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# URBAN SPRAWL EVOLUTION AND ITS IMPACTS ON THE HUMAN SETTLEMENT ENVIRONMENT IN HANGZHOU, CHINA

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**Abstract:** Urban sprawl has become one of the most prominent spatial phenomena in rapidly urbanizing cities, generating profound effects on the ecological environment, economic efficiency, and social sustainability. However, the comprehensive influence of urban sprawl on human settlements remains insufficiently studied in rapidly urbanizing regions of East Asia, particularly in Chinese cities. This paper investigates the spatiotemporal evolution of urban sprawl in Hangzhou, China, from 2014 to 2023, and evaluates its impacts on human settlements using Wu Liangyong's five-system framework. Land use data derived from remote sensing imagery and statistical sources were analyzed with Geographic Information Systems (GIS), the Shannon entropy model, and the Sprawl Index to measure the intensity, direction, and equilibrium of the sprawl. A weighted index system based on the entropy weight method and Stepwise Regression analysis was employed to assess human settlement responses across five subsystems: Natural, Human, Social, Living, and Supportive Networks. Results reveal that Hangzhou experienced a significant expansion of its built-up areas, primarily through the conversion of cultivated land and woodland. The urban structure shifted from a monocentric to a polycentric pattern, with the main urban core approaching saturation and new growth concentrated in suburban centers and along transportation corridors.

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The Comprehensive Settlement Index improved markedly, with the Supportive Network and Living Systems most sensitive to sprawl, while the Natural System lagged behind due to ecological degradation. These findings highlight the dual role of sprawl – enhancing social and infrastructural systems while weakening ecological resilience – and underscore the necessity of integrated planning strategies to balance urban development with environmental sustainability.

**Key words:** urban sprawl, spatiotemporal evolution, GIS, Hangzhou, China.

## 1. INTRODUCTION

Over the past century, global urbanization has accelerated markedly. The share of the world's urban population rose from 30% in 1950 to 55% in 2018 and is projected to reach 68% by 2050 (Li *et al.*, 2022). According to United Nations forecasts, the global urban population will grow by 2.5 billion by 2050, with nearly 90% of this increase occurring in Asia and Africa. India, China, and Nigeria alone are expected to account for about 37% of global urban population growth between 2014 and 2050 (Kohli and Agarwala, 2017). While urbanization has driven significant economic growth and social development, it has also created challenges such as uncontrolled expansion, environmental pollution, ecological degradation, and urban sprawl. Among these, urban sprawl, defined as low-density, dispersed, and peripheral urban development lacking compactness and effective land-use planning, has emerged as a major global concern (Frumkin, 2002).

Empirical studies show that in many regions, urban land expansion has outpaced population growth. For example, European cities expanded their built-up areas by 78% between the mid-1950s and 2000, while the population grew by only 33% (Martins, 2012). Similarly, in the United States, 281 metropolitan areas expanded by 47% between 1982 and 1997, compared with a 17% rise in population (Fulton *et al.*, 2001). In China, rapid urbanization since the 1978 reform and opening-up policy has led to an eightfold increase in built-up areas, with land urbanization significantly exceeding population growth. This trend is evident not only in megacities, but also in smaller inland cities (Kuang *et al.*, 2016; Wang *et al.*, 2020; Tavares *et al.*, 2019).

Quantifying urban sprawl requires diverse methodological approaches. Indicator-based methods assess population and employment density, land-use growth rates, spatial accessibility, fragmentation, and landscape metrics (Fulton *et al.*, 2001). Geospatial approaches utilize GIS and remote sensing to map impervious surfaces, calculate Shannon entropy, and evaluate landscape indices (Gonzales, 2016). Modeling approaches, such as cellular automata, simulate spatial growth under various assumptions and driving forces (Torrens and O'Sullivan, 2001). Increasingly, studies integrate multiple methods, combining indicator analysis

with GIS-based techniques to capture the spatiotemporal dynamics and drivers of urban sprawl (Shifaw *et al.*, 2020).

The drivers of urban sprawl vary across regions and include both natural and anthropogenic factors. In China, economic growth, industrial restructuring, demographic dynamics, government policies, and local interactions are dominant drivers, while the influence of natural geographic factors has diminished over time (Liu *et al.*, 2005). Quantitative approaches, such as regression models, are commonly employed to evaluate the contributions of socioeconomic and policy variables to urban expansion (Harris, 1968).

Classical geographic theories provide valuable insights into the mechanisms linking urban sprawl and human settlements. Central Place Theory (Christaller, 1966) explains the hierarchical organization of urban systems, where peripheral expansion often converts farmland, wetlands, and forests into urban land, resulting in ecological degradation, social inequality, and uneven resource distribution. Agglomeration Theory (Marshall, 1890; Krugman, 1991) describes the spatial clustering of industries, populations, and services, illustrating how peripheral industrial parks and economic zones foster decentralization, exacerbate environmental pressures, and reinforce the spatial segregation of low-income groups in polluted areas. Together, these frameworks illuminate the multiple pathways through which urban sprawl impacts the natural, social, human, residential, and supportive network subsystems.

The concept of the human settlement environment offers a comprehensive framework for analyzing the impacts of urban sprawl. First formalized in the 1976 Vancouver Declaration by the United Nations, human settlements are defined as integrated systems encompassing social, material, organizational, spiritual, and cultural dimensions across urban and rural contexts. In China, Wu (1993) further advanced this concept through human settlement environment science, conceptualizing human settlements as dynamic systems centered on habitation, composed of five interrelated subsystems: natural, human, residential, social, and supportive networks. Building on this foundation, recent studies have developed multidimensional human settlement evaluation frameworks to assess urban development quality and livability across different regions and scales. These studies typically integrate natural, social, and infrastructure subsystems to generate comprehensive assessments of human settlements and reveal their spatial differentiation patterns (Zhang *et al.*, 2023; Liu *et al.*, 2023; Fang *et al.*, 2022). Concurrently, international research on livability, sustainability, and human well-being has produced multidimensional analytical frameworks emphasizing the interactions and coupling among ecological, social, and economic subsystems within urban systems (Stern *et al.*, 2025; Ameen and Mourshed, 2019; Michalina *et al.*, 2021). Although research priorities and theoretical emphases differ, these studies collectively highlight a multisystem integration approach as central to understanding urban complexity.

