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How high-quality development varies in China—a case study of Chongqing based on the EIORES-DEA model

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In this study, an EIORES-DEA high-quality development indicator system based on *efficiency* was constructed by selecting multiple indicators from six aspects: economic development, innovation vitality, openness to the outside world, resource utilization, ecological security, and social progress. The weights of the indicators were determined via the entropy weighting method, and the high-quality development (HQD) efficiency of 38 districts and counties in Chongqing municipality from 2010 to 2021 was measured by the Super epsilon-based measure (EBM) model. The spatial and temporal evolutions of efficiency were visualized by combining GIS technology, and the spatial pattern of the HQD level was determined using the LISA time path. The spatial aggregation characteristics of efficiency were revealed utilizing Moran's *I* index and spatial trend surface analysis. The results showed that the HQD level in Chongqing rose in an N-shaped fluctuation, and the HQD level in the central city was much higher than that in the new main city, southeast Chongqing, and northeast Chongqing. The high-efficiency (H-efficiency) regions were not connected together but rather distributed independently, with most of the medium–high-efficiency districts and counties distributed around the H-efficiency districts and counties. Meanwhile, the H–H agglomeration area had frequent turnovers in different years, indicating that the competition between H-efficiency districts and counties is intense and that the development synergy among them is poor, while the L–L agglomeration area fluctuated greatly in a given year but gradually stabilized in recent years. The spatial trajectory of HQD in Chongqing municipality mainly moved back and forth along the southwest–northeast direction, which is consistent with the direction of the Yangtze River. Finally, the imbalance of HQD development in Chongqing municipality mainly stems from the regional east–west development differences.

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Introduction

Environmental economics has long focused a great deal of research and discussion on the intricate connection between environmental deterioration and economic advancement (Aluko et al., 2022; Rehman et al., 2023). Research has found that when the scale of the economy exceeds a certain threshold, the intensity of human activity will exceed the ecological carrying capacity of the land at an exponential rate. The resulting reduction in ecological land area is irreversible in the short term and will directly cause a chain reaction of natural habitat loss and biodiversity decline (Huang et al., 2023). The increasing severity of extreme weather events, the loss of biodiversity, and the intensification of desertification pose a direct and urgent threat to human survival and development (Ahmad et al., 2023). How to achieve economic development without destroying the environment has become a global concern. "Changing Our World: The 2030 Agenda for Sustainable Development"—a collaborative document intended to holistically address global economic, social, and environmental development concerns—was unanimously accepted by the United Nations Sustainable Development Summit in 2015 (Sachs et al., 2022). The agenda sets out 17 sustainable development goals (SDGs), encompassing long-term sustainability of the environment, climate change, job prospects, social welfare, education, health, and economic growth (Soergel et al., 2021; Biermann et al., 2022; Wang et al., 2022). To achieve the SDGs by 2030, countries must carry out in-depth investigations and evaluations of sustainable development (Schmidt-Traub et al., 2017).

Regarding expediting the realization of the SDGs, China has put forward the notion of high-quality development (HQD) according to its national conditions. A report of the Communist Party of China's 19th National Congress notes that China's economy is currently undergoing a crucial transition from one of rapid expansion to one of high-quality growth. HQD is an intensive development model that emphasizes promoting economic development by increasing resource utilization efficiency rather than depending exclusively on an extensive range of inputs or production variables (Yang et al., 2021). HQD is an urgent requirement to address new circumstances surrounding economic growth and is a major strategy in the upcoming phase to help China's economy break through the current development dilemma and support the country's modernization drive. How to create a scientific assessment framework to gauge the true state of HQD in various regions, find out the advantages and shortcomings of HQD in various regions, and explore the objective gap between and within regions and its changing trend are weighty problems that must be resolved for the in-depth implementation of the HQD strategy.

China's western area has a lower level of economic construction than the eastern region (Ren et al., 2018). In western China, there is a glaring conflict between environmental conservation and economic growth (Ahmad et al., 2020). Western Development (Strategy) is the key to improving the overall level of our nationals (Huang, Xia et al., 2018; Huang, Li et al., 2018). In order to create a new pattern, it is imperative to thoroughly implement a regionally coordinated development strategy and bolster initiatives to support the development of the western region. Situated at the confluence of the Jialing and Yangtze rivers in southwest China, Chongqing is a major western, central hub for the Belt and Road Initiative and one of the local governments directly under the control of the Central Government in that region of China. As a megacity, the process of urban expansion in Chongqing has also inflicted certain damage on the regional ecological environment. Urban expansion, whether through direct deforestation or indirect land-use changes, significantly diminished these regions' ecosystem service supply capacities (Kong et al., 2025). With the rapid progress of new-type industrialization and urbanization, Chongqing's natural environment has suffered because of a few industrial businesses that use numerous energy sources and produce a large number of pollutants. This impact is mainly manifested in the decline of air quality, water pollution, and other problems, which further aggravate the clash between ecology and economy. A comprehensive evaluation of Chongqing's high-level economic, ecological, and social aspects must not only evaluate its economic and social feasibility but also uncover and solve the potential conflicts between ecology and economy in time. This is of far-reaching importance for both fostering the long-term, healthy growth of the local economy and safeguarding the ecological environment of the Yangtze River basin and even the entire southwest region. Therefore, it is imperative to do a thorough HQD assessment of Chongqing.

The remainder of this research is structured as follows. Section "Literature review" reviews the literature on HQD. Section "Data and methods" represents data and methods. Section "Results" describes and analyzes the findings. Section "Discussion" discusses the results. Section "Conclusion and policy recommendations" provides conclusions and policy suggestions.

Literature review

With the economy's rapid development, we now focus more on the quality—rather than the pace—of economic growth. Quantitative growth and qualitative improvement are necessary for economic growth since they are an organic combination of quantity and quality (Thomas, 2000). Under the guidance of this concept, the previous concept of pursuing high-speed, quantitative economic growth at any cost has been gradually abandoned. In particular, the outdated goal of rapid quantitative growth is clearly no longer appropriate, as China's economy approaches an entirely novel period of HQD. As a consequence, we suggest a fresh interpretation of HQD. High-quality economic development (HQED) is the most recent conceptual shift from sustainable development to economic growth quality (Kong et al., 2021). Economic development of superior quality will result from the new vision of creative, coordinated, green, open, and shared development (Wang and Li, 2021). Currently, research on HQD mainly focuses on its essence, characteristics, or the relationship between certain factors and HQD. Some scholars have conducted research on the relationships among industrial agglomeration, urban characteristics, environmental sustainability, and the quality of economic growth (Wilkins and Zurawski, 2014; Lyu et al., 2022). Some scholars have also discussed the quality of education, green finance, and the connection between fintech and HQD (Yang et al., 2021; Van Le and Tran, 2024).

At present, the academic community has yet to establish a unified index system in terms of HQD evaluation. Previously, some scholars tried to use a more comprehensive index to reflect economic growth. Uddin et al. (2023) noted that the human development index (HDI) was used in place of GDP to provide a more scientific and comprehensive comparison of the level of development of countries. A growing number of scholars have begun to study how to assess economic growth and promote it. Based on four dimensions—the ecological environment, the double cycle, economic development, and social development—some academics have developed a high-quality index system for evaluating urban development (Liu and Zhou, 2023). A five-dimensional assessment index system based on innovation, collaboration, green, openness, and sharing has also been developed by certain academics for HQED in the Yellow River Basin (Zhang et al., 2023). Peng et al. (2022) studied the quality of China's

economic growth and created economic growth indicators based on six parameters: innovation, stability, collaboration, effectiveness, sustainability, and sharing. At present, when most scholars build an HQD evaluation index system, they tend to focus on economic indicators and pay relatively insufficient attention to environmental and social indicators. This tendency not only affects the accuracy and objectivity of the evaluation results but also restricts our deep understanding of the connotation of HQD. Therefore, to be able to evaluate the HQD level more comprehensively, accurately, and to ensure that the harmonious development of the economy, society, and environment is fully reflected, it is vital to enhance the evaluation index system and emphasize the consideration of environmental indicators.

Aside from that, previous studies on HQD evaluation mainly used the entropy weight method alone (Sun et al., 2017; Yang et al., 2021; Li et al., 2024), principal component analysis (Yang, 2021), TOPSIS (Sun et al., 2017; Chen et al., 2018), and other static methods. Meanwhile, in recent years, data envelopment analysis (DEA) has become a mainstream method for scholars to quantify efficiency. Zheng et al. (2024) measured the municipal energy environmental effectiveness of 271 Chinese towns using a mix of the Tobit and Super epsilon-based measure (Super-EBM) models. Ding and Liu (2024) measured greenhouse gas emissions in 31 Chinese provinces and towns using the Super-EBM-accident model. Existing studies are often limited to a single static method or a single dynamic method when evaluating HQD, and few attempts are made to combine static and dynamic methods to comprehensively evaluate the HQD level in a certain area. This single evaluation method is difficult to fully reflect the multi-dimensional characteristics and dynamic changes of HQD. Therefore, in order to reveal the full picture of HQD more accurately, we need to explore a comprehensive evaluation path combining static and dynamic methods.

The literature review above makes clear that there is no unified standard for the HQD index system, and most scholars develop an index system based on coordination and environment, which lacks certain comprehensiveness. From the perspective of HQD evaluation, many academics have studied the HQD level in detail using the DEA model; however, there has been comparatively little research on combining DEA and GIS to analyze the HQD level. In addition, with regard to research fields, most scholars' current studies on the HQD level take urban agglomeration as the subject of the study. Although urban agglomeration as the research object can put forward insightful suggestions at the macro and high levels, HQD research still needs to dive deep into the micro level to ensure the full implementation of HQD. Consequently, it is quite important to study the HQD level at the research scale of districts and counties to ensure the full implementation of HQD. The novelty of this paper lies in the following:

(1) This paper constructs the EIORES-DEA assessment index system and measurement model of HQD in terms of six aspects: economic development (E), innovation vitality (I), openness to the outside world (O), resource utilization (R), ecological security (E), and social progress (S). The HQD evaluation index system has been supplemented and improved.

(2) This study used DEA to introduce *efficiency* thinking—combined with GIS technology and time–space transition (LISA time path)—to solve the separation problem between static *HQD level assessment* and dynamic *HQD efficiency measurement*.

(3) In previous studies, most of the literature focused on the discussion at the national or provincial level, and few scholars directed their attention toward the district and county level for in-depth analyses. This study selected 38 districts under the jurisdiction of Chongqing as the research area, aiming to reveal the specific phenomena and laws of this area from a more microscopic perspective.

Data and methods

Study area. Located in southwest China, Chongqing municipality has jurisdiction over 38 districts, including Yuzhong, Dadukou, Jiangbei, Shapingba, Jiulongpo, Nanan, and Beibei (central urban area [Cua]); Yubei, Banan, Fuling, Changshou, Jiangjin, Hechuan, Yongchuan, Nanchuan, Qijiang, Dazu, Tongliang, Bishan, Rongchang, and Tongnan (new main urban area [NDMc]); Qianjiang, Wulong, Shizhu, Xiushan, Youyang, and Pengshui (southeast Chongqing [SE]); and Wanzhou, Liangping, Chengkou, Fengdu, Dianjiang, Zhong, Kaizhou, Yunyang, Fengjie, Wushan, and Wuxi (northeast Chongqing [NE]). This study took the above 38 counties as research areas. This is shown in Fig. 1.

CUa is the central urban area, NDMc is the new main urban area, SE is the Wuling Mountain town group in southeast Chongqing, and NE is the Three Gorges Reservoir town group in northeast Chongqing.

Research method

Entropy weight method. The entropy weight approach, a popular multi-index decision-making technique, has the benefits of great objectivity and precision. This method's evaluation outcomes are mostly based on objective facts, and subjective elements have little effect on the final evaluation results. Therefore, we used the entropy weight method to determine the weight of each index item and then processed the data accordingly to calculate the initial data as the EBM-DEA.

Step 1: Perform dimensionless processing

$$\begin{cases} Z_{ij} = \frac{Z_{ij} - \min\{Z_{ij},\cdots,Z_{nj}\}}{\max\{Z_{ij},\cdots,Z_{nj}\} - \min\{Z_{ij},\cdots,Z_{nj}\}} \text{ for the positive indicator} \\ Z_{ij} = \frac{\max\{Z_{ij},\cdots,Z_{nj}\} - Z_{ij}}{\max\{Z_{ij},\cdots,Z_{nj}\} - \min\{Z_{ij},\cdots,Z_{nj}\}} \text{ for the negative indicator} \end{cases} \tag{1}$$

Z_{ij}: the evaluation object *I*'s initial index for the *j*th index; *n*: the number of evaluation indexes.

