ANALYSIS OF THE IMPACT OF HIGH-DENSITY URBAN DESIGN ON REGIONAL ECOLOGICAL ENVIRONMENT AND EVALUATION IN EASTERN CHINA

Guangxia Luo, Chunli Wang, Miao Cao, Xiaopeng Zhao, Gang Wu, Hui Yu, Ming Li, Ming Liu

Public Basic Education Office, Shanghai Technical Institute of Electronics & Information, Shanghai, 201411, China.

Yang Liu*

Department of Physical Education and Health, Shanghai Lixin University of Accounting and Finance, Shanghai, 201209, China.

liuyang19792019@163.com

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ABSTRACT

As the world's largest developing country, China's rapid economic development has caused more serious damage to the environment, and environmental pollution has become the number one problem in China's development. How to correctly deal with the coexistence of economy and environment is very important for the construction of our country. This paper analyzes the impact of urban design on regional ecology and how these influences can be evaluated, using a high-density city in eastern China as an example. This study takes the layout structure, spatial structure, facility support, flow organization and environmental ecology of the urban space as the direct carrier, and the cultural integration and technical response as the indirect carrier, and carries out the corresponding urban design in the above-mentioned space through the corresponding principles, strategies and methods. The impact of these elements on the urban ecological environment was also analyzed. The results of the study show that the ranking of ecological environment quality score in Anhui Province has been rising, and the number of the top five regions has increased from 20% to 80%.

KEYWORDS

High-density cities; urban design; regional ecological environment; evaluation system; influencing factors

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1. INTRODUCTION

The Earth is the home we depend on for our survival, and its enduring beauty is the cornerstone of the continuous development of human society. However, since 1960, with the global expansion of the industrialist development model, the uncoordinated development of the world's population, resources and environment has led to serious ecological and environmental problems [1-3]. The destruction of the ecological environment has seriously affected human health and life. With the accelerated development of China's economy and society, the construction of ecological civilization is gaining more and more attention from the state, society and people, and China is vigorously promoting the protection and construction of ecosystems [4-6]. And to the current development trend of China's economy, ecological problems have become a constraint for the continued development of China's economy to a certain extent, so the future construction of China must focus on environmental protection [7,8].

Currently, from the perspective of dynamic evolution, the cluster development of cities has become an important trend in urban development. From the objective results, the urban clusters formed by cluster development have become new economic growth poles, and this has led to the accelerated introduction of a series of urban cluster development plans [9-11]. At the same time, years of ultra-high speed and rough development have brought enormous pressure on resources and the environment, making China's green development increasingly important under the new normal [12,13]. In recent years, scholars have explored the issue of urban cluster construction and its green development. Zhang et al [14] predicted the future urban spatial state by using a linear model fitting method in Jinan, China, as an example. A comprehensive analysis of the urbanization development trend of Jinan and its impact on the vegetation cover within the city was also conducted based on the data on urban development trends in recent years. The results showed that the ground conditions and changes in Jinan were accurately reflected by linear model parameter clustering: high-density, stable urban types were found in the city center, while stable dense vegetation types were found in the southern mountainous areas. This approach demonstrates the prospect of urban growth in terms of environmental protection and conservative urban development. Ye et al [15] analyzed the changes in urban green spaces in Macau from 2010 to 2015, and they found that urban green spaces have a significant impact on the lives of urban residents, especially in high-density cities. Based on the prediction results of the two-step floating catchment area model, they concluded that the distribution of urban green space in Macau is extremely uneven, but it will gradually become more uniform over time, which is caused by the upgrading of related facilities and relevant policies. Zhang et al [16] proposed a new three-dimensional spatial design network analysis method for the built environment. They used the high-density urban area of Central, Hong Kong as an example to analyze the spatial configuration and its relationship with human activities in a three-dimensional spatial network. The results indicate that it is unrealistic to consider only outdoor pedestrian networks to study multilevel pedestrian networks in high-density built

