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# *New Perspective to Evaluate the Dynamics of Urban Ecosystem Services by Spatial Structure in Yangtze River Economic Belt*

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***Abstract:*** Exploring the impacts of urban sprawl on ecosystem services is of great significance to the sustainable development of cities in the future. Therefore, this study explored the impact of land use structure change on ecosystem service system in YREB by using InVEST model and GeoDa model based on multi-source data and night light data. The result show that: (1) The urban structure of the YREB has gradually shifted from concentration to multi-centralization and balanced development. (2) The spatial distribution of water production in the YREB is uneven, with obvious regional differences. (3) There is a strong correlation between the three quantified urban spatial structure indices and ecosystem services in the west and southeast. These findings are crucial to the formulation of YREB's ecological and environmental protection and socio-economic development plans, It provides valuable guidance to policymakers and researchers committed to improving the quality of development.

## 1. Introduction

Agenda 2030 emphasizes the necessity for cities to become more inclusive, safe, resilient, and sustainable, highlighting the pivotal role of urbanization in achieving global development goals (SDG 11)(UN General Assembly Resolution 2015). However, rapid urbanization leads to unreasonable urban spatial structure, and then brings about urban heat island effect, resource mismatch, traffic congestion, environmental pollution and other problems[1]. At present, multi-spatial structure has been widely recognized by urban researchers as an important way to reduce pollution and achieve environmental sustainable development[2]. Therefore, exploring urban structure and realizing sustainable development of cities become the main problems of current research.

Close interaction exists between urban spatial structure and ecosystem services. Urban spatial

structure, including land-use types, functional zoning and traffic networks, directly affects the distribution and intensity of ecosystem services[3]. For example, land-use change is one of the key factors affecting ecosystem services, which affects ecosystem functions and services by changing ecosystem composition and structure[4]. Research shows that urban sprawl and land-use change significantly affect supply and demand for ecosystem service[5]. In addition, ecological elements such as urban green spaces, water bodies and open spaces play an important role in providing ecosystem service[6]. Urban green space can not only provide air purification, carbon sequestration and other regulatory services, but also provide cultural services such as leisure and entertainment[7]. Therefore, understanding the relationship between urban spatial structure and ecosystem services is crucial for making scientific and reasonable urban planning and ecological protection strategies.

The interaction between urban spatial structure and ecosystem services in the YREB is affected by many driving factors[8]. For example, the imbalance of ecosystem services caused by urban expansion, in some cities of the YREB, the unreasonable urban functional zoning makes the supply-demand relationship of ecosystem services tense[9]. Changes in urban spatial structure, such as urban sprawl and adjustment of functional areas, will change land use types and landscape patterns, thus having an important impact on ecosystem services[10].

Therefore, this paper takes the YREB as the research area, constructs the index based on the land use structure index of night light data, and explores its driving force by using InVEST model. The purpose is to explore the evolution direction of urban spatial structure and the change of ecosystem service, and further explore the impact of urban spatial structure change on ecosystem service system in the YREB.

## 2. Methods and materials

### 2.1. Data sources

The urban-rural boundary data of the study area used by this institute come from Academician Gong Peng's team（https://www.globalurbandynamics.org/）, with a resolution of 30 meters. Night Light Data Reference (Wu, Shi et al.,2022)with a resolution of 1,000 meters. Average precipitation and evaporation data with resolution of 1,000 m from the National Plateau Data Set Center (https: // doi. org/ 10. 11866/ db. loess. 2021. 001, https: // doi. org/ 10. 5281/zenodo.3185722）. The land use/land cover used is from the Resource and Environmental Science and Data Center of China Academy of Sciences (https://www.resdc.cn/) with a resolution of 1,000 m. Soil data with a resolution of 1,000 m from the National Earth System Science Data Center (http://soil.geodata.cn/).