Step 2: Build a normalized matrix, *M*:

$$M_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{ij}} \tag{2}$$

Step 3: Determine the *j*th index's entropy value. The following is the formula for the *j*th index's entropy value, e_j:

$$\begin{cases} e_j = -k \sum_{i=1}^{n} M_{ij} \times \ln(\mathrm{M_{ij}}) \\ k = \frac{1}{\ln(\mathrm{n})} > 0 \end{cases} \tag{3}$$

Step 4: Determine the redundancy of information entropy, d_j:

$$d_j = 1 - e_j \tag{4}$$

Step 5: Determine the metric's weight in relation to each dimension, W_j:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{5}$$

Super measurement model based on epsilon. The DEA approach is currently the most often used technique for calculating efficiency (Chen and Lin, 2021; Wang and Wang, 2022). Nevertheless, the improvement of relaxation in input or output components is disregarded by conventional DEA models (Charnes et al., 1978; Cooper et al., 1999). Although slack improvements are included in the objective function by the SBM model (Tone, 2001), they cannot capture the characteristics of radial models. Compared with traditional DEA models and models based on the relaxation measure (SBM), Super-EBM models not only consider the relaxation improvement of the input or output components but also maintain the characteristics of the radial model, thus

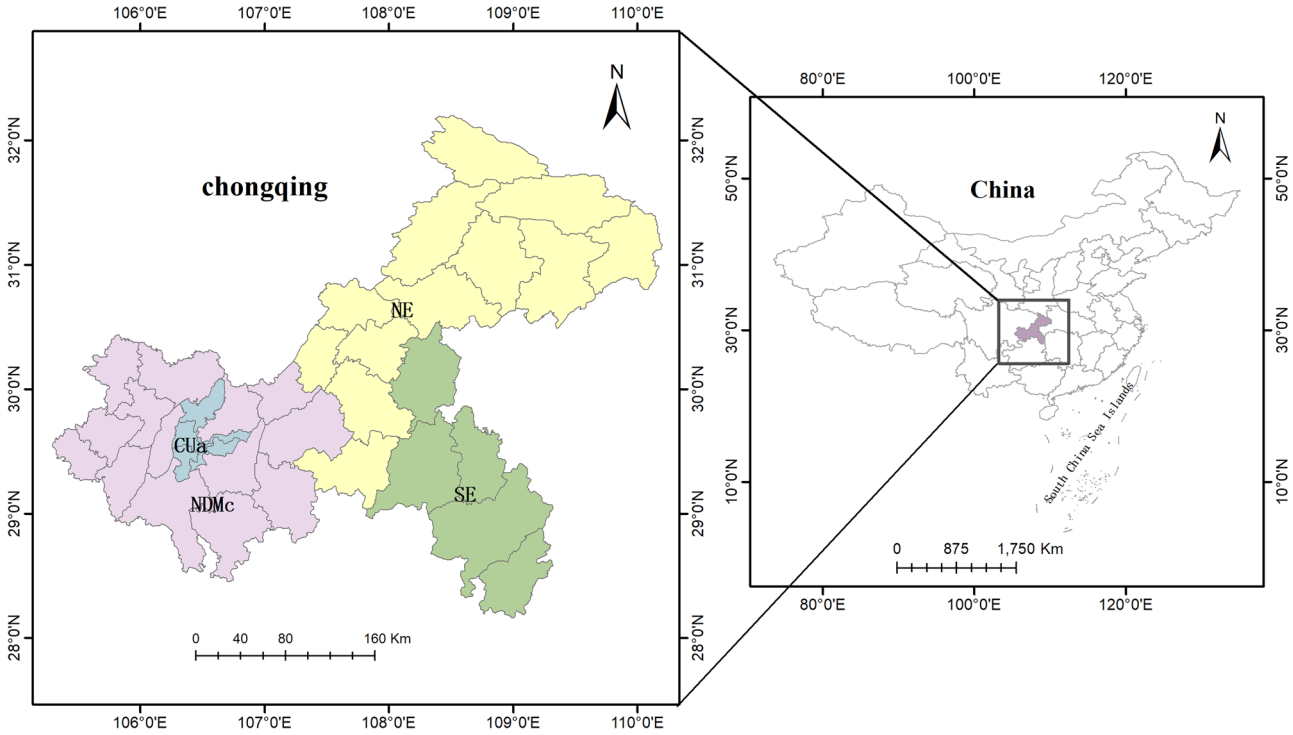

Fig. 1 Study area. All the maps of Chongqing in this paper are made based on the standard map no. GS(2023)2767 downloaded from the standard map service website of the Ministry of Natural Resources, and the base map has not been modified.

providing a more comprehensive efficiency evaluation. Since HQD involves multidimensional and complex systems, such as economy, ecology, and society, there are nonlinear interactions among the dimensions, and it is difficult to determine reasonable weights through subjective assignments (e.g., hierarchical analysis). The Super-EBM model, which is a non-parametric model, does not require preset weights and avoids subjective bias by constructing a production frontier that objectively captures the technical efficiency between multiple inputs and multiple outputs. Therefore, it is necessary to adopt the Super-EBM model to calculate the HQD efficiency of Chongqing districts and counties compared to the Weighted Sum Model method. At the same time, the Super-EBM model is able to incorporate "bad" indicators, such as environmental pollution, into the model as non-desired outputs, which makes up for the shortcomings of the traditional CCR/BCC model, and by breaking through the limitation that the upper limit of the efficiency value is 1, it is able to make a more effective ordering of all the decision-making units (DMUs) (Tone and Tsutsui, 2010). Therefore, we used the Super-EBM model to evaluate the HQD level in Chongqing. The model is as follows:

$$\eta^* = \min\left(\frac{\delta - \varepsilon_X \sum_{i=1}^{m} \frac{w_i^- s_i^-}{x_{ik}}}{\varphi + \varepsilon_y \sum_{r=1}^{q} \frac{w_r^+ s_r^+}{y_{rk}} + \varepsilon_b \sum_{t=1}^{p} \frac{w_t^{b-} s_t^{b-}}{b_{tk}}}\right) \tag{6}$$

$$\text{s.t.}\begin{cases} \delta x_{ik} = \sum_{j=1, j\neq k}^{n} \lambda_j x_{ij} + s_i^-, i = 1, 2, 3, \ldots, l \\ \varphi y_{rk} = \sum_{j=1, j\neq k}^{n} \lambda_j y_{rj} - s_r^+, r = 1, 2, 3, \ldots, m \\ \varphi b_{tk} = \sum_{j=1, j\neq k}^{n} z_{tj} \lambda_j + s_p^{b-}, t = 1, 2, 3, \ldots, q \\ \lambda \geq 0, s_i^-, s_r^+, s_p^{b-} \geq 0 \end{cases} \tag{7}$$

η^*: the HQD level; x_{ij}: the vector of inputs of DMUs; The vectors y_{rj} and z_{tj} represent the DMUs' desired and undesired outputs, respectively. The input and output quantities are, respectively, indicated by l,m and q; w_r^+: desirable outputs; w_t^{b-}: undesirable outputs; s_i^-: the inputs' slack variables; s_r^+: desirable outputs; s_t^{b-}: undesirable outputs; λ: intensity vector; δ: the radial planning parameter; ε_X: the non-radial weights for the input; ε_y: desirable output; ε_b: undesired output.

Global spatial autocorrelation. The purpose of global spatial autocorrelation is to deeply analyze the degree of correlation among spatial objects in the whole study area (Zheng and He, 2022). This method was chosen in this study to reveal the spatial heterogeneity and dependence of HQD levels in Chongqing. Global spatial autocorrelation analysis mainly uses global spatial autocorrelation statistics (e.g., global Moran's I, global Geary's C, and General G) to measure and analyze related problems. Global Moran's I statistics are among the most popular. The particular format looks like this:

$$I = \frac{N}{S_0} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{8}$$

I: the Moran index; n: the number of cities; N: the number of research units; the attribute values of research units I and J are represented by y_i and y_j; $\bar{y}$: the average of y_i; the research units I and J's spatial weight matrix is denoted by w_{ij}; the total of each element in the spatial weight matrix is denoted by S_0. Moran's I has a range of [−1,1]. Moran's $I = 1$: positive correlation; Moran's $I = -1$: negative correlation; when the result is 0, it indicates that the research data are spread randomly, meaning that there is no correlation.

Local spatial autocorrelation. To make sure that more research was done on the precise location of HQD spatial agglomeration in Chongqing, we adopted the local autocorrelation method. The

Table 1 Types and characteristics of LISA spatial and temporal transitions.

Type	Concrete type
Type I	$LH_t \to HH_{t+1}, HL_t \to LL_{t+1}, HH_t \to LH_{t+1}, LL_t \to HL_{t+1}$
Type II	$LH_t \to LL_{t+1}, HL_t \to HH_{t+1}, HH_t \to HL_{t+1}, LL_t \to LH_{t+1}$
Type III	$HL_t \to LH_{t+1}, LH_t \to HL_{t+1}, LL_t \to HH_{t+1}, HH_t \to LL_{t+1}$
Type 0	$HL_t \to LH_{t+1}, LH_t \to HL_{t+1}, LL_t \to HH_{t+1}, HH_t \to LL_{t+1}$

formula is as follows:

$$\text{Local } I = \frac{(y_i - \bar{y})^2 \sum_{j=1}^{n} w_{ij}(y_j - \bar{y})^2}{\sigma^2} \tag{9}$$

In the formula, $\bar{y}$, w_{ij}, n, y_i, andy_j have the same meaning as above. σ^2 is the

standard deviation. $I > 0$: positive correlation; $I < 0$: negative correlation.

LISA time path and LISA time–space transition. The LISA time path can describe the dynamic migration and change of LISA coordinates in the Moran scatter plot in the time dimension and can reveal the stability of LISA coordinates over time, so as to explain the dynamic characteristics of spatio-temporal differences and spatio-temporal interaction changes of county HQD in Chongqing city at the local spatial level. The geometric features of the LISA time path can include the following aspects: relative length, curvature, and transition direction of the LISA time path. The following are the calculation formulas:

$$I_i = \frac{N \times \sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})}{\sum_{i=1}^{N} \sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})} \tag{10}$$

$$\varphi_i = \frac{\sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})}{d(L_{i,1}, L_{i,T})} \tag{11}$$

$$\theta_i = \arctan \frac{\sum_j \sin \theta_j}{\sum_j \cos \theta_j} \tag{12}$$

T: the research time interval; N: the quantity of units in the study case area; $L_{i,t}$: the coordinate position of research unit i in Moran's I scatter plot for year t; $d(L_{i,t}, L_{i,t+1})$: the distance the i county unit moves from $t \to t+1$ years. $I_i > 1$ indicates that the length of coordinate movement change of county unit i is greater than the average value during the study period; the larger I_i is, the more dynamic the local spatial structure of the county unit HQD is, and vice versa. A larger φ_i indicates that the LISA time path of the research unit in domain i is more curved; that is, the research unit in county i is more influenced by the neighboring space, meaning that the local spatial-dependent evolution process of HQD is more volatile. θ_i represents the average movement direction of county research unit i during the study period.

LISA time–space transition is an effective spatial analysis method that can be used to reveal the relationships among different local spaces in the study case area and to study the time evolution characteristics and transfer of local spatial association types in the local Moran's I scatter plot. Four categories of LISA time–space transitions can be distinguished.

As shown in Table 1, Type I indicates that the adjacent county units do not change, and only the county units themselves transition. Type II indicates that the county unit itself does not change, and only the neighboring county unit transitions. Type III indicates that both the adjacent county units and the county units themselves have transitions. Type 0 indicates that neither the neighboring county unit nor the county unit itself has made a transition.

According to the calculated spatial transition types, spatio-temporal condensation was used to further calculate the spatial stability of county HQD in Chongqing. The expression is as follows:

$$SC = \frac{Lt}{m} \tag{13}$$

Lt: the total number of county research units with Type 0 transition in the research period t; m: the number of all potential counties where leapfrogging is possible.