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environments, and indoor and outdoor pedestrians should be considered comprehensively. Wang et al [17] studied the effects of greenways on microclimate in high-density cities using Shenzhen, China as an example. They analyzed the microclimate characteristics such as temperature, relative humidity, light intensity, and wind speed of five green roads in Shenzhen during daytime in summer, and compared the effects of green road microclimate on human comfort under different greening conditions using temperature and humidity index and wind efficiency index as evaluation indexes. The results show that when the summer temperature is high, green roads can significantly reduce the temperature as well as the light intensity and improve human comfort. The presence of green roads can significantly improve the microclimate characteristics of cities and increase the comfort of the population. Shi et al [18] used surface urban heat islands to describe the deteriorating thermal environment in high-density cities. They studied the urban design factors affecting surface urban heat islands in humid subtropical regions of China, using Guangzhou city as a representative city. Based on a series of satellite data as well as GIS databases, they found that surface temperature, vegetation cover, volume ratio, ground emission rate, and building density all have an impact on urban design. Hua et al [19] studied street greenery in Hong Kong using street-view images and deep-learning techniques. They found some spatial variation in street greenery, with less greenery generally occurring in private residences in high-density areas as well as in commercial centers. They also found that integrating street greening with urban morphology in an integrated analysis is very beneficial for urban and greening planning in sustainable and healthy cities.

Due to the misalignment between humans and nature, the relationship between economic development and environmental protection is seriously imbalanced, resulting in major environmental pollution events such as air pollution, river pollution, marine pollution, soil pollution, etc., and due to the inherent characteristics of the atmosphere and water flow, environmental problems also all present a regional character [20-23]. It is not only the focus of attention and ardent hope of the national people to develop the economy while paying more attention to protecting the environment, but also the necessary and proper way to realize the Chinese dream at an early date [24]. Regional eco-environmental co-construction is a new research development trend in the field of ecological compensation, which is a new development model for economic and social development to ensure the healthy operation of the ecosystem and achieve environment-friendly, ecological harmony and efficient use of material and energy [25-27]. Hu et al [28] analyzed the land utilization rate in the rapidly urbanizing region and the ecological effects of the region based on land use data from 2000 and 2015 in the PRD region. The results showed that the ecological quality of the PRD region was relatively stable during these 15 years, but there was a slight overall decline. Land use changes were mainly manifested in the gradual decrease of arable land, forest land, and unused land, indicating that the spatial expansion brought about by urbanization has largely affected the ecological quality of the PRD region. Zhang et al [29] used the entropy value method and the coupled coordination method to address the inconsistency in development between

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the economy and the ecological environment by examining the economic development, logistics development, and ecological environment development of 30 Chinese provinces and cities from 2008-2017, logistics development and ecological environment development levels were analyzed. The results show that the coupled and coordinated development of the economy and ecological environment varies greatly in space. Most cities in China have reached a medium level of coupled and coordinated development of economy and ecological environment, and only a few regions in the Middle East, such as Shanghai, have reached a high-quality level, while the coupled and coordinated level in the western region has been at a low level. Therefore, in future development, it is still necessary to take into account the economy and ecological environment to make the two develop in a coordinated and stable way. Li et al [30] analyzed the factors limiting the sustainable development of the region using the Pearl River Delta urban agglomeration in China as an example. They established a coupled coordination degree model and an ecological security evaluation system. The results showed that the developing regions performed better in terms of the degree of coordination between ecological security and development in terms of sustainable development. Meanwhile, factors such as urban vegetation, per capita GDP and population density can limit the sustainable development level of the urban agglomeration in the Pearl River Delta to a certain extent. In addition, cities with more native environments are more vulnerable to external factors, and cities with developed industries are more lacking in ecological restoration ability. When deploying development planning for urban agglomerations, coordinated development among different cities should be considered. Tian et al [31] analyzed the factors affecting the ecological environment of land reclamation areas from the perspective of land reclamation. Fang et al. [32] established a regional ecosystem management system model based on a two-layer plan to manage the ecosystem and sustainable development in Xiamen, China. The results showed that the main ecological service values of ecosystems are carbon sequestration, oxygen release, and water retention. Compared with the single-level model, this model reduced the system benefits by 15.3% and increased the value of ecological services by 17.6%.

In summary, high-density cities are a state of urban development with a concentrated regional economy, an advanced regional spatial organization brought about by highly developed industrialization and urbanization. The formation of high-density cities often implies a highly developed economy and modernization level of a region, and their economies of scale can bring huge benefits and have far-reaching effects on the regional ecological environment. This paper analyzes the impact of urban design on the regional ecological environment of cities based on high-density cities in eastern China and establishes an ecological index evaluation system to evaluate the regional ecological environment of high-density cities. At the same time, this study also introduces the urban clustering degree and urban eco-efficiency measurement method as a way to examine the time-series evolution of cluster development and eco-efficiency in high-density cities in eastern China.