### 2.2. Measuring urban spatial structure

GINI can measure the unbalanced distribution of urban areas; HHI can indicate the importance of large urban areas; Primacy can indicate the importance of urban entities. The formula is as follows:

$$\Pr imacy = \frac{US_1}{TUS} \tag{1}$$

$$HHI = \left( \sqrt{\sum_{i=1}^{n} \left( \frac{US_i}{TUS} \right)^2} - \sqrt{\frac{1}{n}} \right) \Big/ \left( 1 - \sqrt{\frac{1}{n}} \right) \tag{2}$$

$$Gini = \frac{1}{2n\overline{US}} \sum_{i=1}^{n} \left| US_i - \overline{US} \right| \tag{3}$$

*US* is the highest total NTLS in sub-cities, *TUS* is the total NTLS of all sub-cities in the city, $US_i$ is the total NTLS, $\overline{US}$ of the first sub-city is the average NTLS of the city in the city, and the city is numbered by *n*.

## 2.3. Calculation of ecosystem services

The service function of producing water in ecosystem services is one of its important components. The formula for water production is as follows:

$$Y(a) = [1 - \frac{AET(a)}{P(a)}] \times P(a) \tag{4}$$

*Y* (a) denotes the annual water production (mm) of an as the grid; *AET* (a) denotes the value of actual annual evapotranspiration across the grid (mm); *P* (a) denotes the annual precipitation of an as the grid (mm); *AET* (a) *P* (a) is the approximation of the Budyko curve.

Soil conservation is obtained by subtracting actual soil erosion (USLE) from potential soil erosion (RKLS). Its calculation formula is as follows:

$$RKLS_b = R_b \times K_b \times LS_b \tag{5}$$

$$USLE_b = R_b \times K_b \times LS_b \times C_b \times P_b \tag{6}$$

$R_b$ represents *b* as the rainfall erosion factor of the grid, $K_b$ indicates that *b* is the soil erosion factor of the grid, and $LS_b$ refers to the slope length variable; $C_b$ denotes *b* as the vegetation management factor of the grid, and $P_b$ represents *b* as the soil protection measure factor of the grid.

Habitat quality reflects an ecosystem's capacity to sustainably support the habitation and the growth and improvement of people and groups within specific spatial and temporal parameters.

$$Q_{mn} = H_n(1 - (\frac{D^z_{mn}}{D^z_{mn} + K^z})) \tag{7}$$

$Q_{mn}$ is the HQ score of grid m in *n*-type land use, $H_n$ is the habitat suitability of *n*-type land use, *z* represents the scaling parameter used to adjust the scale of measurements, and *K* is the semi-saturation parameter. $D_{mn}$ is the habitat degradation of grid *m* in *n*-type land use.

The Carbon module of the InVEST model is utilized in this study to evaluate how carbon storage varies across time and space. The calculation formula is as follows:

$$Ctotalx = \sum_{y=1}^{d} A_{xy} \times (Cabove_y + Cbelow_y + Csoil_y + Cdead_y) \tag{8}$$

*Ctotalx* denotes the total carbon sequestered within the area *x*(t); $A_{xy}$ is the area of *y*-type land use in area *x* ($hm^2$); $Cabove_y$、$Cbelow_y$、$Csoil_y$ and $Cdead_y$ are aboveground biological carbon density, underground biological the quantity of carbon stored per unit area in the atmosphere, soil, and dead organic matter, respectively.t/ ($hm^2 \cdot a$) of land use *y*, respectively;*d* is the number of land use types.

In this paper, we standardize the individual ES between 0 and 1 to solve the problem of different dimensions of ESs, and then add them to get TES for subsequent analysis.

$$TES = \sum_{i=1}^{4} \frac{ES_{ij} - ES_{i,\min}}{ES_{i,\max} ES_{i,\min}} \tag{9}$$

$ES_{ij}$ is the original value of ecosystem service *i* in pixel *j*, $ES_{i,min}$ and $ES_{i,max}$ are the minimum and

maximum values of ecosystem service $i$ , respectively.