However, from a theoretical development perspective, existing studies remain largely outcome-oriented, focusing on the assessment of human settlement status or development level, while paying comparatively less attention to the dynamic embedding of urban expansion processes and their driving mechanisms. This limits the capacity to systematically explain the intrinsic mechanisms of urban development. Similarly, urban sprawl research has tended to focus on spatial patterns and driving factors, often treating urban expansion as an independent spatial process, with limited attention to its interactions with human settlement systems. Although some studies have attempted to integrate urban expansion with ecological or social indicators, systematic analyses linking urban sprawl processes, drivers, and multisystem responses in human settlements remain limited.

Zhejiang Province exemplifies the rapid pace of China's urbanization, with Hangzhou, its capital, serving as a representative case. The city's built-up area grew from 433 km<sup>2</sup> in 2010 to 801.63 km<sup>2</sup> in 2022, expanding by approximately 135 km<sup>2</sup> annually, reflecting an intensified sprawl trend. This rapid growth has contributed to rising carbon emissions, encroachment on rural land, farmer unemployment, and intensified urban heat island effects, posing serious challenges to both human well-being and ecological sustainability (Hangzhou Municipal Bureau of Statistics, 2023; Heurlin, 2019).

Examining Hangzhou's urban sprawl provides critical insights into the interactions between spatial expansion and human settlement systems. It enables the identification of key drivers, spatiotemporal dynamics, and impacts across natural, social, human, residential, and infrastructural subsystems. Such understanding is vital for formulating sustainable planning strategies that balance economic development with environmental protection and social equity.

In the context of Hangzhou, a number of studies have examined urban expansion from different perspectives, including land-use change, spatial growth patterns, and socioeconomic drivers. These studies have provided important insights into the rapid urbanization process of the city, particularly in relation to construction land expansion and economic transformation.

However, most existing studies remain fragmented, typically focusing on single dimensions such as land-use dynamics or economic factors, with limited attention to the integrated analysis of spatiotemporal processes, driving mechanisms, and their impacts on the human settlement environment.

Therefore, this study aims to provide a more comprehensive framework by linking urban sprawl processes with multidimensional human settlement systems, thereby offering a more systematic understanding of urban development in Hangzhou.

By integrating theoretical frameworks, quantitative techniques, and empirical evidence, this study aims to provide a comprehensive understanding of how urban expansion interacts with natural, social, human, residential, and infrastructural

subsystems. The findings may offer useful insights for other rapidly urbanizing cities in China and beyond, potentially informing more balanced and sustainable approaches to urban development.

## **2. STUDY AREA**

Hangzhou, the capital of Zhejiang Province on the eastern coast of China, is situated on the southern wing of the Yangtze River Delta Urban Agglomeration. As a sub-provincial city and a core growth pole within one of the world's most dynamic urban agglomerations, Hangzhou plays a pivotal role in China's national urban system. It is also a renowned historical and cultural city and a pilot zone for the innovative development of the digital economy (Figure 1).

Hangzhou lies at the southern edge of the Yangtze River Delta, bordering the Qiantang River and embracing the West Lake, with hilly terrain surrounding its western and southern periphery. These natural conditions historically constrained compact urban development. However, in recent decades, rapid urbanization and infrastructure expansion have driven the city to extend toward suburban plains and peripheral districts and counties. The municipality covers a total administrative area of 16,847 km<sup>2</sup>, with a permanent resident population of approximately 12.5 million and an urbanization rate of 84.8% by the end of 2023.

As a major economic, cultural, and technological hub, Hangzhou has developed a diversified industrial structure dominated by the digital economy, high-tech manufacturing, finance, and tourism. Its gross domestic product (GDP) increased significantly from 834.6 billion RMB in 2014 to 2,005.4 billion RMB in 2023. Meanwhile, large-scale investments in transportation infrastructure, including metro systems, expressways, and high-speed railways, have facilitated suburban expansion and the emergence of multiple growth poles. This process, however, has also introduced challenges such as cultivated land loss, ecological pressure, and changes in the human settlement environment.

Administratively, Hangzhou governs 10 municipal districts, 2 counties, and 1 county-level city. Within China's administrative system, municipal districts constitute the core urban areas of prefecture-level cities and are highly integrated into unified urban planning and governance. Counties function as basic administrative units responsible for coordinating urban-rural development, while county-level cities, although administratively equivalent to counties, exhibit higher levels of urbanization and more developed urban service functions. This three-tier structure of "municipality-district-county (county-level city)" forms the fundamental governance framework of Hangzhou's human settlement system.

From a spatial perspective, Hangzhou has developed a polycentric and networked urban structure. The main urban area – comprising Shangcheng, Gongshu, Xihu, and Binjiang Districts – serves as the primary urban core, concentrating high-level administrative, commercial, and cultural functions. Six sub-central districts

(Xiaoshan, Yuhang, Linping, Qiantang, Fuyang, and Lin'an) function as secondary urban centers, accommodating industrial development, population redistribution, and regional service provision. In addition, county-level areas in the western ecological zone serve as tertiary centers, focusing on ecological conservation, tourism, and local service functions.

Overall, Hangzhou forms a hierarchical urban system consisting of a primary core, multiple secondary sub-centers, and peripheral county-level centers. The municipality encompasses a diverse range of urban and rural settlements, including central city districts, suburban towns, and rural townships. Population distribution across this system is highly uneven, exhibiting a clear pattern of "high density in the east and low density in the west". The eastern plains and core urban areas show population densities exceeding 10,000 persons per km<sup>2</sup>, while western regions such as Chun'an County, Jiande City, and parts of Lin'an District remain relatively sparsely populated. This spatial differentiation reflects the city's development strategy of "advancing along the river and optimizing the east while developing the west", and provides a representative case for examining the impacts of urban sprawl on the human settlement environment.