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2. RELEVANT THEORIES AND MATHEMATICAL MODELS

The protection of ecology and environment needs to fully consider the interrelationship between the natural environment and human society, on the one hand, to deal with the relationship between humans and nature; on the other hand, to coordinate the internal relationship of human society, and to protect the integrity and development of ecological environment with benign development as the driving force. Theoretical disciplines tend to be more complex, and with the help of theories and methods from basic disciplines, combined with the characteristics of ecological environmental protection, several disciplines have been formed, such as ecological environmental science and environmental engineering. Based on the existing theoretical knowledge, the laws of the ecological environment are understood, the relationship between humans and the ecological environment is regulated by using economic and technical means, and the relationship between the ecological environment and social development is revealed by sociological methods.

2.1. BASIC THEORY

2.1.1. ECOLOGICAL RESTORATION THEORY

Ecological restoration refers to the reduction or interruption of human intervention in the ecosystem, and the development of the ecosystem in an orderly and good direction through its self-regulation and organization, or the use of the ecosystem's self-repair and regulation ability to reduce the environmental load pressure, so that the damaged ecosystem gradually restored to its original state. In other words, ecological restoration refers to the work of restoring and rebuilding ecosystems when the environment suddenly changes or suffers damage caused by human activities, either by self-restoration or artificial reconstruction, or both.

2.1.2. SYSTEM SCIENCE THEORY

Systems science is the science of complex systems in different fields, and its main content is to study the laws of structure, function and evolution of the system under study. From a holistic system perspective, systems science is mainly concerned with analyzing the laws of the nature of relatively complex systems, to clarify the correlations between different systems and the laws to be followed in the process of evolution. Ecological and environmental assessment is carried out based on the environment, and in the study, it is necessary to have a comprehensive and specific consideration instead of starting from a single influencing factor. At the same time, it is also necessary to adhere to the dynamic principle in the research process and to evaluate the ecological environment change status comprehensively.

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2.1.3. SUSTAINABLE DEVELOPMENT THEORY

Sustainable development, meaning that development is not a one-time event, is based on the sustainable use of renewable resources, but the concept of sustainable development became popular worldwide in 1987 with the publication of "Our Common Future" by the WCEA. Sustainable development refers to the emphasis on economic, social and ecological coherence and integration to achieve the goal of integrated development. The principle of equity requires that development should focus on the equity of all generations, both horizontally and vertically, and that it should not chase its side of development at the expense of others and squander resources, which is also an international common opinion. Sustainability requires the continuity of development without disturbance, the resources can be developed and renewable, and there will be no vulnerability of resources. Commonality requires all human beings to act together, the world is the whole, one party to destroy sustainable development, the global will be affected.

2.1.4. THEORY OF COLLECTIVE ACTION

The theory of collective action can explain the behavior of each of the subjects in collaborative ecological governance. It is as if each subject is an economic person in the economic society, and they all want to maximize their interests rather than bear the cost of governance, which will only further deteriorate the environment of the region.

2.1.5. THEORY OF EXTERNAL EFFECTS

When there is a conflict between the marginal costs and benefits of the two, private and social, it is difficult to solve the problem by compensating for it, and there should be external forces that exclude both to solve the problem so that the interests of both society and people can be optimized. Because of this, the theory of externalities is widely used in ecological environmental protection.

2.2. ECOLOGICAL ENVIRONMENT QUALITY EVALUATION

Eco-environmental quality is proposed after a series of eco-environmental problems arise from natural factors or human production and living activities, and is a comprehensive concept used to measure the scope, degree, and merit of the impact of human activities on the eco-environment.

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2.2.1. GREENNESS INDEX

Normalized vegetation index ($NDVI$) is one of the most widely used indices among various vegetation indices and is widely used to analyze crop growth, vegetation cover and spatial distribution.

$$NDVI = \frac{(\rho 4 - \rho 3)}{(\rho 4 + \rho 3)} \tag{1}$$

Where $\rho 4$ and $\rho 3$ represent the reflectance in the near-infrared and visible red bands, respectively. the $NDVI$ value represents the vegetation status of the watershed, and the larger the $NDVI$ value after normalization, the higher the vegetation cover.

2.2.2. HUMIDITY INDEX

Moisture components are widely used in ecological monitoring, not only to represent the water resources status of regional rivers and reservoirs but also to calculate the moisture content of arable land, forest land and other land use types.

$$Wet = 0.0315\rho 1 + 0.2021\rho 2 + 0.3102\rho 3 + 0.1594\rho 4 - 0.6806\rho 5 - 0.6109\rho 7 \tag{2}$$

Where ρ_i is the reflectance of each waveband of TM. Wet after the normalization process, higher values represent higher humidity.