Standard deviation ellipse. The standard deviation ellipse (SDE) was proposed by Lefever (1926) as an intuitive method for displaying the spatial distribution characteristics of a set of points in spatial statistics (Du et al., 2019; Yu et al., 2019). SDE is composed of center, angle, standard deviation along the long axis and short axis, and azimuth angle (Xia et al., 2020). The azimuth angles show the primary trend direction of their distribution, the major and minor axes of the ellipse represent directivity and data centripetal force, respectively, and the mean center is typically employed to illustrate the evolutionary trajectory. Thus, we employed this method to represent the spatial evolution trajectory of Chongqing's HQD throughout time. The relevant parameters of SDE are calculated as follows:

$$\begin{cases} \tan \alpha = \dfrac{\left(\sum_{i=1}^{n} \bar{X}_i^{\,2} - \sum_{i=1}^{n} \bar{Y}_i\right) + \sqrt{\left(\left(\sum_{i=1}^{n} \bar{X}_i^{\,2} - \sum_{i=1}^{n} \bar{Y}_i^{\,2}\right)^2 + 4\left(\sum_{i=1}^{n} X_i^{-} Y_i\right)^2\right)}}{2\sum_{i=1}^{n} X_i^{-} Y_i} \\ \sigma_x = \dfrac{\sum_{i=1}^{n} (\bar{X}_i \cos \alpha - \bar{Y}_i \sin \alpha)^2}{n} \\ \sigma_y = \dfrac{\sum_{i=1}^{n} (\bar{X}_i \sin \alpha - \bar{Y}_i \cos \alpha)^2}{n} \\ (\bar{X}, \bar{Y}) = \left(\dfrac{\sum_{i=1}^{n} w_i X_i}{\sum_{i=1}^{n} w_i}, \dfrac{\sum_{i=1}^{n} w_i Y_i}{\sum_{i=1}^{n} w_i}\right) \end{cases} \tag{14}$$

$(X_i Y_i)$: the coordinates of the subject i ($i = 1, 2, 3, \ldots, n$); w_i: the weight; α: the ellipse's azimuth angle; $(\bar{X}_i, \bar{Y}_i)$: the weighted average center; $\bar{X}_i$, $\bar{Y}_i$: the coordinate divergence between each subject's location and the average center; the standard deviation along the X- and Y-axes is represented by the values of σ_x and σ_y.

Trend surface analysis. Trend surface analysis can clearly show the spatial distribution pattern of spatial geographic elements (Feng et al., 2023). The purpose of this study is to explore the distribution of geographical characteristics of Chongqing's HQD through trend surface analysis.

$$Z_i(x_i, y_i) = T_i(x_i, y_i) + \delta_i \tag{15}$$

$Z_i(x_i, y_i)$: actual observed data; $T_i(x_i, y_i)$: trend function; δ_i: random error

Index construction. Based on the existing research literature (Peng et al., 2022; Zhang and Chen, 2022; Zheng et al., 2022), this paper follows the principles of objectivity, scientificity, systematicity, and data availability and constructs the EIORES-DEA high-quality development measurement index system based on efficiency and the Super-EBM model, and according to the perspective of input–output. As shown in Table 2, the index system includes 20 indicators in six dimensions: economic development (E), innovation vitality (I), openness to the outside world (O), resource utilization (R), ecological security (E), and social progress (S).

(1) *Economic development*: In this paper, regional GDP growth, per capita GDP (Zheng et al., 2022), and the GDP percentage of

Table 2 HQD evaluation index selection.

Model	Indicators	Unit	Weights	Indicator attributes	Indicator type
E	Regional GDP growth	10^4CNY	0.0039	+	Output
	Per capita GDP	Yuan	0.0377	+	Output
	Value added of tertiary industry as a proportion of GDP	%	0.0304	+	Output
I	Intensity of R&D expenditure	%	0.0692	+	Input
	The number of invention patents held by 10,000 people	Patents	0.0937	+	Output
	Total labor productivity	Yuan/person- year	0.0279	+	Output
O	Total import and export value	10^4dollars	0.2836	+	Output
	Actual utilization of foreign capital	10^4dollars	0.0503	+	Input
	Actual use of domestic capital	10^4CNY	0.0548	+	Input
R	Water intensity per unit of GDP	Tons/10^4yuan	0.0020	−	Input
	Electricity consumption of the whole society	10^8kWh	0.0277	+	Input
E	CO_2 emission intensity per unit of GDP	Tons/10^4yuan	0.0025	−	Ex-Output
	Total industrial wastewater discharge	10^4 tons	0.004	−	Ex-Output
	Forest coverage rate	%	0.0092	+	Output
S	Rura-urban per capita disposable income ratio	%	0.0136	−	Output
	Urbanization rate of the permanent resident population	%	0.0281	+	Output
	The number of books in the library	Books	0.1264	+	Input
	Per capita educational expenditure	Yuan	0.0257	+	Input
	Number of beds in health institutions per 10,000 people	Beds/10,000 population	0.0357	+	Output
	Number of employees of non-private units in urban areas	10^4people	0.0735	+	Input

added value from the tertiary sector (Peng et al., 2022; Zheng et al., 2022) were chosen as the assessment metrics to gauge Chongqing's level of economic growth.

(2) *Innovation vitality*: In this study, the quantity of invention patents that 10,000 individuals own (Peng et al., 2022), the intensity of Research and Experimental Development (R&D) expenditure, and the total labor productivity of Chongqing were selected as indicators to evaluate the degree of innovation vitality in Chongqing. The change of total labor productivity can reflect the performance of the organization in technological innovation, management, and system innovation, so as to evaluate the strength of its innovation vitality. The intensity of R&D expenditure can directly and deeply reflect the innovation vitality of an enterprise or an economy.

(3) *Openness to the external environment*: The sum of imports and exports overall directly reflects the active degree of a region's participation in international trade. To consider the degree of openness of each district more comprehensively, this study also selected the actual utilization of foreign capital and domestic capital as a supplement. Because the districts of Chongqing were the subject of this research, the external capital had to include not only foreign capital but also capital from other regions in China when measuring the degree of openness.

(4) *Resource utilization*: Given the data's accessibility, this study selected water intensity per unit GDP and the total amount of electricity used by society to reflect the resource utilization of the region. The intensity of water per unit GDP is a way to measure how effectively water sources are used during an economic growth process, and the total amount of electricity used by society can directly reflect the change in energy demand in the area.

(5) *Ecological security*: Combined with the ecological environment status of Chongqing, the forest coverage rate (Zheng et al., 2022), carbon dioxide emission intensity per unit GDP, and total amount of industrial wastewater discharge were taken as evaluation indicators of ecological security in this study. The academic circles usually study ecological security from two aspects: biosafety and environmental protection. The forest is the "green lung" of nature, and the forest coverage rate directly determines the security of the land ecosystem. Carbon dioxide emission intensity per unit GDP was used to reflect the efficiency and level of carbon dioxide emission during the course of economic growth in the area, which directly reflects the impact of economic activities on climate change.

(6) *Social progress*: Therefore, when assessing the social progress of Chongqing, we selected the number of library books (Peng et al., 2022), the per capita investment in education, the quantity of beds in health institutions per 10,000 people (Peng et al., 2022), the proportion of urban to rural areas in per capita disposable income, the urbanization rate of permanent residents (Zhang and Chen, 2022), and the quantity of employees in urban non-private units as evaluation indicators. The first three indicators reflect the social progress in culture, education, and medical care of Chongqing, while the last three indicators represent the evolution of social structure.

The EIORES-DEA model utilized in this study is visualized in Fig. 2. Based on the model requirements in DEA, we classified these 20 indicators from an *input–output* standpoint. The input index includes capital input, labor input, energy input, and cultural and educational input. The output index includes economic output, labor output, social output, green output, and undesired output.

Data source. The 10,000 invention patents used in this study were provided by the Chongqing Intellectual Property Office, the data of R&D fund investment intensity were received from the Chongqing Science and Technology Bureau, the water consumption of each district used in calculating the water consumption per unit GDP was provided by Chongqing the Water Resources Bureau, and the forest coverage rate was offered by the Chongqing Forestry Bureau. The CO_2 emission data used in calculating CO_2 intensity per unit of GDP were obtained from the China Carbon Accounting Database (CEDAs) created by Professor Guan Dabo's team at Tsinghua University, https://www.nature.com/articles/s41597-020-00736-3. Additional data were gathered from the yearbook of statistics for the Chongqing municipality and each district.

Results

Holistic analysis. As observed in the HQD level of the 38 districts in Chongqing, reflected in the box plot in Fig. 3 from 2010 to 2021, the average HQD level of Chongqing showed N-word fluctuations. From 2010 to 2012, the average HQD level increased from 0.95 in 2010 to 0.97 in 2012. The second stage is 2013–2016,

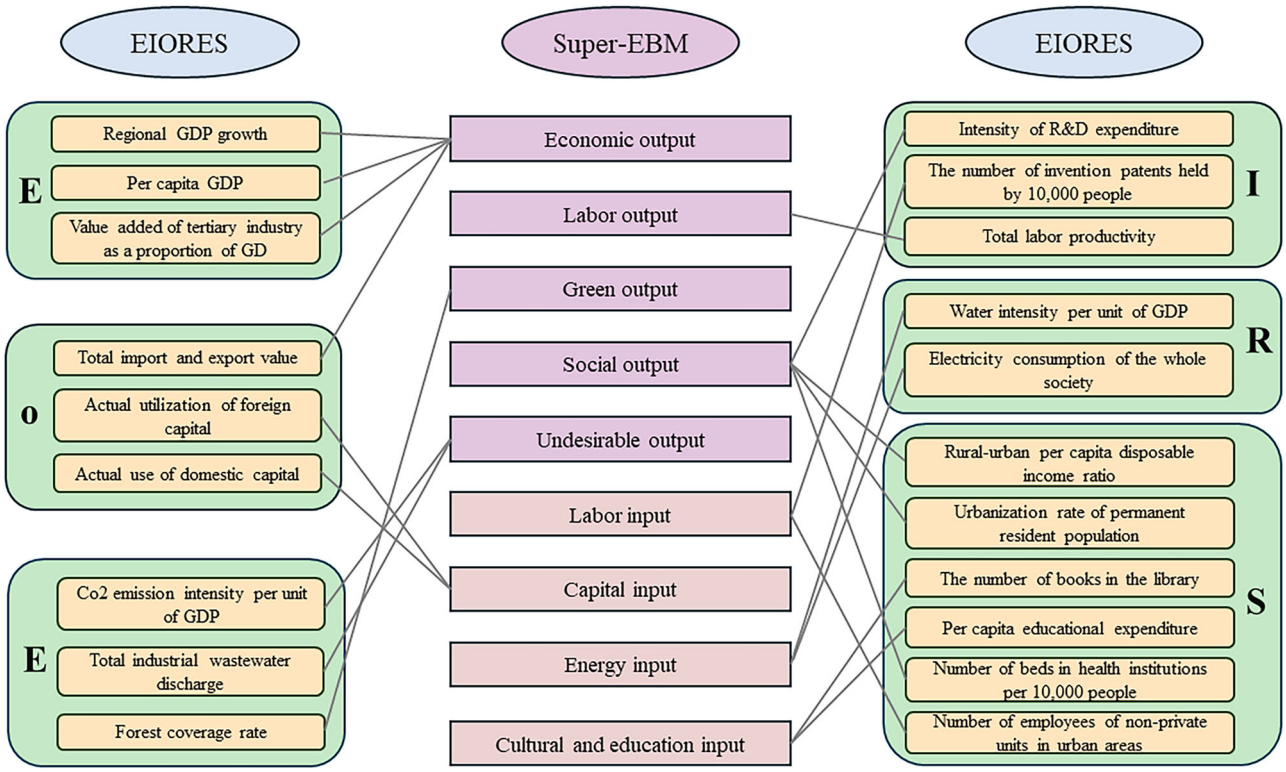

Fig. 2 EIORES system and Super-EBM model. The figure presents the specific indicators corresponding to each of the six dimensions of the EIORES system. These indicators are classified as input, output, and undesirable output variables in the Super-EBM model for subsequent efficiency measurement.

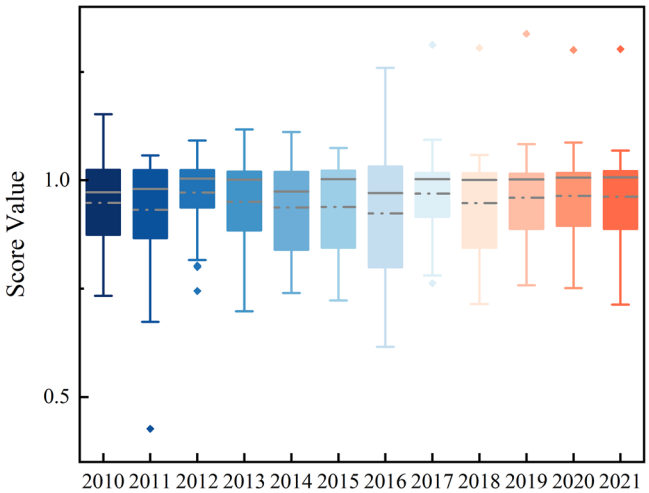

Fig. 3 Box plot of HQD efficiency in Chongqing. The two lines inside the box denote the median and the mean, respectively. The top and bottom of the box correspond to the first and third quartiles. Dots outside the box indicate outliers.

during which the level of HQD in Chongqing showed a fluctuating downward trend, with the overall level decreasing from 0.94 in 2013 to 0.92 in 2016. There were two notable nodes of decline during this period: after the first decline in 2014, there was a brief rebound in 2015, but the decline was repeated in 2016. An analysis of the efficiency of each district and county revealed that Bishan, Dazu, Fuling, Hechuan, Shizhi, Wanzhou, Xiushan, Youyang, and Yunyang experienced declines in HQD efficiency in 2014 and 2016.