Figure 1. Location of Hangzhou city and its administrative divisions (Source: Authors' own elaboration based on administrative boundary data from the National Catalogue Service for Geographic Information, 2023, <http://www.webmap.cn/>)

### 3. METHODS AND PROCEDURES

This study employs a mixed-methods framework to analyze the spatiotemporal dynamics of urban sprawl in Hangzhou from 2014 to 2023 and its effects on human settlement quality. Land-use data were derived from remote sensing images provided by the Zhejiang Geographic Information Public Service Platform, processed through ENVI 5.3 and ArcGIS 10.8 using supervised classification, maximum likelihood estimation, spatial correction, and accuracy verification. Land-use categories followed the LUCC framework of the Chinese Academy of Sciences (Liu, 1996). Socioeconomic and environmental data, including population, GDP, infrastructure, housing, and ecological indicators were collected from the Hangzhou Statistical Yearbook, annual construction reports, and ecological bulletins, and were standardized to ensure temporal and spatial consistency.

Urban sprawl was measured using two complementary approaches. First, the Shannon Entropy Index quantified land-use dispersion across urban zones:

$$H = - \sum_{i=1}^n P_i \ln P_i$$

where  $P_i$  is the proportion of land-use type  $i$ . Values approaching 0 indicate compact development, while values approaching  $\ln(n)$  indicate dispersed sprawl. Second, the Sprawl Index (SI) measured the relative pace of land expansion to population growth (Jiang *et al.*, 2007):

$$SI = \frac{U}{P}$$

where  $U$  and  $P$  denote the growth rates of built-up land and population, respectively;  $SI > 1$  reflects sprawl, whereas  $SI < 1$  suggests compact growth.

This study assesses the impact of urban sprawl on the human settlement environment by adopting an evaluation system rooted in Wu Liangyong's Five-System Framework. Wu Liangyong's Five-System Framework conceptualizes the human settlement environment into five interdependent subsystems: Nature, Human, Society, Live, and Supportive Network (Wu, 2001). This holistic and multi-dimensional approach provides a structured tool for evaluating urban development and human settlement environments. In this regard, it aligns with some general principles of European human geography, such as cultural ecology (Sauer, 1967) and spatial systems analysis (Haggett, 2001), which emphasize the dynamic interaction between human societies and their physical environments. However, compared with the long-established critical and interpretive traditions in European human geography, the Five-System Framework is largely functionalist, focusing on subsystem equilibrium and resource allocation, while giving less attention to power relations, social inequalities, and the socially constructed nature of space (Harvey, 1992). Moreover, European geography emphasizes relationality and multi-scalar flows (Massey, 2013), whereas Wu's framework treats subsystems as relatively bounded and stable, paying limited attention to the impacts of globalization, policy interventions, and inter-regional connectivity.

Despite these differences, given China's rapid urbanization and policy-driven development, the Five-System Framework effectively integrates natural, social, population, and infrastructural factors, providing a practical and comprehensive tool for assessing urban sprawl and human settlements. Therefore, it remains highly applicable in the Chinese context.

Building on existing scholarly research on human settlement environment evaluation, this study further subdivides each of the five core systems into ten indicator layers. Through systematic optimization and screening, the final

evaluation framework is structured into five major systems, ten subsystems, and 25 specific evaluation indicators. To avoid the subjectivity inherent in manual weight determination and address the issue of information overlap among multiple indicator variables, the entropy weight method was employed to assign weights. This objective weighting approach is widely accepted in socio-economic and other research domains and is well-suited for comprehensive evaluations involving multiple indicators (Wehrl, 1978; Zhu *et al.*, 2020). For each indicator  $j$ , normalized proportions were computed as:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}}$$

Entropy values were then calculated as:

$$e_j = -k \sum_{i=1}^m p_{ij} \ln(p_{ij}), \quad k = \frac{1}{\ln m}$$

and final weights obtained as:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)}$$

ensuring that indicators with greater variability contribute more to the composite index. The weighted scores were aggregated to produce annual subsystem and overall settlement quality indices for 2014–2023.

Finally, stepwise regression analysis was applied to examine the relationship between urban sprawl (SI) and Human settlement environment quality (composite score). Diagnostic tests confirmed the absence of severe collinearity and heteroscedasticity, ensuring the robustness of the regression results.

## 4. RESULTS AND DISCUSSION

### 4.1 The evolutionary pattern of urban sprawl phenomenon in Hangzhou, China

#### 4.1.1 Temporal evolution of urban sprawl

The spatiotemporal trajectory of urban sprawl in Hangzhou (2014-2023) shows a structural shift from a demographically constrained compact model to a land-driven expansionist regime. This evolution, marked by inflection points in the Sprawl Index (SI) and divergent growth gaps, unfolded in five phases shaped by state-led policies and exogenous shocks.

- Phase I (2014-2015): The regime of demographic compactness  
Hangzhou initially exhibited compact development, with built-up land expansion lagging behind population growth; SI values remained sub-unity (0.40-0.94). In 2014, the population growth rate (3.38%) was over twice the land expansion rate

(1.37%), aligned with China's New-type urbanization strategy that prioritized demographic optimization and land intensification. Urban growth was functionally clustered, with spatial supply matching the demographic absorption capacity.

- Phase II (2016-2019): Transition to infrastructure-led supply

A 2016 inflection shifted growth to supply-side expansion: average annual built-up land expansion (5.36%) far outpaced population growth (2.84%), pushing SI to 1.36-3.08 (above unity). This structural change stemmed from national regional integration and infrastructure-led development mandates. The 2017 "Along the River" Development Strategy drove eastward expansion along the Qiantang River, reorienting growth from accommodating residents to preemptively building frameworks for economic agglomeration.

- Phase III (2020-2021): Volatility from exogenous shocks and mega-events

This period revealed high sensitivity to external factors. The 2020 COVID-19 pandemic reduced land development to 2.62%, lowering SI to 0.86 despite 3.03% population growth. In 2021, 19<sup>th</sup> Asian Games preparations triggered a land supply surge: built-up area expansion hit 19.02% while population growth slowed to 2.00%, pushing SI to a decadal peak of 9.52. Mega-events thus temporarily decoupled spatial production from demographic trends.

