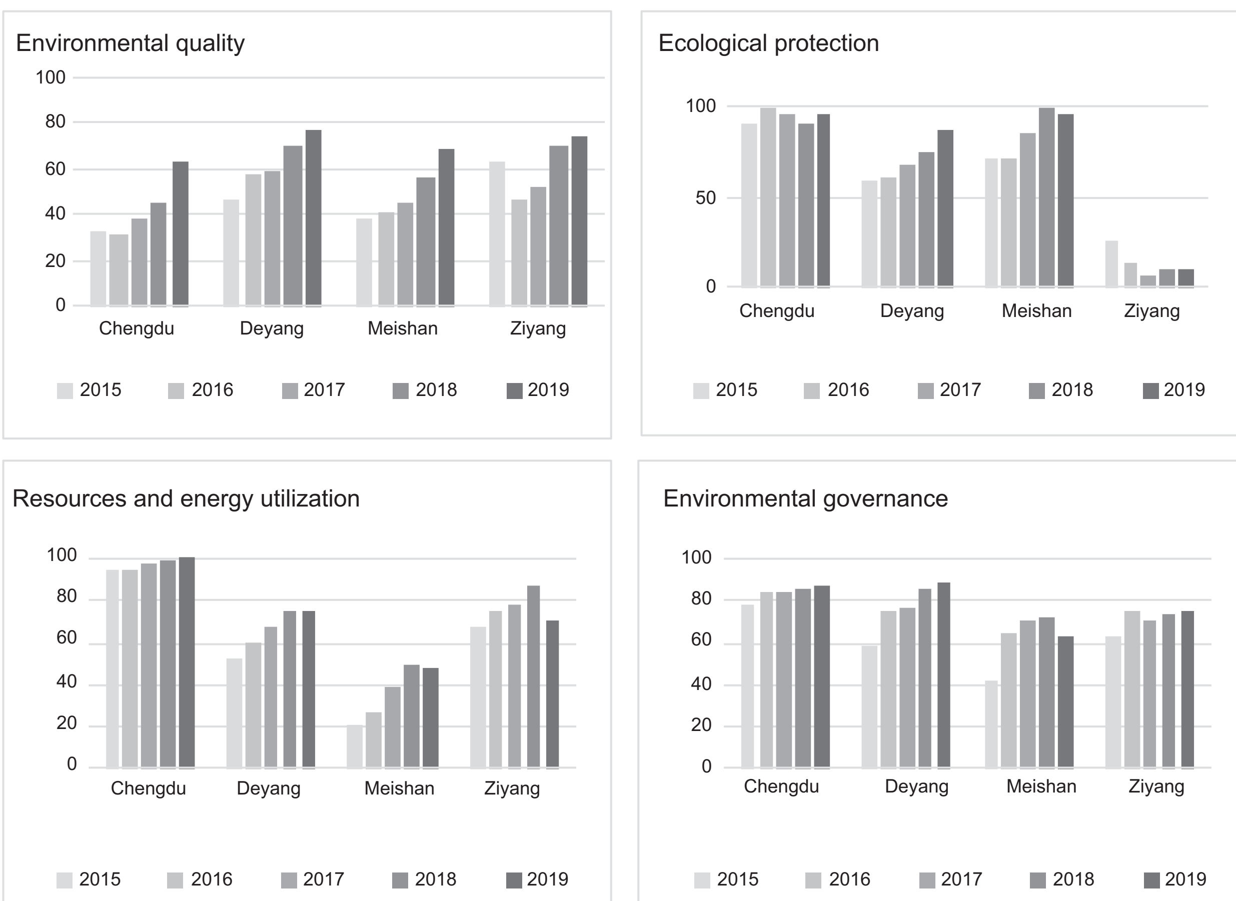

Fig. 3. Performance of each 2nd class indicators from 2015 to 2019.

index, manifesting that the environmental quality performance of regions with high economic development levels may not necessarily be high.