2.2.3. DRYNESS INDEX

The dryness index is used to study the status of land desertification and land degradation in arid zones.

$$NDSI = (SI + IBI)/2 \tag{3}$$

Where SI is the bare earth index and IBI is the building index. The higher $NDSI$ value indicates the more serious land degradation and desertification in the study area and the worse ecological environment quality.

2.2.4. HEAT INDEX

The heat index is expressed in terms of surface temperature, and global and regional thermal environmental problems, which are receiving increasingly widespread attention, and how to mitigate the regional ecological and environmental impacts caused by abnormal changes in surface temperature have become urgent and realistic problems.

$$Ts = [a(1 - C - D) + (b(1 - C - D) + C + D)T6 - DTa]/C \tag{4}$$

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$$C = \varepsilon\tau \tag{5}$$

$$D = (1-\tau)[1+(1-\varepsilon)\tau] \tag{6}$$

Where Ts is the surface temperature, Ta is the atmospheric temperature, and $T6$ is the brightness temperature in the thermal infrared band. a and b are constants. ε is the surface-specific emissivity, and τ is the atmospheric transmittance.

2.3. DETERMINATION OF INDEX WEIGHTS

Principal component analysis (PCA) is a multivariate statistical method and is one of the basic mathematical analysis methods. Its mathematical meaning is to select a small number of important variables from the original numerous indicators with correlation and recombine them into a new set of comprehensive indicators, which helps to analyze the indicator attributes more objectively. In this paper, with the help of ER Mapper software, the normalized 4 indicators are imported into the software for principal component analysis and synthesize the RSEI index. The coefficients of each index after the principal component analysis are large or small, positive or negative, and each index is given different weights and practical meanings, with positive values indicating a positive correlation between the index and the composite index and negative values indicating a negative correlation. The larger the eigenvalue in the principal component analysis, the higher the variance contribution of the "component", and the better it represents the attribute characteristics of each index.

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1p} \\ x_{21} & x_{22} & \dots & x_{2p} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{np} \end{bmatrix} = \left[x_1, x_2, \dots, x_p\right] \tag{7}$$

$$F_i = w_{1i}x_1 + w_{2i}x_2 + \dots + w_{pi}x_p, i = 1,2,\dots,p \tag{8}$$

Using a mathematical method to describe principal component analysis, for a data set X with n samples, $X_1, X_2, \dots, X_P$, P variables. PCA is to synthesize the original P observation variables $X_1, X_2, \dots, X_P$ to form P new variables (comprehensive variables).

2.4. URBAN DESIGN AND EVALUATION

2.4.1. URBAN DESIGN

The development trajectory of urban design can be roughly divided into three important historical stages. "The second generation of urban design emerged in the 1950s, and its design followed the rational guidelines of "economy and technology", focusing on efficiency and function, and meeting the general needs of modern cities. In the 1970s, the third generation of urban design, "green urban design", began to emerge, with the design guidelines of "holistic priority" and "ecological priority", trying to create a harmonious development of the natural and man-made environment and shape a sustainable urban environment. The third generation of urban design, i.e. green urban design, covers different directions of urban design such as environment, economy and society, and needs to be completed from a social-economic-environmental multidisciplinary. The green urban design studied in this paper is the core component of the third-generation green urban design from the perspective of architecture: the green urban design based on bioclimatic conditions.

2.4.2. URBAN DESIGN IMPLEMENTATION ASSESSMENT

Urban design implementation evaluation is an important part of the urban design workflow, which provides feedback and corrections to the urban design implementation and guides the urban design to implement the planning and design content more realistically in the field. In general, the evaluation process is one iteration, and the results and updated design of each iteration will be used as the initial values for the next iteration. The purpose of this evaluation is to improve the urban design, which is an important part of the urban design process from planning to implementation and will become the basis and starting point for the next round of urban design.

The city master plan has a regular assessment and medical examination system. The Beijing Master Plan proposes to establish a scientific and effective planning implementation control system, an urban physical examination and assessment mechanism, a planning implementation supervision and assessment accountability system, and a planning implementation coordination and decision-making mechanism and proposes an evaluation index system for a livable city. To ensure that the target indicators are well implemented, a regular mechanism of periodic assessment will be adopted to evaluate the implementation of planning and design. Therefore, the normalization of urban design implementation evaluation will be a further extension of this work. The main work of urban design in the implementation stage is to form planning and design conditions together with the detailed control plan, and its role is to guide the subsequent architectural design and landscape design by transforming them into legal control elements.