### 2.4. Bivariate spatial autocorrelation model

Local Spatial Autocorrelation (LISA) is a technique that uses local Moran's I to highlight the clustering of factors within a specific region within a study area.

$$\text{LocalMorans } I = \frac{Xi - \bar{X}}{S^2} \sum_{i=1, j\neq 1}^{n} Wij(Xj - \bar{X}) \tag{10}$$

where $X_i$ and $X_j$ are the values of unit $i$ and unit $j$, respectively, $n$ is the number of spatial units, and $W_{ij}$ is the spatial weight matrix. $\bar{X}$is the unit mean, $S^2$ is the observation variance

## 3. Results

### 3.1. Urban Spatial Structure of Yangtze River Economic Belt

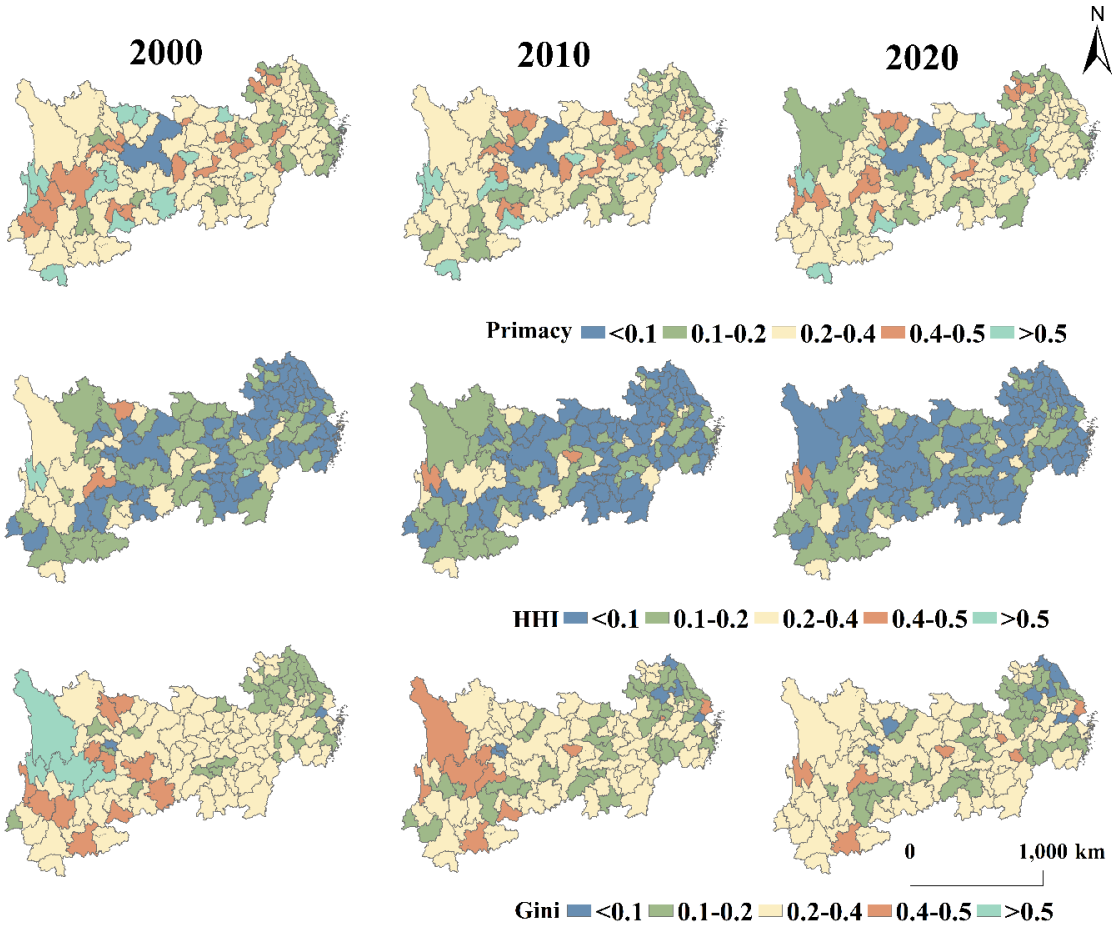



Figure 1: Spatial Distribution of Yangtze River Economic Belt in 2000, 2010 and 2020.