Analysis of the 3rd class and 4th class indicators performance

Performance of each 3rd class indicators from 2015 to 2019 are made into a radar chart (**Fig. 4**), and the environmental performance constraints of each city are identified by tracing the performance of the corresponding 4th class indicators. From the perspective of the overall completion of "Chengdemeizi Urban Integration" region, among ten 3rd class indicators, the performance of water quality, pollution control and pollution treatment indicators are relatively good, and the three indicators of air

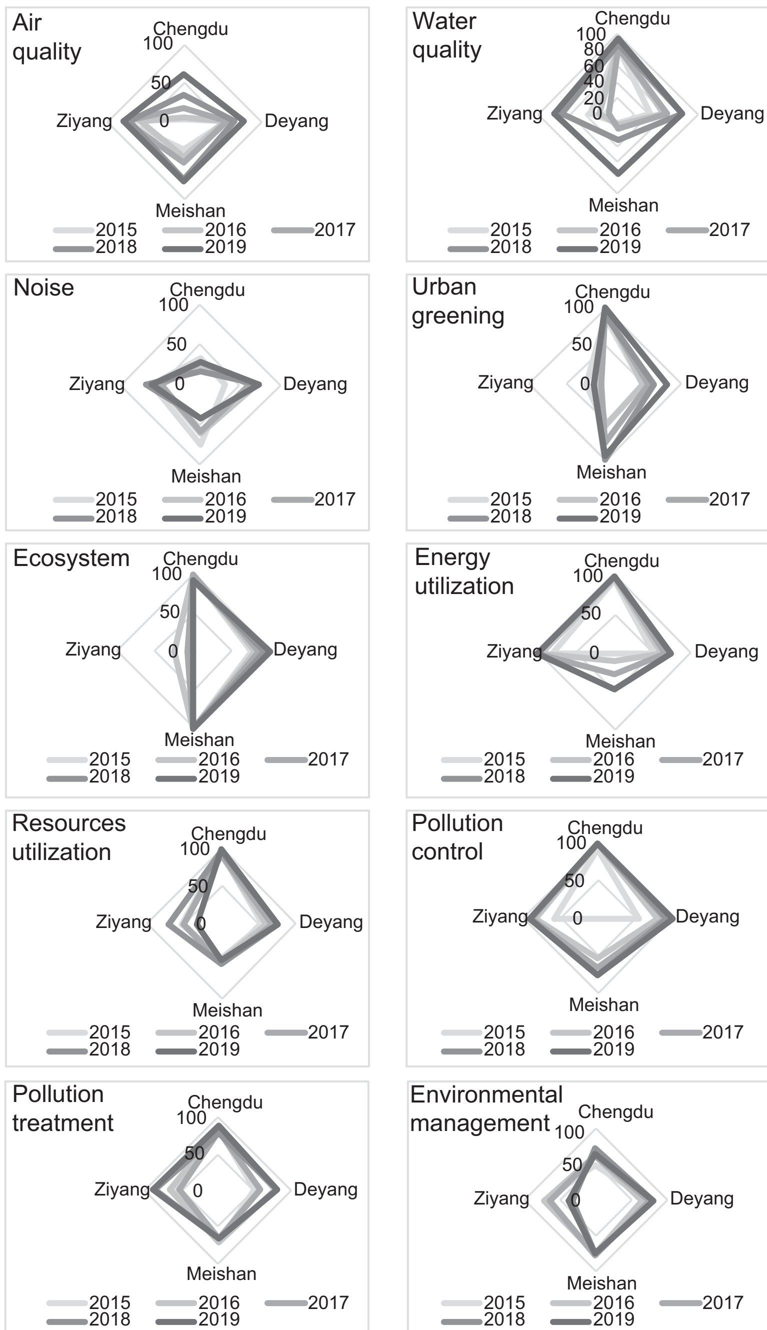

Fig. 4. Performance of each 3rd class indicators from 2015 to 2019.

quality, noise and environmental management are relatively poor, while the four cities have a significant gap in the performance of urban greening, ecosystem, resource utilization, and energy utilization indicators.

By analyzing the restrictive indicators of each city (as shown in **Fig. 5** and **Fig. 6**), Chengdu exhibits a poor performance of air quality and noise indicators, and among the six 4th class indicators, annual concentration of $PM_{2.5}$, daily maximum 8-hour average ozone concentration, road traffic noise, and regional environmental noise are the main restrictive factors.

For Deyang, the performance of air quality, energy utilization, and resource utilization is relatively poor. Among the eight four-level indicators, annual concentration of $PM_{2.5}$, daily maximum 8-hour average ozone concentration, and water consumption per unit of GDP indicators are the main limiting factors.

The overall 3rd class indicators of Meishan and Ziyang perform poor than Chengdu and Deyang. For Meishan, the two 3rd class indicators of energy utilization and resource utilization perform the worst. Among the six 4th class indicators, the total energy consumption per unit of GDP, coal consumption per unit of industrial value added, and water consumption per unit of GDP are the main restrictive factors. For Ziyang, the performance of the 3rd class indicators of urban greening and ecosystem perform poor, and three 4th class indicators of public green area per capita, green coverage rate in built-up area, and eco-environmental status index are the main restrictive factors.