- Phase IV (2022-2023): Stabilization in a land-dominant equilibrium

Post-peak, sprawl intensity eased but did not return to compactness. SI fell from 9.52 to 2.39-2.86, yet average land development (3.37%) remained over double the population growth (1.3%). This indicates a persistent structural shift: Hangzhou entered a "new normal" of moderate land-led expansion, with spatial overcapacity from the infrastructure boom dictating growth even after pandemic and games triggers faded.

Collectively, Hangzhou's urban form evolution reflects a profound land-population decoupling, with SI rising from less than 1.0 (Phase I) to more than 2.0 (Phase V). This outcome, driven by state-led planning (New-type urbanization, Regional Integration) and event mobilization, prioritized spatial capacity building exemplified by 2021's 19.02% land spike over immediate demographic absorption.

#### **4.1.2 Peripheral expansion guided by transport corridors**

Land use change analysis reveals a distinct spatial shift in Hangzhou's urban expansion between 2014 and 2023, with development momentum transitioning markedly from the spatially saturated Main Urban Core to secondary urban centers. The Main Urban Core – encompassing Shangcheng, Gongshu, Binjiang, and Xihu districts – contributed merely 9.4% of the total newly added built-up area, reflecting constrained development potential due to spatial saturation and limited available land resources. In stark contrast, secondary urban centers (Xiaoshan, Fuyang, Yuhang, Lin'an, Qiantang, and Linping districts) absorbed 72.6%

of the newly developed built-up land, exhibiting rapid and multidirectional growth that was predominantly concentrated along major transport corridors (Figures 2 and 3).

Newly developed built-up land was spatially agglomerated around key transportation hubs, including intercity expressways, ring roads, and critical corridors linking Hangzhou to surrounding economic agglomerations. This spatial alignment with major urban transport arteries has fostered a corridor-oriented, linear development pattern. Notably, Hangzhou’s urban sprawl was no longer characterized by continuous outward expansion from the core; instead, it exhibited a dispersed and multi-directional trend, wherein emerging urbanized areas were interconnected through an extensive transportation infrastructure network (Figure 3). This pattern reflects a transition from monocentric expansion to polycentric development, driven by the saturation of core areas and the strategic development of secondary centers supported by transport infrastructure.

Figure 2. Built-up area expansion and its proportion across Hangzhou's districts from 2014 to 2023 (Source: Hangzhou Municipal Bureau of Statistics, 2023, <https://ceidata.cei.cn/>)

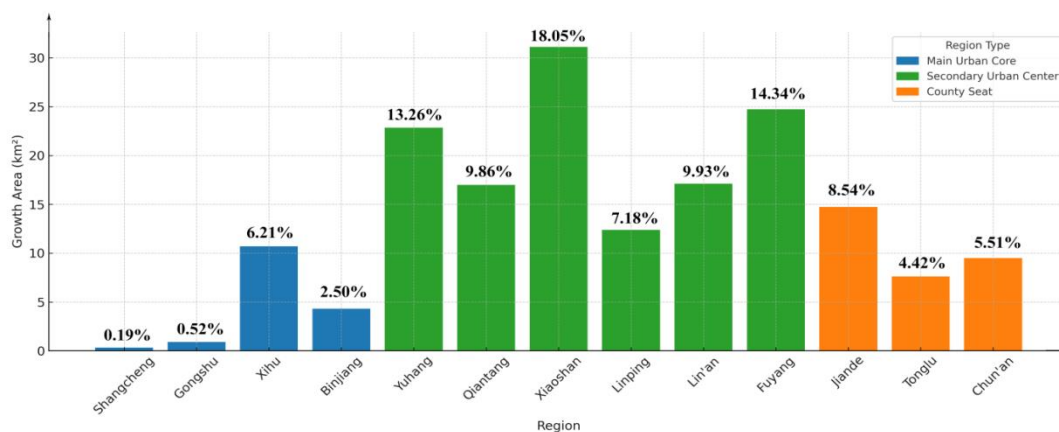
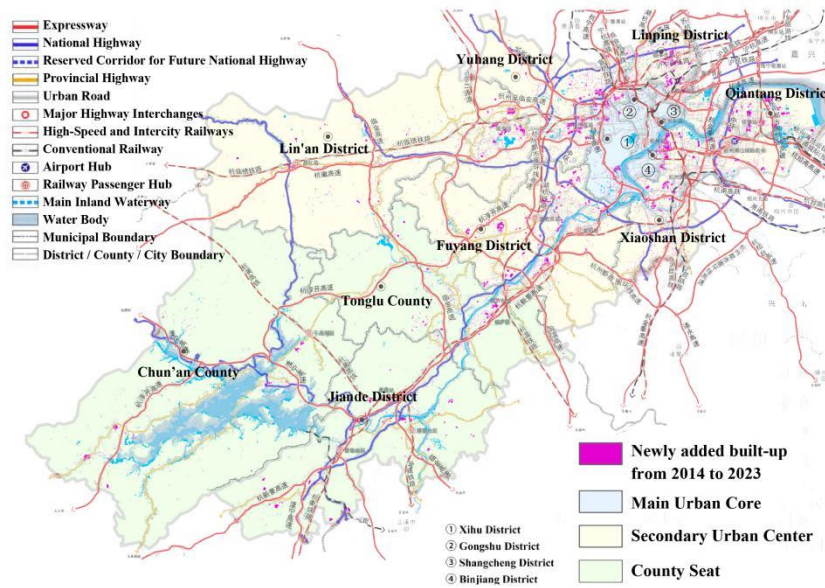