The decline in HQD efficiency in Chongqing municipality in 2014 was mainly due to the unsustainable investment–driven model superimposed on policy tightening and environmental protection pressure. In 2013, Chongqing municipality launched the Five Environmental Protection Actions (water, blue sky, etc.), Bishan Automobile Manufacturing, Dazu Hardware processing, and other industries, due to the rising cost of sewage treatment and emission limitations, resulting in rising industrial costs and a slowdown in the growth rate of all-employee labor productivity. In 2014, the state tightly controlled the scale of local government debt; in Hechuan, Wanzhou, and other regions, relying on infrastructure investment due to financing constraints, inefficient projects were substantially reduced, and the diminishing effect of marginal benefits of investment emerged. By 2016, the HQD efficiency value of Chongqing municipality further dropped to 0.92, and the core contradiction shifted to the deepening of supply-side reform. In 2016, Chongqing municipality implemented the Cutting Overcapacity, Reducing Inventory, Deleveraging, Lowering Costs, and Strengthening Weak Links policy (San Qu Yi Jiang Yi Bu), which considerably impacted energy-intensive industries, such as coal and steel, in districts and counties, including Dazu and Xiushan. At the same time, due to industrial wastewater discharge restrictions, such as Dazu Yutan Lake governance lagging behind, some of the projects stopped rectification. The decline in efficiency was exacerbated by the contraction of traditional high-energy-consuming industries, but emerging industries (e.g., new energy vehicles in Bishan and new materials in Fuling) have not yet formed a large-scale replacement. It should be noted that Tongnan County experienced a precipitous decline in efficiency in 2016 (from 1 to 0.72). The plunge mainly stems from the cliff-like decline in the growth rate of the low-end electronic information industry and the pressure of the transformation of traditional high-energy-consuming

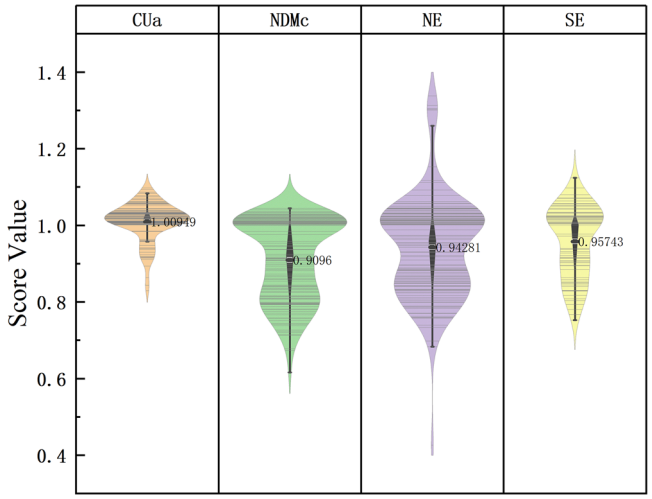

Fig. 4 The various regions' HQD level density. Internal gray lines depict the distribution of values for specific districts and counties within each region. The values marked in the graph represent the region's overall mean HQD value from 2010 to 2021.

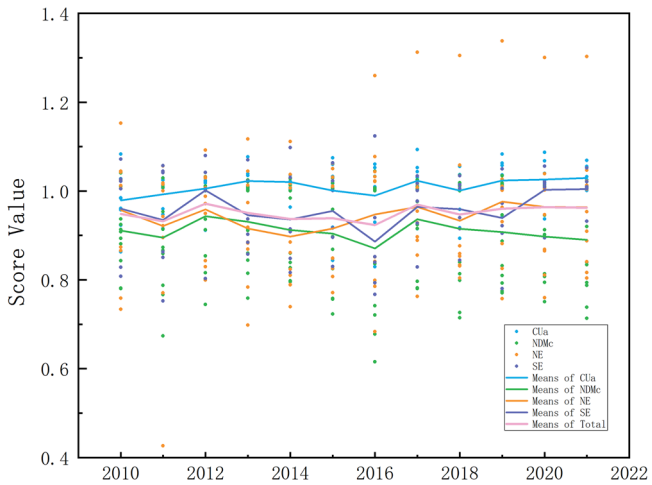

Fig. 5 Variations in HQD levels across various regions. Scatter points of different colors in the figure correspond to the HQD values of specific districts and counties within each region, respectively. The lines represent the temporal trends in the average HQD values for each region and for Chongqing as a whole.

industries, superimposed on the lag in the cultivation of emerging industries.

The third phase was from 2017 to 2021, when HQD efficiency in Chongqing began to grow steadily. This is mainly due to the implementation of the upgraded version of the Cutting Overcapacity, Reducing Inventory, Deleveraging, Lowering Costs, and Strengthening Weak Links policy (Also known as *San Qu Yi Jiang Yi Bu*) in 2017, which guided the upgrading of traditional industries (such as Dazu Hardware and Hechuan Building Materials) through technological reform subsidies and industrial funds. At the same time, in 2017, the Chongqing municipality gradually established an ecological product value realization mechanism to promote the construction of a regional public brand.

To analyze the HQD level of Chongqing further, we used the violin chart (Fig. 4) to reflect the HQD level of each region in Chongqing from 2010 to 2021. Chongqing is divided into four regions: CUa, NDMc, NE, and SE. The analysis revealed the HQD level of CUa to be higher than that of the other three areas, and only the HQD level of the main city's new district was >1, which means it is effective. Observing the HQD level of the other three regions in the past 10 years, the southeast Chongqing region was the best among them. Although the new district of the main city closely surrounds the central city, its level was very low, which is quite different from the southeast of Chongqing and the central city. This also reveals the unbalanced characteristics of HQD in Chongqing.

As can be seen from Fig. 5, since 2016, the efficiency of all districts and counties has been far >1, and in 2019, a maximum efficiency of 1.34 in the past decade appeared. This shows that the development of some districts and counties has made a qualitative leap after 2016. Looking at the four regions, the average efficiency value of CUa is substantially greater than the overall average efficiency value. Although NDMc is the closest to CUa, its average efficiency value is far lower than the overall average efficiency value. However, it can be observed that the overall efficiency of NDMc is not high because the efficiency value of individual districts and counties is too low, resulting in extremely unbalanced development. For example, in 2016, the highest efficiency value of 1.23 and the lowest efficiency value of 0.62 were recorded in this region. The northeastern and southeastern Chongqing fluctuated around the average efficiency of Chongqing as a whole, and their changing trends were almost the same before 2015. Generally speaking, the average value of the central city in the past 10 years was 1.01, which is the only effective area. The average efficiency values of the main city's new district, northeast Chongqing, and Southeast Chongqing were 0.91, 0.94, and 0.96, respectively, while the average efficiency value of Chongqing in the recent 10 years was 0.95.

Space–time evolution analysis. The high-quality development efficiency of Chongqing is divided into four grades: low (L), medium and low (M–L), medium and high (M–H), and high (H). As can be seen from Fig. 6 and Table 3, the number of M–L efficiency counties and H-efficiency counties in Chongqing is relatively stable from 2010 to 2021, while the number of L-efficiency counties and M–H-efficiency counties fluctuates greatly, which means that there are still quite a few regions with HQD rotating at different efficiency levels. There is still much room for improvement in the balance of HQD in Chongqing's districts and counties. In 2012, the H-efficiency region mainly formed three parts, which were mainly distributed in the northeast, southeast, and central urban areas of Chongqing. Chengkou and Wuxi constitute the H-efficiency area in the northeast of Chongqing, Wulong District and Pengshui County constitute the H-efficiency area in the southeast of Chongqing, and the H-efficiency area in the central city is mainly composed of Shapingba and Jiangbei. These districts and counties show excellent performance in efficiency and together build up the efficiency highland of Chongqing. However, these three H-efficiency areas are not linked together but distributed independently. In 2015, 2018, and 2021, although the specific distribution of H-efficiency regions would change to some extent, the overall distribution pattern was still distributed across the northeast, southeast, and central urban areas. At the same time, the geographical distribution of M–H efficiency areas was still mainly around H-efficiency areas, which indicates that H-efficiency areas not only improve their own HQD efficiency but also play a certain leading role. However, the situation in the western region is not optimistic. In 2012 and 2015, there were some M–H efficiency areas in the western region, but in 2018, a large number of L-efficiency areas appeared in the western region.

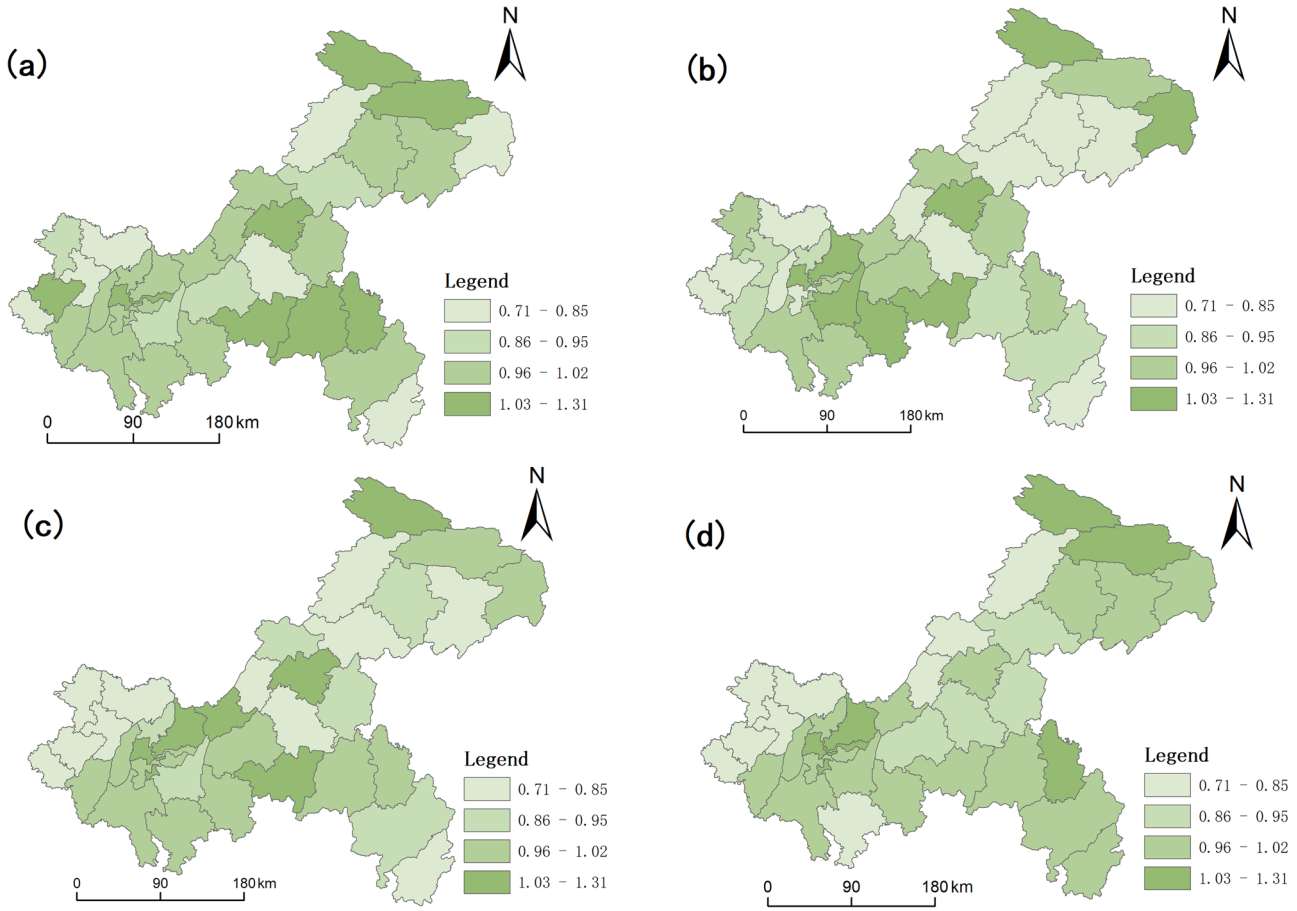

Fig. 6 Chongqing's 2010–2021 HQD level spatial distribution map. a 2012, **b** 2015, **c** 2018, and **d** 2021.