In Figure 1, according to the quantified urban spatial structure index (Primacy, HHI, Gini), the spatial distribution of cities in the YREB has changed from 2000 to 2020. The distribution of the YREB from 2010 to 2020 is shown in Figure 1, with all three indices indicating an overall deepening of polycentricity during the study period. In 2000, the primacy index was less than 0.2 only in some regions, but in 2010 and 2020, the regions with primacy index less than 0.2 gradually expanded

(especially in the southern and northeastern regions of the study area), which indicates that the urban distribution in these regions is dense and balanced, gradually solving the dependence of single urban centers, and further expanding in the region 0.1-0.2 (eastern region) in 2020, indicating that the trend of polycentricity is further consolidated; The HHI index fluctuated between 0 and 0.2 in most regions in 2000, and the number of regions with HHI less than 0.1 increased significantly in 2020 (especially in the eastern, central and western regions), which indicated that the trend of polycentricity was increasingly obvious, indicating that the overall urban spatial structure was developing towards balanced distribution. In 2000, the Gini coefficient was higher than 0.5 in the region distribution (especially in the northwest region), indicating that these regions were relatively high urban concentration and uneven economic and resource distribution at that time, but by 2020, the region with Gini coefficient higher than 0.7 was significantly reduced or even almost disappeared, indicating that these regions gradually realized multi-centralized and balanced development under the promotion of regional economic integration policy.

### 3.2. Ecosystem Services of the Yangtze River Economic Belt

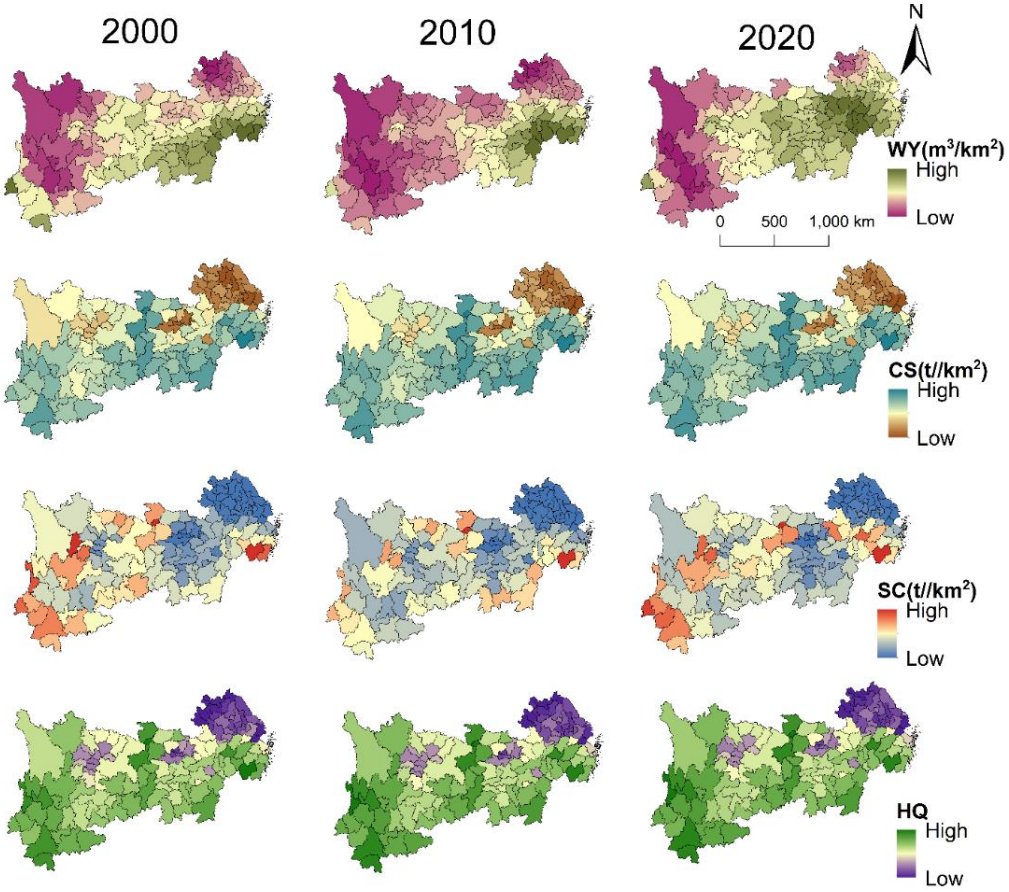



Figure 2: Water production, carbon emission, soil conservation and habitat quality of Yangtze River Economic Belt in 2000, 2010 and 2020.