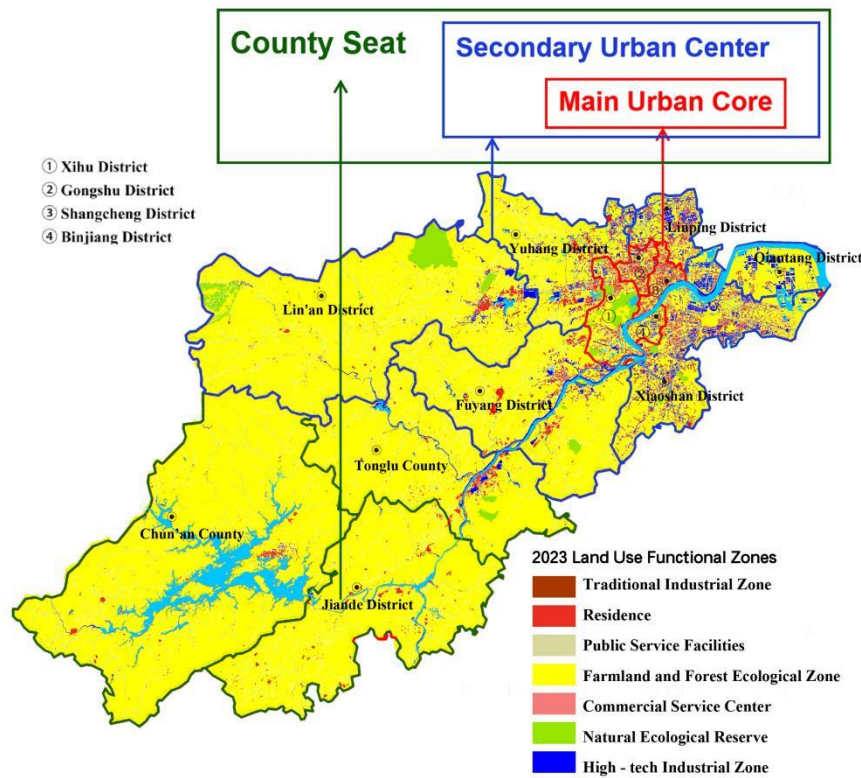
Figure 3. Municipal Comprehensive Transportation Plan Map (2021–2035) with Newly Added Built-up Areas in Hangzhou (Source: Authors)



#### 4.1.3 From monocentric core to polycentric system

Hangzhou’s National Territorial Spatial Plan (2021–2035) defined the spatial framework for urban development and ecological protection through designated urban development boundaries. Xihu, Shangcheng, Gongshu, and Binjiang were heavily constrained by these development boundaries, with minimal room for horizontal expansion. These four core areas exhibited significantly higher population densities and GDP output per unit area than peripheral districts. They served as high-density, high-efficiency urban nodes, concentrating key functions such as financial institutions, technology parks, and commercial service centers. Meanwhile, districts such as Yuhang, Linping, Qiantang, Xiaoshan, Fuyang, and Lin’an have experienced substantial built-up area expansion, functioning as overflow zones for population, industry, and infrastructure. These districts gradually evolved into relatively independent urban sub-centers. The functional areas in these zones were densely distributed and diverse, including high-density residential communities, high-tech industrial parks, and public service facilities – demonstrating a clear trend of “industry-city integration”. Each emerging sub-center formed its own functional identity: Yuhang and Linping focus on digital innovation and artificial intelligence; Qiantang emphasized advanced manufacturing and logistics; Xiaoshan featured a balanced mix of industrial, commercial, and residential uses, acting as a southern transportation hub; while Fuyang and Lin’an played key roles in eco-tourism, cultural heritage, and ecological support for the region (Figure 4).

Figure 4. 2023 Land use functional zones (Source: Authors)



#### 4.1.4 Land use transformation driven by functional reconfiguration

Urban sprawl was inevitably accompanied by a restructuring of land use patterns. Between 2014 and 2023, Hangzhou's built-up area increased by 173.22 km<sup>2</sup>, while the area of cultivated land decreased by 129.49 km<sup>2</sup> (Table 2). Ecological land, such as forested areas and water bodies, remained relatively stable during this period, indicating that urban expansion was primarily achieved through the orderly conversion of agricultural land. This spatial trade-off was evident in the land use maps, where large contiguous tracts of farmland – previously located on the urban periphery – have gradually been transformed into urban construction land, particularly within the expansion zones delineated by the urban development boundaries (Figure 4).

An overlay analysis of functional zoning (Figure 4) and land use change (Figure 3) revealed that the most significant land transformations occurred in Yuhang, Linping, Qiantang, Xiaoshan, Fuyang, and Lin'an districts. These areas, initially dominated by agricultural or ecological functions and located on the urban fringe, have been restructured through functional upgrades and the implementation of new town development plans. They are now evolving into emerging zones of residential, industrial, research, and integrated service functions.

#### 4.1.5 Analysis of land use structure equitability

The analysis of Shannon entropy ( $H$ ) reveals marked spatial differentiation in land use diversity across Hangzhou. The Main urban core ( $H \leq 1$ ) exhibited the lowest diversity and poorest balance, primarily reflecting its advanced stage of urbanization, in which construction land dominated by residential and commercial functions has encroached upon farmland and woodland, resulting in a highly simplified land use structure (Table 1). In contrast, the secondary urban centers and county seats ( $H > 1$ ) demonstrated higher diversity and greater balance. This pattern is attributable to their transitional development stage, whereby these areas simultaneously accommodate the expansion of construction land while retaining significant shares of agricultural and ecological land, thereby preventing dominance by a single land use type.

At the citywide level, Hangzhou's Shannon entropy ( $H$ ), Equitability index ( $EH$ ), and Equivalent number of types ( $Nq$ ) showed a modest upward trend between 2014 and 2023 (Table 2).  $Nq$  is a land use diversity metric derived from Shannon entropy and calculated as  $Nq=e^H$ , which represents the effective number of equally proportioned land use types in a study area. This indicates a slight overall improvement in land use diversity and balance during the study period. As reflected in the land use changes of Table 2 (173.22 km<sup>2</sup> expansion of built-up areas), the spatial expansion of constructed land was accompanied by a gradual population shift from the saturated main urban core to peripheral sub-centers and semi-urban areas: this redistribution alleviated excessive settlement density in the core districts and moderately raised density in the expanding peripheral zones, aligning with the polycentric urban development trend.

Spatially, higher levels of urbanization were associated with greater homogeneity in land use, while peripheral and semi-urban areas with stronger ecological preservation capacity maintained richer diversity. Temporally, expansion of built-up land remained the dominant process, largely at the expense of farmland and woodland. Nonetheless, minor internal adjustments within land categories contributed to a gradual improvement in structural balance.