This section introduces the relevant theories involved in the construction of regional ecological environments, such as ecological restoration theory, system science theory, collective action theory, and sustainable development theory. Then we introduce the methods of ecological quality evaluation and their evaluation indexes. Finally, the high-density urban design method and evaluation guidelines are introduced. The theoretical foundation is laid for the later analysis.

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3. RESULTS AND DISCUSSION

The Yangtze River Delta region is a typical high-density urban area in eastern China, and this section uses the Yangtze River Delta region as a case study to evaluate its ecological environment from 2010 to 2019. This is used to determine the impact of high-density urban design on the regional ecological environment.

3.1. EVALUATION INDEX SYSTEM

From the perspective of ecological economics, the ecological environment quality system includes not only the quantity and quality of natural resources and energy but also the construction of municipal systems, the state of infrastructure construction and the level of basic public services, which reflect and measure the quality of human life, so the index system must be a comprehensive system. Therefore, this paper uses the PSR model established by OECD and UNEP to construct a basic index system reflecting the pressure-state-response of the ecological environment under the principles of scientificity, representativeness, accessibility and comparability, and the index system is shown in Table 1.

Table 1. Ecological environment quality index system

Tier 1 Indicators	Secondary indicators	Tertiary indicators	Marking	Direction
Eco-environmental quality evaluation index	Pressure Indicators	Growth rate of construction land	Y_1	—
		Per capita residential electricity consumption	Y_2	+
		Total industrial wastewater discharge	Y_3	—
		Sulfur dioxide emissions	Y_4	—
		Solid waste generation	Y_5	—
	Status Indicators	Water resources per capita	Y_6	+
		Urban park area per capita	Y_7	+
		Road occupancy per capita	Y_8	+
		Greening coverage of built-up areas	Y_9	+
	Response Metrics	Urban domestic sewage treatment rate	Y_{10}	+
		Comprehensive utilization rate of industrial solid waste	Y_{11}	+
		Harmless disposal rate of domestic waste	Y_{12}	+
		Industrial fume removal	Y_{13}	+

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3.2. OVERALL EVALUATION OF THE LEVEL

Based on the above evaluation index system, the comprehensive scores of ecological environment quality of 26 cities in the Yangtze River Delta city cluster can be measured from 2010 to 2019, as shown in Table 2. As can be seen from Table 2, the scores and rankings of Shanghai and Jiangsu Province show a decreasing trend, those of Anhui Province keep rising, while those of Zhejiang Province remain almost unchanged. In 2010, the top five regions were Shaoxing, Nanjing, Suzhou, Ningbo, and Huzhou, and the provinces involved were Zhejiang and Jiangsu; in 2010, the bottom five regions were Chuzhou, Anqing, Nantong, Zhoushan, and Xuancheng, accounting for 60% of the total in Anhui. The top three cities with the fastest improvement are Chuzhou, Xuancheng and Anqing, all of which are from Anhui Province, which shows that the province's ecological and environmental quality level has improved significantly within the city group, which is due to the following reasons: in the process of regional integrated development, Anhui Province has accelerated its ecological and environmental quality ranking by In 2019, the bottom five regions are Shanghai, Changzhou, Yangzhou, Yancheng, and Suzhou, with Jiangsu Province accounting for 80% of the total, and the province's eco-environmental quality score ranking shows a decreasing trend, which shows that the province's eco-environmental quality level has decreased to a certain extent within the city group, which is related to the high pollution and high energy consumption enterprises in Jiangsu Province. This is closely related to the profit-oriented development model of Jiangsu Province and the heavy industrial density caused by the spread of this model in the provincial area. In addition, the ranking of Zhejiang Province is relatively stable within the city cluster over the 10 years. In the case of the Yangtze River Delta urban agglomeration, the ecological quality scores and rankings of each region show certain changes in different years, and the characteristics of such changes need to be analyzed in detail at the spatial and temporal levels.