CONCLUSION AND RECOMMENDATIONS

From overall view, the average score of comprehensive environmental performance for "Chengdemeizi Urban Integration" region show a continuous improvement trend from 2015 to 2019, and average EPI scores reached above 70 in 2019. Environmental quality performance is the main restrictive factors in 2nd class indicators, and air quality, noise and environmental management are the main restrictive indicators of regional environmental performance

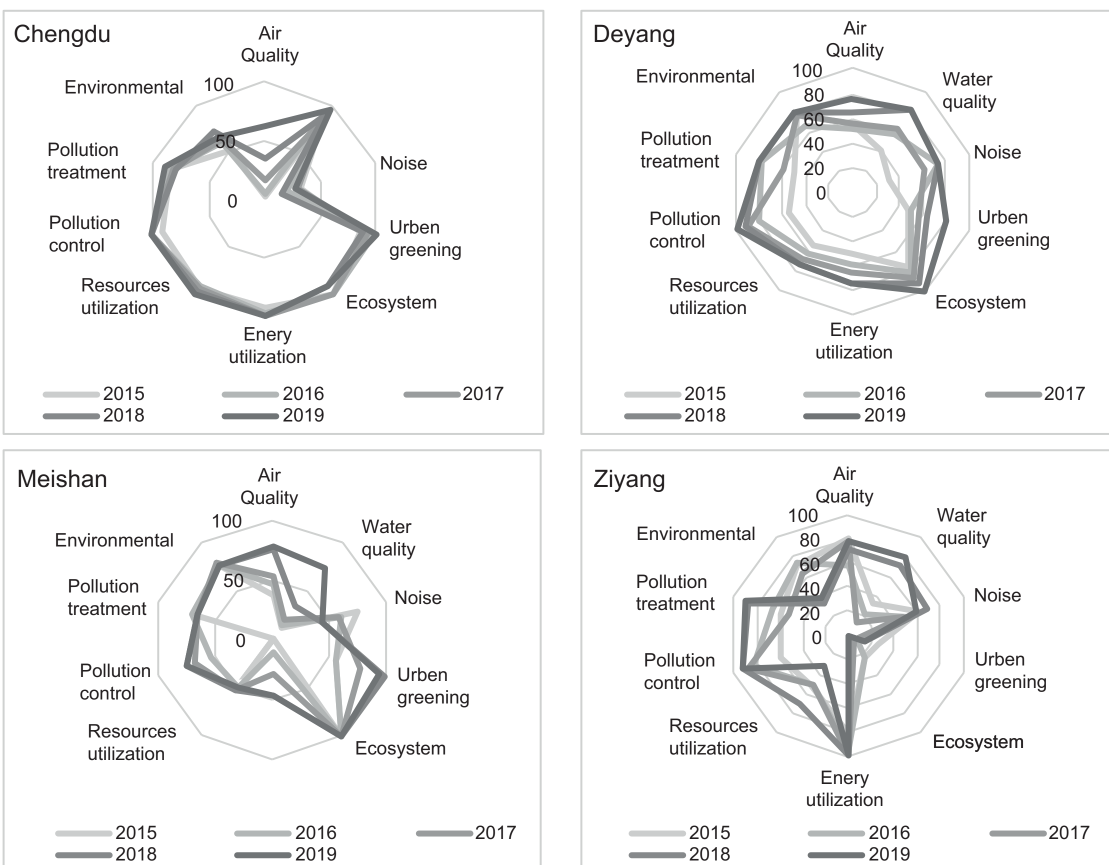

Fig. 5. Performance of 3rd class indicators in each city from 2015 to 2019.