Table 1. Analysis of land diversity in three types of regions (Main urban area, secondary urban center, and county seat) in Hangzhou in 2023 (Source: Authors)

<b>Urban classification</b>	<b>Shannon entropy (H)</b>	<b>Equitability index (EH)</b>	<b>Equivalent number of types (Nq)</b>
<b>Main urban area</b>			
- Shangcheng district	0.84	0.469	2.27
- Gongshu district	0.82	0.458	2.27
- Xihu district	1.00	0.586	2.86
- Binjiang district	0.91	0.508	2.48
<b>Secondary urban center</b>			
- Yuhang district	1.35	0.754	3.86
- Qiantang district	1.15	0.642	3.16
- Xiaoshan district	1.28	0.715	3.60
- Linping district	1.21	0.675	3.35
<b>County seat</b>			
- Jiande city	1.02	0.570	2.77
- Lin'an district	1.32	0.737	3.74
- Fuyang district	1.42	0.793	4.13
- Tonglu county	1.38	0.771	3.97
- Chun'an county	1.25	0.698	3.49

Table 2. Analysis of land diversity in Hangzhou in 2014 to 2023 (Source: Authors)

Code	Classification	2014 area (km <sup>2</sup> )	2023 area (km <sup>2</sup> )	Land change (km <sup>2</sup> )
1	Cultivated land	3,027.18	2,897.69	-129.50
2	Woodland	11,460.05	11,413.62	-46.43
3	Grassland	395.29	398.24	2.95
4	Waters	890.39	890.67	0.28
5	Built-up areas	1,085.30	1,258.52	173.22
6	Unused land	5.99	6.04	0.05
	TOTAL	16,847	16,847	
	Shannon's entropy (H)			1.463 → 1.492
	LN(N)			2.944 → 2.944
	Shannon's equitability (EH)			0.497 → 0.507
	Numbers equivalent (Nq)			4.312 → 4.447

In conclusion, Hangzhou's urban expansion (2014–2023) shifted from population-driven to land-led growth, with core districts saturated and sprawl moving to peripheral sub-centers via transport guidance, transforming the structure from monocentric to polycentric. Built-up areas expanded mainly by converting cultivated land and woodland, while ecology and water remained stable, aligning with planning. Spatially, higher urbanization brought more homogeneous land use, with secondary centers and ecologically preserved counties showing greater diversity; temporally, despite farmland/woodland reduction, land use diversity improved slightly due to internal adjustments.

## 4.2 The driving factors behind urban sprawl

Hangzhou's rapid urban sprawl from 2014 to 2023 was primarily driven by the combined forces of economic growth, industrial upgrading, and demographic expansion. The city's GDP more than doubled (950.2 to 2005.9 billion yuan), accompanied by a 170% increase in cumulative real estate investment and a 54% surge in fixed-asset investment in infrastructure, directly fueling large-scale land conversion for residential and commercial purposes. Meanwhile, the share of Hangzhou's primary, secondary and tertiary industries in GDP shifted from 3.0:41.9:55.1 to 1.7:28.3:70.0, a structural transformation that attests to the rise of the digital economy and high-tech sectors – the core drivers fueling the substantial increase in the tertiary industry's GDP share from 55.1% to 70.0%. Over the same period, the added value of Hangzhou's core digital industries nearly tripled from the initial year to reach 567.5 billion yuan, accounting for 28.3% of the city's gross regional product (GRP). The clustering of technology parks, higher-education zones, and emerging industries such as e-commerce and internet finance reshaped the urban form by driving suburban expansion. In parallel, the permanent population increased from 7.07 to 12.38 million and the urbanization rate rose to 84.2%, while per capita disposable income almost doubled. This demographic and income growth reinforced demand for suburban housing, with residential sales expanding by 34.6%, intensifying outward urban sprawl.

At the same time, infrastructure development, administrative restructuring, and major events acted as structural enablers of spatial expansion. Transport breakthroughs, with metro mileage reaching 516 km, expressways exceeding 500 km, and airport passenger throughput rising from 29.3 to 41.2 million, greatly enhanced connectivity, reinforcing suburbanization and cross-regional integration. Administrative adjustments, such as the incorporation of Fuyang and Lin'an as districts, expanded the urban area from 4,876 to 8,003 km<sup>2</sup> and population by 1.38 million, while the 2023 territorial plan institutionalized a *one main city, six sub-cities, three towns* framework, consolidating a polycentric pattern. Major events provided catalytic momentum: the 2016 G20 Summit spurred upgrades in transport and real estate markets, while the 2023 Asian Games accelerated infrastructure, energy, and cultural construction. Collectively, these forces not only expanded Hangzhou's built-up areas but also transformed its spatial structure from a compact monocentric model toward a decentralized, polycentric metropolitan system.

## 4.3 Urban sprawl impact on Hangzhou's human settlement environment

The evaluation index system for Hangzhou's human settlement environment constructed in this study (Table 3) is based on the Pressure-State-Response (PSR) model proposed by the OECD and UNEP, a classic framework in human settlement and regional development evaluation. Based on the model's core logic, this study accurately maps the indicators to the three "Pressure-State-Response"

dimensions, depicting the evolution mechanism of the human settlement environment under urban sprawl: development disturbances from urban sprawl as the pressure dimension, the actual characteristics of the human settlement environment as the state dimension, and targeted urban governance measures as the response dimension.

The index system was screened based on three scientific principles: conformity with Hangzhou's urban sprawl and human settlement characteristics, the availability and consistent statistical caliber of 2014–2023 panel data, and indicator independence and non-redundancy. It includes 5 first-level indicators (natural, human, social, living, and supportive network systems), each decomposed into three PSR-corresponding second-level indicators (pressure, state, response), with 25 third-level sub-indicators. All indicators and weight analysis cover Hangzhou's entire administrative jurisdiction, with original data from authoritative sources to ensure scientificity and objectivity.

Specifically, pressure-type second-level indicators (environmental, population, economic, housing pressure) characterize urban sprawl's negative impacts; state-type indicators (environmental quality, population benefit, industrial, housing momentum) reflect the human settlement's actual state; response-type indicators (urban consumption, infrastructure) embody Hangzhou's governance measures. These interrelated indicators integrate the PSR model with the index system, reflecting its complete logical chain. All the indicators in Table 3 correspond to the entire urban area of Hangzhou, reflecting the overall evolution of the human settlement environment. In specific analyses, subregional data can be used to examine local evolutionary characteristics, but this evaluation system is primarily intended for the macro level, providing a reference for the overall human settlement development in Hangzhou.