Table 2. Comprehensive ecological and environmental quality scores of 26 cities in the Yangtze River Delta city cluster, 2010-2019

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Shanghai	0.4551	0.3582	0.3415	0.3912	0.3141	0.2584	0.2313	0.2179	0.2366	0.2250
Wuxi	0.4474	0.5165	0.5120	0.5026	0.4752	0.5218	0.3850	0.4340	0.4294	0.4404
Suzhou	0.5015	0.5051	0.5454	0.4734	0.4182	0.4288	0.3458	0.3698	0.4040	0.3494
Yangzhou	0.3844	0.3989	0.3630	0.3915	0.3036	0.3985	0.3385	0.3281	0.3426	0.3169
Taizhou	0.3717	0.3819	0.3134	0.3242	0.3210	0.4028	0.3600	0.3331	0.3234	0.3598
Nanjing	0.5355	0.5182	0.4836	0.4744	0.4653	0.6242	0.4736	0.5241	0.5532	0.4542
Changzhou	0.3666	0.3717	0.3229	0.3771	0.3348	0.3917	0.3489	0.3817	0.3639	0.3095
Nantong	0.3235	0.3463	0.3228	0.3385	0.3110	0.3736	0.3448	0.2937	0.3688	0.3690
Zhenjiang	0.4348	0.4526	0.4114	0.4329	0.3904	0.4801	0.3853	0.3891	0.4019	0.3560

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Yancheng	0.3573	0.3715	0.2745	0.3423	0.2800	0.3687	0.2843	0.3039	0.3377	0.3454
Ningbo	0.4716	0.4494	0.4820	0.5255	0.4778	0.3689	0.3710	0.4414	0.3832	0.3745
Huzhou	0.4604	0.5067	0.5330	0.5177	0.5263	0.6530	0.6262	0.6220	0.6142	0.6381
Zhoushan	0.3254	0.3718	0.3275	0.3635	0.3163	0.3976	0.3758	0.4071	0.3689	0.3767
Hangzhou	0.4398	0.4177	0.4255	0.4109	0.3886	0.4378	0.3915	0.4407	0.3825	0.3521
Jiaxing	0.3545	0.3763	0.3708	0.4003	0.3751	0.4247	0.3895	0.3871	0.3876	0.3688
Introduction	0.6004	0.5970	0.5468	0.5351	0.4404	0.4960	0.4691	0.4602	0.4510	0.4128
Taizhou	0.4240	0.4494	0.4576	0.4714	0.4537	0.3943	0.4052	0.4329	0.4526	0.4072
Jinhua	0.4411	0.4384	0.3997	0.4361	0.4142	0.4220	0.4280	0.4201	0.4263	0.4114
Hefei	0.4243	0.4679	0.3881	0.3788	0.4641	0.5207	0.4132	0.4935	0.5414	0.3997
Ma'anshan	0.4065	0.3978	0.3587	0.3669	0.3691	0.3378	0.3944	0.3982	0.4722	0.3840
Anqing	0.3206	0.3558	0.3339	0.3688	0.3825	0.4280	0.4067	0.4575	0.4383	0.4469
Chizhou	0.4044	0.5044	0.4897	0.5101	0.5448	0.4978	498	0.5768	0.5493	574
Wuhu	0.3686	0.4022	0.3960	0.4164	0.4099	0.5395	0.5482	0.5800	0.5266	0.4573
Tongling	0.4122	0.3834	0.3664	0.4642	0.3570	0.5150	0.5784	0.4927	0.5737	0.4001
Chuzhou	0.3149	0.3083	0.2723	0.2538	0.2990	0.4282	0.4094	0.4475	0.4084	0.5064
Xuancheng	0.3518	0.4238	0.4070	0.4154	0.4339	0.4213	0.3993	0.5004	0.4250	0.4916

3.3. ANALYSIS OF SPATIAL AND TEMPORAL CHARACTERISTICS OF LEVELS

3.3.1. ANALYSIS OF SPATIAL IMBALANCE

By measuring the spatial imbalance of ecological environment quality level in the Yangtze River Delta city cluster, as shown in Figure 1 below. Theoretically, a Gini coefficient within 0.2 indicates a highly balanced state of the spatial distribution of a factor characteristic; above 0.5 indicates a very unbalanced state of the spatial distribution of the factor characteristic. Among them, 0.4 is the critical point of spatial equilibrium and imbalance. Thus, the Gini coefficient provides a clear measure of the spatial unevenness of the comprehensive ecological environmental quality score in each year, but the spatial clustering characteristics of the ecological environmental quality scores of cities in the Yangtze River Delta city cluster in each node year still need to be given a more intuitive analysis and be explored in depth.