Table 3 Changes in the number of H- and L-efficiency districts and counties in Chongqing.

Year	L-efficiency	M-L efficiency	M-H efficiency	H-efficiency
2012	7	4	18	9
2015	12	5	12	9
2018	11	6	13	8
2021	9	4	17	8

It can be seen from Fig. 7 that Chengkou, Jiangbei, Shapingba, Yubei, and Yuzhong were the main H-efficiency districts and counties for a long time, while Dazu, Dijiang, Hexhuan, Kaizhou, Rongchang, Tongliang, and Wushan were the L-efficiency districts and counties for a long time. These districts and counties should learn from H-efficiency districts and counties to improve their own efficiency.

Analysis of global autocorrelation results. In this work, we used the Global Moran's *I* analysis in ArcGIS (10.8) to check whether there was a statistically significant spatial autocorrelation in the HQD level of various districts in Chongqing, that is, whether similar efficiency levels in the HQD level of various districts in Chongqing were clustered together and distributed across the entire analysis region. As Fig. 8 shows, half of the years were significant. In 2014, it was the first time that it was significant, with a P value of 0.0059 (<0.01) and a Z value of 2.7524 (>2.58), indicating that 99% of the grasped elements were clustered; that is, the probability of randomly generating this clustering pattern was <1%. Then, the HQD level of all districts in Chongqing also showed significant spatial autocorrelation in 2015, and the Moreland index was >0; that is, the data displayed a positive spatial correlation. Subsequently, since 2018, the HQD level of 38 districts demonstrated a positive spatial correlation. From the change of the value of the Moreland index in the past 12 years, the Moreland index showed a trend of fluctuation and rise, and reached the maximum value of 0.3326 in 2020. This indicates that HQD levels in the 38 districts of Chongqing display more significant spatial autocorrelation over time.

Analysis of local autocorrelation results. As can be seen from Fig. 9, the number of H–H agglomeration areas showed a certain volatility. In 2012, H–H agglomeration areas were relatively limited in the southeastern Pengshui County. However, during 2015, 2018, and 2021, H–H cluster areas were mainly concentrated in the central urban area and the new main urban area. In 2015, the H–H agglomeration area was most concentrated, and its scope widely covered Banan, Fuling, Nanchuan, Jiangbei, and the South Bank of the central city, and further expanded to Nanchuan in the southwest. In 2015, the H–L cluster appeared in Tongnan district in the west of Chongqing, while in 2018 and 2021, this cluster phenomenon was only seen in Zhongxian county in the northeast. The L–H cluster only appeared in 2012 and 2018, and both appeared in the Banan district of the central city. L–L cluster first appeared in Dazu, Rongchang, and Yongchuan in the western region in 2015 and Yunyang county in the northeast, then stabilized in the western region of Tongnan in 2018 and 2021.

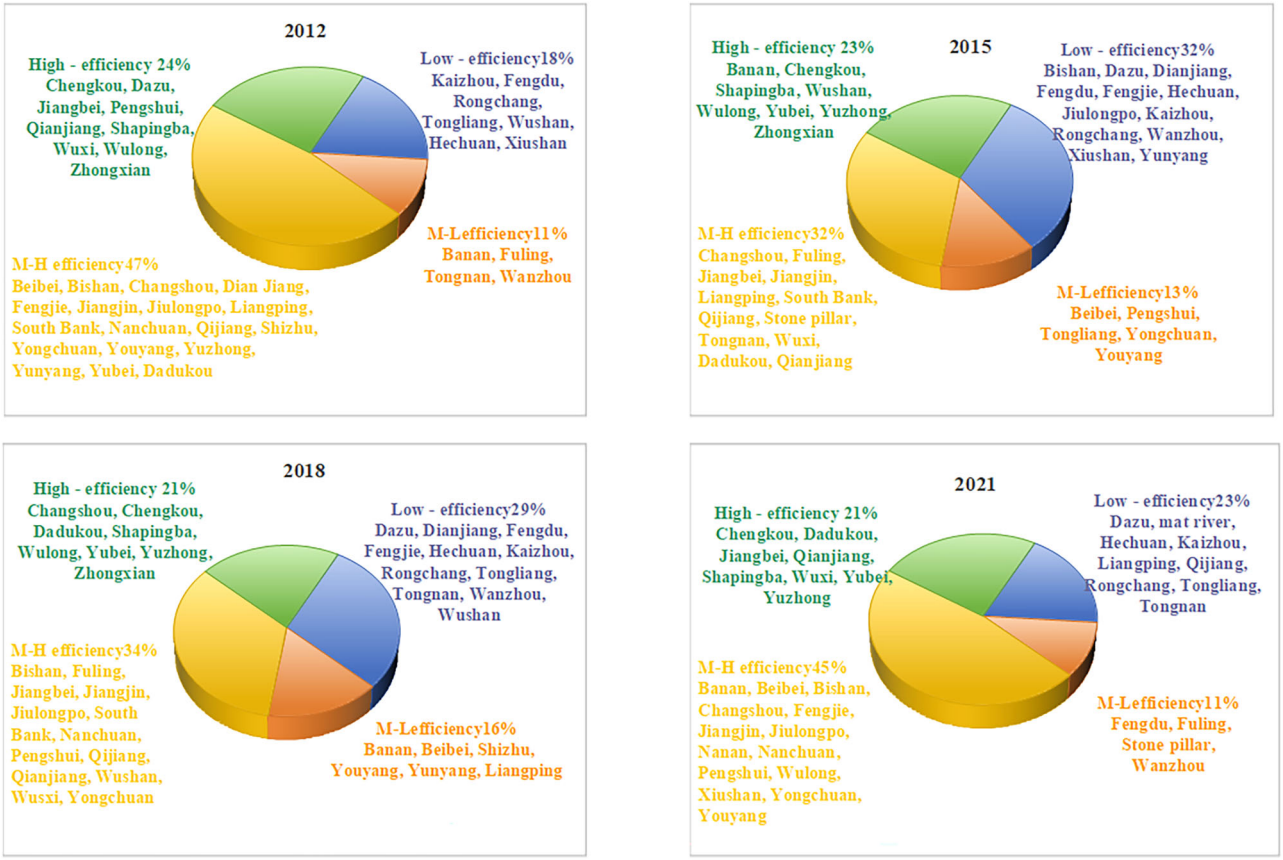

Fig. 7 Specific changes of HQD efficiency in Chongqing from 2010 to 2021. The pie chart presents the proportion of districts and counties at each level of HQD. The text part of the chart lists the specific names of the districts and counties corresponding to each level, respectively.

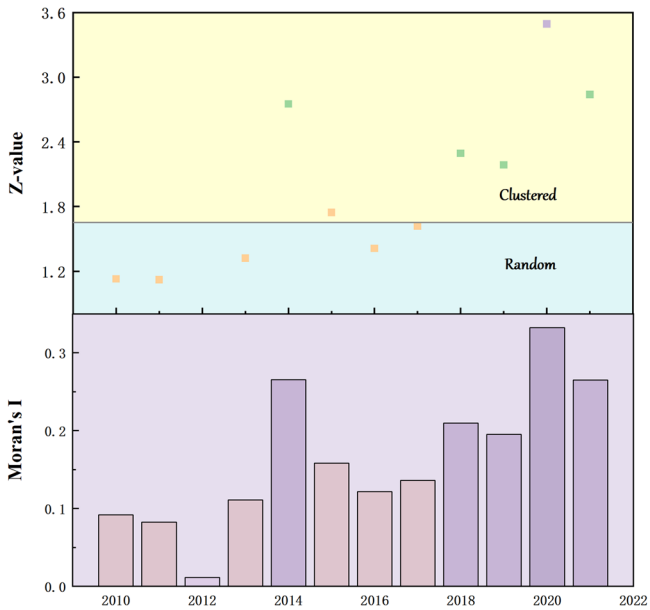

Fig. 8 Global spatial distribution of Chongqing. This graph adopts the form of a combination of bar charts and scatter plots to show the temporal variation trend of the global Moran's I index and its Z value of the HQD in Chongqing from 2010 to 2021.

The results revealed that the H–H agglomeration area showed a notable distribution characteristic of "center polarization–periphery fluctuation": the formation of this spatial pattern is mainly due to the perfect infrastructure support of the central city, the deepening of industrial chain synergy, and the continuous tilting of municipal policies and resources. The central city has long enjoyed the municipal finance, land indicators, major projects priority layout, and the surrounding areas to form a "resource siphon effect." Although the peripheral districts and counties, such as Pengshui, Nanchuan, and Wuxi, have occasionally relied on agricultural and tourism integration projects or cultural and tourism resources to achieve a short-term leap, they have not been able to sustain it due to the weak foundation. Pengshui became an H–H cluster in 2012 due to the centralized release of policy dividends and the regional linkage of the characteristic industrial chain. Around 2012, Pengshui started the relocation and remediation of coal-sinking areas, releasing land resources for large-scale agricultural operations; the county also took sweet potatoes as the core to create geographical indications to enhance the output value of the whole agricultural industry chain. At the same time, Pengshui united with Wulong, Youyang, and other counties to create the Wujiang River Gallery tourism belt, attracting cross-regional tourists. However, after 2013, the strengthening of environmental regulations led to a sharp increase in pressure on the transformation of traditional industries, coupled with lagging transportation infrastructure, resulting in its industrial chain failing to extend to high-value-added (sweet potato processing did not form a brand premium), and ultimately, the efficiency value fell below 1. Nanchuan and Wuxi failed to sustain as H–H clusters due to spatial spillovers constrained by inefficient neighboring districts and counties. Year 2015 saw Nanchuan district leapfrog to become an H–H cluster by virtue of its short-term policy dividends and localized efficiency gains. However, after 2015, its neighbors, Banan and Fuling, had much lower efficiency values than Nanchuan due to

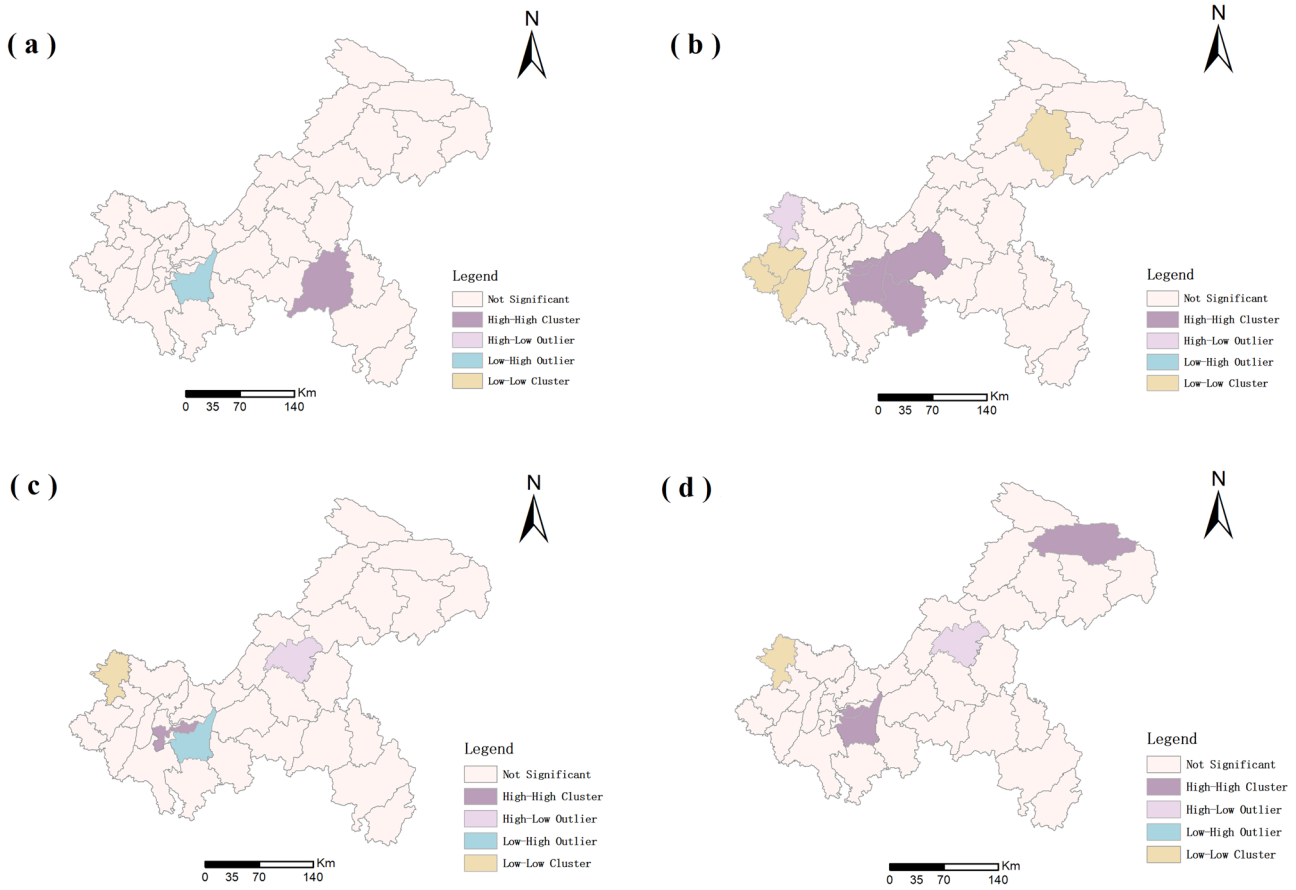

Fig. 9 Local spatial autocorrelation clustering diagram for Chongqing's HQD level from 2010 to 2021. a 2012, **b** 2015, **c** 2018, and **d** 2021.

lagging transformation of traditional industries and low levels of land intensification, and Nanchuan exited the H–H agglomeration. Similarly, before 2021, Wuxi was surrounded by Kaizhou, Yunyang, and Fengjie, whose efficiency values have long been low due to traditional industrial dependence, insufficient policy support, and geographic constraints. After Kaizhou and Yunyang's efficiency briefly improved due to the transfer of industries in 2021, Wuxi became an H–H agglomeration.