The entropy method was used to determine indicator weights, objectively weighting based on the temporal variability of municipal-level indicators during 2014–2023: the larger an indicator's time-series coefficient of variation, the smaller its information entropy and the higher its weight, avoiding subjective biases. The core purpose of weighting is to quantitatively identify key drivers of Hangzhou's municipal human settlement quality evolution under urban sprawl, clarify the relative importance of each dimension and indicator, and lay a scientific foundation for comprehensive evaluation and evolution analysis.

The results (Table 3) show that the Supportive network system (0.244) had the highest weight, indicating that infrastructure and public services exerted the most substantial influence on settlement quality in Hangzhou. In contrast, the Nature system (0.180) carried the lowest weight, reflecting its relatively limited variation during 2014–2023. At the sub-indicator level, per capita urban road area (0.070) and education expenditure ratio (0.057) obtained the largest weights, underscoring the pivotal role of transport and education investments in shaping

livability. Conversely, indicators such as per capita green space (0.024) exhibited lower weights, suggesting more stable conditions with weaker explanatory power. These patterns are consistent with Hangzhou's governance trajectory, whereby infrastructure and social services were prioritized in recent development agendas, while ecological improvements advanced at a steadier pace.

Table 3. Data on the weights of indicators at all levels for Hangzhou's human settlement environment (Source: Authors)

First-level indicator	Weight of first-level indicator $W_s$	Second-level indicator	Sub-indicator of second level	Calculation	Weight of sub-indicator of second Level $W_j$
Nature system	0.180	Environmental stress (E1)	Fine particulate matter concentration (PM2.5)	Annual average PM2.5 concentration measured by urban monitoring stations	0.028
			Per capita industrial wastewater discharge	Total industrial wastewater discharge $\div$ urban population	0.033
			Air quality index	Official AQI value; higher values indicate worse air quality	0.040
		Environmental quality (E2)	Green coverage rate in built-up areas	(Green area in built-up areas $\div$ total built-up area) $\times$ 100	0.055
			Per capita green space and park area	Total green and park area $\div$ urban population	0.024
Human system	0.201	Population pressure (P1)	Unemployment rate	Number of unemployed $\div$	0.025

			labor force × 100			
		Population density	Urban population ÷ built-up area	0.038		
		Urbanization rate of population	Urban population ÷ total population × 100	0.034		
	Population benefit (P2)	Per capita deposit balance	Total deposits in financial institutions ÷ urban population	0.061		
		Average wage of employees	Total wages ÷ number of employed persons	0.043		
<b>Society system</b>	0.174	Economic pressure (S1)	Theil index	Measures regional income inequality using the formula: $T = \frac{1}{N} \sum_{i=1}^N \frac{y_i}{\bar{y}} \ln \frac{y_i}{\bar{y}}$ where $N$ is total population or unit count, $y_i$ is per capita income of unit $i$ , $\bar{y}$ is overall average income.	0.037	
			Consumer price index	CPI published by the statistical bureau, base period = 100	0.019	
			Industrial momentum (S2)	Per capita regional gross domestic product	Regional GDP ÷ total population	0.033
				Economic density	Regional GDP ÷ built-up area	0.040

		Level of industrial agglomeration	Industrial output in clustered areas $\div$ total regional industrial output $\times$ 100	0.045	
<b>Live system</b>	0.200	Housing pressure (L1)	Per capita completed real estate investment amount	Total completed real estate investment $\div$ urban population	0.043
			Transaction price of commercial housing	Average market price of commercial housing per m <sup>2</sup>	0.046
		Housing momentum (L2)	Proportion of urban construction land	Urban construction land $\div$ total urban land $\times$ 100	0.047
			Per Capita Sold Residential Area	Total residential area sold $\div$ urban population	0.065
			Urban consumption (R1)	Per capita water consumption	Total urban water consumption $\div$ urban population
<b>Supportive network</b>	0.244		Electricity consumption per unit of GDP	Total electricity consumption $\div$ GDP $\times$ 10,000	0.025
			Proportion of investment in municipal public facilities	Municipal public facility investment $\div$ total fixed asset investment $\times$ 100	0.041
		Urban infrastructure (R2)	Per capita urban road area	Total urban road area $\div$ urban population	0.070
			Proportion of education expenditure	Education expenditure $\div$ total fiscal expenditure $\times$ 100	0.057

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Per capita number of medical beds	Total hospital beds ÷ urban population	0.024
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However, subsystem dynamics reveal that the benefits of sprawl were unevenly distributed. While the supportive network and living systems recorded the largest gains, the natural system exhibited both the lowest baseline and the weakest growth. Its score rose from 0.0236 in 2014 to 0.1789 in 2023 (Table 4), but during the peak expansion year of 2021, when the sprawl index reached 9.5205, the natural system lagged behind all other subsystems at only 0.1021. This suggests that ecological dimensions are more sensitive to rapid land conversion and large-scale construction than socio-economic dimensions, which improved more consistently.

*Table 4. Hangzhou's urban sprawl index and human settlement environment quality scores (Source: Authors)*

<b>Year</b>	<b>Natural system</b>	<b>Human system</b>	<b>Social system</b>	<b>Living system</b>	<b>Supportive network</b>	<b>Comprehensive evaluation score</b>	<b>Sprawl index</b>
2014	0.0236	0.0369	0.0167	0.0000	0.0630	0.1402	0.4047
2015	0.0387	0.0432	0.0347	0.0326	0.0411	0.1903	0.9390
2016	0.0553	0.0628	0.0402	0.0845	0.0430	0.2857	3.0753
2017	0.0691	0.0591	0.0602	0.0709	0.0679	0.3273	1.7273
2018	0.0898	0.0840	0.0761	0.0746	0.0940	0.4185	1.3566
2019	0.1157	0.0871	0.1157	0.0848	0.1265	0.5298	1.7091
2020	0.1039	0.0946	0.1037	0.0876	0.1120	0.5018	0.8630
2021	0.1021	0.1987	0.1556	0.1884	0.1981	0.8429	9.5205
2022	0.1567	0.1190	0.1501	0.1203	0.1460	0.6921	2.3914

2023	0.1789	0.1577	0.1550	0.1349	0.2060	0.8326	2.8580
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The stepwise regression analysis demonstrates a statistically significant positive association between the sprawl index and the comprehensive livability score ( $\beta = 0.644$ ,  $p = 0.044$ ). This indicates that during 2014–2023, urban expansion in Hangzhou contributed positively to human settlement quality by improving infrastructure provision, housing availability, and accessibility to public services. These results are consistent with previous studies showing that moderate urban sprawl can alleviate congestion in the saturated urban core while extending modern amenities to peripheral areas (Zhang *et al.*, 2022; Wu *et al.*, 2017).