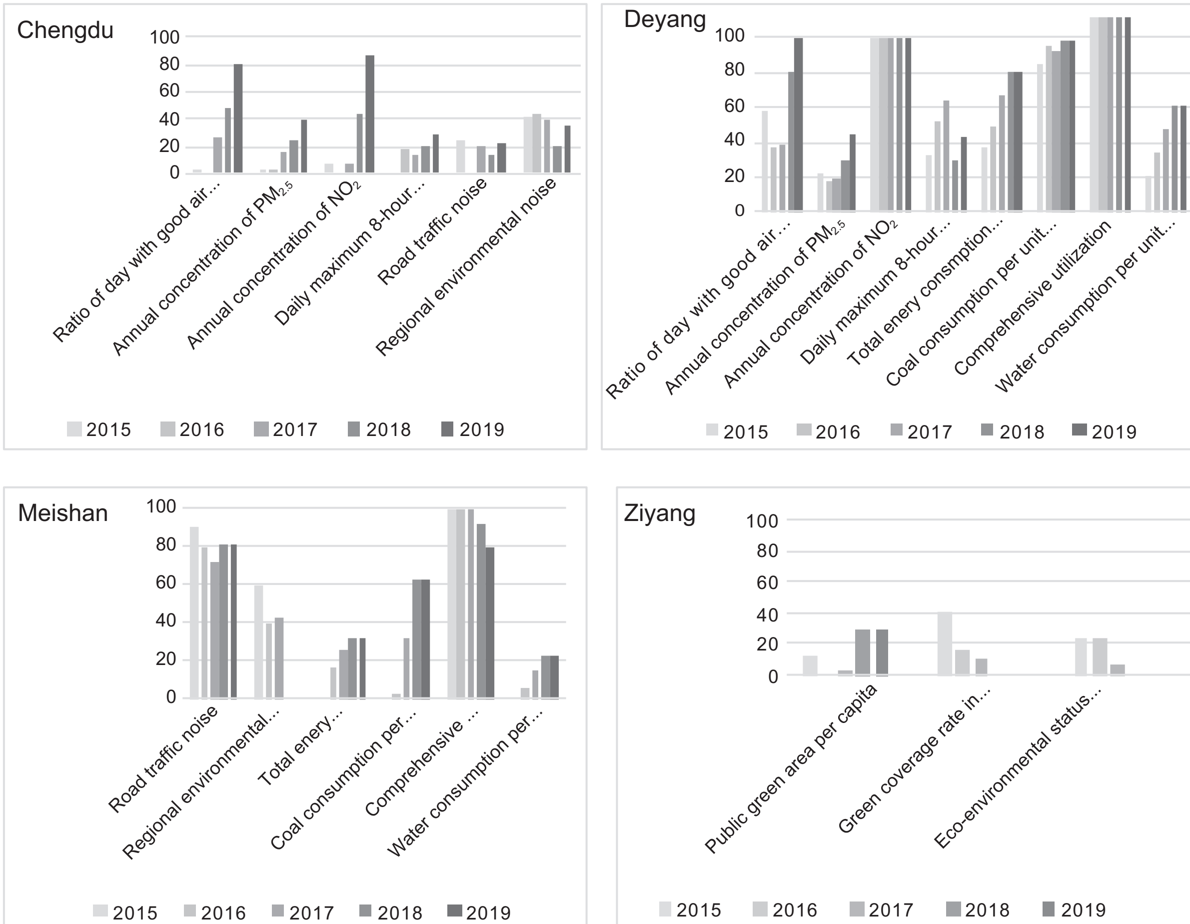

Fig. 6. Performance of 4th class restrictive indicators of each city from 2015 to 2019.

among the 3rd class indicators. On the other hand, the results of Pearson correlation analysis with economic development indicators show that GDP has a significant positive correlation with comprehensive environmental performance and three secondary indicators of ecological protection, sustainable use of resources, and environmental governance. There is no significant correlation with the environmental quality index.

From the perspective of the four cities, the environmental performance and economic level of each city are quite different. The comprehensive environmental performance of Chengdu and Deyang is better than that of Meishan and Ziyang, and Chengdu perform the best. Among the 4th class indicators, the short board indicator of Chengdu is the average annual concentration of $PM_{2.5}$, the maximum 8-hour average of O_3, road traffic noise and regional environmental noise. Deyang's short board indicator is the average annual concentration of $PM_{2.5}$, the maximum 8-hour average of O_3 and water consumption per unit GDP. Meishan's short board indicator is the total energy consumption per unit GDP, coal consumption per unit industrial added value, water consumption per unit GDP. The short board indicator of Ziyang is per capita park green space area, green coverage rate of built-up area and ecological environment index.

Based on the above analysis, the "Chengdemeizi Urban Integration" region must focus on long-term development and speed up regional cooperation. While promoting the urban integration of the economy, we must pay more attention to increasing ecological protection, environmental governance and the sustainable use of resources and energy. In addition, the four cities should continuously improve their respective shortcoming environmental performance indicators on the basis of improving the ecological environment quality, and promote the balanced improvement and improvement of indicators at all levels. Meishan's energy and resource utilization indicators, and Ziyang's ecological protection indicators are relatively significant shortcomings. It is necessary to improve environmental performance through promoting regional industrial upgrades, structural optimization and strengthen the planning of urban construction and the efficient use of resources.

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