In 2015, Tongnan showed a high–low pattern, but the pattern did not last, and then Tongnan turned into a stable low–low pattern. In 2018, Zhongxian county focused on the development of the *four major industrial clusters*, that is, new energy, medicine, intelligent equipment, and resource processing; the introduction of high-end equipment manufacturing enterprises; the use of local resources to develop specialty industries to enhance the value-added; and the efficiency of a substantial increase. This growth momentum, brought about by industrial restructuring, contrasts with the lagging efficiency improvement caused by the single industry structure, loss of talent capital, and insufficient policy suitability in neighboring districts and counties, such as Fengdu and Dianjiang. The resulting spatial efficiency divergence has led to a persistent H–L cluster in Zhongxian. It is worth noting that the evolutionary trajectory of Tongnan's efficiency pattern coincided with the cliff-like decline in efficiency that occurred in Tongnan in 2016 in the above study, further highlighting the constraints of lagging industrial transformation on the efficiency improvement of HQD.

The fact that L–H clusters were only visible in 2012 and 2018, both in Banan, is closely related to the district's locational conditions and lack of strategic planning. Banan belongs to Chongqing's south district, located in the southernmost part of the city, and is not in the main direction of Chongqing's strategic development. At the same time, there is relatively little rail transportation in Banan, and the short-term plan for the future does not cover new places. The strategic marginalization and the backwardness of the regional transportation network have led to a continuous decline in its development momentum, creating an inefficient predicament.

Inefficient agglomerations were concentrated in the Yuxi region (Western Chongqing) as well as Yunyang county in 2015 and continued to be locked in Tongnan after 2018. Around 2015, the traditional industries in the Yuxi region had not yet been upgraded, resulting in weak growth, while the lack of cultivation of emerging industries led to overall low efficiency. For example, Dazu Hardware, elevators, and other traditional manufacturing industries dominated, while the intelligent elevator industry, despite having a certain scale, had excessive reliance on the real estate market, leading to a lack of industrial toughness, with the industry's cyclical adjustment into the development of difficulties. The regional transportation infrastructure shortfall further amplified this predicament. Around 2015, Rongchang had not yet formed a western air cargo node, and Dazu had not yet established the status of an open gateway hub, resulting in weak external economic ties. Moreover, Yunyang, as a typical mountainous poverty-stricken county, has a weak economic foundation superimposed on ecological constraints, and the innate deficiencies of having a small number of enterprises, a small scale, and weak competitiveness are further amplified under the condition of lagging infrastructure. In addition, the structural contradiction of the labor force is also one of the reasons for its inefficiency. Yunyang has a high proportion of agricultural population but a low level of literacy,

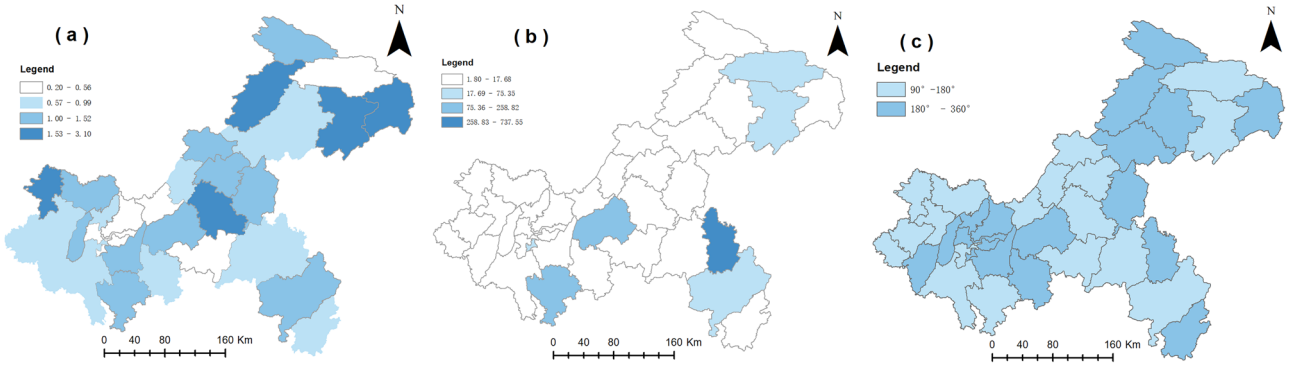

Fig. 10 LISA temporal path spatial characteristics of HQD in Chongqing. a Relative length, **b** curvature, and **c** migration direction.

Table 4 HQD space-time transition matrix.

$t/t+1$	H-H	L-H	L-L	H-L	Type	Quantity	Percentage	SF	SC
H-H	0	0	0	0	I	331	0.791866	0	0.791866
L-H	0	129	0	45	II	0	0		
L--L	0	0	0	0	III	0	0		
H-L	0	42	0	202	IV	87	0.208134		

which leads to the obstruction of the transformation of agricultural scientific and technological achievements.

Spatial distribution direction characteristic analysis. From the standpoint of space and time, the relative length of the LISA time route can show the stability of spatial structure and local spatial dependency. In this study, ArcGIS 10.8 software was used to visualize the relative length of HQD in 38 districts in Chongqing. The relative length of HQD was divided into four categories according to the natural break point classification method. Figure 10a shows the relative length of five regions—Tongnan in the west of Chongqing, Fengdu in the middle of Chongqing, and Kaizhou, Fengjie, and Wushan in the northeast of Chongqing—to be relatively high, which indicates that the spatial evolution of HQD in these regions is more dynamic. Most of these districts and counties were consistent with the districts at low or medium to low levels of HQD. The districts with a low relative length were Yubei, Jiangbei, and Nanan, which are mainly located in the CUa, and the spatial pattern of these districts showed relatively little change. The comparison chart shows that the counties with higher relative length had higher HQD levels. Therefore, it can be concluded that districts with higher HQD would show more stable local spatial structure, while districts with lower HQD would demonstrate stronger instability.

In addition, there are four levels for the LISA time path curvature. The influence of HQD on the neighborhood space (overflow/polarization) increases with curvature value, and its spatial dependence has greater volatility. Figure 10b shows that Qianjiang, Qijiang, and Fuling had a higher curvature of the LISA time path for HQD, reflecting that these regions are more volatile in the direction of spatial dependence. In addition to these three counties, most of the other counties had low curvature of HQD, which indicates that the spatial dependence transition process in these regions is relatively stable. Figure 10c visualizes the migration direction of LISA's time path. During the study period, all 38 districts in Chongqing showed synergistic growth and positive synergistic growth in HQD; that is, they themselves and their neighboring counties showed a positive synergistic growth transition mode. This indicates that the spatial pattern of HQD in Chongqing is very stable.

The movement direction of the LISA coordinate points in each district was determined by varying the position of Moran's I scatter plot, and ArcGIS 10.8 was utilized for visualization (Fig. 10c). If the moving direction is [0°–90°) and [180°–270°), it indicates that the HQD of this region and adjacent regions presents a positive (win–win type) or negative (lose–lose type) growth trend, respectively. If the direction of movement is 90°–180° and 270°–360°, it indicates that the region and the adjacent region show a reverse (win–win and win–lose) growth trend. Figure 10c shows that between 2010 and 2021, Chongqing's HQD movement direction was 90°–180° and 270°–360°, indicating that the HQD level of each district in Chongqing is low (high), while the HQD level of its neighboring districts is high (low). This also once again verifies that the coordination of HQD in various districts of the city was poor, and the degree of spatial integration was low.

We further used the LISA time–space transition to study the characteristics of the inter-transfer process of HQD horizontal local spatial association types in 38 counties of Chongqing. In Table 4, the spatial cohesion of HQD in 38 counties of Chongqing is 0.791866, reflecting that the probability of local spatial correlation between districts and counties of Chongqing not occurring in the past 12 years is 79.19%, which means that the spatial and temporal transition of districts and counties showed strong path-locking characteristics. The order of the probabilities of the four types of time–space transition was as follows: Type I (0.79) > Type IV (0.21) > Type II (0) = Type III (0). The probability of Type I was the highest, which means that it reflects only the transition of the district unit itself. The second highest was Type IV, which indicates that the county unit and its neighborhood unit are still in the same quadrant, and there is no transition.

Spatial distribution direction characteristic analysis. Figure 11 demonstrates the results of the standard deviational ellipse analysis, revealing changes in the spatial distribution pattern of HQD in Chongqing. The ellipses generated in 2012, 2015, 2018, and 2021 were 4.76, 4.78, 4.87, and 4.98, respectively. From the perspective of the ellipse area, the scope of HQD in 2021 was greater than that in 2012, which is a positive signal. At the same time,

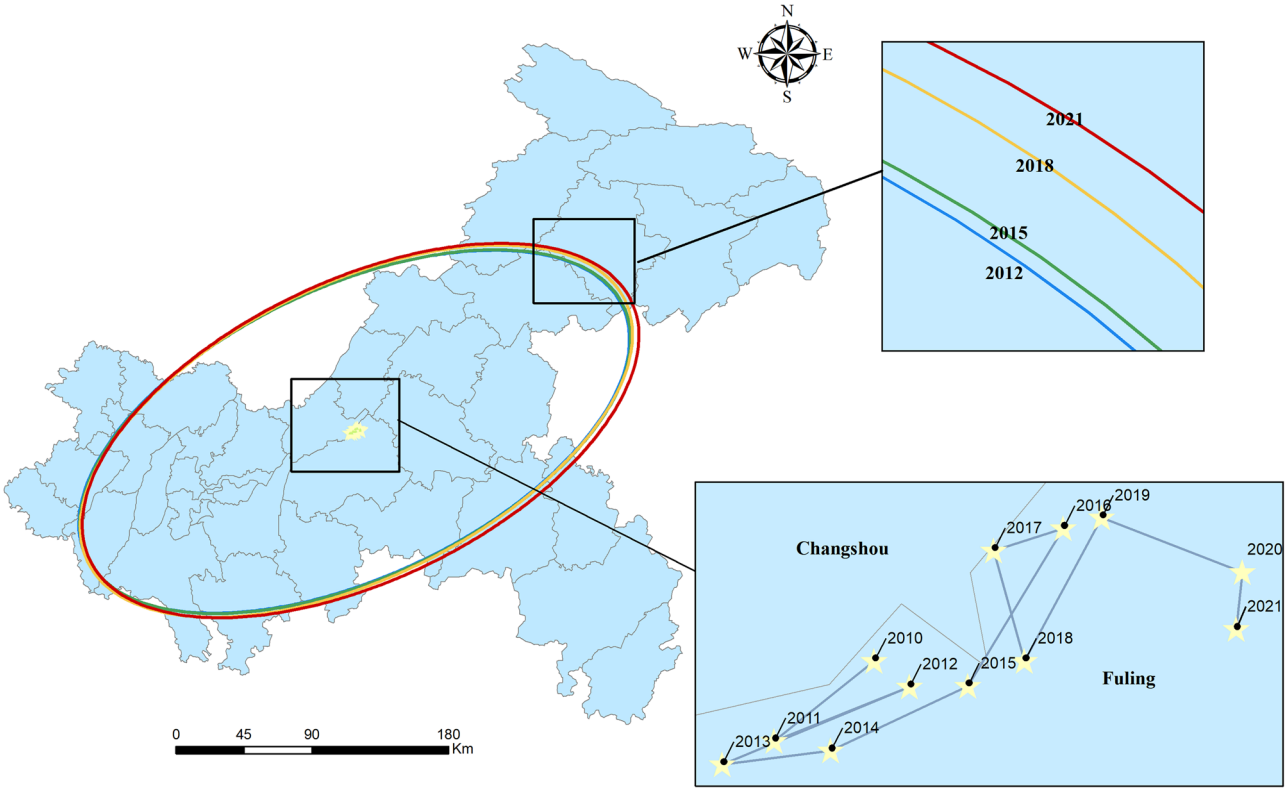

Fig. 11 Changes in the average center of HQD and the standard deviation of the ellipse's spatial distribution in Chongqing. The corresponding year for each ellipse is labeled by color in the upper right corner, and the trajectory of the mean center from 2010 to 2021 is shown in the lower right corner.

from the oblateness, there was a large difference in the value of the semi-axis of the ellipse of HQD in Chongqing, indicating that the HQD level of 38 Chongqing districts and counties is more oriented. From the perspective of spatial rotation, the rotation angle decreased from 65.09° in 2012 to 64.44° in 2021, and the generated ellipse direction was basically consistent with the trend of the Yangtze River, which indicates that the Yangtze River plays a very important role in the HQD of Chongqing. As an important traffic artery of Chongqing, the Yangtze River not only promotes the circulation of materials and personnel exchanges among regions but also provides strong support for the economic development of the areas along the river.