Figure 2 shows the temporal and spatial changes of water yield, carbon emission, soil conservation and habitat quality in the YREB in 2000, 2010 and 2020, among which the annual water yield changes significantly in 2000 and 2020.The average water yield of Jiangsu, Zhejiang and Shanghai in the southeast is relatively high, all of which are steadily above 1000mm, while the average water yield of Sichuan, Chongqing and Yunnan in the northwest and northwest is relatively low, about below 500 mm. The amount of water increases from northwest to southeast. Carbon emissions also show strong

spatial heterogeneity, but its change is relatively flat from 2000 to 2020. In the central section of the YREB, carbon emissions are notably elevated, with the highest value reaching 160.58 t/ha$^2$. Carbon emissions in the western region are relatively low, mostly between 80 and 126 t/ha$^2$. In the eastern region, carbon emissions are at their lowest, with the minimum value amounting to 45.52 t/ha$^2$, and low values are concentrated in the region. Soil conservation in the east and south of the YREB was significantly improved, most of the soil conservation in the southeast was maintained at 0-6t/ha$^2$, while the soil conservation in the upper and middle reaches of the Yangtze River was relatively large, mostly exceeding 18 t/ha $^2$. The highest value of soil conservation reached 75.9 t/ha$^2$ in the west. Habitat quality also did not change dramatically, but in some areas of Shanghai and Jiangsu in the east, the habitat quality improved significantly, while in the middle and south, the average habitat quality maintained high data, and in the northeast, the habitat quality was low, the lowest value was 0.29.