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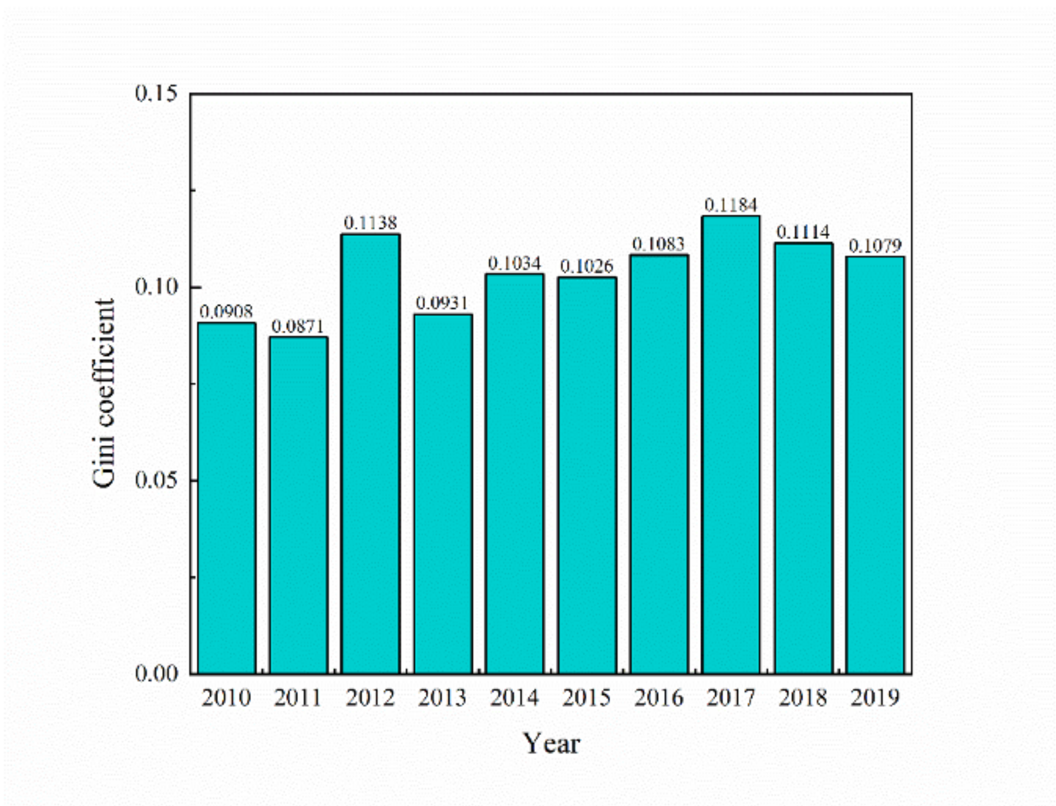

Figure 1. Gini coefficient of ecological and environmental quality in the Yangtze River Delta city cluster, 2010-2019

3.3.2. HOTSPOT ANALYSIS

To further analyze the spatial characteristics of the ecological environment quality of the Yangtze River Delta urban agglomeration, four times sections were selected for 2010, 2013, 2016, and 2019 at a time interval of three years, and the corresponding Gi* values were obtained by Arcgis technology and using Equation (4). Concerning the classification of cold hotspot areas in previous studies, the Gi* values of ecological environment quality in the Yangtze River Delta urban agglomeration were classified into five categories from high to low. This classification refined the previous 3 classifications by Gi* values, making the analysis more detailed and the conclusions more clear, as shown in Table 3.

Table 3. Gi* value range and description

Year	Cold spot area	Secondary cold spot area	Temperature point area	Sub-hotspot area	Hot spot area
2010	[-1.34，-0.68]	[-0.68，-0.05]	[-0.05，0.48]	[0.48，1.37]	[1.37，2.26]
2013	[-1.87，-1.40]	[-1.40，-0.36]	[-0.36，0.44]	[0.44，1.10]	[1.10，1.76]
2016	[-1.89，-1.72]	[-1.73，-0.34]	[-0.34．064]	[0.64，1.36]	[1.36，2.36]
2019	[-1.98，-1.40]	[-1.41，-0.70]	[-0.70，0.14]	[0.13，1.04]	[1.04，2.06]
Description	Eco-environmental quality score low value agglomeration area	Sub-low ecological quality score agglomeration area	Median Eco-environmental Quality Score Clustering Area	Eco-environmental quality score sub-engagement value agglomeration area	Eco-environmental quality score high value agglomeration area

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Taking 2019 as a representative, we list the Gi* values of these 26 cities in Table 4.