Trend surface analysis. The longitude and latitude of the geographical location were taken as independent variables *X* and *Y*, respectively, and the efficiency value of HQD of each district and county was taken as a dependent variable. The results of trend surface analysis are shown in Fig. 12, where the due north direction is represented by the *Y*-axis and the due east direction by the *X*-axis. The blue curve reflects the fitting line of the spatial change of high-quality efficiency value in the north–south direction, and the green curve reflects the fitting line of the spatial change of high-quality efficiency value in the east–west direction. The results showed that in the early stage, the overall distribution of high-quality efficiency in Chongqing had little difference in the north–south direction, but since 2015, the north–south direction gradually began to display a more obvious U-shape, with high values on both sides and low values in the middle. In the east–west direction, there was a relatively obvious inverted U shape, high in the middle and low on both sides, which changed to high in the east and low in the west in 2021. This is basically consistent with the result of our study, which states that the development level of the western part of Chongqing is low.

Discussion

Overall, the HQD level in Chongqing showed an N-shaped change trend. The average level of HQD exhibited an increasing trend during 2010–2012 and a declining trend during 2013–2016. There was an overall upward trend from 2017 to 2021. This change trajectory is slightly inconsistent with the conclusion obtained by Chen (2021) that the HQD level of China's economy is generally on the rise. This further emphasizes the importance of taking specific cities as research units to more accurately grasp the dynamics and differences of HQD in different places. The two declines in Chongqing's HQD efficiency in 2014 and 2016 essentially reflect transitional challenges arising from the withdrawal of traditional growth models and the inadequate succession of emerging drivers. In 2014, the decline in HQD efficiency was mainly due to the tightening of environmental protection policies and investment-driven failure. In 2016, the efficiency declined again because of the impact of deepening supply-side reform and the lagging cultivation of emerging industries.

From the perspective of time and space of HQD, the number of H-efficiency and M–L efficiency counties remained relatively stable, while the number of M–H efficiency and L-efficiency counties fluctuated greatly in a specific stage, which means that there are still many counties with unstable HQD efficiencies; specifically, there is still much room for improvement in HQD equalization in Chongqing. This phenomenon is the same as the development problem raised by the significant difference in the level of HQED among provinces and cities in China, pointed out by Chen (2021). It can be seen that the balance of HQD remains a pressing issue that demands immediate resolution both at the national level and in cities such as Chongqing. Most of the H-efficiency districts and counties in Chongqing in different years are distributed in the northeast region, the southeast region, and CUa. These H-efficiency regions have two major characteristics: first, they are not connected but rather independently distributed.

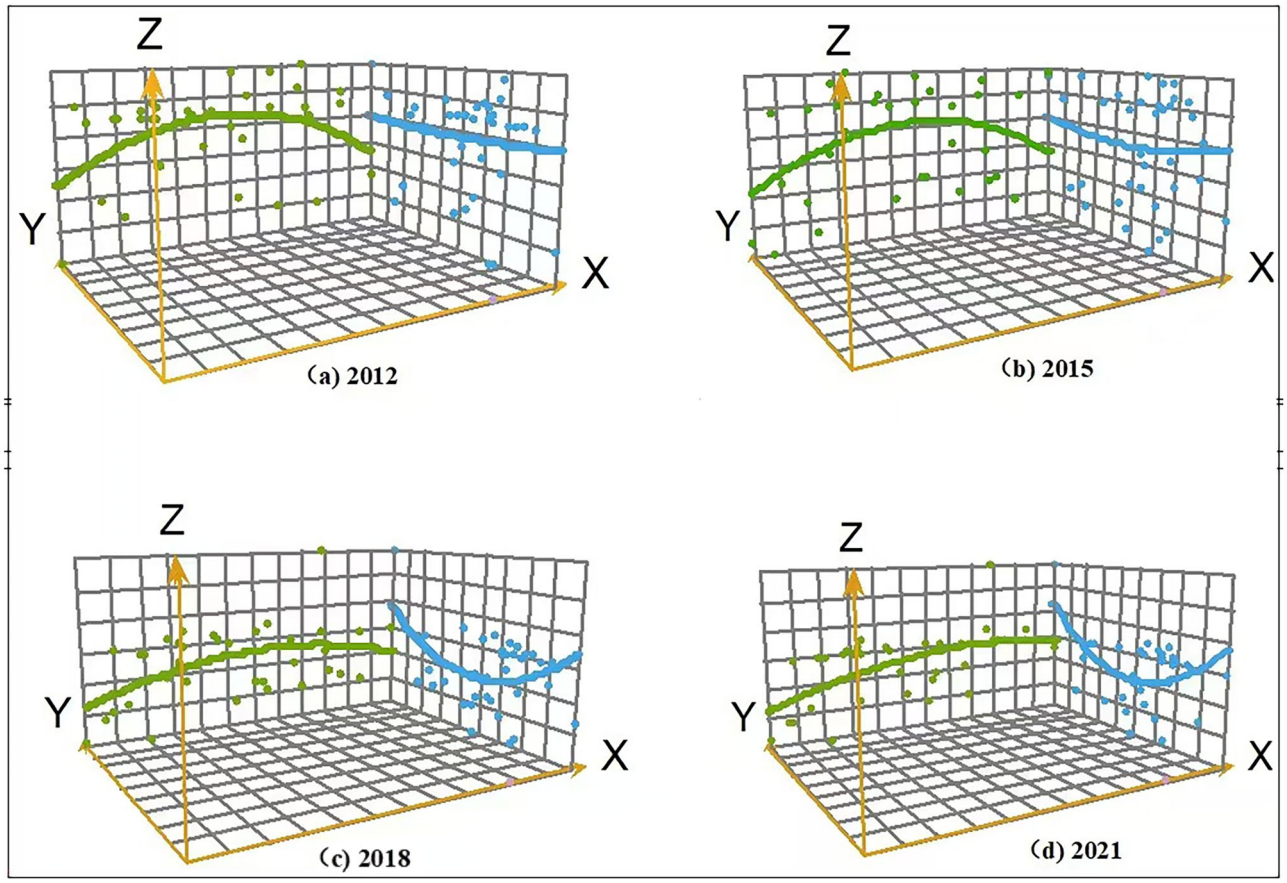

Fig. 12 Trend surface analysis. This picture presents the trend surface analysis results of the HQD level in Chongqing in 2012, 2015, 2018 and 2021. The blue and green curves respectively represent the fitting lines in the north-south and east-west directions.

The vast majority of the M-H-efficiency districts are distributed around the high-efficiency districts, forming a close efficiency circle layer, which together constitutes a relatively complete efficiency improvement belt. Second, these H-efficiency areas are mainly distributed along the Yangtze River in Chongqing, and the location advantage along the Yangtze River has a significant impact on improving the HQD level. In addition, the efficiency of districts and counties in the west of Chongqing has been low for many years, which is similar to the phenomenon of "high in the east and low in the west" in the overall spatio-temporal characteristics of China's Huaihe Ecological Economic Zone revealed in Sun et al.'s (2021) study. If the efficiency level of Western districts is effectively improved, the overall HQD level of Chongqing will be greatly improved.

Based on the analysis of HQD concentration in Chongqing, it was found that the H–H concentration area in Chongqing had a large fluctuation range, and the H–H concentration area changed frequently in different years, indicating that the competition between H-efficiency districts and counties is fierce and that the development coordination among them is poor, which is detrimental to raising Chongqing's general level of development. The fluctuation of L–L agglomeration area in a particular year was large and has gradually tended to be stable in recent years, indicating that the trend of low-value area concentration in Chongqing is not obvious or is gradually slowing down, which helps Chongqing avoid forming a "depression" for regional development. However, it should be noted that Banan has been in the L–H cluster area for a long time and dragged down the average HQD level of the entire CUa. The entire area of Banan belongs to the southern district of Chongqing, which is located in the southernmost part and is not in the main direction of Chongqing's strategic development. At the same time, the rail transit in Banan is relatively small, and the future short-term planning has not covered new places. Therefore, if Banan wants to improve the HQD level, only by making good use of its own advantages and seizing the unique industry of the city can it have a better future.

Using GIS technology in 38 counties in Chongqing HQD relative length, bending, and LISA time path for the visual analysis, some districts and counties in Chongqing were found to show high dynamic HQD spatial evolution, including Tongnan (in the west), Fengdu (in the middle), and Kaizhou, Fengjie, and Wushan in the northeast. The relative length of these regions was relatively high, showing a relatively active HQD development trend, and these districts and counties were often at L-efficiency levels. Concerning Yubei, Jiangbei, and Nanan, the relative length was low, the spatial change was relatively small, and these counties were often at the H-efficiency level. The HQD curvature of most counties was low, which indicates that the spatial dependent transition process in these regions is relatively stable. In order to improve the overall HQD level in Chongqing, it is necessary to pay special attention to the districts and counties with L-efficiency level and high dynamic characteristics, such as Tongnan, Fengdu, Kaizhou, Fengjie, and Wushan; constantly strengthen the coordinated development among the districts and counties; enhance the degree of spatial integration; and pay attention to policy guidance and supervision.

Finally, the results showed that the spatial distribution direction of HQD in Chongqing is basically consistent with that of the Yangtze River, which indicates that the Yangtze River plays a very

important role in the HQD of Chongqing. At the same time, the main reason for the unbalanced regional development in Chongqing is the large HQD gap between the east and the west, which is related to the development plan of Chongqing. The main direction of Chongqing's development is to the north. Chongqing has developed from Guanyin Bridge all the way to the north of Jiangbei Airport, Shuitu, and Longxing area. To enhance the HQD level in the west, the future development of Chongqing should pay attention to the west, make use of the whole western trough and valley, build the western science city, and continue to improve Liangjiang New Area.

As a typical megacity in China, Chongqing's practices in addressing industrial transformation and regional coordination can serve as a reference for other regions seeking high-quality development. In terms of industrial transformation, Chongqing has promoted technological upgrades in traditional industries through technological reform subsidies and industrial funds, reducing environmental compliance costs to alleviate pressure from environmental policies. This has effectively addressed the efficiency decline caused by rising costs due to strict environmental policies and insufficient new growth drivers. This is also a common "adaptation dilemma" faced by resource-intensive regions when transitioning from extensive growth to intensive development. For example, Shanxi—a coal-resource-based region—experienced short-term economic decline when promoting coal production capacity reduction (particularly through investment control policies) to achieve green transition (Yao et al., 2022); similarly, resource-dependent regions in BRICS countries suffered economic downturns due to reduced resource rent income and lagging green technology transition driven by tighter environmental policies (Zhang et al., 2024). Addressing these issues requires fostering new growth drivers while providing transitional support to buffer environmental policy shocks. At the regional coordination level, despite Chongqing's upgrade of the "one-hour economic circle" to the "main city new district" to strengthen the radiating influence of its central area, the issue of uneven development persists. This is a typical dilemma faced by megacities in the global urbanization process—the "core-periphery" dilemma, where resources are highly concentrated in the core while peripheral areas lag behind in development. Experience shows that peripheral regions cannot rely solely on the radiating effect of central areas; targeted interventions are needed, such as addressing key infrastructure shortcomings and cultivating their unique advantageous industries. It is important to recognize that "balanced development" does not equate to "equal distribution" (Kong et al., 2025). Only by implementing targeted measures to address development shortcomings can regional development imbalances be effectively resolved.