### 3.3. Spatial correlation between ecosystem service values and urban land expansion

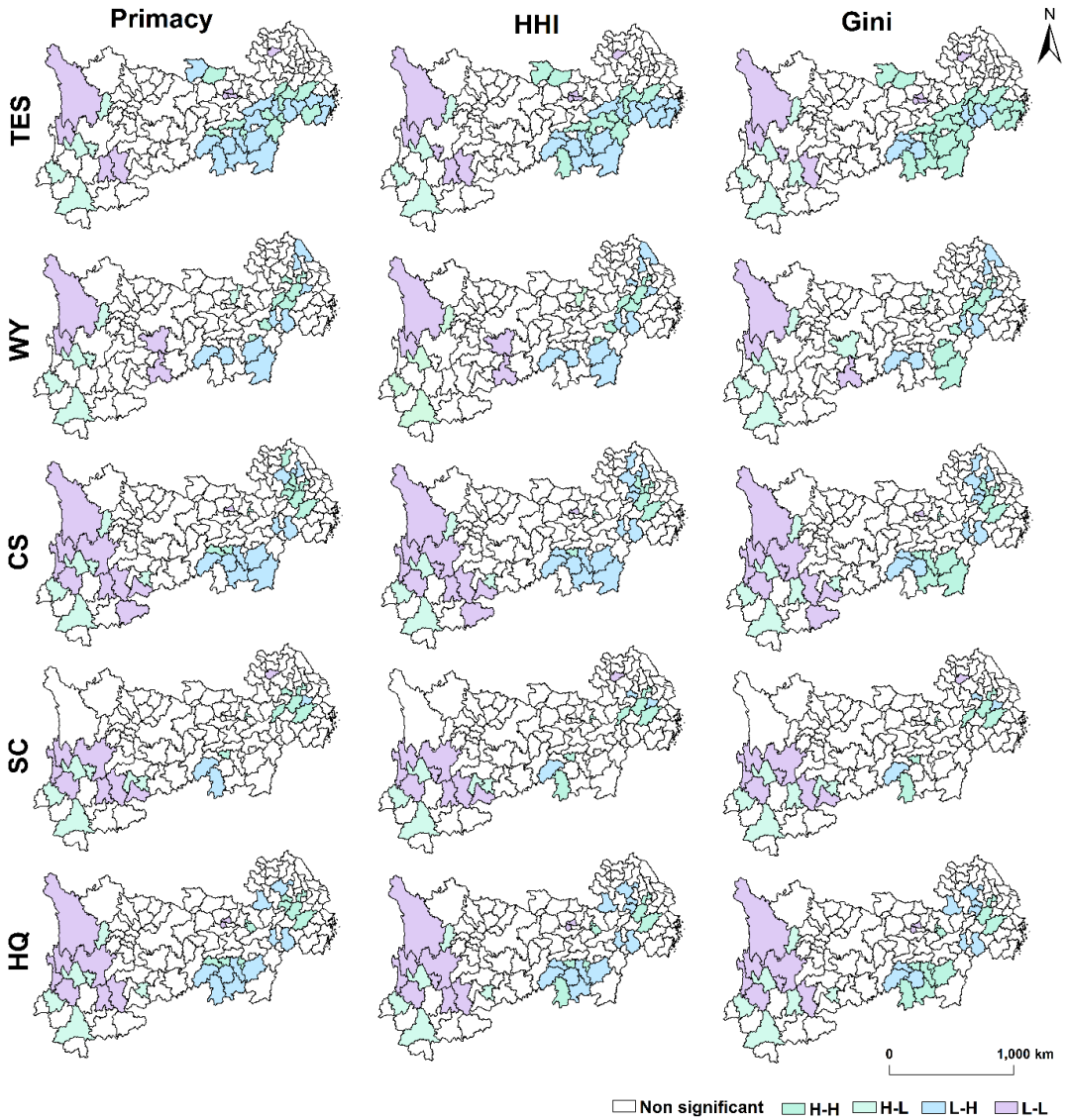



Figure 3: LISA cluster plots between four ecosystem services and total ecosystem services and three urban spatial structures.

According to the spatial relationship between the four ecosystem services and the three urban structures explored in Figure 3, in the local spatial autocorrelation analysis, the YREB shows four types of spatial autocorrelation at the urban level: High ecosystem services-high urbanization agglomeration (H-H), high ecosystem services-low urbanization agglomeration (H-L), low ecosystem services-high urbanization agglomeration (L-H), low urbanization ecosystem services-low urbanization agglomeration (L-L). The spatial distribution of the five ecosystems in the study had great similarity with the quantified urban spatial structure Primacy and HHI index. H-H distribution is narrow, mainly concentrated in the eastern part of the study area; H-L area is scattered, mainly distributed in the southwest; L-H area is mainly distributed in the east and southeast, and the southeast area is aggregated, but the distribution range of SC and urbanized L-H area is smaller in the southeast area; L-L region is widely distributed, WY and SC are slightly different from urbanized H-H region, and H-H region between WY and urbanization is scattered in the middle. But there is a transition from L-H zone to H-L zone between the spatial distribution of the five ecosystems and the quantified Gini index of urban spatial structure, which is mainly distributed in the southeast.

## 4. Conclusions

This study quantifies the urban spatial configuration index, enabling localized evaluations of urban spatial organization. The research employs data from 130 cities at the prefectural level along the Yangtze River Economic Belt between 2000 and 2020 to examine local ecosystem services. the spatial and temporal heterogeneity of urbanization factors on local and peripheral ecosystems are studied by using bivariate spatial autocorrelation. Our main findings are as follows:

(1) In 2020, the quantified urban spatial structure index of all prefecture-level cities in the YREB will decrease slowly as a whole, and the three regions with coefficients higher than 0.5 will decrease significantly or even almost disappear, indicating the comprehensive deepening of urban structure from single orientation and multi-centricity. From the spatial perspective, the most evident changes in urban spatial structure are concentrated in the western YREB, and show a decreasing trend from northwest to southeast.

(2) From 2000 to 2020, the ecosystem service function shows an upward trend on the whole, and the change is obvious in water yield. From the spatial viewpoint, lower ecosystem service function levels are primarily found in the eastern and northeastern parts of the YREB, whereas higher levels are observed in its central part.

(3) Based on Primacy, HHI and Gini index, this study analyzed the geospatial relationship between urban spatial patterns and ecosystem services within the Study Area.The results showed that there were high similarities between regional ecosystem services and Primacy and HHI, but there were obvious differences between Gini and them.

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