Table 4. Gi* value of 26 cities,2019

	Cold spot area	Secondary cold spot area	Temperature point area	Sub-hotspot area	Hot spot area
Shanghai	-1.452	-721	81	391	1.3141
Wuxi	-1.622	-881	-522	502	1.475
Suzhou	-1.588	-864	115	434	1.418
Yangzhou	-1.574	-876	-228	0.3915	1.303
Taizhou	-1.658	-819	-663	342	1.321
Nanjing	-1.524	-931	16	474	1.465
Changzhou	-1.482	-922	27	377	1.334
Nantong	-1.782	-877	-421	385	1.311
Zhenjiang	-1.533	-821	-31	439	1.390
Yancheng	-1.881	-816	121	423	1.280
Ningbo	-1.529	-1.121	-132	525	1.477
Huzhou	-1.886	-1.036	-325	517	1.526
Zhoushan	-1.922	-935	-365	635	1.316
Hangzhou	-1.478	-756	-517	849	1.388
Jiaxing	-1.568	-964	-378	743	1.375
Zhenjiang	-1.635	-1.322	54	535	1.440
Taizhou	-1.616	-1.224	72	474	1.453
Jinhua	-1.469	-1.066	-457	436	1.414
Hefei	-1.769	-891	-699	788	1.464
Ma'anshan	-1.555	-996	-328	669	1.369
Anqing	-1.878	-972	39	688	1.382
Chizhou	-1.855	-1.325	122	951	1.544
Wuhu	-1.699	-1.258	-368	647	1.409
Tongling	-1.522	-1.355	-149	658	1.357
Chuzhou	-1.485	-1.189	136	853	1.299
Xuancheng	-1.621	-1.056	-187	923	1.433

At the temporal level, the ecological environment quality level of each region in the Yangtze River Delta urban agglomeration showed a large fluctuation during 2010-2019, with the level ranking of Anhui Province on the rise, Jiangsu Province and

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Shanghai Municipality on the decline, and Zhejiang Province at a more stable level. At the spatial level, the Gini coefficient of ecological and environmental quality in the region is within 0.2 during 2010-2019, which is in a highly balanced state in space. The hotspot and sub-hotspot areas of ecological environmental quality in the Yangtze River Delta urban agglomeration are mainly in the south of the region, but there are small changes in the hotspot and sub-hotspot areas in different time sections, with the former moving gradually from east to west in the whole area of the urban agglomeration and the latter changing less spatially in the whole area of the urban agglomeration. The cold point and subcool point regions are mainly concentrated in the north, but there are small changes in the cold point and subcool point regions in different time sections, the former is stable in a small part of the whole urban area, while the latter shows the spatial change characteristics of moving from west to east.

4. CONCLUSION

High-density cities are the state of urban development in which the regional economy is concentrated and are the advanced regional spatial organization brought about by highly developed industrialization and urbanization. The formation of high-density cities often implies a highly developed economy and modernization level of a region, and their economies of scale can bring enormous benefits and have far-reaching impacts on the regional ecological environment. This paper evaluates the ecological and environmental performance indicators of the Yangtze River Delta, a typical high-density urban area in eastern China, from 2010 to 2019. This is used to analyze the impact of high-density urban design on the regional ecological environment. The specific findings of the study are as follows.

1. Between the decade of 2010 and 2019. The ecological environment quality scores and rankings of Shanghai and Jiangsu Province show a decreasing trend, while Anhui Province keeps rising and Zhejiang Province remains almost unchanged. 60% of the areas ranked in the bottom five in 2010 and 80% of the areas ranked in the top five in 2019 are occupied by Anhui Province.

2. The spatial and temporal characteristics of the ecological environment quality level of the Yangtze River Delta urban agglomeration show the following pattern, the maximum value of the Gini coefficient is only 0.1184 during 2010-2019, which is much smaller than 0.2. Therefore, the ecological environment quality of the region is in a highly balanced spatial state, and the difference between the ecological environment quality levels of each year is small.

3. The hotspot and sub-hotspot areas of ecological environmental quality in the Yangtze River Delta urban agglomeration are mainly in the south of the region, but there are small changes in the hotspot and sub-hotspot areas at different time cross-sections, with the former moving gradually from east to west in the

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whole area of the urban agglomeration and the latter having smaller spatial changes in the whole area of the urban agglomeration.

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