The relatively low Durbin–Watson value (0.519) indicates residual autocorrelation, reflecting the temporal nature of the dataset. While this does not undermine the robustness of the identified positive association, it suggests that results should be interpreted with caution. Applying panel or dynamic regression models in future research could better capture the long-term causal mechanisms between sprawl and settlement systems.

Overall, these findings confirm that Hangzhou’s sprawl, under a governance framework emphasizing infrastructure and service investment, has functioned as a driver of livability improvement. Yet, the disproportionate vulnerability of the natural system highlights the need for integrating green infrastructure, ecological safeguards, and growth boundary controls into future expansion strategies. Without such measures, socio-economic gains in livability may outpace ecological resilience, creating sustainability risks in the long run.

## 5. CONCLUSIONS

This study systematically examines the spatiotemporal evolution, driving mechanisms, and multidimensional impacts of urban sprawl on the human settlement environment in Hangzhou between 2014 and 2023. The aim is to elucidate the causal pathways of urban expansion under rapid urbanization and provide evidence-based insights for decision-makers, urban planners, and environmental managers. By integrating Geographic Information Systems (GIS), the Sprawl Index, and the entropy weight method within the framework of Wu Liangyong’s five-system theory for human settlements, this research not only characterizes the spatial patterns of sprawl but also reveals the underlying mechanisms and system-level responses.

The results indicate that Hangzhou’s urban sprawl exhibits distinct phased features, transitioning from population-constrained compact development to land-driven peripheral expansion. The core urban areas have reached

developmental saturation, with 72.6% of newly added built-up areas concentrated in peripheral sub-centers, and forming axial agglomeration along major transportation corridors. Land-use conversion primarily involved the transformation of cultivated land and woodland into urban construction areas. Although ecological land remained relatively stable overall, it experienced intermittent disturbances due to rapid development.

Mechanism analysis reveals that the sprawl process is driven by the interaction of three major forces:

1. Planning-led factors: strategies such as the “Development along the river” initiative and broader territorial spatial planning provided institutional guidance, serving as the core drivers of expansion;
2. Market-driven spontaneous factors: digital economy agglomeration, real estate demand, and population mobility generated spillover effects that facilitated peripheral growth;
3. Short-term catalytic events: mega-events such as the G20 Summit and the Asian Games acted as temporary accelerators of construction activities.

This mechanism elucidates a clear causal chain: institutional planning provides direction and governance, market forces drive the actual spatial manifestation, and short-term events accelerate localized expansion, together forming a “planning-led, market-spontaneous, event-catalyzed” compound growth pattern.

Urban sprawl exerted dual effects on Hangzhou’s human settlement environment. On the positive side, the supportive network and living systems were substantially upgraded, with improved infrastructure and expanded public services driving a rise in the comprehensive human settlement index, highlighting the potential benefits of moderate sprawl in alleviating core-area congestion and optimizing spatial efficiency. On the negative side, the natural system was highly sensitive to rapid land conversion and consistently lagged behind socio-economic dimensions, emerging as a critical bottleneck for high-quality human settlement improvement and emphasizing the necessity of ecological protection.

In terms of practical implications, this study provides actionable insights for multiple stakeholders:

1. Urban policymakers can utilize the identified polycentric and corridor-oriented sprawl pattern to delineate growth boundaries and optimize urban structures;
2. Urban planners can design differentiated regulatory strategies based on the observed synergy between planning and market drivers; and
3. Environmental managers gain quantitative evidence on ecological sensitivity, supporting cultivated land protection, green infrastructure development, and strict enforcement of ecological red lines.

Theoretically, this research advances the comprehensive evaluation of sprawl effects by integrating previously fragmented analyses within Wu Liangyong's five-system framework, quantifying the coupling and coordination among subsystems. The findings reveal cascading effects and compensatory mechanisms among human settlement subsystems under rapid urbanization, providing new empirical evidence for understanding complex urban systems.

This study has certain limitations. The relatively short time series, although capturing key transitional phases, may not fully reflect long-term evolutionary dynamics. Micro-scale variations in human settlement responses were also not addressed. Future research could extend the temporal series, employ dynamic or panel regression models to explore causal mechanisms in depth, and incorporate survey-based data to better capture residents' perceptions and micro-level system responses.

Compared with previous studies on urban expansion in Hangzhou and other rapidly urbanizing Chinese cities, the findings of this study are broadly consistent in identifying the outward expansion of built-up areas and the increasing role of economic transformation as key drivers.

However, this study extends existing research in several important ways. First, it reveals the phased and process-oriented characteristics of urban sprawl, rather than treating it as a static outcome. Second, it explicitly links spatial expansion with a composite mechanism involving planning-led, market-driven, and event-catalyzed forces, thereby clarifying the causal pathways underlying urban growth. Third, by incorporating the human settlement framework, this study provides a more comprehensive assessment of the multidimensional impacts of urban sprawl, highlighting both its positive and negative effects across different subsystems.

In summary, this study clarifies the mechanisms of urban sprawl in Hangzhou by distinguishing between planning-led and spontaneous processes, and reveals their differentiated impacts on human settlement systems. It contributes to a more integrated understanding of urban sprawl by linking spatial processes, driving mechanisms, and multidimensional system responses, while offering practical insights for achieving a balance between spatial expansion, ecological protection, and infrastructure development.

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