Conclusions and policy recommendations

Conclusions. Based on the connotation and extension of HQD, this paper introduces efficiency thinking and selects 20 indicators from six dimensions—economic development (E), innovation vitality (I), openness to the outside world (O), resource utilization (R), ecological security (E), and social progress (S)—to construct the EITOS-DEA high-quality development measurement system. Super-EBM model, GIS technology, Moran's *I* index, spatial distribution direction characteristics, spatio-temporal transition, and trend surface analysis were used to analyze the spatial and temporal evolution of HQD in Chongqing, the spatial agglomeration pattern, and the spatial center of gravity shift. The findings indicated the following:

(1) Chongqing's overall HQD level fluctuates in an *N*-shape.

The overall HQD efficiency of Chongqing municipality from 2010 to 2021 was characterized by N-shaped fluctuations, with two efficiency declines in 2014 and 2016 constituting the declining phase of the N-shaped fluctuations. The two declines jointly exposed the core contradiction between the pressure of internalization of environmental costs and the disconnection of the transformation of old and new kinetic energy, highlighting the dilemma of adapting from the crude growth mode to intensive development.

(2) CUa had the highest level of HQD, and the siphoning effect was obvious. HQD levels were unbalanced within Chongqing, with noteworthy regional differences in the distribution of H-efficiency counties.

The HQD level of CUa drastically exceeded the other three regions, and it was the only one that reached and exceeded the threshold of 1, showing an effective trend of HQD. This phenomenon, together with NDMc, constitutes an obvious *siphon* effect. Although NDMc is close to CUa, its development level relatively lagged behind, and there was a big gap compared with SE, let alone CUa. This highlights the imbalance in Chongqing's HQD. The number of L-efficiency and H-efficiency counties in Chongqing was relatively stable, while the number of L-efficiency and M–H-efficiency counties fluctuated greatly. H-efficiency counties were mainly distributed in the northeast, southeast, and CUa of Chongqing. The western region has always had large areas of inefficiency. Chengkou, Jiangbei, Shapingba, Yubei, and Yuzhong districts have been in the H-efficiency district for a long time, while Dazu, Dianjiang, Hechuan, Kaizhou, Rongchang, and other districts and counties have been in the L-efficiency district for a long time.

(3) The H–H agglomeration has turned over frequently in different years, while the Banan district has remained in the L–H agglomeration for a long time.

The HQD level of 38 counties in Chongqing showed a significant spatial autocorrelation, and the HQD concentration in Chongqing displayed an optimal trend in 2015. Overall, the fluctuation range of the H–H agglomeration area in Chongqing was large, and the H–H agglomeration area changed frequently in different years, indicating that competition among H-efficiency districts and counties is fierce and that the development coordination among them is poor. Banan has been in the L–H cluster area for a long time, and its own efficiency was low, but the efficiency of the surrounding counties was high.

(4) The local spatial structure of high HQD districts and counties was more stable, while the spatial trajectory of HQD in Chongqing was consistent with the direction of the Yangtze River.

Counties with higher HQD would show more stable local spatial structure, while counties with lower HQD would show stronger instability. The stability of the transition to space dependence in Qianjiang, Qijiang, and Fuling regions was poor. At the same time, the temporal and spatial transitions of each district and county in Chongqing showed strong path-locking characteristics. The HQD spatial trajectory of Chongqing mainly reciprocated along the southwest to northeast direction, which is basically consistent with the trend of the Yangtze River. Meanwhile, the unbalanced development of Chongqing is mainly caused by the east–west imbalance.

Policy suggestions. First, Coordinated promotion of talent attraction, agricultural value chain upgrading, green transformation of traditional industries, and building new kinetic energy for high-quality development of the county economy.

An innovative investment model and the convergence of capital, technology, talent, and other elements inside and outside the region must be emphasized to develop advantageous resources into an industrial competitive advantage. While

strengthening the introduction of talent, we should also focus on skill training for farmers and accelerate the transformation of scientific and technological achievements into real productivity. For Pengshui and other leading agricultural counties, efforts should be made to extend the industrial chain, fully integrate into the *Ba Shu Yu Zhen* and other regional public brand construction, strengthen the deep processing of agricultural products and agricultural science and technology empowerment, focusing on branding and fostering independent brands with regional characteristics. For Dazu, Xiushan, and other districts and counties relying on high-energy-consuming industries, it is necessary to increase the intensity of investment in science and technology innovation, and in the process of fostering new industries, to simultaneously establish a special fund for environmental protection and transformation. Through technological transformation subsidies, tax relief during the transition period, and other policy combinations, not only to safeguard industrial upgrading, but also to alleviate the pressure of short-term transformation of enterprises, and to realize the virtuous cycle of green development and economic benefits.

The second recommendation concerns building a differentiated policy system for mountainous areas and exploring new paths for the synergistic development of ecological protection and characteristic industries.

Chongqing's pattern of "big city with big countryside" has led to noteworthy differences in policy effects between urban and mountainous areas, so it is necessary to fully consider the urban–rural differential effects of policy implementation and formulate policies based on the unique development constraints and advantages of mountainous areas. In view of the rigid constraints imposed by the ecological protection red line on traditional industrialization in mountainous areas, it is necessary to break through the path of dependence, explore the characteristic development mode of "ecological economic feedback," and focus on cultivating mountain-adapted industrial systems. For example, Wushan has replaced the highly polluting mining industry with the forest economy, and Chengkou has built a clean energy industry cluster based on the advantages of natural resources. For Wulong, Youyang, and other ecological resources–rich areas, we should vigorously develop the integration of agriculture and tourism, systematically improve infrastructure and public service support, beautify the village environment, and innovatively cultivate leisure farms, forest recreation, non-heritage hostels, and other diversified business forms. Moreover, festivals and activities should be performed to attract traffic and digital platforms and promote a variety of ways to effectively activate the endogenous power of the mountain economy and achieve ecological protection, industrial revitalization, and livelihood improvement of the multi-win pattern.

The third suggestion is to strengthen the driving role of CUa and improve the quality of NDMc development to effectively mitigate the siphon effect.

Specifically, for areas such as Jiangbei, Shapingba, Yubei, and Yuzhong, where CUa has long been at the H-efficiency level, resource allocation should be further optimized to strengthen its radiation and driving role in the whole city. Simultaneously, these areas should fully utilize their own driving forces in order to lessen the presence of L–H gathering spots and encourage balanced regional growth. Districts and counties in L–H gathering areas should also speed up their own development and narrow the gap. For example, Banan, which has been in an L–H gathering area for a long time, has low efficiency mainly because it is not in the main direction of strategic development in Chongqing. However, Banan has rich resources of higher vocational colleges, which can be used as an opportunity to focus on the development of a higher vocational city and form a strategic layout of a "university city in the west and higher vocational city in the south." In strengthening the connection between CUa and NDMc, emphasis should be placed on solidifying the construction of transportation infrastructure and promoting the coordinated development of industries, so as to effectively alleviate the siphon effect. Dazu, Dianchang, Hechuan, Kaizhou, and Rongchang, which have been at L-efficiency levels for a long time, should actively learn from H-efficiency districts and counties and their successful experience.

Fourth, it is vital to improve the coordination of development among districts and counties to promote balanced development among districts and counties.

The fluctuation of the number of M–L efficiency counties and L-efficiency counties in a specific stage was large, indicating that there is still much room for improvement in the equalization of HQD of Chongqing's districts and counties. Chongqing should strengthen policy guidance and support for medium-low-efficiency and L-efficiency districts and counties, optimize the development environment, and increase the effectiveness of resource distribution and innovation ability to promote the HQD of these districts and counties. The fluctuation range of the H–H cluster area in Chongqing is large, and the H–H cluster area changes frequently in different years, indicating that the competition between H-efficiency districts and counties is fierce and that the development coordination among them is poor, which is detrimental to raising Chongqing's general development. We should strengthen policy guidance, ensure the continuity and stability of policies, avoid internal friction and disorderly competition, and form a new situation of coordinated development. Shapingba and Jiangbei (central city); Fuling, Nanchuan (main city's new district), Kaizhou, and Wanzhou (northeast Chongqing); Qianjiang and Xiushan (southeast Chongqing), and other regions with excellent development but lagging behind the surrounding areas should give full play to the driving role of radiation. Through the mechanism of resource sharing, industrial collaboration, and technology transfer, it promotes economic growth and social development in the surrounding areas, thus making positive contributions to the overall prosperity and sustainable development of Chongqing.

Fifth, the Yangtze River should be used as an important geographical axis, and the rational distribution of population, industry, and infrastructure should be ensured to achieve more efficient and sustainable urban development.

In view of the convenient transportation and abundant resources along the Yangtze River, Chongqing can plan residential zones along the river to attract people to gather in this area. For example, measures such as optimizing housing policies and improving supporting facilities should be taken to enhance the attractiveness and livability of residential zones along the river. Secondly, with the Yangtze River as the main axis, we will build the core area of the Yangtze River Economic Belt, integrating shipping, water conservancy, tourism, and industry. Through the introduction of high-quality enterprises, improving the technical level, and other measures, the industrial clusters have been formed, such as the shipping industry cluster and the high-end manufacturing industry cluster. Finally, the use of the Yangtze River as a natural waterway strengthens water transportation construction and enhances shipping capacity. Under the constraints of Chongqing's mountainous terrain, transportation construction not only needs to accelerate the construction of new land and sea corridors in western Chongqing and cross-regional trunk lines, such as high-speed railways, along the river to shorten the spatial and temporal distance with the Chengdu–Chongqing Twin Cities Economic Circle and the city clusters in the middle reaches of the Yangtze River and undertake the transfer of industries and spillover resources but also needs to innovate mountainous transportation solutions. For the Wuling Mountains, the Three Gorges Reservoir, and other areas, the traditional

idea of simply copying the highway construction model in the plains should be abandoned; instead, new service models, such as drone logistics and distribution and village-level intelligent posts, should be explored. For example, remote areas, such as Chengkou and Wuxi, can utilize drone distribution as well as village-level logistics points to build a new distribution system. This can not only avoid the high ecological and economic costs of building roads in mountainous areas but also provide a low-cost springboard for marginalized districts and counties to access the large regional market.

Finally, it is important to emphasize the development of the western districts and counties of Chongqing.

The reason for the low level of HQD in the western part of Chongqing is that the development level of eight districts—Jiangjin, Hechuan, Yongchuan, Dazu, Bishan, Tongliang, Tongnan, and Rongchang—in the western part of Chongqing is low. The west Chongqing area should give full play to its advantages of a solid industrial foundation and broad bearing space, accelerate the process of new industrialization, and create a new highland for the development of advanced manufacturing industries in the city. In land space planning, we should strengthen the integration of thinking, avoid regional and separate politics, and form scale effects and brand effects. At the same time, it is necessary to highlight the *city* orientation, perform overall planning, break down barriers, and continue to promote the coordinated cross-regional city development of public services, such as social security, employment, medical care, transportation, and education, so that the masses can share the fruits of regional city development. In addition, the western Chongqing area should continue to increase investment; improve transportation, water conservancy, energy, and other infrastructure networks; and enhance the regional comprehensive carrying capacity. In particular, major transport projects, such as the Bishan Airport, should be accelerated to build a transport hub system that radiates the western region, serves the whole country, and links the world. For Rongchang, Dazu, Yongchuan, and other areas of western Chongqing to be deeply integrated into the Chengdu–Chongqing region of the twin-city economic construction and the city's coordinated development of one area and two clusters. The county can have a decent opportunity for development only by integrating regional cooperation.

Deficiencies and prospects. Although this study conducted an in-depth evaluation of HQD in 38 counties of Chongqing from a new perspective and provided a valuable reference for Chongqing to realize regional coordinated development and solve the problem of unbalanced and inadequate development, there are still shortcomings. This study did not study the factors that influence HQD in Chongqing. Future scholars can further analyze the inner driving forces of HQD in Chongqing from the perspective of influencing factors, so as to provide more comprehensive guidance for HQD in Chongqing.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions

DLM: Supervision, Project administration, Writing–review & editing; RNC: Formal analysis, Methodology, Data curation, Supervision, Writing-original draft, Visualization; JWT: Visualization, Writing-original draft; FTZ: Visualization, Writing-original draft; YY: Writing-review & editing; BTA: Data curation; ZMG: Data curation, software; JWZ:Writing-review & editing.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

Informed consent was not required as the study did not involve human participants.

Additional information

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